Mix4Agroecology Conference

Mixing crops, varieties, disciplines and know-hows for agroecology



Booklet of Abstracts

AgroParisTech, Paris-Saclay, France

7-9 October 2026

Program & informations

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Variety mixtures, heterogeneous populations and species co-cultivation (for example cereal–legume associations) are increasingly recognised as key levers for agroecological transition. These approaches can substantially reduce reliance on pesticides and synthetic fertilisers while improving yield stability under growing climatic uncertainty.

This conference aims to bring together the international scientific community engaged in research on crop diversification. The event will showcase the latest scientific advances in crop mixtures and foster dialogue among international research groups working on varietal and species diversification. It also seeks to strengthen the interdisciplinary collaborations needed to explore emerging scientific questions and to address the technical, agronomic and socio-economic challenges limiting the wider adoption of these practices.

Program and more information on
https://mix4agroecology.colloque.inrae.fr

Program at a glance

Wednesday 7th

9 am
10.30 am Coffee break
12.30 pm Lunch
3.30 pm Coffee break

Plenary session
Amphitheater B1.01

7 pm ..... Gala dinner & concert by Ziveli

Thursday 8th

9 am
10.30 Coffee break

Impact of plant diversity on the extended phenotype
Session 2
Room C1.2.04 (Building C)

Plant Models to decipher plant-plant interactions
Session 3
Amphitheater A -1

Designing mixtures for agroecological value chains
Session 5 (1/2)
Amphitheater B1.01

Can plant diversification promote a more efficient soil functioning and nutrient cycling?
Session 6 - Amphitheater B0.01

12.30 pm ..... Lunch (buffet)

2 pm
3.30 Coffee break

Breeding for inter-individual interactions: from theory to practice
Session 1 (1/2) - Amphi B1.01

Eco-evolutionary dynamics of pathogens in diversified fields
Session 4
Amphitheater A -1

Out-scaling agroecology: transformative sciences
Session 7.A
Amphitheater B0.01

6:30 pm ..... Poster and artwork session + Toasts & bread tasting (drinks and snacks) *Dinner on your own if toasts are not enough for you*

Friday 9th

9 am
10.30 Coffee break

Breeding for inter-individual interactions: from theory to practice
Session 1 (2/2) - Amphi B0.01

Designing mixtures for agroecological value chains
Session 5 (2/2)
Amphitheater A - 1

Out-scaling agroecology: comprehensive approaches
Session 7.B
Room C1.0.06 (Building C)

12.30 pm ..... Lunch (lunchboxes)



Organizing committee

- Executive board: Jean-Benoit Morel and Jérôme Enjalbert
- Marianne Laurençon, Elodie Yan, Michel Amphoux and Lisbeth Michel
- Timothée Flutre, Isabelle Goldringer and Céline Bourhis-Lézier
- Sébastien Barot, Laurent Bedoussac, Elsa Berthet, Nathalie Colbach, Cyril Firmat, Sébastien Fontaine, Elisabeth Fournier, Bernadette Julier, Eric Justes, Gaëtan Louarn, Dan Milbourne, Delphine Moreau, Audrey Niboyet, Raphaël Paut, Mathieu Thomas and Tiphaine Vidal
- Plume Sciences: Alice Vettoretti and Noa N'Diaye

Scientific committees of the Symposia

Symposium 1
Germain Montazeaud
Timothée Flutre
Aduardo Cappa
Ingrid David
Arnaud Desbiez-Piat
Luciano Pecetti
Florence Phocas

Symposium 2
Jean-Benoit Morel
Louis-Valentin Méteignier
Velemir Nincovik
Foteini Paschalidou

Symposium 3
Nathalie Colbach
Delphine Moreau
Christophe Pradal
Jochem Evers
Gaëtan Louarn

Symposium 4
Tiphaine Vidal
Elisabeth Fournier
Clémentine Allinne
Marie Launay
Christophe Le May
Loup Rimbaud
Aurélien Tellier

Symposium 5
Laurent Bedoussac
Nathalie Moutier
Safia Mediene
Raphaël Paut

Symposium 6
Audrey Niboyet
Sébastien Barot
Sébastien Fontaine

Symposium 7
Mathieu Thomas
Elsa Berthet
Isabelle Arpin
Philippe Baret
Sébastien Chaliès
Cyril Firmat
Isabelle Goldringer
Laurent Hazard

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Wednesday 7th October

Plenary session - Amphitheater B1.01

8:00 – 9:00 am – Welcoming participants and coffee break (Forum, AgroParisTech Hall)

9:00 – 9:20 Launch of the conference + Welcoming by MoBiDiv, IntercropValues, IPMORAMA
Jérôme Enjalbert & Jean-Benoit Morel + 9:10 Aline Fugeray-Scarbel, Eric Justes and Tiphaine Vidal

9:20 – 10:05 Introduction: Diversification, from landscape to field
Delphine Renard – Crop diversity as an asset for agricultural resilience
9:50 Elodie Yan – Benefits and adoption dynamics of variety and species mixtures in France: where do we stand?

10:05 – 10:35 Designing mixtures with ecophysiological models
Jochem Evers – Improving our understanding of plant-plant interactions in mixed crops, using 3D plant modelling

10:35 – 11:00 am – Coffee break (Forum, AgroParisTech Hall)

11:00 – 11:30 Designing mixtures with ecophysiological models
Nathalie Colbach – Mixing knowledge and disciplines into a mechanistic model for designing crop mixtures for agroecological weed management
11:15 Sa□a Mediene – Designing crop mixtures using the trait-function-service ecological framework

11:30 – 12:30 The ecology of biological interactions in mixtures
Philippe Hinsinger - Soil ecology and biogeochemistry in diversified agroecosystems: integrating belowground interactions in depth and at depth
12:00 Anna-Liisa Laine – Harnessing biodiversity–ecosystem functioning relationships to guide sustainable agriculture

12:30 – 2:00 pm – Lunch (Forum, AgroParisTech Hall)

2:00 – 2:45 The ecology of biological interactions in mixtures
Laura Mathieu – Beyond intrinsic resistance: integrating neighbor genetic effects to predict disease suppression in wheat mixtures
14:15 Aurélien Tellier – An epidemiology–population genetics framework to infer host x parasite loci of interactions from genome-wide polymorphism data

2:45 – 3:30 Genetics and breeding of inter-individual/social interactions
Piter Bijma – Genetic improvement in animal and plant breeding when individuals interact
15:15 Hélène Fréville – Varietal Mixtures Through The Lens Of Kin Selection

3:30 – 4:00 pm – Coffee break (Forum, AgroParisTech Hall)

4:00 – 4:15 Genetics and breeding of inter-individual/social interactions
Isabelle Goldringer – Intra- and inter-specific mixing of populations: participatory on farm breeding and field trials, within processing chains and organisations

4:15 – 6:00 Mixing for out-scaling agroecology
Henrik Haugaard-Nielsen – An interdisciplinary trajectory from grain legume-cereal niche complementarity to agroecological land and food innovations
16:45 Maria Finckh – Biodiversity, Agroecology and One Health. Perspectives for a healthy Agri-Culture
17:15 Elsa Berthet & Mathieu Thomas – Democracy in transformative research. Lessons from experiences in the field of crop diversity management

6:00 – 6:30 Agroecology: twenty Years and One Day
Philippe Baret

7:00 – 11:30 pm – Opening Gala (Forum, AgroParisTech Hall)



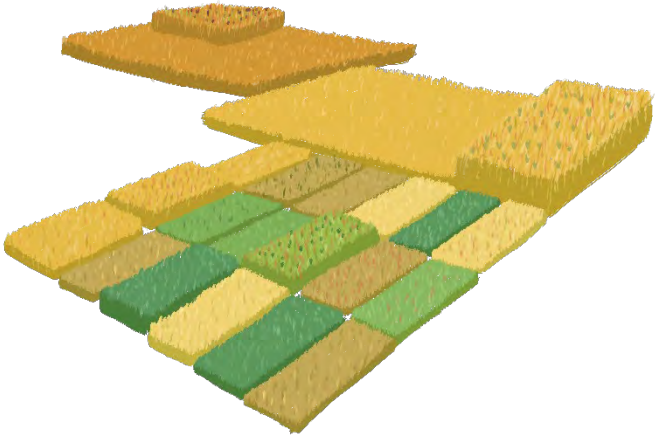
Thursday 8th October 2026 - *Morning*

2. Impact of plant diversity on the extended phenotype Room C1.2.04 (Building C)	3. Plant Models to decipher plant-plant interactions Amphitheater A-1	5. Designing mixtures for agroecological value chains Amphitheater B1.01	6. Can plant diversification promote a more efficient soil functioning and nutrient cycling? Amphitheater B0.01
09:00-09:05 Introduction Symposium 2 *Jean-Benoit Morel* **09:05-09:45 Plant-plant interactions; competition, environmental signals and plasticity** *Franca J Bongers* **09:45-10:00 Wheat mixtures alter root water uptake and plant architecture: non-additive modulation of traits under water deficit** *Samuel Le Gall* **10:00-10:15 Breaking down the effects of companion planting on oilseed rape phenotype: physiological, pest management, and agronomic implications** *Laurie Magnin* **10:15-10:30 Priming at a distance: the role of oviposition-induced volatiles in plant defences against herbivory** *Foteini Pashalidou*	**09 :00 - 09:05 Introduction** *Nathalie Colbach, Gaëtan Louarn, Delphine Moreau* **09:05-09:30 Bridging modelling cultures to study intercropping systems for the agroecological transition** *Noémie Gaudio, Marie Launay* **09:30-09:45 LUCIA-Intercrop: A New Module for Simulating Competition for Light, Water, and Nutrients in Intercrop Systems** *Adam Muhammad Adam, Carsten Marohn, Georg Cadisch* **09:45-10:00 Parameterisation and sensitivity analysis of perhirizal zone processes for winter wheat** *Erik Kopp* **10:00-10:15 Modelling the effects of plant-plant interactions on wheat tillering in wheat-alfalfa intercropping** *Gaëtan Louarn* **10:15-10:20 Flash presentation of posters** *Clara Oliva Gonçalves Bazzo, Daniel Pasquel, Boubacar Adama Traore, Nathalie Colbach, Delphine Moreau*	**09:00-09:15 Exploring the challenges and opportunities of using companion plants in apple orchards** *Julie Borg, Laure Perchepied* **09:15-09:30 Grain Legumes at the Nexus of Intercropping Systems and Agroecological Transition: Barriers and Potentials from a Swedish case study** *Iman Raj Chongtham* **09:30-09:45 Species mixtures beyond the farm: the role of grain collection organisation** *Esther Fouillet* **09:45-10:00 Legume integration modes in French cropping systems often imply intercropping** *Simon Buresi* **10:15-10:30 Flash presentation of posters** *Matteo Petitti, Thierry Marcel, Alain Baranger, Ratha Rien, Louise Blanc, Justine Van Merhaeghe, Indri Fariroh, Madhuri Paul, Daniele Cavalli, Odette Weedon, Alexandro Ferreira, Christine Dillmann, Matteo Petitti, Nuno Bischofberger*	**09:00-09:05 Introduction: Can plant diversification promote a more efficient soil functioning and nutrient cycling?** *Audrey Niboyet, Sébastien Barot, Sébastien Fontaine* **09:05-09:30 How intercropping sustains stable crop productivity and healthy soils? Evidence from long-term field experiments** *Long Li* **09:30-09:50 Shifts in Rhizosphere Microbiomes and Soil Multifunctionality Driven by Cereal–Legume Intercropping and Fertilization Management Across Europe** *Shamina Imran Pathan* **09:50-10:10 Straw incorporation stimulated the intercropping effect to enhance soil carbon sequestration** *Yiwen Zhao* **10:10-10:30 The intercropping of fava bean with winter wheat without nitrogen application supports the crop performance with a reduced risk of nitrogen losses** *Riccardo Picone*
10:30 - 11:00 am – Coffee break (Forum, AgroParisTech Hall)			





2. Impact of plant diversity on the extended phenotype Room C1.2.04 (Building C)	3. Plant Models to decipher plant-plant interactions Amphitheater A-1	5. Designing mixtures for agroecological value chains Amphitheater B1.01	6. Can plant diversification promote a more efficient soil functioning and nutrient cycling? Amphitheater B0.01
11:00–11:30 Genotype-Specific VOC Signalling Drives Aphid Suppression in Cultivar Mixtures *Velemir Ninkovic* **11:30–11:45 Interspecific transfer of a root exudate cocktail is linked to root chromatin reprograming and systemic chemical defenses in rice** *Louis-Valentin Méteignier* **11:45–12:00 How do neighboring wheat genotypes modulate susceptibility to Septoria tritici blotch?** *Laura Mathieu* **12:00–12:15 Plant-plant interactions shape legume nitrogen-fixing symbiosis: genetic and ecophysiological insights from brassicaceae–legume interactions** *Mathieu Hanemian* **12:15–12:25 Concluding remarks Symposium 2** *Jean-Benoit Morel*	**11:00–11:15 Assessing intercrop performance under contrasting water regimes in Mediterranean conditions using the STICS soil-crop model** *Louise Blanc* **11:15–11:30 Macroscopic dynamical models for diversified cropping systems** *Azenor Bideault* **11:30–11:45 Species trait combinations drive yield partitioning more than total yield in a cereal/legume intercropping system** *Dereje Demie* **11:45–12:00 Identification of complementary variety traits for high-performing wheat variety mixtures** *Laura Stefan* **12:00–12:15 Nitrogen stress makes legumes more competitive against weeds in intercrops: a simulation study** *Aurélie Baquet*	**11:00–11:15 Importance of plant dominance in the design of complex service plant mixtures** *Xavier Bousselin* **11:15–11:30 Higher plant diversity increased yields of grassland leys more than application of nitrogen fertiliser, and forage legumes controlled legacy effects in a subsequent crop** *John Finn* **11:30–11:45 Impact of pea genotypes on their performance in intercropping with different species** *Alice Baux* **11:45–12:00 Cultivars impact competition-induced complementarity for nitrogen in intercrops** *Virgilio Freitas* **12:00–12:15 Towards intercrop-adapted varieties: exploring links between phenotypic traits and performance in cereal–legume mixtures** *Julien Leuenberger*	**11:00–11:20 Combining wheat with multi-species prairie strips: effects on aboveground nitrogen production, symbiotic fixation and soil nitrogen dynamics** *Lisa Besson* **11:20–11:40 Effect of crop spatial heterogeneity on above- and below-ground biodiversity at the field scale in a tropical agroecological market-gardening cropping system** *Oliva Razafimahefa* **11:40–12:00 Relationships between vegetable intercropping performance, soil properties, and microbiota: Insights from a participatory study with gardeners and market gardeners** *Léonie Falgous* **12:00–12:30 General discussion - Can plant diversification promote a more efficient soil functioning and nutrient cycling?** *Audrey Niboyet, Sébastien Barot, Sébastien Fontaine*



Thursday 8th October 2026 - *Afternoon*

1.Breeding for inter-individual interactions: from theory to practice Amphitheater B1.01	4. Eco-evolutionary dynamics of pathogens in diversified fields Amphitheater A-1	7.A. Out-scaling agroecology: transformative sciences Amphitheater B0.01
2:00–2:30 Genetic analysis and improvement of social interactions among individuals in group-housed populations of livestock *Piter Bijma* **2:30–2:50 How to breed fish on socially affected traits involving heterogeneous social behaviours?** *Florence Phocas* **2:50–3:10 Simulation study of a fish breeding scheme accounting for social effects, using varying selection strategies, group sizes, and dilution of social effects** *Tristan Kistler* **3:10–3:30 Identifying genetic and social determinants of stress resilience in cage-free laying hens** *Justine Chartrain*	**2:00–2:15 General introduction of Symposium 4** *Tiphaine Vidal* **2:15–2:30 A population genetics framework to infer host x parasite loci of interactions from genome-wide polymorphism data** *Aurélien Tellier* **2:30–2:45 Eco-evolutionary Dynamics of Zymoseptoria tritici Populations in Wheat Cultivar Mixtures** *Chloé Papin* **2:45–3:00 Formalization of plant-plant-pathogen interactions in the Biodiversity Ecosystem-Functioning Framework : case study in wheat varietal mixtures** *Maxence Remérand* **3:00–3:15 Evaluating the reliability of a coupled crop-disease model for simulating intercropping effects on aerial fungal diseases** *Audrey Deheinzelin* **3:15–3:30 Intercropping chickpea with oat combined with inter-row mowing reduces ascochyta blight severity along the main axis and alters the shoot architecture** *Margaux Guy*	**2:00–2:05 Introduction of the session** *Elsa Berthet* **2:05–2:50 When agroecology and transdisciplinary research meet: four matters of concern** *Isabelle Arpin, Kewan Mertens* **2:50–3:10 Expanding the repertoire of experiments for transformative research on crop mixtures** *Léa Collin* **3:10–3:30 When "doing science with others" turns out to be an opportunity for "career transition" for scientists in the context of the agroecological transition** *Mathieu Thomas*
3:30 – 4:00 pm – Coffee break (Forum, AgroParisTech Hall)		
4:00–4:20 Statistical models to analyze oat accessions for their value in oat/pea intercrops *Jean-Luc Jannink* **4:20–4:40 Mechanisms of indirect genetic effects in outbred laboratory rodents and beyond** *Amelie Baud* **4:40–5:00 Impact of selecting for social breeding value on a realistic genotype-environment-phenotype map: a simulation-based study on wheat-pea intercrops** *Timothée Flutre* **5:00–5:20 Plastic responses for intercrop functioning: should we select for more plasticity?** *Franca Bongers*	**4:00–4:15 Multi-facets of intercropping for suppressing soil-borne disease in faba bean** *Rui-Peng Yu* **4:15–4:30 Host genotype and agroecological practices generate context-dependent Fusarium wilt dynamics in diversified banana systems under Foc TR4 pressure** *Pinkham Vongphachanh* **4:30–4:45 Deciphering the mechanisms of crop disease regulation by cover crops and tree hedges: a functional approach applied to grapevine downy mildew** *Charlotte Poeydebat* **4:45–5:00 Agrobiodiversity as a foundation for cocoa tree health through pests and diseases regulation and resources access pathways** *Marie-Thérèse Morrisson* **5:00–5:15 Wrap-up and concluding remarks of symposium 4** *Tiphaine Vidal* **5:15–5:30 Symposium 4: presentation of posters** *Subhasish Basak, Marie Guyard, Manu Affichard, Marion Mesnil, Johnny Louangphan*	**4:00–4:20 Co-creating adapted high-genetic-diversity cultivars for organic agriculture through a European network of Living Labs** *Mariateresa Lazzaro* **4:20–4:40 Exploring the Potential of Farmers' Wheat Cultivars in Organic Conservation Agriculture in Western France** *Stephanie Klaedtke* **4:40–4:50 Co-designing Agroecological Innovations in Semi-Arid Areas: Pathways and Impacts within the Tunisian Agroecological Living Lab** *Hatem Cheikh M'Hamed* **4:50–5:10 A transdisciplinary network to study, co-construct and experiment with vegetable crop associations in urban areas** *Camille Dumat* **5:10–5:20 Flash presentation of posters** *Morgane De Toeuf, Matteo Petitti, Paul Fauchon* **5:20–5:30 Wrap-up of the session and concluding remarks** *Elsa Berthet*
6:30 – 09:00 pm – Poster and artwork session + Toasts and bread tasting (Forum, AgroParisTech Hall)		

Friday 9th October 2026 - *Morning*

1.Breeding for inter-individual interactions: from theory to practice Amphitheater B0.01	5. Designing mixtures for agroecological value chains Amphitheater A-1	7.B. Out-scaling agroecology: comprehensive approaches Room C1.0.06 (Building C)
8:30 – 9:00 am – Coffee break (Forum, AgroParisTech Hall)		
09:00-09:20 Cultivar mixtures improve grain yield and yield stability in winter wheat: insights from over 20 years of official trials *Dario Fè* **09:20-09:40 Spatial Heterogeneity of Disease Infection Attributable to Neighbour Genotypic Identity in Barley Cultivars** *Iqra Akram* **09:40-10:00 gwasvarmix: a simulation framework to optimize experimental designs for dissecting indirect genetic effects in varietal mixtures.** *Germain Montazeaud* **10:00-10:20 Joint analysis of monovarietal and mixed stand performances to study the genetic architecture of indirect genetic effects in wheat cutltivar mixtures** *Maxence Remérand*	**09:00-09:15 Improving soybean yield in relay-cropping under water stress: from genotype selection to cropping system management** *Lea Kervroëdan* **09:15-09:30 Weed management in organic grain legumes: effects of cereal-legume intercropping and chickpea Rhizobium inoculation in an on-farm experimental network across two northern French regions** *Blandine Renault* **09:30-09:45 Impact of a lucerne living mulch managed by mowing in alternate rows with winter cereals in organic farming** *Jérôme Labreuche* **09:45-10:00 Effects of mechanized wide-strip intercropping integrated with soil fertility improvement practices on crop productivity and soil fertility: evidence from field experiment and large-scale commercial production** *Qi-Chang Yang* **10:00-10:15 The IntercropVALUES experimental network: overyielding in contemporary intercropping in- and outside Europe depends on fertilization strategies** *Timothé Wantz*	**09:00-09:05 Introduction of the session** *Mathieu Thomas* **09:05-09:25 Remembering resilience: Drawing on traditional cereal species mixtures to build resilience in our staple crops in Ethiopia and beyond** *Alex McAlvay* **09:25-09:45 Why Farmers Plant Crop Mixtures: Ethnobotanical Perspectives from Ethiopia** *Morgan Ruelle* **09:45-10:05 Understanding on-farm species mixtures' pathways with the action logic framework** *Salomé Grinner, Esther Fouillet* **10:05-10:25 Mixing Crops, Trees and Know-Hows for Mediterranean Agroecology: The RevAgroForMed Living Lab Approach** *Gaio Cesare Pacini*
10:30 – 11:00 am – Coffee break (Forum, AgroParisTech Hall)		
11:00-11:20 Dissecting the genetic architecture of direct and social genetic values: case study in wheat-pea intercrops *Jemay Salomon* **11:20-11:40 Breeding for mixtures: heritable plant-plant interactions and selection strategies in a durum wheat-alfalfa intercrop** *Nicolas Salas* **11:40-12:00 Genetic determinants of maize-bean intercropping performance in European landraces** *Noa Vazeux-Blumental*	**11:00-11:10 Yield Stability, Grain Quality, and Resource-Use Efficiency in Cereal-Legume Intercropping Systems: Insights from Europe-Wide Living Labs** *Shamina Imran Pathan* **11:10-11:20 Participatory Agronomic Diagnosis: A Participatory Framework for Integrating Farmers' Expertise and Agronomic Science** *Michel Turbet Delof* **11:20-11:30 Learnings from a German co-creation case study in wheat and pea intercropping for human consumption: evaluating cultivation and processing of intercropped wheat through seven regional value chains.** *Odette Weedon* **11:30-11:40 Breeding for intercropping: plasticity of winter bread wheat traits between sole crop and intercrop across a diverse panel of 200 varieties** *Nathalie Moutier* **11:40-11:50 Extracting Design Principles for Sustainable Agricultural Systems from Data and Long-Term Ecological Experiments** *Sirio Belga Fedeli* **11:50-12:00 IntercropAgent: AI-assisted literature extraction for intercropping meta-analysis** *Madhuri Paul* **12:00-12:10 Mixing service animal and service plant concepts for agroecology** *Delphine Moreau*	**11:00-11:20 Growing Sorghum bicolor (L.) Moench in varietal mixtures enhances socio-ecological resilience and production reliability in Karamoja, Uganda** *Emiel De Meyer* **11:20-11:40 Farmer collaboration as a pathway to knowledge generation: combining agronomic and social science methods** *Marie-Thérèse Morrisson* **11:40-12:00 Feasible pathways to recognise mixing ability in variety testing** *Pierre Hohmann* **12:00-12:30 Wrap-up of the session and concluding remarks** *Mathieu Thomas* **Poster**: *AgroParisTech students coordinated by Marianne Laurençon and Elodie Yan*
12:30 – 2:00 pm – Lunchboxes (Forum, AgroParisTech Hall)		

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0. Mixing for agroecology: Plenary session

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Jean-Benoît Morel and Jérôme Enjalbert

And all the sessions scientific committees

Crop diversity as an asset for agricultural resilience

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Agriculture has become an increasingly risky enterprise under the combined pressures of climatic variability, biological threats, and economic uncertainty. In this context, agricultural diversification is often presented as a key risk-management strategy. Yet, its contribution to resilience remains insufficiently characterized across the different forms and scales of crop diversity. In this contribution, we present empirical evidence on how crop diversity at intra-specific, specific, and functional levels can enhance mean yield, resistance, and year-to-year stability in the face of perturbations. I examine these effects beyond individual fields, extending the analysis to the farm, landscape, regional, and national scales in order to capture the broader societal benefits that agrobiodiversity-based resilience can generate.

We will discuss how varietal mixtures of cereals within fields perform under contrasting climatic conditions, how species diversity across fields can stabilize production under climatic variability, and how diversification practices from field to landscape contribute to resistance against epidemics. Particular attention will be given to the ecological mechanisms underlying these effects, including selection and complementarity effects. Evidence from studies conducted from the farm to the regional and national levels will further illustrate how the relationship between crop diversity and yield stability scales up to support food security.

Finally, the presentation will highlight the importance of integrating scientific and situated knowledge in the design and management of diversified cropping systems. This will be illustrated through examples from research conducted in France, Senegal, and Madagascar. By connecting ecological theory, agricultural practice, and knowledge systems, this contribution aims to clarify how agrobiodiversity can strengthen the long-term stability and adaptability of agricultural landscapes.

Keywords: Agrobiodiversity, varietal mixtures, intercropping, cross, scale analyses, stability, resistance, local knowledge

Benefits and adoption dynamics of variety and species mixtures in France: where do we stand?

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Mixing varieties and species is a key driver of the agroecological transition, as it promotes biological control mechanisms that reduce the harmful effects of pests while maintaining crop yields through complementarity among varieties or species. In France, we combined quantitative and qualitative analyses to identify and understand the effects of these mixed varieties and species on chemical input use, the factors driving their adoption, and their dynamics at the farm and landscape scales. Thus, in France, variety and species mixtures are grown on an increasing number of fields; however, in commercial farms, contrasting dynamics and effects are observed between variety mixtures and species mixtures – particularly cereal–legume mixtures. While variety mixtures are becoming increasingly widespread (20% of wheat acreage in 2025), species mixtures accounted for only 3.5% of arable land in 2023. Variety mixtures do not consistently lead to reductions in pesticide use on farms (ranging from -44% to +8.7% for wheat mixtures compared to pure varieties, depending on the year), whereas cereal–legume mixtures almost consistently result in reductions of up to -72% compared to species grown in pure stands. This can be explained by the different rationales and motivations behind their adoption: in recent years, variety mixtures appear to have been adopted primarily to simplify farmers' labour, and do not necessitate redesigning cropping systems to be integrated, whereas species mixtures are often part of a broader approach to diversification and self-sufficiency at the farm level and are predominantly adopted in organic farming contexts. Such research was based on structural, administrative, and survey data, some of which are available in other countries (e.g., Land Parcel Identification Systems, agricultural censuses), thereby enabling their replication and enhancing the scalability of results obtained in France, and finally, our overall understanding of these practices and their adoption.

Keywords: crop diversification, intercropping, landscape agronomy, farming system, pathways of adoption

Improving our understanding of plant-plant interactions in mixed crops, using 3D plant modelling

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In mixed-crop systems such as strip crops and intercrops, plants of the same and of different species compete for resources, both above and below ground. Due to the non-uniform nature of such mixed systems, individual plants may show differences in their behaviour in response to neighbouring plants, depending on the abiotic and biotic conditions they experience locally. A range of interactions occur simultaneously during crop development, ultimately resulting in some level of resource use and performance of the mixed crop. Our understanding of which eco-physiological mechanisms play a role here, and how this affects mixed-crop functioning, can be improved with a combination of experiments and 3D plant modelling. Such understanding can be used to improve plant traits and crop management for efficient and sustainable crop systems. In this presentation, I will discuss the in what cases such 3D models can be useful, what they can simulate, and what is needed to design them, while avoiding mathematical and technical details.

Keywords: functional, structural plant modelling, competition, resources, plant architecture

Mixing knowledge and disciplines into a mechanistic model for designing crop mixtures for agroecological weed management

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Arable weeds are highly damaging to crop production and usually controlled with herbicides, but they are also essential for biodiversity. Herbicide-free weed management must combine many mostly preventive and partially efficient techniques over several years, among which species/variety mixtures. Because of the various objectives to reconcile, the many possible scenarios and the impact of climate change, models are essential to synthesize knowledge, and to evaluate and design new management strategies. The FLORSYS model (1) answers to these requirements by simulating each plant of the multispecies crop–weed canopy in 3D, including both aboveground and belowground processes. Seed and plant dynamics are driven by management operations as well as climate and soil variables. The daily outputs are essential to understand biological interactions whereas annual indicators (e.g., yield, yield loss due to weeds, trophic resources for pollinators) allow comparing varieties, management practices or cropping systems. The model can be used to address diverse questions related to crop mixtures, working with optimization algorithms, crop advisors and/or participatory workshops with stakeholders (farmers...) such as: defining variety ideotypes, optimal sowing patterns and species proportions, relative contribution of nitrogen vs shade stress in weed regulation, testing cropping-system prototypes *ex ante*, or redesigning farmers' cropping systems to include mixtures. The many simulations also produced a large data base, which was used to develop a prototype of a decision support system (DeciFlorMix) to guide the choice of varieties, species and management operations for legume–cereal intercrops.

References: (l) Colbach N., Colas F., Cordeau S., Maillot T., Queyrel W., Villerd J., Moreau D., 2021. The FLORSYS crop-weed canopy model, a tool to investigate and promote agroecological weed management. Field Crops Research 261, 108006. https://doi.org/10.1016/j.fcr.2020.108006

Keywords: weeds, cropping system, biological regulation, crop mixture, sustainability, optimization, 3D individual, based model, FLORSYS

Designing crop mixtures using the trait-function-service ecological framework

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The design of crop mixtures presents a major challenge in supporting farmers in experimenting with, using and adopting this agroecological practice. Given the vast number of possible combinations between two species (including crops and service plants), it is necessary to propose a generic method for selecting relevant species and combinations, tailored to farmers' objectives and conditions. To this end, we outline how to assist in the design of crop mixtures by mobilising ecological and agronomic knowledge. Functional ecology is based on establishing links between individual traits involved in the biological and ecological functions that underlie ecosystem services. We have applied this 'trait-function-service' ecological framework to agronomic purposes : oilseed rape grown in combination with service plants and, more generally, all crop mixtures. Our aim is to establish rules for combining traits in order to guide the choice of species to be mixed, based on the expected services and local conditions.

Our overall approach involves three key stages : gathering existing knowledge on mixtures ; constructing functional trees that link and weight traits against functions and services, whilst taking into account the effect of agronomic practices and conditions ; and establishing rules for combining traits within species mixtures. At each of these stages, we have combined scientific and expert knowledge through knowledge-sharing workshops.

All the results have been used to develop two prototypes : CAPS for oilseed rape combined with service plants, and EcosysteMIX for species mixtures. The ecosystem services we studied in the two prototypes were nitrogen recycling and weed regulation, with the CAPS tool also incorporating pest regulation and competition with oilseed rape.These tools still require testing to validate their outputs, but they provide insights into species and mixtures that are useful for design purposes.

Keywords: trait assembly, tool design, knowledge hybridisation, ecosystem services

Soil ecology and biogeochemistry in diversified agroecosystems: integrating belowground interactions in depth and at depth

Philippe Hinsinger, Quentin Gabriac, Esther Guillot, Mickaël Hedde, François-Xavier Joly, Gabin Piton, Elisa Taschen, Isabelle Bertrand

A majority of soils in Europe and worldwide are subject to one or several degradations, especially agricultural soils, as a consequence of input-intensive practices. Soils are however pivotal for a number of key agroecosystem functions, such as the regulation of water, carbon, and nutrient cycling, or the provision of habitats for plant roots and a considerable diversity of organisms, most of which are still unknown. It is indeed estimated that soils host close to 60% of the terrestrial biodiversity. To preserve this unique reservoir of biodiversity and secure these key functions, caring for soil health is one of the thirteen principles of agroecology, while one of the key drivers and principle is diversification. We hypothesize that increasing aboveground (plant) diversity at the plot scale can efficiently improve a range of soil functions through improved belowground functional diversity. Examples will be shown for various types of diversified agroecosystems, from crop variety mixtures to intercropping and agroforestry systems, with a focus on soil functions related to the biogeochemical cycles of carbon, nitrogen and phosphorus. Most of our knowledge is restricted to topsoil properties, but we will also refer to processes occurring at depth.

Keywords: plant-plant interaction, rhizosphere, microbial community, mycorrhizal symbiosis, soil fauna.

Harnessing biodiversity–ecosystem functioning relationships to guide sustainable agriculture

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Intensive agriculture has eroded biodiversity, with consequences for the ecosystem functions that underpin sustainable food production. Ecological theory predicts that increasing plant diversity can promote biodiversity across trophic levels and enhance ecosystem functioning, but much of this understanding comes from experimental systems far removed from modern agriculture. Can diversification generate similar benefits in crop-dominated ecosystems, and do these effects translate to working farms?

We address these questions by combining a large-scale field experiment manipulating plant diversity and composition with a network of farms implementing diversification practices under real-world conditions. Across these complementary studies, we quantify responses of plants, above- and belowground invertebrates, microbial communities and ecosystem functions. Our results show that even modest diversification can reshape communities across trophic levels, alter crop disease and rhizosphere microbial interactions, and affect soil carbon processes. Importantly, responses depend not only on how many plant species are added, but on their identities and composition. Together, our findings reveal both the potential and complexity of using biodiversity to rebuild ecological functions in agricultural systems.

