CALL FOR PROPOSALS
APPEL A PROJETS
CPA - Cultiver et protéger autrement

JUNE 2019 / JUIN 2019

SCIENTIFIC SUBMISSION FORM
DOCUMENT SCIENTIFIQUE

SPECIFICS
Acronyme du projet

***Acronym* / Acronyme**	SPECIFICS		
Project title (in English)	Sustainable PEst Control In Fabaceae-rich Innovative Cropping Systems		
Titre du projet (en français)	Conception de systèmes de culture sans pesticides et riches en légumineuses à graines		
***Key words* / Mots clés (min 5 - max 10)**	Plant ideotypes, Translational genomics, pesticide-free cropping system, co-design, participatory research, multi-criteria performance, plant protein, food market		
***Leading institution* / Etablissement ou organisme coordinateur**	INRA Bourgogne Franche Comté		
***Scientific coordinator* / Responsable scientifique et technique (RST)**	***Last Name, First name, Position, Organisation* / Nom, Prénom, Status, Organisation**		
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***Partner institution(s) involved in the project* / Etablissement(s) partenaire(s) impliqué(s) ***	UMR Agroécologie, INRA Bourgogne Franche Comté 201220381F UMR IGEPP, INRA Bretagne Normandie 201220379D LEVA, ESA Angers 199522196 UMR AGIR, INRA Occitanie Toulouse 200317643U UMR IRHS, INRA Pays de Loire 201220383H URGI, INRA Ile de France 200217796P UE Epoisses, INRA Bourgogne Franche Comté 195517763H UE Bourges, INRA Val de Loire 196417782P UE La Motte, INRA Bretagne 198517749M AFP, INRA Hauts de France 201521250M LISIS, INRA Ile de France 201722406K UMR9221, IESEG, Lille 201521703E		
Project duration* / Durée du projet*	72 Months / Mois		
Requested funding* / Aide demandée**	2 999 565.24 €	***Full cost* / Coût complet**	17 535 945.89 €

***Scientific project type* / Type de projet scientifique** *(sélectionner une seule case)*	☒Projet intégratif ☐Projet ciblé – microbiome des cultures ☐Projet ciblé – déterminants socio-économiques ☐Projet épidémiosurveillance
If applicable: Project links with existing PIA entities (e.g. BTBR, INBS, Labex, etc.) **Le cas échéant: Listes des projets labellisés par le PIA auxquels ce projet est lié (notamment BTBR, INBS, Labex, etc.) ***	BTBR PeaMUST ISITE Agroécologie en BFC
If applicable: Other projects linked to the current project (e.g. EcoPhyto, CASDAR, etc.) **Le cas échéant: autres projets auxquels ce projet est lié (notamment EcoPhyto, CASDAR, etc.) ***	Ecophyto ABC CASDAR RésiLens CASDAR RAID ANR P-Aphid H2020 Diverfarming H2020 DiverIMPACTS H2020 DIVERSify H2020 LegValue H2020 ReMIX H2020 TRUE H2020 ProFaba H2020 GenRes Bridge PSDR-4 ProSys FEADER-Region PROGRAILIVE Plant2Pro SyntenyViewer D2KAB

List of partner institutions / Liste des établissements partenaires

Renseigner une ligne par partenaire, ajouter autant de lignes que nécessaire.

Name of the research organisations **/ Nom des organismes de recherche**	***Legal status*** **/ Statut**
UMR Agroécologie, INRA BFC UMR IGEPP, INRA Bretagne Normandie UMR AGIR, INRA Occitanie UMR IRHS, INRA Pays de Loire URGI, INRA Ile de France UE Epoisses, INRA BFC UE Bourges, INRA Val de Loire UE La Motte, INRA Bretagne AFP, INRA Hauts de France LISIS, INRA Ile de France	EPST EPST EPST EPST EPST EPST EPST EPST EPST EPST
Name of the institutions of higher education and research **/ Nom des établissements d'enseignement supérieur et de recherche**	***Legal status*** **/ Statut**
LEVA, ESA Angers UMR9221, IESEG, Lille (AgroCampusOuest via UMR IGEPP, IRHS) (AgroSupDijon via UMR Agroecologie)	Association à but non lucrative Association à but non lucrative EPST EPST
Name of the agricultural support institutions (technical institute, chamber of agriculture, etc) **/ Nom des organismes d'encadrement de l'agriculture (institut technique, chambre d'agriculture, etc.)**	***Legal status*** **/ Statut**
Other partners (cooperatives, companies, etc.) **/ Autres partenaires (coopératives, entreprises, etc)**	***Field(s) of activity*** **/ Secteur(s) d'activité**

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[1] *Penser à mettre à jour la table des matières avant la finalisation du document scientifique.*

EXECUTIVE SUMMARY OF THE PROPOSED PROJECT / RESUME DU PROJET PROPOSE

Abstract - English version (max. 4000 characters)

SPECIFICS aims to acquire new knowledge for assisting in the design and the development of pesticide-free and legume-rich cropping systems. Pesticide-free farming systems require a profound change from present crop protection using curative methods against pests and pathogens, to biodiversity-based strategies aimed at reducing pest and pathogen pressure through more systemic and agro-ecological approaches. The design of pesticide-free systems requires coordinated action at different scales with different options such as introducing resistant and/or resilient crops and cultivars, diversifying arable crops both in time and space, and designing agro-ecological infrastructures in farms for intensifying biological regulations and thus reducing pest and disease populations by promoting natural enemies and increasing competition against weeds.

Grain legumes, key species at the interface of the agro-ecological and food transitions, are good candidates for diversifying cropping systems. Grain legumes produce seeds rich in protein and are able to acquire nitrogen through symbiosis with nitrogen-fixing bacteria present in soils. Their cultivation thus makes it possible to reduce the use of nitrogen inputs in agrosystems, resulting in fewer greenhouse gas emissions and potentially less water pollution. On the other hand, they themselves are very susceptible to different pests and diseases. How can the resistance of legume species (pea, faba bean, lentil) to various pests (sitones, bruchids, aphids) and diseases (Aphanomyces, ascochyta, powdery mildew), and their competitiveness against weeds, be increased? How can they be inserted into diversified cropping systems to increase biological regulation of bio-aggressors without the use of pesticides? How should the development of these innovative systems be promoted at other scales (farms, value-chain)?

The aim of SPECIFICS is to identify and evaluate various levers to allow for a transition towards pesticide-free and legume-rich farming systems by searching for new sources of resistance, incorporating more biological diversity over time (rotation) and in space (intra- and interspecific intercrops, agro-ecological infrastructures, etc.), by evaluating options for the promotion of these systems. Our project combines a wide range of skills from agronomists, geneticists, pathologists, entomologists, ecologists, economists and sociologists to design varieties, cropping systems, methods of evaluation and transfer to the stakeholders, to ensure economic and agronomic sustainability of pesticide-free farming systems. Our experiments will be based on existing experimental pesticide-free platforms, where a wide range of legume-rich cropping systems are implemented, as well as on extensive surveys and economics data processing.

The methodologies used will range from direct and reverse genomics to search for new sources of varietal resistance to several biotic stresses and the identification of traits of interest for the control of pests, to the analysis of co-evolution of different pests and their natural enemies at different spatial and temporal scales and the testing of innovative spatio-temporal combinations, both in the field and by modeling, and up to the socio-economic study of conditions and levers allowing the transition to pesticide-free farming at the farm and value-chain level.

The results expected are multi-resistant breeding lines and keys to understanding resistance mechanisms to better employ them for the purposes of sustainability; knowledge of biological

regulations (plant-plant interactions, plant-pest-natural enemies, plant- soil microbial community-soil pathogen) at different temporal and spatial scales; tools for enabling the design of diversified, pesticide-free systems for farmers and advisors; delocking strategies for the development of these systems, and new courses and training to ensure the transmission of agro-ecological practices to the new generation of actors.

Résumé en français (max. 4000 caractères)

SPECIFICS vise à acquérir des connaissances nouvelles pour aider à la conception et au développement de systèmes de culture sans pesticides et riches en légumineuses à graines. Ces légumineuses, souvent utilisées pour diversifier les systèmes de culture, sont en effet à l'interface de plusieurs transitions (agro-écologique et alimentaire). Les systèmes de culture riches en légumineuses sont particulièrement adaptés aux enjeux actuels de durabilité des systèmes de production. Les légumineuses à graines produisent des graines riches en protéines et sont capables d'acquérir l'azote via une symbiose avec des bactéries fixatrices d'azote présentes dans les sols. Leur culture permet ainsi de réduire l'utilisation d'engrais azotés, entrainant ainsi moins d'émissions de gaz à effet de serre et potentiellement moins de pollution de l'eau. En revanche, ces plantes sont elles-mêmes très sensibles à différents bio-agresseurs. Comment accroître la résistance des légumineuses à graines (pois, féverole, lentille) à divers ravageurs (sitones, bruches, pucerons) et maladies (Aphanomyces, ascochytose, oïdium) et leur compétitivité vis-à-vis des adventices? comment les insérer dans des systèmes diversifiés pour accroître les régulations biologiques afin de contrôler les bio-agresseurs sans recours aux pesticides? comment favoriser à d'autres échelles (exploitation, filière) le développement de ces systèmes innovants?

L'objectif de SPECIFICS est d'identifier et d'évaluer différents leviers permettant la transition vers des systèmes de grandes cultures sans pesticides et incluant des légumineuses à graines en recherchant de nouvelles sources de résistance, en intégrant davantage de diversité biologique dans le temps (rotation) et dans l'espace (cultures associées intra- et interspécifiques, infrastructures agro-écologiques, etc), en étudiant des solutions de valorisation et de promotion de ces systèmes. Notre projet allie agronomes, généticiens, pathologistes, entomologistes, écologues, économistes et sociologues pour concevoir des variétés, conduites, itinéraires techniques, modes de valorisation et de conseil qui permettront d'atteindre les objectifs de durabilité économique et agronomique des systèmes de culture sans pesticides et intégrant une part importante de légumineuses à graines. Nos expérimentations s'appuieront notamment des plateformes expérimentales en agroécologie, dans lesquelles des systèmes de culture sans pesticides et riches en légumineuses sont largement mis en œuvre, ainsi que sur un large dispositif d'enquêtes et de traitement de données économiques.

Les méthodologies utilisées iront de la génomique directe et inverse pour rechercher des nouvelles sources de résistances variétales à plusieurs stress biotiques et l'identification de traits d'intérêt pour le contrôle de bio-agresseurs, en passant par l'analyse des co-évolutions de différents bio-agresseurs et de leurs ennemis naturels à différentes échelles spatiales et temporelles, le test de combinaisons spatio-temporelles innovantes au champ et par modélisation, et jusqu'à l'étude socio-économique des conditions et des leviers permettant la transition vers des systèmes de culture sans pesticides, à l'échelle des exploitations et des filières.

Les résultats attendus sont des géniteurs multi-résistants et des clés de compréhension des mécanismes de résistance pour mieux les activer dans un objectif de durabilité ; des connaissances sur des régulations biologiques (interactions plantes-plantes, plantes-bioaggresseurs-ennemis naturels, plantes-micro-organismes du sol-pathogène) à différentes échelles temporelles et spatiales jusqu'ici peu explorées ; des outils d'aide à la conception de systèmes diversifiés sans pesticides pour les agriculteurs et conseillers ; des clés pour inciter au dévelopement de ces

systèmes , et de nouveaux cours et formations destinés à former la génération qui sera impliquée dans le développement de ces nouveaux systèmes de culture.

1. CONTEXT, OBJECTIVES AND PREVIOUS ACHIEVEMENTS / CONTEXTE, OBJECTIFS ET REALISATIONS ANTERIEURES

1.1. CONTEXT, OBJECTIVES AND INNOVATIVE FEATURES OF THE PROJECT / CONTEXTE, OBJECTIFS ET CARACTERE INNOVANT DU PROJET

The need for radical changes from simplified systems using pesticides to diversified systems using biological regulations. Accompanying the growing public awareness of threats represented by pesticides on farmers' and public health and the constant decrease in authorized bioactive chemical products for pest control in French agriculture, the "Cultiver et protéger autrement" call addresses the challenge of reducing pesticide use in farming systems. Ten years after the start of the French national Ecophyto plan aimed at reducing by 50% the use of pesticides in France within 10 years, Guichard et al. (1) made the alarming observation that the plan had failed to reach its objective. By focusing mainly on optimizing the use of pesticides and reducing the Treatment Frequency Index, this plan had not fostered more radical changes involving re-design of the farming systems (2). Pesticide-free farming systems require a profound change from present crop protection using curative methods against pests and pathogens, to biodiversity-based strategies aimed at reducing pest and pathogen pressure through more systemic and agro-ecological approaches (3-5). The design of pesticide-free systems need to act conjointly at different scales with different options such as introducing resistant and/or resilient crops and cultivars, diversifying arable crops both in time and space, and designing agro-ecological infrastructures in farms for intensifying biological regulations reducing pest and disease populations promoting natural enemies and increasing competition against weeds.

Grain legumes, key species at the interface of the agro-ecological and food transitions, are good candidates for diversifying cropping systems. Grain legumes are an essential component of sustainable farming systems and could be a major lever for tackling the global challenges of climate change and food security. The global demand for plant proteins for human food is rising fast (https://pulsepod.globalpulses.com/trade-talk/post/expanding-horizons-an-interview-with-roquette-jean-philippe-azoulay). Yet, in 2017, the world grain legume production represented only 95 million tonnes (Mt) compared to 2980 Mt of cereals. In France, this imbalance of production between grain legumes and cereal production was even more pronounced, with respectively 0.8 Mt grain legumes and 64 Mt cereals (6). This imbalance drives both our dependence on plant protein imports and the negative impact of legume crops' reduced area in Europe. Present European farming systems rely heavily on external nitrogen inputs, short rotations, and chemical pest control. Increasing the production of legumes in Europe would reduce our use of nitrogen fertilisers and the greenhouse gas emissions linked to it, these plants being able to acquire nitrogen from a symbiosis with soil bacteria (7-10). It would also contribute to the diversification of arable crops, increase the functional diversity of agro-ecosystems and, potentially, induce less pest pressure for other crops.

Different factors undermine the development of legume-rich pesticide-free cropping systems. Due to differences in yield and price between grain legumes and major crops such as cereals, their insertion in European cropping systems remains limited. This is partly the consequence of the evolution of the agri-food system during the 20th century that favoured cereals and the use of synthetic fertilizers to the detriment of grain legumes. A system of lock-in, including the lack of references for new crops and new management practices, the lack of technical solutions such as machinery, the uncertainty in economic performance and the lack of adapted downstream value chains for products, explains the difficult development of grain legumes (11, 12). Similarly, technical, cognitive and organizational lock-in effects also impact the adoption of pesticide-free production methods by producers (13-16). To counter-balance these lock-ins, quantifying grain legume-rich pesticide-free cropping ecosystem services and dis-services, as well as their ability to cope with temporal variability and spatial heterogeneity in climatic and economic conditions (17-19) are important decision-making aspects. Field experimentation, farm networks or modelling (20) are complementary approaches that can be coupled with productive efficiency, economic performance and cost-effectiveness analyses (21-23) to explore the sustainability of a wide range of farming systems.

Grain legumes are susceptible to multiple diseases and pests. Grain legume crops have long been neglected (24) and investments in related science have been limited. Their yield performances are blamed for lagging behind major crops because of their sensitivity to biotic and abiotic stresses. Aphanomyces root rot, Ascochyta blight, and seed weevils have been the most damaging and studied stresses in France over the past 20 years. Other bio-aggressors, including weeds, aphids and sitona are currently becoming problematic for grain legumes in the light of new regulations about pesticide use. The identification of several resistance loci will foster future improvement but the many new breeding targets emerging from new cropping practices will require a more efficient approaches for discovering relevant ideotypes and mining genetic resources. These will be needed for identifying sources of resistance or plant traits for enhancing competitiveness or escape from pests, to be integrated into breeding varieties for agriculture without pesticides. Genetics and genomics of grain legumes have taken a giant step and produced powerful tools and methods for breeding that should now be efficiently translated (25).

The objective of the present project is to provide new knowledge for the design of farming systems that allow the insertion of grain legumes into pesticide-free cropping systems. Our project involves agronomists, geneticists, pathologists, entomologists, ecologists, and socio-economists to (i) improve grain legume bio-aggressors' management, (ii) design pesticide-free cropping systems rich in grain legumes based on the principles of agro-ecology and (iii) analyse the performance of these farming systems at the socio-economic and technical levels, to rethink the organization of the value-chain and identify levers to accompany the transition towards the designed systems. The experiments will take advantage of the CA-SYS, ABY and BioDiverSystem agroecology platforms, in which pesticide-free and legume-rich farming systems are implemented, as well as on a large dataset on cropping systems (technical data and management strategies) from DEPHY farms.

Innovative features of the project

The radical change from a curative approach to a biodiversity-based approach for managing bio-aggressors opens new perspectives in different fields of research and underlines the urgency of interconnected multi-disciplinarity. Newly defined pesticide-free cropping systems set novel targets for plant breeding and genetics, such as the adaptation to new agricultural practices or the competitiveness against weeds and resistance to insects and diseases that were previously dealt with by pesticides. For agronomy and ecology, the impact of these new agricultural practices, from the choice of crop rotation and arrangement of different crops on the farm to the establishment of semi-natural habitats (e.g. flower, grass strips), on beneficial organisms as well as bio-aggressors is of primary importance. The study of biological interactions at the plant, the field, the landscape scales is essential for understanding their suppressive ability on bio-aggressors. For example, the suppressive ability of soils for the control of soil pathogens and its respective influence compared with plant resistance in the establishment of suppressive soil ability will be evaluated. For economics and sociology, this change in farmers' practices has to be accompanied and thought of, in terms of resiliency, profitability, organisation, and complexity of work. Furthermore, training the futures actors of pesticide-free agroecosystem management is essential and requires transdisciplinary education and holistic approaches. The evolution of curricula of masters and technical training courses will evolve in accordance with the French plan "Enseigner à produire autrement".

A rapid and efficient translation of genetics and genomics advances into the field and from the field to the market is needed. Novel traits, linked to new practices and farm organization constraints will emerge as critical for the success of the system. Plant breeding should be able to more rapidly detect relevant ideotypes. Innovative methodological developments based on image analysis and/or modelling, coupled with bioinformatics tools allowing trait identification in genetic resources, are needed. Novel sources of resistance and protective traits against damaging pests through reverse approaches using translational genomics between closely related species and screenings of mutant populations will be tested. These novel traits should be combined more efficiently using speed breeding to accelerate varietal innovation and tested in innovative cropping systems. If cropping systems with good economic, social and environmental performances are implemented, their adoption on a large scale then requires some changes in socio-economic organization. To overcome identified lock-ins, it is essential to act in the long run on the organisation of the socio-technical system. The impact of market trends and eco-label development on the adoption of new agricultural practices related to legume crop diversification and pesticide use reduction will be assessed. New forms of organisation or counselling favouring these agricultural practices, in terms of economic incentives for farmers, organisations for accelerating knowledge sharing between actors of the value-chain through economic tools such as contractual governance or socio-economic organisation will be devised.

The combination of grain legumes and pesticide-free practices poses global questions about the design and evaluation of ecosystem services and dis-services. The insertion of legumes in cropping systems and their economic and environmental impacts have been mostly addressed through the nitrogen cycle issue, but less for pest management through biodiversity-based practices (e.g. 26, 27). In the perspective of pesticide-free systems, it is essential to analyze not only the services that legumes provide to other crops in the rotation, but also how the system, including the other cash and cover crops and their arrangement in time, can help to reduce the risks of bio-aggressors during the legume crop cycle, with potential impacts on succeeding crops. Spatial and temporal crop diversification are usually studied separately but in pesticide-free systems these strategies need to be better combined. For example, spatial diversification through intercropping of a legume and another crop species in the same field increase the diversity of traits in the field and can help the legume known for its poor competitive ability against weeds. Conversely, increasing the proportion of legumes in successions, including as cash and cover crops, and in the landscape, as part of flowered strips, also increases bio-aggressors' pressure on legumes. To our knowledge, few studies have assessed cropping systems that are both pesticide-free and rich in legume crops. A multi-criterion evaluation of different existing and modelled legume rich pesticide-free cropping systems is essential. In the evaluation of cropping systems, the technical performance criteria are mainly focused on the production and control of weed flora (20). New criteria are needed to assess both benefits and risks of cropping systems on multiple bio-aggressors (e.g. 28).

