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Increasing species richness and genetic diversity in agriculture: results of the Wheatamix project

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1. EXECUTIVE SUMMARY OF THE PROPOSAL

In the 20th century, agriculture has experienced major gains in productivity via homogenization and intensive input use, two key components of the dominant model of agriculture in developed countries. This model is jeopardized with the awareness of rapid global change, increased environmental stochasticity and the need for greater sustainability of agriculture. A new paradigm is emerging, in which biodiversity and the mechanisms underlying its dynamics are considered assets for a sustainable agriculture relying more on ecological functions within agroecosystems. Crop genetic diversity should play an essential role in this context, as a key element contributing to agriculture multi-functionality and to the resilience of agroecosystems under rapid climatic change and decreased chemical inputs. However, the use of genetic diversity within agroecosystems faces ecological, socio-economic, organizational and regulatory challenges.

The main goal of the project is to better evaluate the possible roles of within-crop genetic diversity to reinforce the multi-functionality and resilience of cropping systems under global change. WHEATAMIX focuses on wheat in the Paris production basin, both a central crop and a major component of human nutrition. WHEATAMIX develops a highly multidisciplinary approach involving geneticists, agronomists, ecophysiologicals, ecologists, economists, and management scientists, as well as key stakeholders (“Chambres d’Agriculture”, farmers). It is structured in four complementary work-packages:

- WP1 will characterise key morphological/ecophysiological traits and genetics of wheat varieties, as well as their plasticity under intra- and inter-variety competition. We will examine the plastic response of these traits to plant-plant interactions and test how traits complementarity affects the performance of varieties in blends through experiments and modelling.
- WP2 will quantify multiple ecosystem services provided by variety diversity within wheat fields: yield (including grain quality) and its stability, regulation of foliar diseases, insect pest and weed biocontrol, maintenance of soil fertility, along with biodiversity conservation. We will analyse trade-offs and synergies among ecosystem services, as well as links between particular baskets of services and bundles of traits.
- WP3 will study the techno-economic interest of blends and associated baskets of services for -and their acceptability by- key stakeholders. We will explore the organisational and economic bases of blend choice by the wheat chain (from seed companies to millers), with a focus on the Paris basin. Existing lock-in to the use of within-field diversity will be analysed.

These 3 WPs will use common, complementary experimental approaches: i) individual plant phenotyping to characterize traits and their plasticity for 50 wheat varieties; ii) a main diversity experiment (65 100m² wheat plots with 1, 2, 4 or 8 varieties, under low input) to quantify variety diversity effect on ecosystem services; iii) replicates of the same diversity experiment in 5 sites across France using smaller (7m²) plots, under low and high input, to test the robustness of wheat diversity under a wide range of environmental conditions; iv) a network of 50 farms, encompassing agro-climatic variability in the Paris basin, to compare the ecological and techno-economic performance of blends with that of monocultures, in direct link with key stakeholders.

- WP4 will combine results from WP1-3 (agro-ecological and techno-economic benefits of blends, associated organisational changes) and mobilize key stakeholders to build scenarios of the development of wheat variety blends in the Paris Basin considering various future climatic and economic contexts. Opportunities offered by and impacts of the introduction of wheat variety blends in the Paris production basin will be assessed on the basis of these scenarios. A strategy for the dissemination of project results will also be implemented.

2. CONTEXT, POSITION AND OBJECTIVES OF THE PROPOSAL

Over the last 50 years, **homogenization** has been the dominant paradigm of agriculture in industrialized countries, both within fields (systematic inputs to buffer environmental variations, use of a single, genetically homogeneous crop variety in each field), at landscape scale (consolidation) or country scale (specialization). This model is jeopardized with the awareness of rapid **global change and the need for a more sustainable agriculture** that are becoming challenging issues for agricultural managers and agronomic sciences. This is particularly true in a perspective of reduced fertilizer and pesticide inputs¹. **Crop genetic diversity** may provide essential **ecological services** in low-input agricultural systems^{2,3}, including adaptability to agro-environmental changes, yield stability against environmental stochasticity, and improved resistance to pests

and pathogens. These perspectives, largely based on ecological studies, remain to be tested for agroecosystems and key crop production sectors. Our project is interdisciplinary and combines fundamental and action research to **analyse the ecological, social and economic mechanisms that have to be accounted for when assessing the opportunities offered by and impacts of a better use of agrobiodiversity in agriculture** in a context of **global change**. To this end, we will develop a comprehensive analysis of the agro-ecological and socio-economic effects of **increasing within-field diversity of wheat crop through the use of variety blends** (cultivar mixtures), along with scenarios corresponding to plausible trajectories for the use of variety blends over the next decades, in a major wheat producing area, i.e. the Paris basin (>50% of French wheat production).