Keywords: Crop diversification, biodiversity, microbiota, ecosytem services

Beyond intrinsic resistance: Uncovering neighbor genetic effects on disease severity in wheat mixtures

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Because of their well-known impacts on yield and diseases, cultivar mixtures are a growing practice and also an increasingly studied research topic. Beyond epidemiological effects, a new mechanism has recently been identified in which plant-plant interactions can directly modulate plant susceptibility to pathogens. Our objective was to uncover the genetic determinants responsible for such interactions in wheat. We investigated wheat susceptibility to *Zymoseptoria tritici* in binary mixtures using a new high-throughput image-based phenotyping. By phenotyping 225 two-way mixtures, we first showed that wheat varietal mixtures modulate disease severity through specific plant-plant interactions, impacting the mean and variance of Septoria symptoms. Secondly, we developed a new genome-wide association approach that simultaneously considers the genomes of the two plants composing a mixture. This first plant-plant co-GWAS identified loci involved in these interactions and revealed significant inter-individual epistatic effects on Septoria severity. Our results provide a deeper understanding of the genetic architecture underlying plant-plant interactions in wheat and open new opportunities to account for genetic interactions between plants when designing cultivar mixtures for improved disease management.

An epidemiology–population genetics framework to infer host x parasite loci of interactions from genome-wide polymorphism data

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Host-pathogen coevolution is defined as the reciprocal evolutionary changes in both species due to genotype x genotype (GxG) interactions at the genetic level. The type and strength of the GxG interactions determine the outcome and severity of infection. While recently developed co-analyses of host and pathogen genomes (co-GWAs) allow to pinpoint the interacting genes, they do not reveal which host genotype(s) is/are resistant to which pathogen genotype(s). Furthermore, co-GWAs do not account for coinfection by multiple pathogen strains within a single host, a common scenario for many crop and human diseases.

To bridge this gap, we built GxG models with and without disease epidemiology which are embedded in a Bayesian inference method (random forest Approximate Bayesian Computation, RF-ABC). We first demonstrate the theoretical power of our RF-ABC framework to find out loci of interactions, to identify genetic signatures associated with coinfection, and to infer candidate genes (SNP) involved in multi-strain coexistence.

We apply this framework to a crop pathosystem, wheat–*Zymoseptoria tritici*. We will present results from these analyses to highlight novel insights gained by accounting for coinfection. These insights are critical for developing more sustainable disease-control strategies and anticipating the emergence of resistance-breaking or highly virulent pathogen strains.

Keywords: Host pathogen coevolution, GxG interactions, random forest Approximate Bayesian Computation

Genetic improvement in animal and plant breeding when individuals interact

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As individuals do not live in isolation, individual trait values are typically affected by properties of other individuals and thus by the genotypes of these individuals. Such effects are known as Indirect Genetic Effects (IGE), and have received increasing attention in animal breeding, evolutionary biology, human genetics and plant breeding. Here I show that IGE create a difference between genetic variation expressed in phenotypic variance vs genetic variation that can be used for genetic improvement, and illustrate this distinction with examples from animal and plant breeding. Next, I discuss estimation of IGE, focussing on variance component vs trait-based methods. Finally, I discuss optimal use of IGE for genetic improvement in animals vs plants.

Keywords: Indirect genetic effects, social interactions, quantitative genetics, competition, response to selection

Varietal mixtures through the lens of kin selection

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The positive effects of biodiversity on ecosystem functioning-such as productivity and biotic regulation-are well established, underscoring the importance of genetic diversity. In agriculture, varietal mixtures, the cultivation of multiple genotypes from the same species within a single field, have been proposed as a strategy to harness natural biological processes and promote more sustainable, low-input cropping systems. Indeed, meta-analyses show that genotype mixtures can enhance multiple ecosystem functions, including yield and pest regulation (1). However, mixing effects remain highly variable, and in some cases even negative, and the genetic drivers underlying this variability are poorly understood (2-3). Using durum wheat as a model species, our research group explores how concepts from evolutionary biology can help elucidate the mechanisms driving mixture performance and the adaptive dynamics of genetically diverse crop populations. In this talk, I will present some of our recent work illustrating how the kin selection theory can help a better understanding of the genetics of plant–plant interactions, and how it can help addressing pressing issues in agriculture.

Keywords: Agroecology, Durum Wheat, Kin selection, Plant, plant Interactions, Varietal mixture

Intra- and inter-specific mixing of populations: participatory on farm-breeding and collective design of experiments in the field, within processing chains and within organisations

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The modernization of agriculture in Northern countries has led to a loss of crop diversity, as well as a loss of knowledge, know-how and rights of farmers regarding on-farm seed breeding. Yet, agroecological transformation relies on crop diversication at all levels from field to landscape and a key pathway for this change is for farmers who so wish to regain control over the breeding of population varieties, as well as the ability to experiment on their farms with these populations and their cultivation in mixed-species systems. In France, the Réseau Semences Paysannes (RSP) brings together collectives of actors (farmers, bakers, citizens, gardeners) mobilized in a quest to reclaim these aspects. Participatory research, which brings together groups of stakeholders involved in the fields and research teams, makes it possible to explore avenues for change by grounding them in the local contexts where the solutions developed will be further implemented. In the research presented here, member groups of the RSP and scientific teams from INRAE jointly built 1) experimental set-ups to evaluate different approaches to on-farm selection of wheat population mixtures; and 2) collective design workshops to trial, in the field, within processing channels or within organisations, cereal–legume intercropping using population varieties.

Keywords: participatory research, population breeding, on farm experimentation, collective design, intercropping

An interdisciplinary trajectory from grain legume-cereal niche complementarity to agroecological land and food innovations

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For decades, agricultural development has relied on homogenising landscapes. Today, farmers and society faces a "polycrisis", including demands for e.g., soil carbon sequestration, biodiversity restoration, and groundwater protection, revealing that ecological boundaries have been exceeded. This calls for moving away from dominant sole cropping strategies towards crop diversification, notably through intercropping. Intercropping enhances land-use efficiency by exploiting interspecific interactions, maintaining productivity across environmental gradients and adapting to soil and landscape spatial heterogeneity (1–3). Niche complementarity improves nitrogen dynamics, with legumes increasing biological nitrogen fixation under cereal competition, while reducing weed pressure (1,2). Beyond feed systems, cereal–legume intercropping can achieve cereal grain protein increases (2,3), enabling new food innovation pathways. However, adoption remains limited due to systemic lock-ins beyond the farm gate. Scaling intercropping requires aligning field-scale ecological resilience with value chain innovations. This involves mobilising farmers, agri-food industries, retail and food service actors, among others, through participatory transition processes (4), supported by multi-actor research and co-innovation approaches (5), and informed by design-oriented frameworks for mapping and analysing innovation processes (6).

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Keywords: Intercropping, Ecofunctional intensification, Systemic lockins, Value chain innovation, Multiactor coinnovation

Biodiversity, Agroecology and One Health. Perspectives for a healthy Agri-Culture

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Agroecological approaches to the management of plant health are fundamentally based on the integration of biodiversity at all levels from the microbiome to the landscape. The carbon input by plants is crucial to supply energy to the microorganisms that connect all these levels and that are at the base of soil fertility and health. Pathogens are always present and the question is not so much: Why are plants sick but why are they healthy? Inter- and intraspecific diversity are required to create truly stable and resilient agricultural systems to enhance positive plant-plant interactions for Complementation, Capacity, Compensation, Cooperation and Change.

Keywords: one health, species mixtures, agroecological plant protection, breeding for diversity

Democracy in transformative research. Lessons from experiences in the field of crop diversity management

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As we are facing major social, economic, health and environmental crises, polarisation is increasingly shaping debates over societal choices, in particular those concerning the relationship between technology and nature. As certain epistemic models have become hegemonic and prevented others from emerging, research faces major stakes of democracy: first regarding the way knowledge is produced and accessed, and second avoiding a hegemonic regime to take hold within scientific disciplines. These stakes are particularly topical for transformative research that calls for a reconfiguration of roles in the field of knowledge production, and more broadly for a renewal of the science-society interface. This raises questions about how to conduct transformative research, how to equip oneself to conduct this type of research and the difficulties that can be encountered. We propose in this paper to address these issues in the context of agriculture, a sector particularly affected by environmental problems, and at the heart of food, health and development issues. We draw lessons from empirical experiences in this field, more specifically on the issue of preserving crop diversity, a field emblematic of science's unconditional support for technological solutions to the detriment of biodiversity. The authors of this article have all worked for many years in contact with farmers and food processors' groups aiming to preserve crop diversity. From five empirical and long-term experiences, they move beyond "good practices" to articulate a series of questions and areas of concern for navigating the pitfalls of transformative research. They draw four cross-disciplinary challenges for transformative research: (i) Ensuring objectivity when research is embedded within its object; (ii) Safeguarding equity when working with non-academic actors; (iii) Taking responsibility in transformative approaches and (iv) Scaling out, up and deep case studies.

Keywords: Crop diversity, Generative experimentation, Intervention research, Reflexivity, Agroecology

Agroecology : twenty years and one day

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The journey of agroecology in Europe .began twenty years ago. The aim of this presentation is both to provide a brief overview of the major issues, the role, and the progress of agroecology over the past twenty years, and to bring in some of reflections based on presentations of the first day of the meeting. I will do so from the perspective of a long-standing observer and participant, seeking to offer an approach that is as synthetic as possible, certainly critical, but also forward-looking.

Keywords: Agroecology, transdisciplinary research

1. Breeding for inter-individual interactions: from theory to practice

Scientific committee of Symposium 1

Germain Montazeaud

Timothée Flutre

Aduardo Cappa

Ingrid David

Arnaud Desbiez-Piat

Luciano Pecetti

Florence Phocas

Genetic analysis and improvement of social interactions among individuals in group-housed populations of livestock

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Many traits in group-housed livestock are affected by social interactions among individuals. Examples include not only animal welfare traits related to harmful behavioral interactions, such as tail damage in pigs or mortality due to pecking in laying hens, but also less obvious cases such as growth rate in pigs. Here I present evidence for social genetic effects in pig and poultry populations, and discuss how genetic parameters and breeding values for social genetic effects can be estimated from field data on group-housed animals. The focus is on model specification, identifiability of social genetic effects, trade-offs between estimation of genetic parameters and breeding values, and the factors impacting response to selection.

Keywords: breeding, livestock, social interactions, identifiability, estimation, selection

How to breed fish on socially affected traits involving heterogeneous social behaviours?

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In aquaculture, fish are farmed in large groups, ranging from hundreds to thousands. Social interactions are thus frequent, heterogeneous, and may strongly impact fish productivity, health and welfare. It has been demonstrated that fish behave different towards strangers than to familiar individuals. A substantial part of variation in growth or fin damage has been explained by such social interactions in salmonids, Atlantic cod and Nile tilapia. The use of classical breeding strategies, like mass selection, may lead to unwanted selection responses on socially-affected traits because the best individuals in the classical setting may have negative impact on groupmates. Therefore, selection for socially-affected traits requires to account not only for the direct effect of a focal individual but also the indirect genetic effects of its groupmates on the target phenotype.

This study aims to evaluate the implications of heterogeneous social interaction effects on fish breeding programs using stochastic simulations and the trait-based model framework (1). We simulated a fish breeding program with 2000 selection candidates from 1000 families formed by a partial factorial mating design of 100 males and 100 females. Social interactions were affected by the target phenotype and two latent-personality traits. We investigated how genetic gains and phenotypic variances are affected by the magnitude and direction of social interaction effects on the target phenotype, different selection strategies, and the genetic correlations between the target phenotype and personality traits. Results showed that increased social interaction effects lead to greater phenotypic variability in the target trait. Under mass selection, the genetic means of personality traits change, and these changes depend on the strength and direction of genetic correlations between personality and target traits. To achieve similar genetic gain under group selection, many groups with few families were needed. Phenotypic variability of the target trait and genetic means of the personality traits remained constant under group selection ; however, the rate of inbreeding was increased per generation.

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Keywords: indirect genetic effect, mass selection, group selection, aquaculture

Simulation study of a fish breeding scheme accounting for social effects, using varying selection strategies, group sizes, and dilution of social effects

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When heritable, social effects among group-raised animals can strongly impact selection outcomes (1,2). We used stochastic simulation of a fish breeding scheme with a partial factorial mating design, where offspring of the same mating bloc and sex formed a rearing group. Using a two-trait model in which a focal trait P is affected by a social trait Y expressed by group mates, without feedback (3), we explored the phenotypic and genetic evolution of P, Y, and their (co)variances as well as the inbreeding trend under several selection strategies. Social effects were diluted to varying degrees (4).

In the base population, the proportion of focal trait variance due to social effects and the direct trait variances were fixed across scenarios; direct and social effects were uncorrelated in the founder population; the interaction coefficient varied to maintain constant focal trait variance across dilution levels. The selection candidate population size was 2000, group sizes ranged from 10 to 1000 for each sex, and the selection rate was 10%.

Mass selection (rearing all candidates together and selecting on individual performance) yielded the lowest phenotypic gains, including negative trends, with a greater response variability as the dilution degree decreased. Scenarios with full dilution achieved the highest phenotypic gains; small-group scenarios outperformed larger ones through greater improvement in the social trait, despite a lower direct genetic gain in the focal trait. Group selection, however, generated approximately three times more inbreeding than individual selection. The smaller the rearing groups, the more the genetic correlation between the direct genetic effect of P and of Y was negative.

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Keywords: indirect genetic effect, selective breeding, mass selection, group selection

Identifying genetic and social determinants of stress resilience in cage-free laying hens

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More than 60% of laying hens in Europe are now raised in cage-free systems. While these systems are designed to improve animal welfare, they expose birds to complex social and physical environments, increasing variation in how individuals experience, cope with, and recover from stress. Understanding the social and genetic mechanisms underlying stress resilience is therefore a key challenge for breeding programs to produce hens well adapted to alternative housing systems.

Within a multidisciplinary consortium, the HenCare project explores whether long-term emotional states are associated with stress recovery and identifies the genetic, physiological and social mechanisms underlying this relationship. Two parental cross types derived from pure breeding lines are housed in a three-tier aviary with a winter garden. Each hen carries an RFID tag, enabling continuous recording of its location throughout the laying cycle. From these data, we construct co-occurrence networks and quantify individual social metrics. We then can examine how social network structure changes during and following a standardized health assessment, which serves as a stressor. Finally, we test whether individual social metrics predict variation in resilience-related traits, including behavioural return to routine, physiological responses, and adult hippocampal neurogenesis (AHN), a neurobiological process that serves as an indicator of chronic stress exposure and long-term affective state. These phenotypes are measured by consortium partners and integrated with the social-network data.

The resulting datasets will be used to estimate the heritability of social phenotypes, AHN, and recovery from stressors, and to assess their potential inclusion in breeding programs. Genome-wide association analyses will subsequently identify loci associated with variation in social behaviour, neurogenesis, and stress resilience. By integrating social network position, neurobiological indicators of chronic stress, and genetic variation, our project provides a framework to investigate the genetic basis of social interactions and their potential contribution to indirect genetic effects influencing resilience in group-housed animals. Preliminary analyses of social-network dynamics and individual social phenotypes will be presented. This work directly supports the goals of the European Partnership on Animal Health and Welfare (EUPAHW) by informing breeding strategies for more resilient laying hens adapted to cage-free production systems.

Keywords: animal welfare, social network analysis, genome, wide association study, heritability, RFID tracking

Statistical models to analyze oat accessions for their value in oat/pea intercrops

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Intercropping often leads to greater resource use efficiency than monocropping. A number of reasons may contribute to this efficiency: the crops may capture or use resources at different intensities (e.g., grasses use more soil N, legumes less soil N); the crops may have complementary morphologies (e.g., oat is upright, pea is vining); or the crops may shield each other from pests because of differential susceptibility. Despite these advantages of intercropping, breeders almost uniformly breed crops for the monocropping context. We have begun an experiment to breed oat and pea for intercropping. The primary challenge is that given O oat accessions and P pea accessions, there are O x P possible combinations. Thus, to identify the best accessions and combinations some form of prediction of untested combinations is necessary. We present two models for analyzing joining oat and pea data. The first separates oat and pea yield as two different traits and estimates, for each crop, their producer effect (the impact of their genetics on how much they yield themselves) and the associate effect (the impact of their genetics on how much their companion yields). This model is most directly useful for selection on joint effects. The second model focuses on the oat component and views different pea genotypes as ”environments” in which the oat grows. It estimates a decomposition of the oat x pea interaction which identifies characteristics of the pea that oat genotypes are differentially sensitive to. We hope that this model will be more useful for understanding the biology of the oat/pea intercrop.

Keywords: Intercropping, Breeding, Linear Models, Avena sativa, Pisum sativum

Mechanisms of indirect genetic effects in outbred laboratory rodents and beyond

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We have previously detected and quantified DGE and IGE in outbred laboratory mice (1,2). Our focus is now on the biological and social mechanisms underlying these effects. We aim to identify both general principles and specific mechanisms. We leverage laboratory rodents to optimise experimental design and data access, but also integrate our results with results from other species, including humans and pigs, for example.For this work we leveraged data from multiple cohorts of outbred laboratory mice and rats including genome, phenome, microbiome and cage data, which we analysed using advanced quantitative genetics models.

I will first present the results of a phenome-wide genetic framework that identifies proxy phenotypes for the heritable traits of social partners mediating IGE by estimating genetic correlations between IGE on focal phenotypes and DGE on measured traits. Applying this approach to two large, outbred mouse datasets comprising hundreds of behavioural and physiological phenotypes, we find that behavioural traits are neither more affected by IGE nor better proxies for the traits mediating them, challenging the prevailing behavioural-centric view of social effects. Instead, immune, metabolic and growth phenotypes are both affected by IGE and informative proxies for their underlying mechanisms. We hypothesize that these signals reflect the social transmission of gut microbes between animals sharing a cage(3). I will present a second line of evidence supporting this hypothesis: significant indirect genetic effects on gut microbiome phenotypes detected in outbred rats (4). Finally, I will present ongoing work using epidemiological techniques (bacterial strain tracking) to detect social transmission of gut bacteria between rats sharing a cage, and the integration of these transmission results with IGE on the gut microbiome and on host organismal phenotypes.

Our results shed light on new opportunities to model IGE and gut microbiome transmission and, potentially, to manipulate the gut microbiome to achieve welfare/health and production goals.

References DOIs : (1) 10.1371/journal.pgen.1006498 (2) 10.1186/s13059-021-02415-x (3) 10.64898/2026.03.10.710784 (4) 10.1038/s41467-025-66105-z

Keywords: Mechanisms of IGE, social transmission of gut microbes, outbred laboratory rodent models, cross, species systems biology

Impact of selecting for social breeding value on a realistic genotype-environment-phenotype map: a simulation-based study on wheat-pea intercrops

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Predicting long-term evolution and understanding the constraints to adaptation are major goals of evolutionary biology. Their study requires quantitative genetics to account for the dynamic and non-linear nature of development (1) and to leverage environmental variation driving phenotypic plasticity (2). Such an approach applied to maize breeding explored the genotypic and phenotypic spaces, using a crop model with genetic parameters (3). In agroecology, the phenotypic space expand further, notably when genotypes interact with other species as in intercropping (4). We deployed this strategy to study the genetic and ecophysiological origins of the balance between positive and negative effects of plant-plant interactions (4). As a first step towards this goal, we mobilized the STICS crop model, in its new version improved for intercropping (5), to simulate the yield of genetically diverse and phenotypically contrasted wheat and pea genotypes, in both sole crops and intercrops. Parameters based on field experiments generated realistic values. The yields were then jointly analyzed (i) with classical indices such as the land equivalent ratio (LER), and (ii) with a linear mixed model to estimate direct and social inter-specific breeding values (DBV, SBV) (6). In a preliminary analysis, the simulated LERs were under-estimated and the estimated DBVs and SBVs were positively correlated. The comparison between breeding values and STICS genetic parameters showed how STICS parameters underlied differences in BVs, and hence how selection will impact the distribution of STICS parameters in the next generation. This new methodological approach paves the way to study the interplay between genetic and ecophysiological constraints conditioning the efficiency with which this particular fitness landscape can be explored (7).

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Keywords: plant, plant interactions, quantitative genetics, ecophysiological modeling, intercropping

Plastic responses for intercrop functioning: should we select for more plasticity?

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Phenotypic plasticity is the ability of a single genotype to express different phenotypes across environments. These different phenotypes are the result of plastic responses: the structural and physiological changes in response to environmental signals such as light quantity, quality or chemical compounds (1).

Within species-mixed communities, phenotypic plasticity has been observed and some of this observed phenotypic plasticity has been responsible for the improved functioning of diverse systems over single species systems (reviewed in 1). This suggests that plastic responses can have a benefit for plant and system performance. However, plasticity does not always cause increased plant or system performance (2). Could this be because the plasticity is too little to have influence on growth and performance?

Most experiments performed are using recent crop cultivars; the cultivars that have been selected for high-input single species production systems. Could it be that domestication has selected against plastic responses (3)? Would this mean that performance of diverse cropping systems is underestimated? In this seminar I want to open the floor to exchange thoughts on this hypothesis and explore if we should select for more plasticity in crop cultivars to increase performance of diverse cropping systems.

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Keywords: phenotypic plasticity, domestication, trait selection

Friday 9 October

Cultivar mixtures improve grain yield and yield stability in winter wheat: insights from over 20 years of official trials

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The adoption of wheat cultivar mixtures has increased substantially in recent years. However, their benefits in terms of grain yield and yield stability remain insufficiently quantified at scale. In this study, we analysed data from the VCU (Value for Cultivation and Use) trials for national listing of varieties in Denmark. Data comprised of yield plots from 996 pure wheat lines and 44 cultivar mixtures (comprised of 44 varieties), and were collected across 22 years, at 3 to 6 locations per year. Genotype data were also available for 224 lines (31 of them used in mixtures). We developed a linear mixed model that simultaneously estimates genotype effects for lines grown in both pure stands and cultivar mixtures, allowing direct estimation of the mixture effect and the genetic correlation between lines grown the two production systems. Our results show that cultivars farmed in mixtures achieved higher grain yield compared to when farmed in pure stands, with an average increase of at least 1.0 hkg/ha (+1%). The correlation between genotype effects in pure stands and in mixtures was moderate to high, indicating that high-performing pure lines could be strong candidates for use in mixtures. Yield stability across years and locations was higher in mixtures than in pure stands plots, with most lines exhibiting reduced sensitivity to environmental variation when grown in mixtures. These findings suggest that cultivar mixtures represent a promising and readily implementable strategy to increase grain yield and improve resilience to environmental fluctuations in winter wheat.

Keywords: Wheat, Mixtures, Yield, Stability, VCU trials

Spatial Heterogeneity of Disease Infection Attributable to Neighbour Genotypic Identity in Barley Cultivars

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Pest and disease damage in crop fields show actual spatial heterogeneity across plots, which is often handled as experimental noise in breeding trials. However, fraction of this variation may possibly be driven by genetic interactions among neighboring plants. In this study, we explored whether neighbouring genotypic identity influences spatial variation in disease dynamics in barley cultivars.

We analysed CIMMYT Australia ICARDA Germplasm Evaluation (CAIGE) datasets and aimed on three disease phenotypes: net form net blotch, spot form net blotch, and scald infection. First, we applied Spatial Analysis of Field Trials with Splines (SpATS) to reason for spatial trends in the field. The results implicated residual phenotypic variation that could not be fully explained by spatial smoothing, advocating additional biological factors.

To further explore this, we applied a Neighbor Genome-Wide Association Study (Neighbor GWAS) framework. Our analysis discovered that neighbouring genotypic identity explained approximately 0.1–0.3 fraction of the phenotypic variation across the studied diseases. In addition, we identified two significant loci on chromosome 7H associated with neighbour effects on net form net blotch and scald damage. These variants proven potential beneficial allelic effects contributing to reduced disease severity under mixed genotypic conditions.

Our outcomes revealed that neighbour genotypic identity plays a novel role in defining spatial disease heterogeneity. This highlights its potential application in planning multiline cultivation approaches for improved pest and disease management in barley.

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Keywords: Crop, Neighbor Genome, wide association study, Genotype, genotype interaction, Pest resistance

gwasvarmix: a simulation framework to optimize experimental designs for dissecting indirect genetic effects in varietal mixtures.

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Plant–plant interactions strongly influence ecosystem functioning and agricultural productivity. Growing evidence from annual and perennial species indicates that these interactions are partly determined by indirect genetic effects (IGEs), whereby the genotype of one individual influences the phenotype of its neighbours. In animal breeding, selection on IGEs has successfully improved productivity by reducing competition among individuals. In contrast, the integration of IGEs into plant breeding remains in its infancy, largely because the experimental designs and statistical methods required to estimate IGEs are still underdeveloped. Moreover, because neighbour identity can be precisely controlled and genetically identical replicates readily produced, plant mixtures provide a unique opportunity to estimate direct-by-indirect genetic interactions (DGE × IGE), whereby the performance of a genotype depends on the specific combination of genotypes within a mixture. This raises new methodological challenges for experimental design and statistical inference. To address these challenges, we developed a quantitative-genetics simulation framework using binary varietal mixtures in annual crops as a case study. The framework allows users to specify genetic variance components, genetic architectures, and experimental designs, while integrating multiple statistical approaches for inference. We illustrate three applications. First, we quantify the consequences of model misspecification by evaluating biases in (co)variance component estimates and reductions in BLUP accuracy when genetic effects are omitted. For instance, ignoring DGE–IGE covariance reduces IGE BLUP accuracy, particularly when IGE variance and DGE–IGE covariance are high. Second, we use power analyses to optimize experimental designs for detecting quantitative trait loci (QTLs) underlying IGEs. Our simulations show that replicated, balanced designs can achieve high power to detect IGE QTLs explaining 5–10% of phenotypic variance. Third, we compare alternative experimental designs for estimating DGE × IGE variance and show that unbalanced tester-type designs can outperform balanced designs, highlighting that optimal designs depend on the genetic parameter targeted. The framework is implemented in the R package gwasvarmix, providing a community resource for designing experiments and developing breeding strategies that explicitly account for inter-individual interactions. Although developed for binary varietal mixtures, it is readily extensible to more complex varietal mixtures and interspecific cropping systems, providing a foundation for agroecological breeding.

Keywords: Indirect genetic effects, simulation, varietal mixtures, mixed models, experimental designs, power anlayses, GWAS

Joint analysis of monovarietal and mixed stand performances to study the genetic architecture of indirect genetic effects in wheat cutltivar mixtures.

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Varietal mixtures represent an important agronomical tool, notably to increase yields under lower pesticide use and provide other ecosystemic services. They also contribute to stabilize yield thanks to compensation but other biological mechanisms can play a role, such as complementarity and facilitation. However, the underlying genetic architecture of such ecological interactions in mixtures is still lacking. We designed a two-season, alternate rank field trial to investigate the Direct Breeding Value (DBV) and Social Breeding Value (SBV) of a hundred wheat recombinant lines from a MAGIC population. We analysed jointly pure stands and 3-components varietal mixtures on multiple traits.

We found evidence for a small yet positive overyielding in mixtures, concurring with current litterature, further suggesting varietal mixtures are an interesting agronomical lever to increase yields. Linear mixed modeling was used to seperate DBVs and SBVs from the non-heritable residual components. A GWAS was then performed on the estimated DBVs and SBVs using a 420k-SNP microarray. Several SNPs were associated with DBVs for grain yield and height, and one was associated with SBVs on grain weight. This preliminary result prompts more investigation on the role of indirect effects in mixtures, but is promising to start incorporating such effects in selection schemes for mixing ability.

Keywords: Plant breeding, plant, plant interactions, Social Breeding Value, wheat varietal mixtures

Dissecting the genetic architecture of direct and social genetic values: case study in wheat-pea intercrops

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In intercropping, plant-plant interactions affect varietal performances with significant variety-stand type interactions. However, field trials have been experimented so far with a limited genetic diversity. The relative importance of genetic (co)variances underlying change in varietal ranking between solecrops and intercrops hence remains poorly explored. In this goal, we first developed a genetic model, and its corresponding statistical model, based on direct and social breeding values (DBV, SBV), integrating a social intra-genotypic value (SIGV) to allow the joint analysis of solecrop and intercrop performances. In parallel, we conducted a field trial involving 200 wheat varieties (focal species) and 2 pea varieties (tester species), using a pseudo-randomized complete block design in two sites, and a balanced incomplete one in a third site. Grain yield was obtained per species in all sites. Other yield components (thousand kernel weight), grain protein content and several functional traits (phenological stages, plant height PH etc.) were also scored. The joint model was adapted to account for species-specific spatial heterogeneity patterns, and then applied to estimate the genetic (co)variances per trait in each site. The estimates of the three kinds of breeding values were then separately regressed on 280k SNPs by SNP-by-SNP GWAS. All association p values were then jointly analyzed by meta-analysis. Wheat-pea intercrops produced, on average, 50% more than the monovarietals, as indicated by a land equivalent ratio (LER) centered on 1.5. Heritabilities for grain yield in sole crops and intercrops were moderate, above 0.5 (except in one site) and up to 0.7, with spatial heterogeneity showing differences between species in intercrops. Genetic variances corresponding to DBVs and SIGVs were the largest in all sites, but the one for SBVs was still significant. Surprisingly, genetic correlation between DBV and SBV was weakly negative in one site (-0.18) and positive in the others (0.27 and 0.37), although with a large uncertainty. Significant SNPs were found by GWAS for all traits, with various pleiotropic patterns depending on the breeding values and the traits. Breeding for intercropping is needed and feasible through dedicated designs and models that will improve understanding of the genetic underpinning of how plants interact.

Keywords: plant, plant interactions, indirect genetic effects, heritability, GWAS

Breeding for mixtures: heritable plant–plant interactions and selection strategies in a durum wheat–alfalfa intercrop

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Intercropping and variety mixtures are promising levers for the agroecological transition, but their performance remains hard to predict. In a mixture, the phenotype of a plant depends not only on its own genes (direct genetic effect, DGE) but also on those of its neighbours (indirect genetic effect, IGE) (1), which may belong to the same or to the associated species. We applied a quantitative genetics framework to a semi-controlled durum wheat (Triticum durum) x alfalfa (Medicago sativa) experiment (181 wheat genotypes, 106 alfalfa half-sib families). We phenotyped agronomic and physiological traits on individual plants and found significant IGE for important agronomic traits. Intraspecific IGE from wheat and interspecific IGE from alfalfa explained 3.4% and 6.4% of the phenotypic variance of wheat grain productivity, respectively, and intraspecific IGE from alfalfa explained 5% of the phenotypic variance of dry biomass. In comparison, the DGE explained 8% and 7.5% of the phenotypic variance of these two traits. All results refer to the phenotypic variance remaining after the major fixed effects (block, sowing date, border effects) have been accounted for. These results show that plant-plant interactions have a heritable genetic basis and cannot be neglected.

Because these effects are heritable, such traits are accessible to selection and offer a largely unexploited lever for designing mixtures (2). We simulated breeding programmes over several successive generations and compared selection on indices built from the DGE alone with selection on indices combining direct and indirect genetic effects (1). Including IGE in the indices increased the phenotypic gain of the mixture, or of one chosen partner (here durum wheat), whatever the variance-covariance pattern between genetic effects, whether it corresponded to competitive, neutral or facilitative behaviour. This empirical example illustrates the extent to which accounting for neighbourhood effects improves genetic gain and enables the selection of varieties for mixture performance.

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Keywords: intercropping, indirect genetic effects, quantitative genetics, simulation

Genetic determinants of maize–bean intercropping performance in European landraces

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Within the framework of agroecology, cereal–legume intercropping systems are particularly promising because species interactions can be leveraged to improve agroecosystem resilience. However, the nature of these interactions and their genetic determinants remain poorly understood. Here, we focus on the maize–bean association, a system deeply rooted in Mesoamerican agriculture.
We conducted a two-year intercropping experiment with 200 climbing bean lines grown alongside three maize landraces in France and Romania. We evaluated bean phenotypic responses to maize landraces, treated as distinct biotic environments (E). Direct and indirect genetic effects were assessed by mapping bean and maize phenotypic traits onto the bean genome (G), with G × E interactions tested using contrasts among maize landraces.

Competitive interactions dominated, with maize being the stronger competitor. Maize landraces created distinct biotic environments affecting bean traits. Best-performing bean partners varied across years and countries, while the most productive and balanced mixtures were obtained with the traditionally intercropped maize landrace. We detected several genomic regions involved in species interactions.

This analysis provides new insights into the phenotypic and genetic determinants of maize-bean interactions. It suggests that increased competitive tolerance in legumes and reduced aggressiveness in cereals are key to optimizing species-mixture performance.

Keywords: plant plant interactions, direct and indirect genetic effects, competition, maize bean association

2. Impact of plant diversity on the extended phenotype

Scientific committee of Symposium 2

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Plant-plant interactions shape legume nitrogen-fixing symbiosis: genetic and ecophysiological insights from brassicaceae–legume interactions

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Plant–plant interactions play a central role in both natural and agricultural ecosystems. In intercropping systems, legumes enhance nitrogen availability through niche complementarity and facilitative interactions. Because 40–90% of the nitrogen required for legume growth is supplied by rhizobial symbiosis, legumes compete less intensely for soil nitrogen with their companion crops. As a result, legume-based intercropping can reduce reliance on synthetic nitrogen fertilizers while maintaining crop productivity.

Although the benefits for non-legume crops are relatively well established, the reciprocal effects on legumes themselves-particularly on nodulation-remain largely unexplored. In addition, the influence of the associated crop genotype is rarely considered. Using multiple genotypes of *Arabidopsis thaliana* grown in coculture with *Medicago truncatula*, we tracked using rhizotube® systems how plant–plant interactions shape the establishment of nodulation. We show that cocultivation significantly alters nodule formation, and, strikingly, that the magnitude and direction of this effect strongly depend on the genotype of *A. thaliana*. These findings reveal that the identity of neighbouring plants can modulate legume–rhizobium symbiosis and suggest new opportunities to optimize biological nitrogen fixation through targeted varietal combinations.

We will present a detailed ecophysiological characterization of these interactions, together with complementary results obtained from additional Brassicaceae–legume species pairs.

Keywords: plant, plant interactions, brassicaceae, legume, nitrogen, fixing symbiosis, genetic diversity, ecophysiological response

Wheat mixtures alter root water uptake and plant architecture: non-additive modulation of traits under water deficit

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Crop mixtures can stabilize or even improve yields in the face of climate variability. However, the underlying mechanisms that support these effects are not well understood. We hypothesized that intraspecific wheat mixtures combining deep-rooted and shallow-rooted genotypes would optimize access to resources through the differentiation of hydrological niches and root-to-root interactions.