1.2. *MAIN PREVIOUS ACHIEVEMENTS* / PRINCIPALES REALISATIONS ANTERIEURES

Genetic and genomics resources for grain legume improvement: Extensive genomic resources have been developed for pea and faba bean at INRA over the past ten years. The first pea genome sequence (*Pisum sativum*, 4,5 Gb) was recently released (29) and a gene expression atlas is available (30). A reference transcriptome of faba bean has been produced (Escobar-Herrera et al. in prep. Coll. NORFAB-PeaMUST) and its genome sequencing is underway. Exome resequencing data were obtained using pea and faba bean panels (≈240 lines/panel) displaying a large variability for resistance to biotic stresses and plant architecture. Large collections of accessions; RILs, NILs, GWAS panels in pea, faba bean and lentil and TILLING mutant collections in pea, have been developed and germplasm and loci associated with resistance to Aphanomyces root rot, Ascochyta blight, and seed weevil have been identified (31-35). Recently, sources of resistance to the pea aphid have also been identified and two main loci associated with reduced aphid fecundity. In pea, multiple loci covering seven main genomic regions for partial resistance, including one major-effect locus were integrated into breeding programs (36, 37). However, genes and mechanisms underlying these loci, their effects on multiple pests and their conservation between grain legumes used in same landscapes and rotations, still need to be investigated, in order to accelerate the optimization of breeding strategies and the durable deployment of resistances in cropping systems. The conservation of genes and mechanisms controlling resistance to pests between grain legumes grown in common rotations is unknown and should be analyzed both for transferring knowledge from one species to the other and for the possible impact on durable strategies of deploying the same mechanism in different species present in the same rotation.

Innovative methods have been developed for characterizing plant traits and identifying ideotypes for pest control: High-throughput phenotyping platforms are available for detailed characterization of plant seed establishment (PHENOSEM, INRA Angers), ecophysiological and root architectural traits under abiotic or biotic stressed conditions (4PMI, INRA Dijon). Image analysis systems by 3D X-ray tomography have been developed to quantify seed weevil damage on pea and faba bean seeds and pea leaf weevil damage on nodules (PHENOSEM, INRA Angers). The FLORSYS model has been developed to identify key traits driving competition against weeds and characterizes grain legumes' ability to compete against weeds for light interception (38) and will be extended to competition for water and nitrogen in the present project.

Legumes in intercropping systems: During the last 15 years, we learned a lot about the benefits of cereal-pea intercropping on yield (39), quality (40), N use (39, 41) and weed control in France and in Europe (42). Our work emphasized the key role of competition and complementarity for light and N resources all along the crop cycle (39, 43), Based on this knowledge on resource sharing in intercrops, we proposed decision rules for managing intercrops for different objectives (43). Legume crops in pure stands have a poor competitive ability against weeds (44).The analysis of a wide diversity of combinations of intercrops (oilseed rape-legume, lupin-triticale, soybean-sorghum) showed the need to combine different species with complementary aboveground traits but also root traits for different services (productivity, stability, weed control). (46, 47).

Biological control and agro-ecological management of insect pests: Crop diversification was identified as a promising way for promoting aphid pest control with parasitoid wasps (*47,48*). To better understand resource exploitation strategies in insects (49) and optimize the spatial arrangement of crops in associations for promoting natural pest control, we studied natural enemy diversity in the field using molecular methods (50, 51) and revealed trophic interactions between faba bean weevils and a large diversity of predators (52). Moving from the field to its borders, we studied how spontaneous vegetation or flower strips may influence in-field biological control by providing different types of resources (e.g. habitat, nectar) to both pests and natural enemies (53-57). Recent research highlighted the relevance of the landscape scale for a better understanding of pest-natural enemy interactions (58). Assemblies of natural enemies result from complex multiscale interactions between landscape composition and local variables (e.g. farming systems, insecticide use) and contrasts between natural enemy groups (59-63). At a more global scale, climate change and legume crop area may change the phenology and abundance of aphid legume pests (*64*). We developed modelling approaches combining process models with virtual landscape simulations (65, 66). These integrative tools enable in silico simulations for designing suppressive landscapes.

Functional metagenomics of aphanomyces root rot: Aphanomyces euteiches Drechs. causes root rot diseases on many legumes, with up to 80% losses each year (67,68). This strictly soil-borne pathogen may survive many years in soil and no efficient chemical control is currently available. The disease often appears in patches, which suggests coexistence of varying levels of expression of the pathogenic activity of *A. euteiches.* Inoculum density and soil inoculum potential have been proposed to explain this phenomenon, but the demonstration has never been validated in the field (69, 70). Soils showing suppressiveness to Aphanomyces root rot of pea have been described, and the role of microflora proposed (71). Abiotic and biotic factors (72-75) affect the different components of the consortium responsible for pea rot (including oomycetes from the *Pythium* and *Phytophthora* genera and fungi from the *Fusarium, Rhizoctonia* and *Thielaviopsis* genera) but the diversity of the components makes the identification of factors difficult. Functional metagenomics is thus a promising approach for identifying the functions responsible for aphanomyces suppressiveness in soils.

Multicriterion assessment of farming systems and markets: Multi-criterion evaluation of cropping systems, mobilizing different datasets and methodologies, allows assessing innovative and low-pesticides cropping systems in system experiments on a single site (e.g. 76, 77) or within experimental multi-actor networks (78, 79). Cropping systems performance evaluations within the national Ecophyto DEPHY Ferme network, identified profiles of management strategies relating to pesticide use (80) and studied possible antagonism between reducing pesticide use and economic sustainability performances (81). The analysis of farm accounting management data allowed to evaluate the potential pesticide reductions for cost-efficient farmers (22) and showed that agricultural practices using less pesticide per hectare are unambiguously more cost-competitive in terms of direct inputs while inducing no other substitution costs (23).

Removing technical, cognitive and organizational locking effects: Evolutionary economics studies based on the theory of increasing adoption returns (RCA) have shown a diversity of mechanisms of technical, cognitive and organizational lock-in (82,83) hindering the adoption of production methods without phytosanitary products (13,14). In addition, studies in market sociology have shown how the socio-economic organization of agri-food value-chains defines production methods (85) and influences the sustainability of supply chains (86). But few studies have explained jointly how the socio-economic organization of the value-chain, coupled with the mechanisms of RCA, determines the use of pesticides by farmers. This project aims to renew the analysis of the lock around phyto-dependence, highlighting the mechanisms contributing to a "systemic" lock (that is to say dependent on the organization of markets) in order to give a more in-depth reading of the mechanisms at work and on which the public authorities could act. At the same time, markets are also an area of opportunities where actors seeking differentiation develop alternative practices. The project will study how eco-labels are progressing on the market, can modify consumer expectations and support more ecological production methods. Furthermore, the development of these practices is based on farmers' technical know-how (88) and the development of contracts for these markets offers frameworks for learning alternative practices (88,89). Understanding these organizational arrangements is essential to highlight those that would support the transition to pesticide-free agriculture.

2. *DETAILED PROJECT DESCRIPTION* / DESCRIPTION DETAILLEE DU PROJET

2.1. *PROJECT OUTLINE, SCIENTIFIC STRATEGY* / DESCRIPTION DU PROJET, STRATEGIE SCIENTIFIQUE

SPECIFICS aims at enabling the transition of the agri-food system to pesticide-free agricultural practices through efficient translation of scientific advances obtained at different levels of the system *(Figure 1).* The different levers needed to translate knowledge into successful innovation are usually studied separately in different projects. Working on these different levers simultaneously towards the objective of legume-rich pesticide-free agrosystems should boost the transition by a direct integration of new knowledge from one level to another one into decision rules for the design of diversified free-pesticide legume-rich systems and their adaptive management through meetings and guidelines for farmers, advisers and education.

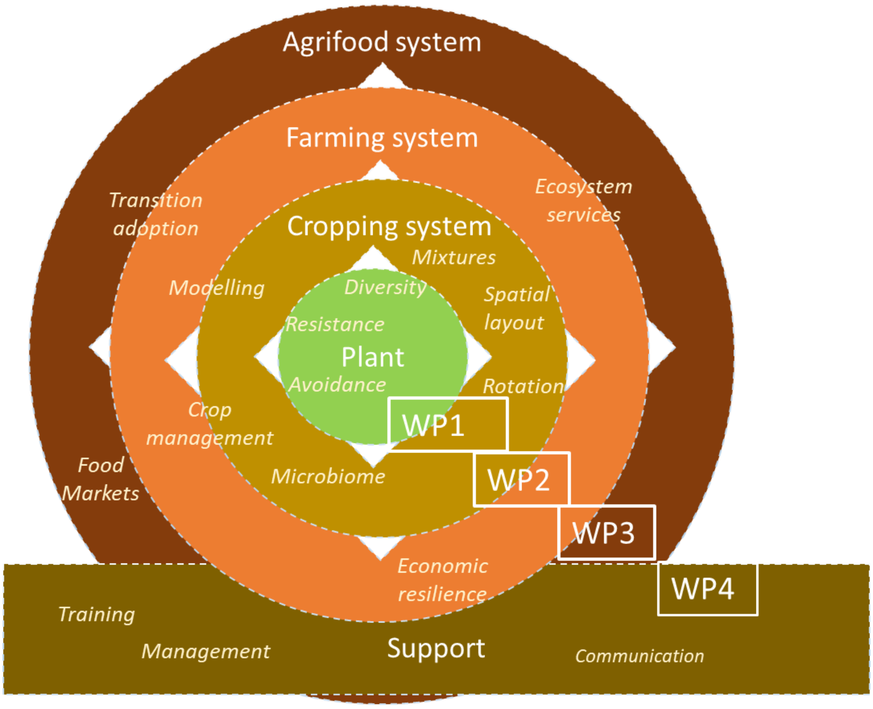

Figure 1: Outline of the SPECIFICS project, integrating the different levels of levers used towards legume-rich pesticide free farming systems.

At the plant level, the objective of WP1 is to foster significant advances in genetics and genomics of grain legumes including association genetics, advanced back-cross QTL analysis, comparative and functional genomics, transcriptomics, proteomics to more efficiently mine alleles, identify resistance genes and utilize this variability for breeding cultivars adapted to new challenges emerging from pesticide-free cropping systems. Three grain legumes will be considered: pea and faba bean, the most widely grown and studied grain legumes in France, and lentil, which has gained a renewed interest in France for food markets. At the cropping system level, the objective of WP2 is to design innovative practices by working on crops' layout in space and succession in time. The impact of diversification in the field (intra- and interspecific intercropping, high crop diversity) and out of the field (natural hedges, flowered strips, wood) on pests, pathogens, weeds and their natural enemies will be investigated both in the context of field platforms under pesticide-free management and through modelling. At the farming and agri-food system level, the objectives are on one hand to quantify the benefits and risks of grain legume-rich pesticide-free farming systems through agronomical and micro-economical multi-criteria approaches and identify the conditions of success, and on the other hand, to imagine new ways out of socio-economic locking such as more adapted counselling, or contractualization. WP4 will assure a smooth progress of the project and its large dissemination towards scientists, students, stakeholders and the public.

2.2. *SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT* / PRESENTATION SCIENTIFIQUE ET TECHNIQUE DU PROJET

WP1: Plant traits for pest control of pulses in pesticide-free cropping systems

Leader: ML Pilet-Nayel (IGEPP)
Partners: Agroécologie, IGEPP, IRHS, URGI, AFP (not funded); Service providers: Terres Inovia
WP1 will focus on the lever of the plant for enhancing protection of pulses and fostering their development in pesticide-free systems. It will aim to (i) identify novel sources of resistance and protective traits against damaging pests in pesticide-free cropping systems, (ii) analyze and exploit genomic conservation between plant species to facilitate gene discovery, integrate omics knowledge of pest resistance in pulses to identify and combine multi-pest resistance loci, and (iii) analyze and compare defense mechanisms of pulses in response to pests to diversify their use in durable pest management and identify future breeding targets.

Task 1.1- Novel sources of resistance and protective traits against pests in pulses *(J. Burstin)*
Partners involved: Agroécologie, IGEPP, IRHS
Objective: Exploit, through innovative methodological developments, collections of pea and faba bean genetic resources for resistance and protective traits against new damaging pests in pesticide-free cropping systems, i.e. weeds, aphid and pea leaf weevil, to identify new germplasm and markers associated with resistance
T1.1.1. Mining genetic resources for ideotype identification (Agroécologie-ECP, URGI)
Unique genetic collections of pea (3000 accessions), fababean (2000 accessions) and lentil (300) are maintained at INRA of Dijon. In each year of the project, 10% of the collections will be grown and plant development traits measured. Seeds will be provided for the screening of sources of resistance to pests conducted in WP1. A database will be developed to enable efficient management and use of the genetic resources (Bauchet et al. 2019). We will implement for our pea, faba bean and lentil collections, an instance of GRIN-Global (Germplasm Resource Information Network), a system developed by the USDA and used internationally for storing and managing information associated with plant genetic resources. The data will then be integrated into the GnpIS Information System. The sustainability of GnpIS and its ability to deliver Digital Object Identifiers (DOI) to each dataset and each plant accession will guarantee their findability and their accessibility. Furthermore, their interoperability and their reusability will be ensured by the quality of the metadata associated to these datasets. Data mining of massive phenotypic data acquired on the collection will be conducted to search for plant traits associated with plant protection against pest identified in WP2. Plant ideotypes combining multiple traits unfavourable to pests will be established. Accessions carrying these traits will be identified as potential progenitors for improving resistance to pests and tested in the other tasks of WP1 and in WP2.
T1.1.2 Competitiveness against weeds (Agroécologie-GESTAD –EcoLeg; IRHS-CONSERTO)
A rapid and homogenous seed establishment and efficiency in taking up and using resources are important traits for competitiveness against weeds as well as for the successful association with other crops in intercropping stands. A first objective of this task is to analyse the genetic variation in stand establishment of 170 contrasted pea genotypes using seeds provided from Task 1.1.1, under conditions mimicking normal and early cold sowing conditions. The kinetics of seedling

establishment (percentage, speed and homogeneity) will be determined using high-throughput automated phenotyping tools available at IRHS-Angers. A genome-wide Association Study (GWAS) will be conducted from the phenotypic data acquired in the project and high-density genotyping data obtained in a previous project from exome sequences, to identify loci associated with seedling establishment. This task will also identify pea genotypes associated with fast and homogenous seedling establishment under (sub) optimal conditions for testing in WP2. The second objective of this task is to enable the characterization of pea and fababean competitiveness against weeds species using the FLOR-SYS model. We will characterize 5-6 pea and fababean accessions contrasted for root/shoot growth and seedling establishment traits in the 4PMI phenotyping platform of INRA Dijon. Plant competitiveness will be characterized by measuring plant traits corresponding to parameters of the FLORSYS model. Since pulse ability to compete for light has been characterized recently, the analysis of plant competitiveness will focus on competition for soil water and nitrogen that have been poorly investigated until now. The response of weed species to pulse competitiveness will also be quantified. The improved FLORSYS model will be tested with data from Task 1.1.1 to identify promising genetic resources for plant competitiveness, and it will be used in WP2 for designing pulse-rich cropping systems promoting biological weed regulation.

T1.1.3. Aphid resistance (IGEPP-EGI, -RA)

Screening of plant resistance/susceptibility to aphids generally relies on aphid counts, which give a reliable measure of resistance phenotype. However, aphid counts are time consuming. In order to reduce phenotyping time, aphid counts will be automated based on image analysis and machine-learning developed in partnership with experts (e.g. Dilepix company, a spin-off of INRIA). This large-scale screening system will then be applied on an INRA reference collection of 250 exome-sequenced accessions of faba bean, representing the diversity of the species, for searching resistance to both *Acyrthosiphon pisum* (pea aphid) and *Aphis fabae* (black bean aphid), in independent screening experiments. The phenotypic data obtained on faba bean genotypes infested either by *A. pisum* or *A. fabae*, will be used to conduct GWAS analyses. Association peaks and haplotypes will be identified and compared to identify shared or specific genomic regions controlling resistance to aphid species in faba bean. They will also be compared to genomic regions previously identified for resistance to *A. pisum* in pea. The identified genomic regions will be projected onto the faba bean and pea genomes, for finer and multi-traits comparisons in Task 1.2. Genotypes resistant to *A. pisum* or *A. fabae*, identified previously in pea and in this project in faba bean, will be further studied for resistance mechanisms in Task 1.3.

T1.1.4. Pea leaf weevil escape (Agroécologie-ECP)

The reference collection of 250 faba bean accessions will be phenotyped for different root architectural traits likely correlated with avoidance of damages caused by *Sitona lineatus* to nodules. The total nodule number, nodule position on the root system and plant growth will be scored during the vegetative phase on the 4PMI high-throughput phenotyping platform in Dijon, using RhizoTubes® and daily imaging. Based on this screening, twenty accessions contrasted for architectural traits will be selected and grown in the greenhouse. Eggs from field-collected mated females of *S. lineatus* will be added to each pot. The conditions of the experiment will be fine-tuned beforehand by running preliminary tests. The damages caused by *S. lineatus* on the nodules will be quantified by X-Ray 3D tomography. Results will provide information about the relationships between architecture/growth traits and the extent of damaged nodules along the root system and thus permit to unravel key breeding targets for plant escape to *S. lineatus*. The collected data on root architecture and nodulation will serve to run GWAS analyses to highlight key genes controlling these traits and will be used for comparative studies with pea under T1.2.2.

Task 1.2- Integrative and translational genomics for multi-pest resistance (*R. Thompson)*

Partners involved: Agroécologie, IGEPP, URGI, AFP

Objectives: analyse and exploit genomic conservation of resistance genetic determinants between plant species and/or pests and integrate "omics" knowledge of pest resistance in pulses to facilitate gene discovery and durable deployment of resistance loci for pest control; and finally combine them using speed-breeding.

T1.2.1. TILLING for susceptibility genes (Agroécologie-FILEAS-ECP-IPM; Provider: Terres Inovia)

Innovative sources of disease resistance will be investigated in pea, by screening the extensive TILLING resources available at UMR Agroécologie for loss-of-function mutations in pathogen susceptibility genes (90). A list of cloned susceptibility genes, which mutations conferred resistance to fungal or oomycete pathogens, has been established. Mutants, identified by screening pea TILLING collections for six susceptibility genes, will be available for the project. The six susceptibility genes were selected from the literature for their trans-species effect on resistance to fungal pathogens or oomycetes. Each gene screened will yield a series of mutant alleles. Two to three predicted loss-of-function mutants for each gene will be backcrossed for two generations using markers to reduce background mutant load, and seed lots will be increased for subsequent pathological tests. Tests of mutants for resistance to three important pathogens, *i.e. Aphanomyces euteiches, Fusarium solani* and *Didymella pinodes*, will be carried out in comparison with non-mutant sibling lines. Pathological tests will be conducted at the young plant stage in controlled conditions, using one reference isolate per pathogen representative of the pathogen populations present in France. Once validated in pea, the homologous genes in *Vicia faba* and *Lens culinaris* will be identified.