Under controlled conditions, depth-specific water stable isotopic labelling combined with individual transpiration chambers allowed us to quantify the fraction of root water uptake (fRWU) specific to each genotype at the booting stage under non-limiting and water-deficient conditions. In monoculture, both genotypes maintained distinct fRWU profiles consistent with their architectures. In a mixed planting, niche complementarity was maintained under water deficit, and both genotypes additionally directed their water uptake towards deeper soil layers. To our knowledge, this is the first evidence of intraspecific hydrological niche complementarity in wheat, as well as the non-additive emergence of this modification in functional water uptake traits in a mixed planting. These results suggest the existence of underlying mechanisms, such as altered root competition and possible underground chemical communication, between genotypes.

A complementary field experiment (TERENO Selhausen, Germany, spring drought, 2023) revealed plasticity in above- and belowground structural traits in mixed cropping systems, accompanied by yields that exceeded those of monocultures. The traits specifically affected by the mixture of the two genotypes included reduced canopy height and increased production of fertile tillers (reflecting the higher number of adventitious roots observed under controlled conditions), as well as root overdensity at a depth of 20 cm (also observed in the column experiment).

Taken together, these results demonstrate that intraspecific mixing modulates the extended phenotype of wheat by reorganizing water uptake functions towards deeper soil layers and reshaping resource allocation within the plant. They also provide some physiological basis for the agronomic benefits of cultivar mixtures during spring drought.

Keywords: wheat mixture, structural traits, root water uptake, non, additive effets

Breaking down the effects of companion planting on oilseed rape phenotype: physiological, pest management, and agronomic implications

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Plant phenotype is a key driver of plant–plant and plant–environment interactions and is central to predicting ecosystem responses in mixed cropping systems. Growing oilseed rape (OSR, *Brassica napus*) with legumes, as an agroecological strategy, can improve crop performance and sustainability. However, the mechanisms driving phenotypic plasticity in companion planting systems (CPS) and the underlying processes responsible for improved performance remain unclear.

Using an interdisciplinary experimental approach integrating methods and concepts from ecophysiology, chemical ecology, and agroecology, we linked OSR phenotypic responses to agronomic outcomes. We compared three OSR varieties grown either as monocrops or with faba bean (FB, *Vicia faba*) companion plants under controlled glasshouse conditions and across two field seasons. We quantified morphological development, phenology, and glucosinolate-based defense traits, while monitoring crop microclimate and insect pests.

Growing OSR with FB companion plants consistently reduced OSR leaf development under both greenhouse and field conditions, mainly because of reduced photosynthetically active radiation under the FB canopy, highlighting light-driven plasticity in early vegetative traits. During the reproductive phase, the release from light competition following FB frost damage allowed OSR to compensate for this initial delay through enhanced stem elongation and branching, contributing to yield maintenance or improvement. In parallel, CPS can contribute to insect pest regulation, potentially through modifications of glucosinolate profiles[2] combined with the visual and physical disruption provided by companion plants[3]. However, glucosinolate concentrations and profiles were strongly influenced by environmental conditions and genotype, indicating context-dependent modulation of plant defense traits. Overall, our results demonstrate that, beyond direct pest suppression, the benefits of CPS can also arise from morphological and phenological adjustments that improve OSR adaptation to interspecific interactions.

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Keywords: Secondary metabolites, plant architecture, phylloclimate, crop diversification.

Priming at a distance: the role of oviposition-induced volatiles in plant defences against herbivory

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Plant-emitted volatile organic compounds (VOCs) constitute essential chemical signals that mediate numerous ecological interactions, both between plants and insects and between plants themselves. Previous work has shown that plants exposed to VOCs emitted by neighbours infested with herbivores can enter a "priming" state, preparing them to respond more effectively to future attacks.

In this study, we examined the role of VOCs in plant-insect interactions at different scales, from the laboratory to the field. In particular, we would like to determine whether oviposition-induced plant volatiles (OIPVs) emitted by *Brassica napus* enhance the defenses of neighboring undamaged plants when these are subsequently infested with *Pieris brassicae* larvae. Our results show that egg-laying triggers the emission of specific volatile compounds - α-pinene, dimethyl trisulfide, and limonene - which may act as early warning cues for neighboring plants against herbivores. To assess their ecological impact, we also tested synthetic blends of these three compounds under field conditions and measured their effects on insect communities.

Keywords: Priming, Plant, plant communication, pest regulation, Volatile Organic Compounds

Genotype-Specific VOC Signalling Drives Aphid Suppression in Cultivar Mixtures

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Increasing plant diversity within fields through the use of cultivar mixtures represents a promising, low-input approach to reducing pest pressure in cropping systems. However, previous studies examining aphid suppression in such mixtures have produced variable results, with some reporting substantial reductions in pest abundance and others finding only limited effects. Identifying the ecological and practical mechanisms underlying these inconsistent outcomes is therefore essential for the reliable implementation of cultivar mixtures in crop protection. Our research emphasizes the important role of volatile organic compounds (VOCs) in mediating plant–plant interactions within cultivar mixtures. We show that specific cultivar combinations can prime defence responses in neighbouring, undamaged plants through VOC-based signalling. These primed plants significantly deterred aphid feeding, reduced aphid performance and settling behaviour, and slowed aphid population growth. Importantly, these effects were observed consistently under both controlled experimental conditions and field settings. The protective effects were strongly genotype-specific, demonstrating that not all cultivar combinations provide the same level of benefit. This finding suggests a practical way forward: cultivar mixtures should be selected not only according to agronomic performance, but also according to their capacity to generate beneficial VOC-mediated interactions. Overall, our findings provide a concrete step toward developing more resilient and pest-suppressive cropping systems. They also support the integration of ecological processes into pest management strategies, thereby reducing dependence on chemical insecticides and contributing to more sustainable and environmentally sound crop production.

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Keywords: aphids, variety mixture, volatile induced defense, crop protection, aphid, plant interactions, volatile interaction beween undamaged plants

Interspecific transfer of a root exudate cocktail is linked to root chromatin reprograming and systemic chemical defenses in rice

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Crop diversification can stabilize yields and enhance ecosystem services, yet the molecular mechanisms by which neighboring plants influence receiver physiology remain poorly understood. In maize-based intercropping systems, benzoxazinoids (BXs), indole-derived specialized metabolites exuded by maize roots, have traditionally been viewed as allelochemicals or defense compounds. However, natural BX cocktails in maize-conditioned soils can improve subsequent crop performance, sometimes independently of detectable microbiota changes, suggesting direct effects on receiver plants. Because BXs can be taken up by roots and accumulate in plant tissues, we asked whether maize-derived BXs can act as interspecific regulatory cues that reprogram rice physiology beyond the root interface. Using an agriculturally relevant rice-maize co-culture system, we show that exposure to BX-containing maize root exudates reduces disease caused by *Magnaporthe oryzae,* a major fungal pathogen of rice, without trade-off on growth. Combining donor genotype comparisons, molecular profiling, chromatin analyses, and metabolomics, we provide evidence that maize BXs taken up by rice roots are associated with histone hyperacetylation, consistent with chromatin activation, and with broad reconfiguration of the rice metabolome. These effects extend to leaves, where rice establishes a systemic defense-related chemical state. Our findings support a model in which the cocktail of specialized metabolites released by one crop species act not only as local biochemical effectors but also as interspecific chemical-epigenetic regulators in neighboring plants. This work provides a molecular framework linking crop diversification, metabolite transfer, chromatin regulation, systemic metabolism, and disease resistance, and opens new perspectives for exploiting natural plant-plant chemical signaling to improve crop resilience in sustainable agroecosystems.

Keywords: root exudates, plant, plant interaction, hormesis, systemic signaling, chemical defense

How do neighboring wheat genotypes reduce susceptibility to Septoria tritici blotch?

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Plant-plant interactions modulate foliar disease severity in intraspecific mixtures. However, the molecular mechanisms underlying these effects remain largely unknown. Here, we investigated how interactions between neighboring bread wheat genotypes reduce susceptibility to Septoria tritici blotch. Using a model varietal mixture, we developed an experimental system that can abolish root-mediated interactions between plants. We then performed transcriptomic and metabolomic analyses to characterize the molecular responses linked to reduced disease severity. Our analysis revealed that disrupting root chemical interactions impaired the reduction in susceptibility to Septoria and identified phenolic compounds as potential key mediators. The plant-plant interactions under study triggered significant molecular changes in specialized metabolism, biotic interactions, transporters, and responses to resources. Disrupting root interactions canceled both the macroscopic and molecular responses, thus providing a strong link between them. These results reveal that neighboring wheat genotypes could reduce foliar disease severity through root-mediated chemical interactions and identify candidate molecular processes underlying this phenomenon. These provide new insights into the molecular basis of plant-plant interactions involved in reducing disease severity in intraspecific mixtures.

Keywords: Cultivar mixtures, co GWAS, multi omics, plant plant interactions, Septoria tritici blotch, wheat.

Plant-plant interactions; competition, environmental signals and plasticity

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Plant-plant interaction, both within and between species, are increasingly recognized as modulating vegetation functioning, e.g., by modulating competition and associated growth and yield. Especially in the transition from homogeneous single crop communities to mixed-species communities, understanding plant-plant interactions is essential to elucidate the functioning of mixed-species communities. This is because the environmental signals that can spur plastic plant responses are much more complex in mixed- than in single-species stands (1). Yet, research on how plant-plant interactions drive functioning in mixed-species vegetations is limited and complex. We present a conceptual approach on what is important and share some findings on the consequences of plant-plant interactions for vegetation functioning. (1) Bongers, FJ., Evers, JB., & Anten, NPR. (2025). npj Sustainable Agriculture, 3;8, https://doi.org/10.1038/s44264-025-00048-2

Keywords: inter and intraspecific interactions, environmental signals, trait plasticity

3. Plant Models to decipher plant-plant interactions

Scientific committee of Symposium 3

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Bridging modelling cultures to study intercropping systems for the agroecological transition

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Modelling intercropping systems as part of the agroecological transition raises questions for modelers regarding the scientific approach to address the challenge of representing greater heterogeneity and fluctuations. Simulating these increasingly complex agrosystems and their interactions, such as competition or complementarity between crop species, is particularly challenging in a world of deep climate uncertainty. Moreover, we expect a new kind of 'performance' to emerge, moving beyond crop yield towards broader metrics of farm adaptability and long-term robustness (1). Together, these challenges call for a paradigm shift and a new scientific approach. We argue that crop modelers, ourselves included, should take a more integrative path (2), necessarily involving dialogue and the sharing of methods and knowledge across scientific communities.
We propose to collectively explore the possibility of bridging the three complementary approaches (or *cultures* (2)) to describe and predict intercropping systems: 1) **data-driven modelling** could help to identify the drivers of observed variability from empirical datasets (*variance culture*) and highlight ecophysiological processes of interest; 2) **mechanistic modelling** could help to describe and understand these processes and interactions, which require many parameters and knowledge of the system (*exactitude culture*); 3) **ecological modelling** relies on broad conceptual frameworks that sacrifice local particularities but would allow us to select the main determinants of the system's features (*coarse-grained culture*).

We contend that combining these cultures in a disruptive way would be favoured by small-scale scientific communities with a moderate degree of interdisciplinarity that put the principles of collective intelligence into practice and provide an environment conducive to scientific creativity. This could provide a more robust and relevant predictive framework for intercropping systems while prompting us to reconsider our modelling choices, including the simplifications we accept, the way we account for climate change beyond general trends, and the role of livestock and humans in this new perspective.

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Keywords: agroecological transition, intercropping, mechanistic modelling, data, driven modelling, ecological modelling, interdisciplinarity

LUCIA-Intercrop: A New Module for Simulating Competition for Light, Water, and Nutrients in Intercrop Systems

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Mixed systems are highly complex, offering numerous design and management options that are difficult to evaluate through field experiments. Process-based models accounting for resource competition are instrumental for exploring these options; once evaluated against field data, they remain generic across different sites and species compositions.

In this study, we introduce a new intercrop module for the spatially distributed, dynamic Land Use Change Impact Assessment tool (LUCIA; Adam et al., submitted; (https://lucia.uni-hohenheim.de/en). This module occupies the intermediate complexity space between big-leaf crop models and functional–structural plant models. It simulates daily light, water, and nutrient competition between two crops per grid cell, alternated within rows, between rows, or in strips. Root systems are simulated by soil horizon and dynamically adapt to resource supply. Canopy shape is plastic and adapts to shading, accounting for differences in plant height, planting distances, and shifting sunlight conditions throughout the day, while also incorporating row orientation.

The model was calibrated to field data from sole cropping and then applied without further changes to mixed cropping systems. Model results evaluated against field data from two contrasting agroecological zones in Northern Ghana demonstrate that the new module performed well in reproducing intercrop grain yield, aboveground biomass, and the fraction of absorbed photosynthetically active radiation (fPAR) across three spatial configurations (within-row, 1:1 alternate-row, and 2:2 strip intercropping) using sole-crop calibration (grain yield: nRMSE = 16.0–19.2%, d = 0.92–0.97, bias = –0.19 to 0.08 Mg ha^{-1}; aboveground biomass: nRMSE = 19.1–21.2%, d = 0.62–0.97, bias = –0.34 to 0.14 Mg ha^{-1}; fPAR: nRMSE = 0.07–15.47%, d = 0.96–1.00, bias = 0.95%). Notably, the module excelled in maize–cowpea systems, though performance in maize–soybean strip arrangements highlighted opportunities for model improvement in the future.
Our findings indicate that the new intercrop module can simulate crop-crop interactions from sole-crop calibration for different spatial designs and intercrop mixtures. Importantly, this module also applies to tree-based systems like agroforestry. Future work will evaluate its capabilities in agroforestry, nitrogen sparing, and landscape-scale applications.

Keywords: canopy plasticity, landscape model, mixed cropping, resource competition

Parameterisation and sensitivity analysis of perhirizal zone processes for winter wheat

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Plant-plant interactions are strongly interrelated with carbon, nitrogen and water processes as well as microbial activity in the perirhizal zone (area of soil around a root). These processes are tightly coupled and simultaneously interacting, together shaping emergent plant behaviour such as growth, transpiration, and nutrient uptake. Incorporating these coupled processes into crop simulations is, however, challenging. Indeed, on the one hand accounting for the perhirizal processes makes it difficult to represent larger area (field) and time spans (cropping periods). On the other hand, upscaling perhirizal zone processes to the crop model scale is non-trivial, since emergent properties arising from the interaction of multiple small-scale processes are not linearly related to small-scale observations (Schnepf et. al. 2022). To address this challenge our projects aims to (1) develop a multi-scale soil-perirhizal zone-plant model that includes water, nitrogen, carbon and microbial reactions and (2) conduct a sensitivity analysis of the perirhizal scale soil-microbial model in different zones of the root system. The sensitivity analysis will allow us to evaluate the importance of the represented processes in different area of the root system which would give important insight for interpreting field observations and guiding upscaling to larger models. Updating and using the FSPM CPlantBox (Giraud et. al. 2026), we ran the full soil-perirhizal zone-plant framework for winter wheat using experimental data from our study site in Selhausen, Germany(50∘52′N, 6∘27′E), (Le Gall et. al., publication in preparation). The experiment in 2025 compared intraspecies cropping of two winter wheat varieties under varying fertilisaiton levels. The simulation results enable us to determine the sensitivities of how much microbial parameters influence drought resilience and nitrogen uptake efficiency differing based on growing year, soil position.

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Schnepf et al. 2022 Plant Soil, doi : 10.1007/s11104-022-05306-7

Giraud et al. 2026 SOIL, doi: 10.5194/soil-12-371-2026

Keywords: virtual plant, rhizosphere, winter wheat, sensitivity analysis

Modelling the effects of plant-plant interactions on wheat tillering in wheat-alfalfa intercropping.

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In living-mulch intercropping, wheat implementation can be hindered if the companion plant's presence creates unfavourable light condition. In this study, we modelled wheat early vegetative development in an alfalfa living mulch by coupling two pre-existing functional-structural plant models (FSPM): CN-Wheat and L-egume. Light repartition between species was computed with the Caribu model, and a soil interface based on Soil3DS simulated nitrogen acquisition. Additionally, our approach utilized a GAI threshold to simulate the blocking of early tiller development in wheat.

To identify early growing conditions that favour wheat, we compare tillering patterns in pure wheat simulation against intercrop scenarios with contrasting alfalfa competitiveness, achieved by varying plant parameters (growth habit, growth rate) and management parameters (mulch defoliation, sowing date).

We also discuss the knowledge gaps regarding wheat tillering that emerged during this modelling effort. Finally, we address current limitations, such as our simulation covering only early vegetative development, and we propose future research directions for a more complete exploration of GenotypexGenotypexManagement interactions through virtual experimentation.

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Keywords: FSP modelling, model coupling, living, mulch, plant, plant interaction, tillering.

Assessing intercrop performance under contrasting water regimes in Mediterranean conditions using the STICS soil-crop model

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Intercropping can improve cropping system sustainability through enhancing land1 and water use efficiency2, yet its representation in crop models remains challenging3. We evaluated the ability of the STICS soil–crop model to simulate three intercrops under Mediterranean conditions: rapeseed-pea, durum wheat-pea, and durum wheat-faba bean. The model was previously calibrated using sole-crop data from irrigated and rainfed experiments in NE Spain. Multi-year simulations (2000–2020) were used to explore management scenarios beyond field experimentation. Intercrops and respective sole crops were simulated under irrigated and rainfed scenarios. Additionally, several sowing dates were tested for rapeseed-pea intercropping to explore the yield gains potentially associated with relay sowing4.

STICS successfully captured year-to-year shifts in species dominance in the rapeseed–pea intercrop and simulated grain yields with acceptable accuracy (mean bias $\leq$ 0.36 t ha–1), although land equivalent ratio was underestimated. Multi-year simulations highlighted the potential of relay-sowing to maximize productivity and land-use efficiency for this intercrop under both rainfed (+11%) and irrigated (+26%) conditions. In contrast, wheat–legume intercrops revealed limitations in representing light competition and crop height dynamics, leading to biased estimates of intercrop functioning. The results highlight the challenges of modelling intercropping in Mediterranean conditions with STICS.

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Keywords: STICS, relay sowing, automatic irrigation, pea, faba bean, durum wheat.

Macroscopic dynamical models for diversified cropping systems

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As agroecosystems become increasingly diversified through intercropping, crop rotations, and other agroecological practices, understanding interactions among plant species is a central challenge. While agronomy and ecophysiology rely on mechanistic models, we explore a complementary strategy based on simplification and the search for general principles.

Two theoretical perspectives motivate this work. Biodiversity theory predicts that weak interactions can promote stability through portfolio effects, buffering ecosystem functioning against environmental fluctuations. Statistical physics further suggests that complex systems may exhibit regularities in interaction structure, enabling simplified representations of complex communities. Their relevance to agroecosystems remains however largely unexplored.

Using data from 37 experiments (Gaudio et al. 2024), we inferred pairwise interaction coefficients among plant species from biomass measurements in sole crops and intercrops. We used a community model inspired by the Lotka–Volterra framework, treating sole crop biomass as a carrying capacity and intercrop biomass as equilibrium abundance. We estimate the interaction coefficient between the two plant species for cereal–legume pairs using analytical estimates, mixed models, and errors-in-variables regressions.

We assessed the robustness of this representation by characterising measurement variability, comparing model parameterisations, and testing whether interaction matrices explain biomass covariance across environments. Results indicate that interaction coefficients can be estimated from agronomic biomass data, but their variability remains substantial. Alternative parameterisations are not fully consistent, and observed covariance is not yet satisfactorily captured by interaction-matrix predictions.

This work is a first step towards a new modelling approach for diversified cropping systems. Applying coarse-grained community models to agriculture is challenging (Enquist et al. 2024) because observations are noisy, environments heterogeneous, and crops are managed and harvested rather than allowed to reach ecological equilibrium. Nevertheless, it may enable a shift from species-specific models towards more generic descriptions of plant communities.

As a next step, we will investigate whether concepts from disordered systems and statistical physics can provide a useful theoretical framework. By bridging empirical agroecological data with theoretical models of complex communities, this work aims to identify general principles that can help explain and ultimately predict the behaviour of diversified cropping systems.

Keywords: interaction, complex system, dynamics, theory

Species trait combinations drive yield partitioning more than total yield in a cereal/legume intercropping system

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Species mixtures offer opportunities to increase yields and promote more sustainable resource use in arable crop production; however, reported advantages vary widely, and growers and breeders lack guidance on how to best tailor species trait combinations and fertilizer applications to achieve desired productive performance across pedoclimatic conditions. There is no feasible experimental approach to resolve the conundrum of identifying trait combinations that maximize intercrop performance across a wide range of pedoclimatic conditions and nitrogen fertilizer management. Here, we used a process-based intercrop model implemented within the SIMPLACE (Scientific Impact Assessment and Modeling Platform for Advanced Crop Ecosystem Management), which simulates an intercropping system and its component sole crops based on LINTUL5. We explored key traits driving competition and complementarity between species in capturing above- and belowground resources: plant height, light extinction coefficient (both driving light capture), and daily root elongation rate (vertical extension of the root front, driving water and nutrient capture). We considered 3 traits per species, each at 4 levels, giving 4096 trait combinations for intercrops and 64 for sole crops, each tested at 4 levels of N input, across 210 sites over 30 years. The simulations showed that interactions between above- and belowground traits with nitrogen fertilizer strongly affect species competitiveness and performance, resulting in diverging patterns of partitioning between species, but absolute yield gains were modest and more dependent on fertilizer management than on species trait combinations. Interactions between N input and root elongation rate relatively strongly influenced the overall yield gain and yield partitioning between the species. Mixtures with faster-rooting faba bean than spring wheat achieved moderate yield at zero N input, with balanced species-specific yield gains. In contrast, mixtures with faster-rooting spring wheat improved total yield gain at higher N levels but reduced the N-fixation advantage. Farmers can optimize root elongation rate combinations and N management strategy based on their desired yield and yield balance between the two species. Breeders may provide farmers with options by providing varieties that differ in root traits. These results show important options and limitations of breeding for intercrops.

Keywords: species mixture, plant traits, complementarity, N fertilizer, rooting depth, productivity

Identification of complementary variety traits for high-performing wheat variety mixtures

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The environmental limitations of intensive agriculture have increased interest in crop diversification strategies that maintain productivity while reducing external inputs. Wheat variety mixtures offer a practical solution because they can improve crop resilience and yield without requiring changes in farming practices. However, most modern wheat cultivars have been bred for performance in pure stands; consequently, there is very little knowledge regarding which varieties could be successfully combined in mixtures.

The present study aimed to use simulation models to evaluate wheat variety mixture performance, identify the mechanisms underlying overyielding, and determine key varietal traits associated with successful mixtures. Eight Swiss wheat varieties were parameterized for the crop simulation model FLORSYS following the methodology of Colbach et al. (2020). Morphological and growth traits were measured under both full-light and shaded conditions to characterize plant responses to competition.

FLORSYS simulations were conducted for pure stands and mixtures containing two, four, six, or eight varieties. Virtual fields were evaluated across six environments and four row spacings. Overyielding and overyielding stability across environments were calculated and related to varietal trait combinations using Classification and Regression Tree (CART) analyses.

The results identified one specific variety as the strongest predictor of overyielding, increasing mixture performance by approximately 0.16 units. Trait-based analyses showed that overyielding was highest when mixtures contained at least one variety with a low relative leaf area height (RLH) at the two-leaf stage, indicating leaf area concentrated closer to the ground. Overyielding also increased with the average height-to-biomass ratio (HBR) of the component varieties, suggesting that taller, more slender plants promote complementary resource use.

These findings highlight the value of FLORSYS for evaluating large numbers of variety combinations and identifying traits associated with high-performing wheat mixtures. Further analyses will investigate traits contributing to mixture stability across environments. Translating these findings into simple selection criteria for breeders and farmers remains a key challenge.

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Keywords: wheat, variety mixtures, overyielding, crop diversification, crop modelling, FLORSYS, varietal traits

Nitrogen stress makes legumes more competitive against weeds in intercrops: a simulation study

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Arable weeds are highly damaging to crop production and usually controlled with herbicides. Species and variety mixtures can contribute to reducing them by increasing biological weed regulation. Multispecies 3D individual-based models such as FlorSys (1) are useful to explore biological interactions in mixtures and to assess the many possible intercropping scenarios. The aim of this study was to evaluate for the first time how nitrogen availability changed legume–cereal–weed interactions, long-term weed dynamics and their impact on crop production. The simulated scenarios included: (1) four cereal–legume species mixtures: wheat (*Triticum aestivum* L.)–faba bean (*Vicia faba* L.), barley (*Hordeum vulgare* L.)–pea (*Pisum sativum L.*), triticale (*Triticosecale*)–faba bean, durum wheat (*Triticum durum* Desf.)–faba bean, with (2) seven species proportions or nine spatial sowing patterns. The mixtures were compared to their corresponding sole crops (controls) with either non-limiting nitrogen availability, or without nitrogen fertilizer. The mixtures (or their controls) were included into rotations simulated with and without weeds, over 30 years and repeated with 10 climate scenarios using weather records from South-Western France. The results showed that plant-plant interactions greatly changed, depending on soil nitrogen availability. When nitrogen was non-limiting, plants competed only for light and then intercropping: (1) reduced yields more in legumes than in cereals compared to sole crops, and (2) reduced weed biomass and yield losses caused by weeds in legumes compared to sole crops. Without N-fertilizer, plants competed for both light and nitrogen and then: (1) legume yields increased and cereal yields decreased compared to non-limiting nitrogen condition, (2) intercropping did not affect legume yields compared to sole crops, and (3) reduced yield losses caused by weeds even more than with non-limiting nitrogen availability. In the future, simulations will also be compared to field observations from the MicMac trial (2) at INRAE Toulouse-Auzeville.

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Keywords: weeds, biological regulation, legume–cereal mixture, 3D individual, based model, plant–plant competition

4. Eco-evolutionary dynamics of pathogens in diversified fields

Scientific committee of Symposium 4

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A population genetics framework to infer host x parasite loci of interactions from genome-wide polymorphism data

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Host-pathogen coevolution is defined as the reciprocal evolutionary changes in both species due to genotype x genotype (GxG) interactions at the genetic level. The type and strength of the GxG interactions determine the outcome and severity of infection. While recently developed co-analyses of host and pathogen genomes (co-GWAs) allow to pinpoint the interacting genes, they do not reveal which host genotype(s) is/are resistant to which pathogen genotype(s). Furthermore, co-GWAs do not account for coinfection by multiple pathogen strains within a single host, a common scenario for many crop and human diseases.

To bridge this gap, we built GxG models with and without disease epidemiology which are embedded in a Bayesian inference method (random forest Approximate Bayesian Computation, RF-ABC). Our model is extending to diploid hosts by designing additional indices and using deviations from the Hardy-Weinberg equilibrium to increase the power of statistical inference.

We apply this framework to two contrasting host–parasite systems: 1) a natural pathosystem, *Daphnia magna* – *Pasteuria ramosa*, and 2) human – HCV. We will present results from these analyses to highlight novel insights gained by accounting for host dominance for resistance. These insights are critical for developing more sustainable disease-control strategies and anticipating the emergence of resistance-breaking or highly virulent pathogen strains.

Keywords: Host pathogen coevolution, GxG interactions, random forest Approximate Bayesian Computation

Eco-evolutionary Dynamics of Zymoseptoria tritici Populations in Wheat Cultivar Mixtures

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Cultivar mixtures are increasingly considered as a key component of agroecological disease management. While their ability to reduce epidemics is well documented, their effects on pathogen evolution remain poorly understood. We investigated the impact of wheat cultivar mixtures with different sources of resistance against Septoria tritici blotch over two field seasons (2024 and 2025) in two locations (west and south of Paris, France), postulating that their effects on the eco-evolution of the pathogen population and the processes driving it increase with the degree of resistance complementarity among cultivars. Binary and ternary mixtures involving cultivars chosen from three, each carrying a different resistance *Stb* gene (*Stb6*, *Stb9*, or *Stb16q*), were compared with pure stands. Disease severity was assessed throughout epidemics, and infected leaf samples were collected for molecular analysis of pathogen populations. Frequencies of avirulence gene variants (*AvrStb6*, *AvrStb9*, and *AvrStb16q*) were estimated using a molecular method based on amplicon sequencing, preliminary developed and cross-validated against a bulk phenotyping method. Disease severity in mixtures was lower than the mean severity of their corresponding pure stands, with effects particularly pronounced for certain cultivar combinations. This result confirms the efficacy of mixtures in reducing disease severity, with effects similar or even exceeding those reported in the literature (Kristoffersen et al., 2019). Molecular analyses revealed shifts in avirulence allele frequencies depending on cultivar combinations. These changes suggest that cultivar mixtures can alter the selective environment experienced by pathogen populations, shifting the relative abundance of virulent and avirulent strains within this population and thereby influencing its overall phenotype. This second set of results is consistent with those obtained in simpler susceptible–resistant mixtures, as well as with the theory of disruptive selection. It shows that "smart" mixtures, selected for complementary resistance sources, may reduce disease severity, while also influencing the long-term effectiveness or durability of resistance genes. By combining field epidemiology and molecular monitoring of avirulence genes, this work contributes to the design of more effective agroecological diversification strategies.

Keywords: Plant disease epidemiology, agroecology, pathogen evolution, resistance durability, avirulence genes, cultivar mixtures

Formalization of plant-plant-pathogen interactions in the Biodiversity Ecosystem-Functioning Framework : case study in wheat varietal mixtures

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The Biodiversity - Ecosystem Functioning (BEF) framework analyses the response of ecosystemic traits (biomass, temporal stability etc) to changes in ecosystem diversity. The trait difference between a diverse and a non diverse ecosystem is called the Net Biodiversity Effect (NBE). Loreau and Hector 2001 decomposed NBE for the first time into two ecological effects : selection and complementarity, helping dissect the interactions that happen in complex ecosystems.

The BEF framework finds positive effects of increased species richness on plant biomass and its temporal stability in grasslands. Similar positive effects of increased intraspecific diversity are found in crop varietal mixtures, making them an important but underused agronomical tool to increase and stabilize yield, especially under lower pesticide use. Varietal mixtures are indeed known to better control diseases, both through ecophysiological and epidemiological processes. However, the interplay between plant-plant interactions and plant-pathogen interactions remains poorly understood.

We designed a field trial, replicated over two years, of 4 wheat varieties, contrasted in their disease resistance and competitive ability. Each cultivar was grown in fungicide-treated vs untreated conditions, in monovarietal stands vs binary mixture. Varietal proportions were estimated by manual spike counting per variety at harvest.

We then leveraged an existing NBE decomposition already accounting for selection, plasticity and density effects (allowed by the assessment of varietal proprotions), and extended it further to jointly analyze both monovarietals vs mixtures as well as low vs high pathogen pressure, separating mixture, disease and their interaction effects. The significance of each term in this new decomposition was then assessed in a linear mixed model.

Compared to the classical decomposition that ignores density changes, we found that plant-plant interactions were mostly controlled through density effects. Moreover, thanks to our new joint decomposition, mixture-disease interactions were significant in some cases whereas separate analyses did not find any disease effect. We also found that plant-plant-pathogen interactions had a significant negative effect on density, linked to lower disease score in mixture. This negative density effect was compensated by an opposite increase in plasticity, i.e., higher yield per spike in mixture.

Keywords: Biodiversity ecosystem, functioning, plant, plant interactions, plant, pathogen interactions, wheat varietal mixtures

Evaluating the reliability of a coupled crop–disease model for simulating intercropping effects on aerial fungal diseases

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Intercropping is a promising lever for reducing aerial fungal disease pressure through dilution and barrier effects as well as microclimate modification. Mechanistic modelling offers a route to scale experimental insights and explore various field combinations which is rarely done in an intercropping context (1).

We present a two-component study using the crop model STICS coupled with the disease model MILA, applied to a wheat–pea-brown rust pathosystem:
- a model evaluation conducted against a new multi-site, multi-year dataset to assess predictive precision and robustness across contrasting pedoclimatic and agronomic conditions. Performance is examined through uncertainty in both simulations and observations (RMSEs, bias, EF, residuals, etc) (3,4);
- concomitant with a cluster-based global sensitivity analysis (2) to: (i) identify parameters exerting dominant control over simulated disease dynamics; (ii) compare the sensitivity-ranked parameter space against values reported in experimental literature, thereby exposing under-constrained parameters; and (iii) use cluster-based analysis of dynamic output trajectories to classify model behavioural regimes and understand how parameter interactions drive divergent disease outcomes under intercropping.

Together, these two approaches provide a structured framework for quantifying what the model can legitimately be used for. Evaluation defines empirical predictive bounds; sensitivity analysis maps the distance between the experimentally accessible parameter space and the full domain in which the model produces plausible outputs - a gap that directly informs confidence in simulated scenarios. This work contributes a transferable methodology for honest model benchmarking in diversified cropping systems, where experimental data remain scarce relative to the diversity of species, variety and environment combinations of interest. The results presented can also provide guidance in the implementation of future experiments.

Keywords: Agroecology, model evaluation, wheat, pea, brow rust, uncertainty quantification, parameter sensitivity

Intercropping chickpea with oat combined with inter-row mowing reduces ascochyta blight severity along the main axis and alters the shoot architecture

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Chickpea is a key species for the agroecological and dietary transitions. Yet, its adoption is hindered by yield fluctuations, notably due to weeds and ascochyta blight (*Ascochyta rabiei*). Introducing service plants can provide weed and disease regulation in low-input cropping systems (1). Still, regulating them may be necessary, for example *via* mowing, to avoid high yield reductions in the cash crop (2). In this study, we investigated the effect of these innovative practices on chickpea's shoot architecture, pod production, and ascochyta blight severity. A two-year field experiment (2023, 2024) was conducted near Angers (France). Chickpea was grown as a sole crop or in intercrop with oat sown in the middle of the inter-rows. Chickpea's inter-rows were either not mowed or mowed once at early flowering. In 2024, an additional earlier mowing was tested in the intercrop. At grain-filling, plant biomass (chickpea, oat, weeds) was measured, chickpea's shoot architecture was described, and ascochyta blight severity on leaves was assessed at each node on the main axis using a 0-4 scale. The two years were very contrasted, with a much higher weed and disease pressure in 2024 than in 2023. Ascochyta blight was always lower in the intercrop, especially under high disease pressure, with visible effects from the first basal nodes. Still, in 2023, introducing oat decreased branching, pod production, and node number, while mowing had no effect. By contrast, in 2024, intercropping had a limited effect on the shoot architecture, while mowing increased branching by 78% on both the sole and intercropped chickpea. In 2024, adding an earlier mowing during the vegetative phase in the intercrop doubled pod production, while maintaining the same level of disease control than the intercrop without mowing or with a single mowing at flowering. This work underlines the relevance of mowed intercropping systems for reducing disease severity, while limiting competition with the cash crop.

References: (1) Moreau et al. (2025). Agron. Sustain. Dev., 45, 38. (2) Guy et al. (2026) Eur. J. Agron., 178.

Keywords: companion plant, inter, row mowing, crop plasticity, disease control

Multi-facets of intercropping for suppressing soil-borne disease in faba bean

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Soil-borne Fusarium wilt threatens legume production worldwide. Intercropping can alleviate this disease, but the underlying mechanisms remain poorly understood. Here, we combined a long-term field experiment (since 2009) with physiological and metabolomic analyses to investigate how faba bean/maize intercropping reduces Fusarium wilt. Across three phosphorus levels (0, 40, 80 kg P ha-1), intercropping consistently reduced disease index by 18–50%, and decreased the rhizosphere abundance of *Fusarium oxysporum* and *F. solani* by 28–60%, compared with monoculture. Intercropping lowered soil temperature by 1.0–1.5∘C and weakened its positive correlation with disease incidence. Disease suppression was also related to enhanced activities of antioxidant enzymes (SOD, CAT, POD) and reduced malondialdehyde (MDA) content in faba bean leaves under moderate phosphorus supply (40 kg P ha^{-1}). Non-targeted metabolomics identified 1,011 differential metabolites between intercropped and monocropped faba bean rhizosphere. Under moderate P, intercropping significantly upregulated antimicrobial and signalling-related metabolites, including isoalantolactone and 2-methoxy-4-nitrophenol. In the maize rhizosphere, intercropping similarly enriched antifungal metabolites such as equisetin and 2′,5′-dihydroxychalcone which were correlated with disease suppression. Importantly, by alleviating Fusarium wilt, intercropping relieved biotic stress on faba bean, and this effect was associated with a 9-28% increase in soil multifunctionality and higher nutrient concentrations in faba bean straw and seeds. Our findings demonstrate that intercropping suppresses soil-borne disease through enhanced host antioxidant defence and enrichment of antifungal metabolites in both the legume and maize rhizospheres. These results provide a mechanistic basis for designing disease-suppressive intercropping systems and reducing pesticide use in sustainable agriculture.

Keywords: antioxidant enzymes, Fusarium wilt, rhizosphere metabolome, soil multifunctionality, sustainable agriculture

Host genotype and agroecological practices generate context-dependent Fusarium wilt dynamics in diversified banana systems under Foc TR4 pressure

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Diversified cropping systems can reduce disease spread and severity, but their effects on pathogen dynamics often emerge from interactions among host identity, associated plant species, and soil practices. Banana systems provide a relevant model to explore these processes because production is often dominated by genetically narrow monocultures that are highly vulnerable to *Fusarium oxysporum* f. sp. *cubense* tropical race 4 (Foc TR4). We used banana as a model pathosystem to test whether host genotype and agroecological practices act additively or interactively to regulate Fusarium wilt.

We combined a Foc TR4-infested on-farm experiment in Laos with a complementary greenhouse experiment designed to disentangle the effects of individual and combined practices. In the field, four banana cultivars, Cavendish 'Grande Naine' cv. 901, Gros Michel, Kuay Nam and Lep Mue Nang, were combined with four management practices: untreated control, *Trichoderma harzianum* application, chicken manure-based organic amendment and lemongrass intercropping. Field disease dynamics were assessed through symptom appearance and internal progression, while a complementary greenhouse experiment tested the same cultivar panel under single and combined agroecological practices. This combined approach allowed us to evaluate whether disease regulation resulted from additive practice effects or from cultivar-dependent interactions. In the field, disease incidence reached 46%. Symptom onset depended on treatment, cultivar and their interaction, while internal progression was mainly structured by management practice. Organic amendment accelerated symptom appearance and increased internal progression, whereas lemongrass intercropping reduced disease progression. *T. harzianum* remained close to the untreated control, and Lep Mue Nang showed the lowest internal disease progression among the tested cultivars. In the greenhouse, most practice combinations were consistent with additivity, but significant cultivar-specific departures occurred.

Together, these results show that disease regulation in diversified banana systems cannot be inferred from average cultivar resistance or individual practice effects alone. Instead, Fusarium wilt dynamics emerge from specific host genotype × practice combinations, which may either suppress or amplify disease depending on the cultivar, the associated plant species and the soil-management context. This highlights the need to design diversified agroecosystems from functional associations between cultivars, service plants and soil practices, rather than from single control levers considered in isolation.

Keywords: Agroecological practices, host diversity, diversified cropping systems, Musa spp., Fusarium oxysporum f. sp. cubense tropical race 4, Lao PDR.

Deciphering the mechanisms of crop disease regulation by cover crops and tree hedges: a functional approach applied to grapevine downy mildew

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Transitioning from input-dependent to more self-sufficient cropping systems is one of the major challenges facing agriculture in the 21st century. In particular, pest and disease control must be achieved using strategies alternative to chemical pesticides, which threaten our health and ecosystems. Extensive ecological research has shown that biodiversity promotes ecosystem functioning. In particular, herbivory and plant parasitism tend to be better regulated in more diverse plant communities. These findings suggest that enhancing plant diversity in cropping system may be an effective strategy to limit crop damage. However, the underlying mechanisms involved in diversification strategies are still poorly understood, and translating this general principle into practical agricultural solutions remains difficult. As a result, farmers often lack clear guidance on which forms of plant diversification are most likely to deliver reliable pest and disease regulation. To address this gap, we will combine a literature review with a two-year field experiment to decipher the mechanisms through which cover crops and tree hedgerows influence epidemics of grapevine downy mildew, an aerial disease caused by the oomycete *Plasmopara viticola*. Using structural equation modelling, we will test for a set of hypotheses whereby the effects of plant diversification on disease dynamics are mediated by changes in i) soil and air microclimatic conditions, ii) the composition of host-associated microbiota, iii) host vigor and chemical defenses, and iv) pathogen dispersal. We will then identify the plant community properties that best predict disease regulation, including taxonomic and functional composition and diversity. Finally, we will develop a trait-based framework linking plant community properties to disease-regulation mechanisms across successive stages of epidemic development. By providing a mechanistic understanding of biodiversity–disease relationships, we aim at providing actionable knowledge for the design of diversified cropping systems that reduce reliance on chemical pesticides.

Keywords: integrated pest and disease management, agroecological infrastructures, trait, based approach, functional diversity, structural equation modeling

Agrobiodiversity as a foundation for cocoa tree health through pests and diseases regulation and resources access pathways

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Cocoa agroforestry systems are complex and diversified plant communities shaped by interactions between cocoa trees, companion trees, neighbouring cocoa trees, pests, diseases and local environmental conditions. This agrobiodiversity may support ecosystem functions that can help reduce yield losses, stabilise production and improve crop health. However, designing and managing such systems requires integrative approaches able to link the species composition and spatial organisation of agrobiodiversity with stress regulation processes and cocoa tree performance, consequently, with cocoa tree health.

Here, we tested the hypothesis that the organisation of agrobiodiversity influences cocoa tree health through two complementary pathways: resource access, which determines attainable yield, and stress regulation, assessed through composite indicators of abiotic and biotic stress and relative yield losses.

In Côte d'Ivoire, 10 organic and 8 conventional cocoa plots were selected along gradients of agrobiodiversity and management intensity using floristic inventories, farmer interviews on management practices and their perception of cocoa tree health. Within each plot, two 400 m^2 zones were delineated: a High perceived health zone (Hph) and a Low perceived health zone (Lph). A tree-centred approach was then applied, characterising each focal cocoa tree in terms of structural attributes, productivity, stress indicators, and the agrobiodiversity structure of its influencing neighbourhood (companion-trees and nearest-neighbour cocoa trees). At the zone scale, soil properties were included as supplementary variables and analysed together with management practices.

Our results show that cocoa health is an emergent and scale-dependent property shaped by the interaction between resource access and biotic stress regulation. At the tree scale, wider cocoa spacing and a higher canopy position of companion-tree increased attainable yield, whereas higher companion-tree abundance decreased it. This reveals both complementary and antagonistic effects of agrobiodiversity. At the zone scale, Hph zones showed higher yields, whereas Lph zones concentrated biotic stress and abiotic stress responses. These patterns were consistent with farmers' perceptions of cocoa health. Organic plots tended to display healthier soils and lower defoliation. These findings suggest that cocoa health reflects the system's capacity to maintain performance under stress. Designing sustainable cocoa agroforestry systems therefore requires accounting for structural characteristics of agrobiodiversity while acknowledging that trade-offs are unavoidable.

Keywords: Theobroma cacao, farmers' perception, companion tree, diversity, neighbourhood effects, biotic stress regulation, abiotic stress responses, attainable yield, yield losses, integrative indicator

Symposium 4: presentation of posters

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Presentation of posters submitted in symposium 4. For abstracts, see the poster section of this document.

Keywords: Symposium 4, Posters

5. Designing mixtures for agroecological value chains

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Exploring the challenges and opportunities of using companion plants in apple orchards

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As part of an agro-ecological approach, the introduction of companion plants in apple orchards can provide a range of ecosystem services including pest regulation, improving soil structure or diversified income sources. However, the orchard management practices involved remain a source of uncertainty for growers, both in terms of their effectiveness and the technical changes they may require.
An assessment of current practices was carried out through semi-structured interviews with apple growers in two major production regions in France. The 34 survey responses revealed that crop diversification practices are rarely used (accounting for 7.2% of all practices mentioned by apple growers), and that they are intended to control aphids in 25% of cases. Apple growers perceive these practices as beneficial for supporting natural enemies and enhancing soil structure, but they require more technical and organizational adjustments as well as additional efforts in other pest management.

The potential for using companion plants was further explored during participatory workshops bringing together stakeholders from research, experimentation and advisory services. These discussions highlighted several technical, economic, and organizational barriers to their adoption in orchards.
Best practices for introducing companion plants have not yet been clearly identified, due to the diversity of production contexts. This highlights the need to coordinate, multi-site field trials and the development of shared guidelines, including common protocols for implementation and monitoring companion plants.
Addressing the identified barriers will require adopting a multi-criteria assessment framework that incorporates technical, economic, and organizational dimensions to meet stakeholders' objectives.

Keywords: apple orchard, companion plants, pest control, economic and organizational factors

Grain Legumes at the Nexus of Intercropping Systems and Agroecological Transition: Barriers and Potentials from a Swedish case study

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The transition toward more sustainable and resilient agri-food systems requires the wider adoption of agroecological practices such as intercropping. For grain legumes, including peas and lentils, intercropping can help address key production challenges such as lodging and weed pressure while enhancing system diversity and resilience. Furthermore, grain legumes provide a valuable source of dietary protein and are associated with lower environmental impacts than many alternative protein sources. Despite these benefits, both grain legumes and intercropping remain marginal in Swedish agriculture.
This study examines the challenges and opportunities for the transformative outscaling of agroecological practices through the case of grain legumes and intercropping. The analysis draws on a multi-stakeholder workshop held at the Swedish University of Agricultural Sciences (SLU) in Alnarp in January 2025 within the Horizon Europe project, IntercropVALUES and the 'Bönan till Bordet' initiative, complemented by interviews with farmers, advisors, and value-chain actors.

Findings show that barriers to outscaling extend beyond farm-level challenges. Low consumer demand for Swedish-grown legumes, limited access to suitable varieties, disease risks due to frequent legume in the crop rotation, insufficient advisory support, and the complexity of managing intercrops all constrain adoption. Infrastructure gaps in drying, sorting, processing, and storage, together with profitability concerns and quality standards favouring uniform products, further limit expansion. At the same time, stakeholders identified important leverage points for change, including stronger procurement from private individual and public kitchens, retailer engagement, supportive policies, farmer-led innovation, improved advisory services, and investments in infrastructure for diversified production systems.

The results suggest that scaling agroecological practices such as intercropping requires transformation across the entire food system. Coordinated action among farmers, advisors, researchers, policymakers, industry, and consumers is needed to move legumes and agroecological innovations from niche to mainstream.

Keywords: Adoption Barrier, Agroecological transition, Grain Legume, Intercropping, Scaling out

Species mixtures beyond the farm: the role of grain collection organisation

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Species mixtures are increasingly promoted to improve the sustainability of cropping systems (1). Their implementation remains highly diverse, with variation in species combinations, spatial arrangements, temporal coexistence, and farmers' objectives. Previous studies have identified several farmer action logics, including the pursuit of farm autonomy, the valorisation of all species within mixtures, and the provision of ecosystem services at the crop level (2,3). In contrast, grain collection organisations (cooperatives and grain merchants), despite their key position at the beginning of the value chain, have received less attention. By deciding which mixtures can be collected and marketed, they strongly influence farmers' choices. This study examines the design logics underlying species mixtures from the perspective of grain collection organisations.

The analysis draws on qualitative interviews with 17 grain collection organisations, including 13 in metropolitan France and four in Switzerland. This paper presents preliminary results from the French sample. Interviews were recorded, transcribed, and coded to identify accepted species mixtures and the rationales guiding organisational decisions.

Thirty-three different mixtures were identified of which 20 were accepted by one organisation. Only one mixture did not include a grain legume. Lentil-based mixtures dominated, with 25 combinations involving six lentil types and eight companion species. Eighteen of these combinations were unique to a single organisation, illustrating extensive local experimentation.

Three preliminary organisational types had emerged. Small fully organic cooperatives (<30 employees) pursue strong diversification strategies through both pure and mixed crops while experimenting with new species mixtures. They accept the widest diversity of mixtures, although limited storage capacity can restrict collection at harvest. Mixed organisations collecting only a few common forage mixtures treat species mixtures as a marginal activity and, in some cases, are considering reducing or discontinuing their collection. A third group of mixed organisations has adapted its logistics to handle five to eight mixtures, including several lentil-based combinations.

These findings confirm that organisations already structured for crop diversification are more likely to support species mixtures (4). They also show that logistical and organisational capacities shape mixture design alongside agronomic considerations, highlighting grain collection organisations as key actors in the development and diffusion of species mixtures.

Keywords: Species mixtures, Grain collection organisations, Value chain, Crop diversification

Legume integration modes in French cropping systems often imply intercropping

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The integration of legumes into cropping systems is one of the key levers for enhancing crop diversification. Legumes, through their capacity to fix atmospheric nitrogen, can reduce energy consumption and greenhouse gas emissions, enhance the yield of subsequent crops, and contribute to the disruption of pests, diseases, and weeds cycle through increased crop diversification. However, the place of legumes in French arable cropping systems remains limited.

A better understanding is needed of how legumes are integrated into cropping systems - either as sole crops or through intercropping - and under which pedoclimatic, socio-economic conditions these integration strategies occur.

In this study, we used data from the DEPHY network database, which provides detailed descriptions of around 10,000 year:cropping systems from French commercial farms between 2010 and 2024. Our objectives were to characterize the diversity of legume integration modes in cropping systems and to investigate more precisely which legumes were often intercropped. Using machine learning algorithms (CART and random forests), we identified the main contextual factors associated with legume richness in cropping systems, based on an original index and the diversity of legume integration modes.

Preliminary results identified 29 legume integration modes, of which 14 are dominant, and 9 include intercropping with legumes. Each integration mode was strongly associated with several legume species. We also showed that organic farming, along with climatic and soil characteristics, is the main driver of legume richness in cropping systems. Ongoing analyses would enable the identification of the main contextual factors associated with the integration of intercropped legumes.

Finally, this study underlines the high diversity of ways to integrate legumes into cropping systems and highlights the link between legume presence in cropping systems and production contexts.

Keywords: crop diversification, DEPHY network, production context, CART – random forest – legume intercropping

Importance of the plant dominance in the design of complex service plant mixtures

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Abstract: Crop diversification through the introduction of service plants into the cropping system allows to provide ecosystem services with relatively moderate evolution within the cropping system and value chain. Nevertheless, to be implemented in practice, service plants intercropped with cash crops must provide multiple services (1). To combine a variety of services, a common approach is to use mixtures of species with contrasting and complementary functional traits. Yet, in our studies, we found that even complex mixtures made of more than 4 species were often largely dominated by a single species governing the provision of ecosystem services. This result was supported by several studies performed on rapeseed-service plants intercropping conducted in Switzerland both in field experiments, farmer field networks, and greenhouse experiments (2, 3). These results question the empirical design approach, based on the plant traits measured in monocrops. It also highlights the need to manage the dominance mechanisms within service plant mixtures. For example, recent work on intercropping spatial arrangement and service plant mowing are promising approaches (4). References: (1) Moreau, D., et al. (2025). Potential of service plants for regulating multiple pests while limiting disservices in agroecosystems. A review. Agronomy for Sustainable Developpement 45, 38. (2) Bousselin, X., et al. (2024). Determinants of oilseed rape-service plant intercropping performance variability across a farmers' fields network in Western Switzerland. Agronomy for Sustainable Development, 44(4). 40. (3) Bousselin, X., et al. (2024). Winter oilseed rape intercropped with complex service plant mixtures: Do all species matter? European Journal of Agronomy, 154, 127097. (4) Guy, M., et al. (2026). Intercropping chickpea with a competitive service plant and mowing the inter-rows controls weeds and ascochyta blight while mitigating interspecific competition. European Journal of Agronomy, 178, 128112.

Keywords: Intercrop, complex plant mixtures, dominance, services plants, functional trait.

Higher plant diversity increased yields of grassland leys more than application of nitrogen fertiliser, and forage legumes controlled legacy effects in a subsequent crop

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Sown productive grasslands are used as leys in a crop rotation, and typically comprise low species diversity. In intensively managed grassland leys, we investigated the effect of experimentally varying the plant diversity of a grassland ley on forage yield and on yield of a follow-on crop (the 'legacy effect'). At each of 26 international LegacyNet sites across 15 countries (1), plant diversity was manipulated from one to six plant species, and managed with moderate levels of chemical nitrogen fertiliser (mean = 110 kg per ha per yr). We also had plots with a single grass species, managed with at least twice the amount of fertiliser (mean = 260 kg per ha per yr). We tested whether adding up to two grasses, two legumes, and two herbs as 'multispecies mixtures' could maintain or improve yields in a grassland ley while reducing the reliance on nitrogen fertiliser. We also investigated the effect of plant diversity in the grassland ley on yield of a subsequent crop i.e. the legacy effect. We used Diversity-Interaction modelling to quantify the effects of varying the sown species proportions on i) yield and ii) the legacy effect. We also tested the inclusion of temperature in the model for yield.

Sowing two grasses, two legumes and two herbs each in approximately equal proportions optimised yield and delivered nitrogen-saving benefits in the grassland ley. The yield advantage of mixtures was greater at warmer sites, indicating a role for plant diversity as a climate adaptation practice in grassland leys. Across all 26 LegacyNet sites, the six-species multispecies mixture yielded 11% more than a grass monoculture with more than double the amount of nitrogen fertiliser, and 18% more than a two-species grass-legume combination. Legacy effects of the grassland ley on yield of the subsequent crop were strong, and driven by the proportion of forage legume in the ley.

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Keywords: mixtures, multispecies, nitrogen, climate, clover, monoculture

Impact of pea genotypes on their performance in intercropping with different species

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Field pea is a grain legume widely used in livestock feed but also popular in human vegetarian diets. Its production in Europe faces many challenges with a constant yield reduction since the 90' and despite an interest for vegetal protein production, its area has sharply decreased. Intercropping is regarded as an efficient strategy for increasing sustainability and resilience of agricultural systems, with particular relevance to pea production given the crop's capacity for biological nitrogen fixation.

We assessed the performance of 12 field pea cultivars in pea-barley and pea-lentil intercropping, compared to monocrop, over two growing seasons. As this study focuses on legume production, the relative sowing densities were 80% / 30% of the recommended densities in pure stand for peas and the associated crop, respectively. We assessed lodging, disease development, grain yield and quality of the harvest.

Intercropping with barley allowed an efficient control of diseases on peas but barley was too competitive to maintain pea yield. Conversely, intercropping with lentils allowed peas to maintain yield under unfavourable years, despite a limited impact on lodging and diseases.

Strong differences among pea cultivars suggested that some pea varieties are more suitable for intercropping than others. Surprisingly, the most sensitive varieties to Ascochyta blight were not the one benefiting most from the addition of barley, despite the improvement of their sanitary status.

These results highlight the importance of an integrated approach that combines species and varietal choice as well as relative sowing density of each species to maximize the benefit of intercropping.

Keywords: intercropping, pea, pea, barley, pea, lentil, variety choice

Cultivars impact competition-induced complementarity for nitrogen in intercrops

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Cereal-legume intercrops have a better usage of resources compared to sole crops (1), notably due to the complementarity between species for nitrogen acquisition (2). However, average allocation to grain tends to be reduced in intercrops (3), with a size threshold for each species above which intercropped plants had a greater yield increase (4). However, the genetic basis of plasticity between stand types remains poorly studied.

We observed in the field 40 wheat cultivars in sole crops and intercropped with a pea tester under a randomized complete block design. They were phenotyped for phenology, above-ground biomass at three wheat stages (tillering, flowering and maturity), grain allocation and protein content. N isotopes were determined in above-ground biomass at tillering and flowering. Linear models were used to test for genotypic deviations from the average reaction norm between stand types, and standardized major axis regression for differences in allometric slopes.

The average land equivalent ratio was 1.30 for above-ground biomass, 1.46 for grain yield and 1.56 for grain protein yield. The respective genetic CV were 20%, 23.5% and 24%, indicating substantial genetic variability. Harvest index had a strong heritability (0.87) and was significantly lower in intercrop, though only by 1.8%. The allometric slope between pea grain yield and above-ground biomass was significant lower (33%, but with a higher intercept) in intercrop than in sole crop. Pea nitrogen derived from symbiotic fixation was higher in intercrop, by 24% at tillering and 18% at flowering, and some wheat genotypes stimulated it more than others. On all these traits, the reaction norm between stand types was significantly different from the main trend for several wheat genotypes. These results demonstrate the substantial genetic variability in wheat on competition-induced complementarity for nitrogen in intercrops, which opens the way to a more physiological approach to breeding for intercropping.

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Keywords: plant, plant interactions, reaction norm, symbiotic fixation, allometry, complementarity

Towards intercrop-adapted varieties: exploring links between phenotypic traits and performance in cereal–legume mixtures

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Breeding varieties adapted to cereal–legume intercropping systems remains challenging, partly because the main phenotypic traits associated with performance under mixed cropping conditions are still poorly identified. In this context, a multi-environment trial network was established at INRAE (France) to evaluate several cereal–legume species combinations under intercropping.

For each experimental design, a panel of varieties was tested in association with a common partner variety, allowing varietal performance to be compared. The trials were conducted across 7 contrasting environments, along both east–west (Dijon-Rennes) and north–south (Amiens-Toulouse) geographical gradients, in order to assess varietal responses under diverse pedoclimatic conditions. Trials focused on four species combinations : wheat-pea, faba bean-triticale; pea-barley and pea-wheat mixtures.

During the growing season, several phenotypic traits were recorded in a subset of trials. At harvest, grain yield, specific weight, grain moisture content and thousand-kernel weight were measured for both cereal and legume components as well as protein content of wheat grain.

The objective of this study was to identify phenotypic traits associated with improved varietal performance in intercropping systems. To this end, adjusted means have been estimated while accounting for block effects within each trial. A hierarchical clustering analysis has then be performed to identify groups of varieties showing contrasting performance profiles. In a second step, phenotypic traits measured during the growing season have been related to harvest performance, in order to identify traits that could be used as selection criteria. In this presentation, we will focus on the results obtained on the wheat-pea mixture. In this trial, 25 wheat varieties, contrasting in their early vigor, height, and earliness to heading, were evaluated in mixture with one Hr pea variety (Flambo) over 12 environments (localization*year).

Keywords: intercrops, breeding, ideotypes, field trials network, phenotypic traits

Friday 9h October

Improving soybean yield in relay-cropping under water stress: from genotype selection to cropping system management

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Relay-cropping is an asynchronous cropping system where planting and harvesting of two crops are staggered, enabling two harvests per year and improving land productivity. However, the second crop (e.g., soybean) often suffers from competition with winter cereals, leading to highly variable yield losses depending on climatic conditions. Given soybean's sensitivity to water stress, developing drought-resistant genotypes is essential, especially under increasing drought frequency and intercropping systems. This study combines field and controlled experiments to assess soybean functional and hydraulic traits under relay-cropping and water stress. Long-term trials (5-years experiment) were conducted in southwestern France to evaluate yield and land equivalent ratio (LER) under irrigated conditions. Additional field experiments in northern France examined barley/soybean relay-cropping under non-irrigated conditions using four contrasting soybean genotypes, focusing on root traits and their plasticity. Controlled experiments on ten genotypes assessed hydraulic traits, including vulnerability to embolism and residual transpiration. Relay-cropping showed strong productivity under irrigation (mean LER 1.62), with no impact on cereals but a 25% average yield reduction in soybean. Under non-irrigated conditions, relay-cropping intensified drought stress, increasing interspecific competition and affecting soybean development. However, phenotypic plasticity of soybean functional root traits to relay cropping was observed under non-irrigated conditions – root traits such as root nodule density, specific root length and lateral root angle increased under relay-cropping. However, it did not allow performance traits interactions and thus contrasted the response of genotypes to relay-cropping. Relay-cropping increases water competition and limits soybean performance, making irrigation critical during early developmental stages. Soybean adapts through root trait plasticity, enhancing water acquisition. This highlights the importance of selecting genotypes suited to relay-cropping based on root traits. Despite its general sensitivity to drought, soybean exhibits sufficient genetic variability to identify more resistant genotypes, with embolism resistance emerging as a promising selection trait.

Keywords: competition, crop association, functional traits, water stress, root plasticity

Weed management in organic grain legumes: effects of cereal-legume intercropping and chickpea Rhizobium inoculation in an on-farm experimental network across two northern French regions

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Integrating grain legumes into cropping systems is a key strategy for crop diversification and the transition toward more plant-based diets. This study aims to evaluate the effects of two management practices for grain legumes (intercropping legumes with cereals, particularly lentil with barley, and chickpea *Rhizobium* inoculation) on weed control under organic farming conditions within a multi-site, multi-year on-farm experimental network.

This on-farm experimental network was co-designed through multi-stakeholder workshops to assess the feasibility of producing five grain legume species (lentil, chickpea, lupin, faba bean, and pea) for human consumption under organic farming conditions across two French regions (Brittany and Grand Est). The experimental design included comparisons of contrasting management practices for a given grain legume species within the same site-year. Comparisons between sole-cropped legumes and cereal-legume intercrops were conducted for six experimental situations in 2025, including three comparisons between lentil and lentil-barley intercrop. Comparisons between inoculated and non-inoculated chickpea were carried out for two experimental situations in 2025 (exclusively in the Grand Est region). We assessed weed above ground biomass and ground cover, as well as lentil harvestability, chickpea *Rhizobium* nodulation, crop aboveground biomass, grain yield, and grain quality. The present study specifically focuses on weed control and is based on data collected in 2025.

Results showed that across the entire experimental network, weed aboveground biomass at crop maturity was negatively associated with crop aboveground biomass. Compared with sole-cropped legumes, legume–cereal intercrops reduced weed aboveground biomass at maturity while increasing crop aboveground biomass. Intercropping lentil with barley reduced weed ground cover relative to sole-cropped lentil as early as the vegetative phase (–35%) and during the flowering-grain filling phase (–64%), and also reduced weed aboveground biomass at maturity (–63%). Chickpea *Rhizobium* inoculation reduced weed ground cover from the vegetative phase onward (–39%) and during the flowering-grain filling phase (–50%), and decreased weed aboveground biomass at maturity (–32%). Chickpea inoculation also doubled grain yield from 4.6 qt/ha to 9.8 qt/ha.

These preliminary analyses suggest that intercropping grain legumes with cereals and inoculating chickpea can enhance weed control under organic farming conditions. These results will be complemented by data collected in 2026.

Keywords: grain legumes, organic farming, weed management, intercropping, chickpea Rhizobium inoculation, on, farm experimentation

Impact of a lucerne living mulch managed by mowing in alternate rows with winter cereals in organic farming

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In organic farming, a lucerne (alfalfa) living mulch was established in alternating rows with cash crops. Its growth and competitivity was managed through repeated passes of a specific inter-row cultivation machine. First results showed that lucerne had no impact on the crop in which it has been established. However, in the following years, this practice reduced winter cereal yields by 35% on average. Despite high amounts of nitrogen returned to the soil through lucerne biomass controls at different periods, no significant benefit was observed for the nitrogen nutrition of cereals. Lucerne appeared to compete strongly with cereals from the end of winter onwards, including nitrogen. Water did not appear to be a limiting factor for winter cereals. Suppressing lucerne growth by mowing alone proved difficult in organic cereal systems, where crop canopy closure is generally limited. Field trials showed that the living mulch competed in most cases quite totally on spring crops. After lucerne termination, winter cereal and maize yields increased by up to 40%. After three years of practice, lucerne living mulch improved organic matter content on 0-20 cm layer and until 40-60 cm. It also had a positive impact on structural stability, earthworm population and microbial biomass. These improvements were brought by lucerne as well as soil tillage intensity reduction. Experiments conducted under various conditions have highlighted how much this technique requires precision in field management, particularly when it comes to maintaining distinct rows between the crop and the associated living mulch. Further progress is also expected on genetic, for example by developing lucerne varieties better adapted to this practice. Cropping system management, especially crop rotation, must also be adapted to successfully implement this practice. Finally, further improvements in inter-row mower equipment could enhance the efficiency of the system.

Keywords: Organic farming, lucerne, cereals, alternated rows, moving.

Effects of mechanized wide-strip intercropping integrated with soil fertility improvement practices on crop productivity and soil fertility: evidence from field experiment and large-scale commercial production

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Wide-strip intercropping offers a mechanization-friendly alternative to traditional narrow strip systems, but its yield advantage, soil fertility improvement, and on-farm economic and environmental benefits remain unclear, as does the potential for integrating soil fertility management practices. To address this gap, a two-year split-plot design field experiment, along with a study combining face-to-face interviews was conducted in Northwest China. Main plots were four soil fertility practices: chemical fertilizer alone (CF), CF with organic manure (CF+OM), CF with straw return (CF+SR), and CF with both manure and straw return (CF+OM+SR). Subplots were five cropping systems: maize, wheat, and pea monocultures, wheat/maize with green manure, and pea/maize with sudangrass.

Intercropping significantly increased productivity over monocultures, mainly by raising maize yields (grain: +10.8–30.7%; biomass: +1.3–18.7%) and whole-system outputs (grain: +8.7–27.6%; biomass: +0.5–17.7%). Land equivalent ratios (grain: 1.04–1.28; biomass: 0.99–1.20) and increased to 1.05–1.47 when double cropping crop was included. Overyielding was driven by temporal niche differentiation, interspecific facilitation, and density effects, with mechanisms differing between wheat/maize (competition-recovery) and pea/maize (border-row advantage and facilitation). Fertility management had no significant yield effect in the first two years but improved soil quality index (SQI) under intercropping, especially in CF+SR and CF+OM (+14.4%), and highest in CF+OM+SR (+20.3%). Ecosystem multifunctionality (EMF) was highest under CF+OM+SR and positively correlated with SQI; CF+OM+SR with intercropping also increased soil C, N, and P cycling gene abundance versus CF monoculture. In practice, wheat/maize increased grain yield (+8.7%) and net income (+27.1%), while pea/maize maintained yield and increased net income (+54.9%). Both intercrops reduced environmental impacts across multiple dimensions (e.g., global warming, water consumption), with pea/maize reducing all assessed categories.

These results demonstrate that wide-strip intercropping delivers yield advantage. When combined with fertility management, it rapidly enhances soil fertility. At the farm level, this study reveals synergies among higher yields, increased income, improved soil health, and reduced environmental impacts, positioning wide-strip intercropping as a viable strategy for ecologically intensified, machinery-operated agriculture.

Keywords: wide strip intercropping, logistic model, temporal niche differentiation, soil fertility, economic benefit, life cycle assessment

The IntercropVALUES experimental network: overyielding in contemporary intercropping in- and outside Europe depends on fertilization strategies

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European agriculture relies heavily on artificial nitrogen fertilizer. Cereal-legume intercropping can reduce this dependency and mitigate the environmental side effects of artificial N fertilizer use. We investigated the performance of various mixtures of cereals and legumes with different fertilization strategies.

The IntercropVALUES experimental network comprised 12 sites, nine in Europe, two in Africa, and one in China. Sole legumes did not receive fertilizer, sole cereals received the recommended dose or no fertilizer, and the intercrops received either no fertilizer or 50% of the recommended dose for the cereal. Four nitrogen input strategies were defined based on the N input in the intercrop and the sole cereal: 1. no input in either (zero strategy); 2. no input in the intercrop, but full dose in the sole cereal (reduction strategy); 3. 50% in the intercrop, and no input in the sole cereal (augmentation strategy), 4. 50% in the intercrop and 100% in the sole cereal (balanced strategy).

Data were collected at each site across two years. We present results on grain yield, Land Equivalent Ratio (LER) and Net Effect (NE). Land equivalent ratio is the sum of relative yields (intercrop/sole) for both species while Net Effect is the difference between total intercrop yield and expected intercrop yield, calculated as a weighted average of sole crop yields.

Total grain yields were similar to the average of those achieved in the sole cropping systems indicating small and mostly insignificant net effects on yield. The LER was not significantly different from one for three fertilizer strategies, and only significantly above one in the augmentation strategy.

Overall, cereal-legume intercrops achieved similar production as sole crops at reduced N fertilizer input.

Keywords: intercropping, nitrogen, fertilizer, multi site experiments, cereal, legume

Yield Stability, Grain Quality, and Resource-Use Efficiency in Cereal–Legume Intercropping Systems: Insights from Europe-Wide Living Labs

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European agriculture is confronted with escalating challenges, such as increasing input costs, more frequent weather extremes, and the imperative to reduce environmental impacts. Although legumes present an opportunity for crop diversification and high-quality protein production while decreasing reliance on mineral fertilizers, their adoption remains limited due to unpredictable annual yields. Legume-cereal intercropping, which involves the simultaneous cultivation of a cereal and a grain legume in the same field, offers a practical strategy to address these challenges by enhancing positive plant interactions to improve resource-use efficiency and stabilize production.