T1.2.2. Multi-species- and multi-pest conservation of resistance loci (Agroécologie-ECP, URGI, IGEPP-RA -EGI, AFP)

An integrative pulse-specific bioinformatics tool will be built using a NoSQL graph database (Neo4j) to extend recently developed tools (Plant Synteny viewer, Legume information System; Coll. URGI, J. Salse). This tool will gather genetic, genomic and –other omics data generated for pea, faba bean and lentil in the present project or in connected projects: QTL, RNASeq transcriptomics and metabolomics data obtained in this WP (Tasks 1.1 and 1.3) or in previous projects analysing resistance to different pests (*A. euteiches, D. pinodes, Bruchus* spp.*, A. pisum* and *A. fabae*), seed establishment, and root/aerial architectural traits related to diseases, will be connected and enriched by genome data of pea, fababean (being sequenced by an international consortium to which we belong) and lentil (being sequenced by international collaborators from University of Saskatchewan). This type of database aggregates and links heterogeneous data to find their connections. The methodology will be developed in close collaboration between Agroécologie and URGI. Hot-spots of QTL for resistance to multiple pests will be connected with a large set of proteome, transcriptome, and metabolome expression data. This graph will also integrate the relationships of homology between the candidate genes and the functional annotations that could be transferred from model species like *Arabidopsis thaliana*, soybean or rice. Legume synteny will identify shared and specific determinants of resistance to *A. euteiches*, *Bruchus* spp., *A. pisum/A.fabae* and root architecture. For example, candidate genes and mechanisms of resistance will be investigated in the three pulses for the pathogen isolate (*A. euteiches*) in relation to root architecture. This will provide useful information for understanding durability of resistance to *A. euteiches* observed the field analytical trial of pea and faba bean successions conducted in WP2.

T1.2.3. Speed-breeding for multi-resistance (Agroécologie-ECP)

Speed-breeding protocols that shorten breeding cycle (91) are promising for introgressing resistance loci for resistance to multiple pests in grain legume elite varieties. The use of these methods would speed up the translation of plant trait discovery into breeding. In pea, introgression of major resistance alleles for *A. euteiches, D. pinodes, Bruchus spp*. into agronomic lines will be conducted by back-cross (BC) assisted selection, from pre-breeding resistance sources and previously identified markers. Speed breeding technologies will be tested as proof of concept for accelerating introgression of resistance genes. Accelerated BC generations (about 4 per year) will be carried out and introgressed lines will be evaluated from year 3 for multi-pest regulation in pure and mixed cropping in pesticide-free field trials in WP2 of the project. New sources of pea resistance and markers associated with resistance phenotypes studied in Task 1.2.1 or multi-pest resistance identified in Task 1.2.2 will be integrated into the genotype construction scheme at mid-project. The resulting pea lines, combining multi-pest resistance loci, will be produced as pre-breeding material delivered for pesticide-free cropping system.

Task 1.3- Defense mechanisms against pests in pulses (*M-L. Pilet-Nayel)*

Partner involved: IGEPP

Objectives: compare genes and metabolic pathways recruited in pea and faba bean in response to pathogens and pests, for using diversified defense mechanisms in durable disease and pest management strategies; analyse root exudates effects on a soil-borne pathogen and identify root exudate compounds associated with resistance.

T1.3.1. Metabolic pathways involved in response to pests (IGEPP-RA –EGI)

Genes and metabolic pathways involved in the resistance against two species of aphid (*A. pisum*, *A. fabae*) and a strain of *A. euteiches* will be examined in pea and faba bean. In pea, transcripts and metabolites associated with a major QTL for resistance to *A. euteiches* will be identified from two NIL pairs carrying or not the QTL challenged by one strain of *A. euteiches*. Gene and metabolite co-expression networks will be analysed and the QTL-driven metabolic pathways will be highlighted. Genes underlying the QTL will be identified by analysing sequence polymorphism between the reference genome of susceptible line Caméor and available genomic sequences of a resistant pea line. These sequences were previously assembled from 10X Chromium reads will be located in the QTL region using an optical map. In faba bean, transcription and metabolic profiles of two resistant and two susceptible faba bean genotypes from Task 1.1 challenged by an aphid strain, will also be generated and analysed. Transcription and metabolic data generated in the project will be compared to data previously obtained in the same way in pea challenged by *A. pisum* and in faba bean challenged by *A. euteiches*. This comparative analysis will provide a broader view on multi-legume-pest interactions to identify commonalities and differences in the interactions. Furthermore, the identified genes and pathways expressed in response to aphids will be compared with the results of GWAS obtained in Task 1, to pinpoint the key genes/pathways involved in multi-pest resistance.

T3.2. Root exudates associated with resistance (IGEPP-RA)

At the root level, effects on pathogens and characterization of phytochemical compounds exudated by plants have been understudied (92), and would constitute relevant targets for breeding. Root exudates from different *A. euteiches*-resistant and susceptible pea and faba bean lines challenged by the pathogen will be extracted using a methodology previously developed at IGEPP on potato roots. The pea and faba bean lines will include NILs and varieties used in an analytical field trial of pea-faba bean successions conducted in an infested field in WP2. The extracted root exudates will be tested for their effects on the attractiveness, encystment and germination of *A. euteiches* zoospores. Root exudates from two resistant and susceptible pea and faba bean lines, showing contrasted effects on pathogen spores, will be analysed for their biochemical composition. Root compounds differing in their natures and their levels will be identified between exudates from resistant and susceptible lines in both species. Exudate compounds significantly associated with resistance will be identified, for future screening of germplasm for key root exudate compounds (Task 1.1).

WP2 Intensification of biological regulations at different spatial and temporal scales for pest, disease and weed control in biodiversity-based systems rich in legumes

WP Leader: Guénaëlle Corre-Hellou (ESA)

Partners: UMR Agroecologie, IGEPP Rennes, IGEPP Angers, UE Epoisses, UE Bourges, UE La Motte

Objectives: Increase knowledge on key mechanisms involved in agroecosystems temporally and spatially diversified for controlling a community of pest, disease and weeds without pesticides in arable systems including grain legumes and transform knowledge into learning tools to guide farmers and advisers in the design and the adaptive management of such systems based on biological regulations.

This WP will provide new insights on how co-evolve a community of weeds, diseases and natural enemies co-evolve in temporally and spatially diversified systems including legumes. Different levers at different scales will be studied: the effects of increasing diversity at the annual scale (spatial diversification through innovative intercropping systems) (T2.1), the evolution of soil pathogens in crop successions in relation to plant resistance in interaction with the microbiota (T2.2), the combined effects of spatial and temporal diversification (T2.3 and T2.4) and the role of spatial diversification out of the field (agro-ecological infrastructures and landscape) (T2.4). This WP will also provide new tools to help the design and the adaptative management of such biodiversity-based systems (T2.5).

Task 2.1 Role of different degrees of spatial diversification on bio-aggressors regulation at field level (*D. Moreau)*

Partners involved: Agroécologie, ESA, IGEPP

Objective: Hierarchize the role of different degrees of diversification on bio-aggressor regulation.

We will analyse which degree of genetic diversification is the most effective in promoting biological regulations. bio-aggressWe will also analyse whether spatial arrangement affect biological regulations. Spatial arrangement has rarely been studied but can be decisive for competition against weeds and the propagation of pests and diseases. bio-aggress

Two field experiments (Dijon and Angers) will be carried out during two successive years to test the effects of the degree of genetic diversification on the regulation of three types of bio-aggressors: weeds, pathogenic fungi and insects (with a focus on bruchids). Monospecies and mono-genotype canopies will be used as controls. At both sites, we will test innovative mixtures including legume-cereal intercrops, legume-legume mixtures such as pea-faba bean, and pea varietal mixtures whose effects on multi-bioa-ggressor regulation have been poorly documented. The partners of the associations will be chosen for their contrasted phenology, morphology and resistance to bio-aggressors. Specific questions will be addressed in each site. In Dijon, a special focus is made on different pea varieties' adaptation to intercropping, by studying the variety x intercropping interaction . In Angers, the focus is put on the effect of spatial arrangement (alternate rows, mixed within the row and strip cropping) on the success of the association. In both sites, the main pests will be quantitatively assessed: weed abundance and biomass, incidence and severity of aerial diseases at different stages, infestation of seeds by bruchids at harvest. The "suppressive ability" of the different combinations in relation to different crop traits and crop architecture will give new insights for the design of innovative intercropping systems for the control of a complex of bio-aggressors. Yield and protein content will be also quantified to assess these production services of tested in pesticide-free systems.

Task 2.2 Influence of soil microbial community and plant resistance on suppressive ability of soils against soil pathogenic microbes S. Mondy)

Partner involved: Agroécologie, IGEPP

Objective: Understand the contribution of soil microbial community and plant resistance to suppressive ability of soils and evolution of soil-borne pathogen populations (Aphanomyces). Our approach is to consider the microbiota and plant as a holobiont, taking into account microbial populations as well as the plant's reaction upon them.

In a first approach, the interactions between beneficial and pathogenic soil microbes will be studied in long-term established suppressive soils to root rot diseases caused by *Aphanomyces*. We will work on two types of contrasting soils (suppressive and conducive soils from the same regions). Plant will be installed in soil with/without pathogen and dual RNAseq will be performed on bulk soil and plant installed soil to decipher the response of microbiota and plant to pathogens. By using metagenomics and meta-transcriptomics on soil, this work will study which microbial function and organism taxa (bacteria, fungi) are candidates for being involved in the function of suppressive soils and which genes of plant are specifically expressed in suppressive soils. It will allow to decipher the mechanism underlying this positive interaction. A second approach will focus on plant-driven effect in the establishment of suppressive soil. A field trial was set up since 2016 in a field naturally infested with root pathogens, especially *A. euteiches*.The objective is to test the effectiveness of combining partial resistance in pea lines carrying QTL and the use of resistant faba bean in rotations, to limit the development of the disease and impact the soil microorganism composition and preserve resistance durability. The pea lines were cultivated both in single-crop or alternating with faba bean. The field trial will be continued for 3 years with same rotation. The evolution of the soil inoculum potential (IP) and the disease severity on the different pea and faba bean genotypes will be monitored. A collection of *A. euteiches* strains will be established during the 3rd year of the field trial. The collection will be genotyped, additionally to two collections previously established in 2016 and 2019, using a SNP-array designed from *A. euteiches* genome sequences. Selected isolates from successions with differential IP evolutions over 8 years will be phenotyped for their pathogenicity level. Soils from low-evolution IP successions will be sampled to analyse the long-term effect, on the microbial community, of pea and/or fababean genotypes grown in these successions in relation to their root exudative compounds characterized in WP1. The validity of the functions identified as associated with soil suppressiveness (soil driven situations) will be tested in the field trial where the role of the plant is emphasized (plant driven situations) The combination of both approaches should permit to determine the respective influence of soil and plant in the establishment of suppressive soil ability and the evolution of pathogen populations, and propose new strategies to limit the impact of pathogen on plant development.

Task 2.3 Combination of temporal and spatial diversification to increase biological regulations (*S. Cordeau)*

Partners involved: Agroécologie, IGEPP, UE Epoisses, UE La Motte, UE Bourges, Service provider: Terres Inovia

<u>Objective</u>**:** Understand the co-evolution of different bio-aggressors linked to the presence of legumes in innovative pesticide-free systems diversified in time and space

T2.3.1. Coevolution of pests, diseases and weeds in diversified systems in existing cropping systems experiments

A network of three (Ca-Sys, ABY, BiodiverSystem, see §3.2) existing pesticide-free long-term experiments will be used to analyse how a community of pests, diseases and weeds co-evolve in several cropping systems diversified in time and space. The fields of the pesticide free-cropping systems of the CA-SYS (Dijon, N=42 fields), ABY (Bourges = N=28 fields) and BiodiverSystem (Rennes, N=6 fields) platforms will be monitored every year for abundancies of pests, weeds, diseases, abundancy of beneficial insect involved in the control of pests, and rate of biological regulation. In addition to effects measured on an annual scale in Task 2.1, temporal surveys of multi-stressors (aphanomyces, weeds, bruchids, leaf weevil, aphids etc..) will be carried out over the years to assess the temporal dynamics of ecological equilibria between pests and beneficial insects. We will assess the agro-ecological performance of the Fabaceae crops in each pesticide free systems, as well as the pest pressure before their establishment (year Y-1) and their legacy effect on the system (year Y+1). This multisite analysis will give new insights into the effects of different levels of diversification in time and space, the type of legume inserted, combined with other agro-ecological practices on pest control in pesticide-free systems rich in legumes.

T2.2.2. Simulation of contrasting diversified systems x genotype on weeds

The real field experiments done in T2.1 and T2.3.1 will be combined with 'virtual field experiments' in order to assess the role of a wider range of strategies on a longer time scale (crucial for weeds due to the buffering effect of the soil seed bank) in interaction with the choice of genotypes (link with WP1) and in a wider range of pedoclimatic and floristic contexts and with criteria which are difficult to measure in 'real fields' (e.g. weed services such as promotion of biodiversity). For this, several production situations (including the CA-SYS situation) will be simulated with the FLORSYS model (completed in WP1).

Task 2.4 Multiple scale approach of pest control (*Y. Tricault)*

Partners: IGEPP

<u>Objective</u>**:** Understand processes involved in pest control on multiple spatial and temporal scales in biodiversity-based systems rich in legumes

T.2.4.1 Field scale natural pest control

We will test the hypothesis that crop diversification, species seasonality and distance to the field border shape the community of natural enemies in legume crops. Among these species, we will identify those predating on the main insect pests: aphids, bean seed beetles and faba bean weevils. For monitoring ground-active arthropod diversity and abundance, we will conduct a mass-collection method using pitfall traps. These traps will be set up near to the border or in the field centre over a network of fields with contrasted levels of crop diversification (e.g. pure stands and intercropping), including long-term experiment sites (T2.3.1). Arthropods will be collected at different times during the growing season to test for seasonal effects. Predatory species will be identified in the lab and tested for pests DNAs by PCR using specific primers (52).

T2.4.2 Pests population dynamics at multiple scales

We will investigate how diversification and legume availability in time and space influence pests-parasitoids interactions at a long-term experimental scale (T2.3.1). In these contrasted cropping systems, we will measure and compare pest abundances and parasitism rates. Landscape studies will be conducted on a network of commercial legume fields around Angers. Fields will be chosen over a landscape gradient of legume crop density. We hypothesise that the distance between legume crops (including previous years' locations), legume areas over the landscape, resources offered by semi natural habitats to both pests and predators, and crop diversification (both in and outside the field) may affect pest pressure and pest control as measured in the fields.

T2.4.3 Modelling pest control at landscape scale

We propose developing a model of multiple pest population dynamics based on landscape predictors. This spatially and temporally explicit simulation model would enable prediction of how land cover variations (e.g. increase of legume acreage) and landscape organisation (e.g. decrease of field size) jointly influence the density of the three main pest species occurring in legume crops and the resulting crop damages. Our model will simulate the biological control of pests as general functions relating habitats to predation. This approach should enable an assessment of the role of surrounding non-crop habitat in providing pest-control services to farmers The results from other tasks will furnish knowledge about the simulated processes (e.g. effect of crop diversification on pest species) and plant resistance (link with WP1) and help parametrize the model. This simulation tool will help in incorporating landscape information in the design of biodiversity-based pesticide-free systems (task 2.5).

Task 2.5 Learning tools for the design and the adaptive management of biodiversity based systems (*G. Piva)*

Partners involved: Agroécologie, IGEPP, service provider: Terres Inovia

Objective**:** Transform knowledge on biological regulations and practices favouring these regulations into learning tools to help farmers and advisers in the transition towards pesticide-free cropping systems rich in legumes

The work will be divided into three steps:

Step 1: At the kick off meeting, a workshop will be organized on key levers available at different scales (plant, field, landscape) for stimulating biological regulation for pest, disease and weed control in order to share existing knowledge and see how it can be transformed into decision rules, indicators of prediction and advice tables.

Step 2: At each annual meeting, a synthesis of the results from the different tasks (WP1, WP2) and their potential contribution for the continuous improvement of tools will be drafted. A guide will be established for the design of pesticide-free systems rich in legumes (decision rules, indicators and advice tables). This guide will help farmers and advisers to identify the best combinations of species in time and space, best varieties/species, and cultural practices in order to regulate weeds, pests and diseases.

Step3. Two workshops will be organized (year 2 and 4) with farmers, advisers and researchers with two objectives: i) mutual learning based on scientific and empirical knowledge on crop diversification in time and space to develop pesticide-free systems based on the results obtained in WP1 and WP2 and their transformation in operational tools and ii) test and continuous improvement of these tools to conceive new cropping systems to favour biological control of bio-aggressors and taking into account landscape information. During these workshops, prototypes of new ways of inserting legumes in such systems, will be co-designed. Some prototypes will be tested in field conditions and the tools will be thus directly tested and improved in a learning process with different actors within the project and in farmers' networks. This last step will be extended with additional funding and other partners searched for during the project to increase its impact and maintain the dynamic in a network of actors after the end of SPECIFICS.

WP3. Performances of pesticide-free legume-rich systems and conditions for their development: from farming systems to markets

Leader: Violaine Deytieux (INRA UE Epoisses)

Partners: UE Epoisses; Agroécologie; AGIR; IESEG School of Management/LEM (UMR CNRS 9221); CESAER; Service provide: Terres Inovia

The WP3 aims at producing knowledge on the performances of legume-rich cropping systems less dependent on pesticides, and on the conditions of their development.

The impacts of legumes' introduction, in pure stand essentially, into cropping systems is well documented for some economic and environmental performance indicators (energy consumption, GHG emissions). In this WP, we will investigate how to introduce grain legumes into diversified low pesticides systems (or pesticide-free systems). Does the strategy for introducing legumes into cropping systems (in associated crops, inter-crop cover, companion -or service plant) either reinforce or reduce their interest at the cropping system scale? What are the best strategies for introducing legumes into pesticide-free cropping, by integrating a diversity of services and penalties and by taking into account the production situation? Knowledge on market trends, as regards to the industrial demand for legumes and free-pesticides practices, is also required to identify the innovation drivers toward agro-ecological transition. In addition, such radical changes in agricultural need strong organisational innovations to support knowledge development on new agricultural practices. Do market trends and eco-label development give new opportunities and favour new agricultural practices related to legume crop diversification and pesticide use reduction? Which new organisational forms favour these agricultural practices: Economic incentives for farmers, organisations which accelerate the sharing of knowledge between actors of the value-chain or through economic tools such as contractual governance or socio-economic organisation?

Task 3.1: Performances of pesticide-free and legume-rich cropping systems (*V Deytieux and J.P Boussemart)*

Partners: UE Epoisses, IESEG, Agroécologie; Service provider: Terres Inovia

Objective: Assess the multicriteria performance of low-pesticide legume-rich cropping systems, and identify promising systems and the drivers of their good performances. Economic, social and environmental performances are considered to assess the overall sustainability of agricultural systems. Agronomic and economic approaches are combined. The same datasets are used to implement the two approaches: data from experiments of pesticide-free cropping systems (CA-SYS, ABY, and BioDiverSystem platforms, Res0Pest network), data on legume-rich farmers' systems identified and described in the PROSYS Project, and data on cropping systems of farmers involved in reducing pesticides use via the DEPHY FERME network implemented since 2010 as part of the national Ecophyto plan.

T3.1.1. Multicriterion assessment of a wide diversity of low-pesticide legume-rich cropping systems

Many methods for sustainability assessment of cropping systems have been developed. However, none of them integrate specific criteria and indicators to report the effect of legume crops in cropping systems, by integrating different spatial and temporal scales (effect at the cropping season scale or long-term effect at the crop succession scale; arrangement of legume crops in the field or at the landscape, …). In order to have a multi-criteria assessment method for assessing low-pesticide legume-rich cropping systems, we will add to existing methods some additional criteria, derived from partners' expertise and stakeholders surveys (e.g. criteria related to pest control and biological regulations, quality and value of products, contribution to plant protein supply). We will develop specific indicators to inform on these criteria, by formalizing WP1&2 operational outputs for the assessment of cropping systems. We aim at evaluating a huge diversity of cropping systems. This diversity has to be characterized both in terms of production situation and of management strategy related to legume crops introduction and pest management. Well performing cropping systems and drivers of their performance related to crop management will be identified . We will also analyse possible trade-offs between performance criteria. Possible modifications in plant protein supply at regional or national scales in case of adoption of some promising cropping systems will be evaluated. In the last year of the project, the multicriterion assessment method developed in this task will be implemented to assess cropping system prototypes designed in the WP2.