This study synthesizes extensive research, practical guidelines, and empirical findings from the European-wide LEGUMINOSE project, which established a network of 189 Living Labs and structured research field trials to evaluate approximately 40 intercrop combinations across various climate zones. The success of an intercropped system depends on selecting compatible species (such as wheat, barley, or oats paired with peas, faba beans, or lupins) that maximize niche differentiation and complement each other's nutrient and water acquisition strategies while minimizing excessive direct competition. Farmers can spatially organize intercrops as mixed, row, or strip systems, balancing agronomic performance with available farm machinery, harvesting requirements, and post-harvest grain processing objectives.

Agronomic data collected throughout the project highlight substantial production benefits: 75% of the examined intercrops demonstrated positive net yield benefits compared to monocultures, with an average 31% increase in grain yield (measured via Net Effect Ratio). Intercrops significantly decrease the C footprint of protein production by 10% as compared to sole cereals. Additionally, intercropping significantly reduced production risks by decreasing yield variability (coefficient of variation) by approximately 10%, particularly protecting farms against climate-induced disruptions and localized pest or disease crop failures. Finally, the approach enhanced grain quality; cereals grown within intercrops consistently exhibited improved nutritional profiles, including a substantial average increase of 2.4 percentage points in protein content, along with elevated concentrations of essential micronutrients. Ultimately, modern legume-cereal intercropping provides a robust, resilient, and productive framework for sustainable food and feed production under changing environmental and economic conditions.

Keywords: Intercropping, Legume, cereal, nutrients, yield, C footprint

Participatory Agronomic Diagnosis: A Participatory Framework for Integrating Farmers' Expertise and Agronomic Science

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Agronomic diagnosis is essential for interpreting on-farm trials, yet current approaches have important limitations. Oral diagnosis, based on farmers' experience, is rapid and inexpensive but remains subjective (1). Regional diagnosis relies on field measurements and agronomic expertise, providing robust analyses but requiring substantial effort while often overlooking farmers' knowledge (2). Automatic diagnosis processes large datasets to explain yield variation across trial networks but is complex and gives limited consideration to practitioner expertise and plot-specific conditions (3).

To overcome these limitations, this study developed a **Participatory Agronomic Diagnosis (PAD)** combining farmers' experiential knowledge with regional agronomic diagnosis. The method was applied to participatory experiments evaluating farmers' bread wheat varieties, mainly farmer mixtures, under organic farming. The objectives were to strengthen farmers' ability to interpret trial results through dialogue with agronomists and to test hypotheses on varietal adaptation to environmental conditions.

In 2022 and 2023, 77 wheat varieties were evaluated in 32 organic trials (farm×year×management), with 20 varieties tested in at least four environments. PAD consisted of five stages: developing a conceptual model of yield-limiting factors, collecting farmers' hypotheses, conducting structured discussions to produce a hybrid diagnosis, identifying reasons for varietal adaptation, and synthesizing results across the network. Measurements included trial context, environmental and agroclimatic variables, crop establishment, yield components, and grain yield. Data were collected jointly by farmers and researchers throughout the crop cycle and analysed statistically across environments.

Yields ranged from 4.8 to 43.1 qha^{-1}. Hybrid diagnosis confirmed 74 farmer-generated hypotheses and generated 43 new ones through discussion. Farmers also questioned several indicators, leading to methodological improvements. Twenty-four yield-limiting factors were identified, with the most frequent being nitrogen deficiency, weed competition, water deficit, high temperatures, and poor crop establishment. Responses of yield components to these stresses were consistent across trials, although only a limited number of hypotheses on varietal adaptation could be conclusively validated. Overall, PAD successfully integrated scientific and farmers' knowledge, improved understanding of site-specific production constraints, and supported consistent analyses across the trial network. Despite the difficulty of validating varietal adaptation, it provides a robust participatory framework that recognizes farmers as active contributors to agronomic knowledge.
Keywords: Agronomic diagnosis, bread wheat, farm mixture, farmer expertise, on, farm trial

Learnings from a German co-creation case study in wheat and pea intercropping for human consumption: evaluating cultivation and processing of intercropped wheat through seven regional value chains.

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A co-creation case study focused on the integration of intercropped wheat and pea within seven German value chains, evaluating each value chain step from cultivation through to processing with farmers, millers and bakers. Seven farmers grew a minimum of 0.5ha intercropped wheat and pea in the same field as both sole crops for comparison over two experimental seasons (2023-2025). Agronomic performance was evaluated through biomass cuts at harvest to determine grain yield, as well as other productivity indices such as Land Equivalent Ratio (LER), Net Effect Ratio (NER) and Transgressive Overyielding Index (TOI)(1). Baking quality was assessed in both the sole and intercropped wheat using protein and wet gluten content, sedimentation value and Hagberg Falling Number. Additionally, a Rapid Mix Test and optimized baking test on both wholemeal and refined flour were performed to assess baking volume and other baking characteristics. As grain separation of intercrops has been highlighted as a barrier to intercropping adoption, we assessed the proportion of pea (whole and broken), as well as the proportion of miscellaneous impurities, during the various grain separation stages from pre-sorting on farm to final grain separation in the mill whilst working closely together with bakers to define the maximum allowable pea fraction that can remain in the wheat grain before baking performance and sensory characteristics are negatively influenced. This process included baking tests with different proportions of pea flour, as well as sensory testing together with the bakers. Results from these various analyses and learnings indicate that baking wheat intercropped with pea can be successfully integrated into the value chain with small adjustments to material, procedural and regulatory dimensions(2); however, without a significant concurrent market for pea, wheat-pea intercropping will most likely remain in the realm of fodder production.

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Keywords: Wheat, pea intercropping, regional value chains, co, creation case study learnings

Breeding for intercropping: plasticity of winter bread wheat traits between sole crop and intercrop across a diverse panel of 200 varieties

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Today, all bread wheat cultivars grown in intercropping with a legume cultivar have been bred under pure stand conditions. However, it is currenlty well-established that best performing cultivars in pure stands are not necessarily those that are best suited for intercropping. Therefore, it appears essential to identify which varietal traits can be reliably assessed in sole crops and which need to be assessed under intercropping conditions. As part of a study aimed at identifying the genetic basis of adaptation to interspecific mixtures in bread wheat, we investigated the effects of intercropping as well as the varietal effect of the companion legume tester on wheat varietal traits.

We evaluated a panel of 200 winter bread wheat genotypes displaying a wide diversity in phenological earliness, levels of resistance to major diseases, plant architecture, yield potential and bread-making technological characteristics under sole crop conditions. These wheat cultivars were intercropped with two winter field pea cultivar testers exhibiting contrasting architectures to account for potential effects of the companion legume.

Both companion legumes performed well under field conditions and exhibited the expected diversity in plant architecture, ground cover, resource competition and yield, thus providing the expected range of competitive environments for evaluating wheat genotypes. A series of two-way analyses of variance showed that both intercropping and the identity of the companion legume significantly affected wheat grain yield and grain protein content as expected, but also increased grain specific weight and canopy height, whereas heading date remained unchanged.
In light of the additional breeding effort required under intercropping conditions, these results demonstrate that most traits studied are strongly influenced by both the presence or/and the identity of the companion legume. These results confirm the relevance of intercropping for increasing technological characteristics of bread wheat, and also highlight the effect of intercropping on traits known to be highly heritable in bread wheat, such as canopy height. These first results pave the way for future guidelines for bread wheat breeding.

Keywords: intercrops, breeding, field trials, phenotypic traits

Extracting Design Principles for Sustainable Agricultural Systems from Data and Long-Term Ecological Experiments

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Modern industrial agriculture relies heavily on monocultures, despite their vulnerability to environmental fluctuations and substantial impacts on soil, water, and biodiversity. Developing productive, resilient, and resource-efficient alternatives is essential for ensuring food security while reducing the environmental footprints. In this talk, I will present a data-driven approach to the design of multi-species agricultural systems. Focusing on intercropping, the practice of growing multiple crop species together, I will analyze a dataset comprising 2258 field experiments involving 274 crop pairs drawn from 69 plant species and characterized by 25 environmental, management, and plant-related variables. Using machine learning and concepts from systems biology, I will show how this complexity can be reduced to a small number of effective variables that retain substantial predictive power for crop performance. This approach makes it possible to identify favorable crop combinations, estimate their expected productivity relative to monocultures, and assess their robustness to environmental variability. I will explore whether classical design principles of intercropping, such as complementarity and niche differentiation, emerge from the data and to what extent they contribute to explaining crop performance. I will also briefly discuss a recent work based on long-term ecological experiments, showing that the effects of soil management and weather variability on biomass production can be disentangled. Taken together, these studies illustrate how quantitative and statistical methods can contribute to the development of agro-ecological systems.

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Keywords: intercropping, plant interactions, long term experiments, machine learning

IntercropAgent: AI-assisted literature extraction for intercropping meta-analysis

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Meta-analysis, a systematic approach for synthesizing data from multiple studies, enables researchers to draw more robust and reliable conclusions than any individual study by going beyond the limitations of small number of environments per study. However, the rapidly increasing number of scientific publications has created a highly time-consuming and often unmanageable workload for researchers conducting meta-analyses, in particular the extraction of (meta)data from individual studies. Therefore, we decided to develop an AI-based system that can automatically extract information from scientific literature, aiming to reduce workload and accelerate the intercropping meta-analysis process by combining Artificial Intelligence (AI), Machine Learning (ML), and domain-specific expertise.

We began developing this AI model, called IntercropAgent, during the 4th BioHackathon Germany held in Walsrode from 1–5 December 20251. After five months of regular meetings, continuous updates, and extensive testing, we developed an AI model capable of effectively and automatically extracting raw data from research articles. Although the tool is still under development and requires further improvement, we can already confidently report that the model substantially reduces the time and effort required for laborious data extraction tasks. In addition, it can serve as a valuable 'secondary reviewer' for intercropping meta-analyses, helping researchers improve both efficiency and consistency in data collection.

References (l) Paul, M., Döring, T., & van der Werf, W. (2025). Implementing AI in Meta-analysis: Can domain-specific paper selection and data extraction be done effectively? 4th BioHackathon, de.NBI. 1-5 december 2025, Germany.

Keywords: literature extraction, AI, model, crop, mixture, meta, analysis

Mixing service animal and service plant concepts for agroecology

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Service plants are used in agroecosystems primarily to provide ecosystem services other than crop production (i.e., promoting nutrient cycling, supporting pollinators, regulating pests, etc). Whilst this concept is well defined and developed (1), both theoretically and in practice, the mirror concept of 'service animals' is emerging (2). What roles can service animals play (alone or in combination with service plants) in order to promote the provision of ecosystem services, particularly in relation to the regulation of crop pests (weeds, pests, pathogens/parasites)?

This study aims to lay the foundations for the concept of service animals, by drawing on various disciplines and areas of expertise (animal science, agronomy, ecology, humanities and social sciences). The study also builds on existing knowledge of service plants and the practical challenges faced by farmers and livestock breeders. Specifically, the study seeks to identify which animals can be used as service animals, and the services and disservices that they can provide (the place of their economic value is discussed). The modes of action involved in pest regulation by service animals are also examined.

The study also seeks to identify ways to promote synergies between service animals and service plants in the regulation of crop pests. We hypothesise that a combined systemic approach to these two concepts could reconnect plant and animal systems, leading to (1) the development of integrated crop and livestock systems for pest management and (2) the mutual health of crops and animals, as well as soils and humans ('one health concept').

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Keywords: Ecosystem service, Disservice, Crop pest regulation, Crop Livestock integration

6. Can plant diversification promote a more efficient soil functioning and nutrient cycling?

Scientific committee of Symposium 6

Audrey Niboyet

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Introduction - Can plant diversification promote a more efficient soil functioning and nutrient cycling?

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In natural or semi-natural ecosystems, it has been demonstrated that plant diversity enhances ecosystem performance via complementary and sampling effects. While the influence of species richness on biomass production was initially emphasised, it has since been demonstrated that genetic diversity within species is also influential, improving the provision of ecosystem services beyond merely biomass production. Complementarity and sampling effects require functional differences between plant species and genotypes, involving multiple interactions between plants, soils, and soil organisms. These effects have been observed in natural ecosystems and must be implemented more widely in agroecosystems to improve agricultural sustainability, while maintaining productivity by using the natural capacity of soil ecosystems to supply plants in available nutrients. The aim of the workshop is to explore these effects and the underlying mechanisms. These mechanisms include: (1) plant complementarity in the use of soil resources (e.g. mineral nutrients and water); (2) complementarity in interactions with symbionts; (3) interactions with soil herbivores and pathogens; (4) synchronisation of plant demand for mineral nutrients with provision by soil microbial communities; (5) nitrogen fixation and phosphorus solubilisation. The symposium will address studies on these fundamental mechanisms and how to harness them in agroecosystems. We will for example examine how other practices (e.g. fertilisation) influence the outcome of these mechanisms and how selection of new varieties can favour them.

Keywords: plant diversity, functional diversity, soil ecology, soil nutrient cycles, plant, soil interactions

How intercropping sustains stable crop productivity and healthy soils? Evidence from long-term field experiments

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Intercropping has been consistently demonstrated to enhance productivity, to utilize resources efficiently, to stabilize year-to-year yields, and to improve soil fertility. However, it has been not well understood that how intercropping improves temporal stability of crop yields and soil health. Based on long-term field experiments established in 2003 and 2009 in China, with various intercropping of chickpea/maize, faba bean/maize, oilseed rape/maize, soybean/maize, wheat/maize and wheat/faba bean, and corresponding monocultures, firstly we systematically investigated the relationship between crop yield stability and interspecific interactions, and between the stability and changes of crop traits driven by interspecific interactions. Secondly, intercropping improves soil multi-functionality by 34.6%, compared with the weighted mean values of monocultures. Intercropping also significantly increased the relative abundance of genes related to C-, N-, and P-cycling functions by 15.2%, 10.8%, and 26.3%, and the relative abundance of genes was related to weighted mean diameter of aggregates, soil compaction, total nitrogen, soil microbial biomass carbon, soil respiration, soil nitrate reductase, β-cellobiohydrolase and leucine aminopeptidase. The positive effect of intercropping on soil multifunctionality was associated with enhanced enzyme activities and other soil properties and consequently increased crop yields. The results highlight the important role of intercropping in sustaining soil function and sustainable agriculture. I also will show some practical applications by farmers by mechanized wide-strip intercropping in China in recent years.

Keywords: Intercropping, Soil health, Soil Fertility, Soil multifunctionality, Temporal stability of yields

Shifts in Rhizosphere Microbiomes and Soil Multifunctionality Driven by Cereal–Legume Intercropping and Fertilization Management Across Europe

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Modern intensive agriculture often depends on monoculture systems with substantial external inputs, resulting in degraded soil health and reduced ecological functions. Cereal–legume intercropping presents a sustainable alternative to improve resource-use efficiency. Although its agronomic benefits are well documented, its broader effects on biological soil health, compartment-specific microbial communities, and the maintenance of multiple soil ecosystem functions (soil multifunctionality) are less understood. As part of the pan-European LEGUMINOSE project, we assessed functional microbial traits, community dynamics, and overall soil properties across a network of research field trials in diverse climate zones. We employed meta-barcoding (16S rRNA gene and ITS region) to map bacterial and fungal community composition across three soil compartments: bulk soil, rhizosphere soil, and root microbiome. Additionally, 25 physical, chemical, and biological soil parameters were combined to compute a comprehensive soil multifunctionality index, evaluating how intercrops affect soil ecosystem performance relative to monocultures. Sequencing data indicated that bacterial and fungal communities respond distinctly to management inputs and host plant interactions depending on spatial compartment. Fertilization management exerted a dominant influence on the broader soil community, with the greatest impact in bulk soil and the weakest on the root endosphere. Conversely, plant community composition and host species identities exhibited a strong, localized selection gradient, exerting the maximum impact on the root-associated bacteriome and mycobiome, followed by the rhizosphere, and the least influence on bulk soils. Functionally, legumes stimulated rhizosphere microorganisms involved in nitrogen cycling, creating a highly active, tightly coupled nutrient loop that facilitated nitrogen uptake by the companion cereal. Intercropped soils also supported microbial communities with increased genetic capacity to mitigate climate impacts by converting nitrous oxide into harmless atmospheric nitrogen. Post-harvest evaluations revealed that intercrops minimized environmental leakage risks, reducing residual post-harvest mineral nitrogen stocks by 28% to 32% compared to sole faba bean crops. Aggregating these multi-compartment metrics, the comprehensive soil multifunctionality index was consistently higher in cereal–legume intercrops than in sole crops, particularly under low-input, resource-scarce conditions. Cereal–legume intercropping serves as an effective ecological mechanism to regenerate soil biological activity and optimize nutrient cycling. Intercrops promote long-term soil fertility and resilience.

Keywords: Intercropping, Legume, cereal, Soil health, multifunctionality

Straw incorporation stimulated the intercropping effect to enhance soil carbon sequestration

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Intercropping has been shown to enhance soil carbon pool; however, carbon sequestration process in such systems is often slow. Integrating straw incorporation offers a synergistic approach to enhance soil organic carbon (SOC) more effectively, yet the underlying mechanisms, particularly through microbial and micro-food web pathways, remain inadequately understood. Based on a long-term field experiment with different residue management practices and cropping systems, we combined soil carbon fraction measurements with amplicon and metagenomic sequencing to investigate how intercropping and straw incorporation interact to influence SOC dynamics.

Across both residue management treatments, intercropping modestly but consistently increased SOC and mineral-associated organic carbon (MAOC) concentrations by 3.7% and 4.8%, respectively, compared with monoculture, with stronger effects observed under straw incorporation. Across both cropping systems, straw incorporation significantly increased SOC and MAOC concentrations by 18.6% and 19.5%, respectively, relative to straw removal. Importantly, intercropping significantly increased microbial biomass carbon (MBC) concentration and C-acquiring enzyme activities only under straw incorporation, indicating that straw return is a prerequisite for activating intercropping-induced microbial carbon transformation. Network analysis showed that intercropping, under straw incorporation, was associated with a higher proportion of potential protist-mediated interactions and a greater number of keystones, which were positively correlated with SOC, with Cercozoa and Ciliophora being dominant groups. Metagenomic analysis revealed that straw incorporation increased the abundance of carbon fixation modules and labile plant-derived carbon degradation genes, while intercropping under straw incorporation further enriched key carbon cycling genes that were positively correlated with soil carbon pools.

Overall, these findings collectively demonstrate that straw incorporation amplifies the intercropping effect on soil carbon sequestration primarily by enhancing microbial-mediated carbon transformation and MAOC formation efficiency, rather than by increasing total carbon inputs alone. This study highlights the importance of integrating intercropping with appropriate residue management in conservation tillage systems to promote long-term soil carbon stabilization.

Keywords: Intercropping, Straw incorporation, Multitrophic interactions, Keystones, C cycling genes

The intercropping of fava bean with winter wheat without nitrogen application supports the crop performance with a reduced risk of nitrogen losses

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The intercropping of legumes with cereals has the potential of eliciting facilitative biogeochemical mechanisms that sustain the yield of both crops. Understanding how the nitrogen (N) transformation processes change under this cropping system is fundamental to maximize the benefits deriving from its complementary use. A field experiment was conducted to test the intercropping of fava bean with winter wheat under contrasting N fertilization levels corresponding to the optimal dose for the wheat (standard N) and the zero N dose (zero N). We integrated the quantification of microbial phylogenetic markers and N-cycling genes in soil through DNA-based qPCR during the plant reproductive phase with the assessment of the soil N stocks, the crop N acquisition, their grain yield, and the soil greenhouse gas emissions during the entire cropping season. The findings indicated that the intercropping sustained the grain yield per plant comparably or more than the corresponding sole cropping system under the same N dose while significantly promoting the wheat N acquisition under the zero N. The topsoil N stocks did not vary across the treatments during the plant reproductive phase, even though the standard N induced a consistent increase compared to the zero N during the preceding growth stages. The fava bean induced a significantly lower ammonia-oxidizing archaea-to-bacteria ratio in the rhizosphere than the wheat and the intercropping under the zero N, which might be indicative of a consistently faster nitrification. The N fertilization induced an increase in the *nirK*/*nirS* ratio to a similar extent in the intercropping and the sole wheat bulk and rhizosphere soil, which might underpin a faster transformation of nitrite to nitric oxide. However, the N2O-N emissions did not change across the treatments. Comprehensively, the fertilizer N application was much more impactful than the cropping system in determining the microbial N-cycling potential. Nonetheless, the intercropping under the zero N was identified as a possible cropping solution to reduce the risk of N losses deriving from a rapid nitrification or nitrite reduction to nitric oxide during the critical time of the plant reproductive phase while still supporting the N nutrition and the yield of both crops.

Keywords: intercropping, legumes, cereals, soil N cycle, microbial functional genes, greenhouse gases

Combining wheat with multi-species prairie strips: effects on aboveground nitrogen production, symbiotic fixation and soil nitrogen dynamics

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Diversification strategies such as cover cropping, intercropping, and living mulches can reduce reliance on nitrogen fertilizers and limit nitrogen losses in agroecosystems. However, their effectiveness is constrained by short implementation periods and the range of species tested. Prairies, owing to perenniality and diversity, may enhance plant nitrogen acquisition and ecosystem nitrogen retention. This study investigated "agroprairies," an agroecosystem combining alternating strips (~40 cm) of wheat and multispecies prairies (~12 species). Two prairie types were tested, with species having *a priori* acquisitive vs. conservative resource-use traits.

We evaluated their effects on three nitrogen-related dimensions: (i) aboveground nitrogen production, (ii) symbiotic fixation and nitrogen mineralization, and (iii) soil inorganic nitrogen across depths. We hypothesized that agroprairies would modify these dimensions compared with sole systems, and that interactions with wheat would depend on prairie growth strategies. In a two-year field experiment, we quantified aboveground nitrogen production and contributions of fixed and non-fixed nitrogen to plant biomass. Soil nitrogen mineralization was assessed using the 15N pool dilution technique in winter and spring, and residual inorganic nitrogen was measured in autumn and winter along a 0-90 cm soil profile.

Selection effects and species plasticity in response to soil and climatic conditions led the prairie initially characterized by more conservative resource-use traits to exhibit an acquisitive trait syndrome in the first year, whereas the prairie initially characterized by more acquisitive traits exhibited a conservative trait syndrome. This pattern may have been partly driven by vigorous legume growth. This prairie type increased nitrogen production through high fixed nitrogen inputs, enhanced soil nitrogen mineralization, and promoted inorganic nitrogen accumulation throughout the soil profile compared with the prairie with conservative traits and sole wheat. When combined with wheat, it promoted synergistic nitrogen acquisition, likely through complementarity or facilitation driven by high nitrogen fixation in the first year and progressive stimulation of soil nitrogen mineralization. In contrast, the prairie exhibiting a more conservative strategy in the first year and lower legume abundance showed limited positive interactions with wheat. Overall, agroprairies appear promising for increasing grain and forage nitrogen production without fertilization, although their performance depends on species traits and composition.

Keywords: Intercropping, soil nitrogen cycling, acquisitive vs. conservative resource, use strategies, perennial species, prairies, positive interactions

Effect of crop spatial heterogeneity on above- and below-ground biodiversity at the field scale in a tropical agroecological market-gardening cropping system

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Co-cropping is a common practice in agroecology and is widely used by tropical farmers growing vegetables in the Malagasy highlands, aiming to foster productivity on limited land surface, control pests and sustain profitable production (1). From an ecological perspective, co-cropping promotes spatial heterogeneity, commonly assumed to drive biodiversity and ecosystem functioning at larger scales. However, at the field scale, this assumption remains poorly documented, especially in tropical areas. This study investigated how spatial heterogeneity from vegetable co-cropping at the field scale drives aboveground entomofauna and soil microarthropod communities. Experimental design consisted of nine 4x1.2 m2 fields varying in crop number (two, five, and eight crops) and spatial arrangement (bloc, row, border, mixed), implemented in Madagascar highlands. Within each field, soils were sampled on 16 systematic non-aligned points at the peak of the vegetation period to characterize soil properties and microarthropods, while entomofauna was sampled on eight points, three times during the growing season. Vegetation and soil microhabitat conditions around sampling points (30 and 50 cm buffers) were characterized adapting landscape ecology methods (2) using georeferenced map of the plot design and aerial imagery. Relations between plant heterogeneity, soil properties and above- and belowground communities were investigated using general least square models (3). Results showed that plant identity and plant heterogeneity explained 47 % and 54.1 % of aboveground entomofauna abundance, respectively. For soil microarthropods, these variables also appeared as significant drivers explaining 18.4 % and 25.4 % of the abundance of Collembola and Acari, respectively. In addition, soil properties such as pH, soil temperature, and soil micro-porosity ($< 50\ \mu$m) explained together 13 % of the Collembolan abundance, while soil temperature explained 9.1% of the Acari abundance. Although based on single season and site, the original method proposed provides first quantitative evidence of the effect of crop spatial heterogeneity at the field scale as a driver of aboveground biodiversity, and as co-driver of belowground biodiversity together with microscale soil properties. Crop productivity also increased with crop number and heterogeneous spatial arrangement, suggesting that increasing crop spatial heterogeneity is a promising strategy for promoting biodiversity and productivity in tropical smallholder agroecosystems.

Keywords: Co cropping, vegetables, spatial heterogeneity, entomofauna, microarthropods, landscape ecology

Relationships between vegetable intercropping performance, soil properties, and microbiota: Insights from a participatory study with gardeners and market gardeners

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As a lever of agroecology, plant diversification through intercropping consists of growing different crop species simultaneously on the same land area. This practice delivers multiple ecosystem services, such as enhanced soil fertility and structure, stable yields, reduced pest damage, and a lower reliance on chemical inputs (*Brooker & al. 2015*). Although research on intercropping has expanded significantly in recent years, it remains largely focused on large-scale field crop systems, particularly on cereal-legume intercropping. However, there is a notable lack of literature regarding vegetable intercropping in temperate climates (*Paut & al. 2024*). This knowledge gap remains a major barrier, impeding the understanding, the design and thus, the development of these practices in market gardening field.

To address this challenge and generate an exhaustive and robust dataset, we engaged gardeners and market gardeners in a large-scale citizen science project. This multi-environment study evaluates how vegetable intercropping impacts plant performance (physiology and yield), soil properties, and rhizosphere microbiota.

As a first step, we co-designed an intercropping model combining tomato and bush bean, together with market gardeners and gardeners. This experimental system was implemented over three consecutive years across a wide range of soil types and management practices, supported by a network of 130 contributors by 2026, mostly amateur gardeners.

Our results showed that tomato yield is similar in intercropping compared to sole crop while bush beans yield decreased in intercropping. Nevertheless, taking in account both species, overall yield per unit area increased significantly. Soil analyses revealed that intercropping systematically shifted the rhizosphere microbiota structure irrespective of soil types, reshaping the belowground ecosystem and potentially driving beneficial functions. Finally, weed biomass was significantly reduced in intercropping, demonstrating an ecosystem service for weed management.

These findings provide a valuable foundation for understanding how plant-plant interactions modulate belowground microbial networks to support plant and global health. Furthermore, they open up promising perspectives to maximize sustainable local food production on small surfaces.

References: Brooker.&al. 2015 Improving Intercropping: A Synthesis of Research in Agronomy, Plant Physiology and Ecology. New Phytologist. Paut.&al. 2024 A Global Dataset of Experimental Intercropping and Agroforestry Studies in Horticulture. Scientific Data.

Keywords: Intercropping, Vegetable Crops, Agroecology, Citizen Science, Market Garden, Microbiota, Plant Plant Interaction

General discussion - Can plant diversification promote a more efficient soil functioning and nutrient cycling?

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Following the presentations in Symposium 6, we will conclude with a general discussion on the links between plant diversification and soil functioning, involving all the speakers and the audience.

Keywords: plant diversity, functional diversity, soil ecology, soil nutrient cycles, plant, soil interactions

7.A Out-scaling agroecology: transformative sciences

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When agroecology and transdisciplinary research meet: four matters of concern

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Transdisciplinary research (TDR) is a mode of research that brings together multiple disciplines and societal actors to address complex societal challenges. As such, TDR shakes up traditional ways of doing research. It therefore becomes a matter of concern and debate within research communities such as agroecology. What would be "good" research in agroecology according to TDR literature? As sociologists of science interested in TDR, we propose to open a conversation with the agroecology community. We identified different processes through which 'good' TDR is continuously given shape: naming, defining, organising, and justifying. Drawing on a recent systematic literature review, we pay particular attention to the matter of justification: how can TDR be justified and evaluated, and how is its success understood and demonstrated? We illustrate our argument with the running example of an agroecological research project aimed at preserving Alpine hay meadows under climate change. Approaching TDR as a matter of concern for researchers themselves leads us to characterise it as a negotiated, situated, personal, and potentially transformative way of doing research, which is continuously brought into being rather than predefined.

Keywords: Transdisciplinary Research, Science and Technology Studies, Transformations, Literature Review

Expanding the repertoire of experiments for transformative research on crop mixtures

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Abstract. Incentives to mobilize agricultural research for transition toward more sustainable agriculture challenge researchers to reconsider the conditions under which knowledge is produced. Experiment, as a central mode of knowledge production in agricultural research, must be reassessed and diversified in light of this requirement. In its broader sense, experiment consists in one or more intentional interventions, more or less framed, designed to generate learning about a given problematic situation. Such a device shapes what can be known, who is legitimate to experiment, and which futures become actionable. While a diversity of experiments has emerged, agricultural research remains largely structured around one dominant model: the controlled experiment. This raises a question: what is at stake in choosing one experiment over another when facing transformative incentives? To address this issue, we first describe the range of possible experimental approaches for sustainability changes, and second, survey what type of experimental approach do academic researchers in agricultural sciences choose, why, and how is that choice being challenged by new incentives. Our analysis is based on an empirical investigation within the French research project "Mobidiv", a six-year initiative aiming to generate decisive advances in crop diversification, especially varietal mixtures and intercropping, to reduce pesticide use. We conducted interviews with researchers about experiments they design to study and mobilize crop mixtures under diverse conditions. Our results reveal that when researchers engage with transformative intentions, their choice of experiments reflect arrangements between fitting with academical standards and supporting change process working with stakeholders. These arrangements may guide researchers beyond their comfort zone. Beyond institutional and disciplinary frameworks, experiments appear as epistemic arrangements through which researchers negotiate legitimacy, relevance and agency. This contribution aims to foster reflexivity on the alignment between experimental means and transformative ends. We hope it may invite dialogue between controlled experiments and other forms of experiments, viewing them as complementary ways of knowing and acting for more sustainable agricultures.

Keywords: Experiments, transformative incentives, comfort zone, research stances

When "doing science with others" turns out to be an opportunity for "career transition" for scientists in the context of the agroecological transition

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This paper reports on the results and discussion points of an interdisciplinary working groups (IWG) that aims to study and support the impact of inter- and transdisciplinarity on scientific practices when they focus on the transition of agricultural and food systems toward agroecology.
Over the course of two years, a group of about fifteen scientists from the life sciences (biology, genetics, animal science, agronomy), the humanities and social sciences (anthropology, economics, sociology, education), participated in a program designed to share and analyze professional practices and the associated lived experiences gained during research projects in agroecology conducted with others-both scientists and non-scientists. From a methodological standpoint, this process of sharing and analysis consisted of three phases repeated for each of the research projects under discussion:

- Phase 1: narrating the research project in question and, within it, the activities and experiences considered relevant to professional transition (tentative, desired, emerging, impromptu, etc.);
- Phase 2: co-analysis at the IWG level through "conflictual cooperation on work well done " ;
- Phase 3: the institutionalization of a shared professional culture through the gradual categorization of "typical" research practices for conducting science together and the associated practical rules and reasoning.

The findings of the work conducted by the IWG highlight four main characteristics of the professional transition for scientists who engage in projects requiring them to conduct interdisciplinary and transdisciplinary research : the need to "co-create in order to experiment differently," to "team up differently throughout the research process," to "report on research differently to foster ownership, share knowledge, and drive change," and to "fund research differently." Each of these characteristics encompasses a set of actual professional practices that scientists adapt with varying degrees of ease, associated with experiences that are more or less positive and with fragile professional satisfaction.

Beyond identifying these characteristics of scientists' career transitions, the work carried out by this IWG highlights a number of needs and avenues for updating their initial and continuing education. Furthermore, it contributes, within its own scope, to ongoing discussions about the role of intermediation in research initiatives with an interdisciplinary and/or transdisciplinary dimension.

Keywords: reflexivity, intermediation, interdisciplinarity, transdisciplinarity

Co-creating adapted high-genetic-diversity cultivars for organic agriculture through a European network of Living Labs

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Organic production systems require cultivars with specific traits that are often absent in varieties developed for conventional, high-input agriculture. The prevalent use of these conventional varieties in organic farming leads to suboptimal performance, particularly in traits like nitrogen use efficiency, weed competitiveness, and resistance to soil-borne diseases. There is proof that selection under organic farming and breeding for higher level of diversity improves local adaptation and buffering capacity to various stresses. A breeding process based on greater genetic diversity between and within the populations is therefore essential to develop locally adapted, resilient, and productive cultivars for organic and agroecology-oriented farming systems.

This research leverages the Living Lab approach, bringing together a multi-stakeholder network for co-creation, to accelerate innovation in organic seed systems. Agroecology-oriented Living Labs include farmers, researchers and other stakeholders in the food system for collaborative learning and design processes, making them a suitable framework for participatory plant breeding (PPB). Through the LiveSeeding project, 17 Living Labs across Europe are implementing dynamic management of plant genetic resources (PGR) and developing Organic Heterogeneous Material (OHM) and Organic Varieties (OV), new cultivar types promoted by EU Regulation 2018/848, which are characterized by high genetic diversity.

This presentation will provide a systematic overview of the breeding methodologies employed across 20 crop species within the OHM and OV breeding programmes. We will analyze exemplary cases for OHM development, comparing the initial genetic diversity, parental material, selection environments, and the degree of actor involvement. The outcomes are intended to provide evidence-based best practices for breeding high-diversity cultivars for organic and agroecological seed systems, contributing to the transition to a more sustainable and resilient food system.

Keywords: PGR, Organic Heterogeneous Material, Organic Variety, Organic Plant Breeding, Participatory Breeding, Living Lab

Exploring the Potential of Farmers' Wheat Cultivars in Organic Conservation Agriculture in Western France

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The SOLBLEBIO project aims to integrate the use of farmers' seeds and cultivars with organic soil conservation agriculture (hereinafter OCA) practices in the Pays de la Loire region of France. OCA is defined as a toolbox mixing the principles of soil conservation agriculture (CA) and organic agriculture (OA), including cover crops, mixed cropping, no or reduced tillage and diversified crop rotations. Weed management without tillage and without using herbicides is the main challenge here.

Farmers' organisations and researchers collaborated to experiment the use of farmers' wheat (Triticum aestivum) cultivars in OCA systems. Farmers' cultivars include diversified populations or cultivar mixes managed within farmers' seed systems and thus co-evolving with the crop environment and management practices. Eight farmers participated in a survey to identify the most important traits required in a wheat cultivar to be adapted to OCA systems, followed by a workshop. To better understand success factors when cultivating farmers' cultivars in OCA systems, a total of 32 crops of farmers' cultivars in OCA systems were followed, covering 3 years. Agronomic observations included the general development of the crop, plant height, lodging, crop health and yield. The economic outcome was estimated.

Good seed vigor and early seedling vigor are identified as key factors for the success of crops in OA and CA. This was also confirmed by farmers in the project's survey, according to their experience in the region Pays de la Loire. In this regard, SOLBLEBIO pursued two main objectives. First, identifying the population varieties best suited for OCA. Second, assessing the vigor of farm saved seeds in the network and, where appropriate, identify avenues for improving seed-saving practices. For two years, a wheat cultivar collection was scored for early vigour in a field trial and seed vigour of collection or farm-saved seed lots studied.

The study identifies one wheat population combining seed and early vigour with satisfactory yield as a promising candidate for cultivation in OCA. Reducing mechanical damage is identified as a potential avenue for improving the quality of seeds produced by the network of farms participating in the project.

Keywords: Organic conservation agriculture, farmers' seeds, wheat, organic farming, collaborative research

Co-designing Agroecological Innovations in Semi-Arid Areas: Pathways and Impacts within the Tunisian Agroecological Living Lab

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Rainfed agriculture in Tunisia is increasingly challenged by soil degradation, water scarcity, and unstable crop yields, all of which are accentuated by climate change. Addressing these challenges requires a transition toward agroecological production systems that can enhance environmental sustainability while maintaining agricultural productivity.

This study presents the methodology adopted by a research-for-development consortium to co-design process of technological and socio-technical innovations developed through the Agroecological Living Lab, established along the Kef–Siliana transect, a semi-arid region characterized by mixed crop–livestock systems and olive-based production systems. The study is conducted within the framework of the "Agroecology Initiative", funded by CGIAR, managed and implemented in Tunisia by ICARDA in collaboration with INRAT, implemented between 2022 and 2024.

The Living Lab adopted a multi-stakeholder participatory approach. The co-design process of agroecological innovation packages was structured into five successive phases: (i) participatory visioning with six local communities to diagnostic current agricultural situation and to define shared agricultural futures and ambitions; (ii) stakeholder engagement leading to the development of a common agroecological charter; (iii) co-design of context-specific innovation packages; (iv) implementation of more than 150 on-farm experiments, trials, and demonstrations; and (v) co-design of localized indicators for participatory monitoring and evaluation.

Six socio-technical packages of agroecological innovations were developed and tested one for each community based on the specific context and farmers needs for each community. In crop–livestock systems, forage mixtures under conservation agriculture improved forage quality, reduced dependence on external feed resources. Rhizobial biofertilizers increased sulla productivity and improved soil nitrogen status. In olive-based systems, the combined use of olive by-product compost and locally produced biochar enhanced soil structure and water retention. Diversification and market-oriented innovations, including melliferous crops in Kessra and a geographical indication for olive oil in Elles-Sers, contributed to greater value addition and farm income.

Behavioral surveys involving 102 farmers revealed significant improvements in agroecological knowledge, awareness, and adoption between 2022 and 2024. The findings highlight the potential of Living Labs to transform farmers into active co-creators of innovation and identify early stakeholder engagement, local knowledge integration, and gender-inclusive participation as key drivers of successful agroecological transitions.

Keywords: Agroecology, Living Lab, Co, design, Semi, arid Tunisia, Crop–livestock integration

A transdisciplinary network to study, co-construct and experiment with vegetable crop associations in urban areas.

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In a context of intense questioning regarding the impacts of conventional agriculture on human health and ecosystems (global health), participatory research science projects such as "CoCultures" support biodiversity for more efficient agriculture, particularly by exploring intercropping vegetables (IV). This presentation outlines the origins and methodology of the CoCultures network, which brings together gardeners, market gardeners, associations, local authorities, and researchers in the Occitanie region of France, all committed to a collaborative approach to developing and experimenting with IV in urban areas. The aim is to shed light on the interplay between agrobiological and sociological approaches in the network study of the dynamics of conservation agriculture adoption. This includes both convergences and epistemological and methodological divergences, which underscore the need to move beyond disciplinary boundaries to facilitate transitions. How market gardeners and gardeners appropriate and understand IV are explored. To robustly inform the agrobiological aspects, the experiment is conducted on approximately one hundred sites (gardens, market gardens) with varying soil and climate conditions and practices. Initial findings indicate that questions concerning soil health and its microbiota bring together stakeholders involved in global health: attention to biodiversity, plant health, water quality, food quality, and ultimately, one's own health. Networking generates rich transdisciplinary exchanges, fostering a widely disseminated multi-criteria approach.

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Keywords: intercropping vegetables, urban agriculture, agroecology transition, participative sciences.

7.B Out-scaling agroecology: comprehensive approaches

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Remembering resilience: Drawing on traditional cereal species mixtures to build resilience in our staple crops in Ethiopia and beyond

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Food security depends on the ability of staple crops to tolerate new environmental stresses. Wheat, barley, and other small grains face substantial yield losses under all climate change scenarios. The sowing of maslins, or mixtures of multiple small cereal species, represents a risk management strategy for climate variability, but the global extent of these practices is unclear. We reviewed historical records and scientific literature pertaining to traditional maslin cultivation worldwide. In addition, we conducted mother-baby agronomic trials of traditional wheat-barley mixtures for two years across three sites in Ethiopia, and analyzed nutritional profiles of the grain. Our review found that maslins were formerly widespread in Eurasia and Africa, but have recently declined due to market forces and policy pressures. Nonetheless, our trials comparing mixtures at various ratios with monocultures found that mixtures with 3:1 ratios of wheat to barley consistently outperformed monocultures across sites and years. Farmers participating in the baby trials reported that mixtures increased yield, suppressed disease, and provided culinary advantages. Nutritional analyses showed complementarity between mixture components, with mixtures having a more balanced profile in terms of protein, polyphenols, and minerals, while diluting antinutritive compounds like phytates and oxalates. Traditional mixtures, developed over thousands of years of observation and experimentation may maximize complementarity between components. Trait-based studies to understand the mechanisms underlying performance in traditional mixtures may lead to insights around what makes mixture components compatible. Investigation, preserving, and revitalizing maslins as a climate-smart farming strategy may be a key approach to ensure stable availability to staple cereals into the future.

Keywords: ethnobotany, traditional knowledge, Ethiopia, maslins

Why Farmers Plant Crop Mixtures: Ethnobotanical Perspectives from Ethiopia

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Agricultural development policies tend to emphasize monocrop production of globally traded commodities, downplaying the value of traditional practices that maintain diversity within food and farming systems. In Ethiopia, however, farmers continue to cultivate traditional crop mixtures of multiple species or varieties despite limited support from government and market institutions. Understanding why these systems persist requires attention to the ecological knowledge and decision-making of the farmers who maintain them. Our Ethiopian and U.S. research team conducted 1,357 interviews with farmers in the South Wollo Zone to understand their knowledge and management of four traditional crop mixtures: wheat and barley, faba bean and field pea, teff varieties, and sorghum varieties. Comparison of farmers' perspectives across these systems revealed that mixtures are used to manage climatic variability, enhance productivity on less fertile soils, reduce pest and disease pressures, and sustain local foodways. Farmers also identified mixture-specific benefits and drawbacks related to the biological characteristics and interactions among particular crops and varieties. Our findings demonstrate that traditional crop mixtures represent adaptive management strategies enabled by nuanced ecological knowledge of crops, soils, and landscapes. The benefits and barriers identified by farmers suggest a need for research, extension, and market initiatives to support traditional crop mixtures. Public procurement programs involving schools may offer one pathway for creating markets for mixtures, advancing nutrition among school children while supporting climate-resilient farming.

Keywords: ethnobotany, farmer knowledge, traditional crop mixtures, Ethiopia

Understanding on-farm species mixtures' pathways with the action logic framework

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Species mixtures provide numerous agroecological services (1). However, their adoption remains low in France and farmers face several challenges implementing them (2). Species mixtures practices are diverse and depend on the farm situation and the farmer's objectives.

This work aims at understanding how species mixtures are introduced on farms, and how their management evolves. We conducted 16 interviews with organic and conventional farmers who have been growing species mixtures for at least 10 years, in both arable and mixed crop-livestock systems across France. We analyzed (i) the diversity of species mixtures with the concept of action logic, i.e. the reasons highlighted by farmers to explain their actions in their situation, (ii) and then analyzed action logic pathways concerning species mixtures. Species mixtures were categorized through a typology of action logics that considered the farm situation, the farmers' objectives and satisfaction criteria, and the cultivated area of the species mixture. Farmers' pathways were categorized through hierarchical clustering based on pathways' structural diversity, homogeneity, change dynamics, and intensity. We identified (i) six types of action logics, e.g., action logic 5 refers to growing a species mixture to ensure the development of a crop and enhance soil cover while limiting workload, and (ii) four pathway clusters with diverse dynamics, e.g., cluster 3 is characterized by intense practice change with diversified pathways, while cluster 4 is characterized by stable and low-diversified pathways. The results highlight the importance of supporting drivers of change such as access to knowledge or an outlet, to foster the development and diversification of species mixtures' practices. References (l) Bedoussac, L., et al. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for Sustainable Development, 35(3), 911–935. (2) Timaeus, J., et al. (2022). Adoption of Food Species Mixtures from Farmers' Perspectives in Germany: Managing Complexity and Harnessing Advantages. Agriculture 12, 697.

Keywords: Intercropping – practice – change – service crop – arable crop

Mixing Crops, Trees and Know-Hows for Mediterranean Agroecology: The RevAgroForMed Living Lab Approach

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Mediterranean agroecosystems are increasingly affected by soil degradation, low soil organic matter, water scarcity and climate instability, requiring innovative strategies able to enhance productivity while strengthening ecological resilience. In this context, diversified agroforestry systems represent a promising pathway for agroecological transition, as they combine trees, crops, animals and local know-hows within multifunctional landscapes, contributing to biodiversity conservation and ecosystem service provision. This contribution presents the approach of the PRIMA project RevAgroForMed - REVitalization of AGROFORestry systems through agroecological transition for increasing farm productivity in the MEDiterranean - which aims to revitalise traditional Mediterranean agroforestry systems through crop diversification, participatory innovation and Living Lab methodologies.

RevAgroForMed is implemented through a network of Agroforestry Living Labs across six Mediterranean countries: Algeria, France, Jordan, Italy, Slovenia and Spain. The project tests and validates diversified agroforestry systems adapted to local pedo-climatic and socio-economic conditions, including wheat Organic Heterogeneous Material grown in monumental olive groves, diversified rotations with minor cereals and legumes between olive and vine rows, cover crops in vineyards and olive orchards, local grass species mixtures in silvo-pastoral systems, and agro-silvo-pastoral systems integrating horticultural crops and free-range grazing. These experimental designs are consistent with biodiversity-based approaches to agroecology, which rely on functional diversification to enhance ecosystem services and reduce dependence on external inputs. They are also combined with cross-cutting innovations such as precision agriculture, composting of pruning residues and other organic wastes, and the use of saline- and drought-tolerance-inducing symbiotic rhizobia.

The project adopts the AESIS framework to assess the sustainability of proposed innovations at field, farm and landscape scales, considering productivity, soil quality, biodiversity, climate resilience and socio-economic dimensions. Particular attention is given to soil health assessment through biological indicators, including soil microbial diversity, microarthropod communities, visual soil evaluation and earthworm counts. Soil microarthropod communities, in particular, are widely used as indicators of soil biological quality and biodiversity. By integrating varietal, species and functional diversification with multi-actor co-design,

RevAgroForMed provides a Mediterranean case study on how crop mixtures, heterogeneous populations and local know-hows can support the transition towards more resilient and sustainable agroforestry landscapes.

Keywords: Agroforestry, Crop diversification, Living Labs, Mediterranean agriculture, Soil health, Agroecology.

Growing Sorghum bicolor (L.) Moench in varietal mixtures enhances socio-ecological resilience and production reliability in Karamoja, Uganda

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This study is the first academic report on the use of variety mixtures for sorghum (*Sorghum bicolor* (L.) Moench) production in Karamoja, northern Uganda, where the main livelihood system is agropastoralism. Sorghum is the main staple crop in much of the region. Through transect assessments, surveys and focus group discussions conducted across nine villages in Moroto and Napak districts, and interviews with agricultural officers, we documented sorghum cropping practices, landrace diversity, the uses of different sorghum plant parts, and its complementarity with pastoralism. Results show that sorghum is predominantly cultivated in mixtures of landraces. These varietal mixtures increase crop performance by contributing to yield stability and reliability under variable climatic conditions, as well as under pressure from pests and bird predation. In addition, different varieties and plant parts fulfill multiple and complementary subsistence, economic and social functions. In this context, sorghum production and the different uses of sorghum plant parts directly and indirectly underpin and complement pastoralist practices. Households in Karamoja have distinct varietal preferences linked to particular uses, indicating that sorghum varietal mixtures are maintained not only to ensure agronomic performance and food security but also for their socio-economic functional roles within households. The breadth and significance of these functions suggest that sorghum can be considered a cultural keystone species in Karamoja. Both local sorghum varieties and the cropping system based on varietal mixtures constitute a biocultural heritage that contributes to the reliability and resilience of agropastoralist food systems.

Keywords: sorghum, pastoralism, Uganda

Farmer collaboration as a pathway to knowledge generation: combining agronomic and social science methods

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Designing agroecological cropping systems based on agrobiodiversity requires the articulation of scientific knowledge from agronomy and ecology with the empirical knowledge developed by farmers. From this perspective, farmers should be considered as active components of cropping systems, interacting with the agroecosystem through their practices. This study aims to understand how the analysis of farming practices can reveal the knowledge mobilised by cocoa farmers in managing the health of cocoa trees within agroforestry systems.

We hypothesise that farming practices are triggered by indicators perceived by farmers, whose interpretation depends on their reasoning, the socio-technical history of the farm, and the structural heterogeneity of cocoa plantations. The study was conducted with 18 cocoa farmers in Côte d'Ivoire. It is based on a methodology combining semi-structured interviews with an activity analysis inspired by the course-of-action research programme, derived from the educational sciences, primarily through simultaneous, delayed and interruptive verbalisation interviews designed to analyse human activity as it unfolds.

The semi-structured interviews made it possible to identify the general rules guiding practices at the agroecosystem scale, particularly for weeding, pesticide application, fertilisation and pruning. They highlighted spatial triggering indicators, such as the height or abundance of weeds, as well as temporal indicators, such as seasonality or the physiological stage of the cocoa tree. Activity analysis complements this approach by observing practices in context, at the fine scale of the individual cocoa tree or a restricted area of the plot. It makes it possible to reconstruct the perception–action process, contextual adjustments and the knowledge mobilised.

This methodological complementarity shows that cocoa tree health is managed through a combination of practices deployed across time and space, revealing the diversity of farmers' decision-making logics.

Keywords: Farmer's practices, Indicators, Activity analysis, Agroforestry systems, Theobroma cacao

Feasible pathways to recognise mixing ability in variety testing

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Species mixtures are increasingly recognised as key levers for agroecological transition, yet their uptake remains constrained by two bottlenecks: farmers and advisers rarely receive reliable information on which varieties are suited to mixture cultivation, while breeders have limited incentives to select for traits that official testing systems do not assess, report or reward. Current variety testing and registration systems are largely built around pure stands, meaning that mixture-adapted varieties may be neither identified nor valued. This contribution asks how variety testing could be adapted without making official testing unworkable.

Based on prior work and exchanges with the agricultural sector, I propose a tiered route for implementation. First, pure-stand yield alone is an incomplete proxy for mixture performance, but low-cost pure-stand traits related to competitive ability and complementarity can support early screening in breeding and provide an easy-to-implement entry point for variety testing. Second, for crop combinations with established or emerging practical use, targeted mixture sub-trials with standard testers can validate whether these traits translate into actual mixture performance. Rather than requiring mixture testing for all candidates, testing authorities could allow breeders to request mixing-ability testing for selected variety candidates intended for intercropping. The long-standing Swiss forage-testing system provides a complementary practical example: simple mixture trials focused on competitive ability and yield proportion have informed official variety recommendations for decades.

Finally, I will discuss how these approaches could be embedded in breeding programmes, official VCU trials, complementary post-registration testing, participatory networks, and open data infrastructures. The ongoing EU Seed Law Revision and its proposed sustainability traits offer a timely policy lever. If mixture performance and mixture-relevant traits can count towards VCU as sustainability-related value, variety testing could better align breeding incentives, seed regulation and farmer needs. Rather than treating crop mixtures as exceptions to standard variety evaluation, testing systems could help make them a credible, scalable option for agroecological farming.

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Keywords: intercropping, variety testing, plant breeding, mixing ability, VCU, sustainability traits

POSTER SESSION

1. POSTERS - Breeding for inter-individual interactions: from theory to practice

Cultivar choice and nitrogen fertilization affect the competitive-complementary balance of bread wheat-pea intercropping system

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Wheat-pea intercropping is a productive cultivation system especially under low-input conditions. However, wheat-pea intercropping can be more productive than the respective sole crops, even with some nitrogen fertilization. Furthermore, cultivar traits are bred under monoculture conditions and therefore a high yielding cultivar may not be suitable for an intercropping system, where complementarity and facilitation are required. The aim of the present study was to assess cultivars of wheat and pea in a cereal-legume intercropping system under different nitrogen fertilization levels. The experiments conducted over two consecutive years (2023-2024 and 2024-2025) under rainfed Mediterranean conditions at the experimental farm of the Aristotle University of Thessaloniki in northern Greece (40∘32'14.3 "N 22∘59'24.7 "E). Grain yield data from the field experiments were used to calculate partial Land Equivalent Ratio (pLER) and Land Equivalent Ratio (LER), Net Effect Ratio (NER) and Transgressive Overyielding Index (TOI) in order to evaluate land-use efficiency, performance relative to the expected yield and compared with the best sole crop. According to the results, pLER of wheat cultivars was higher when combined with Furious cultivar. Furthermore, nitrogen fertilization increased pLER of both wheat cultivars, apart from Elissavet-Furious combination. Arvika pea cultivar obtained a higher pLER than Furious cultivar and was more competitive, regardless of nitrogen fertilization. In 2023-2024 5 out of 8 combinations obtained LER> 1, while in 2024-2025 all combinations were advantageous. N fertilization decreased LER values in 2024-2025, while there was no clear effect in 2023-2024. Elissavet-Furious mixture achieved highest net productivity for both years regardless of nitrogen fertilization. Only in 2024-2025 combinations achieved transgressive overyielding. Flamenko-Furious mixture, regardless of nitrogen fertilization, obtained TOI values above 1. In conclusion, cultivar traits are very important for the development of competitive and complementary dynamics in the intercropping system. Finally, nitrogen fertilization affects the competitive balance of the mixture, but the effect of the cultivars chosen is of utmost importance.

Keywords: Mixture, genotype, interactions, Land Equivalent Ratio, Net Effect Ratio, Transgressive Overyielding Index.

Designing cereal-legume mixtures through productivity, competition and economic indicators

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Cereal-legume intercropping is a promising strategy for agroecological transition, particularly in low-input and rainfed systems where crop diversification may improve resource use and yield stability. However, the evaluation of intercrops should not rely only on total grain yield since higher mixture productivity may result either from complementarity between species or from the dominance of one component. The aim of the present study was to assess cereal-legume mixtures focusing on two intercropping systems with a) two cultivars of bread wheat and two of field pea and b) two cultivars of bread wheat and four of faba bean. The cultivars used were Elissavet and Flamenko for bread wheat, Arvika and Furious for pea and Bumble, Nebraska, Organdi and Polycarpi for faba bean. The experiments conducted over two consecutive years (2022-2023 and 2023-2024) under rainfed Mediterranean conditions at the experimental farm of the Aristotle University of Thessaloniki in northern Greece (40∘32'07.7"N 22∘59'20.5"E). Grain yield data from the field experiments were used to calculate Land Equivalent Ratio (LER), Net Effect Ratio (NER), Transgressive Overyielding Index (TOI) and Intercropping Advantage (IA) in order to evaluate land-use efficiency, performance relative to the expected yield and the best sole crop and also the economic advantage of intercrops. According to the results, most mixtures showed LER values above one, indicating a land-use advantage compared with the corresponding sole crops, although the contribution of wheat and legumes varied among years and variety combinations. In the wheat-pea system, the Flamenko-Arvika combination showed the most consistent performance across growing seasons, combining positive land-use and net productivity with high total economic advantage. In the wheat-faba bean treatments differences across years were observed as there was not a specific combination consistent across them, but treatments such as Flamenko-Bumble, Elissavet-Nebraska and Elissavet-Organdi outperformed depending on the growing season. The IA showed the contribution of each species was not always balanced, although there was an economic benefit. Overall, the combined use of LER, NER, TOI and IA provides a simple and robust way for identifying cereal-legume mixtures with agronomic and economic relevance for Mediterranean agroecological cropping systems.

Keywords: wheat, pea, faba bean, Land Equivalent Ratio, Net Effect Ratio, Transgressive Overyielding Index, Intercropping Advantage

Agro-Climatic Drivers of Genotype Group- and Site-Specific Wheat Yield Responses

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Climate change severely impacts wheat yield stability, threatening agricultural productivity and food security. This calls for genotype selection and agricultural management strategies that consider agro-climatic interlinkages across multiple sites and plant genotypes. This study utilizes the BRIWECS dataset to investigate genotype group-specific climate responses using a large pool of wheat genotypes (220 genotypes) across six sites in Germany (Gross Gerau, GGE; Hannover, HAN; Klein Altendorf, KAL; Kiel, KIE; Quedlinburg, QLB; and Rauischholzhausen; RHH) and phenological phases. It aims to identify the main drivers of wheat yield variability and assess its interaction with genotype variability across site conditions. Four main genotype groups were considered based on phenology and height: early-tall, ET; early-short, ES; late-tall, LT; and late-short, LS. Six agro-climatic indices (Intensity of hot days, HI; Frequency of hot days, HF; Duration of hot days, HD; Sum of precipitation, PS; Frequency of dry period, DF; Duration of dry period, DD) were calculated. The phenological phases were sowing to end of heading (BBCH59, stage 1), end of heading to maturity (BBCH59 to BBCH87, stage 2), and sowing to maturity (BBCH87, stage 3). A tree-based machine learning approach (Conditional inference tree (CTree)) was implemented, offering insights into group- and site-specific yield responses. The results suggested site as the most dominant factor driving wheat yield, followed by agro-climatic indices, and genotype groups. Overall, KAL continued to yield higher than the other five sites even under heat stress. At KAL, under lower HI2 levels (normal condition), late genotypes (LS and LT) yielded about 13.9% more than early genotypes (ES and ET). Possibly, late genotypes have in total more time for assimilation thus they show higher biomass accumulation, especially when heat intensity is low. Additionally, the spring drought effect (DF1) was observed specifically in GGE and QLB sites, showing yield reduction with higher number of dry days. These results and framework contribute to a better understanding of how different genotypes respond to various agro-climatic indices in different sites. This will be particularly important for agricultural management under emerging climate extremes and supporting future climate resilient genotype selection and breeding schemes aimed for adaption to climate change.

Keywords: winter wheat, cultivar groups, environmental indices, genotype, by, environment interaction, conditional inference tree

Who your neighbor is matters: Genetic insights into wheat-wheat interactions modulating Septoria tritici blotch severity

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Crop diversification is increasingly recognized as a key strategy for sustainable agriculture and agroecological crop protection. Wheat cultivar mixtures represent a promising and readily adoptable approach to reduce disease and stabilize yield. However, their effects vary substantially among mixture combinations, suggesting that their benefits may depend on the genetics of the component cultivars and their interactions. Recent work has shown that interactions among plants in wheat varietal mixtures can influence their susceptibility to disease. Yet , the genetic basis of these plant-plant interactions remains largely unknown, including their role in resistance against Septoria tritici blotch, a major disease of wheat in Europe.

In a controlled greenhouse experiment, we evaluated 650 binary mixtures and 150 corresponding monocultures of bread wheat genotypes from the GABI-WHEAT panel. Following inoculation with a mixture of seven *Zymoseptoria tritici* strains, Septoria severity was quantified using SeptoSympto, an automated image-analysis pipeline. Two disease-related traits were analyzed: lesion damage (necrotic leaf area) and pathogen reproduction (pycnidia area).

We hypothesize that plant-plant interactions significantly modulate Septoria severity independently of epidemic effects and that specific loci associated with such neighbor-mediated modulation of disease severity can be identified. We will present the result of our genome-wide association study, aimed to identify the genetic determinants of plant-plant interactions influencing Septoria severity. With this approach, we hope to contribute to the development of genetically optimized cultivar mixtures that enhance Septoria suppression, reduce fungicide dependency, and support more sustainable wheat production.

Keywords: Septoria tritici blotch, GWAS, intraspecific wheat mixtures, plant–plant interactions, genetic architecture

An exploratory study on plant-plant interactions between oat varieties

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Plant-plant interactions drive agroecosystem productivity, but their genetic and morphological mechanisms in forage crops like oats (*Avena sativa* L.) remain poorly understood. Specifically, whether oat genotypes exhibit kin recognition to shift strategies between cooperation and competition is unclear. We conducted an 18-day greenhouse pot trial using ten diverse oat genotypes in monocultures and binary mixtures to assess early competitive outcomes and biomass allocation. Genotypes displayed strong, contrasting responses to neighbour identity. Some showed reduced performance in monocultures but increased growth in mixtures, indicating release from intraspecific competition, whereas others excelled in monocultures. Growth rate, height, and biomass responses were decoupled, revealing distinct interaction strategies. Genetic similarity did not predict interaction outcomes, providing no evidence for early-stage preferential cooperation among kin. Instead, dynamics were driven by context-dependent competition and functional complementarity, highlighting the need for future studies with broader genetic diversity.

Keywords: Avena sativa L., biomass allocation, kin recognition, plant, plant interactions

Phenotyping host response to coccidiosis in mixed-breed broiler groups: an experimental design to estimate susceptibility, infectivity and infection duration as a basis for epidemio-genetic approaches in poultry

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Improving disease resilience in livestock is a key lever for agroecological transition, both to reduce antimicrobial use and to support extensive, outdoor-friendly production systems. Classical quantitative genetics underestimates genetic variance for infectious traits because host–host interactions and disease dynamics are ignored (1). Epidemio-genetic frameworks decompose host response into susceptibility, infectivity, and infection duration- three traits that capture indirect genetic effects (IGE) in a population context (2). We designed a controlled coccidiosis challenge experiment to phenotype these traits in two contrasted broiler breeds reared in mixed-breed groups: Fayoumi, reported as resistant to Eimeria spp., and the commercial line Hubbard JA787. The mixed-breed design allows breed-specific susceptibility and infectivity to be disentangled while controlling for shared environment, providing the experimental support needed to fit IGE models with breed as a proxy for genetic background. The work is intended as a proof of concept supporting larger-scale genetic-parameter estimation and the longer-term integration of social breeding values into poultry selection for endemic infectious diseases.

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Keywords: epidemio, genetics, Eimeria acervulina, broiler, disease resilience

Efficient Optimization of Genotype Pairs for Intercropping Using Genomic Prediction and Bayesian Optimization

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Intercropping can improve crop productivity and sustainability, but identifying promising genotype combinations is difficult because the number of possible pairs rapidly increases as the number of candidate genotypes increases. This creates a practical bottleneck because field evaluation of all combinations is infeasible under realistic resource constraints. Here, we propose a framework integrating genomic prediction and Bayesian optimization for efficient genotype-pair selection in intercropping systems. Using genome-wide marker data from two crop species, we simulated intercropping performance for all genotype pairs under genetic architectures varying in heritability, correlations between direct and indirect genetic effects, and the contribution of pair-specific interactions.

The optimization objective was to identify the pair maximizing the sum of the genotypic values of both crops. From a common initial set, each strategy independently repeated evaluation cycles. In each cycle, a fixed number of unevaluated pairs was selected by random search, genomic-diversity-based search, or two genomic-prediction-based strategies: selection based only on the posterior mean and Bayesian optimization acquisition functions combining the posterior mean with predictive uncertainty. Then the simulated phenotypes of the selected pairs were revealed, added to the strategy-specific training data, and used to update genomic prediction before the next cycle. Thus, an evaluation cycle denotes one round of selection, evaluation, and model updating.

As a result, compared with random search, the two genomic-prediction-based strategies identified superior genotype pairs in fewer evaluation cycles. Selection based only on the posterior mean was sufficient in simple scenarios without pair-specific interaction effects or with high heritability and a strong positive correlation between direct and indirect genetic effects. In contrast, Bayesian optimization acquisition functions were more effective in complex scenarios involving pair-specific interactions or negative correlations between direct and indirect genetic effects, where exploration of uncertain regions became important. By incorporating predictive uncertainty, Bayesian optimization explored broader regions of the genotype-pair space and increased the chance of identifying the optimal pair. These results demonstrate that Bayesian optimization can further improve genomic-prediction-guided genotype-pair selection, thereby reducing the experimental burden associated with intercropping design.

Keywords: Intercropping, genomic prediction, Bayesian optimization, indirect genetic effects, genotype, pair selection

Genomic Selection of Maize Landraces to Diversify Productions and Adaptations

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Crop diversity is a cornerstone of agroecology. Breeding programs have to be rethought to work on more species but also to create varieties adapted to new and more uses. Hence, breeding programs may increase in number which reduce budget allocated for each one. Large genetic diversity is needed to select for breeding targets different of those of current breeding programs. An increase of intra-field diversity is also one potential lever for agroecological transition. For maize, landraces appears to be good candidates to achieve these purposes as they display a large phenotypic and genetic diversity as well as a large intra-population diversity. However, they are underutilised because of their low agronomic performances. One question to assess is whether genomic prediction and diversity monitoring based on dense genotyping data can be useful to improve efficiency of landrace breeding schemes. Here, we present first results a locally integrated experimental breeding program of an Italian maize landrace suited for polenta production started in 2024. The original breeding strategy is based on the evaluation of full-sibs families and supported by genomic prediction. Preliminary results can be divided into three parts. (i) We tried to evaluate an original trait: semolina productivity. (ii) We also evaluated genomic prediction accuracy in first year of field trial with a cross validation strategy. Several single and multi-environment models including additive and non-additive effects were compared. (iii) Finally, the experimental breeding program was compared to others using stochastic simulations. Each simulated breeding program was declined in both phenotypic and genomic selection version.

Keywords: Maize, landrace, breeding, genomic prediction, diversity

White lupin root architecture in intercropping: contrasting shoot morphology is associated with different root phenotypes

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Intercropping is a valid means to increase sustainability in agriculture. Cultivars developed for monocrops are not necessarily the best suited for intercropping, highlighting the need of target breeding approaches. A specific goal in legume breeding for intercropping is to select for a legume phenotype able to maintain productivity under cereal competition (Annicchiarico et al., 2019). Root traits play a key role in interspecific relationships as root space filling capacity influences the access to resources and competition between species.

In this work we examined genotype x management (GxM) effects on root traits phenotyping two white lupin (*Lupinus albus* L) genotypes intercropped with spring wheat. Genotypes were chosen based on their contrasting shoot morphology. The experiment was conducted in rhizoboxes: a medium tall lupin genotype (5.23) and a short one (17.124), were grown in a 1:1 mix with wheat (cv Nefertari), and in pure stand. We hypothesized that differences in lupin shoot morphology were associated to different root phenotypes in intercropping.

We found a significant genetic variation in cluster in root length with genotype 5.23 outperforming 17.124 in both pure and in mixed stand (P=0.004). A significant cross-over GxM interaction was found for total (cluster + non-cluster) root length and volume with the difference between genotypes increasing under intercropping: 5.23 produced +42% and +40% more total root length and volume, respectively, than genotype 17.124 in intercropping. Wheat produced more roots in pure stand. No significant differences in wheat root length were observed between mixtures with the two lupin genotypes. Intercropping indexes calculated on root length indicate that both lupin genotypes have LERroot> 1 in intercropping. Our results suggest that shoot morphology could be used as a proxy for root vigour in intercropping, but this hypothesis needs to be validated on a broader range of genotypes.

Keywords: Intercropping, root, phenotyping, legumes, lupin, cluster roots

Durum wheat breeding and variety adoption and Its Resilience to Climate Change Impacts in Smallholders

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In recent years, durum wheat (*Triticum durum* Desf.) production has been threatened by climate change and the extreme weather events that pose a serious risk to social, economic, and political stability in the Mediterranean countries, particularly in Tunisia. Stabilizing and increasing production under these conditions will be a real challenge for Tunisia, requiring an improvement in technical and economic efficiencies. Accordingly, adaptation strategies that are resilient to such changes across different climates should be implemented immediately, and the government must take decisive action to ensure sustainable food production. From these measures, crop genetics and management strategies, such as technological advances, certified seeds and fertilizers, the adoption of new cultivar, and better farming practices, can be options to increase production by the smallholders that represent 80% of Tunisian farmers. Several regions already showed large yield gaps caused by the lack of some of these components. To boost the productivity of Tunisian farmers, especially in rainfed environments, great efforts were made by the national breeding program, resulting in the registering of several durum wheat cultivars in the national catalogue (e.g., 'Karim', 'Razzek', 'Om Rabiaa', 'Khiar', 'Nasr', 'Maali', 'Salim', INRAT 100 and Dhahbi). In particular, increasing yield genetic potential under water-deficit conditions is one of the major objectives and the principal selection index of the durum wheat breeding programs. Promoting the adoption of high-yielding cultivars with the recommended practices in a sustainable manner helps to improve the livelihoods of rural farmers. In particular, on-farm demonstrations, which are key to teaching in the extension system, gained the confidence of farmers who toured the farms, leading to the successful adoption of the package and the showing of new practices to the farmers. Accordingly, there is a need for adoption studies to consider the farmers' perceptions of the technology attributes in the evaluation of the durum wheat cultivar adoption decisions. Statistical model was used as reliable tool for the quantitative prediction of crop yield with or without considering the technological advances at both the regional and the global scales in the context of climate changes.