T3.1.2. Economic analysis of the sustainability of low-pesticide legume-rich cropping systems

This task will assess the economic and environmental costs associated with innovative cropping systems compared to current cropping systems in terms of technical, environmental and socio-economic dimensions. The sustainability of these innovative cropping systems will also be studied in terms of their resilience or robustness, which is defined as the ability of systems to achieve a relatively high level of output with low susceptibility to variability in pedoclimatic and market conditions. We will use non-parametric methods for estimating production boundaries such as Data Envelopment Analysis (DEA) or Free Disposal Hull (FDH). The robustness can be assessed with an extension of the DEA method called cross-efficiency. To identify sustainable cropping systems and measure their performance, we will use two complementary approaches: data analysis of real cropping systems (tested cropping systems or DEPHY FERME cropping systems) and simulated cropping systems. Real cropping systems data will allow an evaluation of eco-efficiency based on the three pillars of sustainability (economic, environmental and social). Thus the sustainability levels of the low pesticide legume-rich cropping systems will be compared to those of more conventional systems. Next, a modelling approach will combine agronomic modelling with efficiency frontier analysis methods in order to examine very innovative systems. We will test the ability of pre-existing models such as PERSYST or STICS or FLORSYS to generate different scenarios of farming practices in all their technical, geographical and social complexity, to extract the main performance indicators from an economic, environmental and social point of view. The relevance of these simulations will depend on the close collaboration between economists, agroecologists and agronomists respectively involved in WP2 and WP3 (Task 3.1.1). As a result, it will be possible to identify some "win-win" strategies between producers and other actors in society related to low pesticide legume-rich cropping systems, or some cases of a possible loss of cost competitiveness. In those cases, we will discuss about possible compensation and incentives for adopting cropping systems that achieve the results expected by society in terms of reducing environmental costs and social gain..

Task 3.2. Tools for transitioning the system (MB Magrini)

<u>Objective</u>: Analyse market trends, over the last 10 years, in the development of agri-food products based on legumes with a specific focus on plant proteins that sustain agro-ecological and dietary transitions; Assess the development of eco-labels in markets favourable to the deployment of agro-ecological practices and pesticides-free cropping systems, and then, how organizational arrangements with production contracts can favour crop diversification and agro-ecological practices less dependent on pesticides.

T3.2.1 Analysis of market trends in the development of agri-food products based on legumes and derived from ecological practices

Path-dependency economics theories advance the incremental trajectory of innovations in agribusiness that strengthen, over time, the dominant position of major crops (e.g. 83). The challenge is, firstly, to empirically consolidate this theory by analysing the shares of major field crops in the composition of agri-food innovations over the last 10 years on the French market, compared to the rest of the world. The next step will be to analyse in greater depth how eco-labels linked to pesticide use reduction are progressing on the market, and to which types of products they are associated. For example, does the agri-food innovation dynamic on protein fractions from peas is accompanied by the development of environmental labels for the products using those protein fractions, compared to the supply of agri-food products based on whole cereal grains. This analysis will be conducted from MINTEL-GNPD dataset, which lists new products launched in 86 countries around the world since the 2000s. The ambition of this task is to bring, to our knowledge, the first “major” analysis of agrofood firms’ strategies regarding eco-labels through various countries in the world for legumes. This will assess whether a transition to agroecology starts with the evolution of the agri-food supply, or if the weight of eco-innovations remains low compared with the recommended evolution expected from various reports in favour of more legume-based diets. Depending on the situation analysed, this will call for a reorientation of public policies that support pesticide-free systems and legume development for food. This task will also identify which companies promote agro-food eco-innovations (large industrial groups versus SMEs or start-ups), in order to test the theories of transition studies which tend to oppose the innovation trajectories chosen by large industrial groups (favouring the incumbent system) and those by small firms (favouring more radical change).

Task 3.2.2. Contractual Arrangements for Crop Diversification with legumes

Technical know-how on legume crops remains very heterogeneous among farmers, necessitating a reinforcement of learning and sharing of knowledge. Specific organizational arrangements could develop crop diversification, such as production contracts which are a hybrid form between the market and integration (88). Although these production contracts are now increasingly developed in field crops (89), no database exists on those contracts, making case studies necessary to understand the way by which contractual governance i) offers sufficient economic incentives for the farmer to engage him in new and risky practices; ii) builds a governance of the supply chain that accelerates the sharing of knowledge between farmers, storage and industrial organizations. This task will analyse how the contractual governance, via production contracts, engages operators in a long-term collective learning approach on new cropping systems (diversified cropping systems with legumes and without pesticides). A better understanding of the drivers of this contractual governance, its impact on technical knowledge sharing on crops and the transformation of farming systems, is essential for supporting new forms of organizations over commodities markets that will promote the construction of a differentiated agriculture without pesticides. In particular, as an extension of recent work on this topic (88), it will be important to understand how storage organizations can pool "separate" contracts with manufacturers on different crops (wheat, peas, rape, etc.) in "unified" crop production contracts with farmers to organize technical advice promoting standard rotations based on the crops under contracts. To understand how the contractual governance between industrialists / storage agencies / farmers, allows building a renewed offer of advice to farmers to develop diversified farming systems, the ambition is to combine in an original way the theory of transaction costs and theories of organizational learning to develop a dynamic analytical framework for transaction cost analysis of the agricultural sector. Links will be established with task 3.2.1 by conducting specific interviews of agri-food firms identified in the MINTEL dataset that develop legume-based products with agro-ecological practices in France to understand which organizational arrangements they develop to supply crops from ecological practices. Links will be established with task 3.3 to understand how the market organisation impacts the use of the production practices.

Task 3.3: Acceptability of pesticide-free practices (T. Debril)
Partners: AGIR, LISIS
Objective: Understand based on two field-crop case studies, how the socio-economic organisation of the value-chain maintains production systems dependent on pesticides and how alternatives to pesticides proposed by scientists are developed and implemented ; Suggest market and scientific organization making possible implementation of alternatives and the bypass of pesticides.
First, we will study how to produce without pesticides by analysing the dependency on pesticides through the case of the value-chain organisations (field crop case studies related to a legume crop (pea) and a non-legume crop (such as wheat or barley) in order to better understand the systemic effects of lock-in related to the socio-economic organization of the value-chain. By mobilizing the theoretical framework of the sociology of organized action (93, 94), we will try to understand how two different field crop sectors are organized by characterizing the strategies of the actors involved (from producers to consumers), describing the nature of the arrangements negotiated between actors and specifying the related specific regulation. By comparing these two sectors, we will analyse how their organizations influence production methods and determine pesticide use and provide strategic elements for reducing faring systems' dependency on pesticides. Next, we will study how to cope with pests when no chemical control is possible, by analysing the development and implantation of alternatives within a sector. We will examine the processes by which alternatives to pesticides are gradually developed and adopted. Through the case of the management of Aphanomyces euteiches risk in pea for which there is no chemical solution, we will examine how the problems posed by this pathogen to producers are put on the scientists' agenda, how these scientists develop alternative control methods and how these solutions question, or not, the market organization. This will involve a better understanding of how genetic selection strategies are developed to increase pea resistance to AE, how escape strategies leading to winter pea development or alternative strategies leading to redesigning crop rotations are suggested. As a result we will suggest new forms of organisation to be promoted in order to favour agro-ecological pesticide-free practices.

WP4: Management, communication and training

Leader: J. Burstin and S. Cordeau (INRA - UMR Agroecologie)
Partners: All
Objectives: Ensure a smooth operation of actions through transparent and efficient management and internal communication. Reporting conformity will guarantee a high standard for results as regards to their timing, resources spent and scientific quality. The mid-term assessment will ensure that the outcomes of the project will support the development of pulse-based agro-ecological cropping systems, by targeted communication and pioneering training courses. Project outcomes will be disseminated to different stakeholders (breeders and food processing industries, farmers, scientists, consumers and policy makers).

Task 4.1: Scientific and technical management (J. Burstin)
The scientific and technical management will ensure the relevance of the SPECIFICS work plan, structure, partnership, resources and planning as regards its objectives and external scientific, technological, legal or economic circumstances. The coordinator will take care of matching SPECIFICS with national/international projects and evolutions. Coordination of scientific activities among partners will include monitoring work progress and control of expenses, but also an appraisal

of scientific and technological developments internationally and the analysis of socio-economic context and needs expressed by stakeholders (see §4.2). Appropriate mitigation measures to fulfil emergent needs or deal with obsolescence of techniques will be discussed with the Executive Committee. These corrective actions could be accompanied by reallocation of resources or responsibilities among the project partners. At mid-term, a review of the entire project will be organised with the help of an international scientific advisory panel. A kick-off meeting will be organised and to organise the work starting in year 1, to ensure good coordination between WPs. Then, whole-project yearly meetings will discuss progress and, where necessary, revise work plans of individual WPs, and resolve problems within the consortium. The Executive Committee of the project will comprise the coordinator, the WP leaders and the manager of the project and will meet regularly (at least twice a year) for discussing the general progress, the organisation of meetings and events, the intellectual property issues. The project manager will be responsible for the administration and preparation of minutes and follow up on its decisions. The administrative and financial management will be done by a project manager hired for the duration of the project. It will cover (i) day-to-day administrative and logistic issues, (ii) appraisal of costs to monitor and control the costs incurred and ANR support granted, (iii) maintenance of the consortium agreement, and (iv) assistance to individual project partners on specific administrative issues. The technical and financial reporting to the ANR will include consolidated annual technical and financial reports, deliverables and follow-up of ANR payments.

Task 4.2: Communication (S. Cordeau)

Objective: Organize an efficient communication among partners of the project and to communicate on research achievements and the interdisciplinary research approach to the public.
For internal communication, the project website will include a collaborative project workspace to which access via username and password only will be established. It will include (i) a shared group calendar to schedule meetings and deadlines, (ii) project management guidelines such as reporting requirements, deliverable procedures, and templates for all project documents, and (iii) information about WP progress including presentations done at annual meetings. The project manager will create and update the project website. For external communication, the project website will be a platform for communicating the project objectives, major scientific and technical breakthroughs. A brochure and booklets about grain legumes' agro-ecological pest management will be prepared. Portraits of participants, platforms, experiments will be filmed. The project will also communicate via social media. Project's scientific results will be disseminated through publications, articles and communications at scientific and technological events. Publications will be monitored and encouraged. Two stakeholder conferences at mid-term and the end of the project will present the objectives and results of the project to socio-economic actors interested in grain legume production or transformation, such as farmers from the Dephy network, extension services, cooperatives, breeders, or transformation industries, and collect their feedbacks on progress and objectives.

Task 4.3: Training (C. Le May)

The objective of this task is to promote to students and partners approaches and methods for reducing the use of pesticides (courses, follow-up field tests, engineer's projects). In this task, teachers and researchers will (i) expand the content of the courses offered by the various partners (AgroCampusOuest, AgroSupDijon, ESA Angers) by courses about the agro-ecological protection of crops; (ii) establish a participatory approach for students, and render accessible to students the work done on the various platforms (via engineering projects, scientific approaches, test follow-ups in the framework of UEs, internships); (iii) organise yearly one-day training courses about grain legumes' agro-ecological protection for students and partners involved in the project. Students finishing their work on the project will be encouraged to present their results at these training courses. A booklet will be prepared collectively for this training course and (iv) develop a MOOC with the help of communication students, on agro-ecological protection of legume rich cropping systems. All reports prepared by the students working in the project will be publicized on the project website (master students, technological diploma students, PhD students, as well as engineer's project reports).

2.3. *RESEARCH-LEARNING INTERFACE* / ARTICULATION RECHERCHE-FORMATION

An active research-learning interface will be set up during the project for efficient transfer of knowledge. The project's Task 4.3 will focus on the link between the project's research, teaching courses, and training sessions. The objective is to train the future actors of agri-food sector to agroecological practices and provide a coherent connection between research and training courses and internships linked with the project. Research and education should advance together to induce major evolutions of agricultural systems towards agroecology. Pesticide-free agroecosystem management requires transdisciplinary education and holistic approaches. The evolution of curricula of masters and technical training courses requires also an adapted pedagogy and therefore the educational support of teachers. It is the objective of the French plan "Enseigner à produire autrement".
Different tools will be employed to deliver new knowledge about the agro-ecological protection of grain legumes against multiple pests. This includes (i) new courses for different partner schools curicula, (ii) students' projects on the themes of SPECIFICS, (iii) specific training of interns working in the project, and (iv) a Massiv Open Online Course on pesticide-free legume-rich cropping systems' management. Knowledge in genetics, agronomy, ecology, and socio-economics will be shared by the partners of the project. Different Master courses will benefit from SPECIFICS outputs and knowledge, in Rennes (Agroecology, Plant and Environment Protection), Dijon (Territory Agriculture, Agroecology for sustainable plant productions), and Angers (Agroecology and Plant Productions, Environmental Transition and Sustainability). Many students will be trained in the frame of the project: 6 PhD students and 21 Master or DUT students will be hired in the project and will in the future be the spearhead of agro-ecological practices' development. The network of collaborators will be at the disposal of the trainees. Furthermore, one-day training courses will be organised for students, trainees, and interested farmers or stakeholders.

3. *PROJECT ORGANISATION AND MANAGEMENT* / ORGANISATION ET PILOTAGE DU PROJET

3.1. *PROJECT MANAGER* / RESPONSABLE DU PROJET

Dr <u>Judith BURSTIN</u> is Director of research at UMR Agroecology, INRA Dijon. With a background in agronomy, quantitative genetics and plant breeding, she acquired competencies in genomics and post-genomics methodologies. Her research aims at improving pea seed productivity and quality in the context of low-input farming systems and climate change and focuses on pea adaptation to new cropping systems. She develops multidisciplinary research with colleagues from various disciplines (plant physiology, ecophysiology, animal nutrition, agronomy, microbial ecology, biochemistry), connected to the expectations of the protein crop value-chain (private breeders, industrial processing and biotechnology, farmers) and society, and with strong collaborations at national and international levels. She leads a group of 30 people and has authored or co-authored 54 publications in peer-reviewed scientific journals (WOS H-factor: 27, Total citations: 2077), 7 book chapters, and made 37 oral presentations at international conferences as speaker, including 22 invited talks. She has been coordinating several large national and international projects in the past 20 years, such as the International Pea Genome Sequencing Consortium (2012-2019, > 2M€, 8 partners) and the multi-disciplinary Investment for the Future project PEAMUST (2012-2020, 5.5 M€, 28 partners). She has been involved in the supervision of Master students (6) PhD students (4) and postdocs (8), and she has given Master Courses in Plant Genetics (1998-2016). J. Burstin was elected member of the Scientific committee of INRA Plant Breeding Department (2002-2011), member of the Scientific Committee of the European Association of Protein Crops (2004-2013), Vice-President of the European Association of Protein Crops (2007-2013), Member of the Scientific Committee of International Conferences on Legume Genetics and Genomics (2014-).

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3.2. *ORGANIZATION OF THE PARTNERSHIP* / ORGANISATION DU PARTENARIAT

- **SPECIFICS partners' short description**

UMR Agroécologie (UMR1347 INRA, AgroSup Dijon, Univ. Bourgogne, Univ. Bourgogne-Franche-Comté)

UMR Agroécologie aims at developing sustainable agro-systems, providing sufficient and quality production, while preserving a safe and healthy environment. Researches lead in the Agroecology Joint Research Unit aims at understanding the biotic interactions and regulations within agro-ecosystem communities with various spatial and temporal scales, in order to design innovative and environment-friendly agro-systems based on biological regulations. Researches are led to various levels of integration from the molecule to the community and different spatiotemporal scales like microcosm, farm plot, landscape, crop cycle, rotation. They implement complementary expertise such as agronomy; ecology; biology; physiology and ecophysiology; genetics; microbiology and modelling.

The GEAPSI team studies the genetic and environmental determinisms of legume plant adaptation to innovative cropping systems, with the view of identifying, designing and selecting plant ideotypes for more input-efficient cropping systems. In particular, this team develops integrative researches on pea and fababean and focuses on important traits in the context of low-input farming systems and climate change (ie resistance to pests, adaptation to intercropping, symbiosis, adaptation to climate change). The team has played a leading role in the development of unique genomic resources for pea and fababean, such as the first pea genome sequence (Kreplak et al. 2019); Gene Expression Atlases visualizing expression profiles of any gene of interest in various tissues of pea and fababean; re-sequencing data for diverse pea and fababean genotypes. The team is involved in various aspects of pulse breeding strategies and integrative actions and manages an ex situ collection of spontaneous genetic resources of pea (*Pisum sativum* L.), Faba bean (*Vicia faba* L.) and white lupin (*Lupinus albus* L.), as well as a large TILLING mutant resource for pea.

The GESTAD team analyses and models the effects of cropping systems on the biophysical processes underlying weed dynamics, with the ultimate goal of designing agroeocological cropping systems that reconcile multiple objectives (e.g. maintain crop production, reduce pesticide inputs, reduce weed harmfulness, promote biodiversity etc). The team specializes in (1) investigating the processes underlying biological interactions, (2) developing simulation and decision aid tools, (3) performing system experiments and (4) developing and applying methodologies for co-designing cropping systems.

The IPM team aims at decreasing the use of pesticides and fertilizers in the global context of a sustainable agriculture through three main approaches: (i) the control of the soil inoculum potential and the soil suppressivness; (ii) the use of beneficial microorganisms; (iii) and the induction of plant defense reactions against microbial pathogens. The team is interested in elucidating the mechanisms underlying these three topics and in studying the conditions allowing their introduction into innovative cultural systems.

The GENOSOL platform provide a logistic and technical structure for the acquisition, conservation, characterization and provision of soil microbial genetic resources (DNA) derived from wide-scale soil sampling (several hundred to several thousand samples corresponding to large spatial and/or time scales). This platform is a product of the Agroecology unit's expertise and savoir-faire not only in standardizing molecular tools for the characterization of soil microbial communities, but also in setting up a library and a data base of the microbial genetic resources of soils used to interpret these analyses on a large scale (time, space). https://www2.dijon.inra.fr/plateforme_genosol/en

UMR IGEPP, INRA Bretagne - Normandie

IGEPP is a large research unit of more than 250 employees co-supervised by INRA, Agrocampus Ouest and University of Rennes 1. Research at IGEPP is focused on the reduction of pesticides. IGEPP's objective is to describe, understand and predict the functioning of plants, their associated organisms and the agroecosystems, to develop new methods improving plant health and protection against biotic and abiotic aggressions. IGEPP research activities are conducted by five research teams developing works whose final application aims to solve specific problems of the French and European agricultural sector. The research covers a wide range of field crops including peas, rapeseed, potatoes and wheat and their main associated organisms (pests, pathogens and natural enemies). The research is multi-disciplinary, including genetics, cytogenetics, genomics and bioinformatics, plant pathology, ecology, epidemiology, evolutionary biology and modelling, physiology and biochemistry. IGEPP has strong expertise in the field of agro-ecosystem ecology, thanks to the integration of plant genetics and pathogens/pests ecology disciplines in a combination of different crops. The unit is supported by six internal technological platforms in Bioinformatics, Genetic Resources, Cytogenetics, Metabolomics, Molecular Biology and Greenhouses. IGEPP hosts staff from Terres Inovia, the technical center for oilseed crops and grain legumes, who have strong expertise in pathology and epidemiology in legumes.

LEVA, ESA Angers

The Ecole Supérieure d'Agricultures of Angers (ESA) is one of the largest institute of higher education for life sciences in France. The LEVA research group, under contract with the French National Institute for Agricultural Research (INRA), brings together agronomists, plant ecophysiologists and soil biologists who have recognized expertise in the agro-ecological functions of grain legumes (pea, faba bean, lupin, soybean) in cropping systems to improve nitrogen use efficiency, soil fertility and weed control. The team has long experience in spatial diversification and works especially on plant-plant and plant-soil interactions in intercropping systems to design innovative low input cropping systems. The LEVA works in collaboration with farmers and stakeholders, and develops tools to help farmers manage their cropping systems. This team is strongly involved in teaching in agroecology at ESA.

UMR AGIR, INRA Occitanie

The team ODYCEE from UMR AGIR is a social science research team on innovation and transition processes in agricultural sector and territories. The analysis of the transformations of agriculture is based on the understanding of the organizational structures of the stakeholders; the market dynamics and societal expectations that guide agricultural production, especially with regard to the evolution of vegetable proteins and transition to agroecology. Researchers mobilize a wide range of research postures from analysis and observation to research-intervention; and various methods, both quantitative (statistics, econometrics, lexicometric analysis, network analysis, etc.) and qualitative (interviews, focus group, participatory workshops, ...).

UMR IRHS, INRA Pays de Loire

The CONSERTO team (Seed conservation and stress tolerance) aims to understand how developing seeds acquire various performance characteristics such as seed longevity, germination and seedling emergence that will allow vigorous plant establishment, a prerequisite for crop yield and efficient sustainable weeding strategies. By integrating molecular physiology, genetics and epigenetics, we develop a holistic approach by disturbing the interactions between the developing seeds and its maternal environment using abiotic stress combining GWAS, high-throughput phenotyping, gene network inference to discover key regulatory genes that are characterized using functional genomics. Funded by the ANR Reguleg and H2020 Eucleg, we study grain legumes such as Medicago truncatula, pea and soybean.

LEM-IESEG School of Management, Lille

LEM production economists work on measuring productivity and performance of organizations. Their field of applications extends from market sectors (industries, banks, agriculture...) to non-market activities such as the hospital sector. In the sector of agriculture and environment, they have already been involved in two research programs Systerra funded through ANR projects. The first was on the evaluation of pesticide reductions in crop systems (POPSY project). The second one analyzed the environmental efficiency of animal production for sustainable development (EPAD). LEM economists are located in Lille, on the IESEG campus, one of the funding institutions for LEM research laboratory. In SPECIFICS, the LEM-IESEG economists will work closely with Stéphane Blancard from CESAER (UMR AgroSup Dijon, INRA, UBFC) who is currently involved in the ISITE project « Agroécologie en Bourgogne Franche-Comté ». Based on data extracted from farms involved in the DEPHY network, Nicolas Munier-Jolain analyzes strategies for setting up an agriculture less dependent on crop protection products. In addition, Marie-Hélène Jeuffroy (UMR Agronomie INRA-AgroParisTech) will provide expertise. Her research in agronomy focuses on the design and evaluation of sustainable cropping systems through the analysis and modeling of crop operations as well as the reasoning of cropping techniques. Finally, this task will involve the coordinator and regional facilitator of the "DEPHY-Fermes" network, Bruno Pottiez from the Chamber of Agriculture Nord-Pas de Calais. The objective of this collaboration is to facilitate regular exchanges between researchers and members of the DEPHY network in order to assess the hypotheses, discuss the progress of the work and validate the results empirically.

URGI (Unité de Recherche Génomique Info) INRA Ile de France

URGI is a research unit in genomics and bioinformatics at INRA, dedicated to plants and crop pathogens. URGI's research activities cover data integration as well as the study of genome structure and dynamics. URGI hosts a bioinformatics platform, which belongs to the Institut Français de Bioinformatique (IFB). IFB is the French node of ELIXIR, the European infrastructure of bioinformatics for Life Sciences. URGI co-coordinates the ELIXIR Plant Science community which drives ELIXIR's services towards this specific community of users. The main mission of the platform is to contribute to an open science-compatible management of plant (crops and forest trees) patrimonial data produced by INRA and its partners. The second mission is to propose tools and a suitable environment (including training) for data analysis to INRA's researchers. The platform maintains an information system for plant and pest genomic and genetic data, called GnpIS (https://urgi.versailles.inra.fr/gnpis/). It enables scientists to mine genomic and genetic data, to extract valuable information on genes of agronomical interest and on genome structure and evolution. The platform also develops a complete annotation system to annotate genes and repeats based on the REPET pipeline, to distribute manual curations among dispersed experts, and to store and to visualize annotations (as part of GnpIS). Finally, the platform develops and provides trainings and hackathon at the national level or at the European level in the frame of ELIXIR.

UE Epoisses, INRA BFC

The INRA Unit « Domaine d'Epoisses » is an 140-hectare experimental farm specialised in field arable crop experimentation. The two main missions of the unit are (i) to contribute to plant breeding and the development of cultivars adapted to agro-ecological systems, and (ii) to contribute to the design and evaluation of cropping systems based on integrated crop protection principles. More recently, the unit is in charge of the implementation of the CA-SYS platform, which is a unique, ambitious, multi-scale, agricultural experimental infrastructure dedicated to research in agroecology. Since 2018, the unit has been involved in the agro-ecological transition: all fields are now managed according to pesticide-free agro-ecological principles. The unit experiments regarding two approaches: (multi-)factorial experiment and system experiment. The unit has more than 30 years of expertise on experiment on legumes crops (genetics, ecophysiology, pathology) and 20 years of expertise on experiment of innovative low-input cropping systems. The unit is key component of the regional and national research and development system.

UE Bourges, INRA Val de Loire

The Bourges experimental unit is an important tool in the INRA's Animal Genetics research department, to meet the needs of animal industries and the expectations of research. The experiments are linked with the breeding programs of the INRA centers of Jouy-en-Josas and Toulouse, as well as with researchers from Tours and Clermont-Ferrand, who are members of the

Animal Physiology and Livestock Systems research and Animal Health research departments. The aims of these studies are to increase the prolificity of the herds; to improve beefing skills, meat quality, cheese yield; and to breed for resistant to infectious and parasitic diseases and transfer the original phenotypes to breeders. The unit is composed of two domains distant from 10 km: Domaine de La Sapinière with sheep farming: 2,000 ewes and two lambing periods in August and November and the domain of Galle with goat farming: 450 goats in Protected Designation of Origin Crottin de Chavignol. The agricultural exploitation which extends on these two sites with 90 Ha of surface reserved for the implementation of agroecology, and 210 Ha of cereal crops and 310 Ha of forage crops. Twenty-nine people (engineers, technicians and administrators) study the two main species of domestic animals and ensure the production of the fodder necessary for their feeding on Domaine de la Sapinière at OSMOY and that of Galle at AVORD.

UE La Motte, INRA Bretagne - Normandie

The Experimental Unit of La Motte is a mixed crop-livestock INRA experimental farm area of 280 ha located near Le Rheu (Ille-et-Vilaine). It conducts plant and agronomic field trials for research and breeding programs. Because located at the core of an area where plant diseases are main limiting factors of yield for cereals and grain legumes, the place is noteworthy to carry out genetic studies on biotic stresses at the field scale and on new cropping systems with lower inputs;

Our team is composed of one research engineer, nine research technicians and technical assistants. We bring together the wide range of multiples skills needs for the activities: field trial design, crop management over size areas from micro-plots to agriculture parcel, whole plant knowledges and phenotyping. We own a large range of agricultural machineries and special field research equipments such as six plots seeders and five harvesters for micro-plots.

More than one hundred trials (about 7000 micro-plots) was carried out each year by the team. In the last years, we are involved into several research projects of the French Investments for the Future programme (PIA): Peamust, Breedwheat and Rapsodyn; Since 2012, we managed an experimental crop system without pesticide as part of “Dephy EXPE- Ecophyto” project. P. Bertin, the team manager, is one of the coordinators of the BioDiverSystem platform since autumn 2018 and several technicians perform the cultural management and the monitoring crops.

AFP, INRA Hauts de France

The research program of the partner "Institut Charles Viollette-Adaptation au Froid du Pois" aims at elucidating the determinism of frost tolerance within grain legumes in order to breed for winter varieties. Former results allowed us to identify 4 genomic regions (QTLs) controlling frost tolerance in pea, which proved to be consistent among environments and genetic backgrounds. These regions were also found to coincide with QTLs governing the resistance to ascochyta blight due to Didymella pinodes (4 same regions) and to root rot caused by Aphanomyces euteiches (2 regions among 4). For this reason, we share a common goal with the partner IGEPP, which is to identify the genes underlying reduced confidence intervals of these QTLs. We are currently producing information and tools (BAC sequences of frost tolerant/disease resistant accessions at main QTLs, TILLING mutants at frost tolerance-candidate genes) which will allow us to test two hypothesis that are not mutually exclusive : i) different stress-specific causal genes are neighbouring at the same physical position and ii) some candidate genes are responsible for common frost tolerance/disease resistance mechanisms.

- **SPECIFICS partners’ complementarity is summarized in the table below:**

N° partner	Structure	Team	Field	Ability / Expertise
1	*UMR Agroecologie*	*GEAPSI*	*Legume genetics & ecophysiology*	*Legume Genetics, Genomics, and Ecophysiology – TILLING – Resistance to bruchids and sitona – Adaptation to intercropping*
1	*UMR Agroecologie*	*GESTAD*	*Weed science*	*Agronomy –Cropping systems design – Models – Weed competitiveness*
1	*UMR Agroecologie*	*IPM*	*Plant Microbe interactions*	*Ecology of soil-borne fungi– Pathogenicity – Symbiosis - Biocontrol – Soil suppressiveness*
1	*UMR Agroecologie*	*GENOSOL*	*Soil Metagenomics*	*Epidemiology – Population genetics – Biodiversity - Rhizobiome - Microbiome*
1	*UE Epoisses*	*UE*	*Field Experimentation*	*Agro-ecological practices – Agronomy – Analytical and System experiments - Cropping system design and multicriteria assessment*
2	*IGEPP*	*RA*	*Plant resistance to diseases*	*Quantitative genetics and genomics – Resistance to Aphanomyces and ascochyta – Ecology and populations genetics of pathogens*
2	*IGEPP*	*EGI*	*Ecology and genomics of insects*	*Aphid genomic genetics and ecology – Legume resistance to aphids – Plant-pest interactions*
2	*UE La Motte*	*UE*	*Field Experimentation*	*Crops and animals – Disease management*
3	*IRHS*	*CONSERTO*	*Plant physiology*	*Seed germination – High throughput phenotyping*
4	*UE Bourges*	*UE*	*Field experimentation*	*Crops and animals – Agroecology*
5	*URGI*	*URGI*	*Genomics Information system*	*BioInformatics – Databases – FAIR data - Genomics*
5	*LISIS*	*LISIS*	*Science and Innovations in society*	*Sociology – Stakeholders strategies on markets*
6	*ESA*	*LEVA*	*Legume crop physiology and agroecology*	*Agronomy – Cropping systems design – Intercropping and crop diversification*
7	*AGIR*	*ODYCEE*	*Innovation dynamics and supply chain organization in territories*	*Economics and sociology – Innovation and transition in value chains and markets*
8	*IESEG*	*LEM*	*Economics & Management*	*Production economics - Analysis of efficiency and productivity of private and public organizations*
9	*AFP*	*AFP*	*Pea adaptation to winter*	*Genetics of pea winter tolerance – Frost – Winter aerial diseases*

The research partners funded in the project have strong collaborations with other structures in national networks (e.g. mixed technology network) or multi-partner structures who support this project (e.g. competitiveness clusters Vegepolys Valley and Vitagora gathering firms, research and training centers in the plant field and food and agri-business innovations respectively). The complementary expertise of these partners not directly funded will be mobilized in this project either through workshops and stakeholders committees, or through direct involvement in project tasks. Especially, Terres Inovia will provide its expertise for the screening of mutants, for the monitoring and multicriteria assessment of experimental cropping systems (T2.3 and T3.1), for discussions on the integration of legumes into cropping systems and the development of tools to support advice to farmers (T2.5).

- **CV of coordinators, work-package and task leaders**

These different expertises are represented by leaders of Work-Packages and Tasks that come from the different partners of the consortium:

Judith Burstin (Agroécologie) Coordinator of SPECIFICS, Co-WP leader WP4, Leader of Task 1.1 and 4.1

See CV in main text, section 3.1

Stéphane Cordeau (UMR Agroécologie) Co-coordinator of SPECIFICS, Leader of Task 2.2 and 4.2

Dr Stéphane CORDEAU is a researcher at UMR Agroécologie (31 publications - WoS Hindex = 10, Google scholar Hindex = 10). In 2015-2016, he was an invited visiting scientist at Cornell University, NY, USA. He leads researches on the impact of cropping systems on weed communities, their biological regulation both in terms of mechanisms and practical implementation in agroecosystem management. The scientific objectives of his research are two-fold: (i) to understand how weed communities respond to agricultural management over time (i.e. changes in population size, diversity and functional traits) and (ii) to evaluate to what extent biological regulation of weeds can help to reduce reliance on herbicides. The practical objective of his research is to design biodiversity-based cropping systems that reduce herbicide use by implementation of no-till and cover crop management and to assess system sustainability in terms of weed regulation and economic viability. He currently leads with Violaine Deytieux the scientific and operational aspects of the INRA CA-SYS platform (described in details below). The platform CA-SYS is one of the major tool he co-develop with farmers, crop advisors, researchers, etc. and now managed to test the hypothesis that wild and cropped diversity could be a means to production sustainable pesticide-free productions. He is a member of the CTPS (French Plant Variety Registration Office) section evaluating cover crop varieties before their registration on the French and European official list. He is also member of the scientific committee Terres Inovia, the technical center for oil and protein crops.

Adeux, G., …, Cordeau, S., 2019. Mitigating crop yield losses through weed diversity. Nature Sustainability 2, 1018-1026. https://www.nature.com/articles/s41893-019-0415-y

Adeux, G., Munier, J., N.M., Meunier, D., Farcy, P., Carlesi, S., Barberi, P., Cordeau, S., 2019. Diversified grain-based cropping systems provide long term weed control while limiting herbicide use and yield losses. Agron. Sustainable Dev. 39, 42. https://link.springer.com/article/10.1007/s13593-019-0587-x

Romdhane, S., …, Cordeau, S., 2019. Cover crop management practices rather than the composition of cover crop mixtures affect microbial communities in no-till agroecosystems. Frontiers in Microbiology 10. https://www.frontiersin.org/articles/10.3389/fmicb.2019.01618/full

Colbach, N., Cordeau, S., 2018. Reduced herbicide use does not increase crop yield loss if it is compensated by alternative preventive and curative measures. European Journal of Agronomy 94, 67-78. https://www.sciencedirect.com/science/article/pii/S1161030117301892

Quinio, M., De Waele, M., Dessaint, F., Biju-Duval, L., Buthiot, M., Cadet, E., Bybee-Finley, A.K., Guillemin, J.-P., Cordeau, S., 2017. Separating the confounding effects of farming practices on weeds and winter wheat production using path modelling. European Journal of Agronomy 82, 134-143. https://www.sciencedirect.com/science/article/pii/S1161030116302052

Dr Marie Laure Pilet-Nayel (IGEPP) Leader of WP1 and Task 1.3

Dr Marie-Laure PILET-NAYEL (48 years-old) is a Director of Research at INRA IGEPP. She has expertise in quantitative genetics and genomics, marker-assisted-selection and disease resistance in plants. After a post-doc period at USDA-ARS, WA, USA (1999-2000), she has managed research programs in genetics and genomics of Aphanomyces resistance in legumes for the past 20 years, in tight collaborations with pathologists, physiologists and breeders especially from France (INRA, University of Toulouse, GSP) and the USA (USDA). She has led a French-America collaborative network on root rot diseases in legumes for more than 15 years, resulting in numerous workshops (https://workshop.inra.fr/ilrd8). She has coordinated large multi-disciplinary and multi-sectorial collaborative projects or work-packages, funded by ANR for Investments of the Future (WP2-PeaMUST), Europe and the Brittany region (SP3.9 FEADER-Prograilive), the French Agricultural Ministry (SAMPOIS), the technical institute Terres Inovia. She has experience of working at the interface between public research and breeding companies and she is an expert for the French variety registration office. She has authored or co-authored 38 publications in peer-reviewed international journals (WoS H-index=20, nb citations=1106; ORCID:0000-0002-4505-1907), more than 90 communications in congress and 45 transfer communications to breeders and technical institutes. She (co)-supervised 3 PhD students, 13 Master students and 12 temporal scientists, engineers or technicians. She (co-)manages 7 permanent technicians from IGEPP who has contributed to her projects.

Coyne CJ, Porter LD, Boutet G, Ma Y, McGee RJ, Lesné A, Baranger A, Pilet-Nayel M-L (2019). Confirmation of Fusarium root rot resistance QTL Fsp-Ps 2.1 of pea under controlled conditions. BMC Plant Biol 19:98

Bonhomme M, Fariello MI, Navier H, Hajri A, Badis Y, Miteul H, Samac DA, Dumas B, Baranger A, Jacquet C*, Pilet-Nayel M-L* (2019). A local score approach improves GWAS resolution and detects minor QTL: application to Medicago truncatula quantitative disease resistance to multiple Aphanomyces euteiches isolates. Heredity, 123:517–531

Quillévéré-Hamard A, Le Roy G, Moussart A, Baranger A, Didier A, Pilet-Nayel M-L*, Le May C* (2018). Genetic and pathogenicity diversity of Aphanomyces euteiches populations from pea-growing regions in France. Frontiers in Plant Sci 9:1673

Desgroux A, Baudais V, Aubert V, Le Roy G, de Larambergue H, Miteul H, Aubert G, Boutet G, Duc G, Baranger A, Burstin J, Manzanares-Dauleux M, Pilet-Nayel M-L*, Bourion V* (2018). Comparative Genome-Wide-Association Mapping identifies common loci controlling root system architecture and resistance to Aphanomyces euteiches in pea. Frontiers in Plant Sci., 8:2195

Pilet-Nayel M-L, Moury B, Caffier V, Montarry J, Kerlan M-C, Fournet S, Durel C-E, Delourme R (2017). Quantitative resistance to pathogens in plant pyramiding strategies for durable crop protection. Frontiers in Plant Sci. 8:1838

Dr Guénaëlle Corre-Hellou (ESA) Leader of WP2

Dr. Guénaëlle Corre-Hellou (43 years-old), agronomist, senior scientist (USC LEVA, ESA-INRA), leads research on the agro-ecological functions of grain legumes in cropping systems less dependent on external inputs. She has 18-years expertise on legume-cereal intercrops (plant-plant interactions, light and N sharing, above and belowground growth of intercropped species, competitive ability of intercrops against weeds). She develops her research in multidisciplinary projects on crop diversification with various actors from research and development (leader of a 25-partner national CASDAR research project on intercropping, WP leader in ANR PerfCom, ANR Legitimes and H2020 DiverIMPACTS (EU)). Authored or co-authored 31 peer reviews research papers related to legumes in cropping systems. WoS H-index=18.

Bédoussac L., …., Corre-Hellou G., et al.. 2015. Ecological principles underlying the increase of productivity achieved by cereal-legume intercrops in organic farming: a review. Agronomy for Sustainable Development 4, 71-78. https://doi.org/10.1007/s13593-014-0277-7

Pelzer E., … Corre-Hellou G., et al. 2012. Pea–wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. European Journal of Agronomy 40, 39-53. https://doi.org/10.1016/j.eja.2012.01.010.

Corre-Hellou G., et al. 2011. Competitive ability of pea-barley intercrops against weeds and interactions with crop productivity and soil N acquisition, Field Crops Research, 122: 264-272. https://doi.org/10.1016/j.fcr.2011.04.004.

Corre-Hellou G., et al. 2006. Interspecific competition for soil N and its interaction with N2 fixation, leaf expansion and crop growth in pea-barley intercrops. Plant and Soil, 282: 195-208. https://doi.org/10.1007/s11104-005-5777-4

Corre-Hellou G. and Crozat Y. 2005 - N2 fixation and N supply in organic pea (Pisum sativum L.) cropping systems as affected by weeds and peaweevil (Sitona lineatus L.). European Journal of Agronomy, 22 (4): 449-458. https://doi.org/10.1016/j.eja.2004.05.005

Dr Violaine Deytieux (INRA UE Epoisses) Leader of WP3 and Task 3.1

Dr Violaine Deytieux is an agronomist who has been working at the experimental station of INRA, Domaine d'Epoisses, as research engineer for over 13 years. Her main field of expertise is design/evaluation of low-pesticide cropping systems based on IPM and agro-ecological principles through system experiment and use of multi-criteria assessment methods. She contributes to the coordination and animation of cropping system experiment networks (Mixed Technology Network for Innovative Cropping Systems, Res0Pest). One main characteristic of her research is the multidisciplinary approach through several collaborations with research, development and training actors and farmers to design and test agro-ecological systems, allowing (i) to develop methods and tools for system experiment and co-design of agro-ecological systems, and (ii) to analyse experimental network datasets. Since 2017, she has been deputy director of the experimental station Domaine d'Epoisses. She is scientific project leader and is involved in the coordination and running of the CA-SYS platform, a co-designed agro-ecological system experiment (financed in particular within the Ecophyto DEPHY EXPE national network).