Keywords: climate change, durum Wheat, adoption, resilience

Intraspecies Competition of Lentil Accessions

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Intercropping is an environmentally friendly agricultural practice that can increase productivity and improve resource efficiency. Achieving the full benefits of intercropping of cereals and legumes requires agronomic and genetic studies of crop compatibility, intra- and interspecific competition, and the ability of varieties to grow under intercropping conditions and global change.

Lentils are the fifth most important grain legume in the world. Recent studies have shown that well-designed intercropping systems of cereals and lentils can improve yield, product quality, and sustainability. However, the mechanisms of crop interactions and the identification of varieties suitable for intercropping remain poorly understood.

This study examined competitive interactions among lentil plants of the same genotype under controlled greenhouse conditions and evaluated genotype suitability for mixed-cropping systems based on their level of intraspecific competition. The experiment was conducted in 2023-2024 using 153 lentil accessions from 24 countries maintained in the INRAE genetic resources collection. Forty-one accessions (27%) originated from France, and the Simpson diversity index by country of origin was 0.88.

To assess phenological, morphological, and agronomic traits, four seeds of each accession were sown per pot in two replicate pots. Natural variation in seed viability resulted in densities ranging from one to four plants per pot, creating different levels of competition. For all samples, yield per pot (as total seed weight), productivity (seed weight from 1 plant), number of seeds per pot and per plant, and seed size (weight of 100 seeds) were measured. Two-way ANOVA was used to evaluate the contribution of genotype to yield-related traits. Intraspecific competition was analysed using a hyperbolic competition model adapted from Spitters (1983). A common-coefficient model and a genotype-specific competition model were compared.

Genotype significantly affected yield, and plant productivity was the trait most responsive to plant density. The genotype-specific model provided a significantly better fit, demonstrating that competition intensity depends on genotype. Among 58 genotypes suitable for modelling, 19 showed strong competitive effects and may be less suitable for mixed cropping, whereas 30 exhibited no or low competition, indicating high potential for intercropping. These results provide a practical approach for identifying lentil accessions adapted to mixed-cropping systems.

Keywords: Lens culinaris, mixed crops, competition coefficient

Developing Models and Approaches to Breed for Resilient Variety Mixtures

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This project aims to improve breeding methodologies for a variety of mixtures by developing optimized strategies for their selection and assembly. It will explore how phenotypic and genomic data can be integrated to design mixtures that deliver higher yields and greater resilience across diverse environments. The project will test the hypothesis that combin-ing genotypes with contrasting environmental reaction norms results in more stable and robust mixtures. Winter wheat (T. aestivum L.) will be used as a model crop to test this hypothesis and will be grown in 2- and 3-way mixtures, as well as in pure stands, in a multi-environment trial (MET). Based on these results and a larger historical MET that includes only pure stands, a comprehensive framework for mixture assembly will be developed to predict mixture stability across locations and into untested growing seasons. Further focus lies on developing methods to separate mixture component yields, as well as quantitative ge-netic models to describe genotypic effects in genotype mixtures of any number or proportion. These developments will enable future genetic gain through dedicated breeding for variety mixtures. Collectively, these approaches will expand the toolbox available for the breeding and deployment of variety mixtures. The project is funded within the public part of the CropXR consortium, AgroXR. CropXR is a digital institute with the mission of developing resilient crops through data-driven design. This particular project runs from 2025 through 2028 and includes three experimental years. All research takes place under organic or low-input management. Preliminary results from the first season show that the overall effects of variety mixtures depend on the specific growing environment.

Keywords: variety mixtures, wheat, crop diversification, organic agriculture, yield stability, climate resilient agriculture

Estimation of genetic cultivar mixture population effects

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Plant breeding has historically focused on improving the performance of pure stand cultivars; however, pure stand cultivars are increasingly challenged by the need for sustainable agricultural systems that are resilient to climate variability, pests, and diseases. Cultivar mixtures, defined as the simultaneous cultiva-tion of multiple genotypes within the same field, have been suggested as a promising alternative. Additionally, microbiome research has revealed that the rhizosphere microbiome influences nutrient uptake, stress tolerance, and disease resistance of the plants. Plant genotypes can shape microbiome composition, and in turn microbiomes can modulate plant phenotypes. Thus, in the current PhD-project we aimed to study how pure stand cultivars correlated to cultivar mixtures and how it affected the soil microbiome in the near root zone. New genetic models will be developed to integrate genotype information with phenotype information of pure stand cultivars and cultivar mixtures along with microbiome recordings in the root zone. There is a critical need to develop novel statistical models that integrate: 1) genetic effects in cultivar mixtures, 2) G×E interactions, and 3) host-microbiome interactions. The genetic models will be based on a mix-model estimator estimating genotype variation of associated traits including prediction of GBLUP values of the individual cultivars. The study will be supported by experimental data recorded from an experiment managed by the Danish breeding company NordicSeed and cover 75 three cultivar-mixtures each year along with pure line cultivars of their elite line in winter wheat.

Keywords: winter wheat, cultivar mixtures, quantitative genetics, mixed model equations

2. POSTERS- Impact of plant diversity on the extended phenotype

Plastic response of plants in intercropping systems: A bibliometric analysis

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Intercropping has emerged as a potential solution to address several intertwined agricultural challenges including biodiversity loss, climate change and the yield plateau. Plants in intercropping systems face heterogeneous canopy and soil environments due to diverse neighbouring plants. Such heterogeneity can induce strong plastic responses that might ultimately lead to overyielding. However, research trends and thematic developments regarding plant plasticity in intercropping systems remain insufficiently synthesized. Scopus and the Web of Science Core Collection were searched to identify relevant literature published from 1980 to 2026. A total of 350 documents were retrieved. After manual cleaning and duplicate removal using *BiblioMerge*, 172 documents were retained for the final bibliometric analysis. *Biblioshiny* and *VOSviewer* 1.6.20 were used to assess key bibliometric indicators including annual publication trends, contributing authors, collaborative networks and thematic domains. Results revealed that research on plasticity in intercropping systems has an interdisciplinary nature and relies heavily on teamwork (6.62 co-authors per document). The number of publications on the topic also showed an increasing trend with a mean annual growth rate of 5.9%. Keyword co-occurrence analysis showed six thematic clusters while seven research trends were identified by the citation analysis. Wheat and maize were the most studied crops. The citation trend shifted from early works focusing on plasticity theory (2015) to field-based light interception studies (2017–2021) and to contemporary simulation and precision crop design (2024–2026). Wageningen University and Research and INRAE emerged as main global collaboration hubs. In contrast, China leads in terms of research output and impact. Overall, plasticity research in intercropping is a growing, collaborative and increasingly influential research domain. Future research on intercropping should focus on integrating crop plasticity with plant-soil-microbe interactions for optimizing complementarity, resilience and productivity under changing environmental conditions.

Keywords: phenotypic plasticity, plant architecture, root plasticity, rhizosphere facilitation, light partitioning, functional structural plant modelling, overyielding, resource use efficiency

Intraspecific interactions modulate susceptibility to barley leaf rust in varietal mixtures

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Puccinia hordei, the causal agent of barley leaf rust, is a biotrophic fungal pathogen affecting barley (*Hordeum vulgare*). Disease management still relies largely on chemical fungicides, highlighting the need for alternative and more sustainable strategies. Recent studies have shown that intraspecific plant–plant interactions can modulate disease susceptibility through the phenomenon of neighbor modulated susceptibility (NMS), where the genotype of a neighboring plant influences the response of a focal plant to pathogens. Such effects have already been reported in wheat and rice but remain unexplored in barley. In this work, we aimed to better understand how intraspecific interactions between barley cultivars modulate disease susceptibility to leaf rust in varietal mixtures. Ten barley cultivars were grown either in monoculture or in binary mixtures and inoculated with *P. hordei* under controlled conditions. Disease severity was measured on focal plants to evaluate the impact of neighboring genotypes to identify varietal combinations associated with increased or reduced symptom severity. Results from these experiments will be presented and discussed in the light of the data already obtained on other pathosystems.

Keywords: Puccinia hordei, barley, plant, plant interactions, varietal mixtures, neighbor, modulated susceptibility

3. POSTER SESSION - Plant Models to decipher plant-plant interactions

FLORSYS – a 3D individual-based model to investigate biological weed regulation in crop and variety mixtures

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Arable weeds are highly damaging to crop production and usually controlled with herbicides. Species/variety mixtures can contribute to reducing herbicide use, by increasing biological weed regulation. Models allow exploring the underlying biological interactions and assessing the many possible intercropping scenarios. Because crop–crop–weed canopies are multispecies and heterogeneous (e.g., different weed emergence cohorts, weed patches, intercrop sowing patterns), such models must be dynamic and 3D individual-based. The FlorSys model started twenty years ago following these principles, focusing on crop diversification and biological interactions (1). Crop and weed plants are represented individually as simple volumes (cylinders and spilled cones), which grow or shrink based on photosynthesis, respiration and damage (frost, chemical, mechanical). The space is discretized with voxels (3D pixels) including biomass, leaf area, root lengths of different plants. Plants compete for light (when plants shade their neighbours), water and nitrogen (when their roots are in the same voxels with insufficient resource availability). For pre-emergent processes, the soil is discretized into finer 1-cm layers, where seed death, dormancy, germination and preemergent growth depend on seed depth and soil state variables (predicted by the STICS soil submodel included in FlorSys). Recent improvements added key processes for intercropping (e.g., nitrogen competition, allelopathy (2)). Functions are the same for all species, only parameter values vary with species and variety. Seed and plant dynamics are driven by management operations, climate and soil variables. The daily outputs are essential to understand biological interactions whereas annual indicators (e.g., yield, yield loss due to weeds, trophic resources for pollinators) allow stakeholders (farmers, crop advisors, breeders) to compare varieties, management practices or cropping systems (1)(3)(4).

References: (l) Colbach et al., 2021. The FLORSYS crop-weed canopy model, a tool to investigate and promote agroecological weed management. Field Crops Research 261. https://doi.org/10.1016/j.fcr.2020.108006

From the Mix4Agroecology Conference, Paris-Saclay (France), 7-9 Oct 2026: (2) Moreau et al., 2026. Developing a modelling approach to decipher the role of allelopathy in crop-weed interactions. (3) Colbach et al., 2026. Mixing knowledge and disciplines into a mechanistic model for designing crop mixtures for agroecological weed management. (4) Baquet et al., 2026. Nitrogen stress makes legume crops more competitive against weeds in intercrops.

Keywords: weeds, cropping system, crop mixture, agroecology, competition, crop model

Linking crop models and agrobiodiversity to support diversified cropping systems

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Associated agrobiodiversity supports key ecosystem functions in agricultural landscapes, yet it remains only partially represented in crop-modelling approaches. This is particularly relevant for diversified cropping systems, such as intercropping, crop mixtures and agroforestry, where interactions among crops, non-crop species, management and landscape context affect both crop performance and associated agrobiodiversity. Crop models can describe crop growth, management effects, and production outcomes in detail, whereas biodiversity models often capture ecological responses to land use, management, and environmental change. However, these modelling traditions remain weakly connected because they differ in spatial and temporal resolution, data requirements, and in the way they represent management and ecological processes. We reviewed studies that explicitly connected crop-model outputs or crop-related modelling variables with floral or faunal associated agrobiodiversity. Literature searches in Web of Science and Google Scholar, conducted up to July 2025, resulted in 37 studies included in the synthesis. We classified these studies according to spatial scale, study objective, integration strategy, and biodiversity component, using the Essential Biodiversity Variables framework to organize how agrobiodiversity was represented. Based on the patterns identified in the studies, we suggested three integration pathways: mechanistic integration of agrobiodiversity within crop models; coupled and hybrid workflows translating agricultural or land-use change into biodiversity responses; and integrated socio-ecological approaches linking biodiversity outcomes to management and decision processes. These pathways clarify how crop models currently address biodiversity-related questions and where important limitations remain. We argue that future progress requires better alignment between biodiversity components, modelling architectures and spatial scales, as well as stronger data interfaces, trait-based representations and monitoring approaches to support scalable crop–agrobiodiversity integration.

Keywords: associated agrobiodiversity, agroecosystems, process, based, model coupling, variables, management disturbance, land, use intensity.

Developing a modelling approach to decipher the role of allelopathy in crop-weed interactions

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Various mechanisms can influence plant-plant interactions in heterogeneous plant canopies. Competition for resources (light, water and minerals) is considered as the main mechanism and has been extensively studied. Conversely, the role of allelopathy (viewed here as a mechanism by which a plant can affect the growth of a neighboring plant through the release of allelochemical compounds into the rhizosphere during its life cycle) has been little investigated. Yet, the use of allelopathic species/varieties is regularly proposed as an agroecological lever to promote weed regulation. However, the simultaneous occurrence of allelopathy and competition makes it difficult to quantify the effects strictly attributable to allelopathy in the field (1).

Mechanistic models are valuable tools for quantifying variables/mechanisms that are difficult to measure in the field. The FLORSYS model is the only mechanistic model quantifying the effects of cropping systems, in interaction with soil and climate conditions, on the dynamics of multi-species weed flora and the impacts on arable crop production (2). This model takes into account plant competition, but not yet allelopathic interactions.

The aim of the presentation is to outline the work we are currently undertaking to develop an 'allelopathy submodel' to integrate into FLORSYS, in order to account for the ability of certain plants to affect the growth of neighboring plants by releasing allelochemicals into the rhizosphere during their life cycle. This work draws on experimental and literature-based data, as well as expert knowledge.

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Keywords: Weeds, agroecology, biological regulation, specialized metabolites, root exudates

Crop models need to account for microclimate conditions so that they reliably simulate annual crop mixtures

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Increasing crop diversity through intercropping of varietal or species mixtures is a promising strategy to enhance agroecosystem sustainability. The resulting complex canopies create specific microclimates (1) conditions - solar radiation, temperature, humidity and wind speed "sensed" by organs (1) - that influence crop performance, resilience to climate extremes, and pest regulation (2). Microclimate governs phenological development and therefore resource competition/complementarity within crop mixture. Crop growth models (CGMs) often neglect microclimate conditions (3) since most formalisms have been developed and evaluated under monocropping conditions (4). Therefore, it remains unclear whether CGMs can accurately reproduce and account for the microclimate of complex canopies (4). This work assesses the ability of CGMs to simulate within-canopy microclimates in varietal mixtures and intercropping systems compared with monocultures. We evaluate whether current formalisms linking organ-scale processes to whole-plant functioning are sufficient to represent the spatio-temporal heterogeneity of microclimatic conditions in complex canopies. Based on a review of CGM formalisms, we aim to identify improvements for simulating microclimate conditions. The review highlights the link between microclimate determinants and the water balance, itself connected to radiative and energy balances. The next step should be to assess existing CGM performances and, if needed, modify their formalisms while avoiding any increase in model complexity that would be required to accurately simulate canopy microclimates.

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Keywords: heterogeneous canopy, crop growth models, microclimate, plant x plant interaction, varietal mixtures, intercropping, model parsimony

Architectural plasticity enhances light-use complementarity in camelina–lentil intercrops: a 3D modelling approach

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Crop mixtures are increasingly promoted for agroecological systems, but their performance depends on interactions between species, particularly light competition. Camelina sativa, a low-input oilseed crop, is promising for intercropping with lentil due to their synchronized crop cycles and complementary nitrogen use (1–3). However, the architectural traits that regulate light capture in camelina–lentil mixtures remain poorly understood. This study compares two contrasted camelina phenotypes, "Intercrop" and "Monocrop", to identify architectural traits favourable to light interception. Using the 3D structural model Colzette, implemented in OpenAlea and coupled with the CARIBU light model (4), we simulated canopy architecture and absorbed radiation at the vegetative stage.

Phenotypes were parameterized from field micro-plot data collected in Orsonville, France, in 2025. Simulations were conducted under monocrop conditions comparing two phenotypes at two densities: 72 and 129 plants m^{-2}. The simulations showed that plant density was the main driver of total light absorption through faster canopy closure. However, at equivalent density, the Intercrop phenotype consistently intercepted more light than the Monocrop phenotype. This advantage was independent of density and was associated with differences in plant height, leaf spread, spatial leaf distribution and growth dynamics. These findings highlight the role of architectural plasticity in improving light capture and support the design of camelina ideotypes better adapted to lentil-based intercropping systems.

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Keywords: Intercropping, camelina, lentil, agroecology, architectural plasticity, light interception, structural plant model.

4. POSTERS - Eco-evolutionary dynamics of pathogens in diversified fields

Identifying key canopy traits to maintain high green leaf area - A case study on sole and intercropped pea.

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Efficient sustainable disease management is urgently needed. Canopy architecture can play a major role in slowing down foliar epidemics. With a two-year trial of pure stand pea and intercropped with wheat in France, we investigate the link between canopy architectural features of four pea cultivars and disease pressure of anthracnosis and Ascochyta blight. Severity was assessed on each leaf level at five time points as well as canopy traits (leaf area, internode length, height and plant length). Using a novel approach to model whole-plant pathogen dispersal, we compared disease diffusion at plant scale between pure stands and intercrop pea. Also, we estimated architectural features contribution to green leaf area. Results show that, both years, pathogen diffusion speed is reduced in intercrop compare to pure stand pea. We identified that early plant traits explain around 50% of post flowering green leaf area variability with only two key traits. Finally, we propose a disease avoidance ideotype for each cropping system combining dispersal reduction trait.

Keywords: Disease, avoidance, ideotype, canopy traits, foliar disease, intercrop.

Evaluation of Varietal Diversification for Sustainable Control of Septoria Tritici Blotch: a Multi-scale Modeling Approach

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Septoria tritici blotch, caused by *Zymoseptoria tritici*, is one of the most damaging diseases affecting wheat production in Europe. While resistance *Stb* genes can effectively reduce disease severity (1), their widespread deployment may accelerate the emergence and selection of virulent pathogen strains, threatening resistance durability. Varietal mixtures (2), which introduce a limited yet practical level of intra-parcel genetic diversity while retaining some of the resilience associated with landraces (3), is a promising strategy to combine disease control and resistance durability management. In particular, field experiments showed that binary mixtures of resistant (cv. Cellule carrying *Stb16q*) and susceptible (cv. Apache) cultivars reduced the frequency of virulent strains, a benefit that may persist across growing seasons (4).

To generalize these observations and investigate long-term epidemiological and evolutionary dynamics, we develop a multi-scale modeling framework based on the simulation model *Landsepi* (5). The objective is to compare different deployment strategies of *Stb* genes based on their ability to provide effective control of Septoria tritici blotch and slow the adaptation of virulence in *Z. tritici* populations. The model simulates the infection levels at field and/or landscape scales and the dynamic of virulence frequencies both within and across cropping seasons, with respect to the *Stb* genes considered.

The present work focuses on field-scale simulations of varietal mixtures. A global sensitivity analysis based on first, second, and total order Sobol indices was conducted to identify the most influential model parameters in *Landsepi* governing the primary quantities of interest, namely disease severity and pathogen virulence frequency. The presentation will describe the calibration strategy developed for *Landsepi* using field observations (4) of these quantities of interest and will demonstrate the quality of the resulting fit. The approach will be extended to landscape-scale simulations to compare different strategies of deployment of resistance *Stb* genes, including cultivar mosaics of homogeneous parcels (pure stands) and heterogeneous parcels (varietal mixtures).

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Keywords: Zymoseptoria tritici, Resistance durability, Landsepi, Demo, genetic model, Wheat varietal mixtures

Wheat cultivar mixtures targeting multiple diseases reduce disease level and increase green leaf area

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Cultivar mixtures have shown their capacity to limit disease progression, in particular in the case of wheat rusts. Several mechanisms may explain the benefits of cultivar mixtures, including dilution and barrier effect. Though these mechanisms have been observed mainly in cases where a single disease was targeted, they could be applied to manage several diseases, provided an adequate mixture design is chosen. The objective of this work was to test the capacity of cultivar mixtures to control several diseases simultaneously, in particular yellow and brown rust, by using cultivars with complementary resistances.

Three mixtures were designed, each constituted of three wheat cultivars. Two of these mixtures were composed of one cultivar resistant to both rusts, as well as two cultivars with complementary resistance to yellow rust and brown rust. The third one was constituted of top commercialized cultivars, without taking into account yellow and brown rusts resistances. Disease progression of yellow rust, brown rust and septoria were measured. The level of disease between mixtures and the mean of components in pure stands were compared for 8 dates and up to 5 leaf layers.

Disease pressure was moderate for yellow rust (mean of 0.5 and up to 50% severity, maximum disease level on May 19th), but higher for leaf rust (mean of 1.9% and up to 95% severity, maximum disease level on June 16th). Among the 8 dates x 5 leaf layers, significant effects of mixtures were observed in 3 cases for yellow rust (mean effect of 1%, up to 2%), 3 cases for brown rust (mean effect of 7%, up to 12%) and 5 cases for septoria tritici blotch (mean effect of 7%, up to 20%). Though disease reductions in mixture were observed for leaf rust, we were not able to fully assess the capacity of tested mixtures to control both yellow and brown rust, due to the low yellow rust pressure. To further test our ability to combine resistance to sevral diseases, in a diversity of situations, the experiment will be replicated in additional sites and years.

Keywords: cultivar mixtures, fungal disease, wheat

Role of Tree Community on Coffee Pests and Diseases Regulation under Agroforestry Systems in Northern Laos

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Coffee agroforestry systems provide ecological services beyond production, yet the mechanisms by which associated tree communities regulate pest and disease pressure remain lacking insights (1). This study examines how associated tree diversity, abundance, canopy structure influences pest and disease regulation across 62 smallholder coffee gardens in three provinces of Laos, spanning gardens aged 4–20 years. Pest and disease assessments on 1,550 coffee trees were integrated with spatial tree arrangement and hemispherical canopy measurements. The analysis reveals that regulation service emerges from multiple mechanisms operating at different scales within the agroecosystem: canopy openness is positively associated with leaf rust severity, associated tree abundance shows a negative association with coffee berry borer, and shade tree diversity negatively correlated with stem borer incidence. Species richness alone was not significant, indicating that canopy structure is a more proximate regulatory driver than compositional diversity. We further investigate the distance at which trees influence pest and disease regulation. These findings are expected to inform tree selection, spatial arrangement, and shade management strategies for smallholder producers in Laos to enhance ecosystem-mediated pest and disease regulation.

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Keywords: Shade trees, Coffee berry borer, Leaf rust, Canopy openness, Spatial organization, Pest and disease regulation

Dynamics of wheat pathogens in agroecological systems: role of the primary inoculum, biotic interactions, and the microbiota

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The European SOILES project has for purpose of enhancing soil health and improving crop resilience by studying sustainable agricultural practices. The priority is to exploit the biodiversity and to work with the soil-plant microbiome continuum. This project includes six experimental sites located in countries with variables climates (Denmark, Finland, France, Hungary, Italy and Portugal). The French site, located in Clermont-Ferrand studies a new agroecosystem, called "agroprairie", which consists of an association of annual crops (e.g., cereal crops – Triticum aestivum, Secale strictum) with multispecies perennial prairies in alternating strips. The management practices include no inputs (fertilizers and pesticides), reduced tilled and bare soil areas by up to 50%. I will present my thesis (May 2026 – April 2029), entitled "Dynamics of wheat pathogens in agroecological systems: role of the primary inoculum, biotic interactions, and the microbiota", included in the Europen SOILRES project. This thesis aims to characterize the dynamics of wheat pathogens focusing on the four components of the disease tetrahedron: the host, the pathogens, the microbiome, and the environment (Brader et al., 2017). This thesis is structured around three axes. The first axis aims to analyze how agroecological systems influence the dynamics of wheat diseases across the different pedoclimatic conditions of European sites. Several foliar diseases (septoria, rusts, fusarium, and others depending on presence) will be monitored in the different SOILRES sites. By focusing on the French site, the second axis will focus on the fate of the primary inoculum in the agroprairie system compared to the monocrop control. The dynamics of microbial pathogens will be monitored after dispersion of wheat debris infected with septoria or fusarium on the studied agrosystems. Finally, the third axis will seek to understand the influence of the primary inoculum on the soil microbiome and on the activation of wheat defense genes. Presence of antagonist microorganisms toward pathogens and their ecological interactions (if possible) will be studied.

Keywords: wheat diseases, agroecosystems, primary inoculum, soil microbial diversity

5. POSTERS – Designing mixtures for agroecological value chains

BBSoCoul : Breeding durum wheat under an alfalfa living-mulch in organic farming

Alain Baranger [1], Mathieu Marguerie [2], Pierre Auriel , Martin Ecarnot [3], Olivier Gardet , Antonin Grau [4], Regis Helias [5], Frederic Minard [6], Elodie Parquet [7], Basile Ploteau , Aline Rocher [8], Nicolas Salas [9], Benoît De Solan [10], Bruno Tisseyre [9], Jacques David [9]

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The BBSoCoul project aims at breeding durum wheat for its adaptation to cropping under a perennial alfalfa cover used as a living-mulch in organic agricultural systems. The main purpose is to use alfalfa as a service species for the control of weeds and the nitrogen return to durum wheat in cropping mixtures. The project includes the co-construction of an agricultural practise (cocultivation of alternate raws of both species where alfalfa competition is regulated through regular cuttings) together with genetics and breeding to identify traits and breeding strategies for durum wheat and alfalfa ideotyping and ideomixing. The project calls upon large within species variability in mixture components, in disruptive technologies in agronomy (GPS-RTK driven alfalfa cuttings), in high-throughput phenotyping techniques both during cropping at the canopy and plant scales and post-harvesting at the spike and grain scales, and finally in the development of adequate models in genetics to consider plantxplant interactions and extended phenotypes. Consequences for durum wheat breeding strategies to achieve producers as well as end-users expectations are also considered.

Keywords: Intercropping, Triticum durum, Medicago sativa

Predicting Overyielding in Wheat Variety Mixtures Using Environmental Reaction Norms

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Growing mixtures of crop varieties can increase productivity through biodiversity effects. However, this benefit varies substantially among combinations of genotypes. It therefore is essential to be able to predict which mixtures are most likely to overyield. Traditional functional traits have been proposed to characterize the functional complementarity between varieties that causes overyielding, but success has been limited to date (van der Plas et al. 2020; Wuest et al. 2023). Here, we explore genotype-specific reaction norms to characterize niche differences between wheat varieties and predict overyielding. We hypothesize that reaction norms capture functional differences not manifested in traditional traits. Using multi-environment wheat variety-testing data, including data from SEGES Innovation ("SEGES Innovation – Sustainable Foods of the Future," n.d.), we compare different measures of reaction norm similarity, including Pianka's overlap index, and investigate their correlation with mixture overyielding. Our findings suggest that reaction norms allow to predict both overyielding and yield stability.

Keywords: wheat variety mixtures, reaction norms, genotype, by, environment interaction, niche differences, overyielding, biodiversity effects

Holistic screening of legume cultivar suitability for intercropping and low-input systems

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Grain legumes are a key lever to reduce synthetic nitrogen (N) inputs in crop rotations. However, their cultivation remains limited in Europe, partly due to sensitivity to weeds, diseases and insect pests. Intercropping with cereals1,2 and reduced sowing density3 can mitigate these constraints, but performance strongly depends on genotype, environment and management, highlighting the need to evaluate cultivar x system interactions. We designed a multi-level, multidisciplinary field experiment to assess legume cultivar suitability for intercropping and low-input systems within an integrated pest management framework over three years (2025-2028) in Western Switzerland. A panel of cultivars (8 winter pea, 12 spring pea and 6 spring faba bean) is evaluated as sole crops and in intercrops with cereals (pea-barley, faba bean-wheat) using an additive design (legume 100-cereal 20). Two weed management strategies are compared: chemical control in sole crops and mechanical weeding in intercrops. A subset of two cultivars per group (species x crop type) is further tested across both weeding strategies and cropping systems, including sole crops, intercrops, reduced-density sole crop (50%), and pea-faba bean intercrop. The experiment follows an incomplete split-plot design with four blocks.

First season results will include biotic pressure and crop performance, including weed incidence (density, coverage, biomass), fungal disease severity, and insects damage (*Sitona lineatus* and bruchids), together with key crop traits: early vigour, phenology, canopy architecture (LAI, ramification number, height), above-ground biomass, grain yield, N content, and N fixation (in selected treatments). This integrated assessment aims to identify cultivar x management combinations suitable for agroecological production, particularly for intercropping under temperate conditions.

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Keywords: pea, faba bean, weed control, insect pests, integrated pest management.

Effect of legume variety type and crop management on the performance of white lupin-cereal intercrops in Northern Italy

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Greater knowledge is required for the effect of factors involved when implementing an intercrop, such as the ideotype of the main crop, the companion species, the fertilization level, and the sowing season. Little is known also on the value of evolutionary populations (EPs) in intercropping as an alternative variety model to pure-line varieties.

Two white lupin EPs evolved in pure stand (PS) or mixed stand (MS) with winter cereals, and two elite lupin lines representing a tall and a semi-dwarf plant type were evaluated in Lodi (Northern Italy) in MS with bread wheat or triticale, as well as in pure stand. Two sowing seasons (autumn and late winter) and two nitrogen (N) fertilization levels of the intercrops (zero N and 50% of the N fertilization for cereal pure stand) were tested. In each MS environment we recorded lupin grain yield, total (lupin + cereal) grain yield, and lupin proportion (on total harvested grain yield). Intercropping efficiency was assessed by LER.

Lupin was at severe competitive disadvantage in just a few MS environments. Lupin type rank for mean grain yield in MS was: EP evolved in MS > EP evolved in PS > tall inbred line > semi-dwarf inbred line. The most productive and competitive ideotype in MS also maximized total MS grain yield. Season of sowing, cereal species, and N fertilization level mostly revealed significant trait variation. No significant interaction of lupin variety type with the other factors was observed. Lupin grain yield and proportion of the overall best variety type in MS (EP evolved in MS) were generally favoured by autumn sowing, intercropping with wheat (shorter than triticale), and no N fertilization in MS (the latter also resulting in greater LER compared with the 50% N treatment). This variety type intercropped with triticale, with autumn sowing and no N fertilization, provided the highest total yield and a legume proportion of 41%.

The results highlighted the great potential in MS of the EP adaptively evolved in intercropping (obtained in a relatively short time and at very low selection costs), and a general advantage of tall over semi-dwarf lupin plant type.

Keywords: competitive ability, evolutionary breeding, heterogeneous population, Lupinus albus, plant morphology

Maize for human fooding : A case study of participatory plant breeding from seed to plate

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Our objective is to provide with case studies to build local food supply chains that are environmentally friendly and respectful of people, offer affordable prices to consumers, and provide fair and equitable income for every stakeholder in the supply chain. The example chosen is the establishment of a short supply chain for the marketing of polenta semolina, " La polenta de Saclay ", ranging from the selection of a high-quality corn variety suited to the Île-de-France region, to its processing, and its direct sale, including local associative structures, restaurants, and canteens. The project started with and italian maize landrace that is currently undergoing an original breeding scheme based on full-sib matings and genomic selection, with the aim of notifying the selected population as Organic Heterogeneous Material (OHM). Selection objectives are constructed in a collaborative manner along with the setting-up of the food-chain value. The co-design approach involves farmers, millers, processors, distributors, consumers and researchers in a research/action mode. At the farm level, we question the place of maize in the rotation and the cost of purchasing seeds. At the processing level, we try to optimize the semolina yield taking into account available local infrastructures. At the consumer level, we're working on the product branding and the sharing-out of cooking recipees. After three years since the project's onset, we'll analyse the successes and failures. We propose indicators to evaluate the adoption of new germplasm and would like to share ideas about the on-farm management of genetic resources and how to establish a local seed sector, including seed certification for population varieties in outcrossing species.

Keywords: Participatory Plant Breeding, food chain value, on farm management of genetic resources

Metabolomic approach of oil palm fruit and seed, combined to environmental assessment under intercropping system with upland rice and K fertilization

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Oil palm (*Elaeis guineensis* Jacq.) is the world's most productive oil crop, yet environmental concerns and restrictions on plantation expansion require more sustainable strategies to improve productivity within existing cultivated areas. Intercropping with upland rice could enhance land-use efficiency, soil quality, biodiversity, smallholder income and food security. This cropping system design "oil palm/rice", still quite rare, remains poorly documented and its impact on oil (palm and palm kernel oil) quality as well as the perception of this new Indonesian governmental policy by smallholders. It is the reason why this study aims to evaluate the feasibility of oil palm–upland rice intercropping through (1) a farming system approach to evaluate the potential of adoption of this new initiative and (2) a metabolomic and an integrated environmental assessment under K fertilization gradient. More broadly, the study is framed as an interdisciplinary feasibility study, combining approaches ranging from socio-economic to genomic tool as metabolomic. Field experiments will be conducted in North Sumatra, Indonesia, comparing oil palm monoculture and oil palm intercropped with upland rice across 2, 4, 6, 8 years old under two K fertilization levels: K0 (without KCl application) and K1 (4.5 kg KCl $tree^{-1}$ $year^{-1}$). Agronomic, physiological, environmental, and metabolomic traits will be assessed to identify indicators associated with cropping systems impacts under K nutrition, as well as tracers of oil origin to support the development of more sustainable oil palm production systems. Machine learning will be used to identify with also socio-economics enquiries best transition agroforestry system based on oil palm/rice.