Voisin A-S., …, Deytieux V. (2019). Mobilisation of functional properties of diverse legumes species at various scales in the CA-SYS Long Term Experimental Platform on Agroecology: expected services and prospects. Poster presented DiverIMPACTS, European Conference on Crop Diversification. September 18-21, 2019, Budapest, Hungary. Book of abstracts, 142-143.

Schaub A., …, Deytieux V. (2019). INNOViPEST : Développer des alternatives à des systèmes de culture Maïs-Blé en polyculture-élevage sans irrigation : enseignements de trois expérimentations conduites dans différentes régions françaises. Innovations Agronomiques 76, 169-187. dx.doi.org/10.15454/mbltkd

Cellier, V., …., Deytieux, V., et al. (2018). Évaluation multicritère de systèmes de culture zéro-pesticides en grande culture et polyculture-élevage (Réseau Rés0Pest). Innovations Agronomiques, 70, 273-289. , https://doi.org/10.15454/y8fy5s

Deytieux, V. Performances de prototypes de systèmes de grandes cultures : Analyse d'un réseau expérimental. (2017). Thèse de doctorat de l'Université de Bourgogne Franche-Comté. 298pp.

Richard Thompson (Agroecologie) Leader of Task 1.2

Dr Richard Thompson main research theme is the genetic control of legume seed development and composition. Using transcriptomics and proteomics data, we have identified loci regulating seed storage protein composition and seed size, as well as starch accumulation. The genes responsible include seed-specific transcription factors and a subtilase. An important role for auxin synthesis in seed development was also uncovered. Part of our work involves functional analysis through analyzing phenotypes of mutant plants. For this we have created populations of mutant resources and organized them to allow "TILLING" screenings in spring pea and for the model legume *Medicago truncatula*. Recently we have produced a new winter pea TILLING population to facilitate the evaluation of traits of importance for winter cultivation. The populations are exploited worldwide by the pea research community as they permit analysis of any gene of interest.

McAdam, E. L., …R Thompson, et al.. "Evidence that auxin is required for normal seed size and starch synthesis in pea." New Phytologist (2017) online. DOI: 10.1111/nph.14690

Noguero, M., …Thompson, R., Verdier, J. (2015). DASH transcription factor impacts Medicago truncatula seed size by its action on embryo morphogenesis and auxin homeostasis. Plant Journal, 81 (3), 453-466. DOI : 10.1111/tpj.12742

Tivendale, N. D., …Thompson, R et al. (2012). Biosynthesis of the halogenated auxin, 4-chloroindole-3-acetic acid. Plant Physiology, 159 (3), 1055-1063. DOI : 10.1104/pp.112.198457

Le Signor, C., …, Thompson, R. (2009). Optimizing TILLING populations for reverse genetics in Medicago truncatula. Plant Biotechnology Journal, 7 (5), 430-441. DOI : 10.1111/j.1467-7652.2009.00410.x

Dalmais, M., … Thompson, R., Bendahmane, A. (2008). UTILLdb, a Pisum sativum in silico forward and reverse genetics tool. Genome Biology, 9 (2), R43, 12p. DOI : 10.1186/gb-2008-9-2-r43

Delphine Moreau, (Agroécologie) Leader of Task 2.1

Dr Delphine Moreau (40 years; https://publons.com/researcher/1300321/delphine-moreau/) is agronomist (Institut Supérieur d'Agriculture Lille), with a Master degree in crop sciences (Univ. Orsay, AgroParisTech), a PhD in plant ecophysiology (2007, Univ. Bourgogne-Franche-Comté) and a habilitation for directing research (2017, Univ. Bourgogne-Franche-Comté). She leads the SYSTEME team at UMR Agroécologie. Her research field is about crop-weed competition for resources (especially soil resources). Her approach aims at understanding the determinants of these interactions and their consequences on plant community assembly, in order to identify cultural techniques that promote biological weed regulation in cropping systems. She is currently coordinating the Casdar RAID project and a task in the European project ReMIX. In the past, she has coordinated a WP of the ANR project Cosac.

Moreau D, … (in revision) In which cropping systems can residual weeds reduce nitrate leaching and soil erosion? European Journal of Agronomy.

Colbach N, Gardarin A, Moreau D (2019) The response of weed and crop species to shading. Which parameters explain weed impacts on crop production? Field crops research 238, 45-55.

Moreau D, et al. (2017) Plant root architecture parameters are more affected by interspecific differences than by soil-nitrogen availability in a range of weed and crop species. Annals of Applied Biology 171, 103-116.

Moreau D, et al. (2016) Trophic relationships between the parasitic plant species Phelipanche ramosa (L.) and different hosts depending on host phenological stage and host growth rate. Frontiers in Plant Science 7, 1033.

Moreau D, et al. (2015). Plant traits related to nitrogen uptake influence plant-microbe competition. Ecology 96, 2300-2310.

Samuel Mondy (Agroécologie) Leader of Task 2.2

Dr Samuel Mondy is a bioinformatician specialized in metagenomic data analysis, responsible for the GenoSol platform, a collective research tool focused on soil biology. This unique structure allows the research engineer to describe microbial community structures of soils and to store soil samples efficiently and sustainably. After graduating from university, Samuel Mondy obtained his PhD in Cellular and Molecular Physiology of Plants in 2004. His PhD focused on the use of mutagenesis by T-DNA in the legume plant model Medicago truncatula. He began his professional career at CEA where he worked on the characterization of the response of the model species Arabidopsis thaliana during biotic and abiotic oxidative stress. He later joined the CNRS in projects to determine the impacts of genetically modified plants on the microbial community of the rhizosphere. He also specializes in bioinformatics, particularly in the field of metagenomics. He then worked at the Genoscope (CEA) as part of the TARA Oceans project on the characterization of marine unicellular eukaryotes using a Single Cell approach combined with the use of metagenomic datasets.
https://scholar.google.fr/citations?user=Y7a66rAAAAAJ&hl=fr

Montillet, J.-L., Leonhardt, N., Mondy, S., …., 2013. An abscisic acid-independent oxylipin pathway controls stomatal closure and immune defense in Arabidopsis. PLoS Biol. 11, e1001513.

Mougin, C., … Mondy, S., …, 2018. BRC4Env, a network of Biological Resource Centres for research in environmental and agricultural sciences. Environmental Science and Pollution Research 25, 33849-33857.

Seeleuthner, Y., Mondy, S., …., 2018. Single-cell genomics of multiple uncultured stramenopiles reveals underestimated functional diversity across oceans. Nat Commun 9, 310.

Lemanceau, P., …, Mondy, S., …., 2017. Plant communication with associated microbiota in the spermosphere, rhizosphere and phyllosphere. Advances in Botanical Research. Elsevier, pp. 101-133.

Yann Tricault (IGEPP) Leader of Task 2.3

Dr Yann Tricault is based at Agrocampus-Ouest, Angers (France), where he holds a position of Lecturer in ‘ecology applied to plant protection’ (since 2009). His teaching experience includes all levels from undergraduate to PhD students with main topics on agricultural entomology and ecological modelling. He co-heads Graduate and Master Programs in plant health. Yann Tricault is a member of the team ‘Ecology and Genetic of Insects’ belonging to the IGEPP joint research unit.

He develops an agro-ecological approach of pest management for reducing the reliance on pesticides. He is mainly interested in better understanding the relationships between biodiversity and agriculture at multiple spatial scales (from field to landscape) and temporal scales (from growing season to multi-year dynamics). His recent research aims at quantifying the processes and factors involved in the delivery of ecosystem services, taking biological control as a research object. Yann Tricault has extensive experience in Arthropod diversity analysis, data analysis and modelling, landscape analysis and in the development of simulation models.

Mesmin X, .. Tricault Y, et al. (2019) Assessing the relationship between pest density and plant damage: a case study with the belowground herbivore Delia radicum (Diptera: Anthomyiidae) on broccoli. Applied Entomology and Zoology, 54, 155-165

Pollier A., Tricault Y, et al. (2019) Sowing of margin strips rich in floral resources improves herbivore control in adjacent crop fields. Agricultural and Forest Entomology, 21, 119-129

Pollier A, … Tricault Y, et al. (2018) Effects of spontaneous field margin vegetation on the regulation of herbivores in two winter crops. Basic and Applied Ecology, 27, 71–82.

Karp D, …Tricault Y et al. (2018) Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. Proceedings of the National Academy of Sciences, 115, E7863-E7870.

Pollier A, …, Tricault Y, et al. (2016) Using the stable isotope marker 13C to study extrafloral nectar uptake by parasitoids under controlled conditions and in the field. Entomologia Experimentalis et Applicata, 161, 131-140

Guillaume Piva (ESA) Leader of Task 2.4

Dr. Guillaume PIVA, agronomist, lecturer (USC LEVA, ESA-INRA), leads research on the agro-ecological functions of grain legumes in cropping systems less dependent on external inputs. he has 10 years expertise on legume-cereal intercrops (belowground growth of intercropped species and competitive ability of intercrops against weeds) and insertion of minor crops such as Quinoa in cropping systems. He develops his research in multidisciplinary projects on the study legumes in cropping system with various actors from research and development (WP leader of FEADER PEI-AGRI research project: PROGRAILIVE). He has also research experience on the biochemical quality of legumes seed response to field practices. His teaching main topic (undergraduate to master level) is agronomy at differents scales: field, cropping system and farm diagnosis.

Carton N., Naudin C., Piva G., Corre-Hellou G. 2018. Variability of traits associated with early N acquisition in lupin and early complementarity in lupin-triticale mixed stands. AoB Plants https://doi.org/10.1093/aobpla/ply001.

Dayoub E., Naudin C., Piva G., Shirtliffe S.J., Fustec J., Corre-Hellou G. 2017. Traits affecting early season nitrogen uptake in nine legume species. Heliyon 3, DOI: 10.1016/j.heliyon.2017.e00244

Jamont M., Piva G., Fustec J. (2013). Sharing N resources in the early growth of rapeseed intercropped with faba bean: does N transfer matter? Plant and Soil 371, 641-653.

Piva G., Brasse C., Mehinagic. (2013). Quinoa d'Anjou : The Beginning of a French quinoa sector. In State of the art report on quinoa around the world in 2013., Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). 2015. Rome: FAO-CIRAD, 603 p.

J.P Boussemart (IESEG/LEM UMR CNRS 9221) Leader of Task 3.1

Pr Jean-Philippe Boussemart is Professor in economics at the University of Lille and IESEG School of Management. He was the Dean of the Faculty of law, economics and management at the

University of La Réunion from 1994 to 1998 and the Dean of the Faculty of mathematics, statistics and social sciences at the University of Lille 3 from 1999 to 2004. He is a member of Lille Economie Management (LEM), a CNRS research laboratory and has recently been named corresponding member of the Académie d'Agriculture de France. His researches focus on production economics and more specifically on the analysis of efficiency and productivity of private and public organizations. The fields of application of his research are varied (health, banking, manufacturing industries, …) but a particular attention is paid to farming activities and their impact on the environment.

J-Ph. Boussemart, et al. (2019): "Effects of direct payments on technical catching-up in a selection of French farms", European Review of Agricultural Economics, 46(2), 215-235, (https://doi.org/10.1093/erae/jby023).

Z. Shen, J-Ph. Boussemart, H. Leleu, (2017): "Aggregate green productivity growth in OECD's countries", International Journal of Production Economics, 189, 30-39, (http://dx.doi.org/10.1016/j.ijpe.2017.04.007).

J-Ph. Boussemart, et al. (2016): "Exploring cost dominance in crop farming systems between high and low pesticide use", Journal of Productivity Analysis,45(2), 197-214 (http://dx.doi.org/10.1007/s11123-015-0443-1).

D. Berre, …J-Ph. Boussemart, et al. (2014): "Finding the right compromise between productivity and environmental efficiency - a case study in high input tropical dairy farms", Journal of Environmental Management, 146, 235-244, (http://dx.doi.org/10.1016/j.jenvman.2014.07.008).

J-Ph. Boussemart, et al. (2013): "The spread of pesticide practices among cost efficient farmers", Environmental Modeling and Assesment, 18, 523-532, (http://dx.doi.org/10.1007/s10666-013-9363-5).

Marie-Benoit Magrini (UMR AGIR) Leader of Task 3.2 and T3.3

Dr Marie-Benoit Magrini, 41, research engineer in economics (HDR) in the team ODYCEE of the unit AGIR since 2007. She conducts analyses on lock-in mechanisms, innovation and transition processes in agricultural and food sectors. She is particularly interested in understanding the links between the inter-organisational arrangements in value chains (such as contracts) and the capacity to change of the stakeholders. She works in several regional, national and European projects. Much of her works deal with the question of legumes development. Since 2017, she has managed the Legumes research group at INRA gathering researchers from different disciplines to stimulate interdisciplinarity between life and social sciences, and communication with partners. She coordinated the last edition of the French-speaking Legumes Meeting of 2018. She has published over 40 articles in SCI journals, public reports and book chapters.

Cholez, C., Magrini, M.B., Galliano, D., 2017. Field Crop Production Contracts. Incentives and Coordination under Technical Uncertainty, in French Cooperatives. Économie rurale, (4), 65-83.

Lascialfari M., Magrini M-B., Triboulet P., 2019, The drivers of product innovations in pulse-based foods: insights from case studies in France, Italy and USA. Journal of Innovation Economics Management, (1), 111-143.

Magrini M-B., 2018, Economie de l'innovation et des transitions : analyser et accompagner. Comprendre les processus sociotechniques de l'innovation et des transitions pour accompagner la transition agroécologique et nutritionnelle. Rapport d'Habilitation à diriger des Recherches, soutenu le 18 décembre 2018 à l'Université Toulouse 1.

Magrini M-B., et al.., 2018a, Pulses for sustainability: breaking agriculture and food sectors out of lock-in., Frontiers in Sustainable Food Systems, section Nutrition and Environmental Sustainability, https://doi.org/10.3389/fsufs.2018.00064

Magrini M-B., et al.., 2019, Technological Lock-In and Pathways for Crop Diversification in the Bio-Economy. In Agroecosystem Diversity: Reconciling Contemporary Agriculture and Environment Quality. Lemaire, Recous, Kronberg, and Carvalho (eds). Elsevier.

Thomas Debril (UMR AGIR) Leader of T3.4

Dr Thomas Debril, 46, is a research engineer in sociology, since 2010, in the team Odycee of UMR AGIR. He analyses transition processes in agricultural and food sectors.He is interested in understanding the implementation of environmental policies. In particular, he shows how the environmental objectives associated with these policies come up against actors games in which farmers play a decisive role. He is also interested in understanding the organization of agri-food sectors. He characterizes socio-economic drivers of different forms of sustainable agriculture and the ways in which these markets affect the agro-ecological transition. He works in several regional, national projects. He has published over 20 articles in SCI journals and book chapters.

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Christophe Le May Task 4.3

Dr Christophe Le May (EC-HC, UMR INRA IGEPP, Agrocampus Ouest) is Lecturer in plant pathology at Agrocampus Ouest, Rennes. Since 2003, he develops researches on population biology and parasitic ecology. In particular, he analyzes the genetic diversity of fungal pathogens of legume species (pea, faba bean) and evaluate the impact of plant protection strategies on pathogen populations. The last four years, he has developed research strategies aiming at evaluating the sustainability of the resistance of pea cultivars to the root rot pathogen *Aphanomyces euteiches.* He also describes and measures Life History Traits and their variability in field isolates of the two main species of the Ascochyta blight complex of peas. This LHT description has then been used to determine whether partially resistant hosts affect these LHT and their distributions, and to explain the conditions of coexistence of these two species on the same host.

Omri-Benyoussef N., Kerdraon L., Mieuzet L., Halila I., Jammezi N., Mbazia A., Kharrat M., Le May C., 2018. Population structure of the faba bean blight pathogen Ascochyta fabae Speg. (teleomorph: Didymella fabae Jellis & Punith) in Tunisia. Phytopathologia Mediterranea, 58 (1): 81-94. (IF : 1.367)

Le May C., Onfroy C., Moussart A., Andrivon D., Baranger A., Pilet-Nayel M.L., Vandemark G., 2018. Genetic structure of aphanomyces euteiches populations sampled from United States and France pea nurseries. European Journal of Plant Pathology, 150 (2): 275-286. (IF : 1.744)

Quillévére-Hamard A., Le Roy G., Moussart A., Baranger A., Andrivon D., Pilet-Nayel M.L., Le May C., 2018. Genetic and pathogenicity diversity of Aphanomyces euteiches populations from pea-growing regions in France. Frontiers in Plant Sciences, https://doi.org/10.3389/fpls.2018.01673 (IF : 4.106)

Billard E., Quillévéré-Hamard A., Lavaud C., Pilet-Nayel M.L., Le May C., 2019. Testing of life history traits of a soil borne pathogen in vitro: Do characteristics of oospores change according the strains of Aphanomyces euteiches and the host plant infected by the pathogen? Journal of Phytopathology, 167 (6): 313-320. (IF : 1.097)

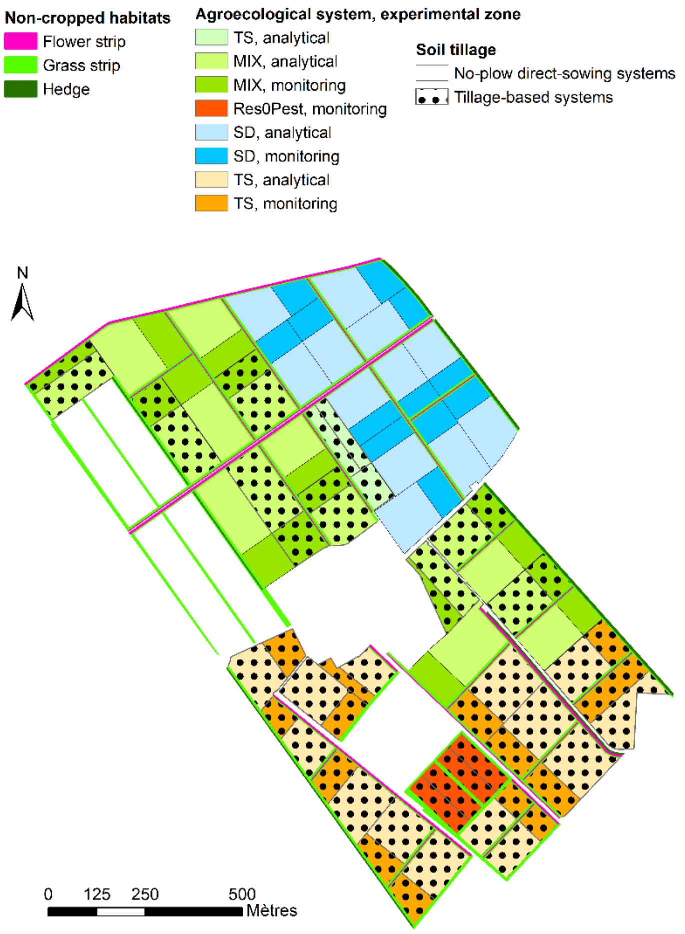
Dutt A., Andrivon D., Leclerc M., Le Roy G., Jumel S., Baranger A., Le May C., 2019. Life history traits intra and interspecific diversity of the disease complex Ascochyta blight of pea. Plant Pathology (accepté) (IF : 2.303)

- **Description of the experimental agro-ecological platforms**

The project builds on three experimental agro-ecological platforms that show different characteristics in terms of cropping area, landscape and practices.

CA-SYS platform (INRA Bourgogne-Franche Comté)

Within the INRA 'Domaine Epoisses' experimental unit (located close to Dijon), the CA-SYS platform is experimenting since the summer 2018, a diversity of pesticide-free agro-ecological systems for field crops (wheat, barley, rapeseed, pea, soybean, fababean, etc.) on 125 ha divided into 42 plots of 2.5 ha on average. Neither pesticides including those authorized in organic agriculture, nor bioproducts is applied in the CA-SYS platform. The overarching objective of the CA-SYS platform is to design and test the feasibility and performances of pesticide-free agriculture using (cropped and wild) biodiversity in support of production, i.e. biodiversity-based forms of agriculture. The management of each plot is governed by a body of decision rules defining the cropping system to which it is attached; the practices are adapted for each plot according to the objectives and constraints assigned to each cropping system and according to the observed conditions of the plot (soil humidity, pest pressure, legacy of past crops, etc.). Four pesticide-free cropping systems are tested, identifying two relevant agricultural pathways to address agro-ecological challenges: one inspired by organic agriculture is a tillage-based systems (non-recurrent plowing, false seedbed, mechanical weeding = hereafter named **TS**); the other inspired from conservation agriculture is a no-plow direct-sowing systems maximizing soil cover (named **SD**). These two options mobilize a wide diversity of crops in a temporal (at the scale of crop succession) and spatial (mixtures of species and/or varieties) way. Within the two pathways, i.e. SD and TS, two cropping systems are tested.



TS1 refers to tillage-based systems allowing the use of exogenous N fertilizers whereas **TS2** targets the autofertility and ban the use of exogenous N fertilizers. As a matter of fact, and following the cropping-system way of thinking, crop rotation and association practices differs. **SD1** refers to permanent no-till systems whereas **SD2** allows the use of superficial tillage if necessary, no more than once a year, before crop sowing to terminate weeds, crop volunteers or cover crops. No P and K fertilizers is applied in any of the crops of the 4 cropping systems.

Another originality of the CA-SYS platform also lies in the combination of two experimental approaches: a system approach to design and evaluate agro-ecological systems, a factorial approach to gain a better understanding of the processes involved in agro-ecological systems (beneficial plant/microorganism interactions), selecting plant material adapted to agro-ecological conditions, understanding the effect of certain practices (e.g. test methods for terminating cover crop). On top of that, factorial experiments are nested in cropping system experiment. Thus, each plot is divided into two zones, one reserved for the long-term monitoring of the effects of the cropping system applied (**= monitoring zone**), and one dedicated to factorial experiments once every 3 years

(**= analytical zone**), the time to homogenize the legacy effect of past factorial experiment. For more details on the experimental design of the 125-ha CA-SYS platform and on the crop rotation, see the pdf attached to https://www6.inra.fr/plateforme-casys_eng/.

ABY platform (INRA Bourges)

With 610 ha on two sites separated by 10 km, the plan is divided into 90 ha reserved for agroecology (here used in the SPECIFICS project), 210 ha in main crop (wheat, barley, rapeseed), 310 ha of meadows of which more than 60% mixed grass-legumes with grazing for sheep; the implementation of early harvests through wrapping; the use of legumes to fix nitrogen; the use of manure after systematic composting for a large majority on meadow each year. For more than 10 years, perfect fodder autonomy has been obtained with reduced nitrogen fertilization. Since 2018, supported by the DEPHY EXPE II project ABC 'Agroécologie en Bourgogne et region Centre', the experimental unit of Bourges has set up an agro-ecological system experiment, following the same principles as those implemented on the CA-SYS platform. The originality relies on the link between arable crop production and sheep. Some cropping systems has been design to take the opportunity to use sheep for terminating cover crop, grazing lucerne, etc… **Thus, two cropping systems (with and without plowing) in a polyculture-livestock context and two cropping systems (with and without plowing) in a context without livestock has been designed and set up in 2018.** They cover 90ha splitted into 28 fields, where all the crops of the crop rotation are cropped every year. http://translate.google.com/translate?sl=fr&tl=en&u=https%3A%2F%2Fwww6.val-de-loire.inra.fr%2Fue-bourges%2F

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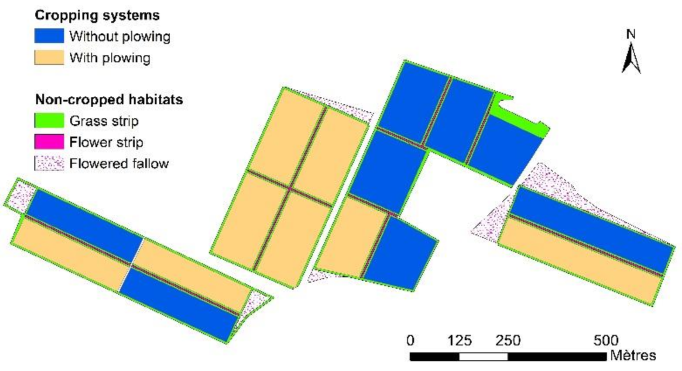
Osmoy Site,
In polyculture-livestock context
Total area: 53,6 ha
Average area of a plot: 2,3 ha



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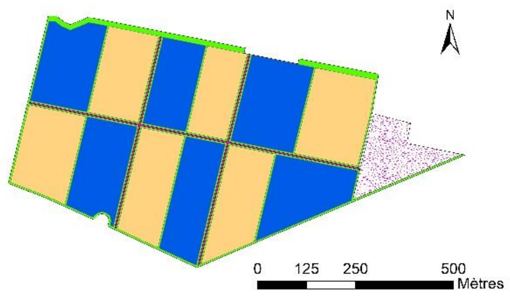
Avord Site,
in arable crops context, without livestock
Total area: 44,9 ha
Average area of a plot: 3 ha



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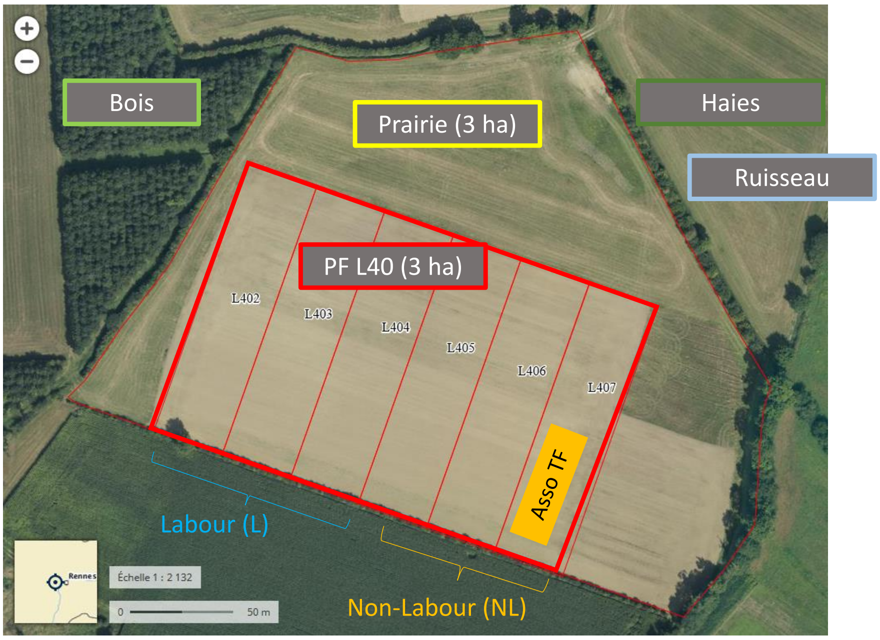
BiodiverSystem platform (INRA Rennes)

The Experimental Unit of La Motte (50 hectares) supports research on genetics and quality of rape seed, genetic factors and plant resistance to diseases, sustainable management of plant resistance to diseases and plant / plant cover crop and soil / systems epidemiology. The BiodiverSystem platform set up in autumn 2018, for a period of 6 years minimum. It evaluates new agro-ecological, multi-performant and sustainable cropping systems reducing the reliance on plant protection products (between 75% and 100% reduction), by optimizing the services offered by wild and cultivated biodiversity in and around plots. The platform allows to quantify the level of biological control possible for different pests in each of the systems tested, and to test, in large plots, many levers usually tested in microplots, to highlight those that can synergistically manage pools of pests, to see if there are synergies / antagonisms between these levers usually tested separately. Two cropping systems has tested, **a plowing-based and a no-plow systems**, replicated on 3 fields of 0.5ha each (i.e. 6 plots, 3 terms of the rotation present each year). The crop rotation includes Triticale-faba bean/cauliflower-chinese cabbage+broccoli/wheat/potatoes/wheat-pea/maize. **The diversification in time and space at the plot level** is characterized by a rotation with spring, summer and winter crops; 6 years, 8 species, 4 families; 2 legume species (faba bean and pea) intercropped with cereals (2/6 of crops with legumes and with intercrops); and a non permanent use of multispecific cover crops inclunding legumes. **Strategies at the crop level** is characterized by the use of resistant cultivars, mechanical weeding, push-pull, shift of sowing dates.

Structure de la plateforme L40 et espèces présentes en 2018/19



3.3. *MANAGEMENT FRAMEWORK* / PILOTAGE

The coordination of the project is ensured by three main bodies, the Coordinators, the Governing Council and the Executive Committee.

- The **Coordinators** will represent the project, notably towards the ANR, other academics, private sector stakeholders, and the general public. They will chair the Executive Committee and be responsible for the smooth operation of the project: work plan maintenance, monitoring project progress through the production of milestones and deliverables (See Annex for the list of Milestones and deliverables of the project), risks and consequences for future research.
  As support to the Coordinator, **a Project Manager** will be hired and be responsible for project administration (including planning, preparation and follow-up of the Governing Council, Executive Committee and SAB's meetings), financial administration (monitoring of expenses against budget allocations, consolidation of financial summary sheets, etc.), consolidation of the

annual project reports and control of the annual cost claims according to the contractual requirements, their conformity with the work done, and assistance to individual project partners on specific administrative issues.

- **The Governing Council** (GC) will be the decision-making body of the project. Chaired by the project coordinator, it will be composed of one representative per partner team, each having one vote for decision making. The GC will be responsible for the strategic and political orientation of the Project: overall direction of all activities – research, training and management – and re-orientation whenever necessary, budget revision. It will also be responsible for Intellectual Property management, in close connection with legal services of partner institutions. Meetings of the Governing Council will be held once a year and make decisions upon simple majority with a casting vote for the coordinator representative, in case of equality of votes.
- **The Executive Committee** (ExCom) will be the decision-implementing body of the project. It will be made of the leaders of each WP. The Executive Committee will be in charge of the operational management of all the activities of the Project. The Executive Committee will also be in charge of financial management of WPs. Meetings of the Executive Committee will be held twice a year, and it makes decisions upon simple majority with casting vote for the coordinator in case of equality of votes.

As additional resources, two committees will provide an advisory role to the whole group:

- An **International Scientific Advisory Board** (SAB), composed of 3 external international leading scientists recognized for their expertise, will contribute to monitor and maintain scientific and technological excellence of the project at project mid-term.
- A **Stakeholder Committee**, composed of partners from the economic sector interested in the production and exploitation of leguminous seeds. We have already received support from ***VegePolys, Vitagora, Roquette, AgroNov, VegeNov, Terres Inovia, Dijon Céréales, and AgriObtentions***. This committee will meet twice, at mid-project and at the end of the project, to communicate and discuss actions and results. This committee will contribute to the dissemination of the project results.

3.4. *Institutional strategy* / Strategie des etablissements

SPECIFICS is, in several ways, at the heart of its partner institution's strategic objectives.
SPECIFICS is fully in line with the main objectives of the **French National Institute for Agronomic Research (INRAe)** for the next 10 years. The goal of the Institute is to develop agricultural systems that better meet people's nutritional needs, are efficient and competitive, respect the environment and natural resources, and use land responsibly. By targeting the design of pesticide-free cropping systems we comply with the objective of protecting our environment; by focusing on grain legume crops, we doubly comply on the development of food security and environmental preservation, thanks to the numerous ecosystem services provided by these crops; and finally, by connecting biotechnical research to social and economic impact of these cropping systems on farms, food supply chain and markets, we aim to tackle the efficiency and competitiveness of cropping systems. SPECIFICS will foster the strategic plan of partner institutions. **AgroSupDijon's** strategic plan includes, in Axis 1, the objective of Innovating and training graduates for sustainable agri-food systems at the service of development and the environment, health and taste. Similarly, **AgroCampus Ouest**'s strategic project is to prepare graduates to have a major role to play in building efficient transitions to sustainable agricultural, food, urban and rural models in the face of climate change, energy, food, health and biodiversity conservation issues. Sustainable development

is at the heart of the institution's activities to promote efficient production systems in healthy and productive ecosystems. SPECIFICS namely addresses these goals and will provide insights into Axis 1 of AgroSupDijon, as well as several of the 5 thematic axes of AgroCampus Ouest. In particular, Axis 1) on Plants, animals, systems (Genetics and genomics of biological resources for agriculture, Integrative biology of microbial, agro-ecological management of pests and diseases, multi-criteria evaluation and agro-ecological design of mixed agricultural production systems) but also Axis 4) Food (levers for agri-food innovation) and Axis 5) on Landscapes (Landscape dynamics, landscape projects).

ESA (Ecole Supérieure d'Agricultures) is one of the largest institutes of higher education for life sciences in France (2500 students). ESA offers a wide range of courses in different sectors of activity: farming systems, food systems, landscape management and agribusiness management. The agro-ecological transition is one key strategic and transversal axis of the Institute both for its research and education activities. ESA promotes multidisciplinary and multi-actor research. ESA research aims to create and transfer scientific knowledge that guides agricultural and agri-food decision-making and helps to design sustainable agriculture and food systems. SPECIFICS, through its objective of designing agricultural systems based on agro-ecological strategies, thanks to a multidisciplinary approach, and adapting existing programs of education to favour the agro-ecological transition, is clearly in line with ESA strategy and with that of its research unit LEVA.

The **LEM-IESEG School of Management** develops an Axis of research on the Analysis of the performance of organizations (APO). The research work carried out under the 3.1 task of the Work-package 3 is fully in line with the research themes developed in this axis. Researchers of this axis are specialized either in microeconomics or management and work on diverse fields such as entrepreneurship, productivity measures or establishing business models. They study either private or public institutions, that may already exist or which are about to be created. In this perspective, the micro-economists involved in the SPECIFICS project are interested in the analysis of eco-efficiency of farms and agricultural activities in general, with regard to the three pillars of sustainability (economic, environmental and social performance) to enable transitioning.

4. *EXPECTED OUTCOMES OF THE PROJECT* / IMPACT ET RETOMBEES DU PROJET

New knowledge and resources for breeding of grain legume varieties for pesticide-free cropping systems

SPECIFICS will provide new knowledge and resources for breeding of grain legume varieties (WP1), to be integrated into multi-pest management strategies in pesticide-free cropping systems. Resources will include (i) sources (accessions, mutants) of resistance or other plant traits in pea and faba bean to regulate weeds, aphids or pea leaf weevil without pesticides, characterized for their content in favorable alleles/haplotypes, which will be useful as genitors in breeding programs; (ii) markers fully or closely linked to genomic regions and genes controlling resistance to single or multiple-pests in pea and faba, including aphanomyces and fusarium root rot, ascochyta blight, seed weevil and aphids, to increase efficiency of marker-assisted selection and (iii) breeding lines having integrated resistance alleles to multiple pests, produced by speed-breeding, for further evaluation in pesticide-free conditions. Knowledge will include information about diversity, conservation and multiple effects of genomic regions/genes controlling resistance or regulation of pests, as well as defense pathways and phytochemical compounds associated with plant responses to pests. This information will be useful to optimize strategies of QTL combination in breeding of durable resistant varieties to multiple pests. Additionally, WP1 will provide original basic knowledge in plant science about genes and metabolic pathways underlying quantitative resistance to two pests studied as models in the project, *A. euteiches* and *A. pisum*.

Expected results:

- Databases for the storage and information management of genetic resources (T1.1.1)
- Bioinformatic tool for integrative and translational genomics (T1.2.2)
- Identification of germplasm and loci associated with plant competitiveness-related traits, resistance to aphids or pea leaf weevil in pea and/or faba bean (T1.1.2, T1.1.3, T1.1.4)
- Identification of loss-of-function alleles in pea genes needed for susceptibility to pathogens; Production of lines possessing novel sources of resistance to major fungal pathogens of Pea (T1.2.1)
- Identification of loci and genes controlling resistance to multiple pests in pea and faba bean, as well as genes controlling resistance to seed weevil, aphids or aphanomyces root rot in relation with root architecture in pea and the corresponding loci in closely related legume species (T1.2.2).
- Rapid integration of promising resistance alleles from T1.2.1 and T1.2.2 into breeding programmes by exploiting speed breeding approaches (T1.2.3).
- Identification of genes, metabolic pathways and/or root exudate compounds underlying quantitative resistance to *A. euteiches or A. pisum* in pea and faba bean (T1.3.1, T1.3.2)

All the lines putatively bearing new sources of disease resistance or favourable traits for plant competitiveness against weeds will be of potential interest for plant breeders. They will be informed on a regular basis of the progress made with a view to transfer of material.

New knowledge for a radical change of crop protection and the design of diversified cropping systems with farmers and stakeholders

The results of SPECIFICS will contribute to change radically the present crop protection approaches using curative methods to biodiversity-based strategies aiming to reduce pest and pathogen pressure through more systemic and agro-ecological approaches. In contrast with current initiatives in France aiming to reduce the level of pesticides, SPECIFICS will be the starting point of initiatives aiming to intensify biological regulations. Thanks to strong relations of the consortium with technical institutes (Terres Inovia), the research questions and the results obtained will be continuously shared with them to increase the impacts. Thanks to the strong implication of the consortium in Education; the radical changes expected will be accelerated by preparing future actors of agricultural sectors in this new approach directly with the results of the project (see dissemination strategy). Moreover; the research consortium is strongly involved in the European cluster of H2020 projects on crop diversification and will have a decisive role in the dynamic of research in this area.

Expected results:

- Identification of best combinations of species in time and space to intensify biological regulations of pests, diseases (aerial and aboveground pathogens) and weeds; decision rules to guide the design of pesticide-free diversified systems (T2.1, T2.2, T2.3) including landscape information (T2.4).
- Indicators and models to better predict the intensity of biological regulations at different scales (T2.1, T2.2, T2.3, T2.4, T2.5) and better asses their impacts (T3.1)
- New ideotypes for such diversified systems (T2.1, T2.2, T2.3, T2.4, T2.5)
- Strategies of biocontrol (biostimulation of microbial populations) to increase soil suppressivness to root rot diseases and adaptation of rotations to the functionality of soils (T2.2)
- Sustainability assessments to identify promising cropping systems for several objectives (environmental, economic, social) (T3.1)

A guide for farmers and advisers will be built for the design of pesticide-free systems rich in legumes (decision rules, indicators and advice tables) based on the above scientific results in order to help a wide range of initiatives in different national networks. The performance results will be communicated during visits to the experimental platforms mobilized in the project, which will be seen as places for multi-stakeholder and students exchanges conducive to the agro-ecological transition with all agricultural actors. The results will be included in different tools for students developed in WP4.

Elements to guide public decision-makers

The results (from WP2 and WP3) could give clear arguments on the benefits and risks of crop diversification in cropping systems for a pesticide-free agriculture and help to support different strategies of crop diversification.

Moreover, the results of the project could nourish reflexions in the national food program (and the territorial food projects) by identifying good opportunities and conditions for developing sustainable cropping systems providing plant protein.

At the end of the project, we will give some information for guiding public decision-making.

Expected results:

- Arguments on the benefits and risks of crop diversification from results obtained in innovative pesticide-free cropping systems studied and assessed in WP2 and WP3.
- Win-win strategy between producers and other actors: As a result of T3.2 and T3.3, it will be possible to know whether or not a "win-win" strategy between producers and other actors in society is possible if these new pesticide-free legume-rich cropping systems are adopted. In the case of loss of cost competitiveness, it would be essential to know the order of magnitude of the results expected by society in terms of reducing environmental costs (greenhouse gases, nitrogen surplus, etc.) and social gains (maintaining activity in agricultural areas, landscape management, etc.) in order to bring them closer to the economic costs borne by producers in terms of possible compensation and incentives to adopting these cultural innovations.
- The analysis of agrifood innovation evolution will allow public authorities to assess whether the transition to agroecology starts with the evolution of the agri-food supply, or if the effect of eco-innovations is low compared to the recommended evolution given in reports favouring more legume-based diets (T3.2.1).
- A better understanding of the drivers of the contractual governance and of social mechanisms in a sector could shed light on conditions for favouring support of new forms of organisations (T3.2.2)

Dissemination strategy

The dissemination of work progress and key discoveries made by the project to the **scientific community** will be carried out through:

(i) publications in peer-reviewed international scientific journals in the different disciplinary fields of plant genetics, biocontrol, agronomy socio-economy.