Keywords: Metabolomics, palm oil quality, palm kernel, potassium fertilization, upland rice intercropping

Strip intercropping with industrial crops as a sustainable practice to manage marginal land

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Marginal lands are considered strategic areas for industrial crop cultivation within the European bioeconomy and climate-neutrality framework, where low-input diversified strategies such as wide-strip intercropping can support biomass production while preserving ecosystem services. This study evaluated a strip intercropping system including hemp, safflower, crambe and miscanthus on sloping marginal land (15% slope) in Ozzano dell'Emilia (BO), arranged in three replicated blocks. Annual crops followed a randomized complete block design (RCBD), while miscanthus strips remained fixed throughout the experiment. Each strip was 6-m-wide to ensure machinery compatibility, with an ex-ante crop rotation (crambe–safflower–hemp) determining the position of neighboring strips. The objective was to assess crop interactions within the system and the suitability of the four crops under sloping conditions. No significant interactions among crops were observed in terms of yield, indicating that wide-strip intercropping can promote diversification without compromising individual crop performance, even among species with different competitive abilities. However, the crops differed markedly in their response to slope. Hemp was the best-suited and most stable crop (CV: 26%), with biomass yields (12.8 Mg ha^{-1}) comparable to favorable conditions (11–14 Mg ha^{-1}). Crambe also showed good adaptability (seed yield: 1.6 Mg ha^{-1}; CV: 34%), close to favorable-condition values (1.8–2.8 Mg ha^{-1}). Safflower showed the lowest adaptability, with the lowest and most variable yields (seed: 1.1 Mg ha^{-1}; CV: 56%), about 50% below non-marginal conditions. Seed quality (oil content, fatty acid composition) remained stable for both safflower and crambe (35% and 34% oil, respectively), whereas hemp biomass quality declined over time, with stems progressively heavier (12 g in 2023 to 30 g in 2025), suggesting increased secondary growth and reduced fiber quality. Miscanthus establishment was hindered by adverse weather and weed competition in 2023, with low biomass in 2024 (2.4 Mg ha^{-1}) but a marked increase in 2025 (5.0 Mg ha^{-1}), consistent with a transition toward the productive phase. Overall, wide-strip intercropping was a viable practice for diversification on marginal land. Among annual crops, hemp showed the highest adaptability, followed by miscanthus, crambe and safflower. Future analyses will explore associated changes in soil fertility and microbial dynamics.

Keywords: Marginal land, Industrial crop, Bioeconomy, Strip intercropping, Oilseed crop, Lignocellulosic crop

Cultivated diversity and seed management as drivers of agroecological disease regulation in Tunisian durum wheat

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Agroecological crop protection requires a better understanding of how resistant varieties can be deployed within agricultural landscapes. Beyond the deployment of individual resistant varieties, cultivated diversity, including cultivar mixtures and traditional landraces, offers promising opportunities to enhance the natural regulation of crop diseases. Tunisia, with its continuum of climatic conditions and diversification practices, provides a unique case study for exploring these questions. Durum wheat occupies nearly half of the national cereal acreage and is cultivated from humid northern regions to arid southern areas. The coexistence of certified varieties, cultivar mixtures, traditional landraces, diverse seed exchange networks and rapidly changing climatic-driven epidemiological contexts create a remarkable setting to investigate the relationships between seed management, cultivated diversity and disease resilience.

We characterized cultivated diversity at the field scale while documenting farmers' agronomic practices, seed exchange networks and decision-making processes, in order to identify the mechanisms underpinning durable resistance to wheat diseases. Genetic analyses revealed remarkably high levels of within-field diversity in traditional landraces. These genetically heterogeneous populations showed strong resistance to diseases, and notably to Septoria tritici blotch. Diagnostic surveys involving more than one hundred wheat producers further revealed the coexistence of three contrasting agroecosystems. A conventional system relies almost exclusively on certified varieties and fungicide applications to maximize yield under favorable conditions. A traditional system is based on farmer-managed landraces, where disease regulation depends primarily on intraspecific genetic diversity. Among the two, we identified an original composite system cultivating both traditional and modern varieties with locally adapted management strategies that reconcile yield stability, reduced pesticide use and adaptation to local environmental conditions. The distribution of these systems closely follows Tunisia's climatic gradient.

These findings indicate that disease regulation depends not only on the genetic composition of cultivated varieties but also on farmers' knowledge, seed management strategies and agronomic practices, highlighting cultivated diversity as a key component of agroecological transitions and sustainable crop protection.

Keywords: Cultivated diversity, Farming systems, Disease resistance, Durum wheat landraces

Performance of cereal/legume intercropping in Europe: a meta-analysis

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Intercropping, the simultaneous cultivation of multiple crops on the same land area, can enhance land-use efficiency relative to sole cropping. Reported land equivalent ratios (LER) of 1.16–1.32 indicate land savings of approximately 14–24%, showing that intercropping reduces land requirements compared to monocultures. Cereal–legume intercropping is particularly advantageous because of the complementary use of nitrogen. Legumes fix atmospheric nitrogen through symbiotic N_2 fixation, which reduces competition with cereals and contributes to overall nitrogen uptake and productivity. This process can also allow for reduced nitrogen fertilizer inputs while maintaining yields (Paul et al., 2024). Despite these benefits, intercropping has declined in Europe since the mid-20th century, as agricultural systems have shifted towards monocultures. This trend has been driven by the complexity of managing and harvesting crop mixtures, as well as challenges in downstream processing, such as maintaining product purity. While monocultures can be economically efficient in the short term, they may be less sustainable in the long term due to high fertilizer inputs and associated environmental impacts. Therefore, diversified systems such as intercropping are increasingly being reconsidered as pathways toward more sustainable agricultural production in Europe.

Most meta-analyses on intercropping performance have focused on global datasets or specific regions, and there is limited synthesis focusing exclusively on Europe. To address this gap, we conducted a meta-analysis across Europe. A total of 80 articles met the inclusion criteria and were used for analysis. Our results show that cereal–legume intercrops in Europe outperform monocultures in terms of land-use efficiency, with a mean LER of 1.20 $\pm$ 0.01. This corresponds to a land saving of approximately 17% compared to sole cropping. The performance of intercropping systems varied depending on growing conditions. For example, the mean LER was 1.23 under organic management, whereas in conventional systems it was 1.24 without nitrogen fertilizer and 1.15 with nitrogen fertilizer.

Reference: Paul, M. R., Demie, D. T., Seidel, S. J., Döring, T. F. (2024). Evaluation of multiple spring wheat cultivars in diverse intercropping systems. European Journal of Agronomy, 152, 127024. doi:10.1016/j.eja.2023.127024

Keywords: Cereal–legume intercropping, LER, organic system, conventional system, meta, analysis.

Participatory Breeding of Rice Organic Heterogeneous Material in Northern Italy: Integrating Genetic, Ecological, and Social Dimensions of Agroecology

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The agroecological transition requires a holistic approach that reconciles agricultural production with wider ecosystem processes. In Northern Italy, organic rice fields function as surrogates for natural wetlands, acting as biodiversity hotspots, within landscapes otherwise dominated by intensive conventional agriculture. Lepidoptera and Odonata can serve as ecological indicators in these systems: organic management has been shown to markedly increase insect abundance compared with conventional systems, whereas species richness appears to be more strongly shaped by the broader environmental context (1).

Since 2018, Rete Semi Rurali has facilitated a "Seed to Fork" Living Lab (LL) in Rovasenda, Vercelli Province, Piedmont, involving a network of organic rice farmers, rice seed producers, processors, researchers, and citizens in the co-design and implementation of agroecological innovations (2). The main objective of this LL has been to develop rice cultivars specifically adapted to agroecological management and capable of dynamically adapting to organic rice agroecosystems.

Rice dynamic populations (DPs) were co-designed through the participatory selection of a large rematriated Italian rice germplasm collection, followed by processing and cooking tests aimed at assembling populations with compatible grain sizes and quality traits. Medium- and long-grain DPs were subsequently packaged and distributed to citizens and consumers for broader culinary evaluation under real-life home-cooking conditions. Meanwhile, the DPs were agronomically evaluated at field scale in the organic farms of the LL. The results indicated good local adaptation and a high level of appreciation by both farmers and consumers, leading to the notification of the medium-grain DP as Organic Heterogeneous Material, while the long-grain DP is currently undergoing field scale multiplication for both seed and paddy rice production.

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Keywords: Organic Heterogeneous Material, Rice, Culinary Breeding, Action Research, Wetland, Biodiversity Indicators, Agrobiodiversity

Intercropping for Organic Agriculture: Barriers, Creative Solutions and Perspectives in a Co-Innovation Case Study in Italy

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Despite its agroecological benefits, intercropping is not a common practice in Italy. Several barriers hinder its adoption: (i) insufficient knowledge among farmers, agricultural contractors, and advisors; (ii) reliance on machinery that is not always adaptable to mixed sowing and harvesting operations; (iii) difficulties in post-harvest management and crop separation; (iv) absence of a value chain capable of dealing with the products; (v) lack of consumer awareness; and (vi) bureaucratic constraints.

Within the IntercropVALUES project, a Co-Innovation Case Study (CICS) was established in Italy by Rete Semi Rurali as a network of 7 organic farms, committed to developing and adapting intercropping to their specific agroecological context and production models. During the four years of the project (2022-2026) the CICS farmers have largely succeeded in overcoming the main barriers adopting a variety of strategies. The key elements of success identified are:

- Propensity for empirical field experimentation: The small size of the farms, together with greater flexibility and autonomy in decision-making, have empowered farmers to acquire practical experience forf different types of intercrops and their management;
- Investment in grain cleaning facilities: Two grain crop farms have acquired grain-cleaning equipment for the separation of harvested grains;
- Short supply chains: Products derived from intercropping are sold directly enabling direct communication with consumers who are willing to accept a certain degree of impurity in grains obtained from intercropping systems;
- Openness to engagement with citizens and collaboration with local farms: The farms involved in the Italian CICS are actively informing the public through social media and on-farm open days;
- Agroecological farm management: All CICS farms are certified organic and follow agroecological strategies in their farm management.

The main critical aspect remaining outside of CICS farmers and facilitators' control, concerns bureaucracy. In Italy, there is no possibility to declare intercrops on the official farm records, leading to difficulties in production traceability and managing crop rotation according to organic standards, forcing farmers to resort to rather inventive workarounds. Including new specific codes for intercrop combinations within the National electronic farm dossier system, would represent a simple solution and an important step toward giving intercropping official recognition.

Keywords: Intercropping, Organic agriculture, Co Innovation, Living Lab, Value Chain, Crop Diversification, Agroecology, Regulatory Barriers, Ecosystem Services

Harnessing crop diversity to co-design diversified farming systems in Cambodia

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Cambodia possesses a rich diversity of traditional crops that have long supported rural livelihoods. However, many local crop species, particularly neglected and underutilized species (NUS), are disappearing due to agricultural intensification and shifting market demands. This decline threatens the resilience of rice-based farming systems against climate variability, soil degradation, and economic uncertainty. Consequently, crop diversification is vital for achieving sustainable and resilient agriculture.

This PhD research investigates how crop diversity can drive innovative farming systems in Cambodia. By combining agroecological research on crop diversity with serious games as a participatory co-design tool, the study integrates scientific data with farmers' local experience to design diversified cropping systems.

The project begins by documenting the crop diversity currently maintained by farmers focusing on NUS to evaluate their contributions to food security, livelihoods, and environmental sustainability. Using these insights, the research will collaboratively co-design diversified cropping systems adapted to local needs. These systems will incorporate practices like crop rotation, intercropping, and the reintroduction of traditional species into rice production. Subsequently, the performance of these co-designed systems will be evaluated using agronomic, socio-economic, and environmental indicators.

Ultimately, this research will demonstrate that integrating crop diversity in cropping systems, through participatory co-design can strengthen the sustainability of Cambodian agriculture, generating practical recommendations to strengthen rural livelihoods and resilient rice-based farming systems.

Keywords: agrobiodiversity, agroecology, crop diversification, neglected and underutilized species, participatory research, farming systems, sustainable agriculture, Cambodia.

Legume Crops Co-cultivation as a Protein Source Under Current Variable Climate

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As part of the agroecological transition, increasing the proportion of legumes in crop rotations is a highly promising strategy. Legume crops offer a wide range of social, economic, and environmental benefits, such as their ability to fix atmospheric nitrogen, which leads to reduced reliance on chemical inputs.

For the past two years, in parallel with variety trials on pure stands of winter and spring peas and faba beans, trials involving a mixture of these two species have been conducted in Wallonia (Belgium). Datasets were consolidated, aiming at evaluating their agronomic potential and the ability for each species to compensate in case of failure of the other, in sustaining protein production.

Results revealed both pure species exhibiting contrasted responses to climatic conditions: peas were found to be more sensitive to wet years, whereas faba beans show greater sensitivity to dry years. As for the results of the mixtures in 2025, the winter mixture had a land equivalent ratio (LER) of 1.14, indicating that the mixed crop was more productive than growing the two species separately. For the spring mixture, the LER was 0.9, due to an excellent year for the yield of pure stands of peas. As for this year's results, the crops have not yet been harvested, but following a severe hailstorm in late May, the pure winter faba beans suffered significant hail damages and/or lodging. The association of crops seemed so far to resist better, we expect consequently the LER to exceed 1 for the winter mixed crop this year.

Promising agronomic strategies, such as species mixtures of leguminous crop emerge as potential approaches to enhance yield stability. As with pure legume crop stands, yields from the pea-faba bean mixture are expected to vary from year to year, primarily due to interannual climatic conditions. Further field trials over a longer period of time are therefore needed to be conducted to cover a wider range of climatic conditions before any broad trends can be identified.

Keywords: Intercropping, legume crops, faba bean, pea.

The agronomic potential of wheat and pea intercrops in German on-farm experiments over two experimental seasons (2023-2025).

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A co-creation case study focused on the integration of intercropped baking wheat and pea within seven regional value chains in Germany, evaluating every value chain step from cultivation through to processing with farmers, millers and bakers. Seven organic farmers grew a minimum of 0.5ha intercropped wheat and pea in the same field as both sole crops for comparison over two experimental seasons (2023-2025). Four farmers grew winter crops and 3 farmers spring crops with the crop cultivars for both winter and spring crops selected to be grown across farms. Biomass cuts at harvest (total 4m2 per cropping system and farm) were made to determine grain yield and other yield parameters. The productivity indices Land Equivalent Ratio (LER), Net Effect Ratio (NER) and Transgressive Overyielding Index (TOI) were calculated from grain yield (1). Grain protein and wet gluten content were also measured. Yields of winter pea in the first experimental season (2023/24) were poor due to high rainfall and pathogen pressure, and the majority of farmers ploughed the sole crop winter pea under in spring due to poor performance and high weed pressure. In both seasons, average yields of the intercropped wheat were not significantly lower than the sole crop wheat and the productivity indices were positive (> 1) for the winter intercrop in both experimental seasons. Productivity indices were positive for the spring intercrops in 2024, but not in 2025. Grain protein and wet gluten content were slightly higher in the intercropped wheat in comparison to the sole wheat. Results indicate the agronomic potential of the selected winter intercrop combination in terms of yield and grain quality; however, the performance of the selected spring cultivar intercrop indicate the need for careful cultivar selection to maximise intercrop performance.

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Keywords: Wheat, pea intercrop, agronomic performance, productivity indicators, on, farm experiments

6. POSTERS - Can plant diversification promote a more efficient soil functioning and nutrient cycling?

Plant diversification through pea–wheat strip cropping: preliminary results on soil organic matter status in organic farming

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Crop diversification is an agroecological strategy for improving the functionality and resilience of production systems, while intercropping links diversification with agroecosystem functioning and sustainability. Having in mind that cereal-legume systems may influence residue decomposition and soil organic carbon stability, this study presents a preliminary on-farm assessment of pea and wheat strip cropping under organic farming conditions in Serbia, with attention to soil organic matter (SOM) status. The demonstration plot was established in November 2025 as alternating pea (NS Pionir at 150 kg ha^{-1}) and winter wheat (NS Epoha at 230 kg ha^{-1}) strips. Baseline soil analysis was performed in the 0–30 cm layer at establishment, while follow-up soil samples were collected separately from pea and wheat in June 2026. SOM status was assessed based on humus content and total nitrogen, while pH, $CaCO_3$, available phosphorus and potassium were used as additional soil fertility indicators. Due to the on-farm demonstration character and limited sample size, June data were interpreted using descriptive statistics and an exploratory Welch's t-test. Baseline soil analysis in November 2025 showed a favourable SOM status, with 3.65% humus and 0.250% total nitrogen in the 0–30 cm layer. In June 2026, humus content averaged 3.70% in pea and 3.64% in wheat, while total nitrogen averaged 0.254% and 0.249%, respectively. Welch's t-test indicated no significant differences between pea and wheat for humus, total nitrogen, pH, $CaCO_3$, phosphorus or potassium, suggesting relatively uniform soil conditions across the strip cropping system. Humus content ranged from 3.47 to 3.93% in pea and from 3.55 to 3.72% in wheat. Although available data do not allow conclusions on long-term changes in SOM, these preliminary results indicate that pea and wheat strip cropping can maintain a favourable SOM status during the first season of implementation. Results also highlight the importance of combining field-based agroecological practices with soil monitoring to better understand how diversified cropping systems may contribute to soil functioning and SOM management. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (GN 451-03-33/2026-03/200032) and the EUKI project *"Improving C-Balances on Organic Farms II".*

Keywords: strip cropping, pea, wheat, organic farming, soil organic matter, humus, system diversification

Investigating Agronomic and Soil Microbiome Responses to Cereal-Legume Intercropping on the Island of Ireland.

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Cereal-legume intercropping has regained interest due to its potential to improve nitrogen-use efficiency and reduce dependence on synthetic fertiliser inputs (Bedoussac, et al. 2015, Jensen, Carlsson and Hauggaard-Nielsen 2020). However, the belowground processes that contribute to these benefits remain underexplored, particularly how crop combinations, management practices, and environmental conditions influence soil and root-associated microbial communities (Picone, et al. 2025). Understanding these belowground responses is important for identifying the plant-soil microbe interaction that support productive, low input cereal-legume cropping systems.

This project investigates how cereal-legume diversification influences agronomic performance and root-associated microbial communities within cropping systems on the island of Ireland. Initial multi-site field experiments were conducted to screen spring oats (*Avena sativa L.*) and faba bean (*Vicia faba L.*) genotypes for phenology, crop height, standing power, disease response, and harvest compatibility. Selected genotypes will be evaluated in spring oat-faba bean intercrops across contrasting crop proportions and nitrogen inputs, with a small winter wheat-faba bean system providing a second cereal-legume comparison.

Microbial communities are initially being characterised using 16S rRNA gene and ITS amplicon sequencing to establish patterns across bulk soil and root-associated environments. In the intercropping experiment, shotgun metagenomic sequencing will be used to assess microbial functional potential. Bioinformatic analysis will investigate how crop combinations and nitrogen inputs influence microbial diversity, taxonomic structure and functional pathways and integrate these findings with agronomic measurements.

By integrating agronomic and metagenomic datasets, this research will provide new insights into the mechanisms by which crop diversification and nitrogen management influence microbial communities and cropping system performance on the island of Ireland.

Keywords : Cereal-legume intercropping, Soil Microbiome, crop diversification, Plant-soil interactions

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Spatial Arrangement as a Lever for Nitrogen Fixation in Legume-Based Intercropping Systems

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Legume-based intercrops represent a promising strategy for reducing reliance on synthetic nitrogen fertilizers by enhancing symbiotic nitrogen fixation (1). This benefit depends on interspecific interactions such as competition and complementarity, which determine how effectively legumes fix atmospheric nitrogen in mixed cropping systems (2). Among the available design options, spatial arrangement modulates the degree of interspecific proximity (3) and may therefore be a key lever for optimising nitrogen fixation. However, its effect remains poorly documented (4). We conducted a field experiment in western France comparing two spatial arrangements, within-row mixing and alternate-row mixing, in two intercropping systems: lentil-camelina and pea-barley. The percentage of nitrogen derived from the atmosphere (%Ndfa) was quantified using the 15N natural abundance method at flowering. Preliminary results from a 2025 lentil-camelina field experiment suggest that closer interspecific mixing increases %Ndfa. The ongoing 2026 experiment will determine whether this response is consistent across systems differing in species traits and competitive dynamics. References (1) Jensen, E.S., et al. (2020). Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. Agronomy for Sustainable Development, 40(1) (2) Bedoussac, L., et al. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for Sustainable Development, 35, 911–935. (3) Stefan, L., et al. (2022). Using spatially-explicit plant competition models to optimise crop productivity in intercropped systems. Basic and Applied Ecology, 63, 1–15. (4) Chapagain, T., & Riseman, A., (2020). Barley–pea intercropping: Effects on land productivity, carbon and nitrogen transformations. Field Crops Research, 166, 18–25.

Keywords: Nitrogen fixation, intercropping, spatial arrangement, legumes

Vegetable Intercropping impact on labile soil carbon studied with urban farmers and gardeners to highlight the implication on soil health and ecosystem services

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Soil labile carbon, readily decomposed by microorganisms, plays a key role in soil fertility. Vegetable gardens, thanks to their regular organic inputs and diversified management, could maintain high levels of labile carbon; conversely, field crops, often depleted of organic matter and subjected to intensive practices, see their labile C content decrease, with negative consequences for soil health and the environment. In that context, the objective of our participatory research project in Occitanie was to analyze the soil bio-physicochemical characteristics with a focus on labile C, for various experimental gardens and vegetable farms implemented with pure and intercropping vegetables. Furthermore, water infiltration into the soil (a crucial ecosystem service), linked to its porosity, has been studied in the field. Factors Influencing labile C are: residue Management ; plant Diversity. Tillage in arable farming accelerates organic matter decomposition and reduces its persistence.

Field results indicate that agroecological practices can improve the soil labile carbon content (476 - 1 125 ppm), with possible consequences on the microbiota; and soil water infiltration was also strongly increased in comparison with conventional farms. Vegetable gardens (often rich in organic matter) and large-scale crops (often intensive and mechanized) exhibit distinct SLC dynamics, influenced by their management practices. Develop new databases and references for gardens is needed in order to better take into account the ecosystem services and roles in the connectivity of urban and peri-urban spaces.

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Keywords: Vegetable Intercropping, labile soil carbon, urban agriculture, soil health and ecosystem services

Organic Heterogeneous Material of Common wheat in agroforestry for agroecological transition

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This study investigates the performance of the Common or bread wheat (Triticum aestivum L. subsp. aestivum) Evolutionary Population FURAT within an agroforestry system at the Montepaldi Long-Term Experiment (MoLTE, University of Florence, Italy), a 30-year organic field trial (2). A comparative agronomic evaluation, initiated in November 2025, is conducted between EP FURAT and a varietal mixture of heritage wheat varieties (Miscuglio Montespertoli, composed of Andriolo, Inallettabile, and Gentil Rosso). The comparison was carried out across two hedgerow contexts and within crop rotations.

The analysis integrates yield performance, stability, and adaptability with soil health indicators, including microbial diversity (16S rRNA and ITS metabarcoding), microarthropod communities (QBS-ar index), and field-based bioindicators. This multi-level approach allows the exploration of interactions between intra-specific genetic diversity, management practices, and soil biological processes.

Results are expected to provide insights into the potential of Evolutionary Populations to buffer environmental variability and support more stable yields, while contributing to enhanced soil and environmental biodiversity(l). The FURAT population is officially registered, and with this year's harvest it will be marketable under organic regulations (3).

The study aims to clarify the role of Organic Heterogeneous Material (OHM) as a component of diversified cropping systems and to assess its relevance in low-input systems in agroecosystems.

Keywords: agroecology, agroforestry, OHM, evolutionary population, soil health, climate resilience.

Interactions between plant diversity, soil microbial diversity, and nutrient cycles in agroecosystems

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The ecological transition of cropping systems is currently explored through two main approaches: the diversification and perennialization of plant cover, and the application of bioinoculants to soils. Yet their individual and combined effects on crop nutrition, nutrient retention, and soil microbial communities remain poorly understood.

The European SOILRES project aims to improve soil health and enhance crop resilience by harnessing biodiversity and studying the soil-plant-microbiome continuum. The project relies on six experimental sites implementing different ecological practices across a range of soil and climate zones. Among these, the French site, in Clermont-Ferrand, combines annual crops (e.g., cereal crops – Triticum aestivum, Secale strictum) with multispecies perennial prairies in alternating strips, thereby defining a new agroecosystem termed "agroprairie". These agroecosystems are managed without inputs (fertilizers and pesticides), exhibit a high level of diversity and long-term plant cover, and reduce tilled and bare soil areas by up to 50%.

I will present my thesis (May 2026 - April 2029) entitled "Interactions between plant diversity, soil microbial diversity, and nutrient cycles in agroecosystems", and carried out within the European SOILRES project. The thesis is structured around three main axes:

- The first axis will evaluate the effects of agroecological practices, bioinoculants, and their interactions on wheat nutrition, nitrogen retention in the plant-soil system, and relationships between these variables and soil microbial communities. It relies on multi-element nutritional analysis (C, N, P, K, S) of plant biomass in combination with the characterisation of soil nutrient availability and basic related biogeochemical functions, and analysis of the taxonomic and functional composition of the soil microbial communities across the six experimental SOILRES sites.

- The second axis will assess the effects of wheat-prairie associations on the soil microbiome and C and N biogeochemical cycles at the French agroprairie site. Using metabarcoding approach and qPCR data, it explores relationships between plant functional diversity, soil microbial diversity, and biogeochemical cycles.

- The third axis will examine wheat and prairie productions over time in agroprairies. It will examine whether production responses (in quantity and quality) to wheat-prairie associations persist, strengthen, or diminish across successive cropping cycles, and how inter-annual variability (climate, management) modulates these dynamics.

Keywords: plant diversity, soil microbial diversity, biogeochemical cycles, agroecosystems

How intercropping influences microbial carbon use efficiency (CUE) during root decomposition over time

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Intercropping changes the quality and quantity of root litter inputs into soils (Cong et al., 2015b, 2015a). However, how these complex plant residues influence microbial physiological traits over time remains poorly understood. Carbon use efficiency (CUE) is a fundamental parameter informing on microbial physiology, and it is critical to quantify and understand the fate of C (Sinsabaugh et al., 2013). The objective of this study is to explore how root litter inputs quality and quantity influence microbial CUE over time. An incubation experiment was established using a temperate cultivated Luvisol. Four different litter treatments consisting of pure Lentil, pure Cameline, and two mixed ratios to reproduce field experimental conditions were applied at two levels (1% and 5% by mass). Respiration was monitored periodically, and destructive sampling was conducted at three time points, to quantify microbial biomass and measure CUE.

Results from 117-day soil mineralization and 3-time point respiration test showed that accumulated CO2 and its production rates were always higher with 5% litter input and pure Lentil treatment. Diversity calculation showed that there was no significant difference between measured and predicted respiration in the early stage of mixed treatments, while measured respiration in mixtures was more than could be predicted from the respiration rate of pure litters in the middle and later stages, indicating a clear diversity effect.

While preliminary mineralization results highlight synergetic effects of mixed litter, analyses on microbial CUE (18O-H2O labeling) (Schwartz, 2007), extracellular enzymatic activities, and microbial community sequencing are currently under way. This project aims to mechanistically understand how intercropping influences microbial-driven soil carbon cycling dynamics.

Keywords: Intercropping, Carbon use efficiency, Biodiversity effect, Microbial physiology, Soil science

7.A POSTERS - Out-scaling agroecology: transformative sciences

Can plant traits reliably predict Nature's Contributions to People?

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Plant functional traits are increasingly used to predict ecosystem functioning and Nature's Contributions to People (NCP), with the potential to inform the design of multifunctional ecosystems, including agroecosystems. However, evidence linking traits to NCP has accumulated through heterogeneous literature reviews that differ in ecological scope and synthesis methods, making it unclear whether reported relationships reflect robust ecological mechanisms or context-dependent patterns.
We conducted a second-order systematic review of systematic reviews and meta-analyses reporting relationships between terrestrial plant functional traits and NCP. Twenty-two reviews met our inclusion criteria, representing 474 unique trait–NCP relationships and 2,203 primary-study outcomes. To quantify the consistency of reported relationships while accounting for review quality, overlap among reviews and incomplete reporting, we developed a Bayesian hierarchical ordinal model.

Our analyses reveal that the current evidence base is dominated by contextual variation. Differences among reviews accounted for nearly 90% of the variance in reported trait–NCP relationships, whereas trait identity and NCP identity explained only a small proportion of the observed variation. This heterogeneity was not explained by methodological quality or commonly reported review characteristics. Nevertheless, a subset of biologically coherent relationships remained consistently supported across syntheses, including positive associations between ressource-acquisition traits and soil-related NCPs, positive effects of floral traits on pollination, and negative associations between specific leaf area and several regulating NCPs.

These results suggest that broad trait-based generalisations should be interpreted cautiously, while highlighting a restricted set of robust relationships that provide a stronger evidence base for developing predictive, trait-based approaches in agroecology and ecosystem management.

Keywords: Plant functional traits, Nature's Contributions to People, ecosystem services, systematic review, meta analysis, Bayesian hierarchical modelling, evidence synthesis

Turning Tomato Production Towards Agroecology: Participatory Breeding for Organic Outdoor Tomato Cultivation in Germany

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In Germany, commercial outdoor tomato production is severely constrained by *Phytophthora infestans*, while the increased frequency of drought events associated with the climate crisis represents an additional and growing threat. Breeding tomato cultivars adapted to organic outdoor production has been the main objective of the Organic Outdoor Tomato Project (OOTP), a decentralised participatory plant-breeding network with roots in 1996. In recent years, the activities have expanded from indeterminate cultivars for the fresh market to determinate processing tomatoes. In Germany, only 3.5% of fresh tomato demand is met by domestic greenhouse production, while processed tomato products, which account for most tomato consumption, are almost entirely imported. Outdoor tomato production can therefore be considered an emerging novel crop within the German organic horticultural landscape, with substantial development potential.

The OOTP is developing its breeding activities by adopting and operating through a Living Lab approach, structured around the 13 principles of agroecology, with particular attention to:

- **Input reduction**: organic outdoor tomatoes have a carbon footprint up to 45 times lower than their conventional indoor counterparts. Breeding for *Phytophthora* resistance and drought tolerance can reduce or eliminate the need for plant-protection treatments and irrigation; practices like crop rotation, cover crops, and mulching reduce or eliminate the need for fertilisers and weed-control measures.
- **Soil health**: selection of parental material and breeding lines takes into account plant–microbiome interactions, particularly arbuscular mycorrhizal tomato root colonisation.
- **Biodiversity**: the introduction of novel crop types and cultivars contributes to increasing cultivated biodiversity, while agroecological management practices support below- and above-ground biodiversity.
- **Economic diversification and Connectivity**: the OOTP network includes actors across the value chain and promotes diverse marketing channels, from amateur production direct sales of fresh and processed tomatoes to larger-scale organic tomato juice production.
- **Social values and diets**: emphasis on quality traits, including the Breeders' Sensory Test, has led to the release of cultivars with superior organoleptic characteristics.
- **Co-creation of knowledge, Participation, and Fairness:** the OOTP promotes horizontal exchange of knowledge and breeding material within the network. It supports the Open-Source Seed Licence and released 'Sunviva', the first cultivar worldwide distributed under this licence.

Keywords: Tomato, Organic Plant Breeding, Climate Crisis, Culinary Breeding, Agroecology, Living Lab, Value Chain

From regional pest pressure to pesticide treatment: a multi-scale framework integrating landscape infrastructure, crop diversity and farming management

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Regional pest pressure does not translate mechanically into pesticide treatments. Pesticide applications emerge from the interaction between biological pressure, landscape context, crop diversification strategies and farm management decisions. In this poster, we propose a conceptual and analytical framework linking regional pest pressure to pesticide treatment intensity in diversified cropping systems.

We illustrate the first application of this framework using French national datasets combining Vigicultures® 2.0 pest-monitoring observations and DEPHY pesticide-use records. The analysis included 45,267 paired pest-pressure and pesticide-application observations across nine major crops over 16 years (2009–2024). Regional pest pressure was quantified from weekly observations of insect pests and fungal diseases integrated over crop-specific growing periods, while crop diversification was described using crop richness and complementary diversity indicators derived from cropping-system composition. Using Tweedie generalised linear mixed-effects models, we tested how regional pest pressure and crop diversification jointly relate to pesticide use.

Preliminary results show that crop diversity effects remained largely stable under varied pest pressure levels, with only the number of botanical family of crops interact with fungal disease pressure.These preliminary results highlight the importance of explicitly defining the spatial scale at which pest pressure is measured. Regional, landscape and field-level pest pressures may differ substantially because of filtering effects generated by landscape infrastructure, crop diversity and farm management. They also suggest that regional pest pressure and crop diversification indicators alone capture only part of the processes linking pest dynamics to pesticide treatments. The proposed framework therefore identifies the intermediate filtering steps that need to be quantified to understand when diversification can effectively reduce pesticide treatment intensity. By making these filters explicit, it provides a common structure for interdisciplinary dialogue among ecologists, agronomists, modellers and advisors working on the out-scaling of agroecology.

This work is part of the DiRoDur project (OFB-24-1716), funded under the Ecophyto II+ plan, with financial support of the French Office for Biodiversity.

Keywords: Regional pest pressure, pesticide treatment, crop diversity, landscape infrastructure, farming management

7.B – POSTER - Out-scaling agroecology: comprehensive approaches

The intercropping sector in France: identification of constraints and opportunities

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Crop diversification, a key element of agroecology, can take place at various scales, from the plot level (with intra- and inter-specific mixtures) to the landscape level. Inter-specific mixtures provide numerous ecosystem services relating to the management of diseases, pests and weeds, soil quality and nutrient cycling, thereby reducing the need for inputs during the growing season whilst stabilising yields from one year to the next. Despite these advantages, their adoption by farmers remains limited by technical, material, and economic barriers, as well as by the lack of varieties specifically selected for these systems. It is necessary to remove these barriers in the coming years to support farmers' transition to agroecology. To introduce students to the current challenges and barriers associated with crop mixtures, we designed a three-week interdisciplinary teaching unit dedicated to this topic.

The students conducted semi-structured interviews with nine professionals to understand the main challenges of integrating crop mixtures into agricultural practices and value chains. They also linked those challenges to plant traits and variety selection by carrying out phenotyping at IDEEV on a genetic field trial of wheat-pea intercropping involving 116 wheat varieties and 2 pea varieties. In Versailles, they participated in phenotyping an agronomic field trial of camelina-lentil intercropping, with different sowing densities and modalities. The traits studied were plant height, number of plants, number of ears and lodging.

A comparison between sole crops and intercrops highlighted the benefits of intercropping, resulting in a reduction in the non-green leaf area in wheat, the identification of promising varieties, and the identification of traits to be selected, such as stem strength in camelina to resist lodging when intercropped with lentils. These results complement the leverages identified during the interviews, such as influencing public policy to stimulate investment in sorting machines, developing training programs for farmers, or developing seed drills adapted to these practices. These measures, with others, could ultimately help to increase intercropping areas in France.

Keywords: interviews, phenotyping, wheat, pea, camelina, lentil

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