(ii) scientific presentations during international or European conferences, such as the Plant and Animal Genome conference, International Legume Society (ILS) conference, International conference on grain legume genetics and genomics (ICLGG)

(iii) national annual seminars with collaborators or professional partners (Terres Univia/GSP, GIS-BV).

Several project partners are part of scientific committees of international congress (e.g., ICLGG, ILS) or journal editing (e.g. Legume Science), which would facilitate the dissemination of results of the project at the international level for a pesticide-free agriculture.

Dissemination of the scientific results and potential protection of Intellectual Property Rights will be managed with the support of the INRA local Partnership service and national Direction of Partnership and Transfer for Innovation (DPTI), according to the INRA Charter of Intellectual Property and the recommendations of the European IPR Helpdesk.
Dissemination of results to **stakeholders** (breeders, scientists, extension services, food and feed industries) could take place through different ways, including:

(i) The intranet website and collaborative plat-form of the project (WP4), for dissemination in the federative French legume research and extension network.

(ii) Meetings organized by SPECIFICS with stakeholders at mid-project and at the end of the project.

Dissemination of key results will also be done to **regional, national and European policy makers** (French Ministries of Research and Agriculture, European commission), thanks to the strong connections of the project to other projects in which the partners are involved, supported by Europe (e.g. Diverfarming, DiverIMPACTS, DIVERSify, LegValue, ReMIX, TRUE, PROGRAILIVE).

The project activities and highlights will be communicated to an **"informed" public in agriculture** (students in agriculture, farmers…), through:
(i)- presentations to initial or advanced courses and training of master students. Particularly, the partner institutions of the project, AgroSup Dijon, Agrocampus-Ouest, ESA, LEM-IESEG, will enable to communicate results to students. It will also offer opportunities to train students in partner laboratories to plant genetics, pathology, entomology, agronomy, social and economy sciences, in relation to the project. The action will be integrated into the training plans of the project, which will organise courses available via an online course website.
(ii)- articles and notes in national and regional agricultural magazines addressed to farmers and technical advisors (Perspectives Agricoles, Semences et progrès, UNILET-Info…).
Notably, the results will be transferred to the French plan "Enseigner à produire autrement" to allow the evolution of curricula of masters and technical training courses including adapted pedagogy for the transition to pesticide-free agriculture.

The project activities will also be communicated to the **general public**, through internet website of the project, external newsletters, annual specific open-access seminars, interviews in the local press or presentations at open days or annual scientific events (for example: Fête la Science, Salon International de l'Agriculture, Fascination Plant days (EPSO), research career presentation in agricultural schools).

Project outcomes will be delivered according to the following planning of WorkPackages, Milestones and Deliverables

	6	12	18	24	30	36	42	48	54	60	66	72
Workpackage 1												
T1.1.1						M1.1		D1.1a				D1.1b
T1.1.2		M1.2		M1.3			D1.2	D1.3				
T1.1.3		M1.4					M1.5		D1.4			
T1.1.4						M1.6		M1.7				D1.5
T1.2.1				M1.8	M1.9	D1.6						
T1.2.2							D1.7	D1.8-D1.9				D1.10
T1.2.3			M1.10			D1.11a						D1.11b
T1.3.1							D1.12					D1.13
T1.3.2				M1.11				D1.14				
Workpackage 2												
T2.1			M2.1							D2.1		
T2.2		M2.2				D2.3, D2.4		D2.5		D2.2		
T2.3.1		M2.3, M2.4				D2.6				M2.5	M2.6 D2.8	D2.7
T2.3.2				M2.7, M2.8							D2.9 M2.9	
T2.4.1		M2.10								D2.11		
T2.4.2										D2.12		
T2.4.3												D2.13, D2.14
T2.5		D2.15		M2.12	M2.13			M2.14 D2.16				D2.17
Workpackage 3												
T3.1.1		D3.1		M3.1	M3.2, D3.2	D3.3	M3.3		D3.4			M3.4, D3.5
T3.1.2			M3.5		D3.6	D3.7	M3.6	D3.8	M3.7	M3.8	M3.9, D3.9	D3.10
T3.2.1	M3.10	M3.11	D3.11, M3.12									
T3.2.2				M3.13			D.3.12					
T3.3		D3.13			M3.14			M3.15				D3.14
Workpackage 4												
T4.1	D4.1	D4.2; D4.3		D4.2-D.4.4		D4.2, D4.3 D4.5		D4.2; D4.3		D4.2; D4.3		D4.2,4.4,4.6
T4.2	D4.7											
T4.3		D4.8		D4.9		D4.10		D4.11		D4.12		D4.13

5. *FUNDING JUSTIFICATION* / JUSTIFICATION DES MOYENS DEMANDES

The total budget of the SPECIFICS project is 17 543 945 € including 2 999 565 € of requested funding. The project mobilizes 1945 person months. The distribution of the requested budget among WP is 37% for WP1, 31% for WP2, 18% for WP3, and 14% for WP4. The major item of the requested budget is Staff (ca. 1.67 M€), with 674 person.months hired throughout the project, representing 35% of total human investment. This human support includes 6 PhD students and 21 Master or DUT students. The second item is Other Expenses (0.65 M€), including experimental glasshouse, field and laboratory costs. The third item is for travels (ca. 0.191 M€), the fourth item is for subcontracting (ca. 0.165 M€). The smallest item is Equipment (ca. 16 k€) which reflects the good capacity of existing facilities of partners. Management fees represent 0.24 M€. A summary of requested budget allocation among partners and items is given in the Table below. Detailed budget for each partner is described in the financial annex of the project.

Partner	Equipment	Staff (months)	Subcontracting	Travels	Expenses for inward billing	Other expenses
1	▪ Tissue Lyser **8 000 €**	▪Project manager: 72 ▪Engineer: 54 ▪Technician: 59 ▪PhD and students: 180 **922 881 €**	▪Expertise from Terres Inovia ▪Chemical analyses ▪Tomography **52 000 €**	▪International conferences ▪Annual meetings ▪Trial visits **94 000 €**	▪Data storage **35 000 €**	▪Field trials ▪Greenhouses ▪Consumables **486 500 €**
2	▪ Image Analysis System **8 000 €**	▪Engineer : 17 ▪Technician: 20 ▪PhD and students: 108 **322 285 €**	▪Field rental ▪Analyses ▪Image analysis **55 520 €**	▪International conferences ▪Annual meetings ▪Trial visits, Training **58 500 €**	▪Omics platforms **60 000 €**	▪Greenhouse ▪Consumables **92 000 €**
3	X	▪Postdoc : 6 **23 523 €**	▪Publication **2 700 €**	▪Project meetings ▪Conferences **5 000 €**	X	▪Consumables ▪Maintenance **38 000 €**
4	X	X	▪Chemical analyses **24 400 €**	▪Project meetings **600 €**	X	▪Consumables **20 000 €**
5	X	▪Data manager: 6 **20 153 €**	X	▪Project meeting ▪Conferences **3 000 €**	X	▪Data storage **2 000 €**
6	X	▪Post-doc: 12 ▪Student : 12 ▪Technician: 1 **70 930 €**	▪Field experiments ▪Chemical analyses **11 000 €**	▪Project meetings ▪Conferences **5 000 €**	X	▪Informatics ▪Publication **3 000 €**
7	X	▪Engineer: 36 ▪PhD and student : 24 **168 990 €**	▪Database ▪Meeting organization ▪Editing **17 500 €**	▪Project meetings ▪Conferences ▪Surveys **11 000 €**	X	▪Informatics **3 000 €**
8	X	▪Engineer: 12 ▪PhD and student : 42 **142 800 €**	▪Expertise **2 500 €**	▪Project meetings ▪Conferences **11 000 €**	X	▪Informatics ▪Software **4 500 €**

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7. *LINKED PROJECTS* / PROJETS LIÉS

SPECIFICS will build on numerous past and present projects, in which one or several participants of the consortium of SPECIFICS is involved. We will cite here the main projects connected projects:

PIA PeaMUST is an 8-year French national project (2012-2020) financed under the Biotechnology-Bioresources call of the Investments for the future initiative. Gathering 28 public and private partners* from the pea industry, it aims at developing new varieties of peas and optimizing their symbiotic interactions to stabilize the yield and quality of pea seeds in the current context of climate change and reduction of inputs use. Benefiting from a multidisciplinary approach and high-throughput genotyping and phenotyping tools, it aims at finding solutions against multiple stresses and irregular yield and quality affecting pea crops. PeaMUST strategies included gene cloning, synteny with fababean, genomic selection and plant architecture traits interactions with stress resistance to develop innovative advanced pea and fababean lines. With over 7000 pea lines and 600 faba bean lines generated a/o used in the project, several millions of SNP markers identified on germplasm collections and a wide range of innovative technologies (x-ray tomography, Virus Induced Gene Silencing technique …), PeaMUST has been a major research project targeting pea multi-stress resistance.

The crop diversification cluster brings together research projects which operate in countries across Europe to increase the impact of crop diversification research. The cluster encourages sustained uptake of diversification measures by European farmers and through innovations across the agri-value chain. The projects in the cluster - Diverfarming, DiverIMPACTS, DIVERSify, LegValue, ReMIX and TRUE received funding from the EU Horizon 2020 research and innovation programme and started in 2017 for 4 or 5 years.
Projects within the cluster are collaborating to increase the impact of crop diversification research and encourage sustained uptake of diversification measures by farmers in Europe through innovations across the agri-value chain.

The diversification of crops through rotation, multiple cropping and species mixtures can allow farming systems to become more resource-efficient with fewer agronomic inputs. Diversified systems can help meet the needs of end users for food, feed and industrial products and simultaneously deliver other ecosystem services and public goods.
The cluster projects are working together to demonstrate the benefits of crop diversification to farmers and society, and to engage with stakeholders in the upstream and downstream value chains, by transferring knowledge in:

- Barriers to crop diversification and their solutions
- Innovative cropping methods, decision tools and new resources for crop diversification
- New end user focused approaches and field demonstrations across pedo-climatic regions of Europe to share innovations and crop diversification experiences
- Multi-criteria assessment of system performance at field, farm, value chain and landscape levels
- Policy recommendations to facilitate uptake of crop diversification
- Communicating joint activities in the cluster

Diversify and Remix are focused on species mixtures; LegValue and True study the insertion of grain legumes in agrifood systems; DiverIMPACTS and Diverfarming study different strategies of crop diversification in time and space and the innovations needed at different scales from farm to value-chains.
LegValue (H2020 n°727672, coordinated by F. Muel, Terres Inovia, 2017-2021) assesses both the economic and environmental benefits for the EU agro industry of widely producing and using legumes in a sustainable manner. Reflecting the market diversity, LegValue will demonstrate the added value of various existing legume value chains and will provide a range of alternative solutions that would improve the economic situation of each actor involved in the various chains described. LegValue will contribute to increase the autonomy of the EU regarding the production of legume proteins for both feed and food. The project is composed of WP1 – On-farm assessment of innovative legume crop management practices and ecosystem services: from field to European scales; WP2 – Development of legume value chains; WP3 – Economic analysis of European legume markets; WP4 – Identification of levers for EU and national policies to facilitate the development of legumes in Europe ; WP5 – Transition path analysis.

CASDAR RAID. Bringing together a research institute (UMR Agroécologie), a technical institute (ARVALIS) and a seed company (Jouffray-Drillaud), the Casdar RAID project (2018-2021) aims to: (1) better understand crop competitive ability, (2) evaluate crop performance in cropping systems in terms of weed control and impacts on agricultural production and biodiversity and (3) prospectively, identify the 'ideal characteristics' of crops/cover crops (ideotypes) favoring weed regulation. RAID focuses on a cash crop (pea) and cover crop species. It combines experiments under controlled conditions, in the field and virtual experiments carried out with the FLORSYS model that simulates the effects of cropping systems on weed dynamics and crop yield. This project should provide grids of advice to guide farmers in the choice of species/varieties to be sown to promote the regulation of weeds. It should also guide breeders on the criteria to be measured to select on crop ability to compete for resources.

PSDR-4 ProSys (2016-2020, Coord. C. Lecomte, M Ubertosi, https://www6.inra.fr/psdr-bourgogne/Le-projet-ProSys/Presentation**).**

The PSDR project is supported both by INRA and French regions for the 2016-2020 period, and aims to encourage common construction of knowledge between scientists and agricultural and civil society professionals. It questions ways to transmit knowledge and adopt innovations, especially with farmers. In Bourgogne-Franche-Comté, ProSys-PSDR intends to promote cropping systems based on legume crops, to increase nitrogen supply to crops while reducing mineral nitrogen and pesticides incomes. Task 1 estimates the potential of production and impact of limiting factors for legume crops in the Bourgogne-Franche-Comté region. Task 2 studies the interest of 10 different legume crops as previous crop for enhancing the nitrogen nutrition and quality of the following crop and for limiting negative environmental impacts of the cropping system. Task 3 identifies innovative cropping systems producing proteins tested by farmers and characterized agronomically, economically, and environmentally. Task 4 analyzes the manner in which farmers change their practices, identify favouring or hindering factors, to build with them acceptable paths of evolution towards protein producing cropping systems.

ANR P-Aphid (2019-2022, Coord. A. Sugio)
The P-Aphid project takes advantage of well-developed pea aphid (*Acyrthosiphon pisum*) system to study plant-aphid interactions at a molecular level. P-Aphid will examine *A. pisum* biotypes and host legume interactions to identify and characterize the compatibility and incompatibility factors in both aphids and plants and examine the plant signaling pathways involved in the interactions. Based on the acquired data, the project will first conduct genome wide association study (GWAS) and identify the loci involved in plant resistance or susceptibility. It will then select accessions with extreme resistance/susceptible phenotypes and conduct metabolomics and transcriptomics to identify the signaling pathways involved in the plant interactions with aphids. Finally, *P. sativum* TILLING mutants will be screened to find the mutants of key resistance pathways, effector targets and resistance genes. The project will provide valuable data and materials useful for both fundamental and applied researches and create the knowledge that can contribute to select or create aphid resistant crops.

FEADER-Region PROGRAILIVE(2016-2020, Coord. Végépolys)
The PROGRAILIVE project has been built based on farmers' request, to address the overall issue of securing and increasing the production of grain legumes for animal breeding in the west of France (Brittany and Pays de la Loire). It gathers economical actors, professional agricultural organizations, research teams, agricultural schools and universities from western France. It especially focus on cereal-leguminous mixed crops. Three grain legumes are studied, pea, lupine and faba bean, to increase the protein self-sufficiency for farmers. Research workpackages of the project aim to select the best practices to increase the production of leguminous, evaluate the best solutions to produce grain legumes, by analyzing field trials on experimental farms and in agriculture schools, diagnose diseases and pest on grain legumes and study methods of pest management, optimise lupine production by weed control using mixed crops and study the populations of grain legume pests and insect auxiliary to identify agro-ecological methods of control.

EC-H2020-SFS GenRes Bridge (2019 – 2021, No. 817580, Coord: M. Bozzano European Forest Institute).
Genetic resources (GenRes) underpin production in agriculture and forestry; they are essential for long-term food security, delivery of non-food products and adaptation to changing climate. Still, their potential remains largely unharnessed. Collaboration among GenRes and wider biodiversity actors

will widen capacities and increase the effectiveness of sustainable management of GenRes through an integrated GenRes strategy, tools and user-oriented services and policy recommendations.
Website: http://www.genresbridge.eu/

D2KAB - Data to Knowledge in Agronomy and Biodiversity, (2019-2023, Coord: C. Jonquet University of Montpellier & CNRS - LIRMM)
D2KAB's primary objective is to create a framework to turn agronomy and biodiversity data into knowledge –semantically described, interoperable, actionable, open– and investigate scientific methods and tools to exploit this knowledge for applications in science & agriculture. Agronomy/agriculture and biodiversity (ag & biodiv) face several major societal, economical, and environmental challenges, a semantic data science approach will help to address. We shall provide the means –ontologies and linked open data– for ag & biodiv to embrace the semantic Web to produce and exploit FAIR data. To do so, we will develop new original methods and algorithms in the following areas: data integration, text mining, semantic annotation, ontology alignment and linked data exploitation. (Website: www.d2kab.org;)

Plant2Pro SyntenyViewer (2018-2020, Jérôme Salse INRA - GDEC)
The aim of the SyntenyViewer project is to develop and make available to the scientific community a translational research tool allowing the transfer of fundamental knowledge in genomics and genetics from model plants to the applied field of improving species of agronomic interest.

ABC: Agroécologie en Bourgogne et région Centre. (Ecophyto DEPHY EXPE II, 2018-2023, coordinator: V. Deytieux)
The ABC project aims to co-design, implement and evaluate five agro-ecological systems, defined as mosaics of cropping systems implementing the principles of agroecology and agro-ecological infrastructures managed over several hectares (~30-40ha) so that biological processes can be enhanced at different spatial and temporal scales, including the landscape. The project brings together two experimental sites, in the Dijon plain (**CA-SYS Platform https://www6.inra.fr/plateforme-casys_eng/**) and in the Berry (ABY Platform), in medium to deep clay-limestone soils with good potential. All cropping system are highly diversified at the temporal (crop succession) and spatial (crop and cultivar association) scale. A set a common measurements has been defined at the the project kick off. An initial state has been implemented to characterize the main components of the agroecosystem (soil, biotic pressures, biodiversity). Particular attention is paid to assessing the transition of these components of the agroecosystem underlying the effect of agro-ecological systems. The project aims to produce scientific and technical knowledge on agro-ecological systems and their performance as well as on the biological regulation processes that are set up at the field and supra-field scale. The project will also contribute to the development of methods for assessing agro-ecological systems at the supra-field scale, integrating in particular the benefits and costs associated to the implementation of semi-natural habitats. The project aims to support a territorial dynamic of in situ testing of agro-ecological systems by involving the agricultural community in the design and monitoring of experiments.

CASDAR RésiLens (2019-2021, Coord. N. Tayeh, 7 private and public partners: ANILS, GEVES, AO, UMR Agroécologie, CBGP, URGI, EPGV) is a French research project funded by CASDAR. It aims at providing pre-breeding tools to improve lentil response to root rot and bruchid seed damage. It comprises 4 workpackages with the first being dedicated for the development and characterization of a genetic resource collection and the last for the scientific dissemination and management. The two other workpackages each focuses on one of the targeted biotic stresses. The information on bruchid resistance and root architecture obtained on the panel of 300 diverse lentil accessions will be useful for the comparative genomics for these traits that is planned in T1.2.2.

H2020 ProFaba (2019-2022, Coord. S. Uggerhøj Andersen, 11 partners from 7 countries: Denmark, Finland, Germany, Spain, France, England and Ireland) is a European Suscrop ERA-NET project addressing challenges facing faba bean production in Europe. It includes 6 workpages that are dedicated respectively for: genetic resource collection management, phenotyping trial management, phenological simulation for climate change adaptation, data curation and analysis, loci and gene identification, and dissemination and communication. Bruchid resistance is one of the key questions in this project: phenotypic data will be collected from different environments and genome-wide association analyses are planned to identify key loci. Bruchid resistance data on faba bean produced in ProFaba, together with those from PeaMUST, will be feeding the comparative genomics section in T1.2.2.

ISITE Agroécologie en BFC (2017-2020, Coord. N. Munier-Jolain, UMR Agroécologie, AgrOnov et Dijon Céréales) : The general objective of the project is to produce a multidisciplinary set of knowledge about agroecology, which should foster evolutions of the whole agro-food sector in BFC so as to improve the sustainability, i.e. to enhance the economic vitality of the sector, based on agricultural products with high intrinsic qualities, while decreasing the negative impacts on the environment and safeguarding the health of persons. The knowledge produced might be classified into three main fields: multi-sector performances of agroecological systems (network of 17 sites across BFC), biological and ecological processes and the social and economic issues at the level of the whole agro-food sector.

APPENDIX / ANNEXE

See Joint Appendix file