2.1. OBJECTIVES, ORIGINALITY AND NOVELTY OF THE PROJECT

The overall objective of this project is to study the agro-ecological benefits of an innovation (use of variety blends within wheat fields) in the context of a multifunctional agriculture under global change, and to analyse the opportunities and challenges of this innovation for the economy, organisation and regulation of the wheat sector. To achieve this goal, we will address the following questions:

- What is the range of **wheat variety traits and their plasticity in blends** (i.e. potential range of functional diversity offered by the use of variety blends)?
- Can we combine traits within variety blends to increase complementarity in terms of resource use?
- To what extent **can intra-field diversity foster the delivery of multiple ecosystem services** under a range of environmental conditions and address the need for more sustainable agriculture?
- **Can we design blends on the basis of variety traits** in order to enhance yield and its stability, the delivery of baskets of ecosystem services, and the sustainability of wheat cropping systems?
- What is the **impact (opportunities and challenges) of introduction of variety blends on the organisation and economics of the wheat supply chain**?

Variety blends have long received attention in agricultural sciences. However our proposed research is novel in at least four ways:

First, we will renew the analysis of variety functional diversity and plasticity within blends, taking advantage of (1) **novel trait-based approaches** to quantify variety diversity and its potential effects in the field and (2) novel experimental and modelling approaches in ecophysiology and genetics. Until now, variety blends were mainly studied under a disease resistance perspective, and variety traits involved in other aspects of agroecosystem functioning and services have been ill-studied. This largely impedes blend design in a context of multifunctionality and sustainability of agriculture.

Second, we will develop a **unique study of the mechanisms linking variety diversity to agroecosystem functioning and the delivery of a range of ecosystem (dis)services**. We will promote a close collaboration between teams involved in ecology, microbial ecology, phytopathology and agronomy, to assess 6 services: yield and yield stability (including grain quality), regulation of foliar diseases, biocontrol of pests, biocontrol of weeds, maintenance of soil fertility, and biodiversity conservation. We will use complementary approaches, from a main diversity experiment inspired by up-to-date designs used in ecosystem ecology to analyse and understand plant diversity effects (e.g. in North America^{4,5}, Europe BIODEPTH and Jena biodiversity experiment^{6,7}), to a network of wheat fields (variety blends versus the corresponding pure variety cultures) in Paris basin farms to test the robustness of our findings and their relevance in a real agricultural context. This will be a key step in understanding the relationships between bundles of variety functional traits and baskets of ecosystem services to be delivered.

Third, we will develop a multidisciplinary and multi-actors approach involving both researchers (economists, ecologists, ecophysicists, geneticists, and agronomists) and agricultural stakeholders (farmers, 'Chambres d'Agriculture') to **characterize the opportunities and lock-ins for the management of genetic diversity within agroecosystems**. Thanks to a farm network animated by 6 Chambres d'Agriculture, we will perform an ideotype conception for wheat blends in Paris Basin. The techno-economic benefits of these blends will be tested under different farming strategies including contrasting input levels (fertilizer, pesticide). Exchanges with stakeholders of the wheat sector will help to pinpoint the agro-economic conditions under which blends may provide increased services.

Fourth, we will **develop scenarios of variety blend use in the wheat sector, corresponding to realistic and timely options for the development of blends in the Paris Basin**, linking their ecological and techno-economic interests in a global change (climate and management) context.

Expected results – This project will provide a general overview of the possible impacts of an introduction of wheat blends in the Paris basin on multiple ecosystem-services provided by wheat cultivation, with a specific attention to the stability of production under increased agro-climatic stochasticity. Due to the dominant role of wheat in the Paris basin, the project would have significant implications at the regional scale. The main outcomes of WHEATAMIX will be:

- **Identification of key wheat phenotypic traits** involved in the performance of wheat blends, both through experimental and modelling approaches (WP1 & 2)
- **Quantification of tradeoffs and synergies among services provided by variety blends** and associated bundles of traits, and baskets of services that can be delivered or not in a context of reduced fertilizer and pesticide inputs, increased agrobiodiversity and/or increased weather stochasticity (WP2)
- **Delivery of new breeding methods to select varieties for blends**, and guidelines to efficiently combine varieties, and evaluate blend performance (WP1-4)
- **Delivery of scenarios of variety blend use in the wheat sector and identification of leverages for a beneficial use of variety diversity in the wheat chain in the Paris basin** (WP3 & 4)

Various actors of the wheat chain will benefit from WHEATAMIX:

- Farmers and farm networks, through a better stability of production and quality under reduced inputs (eg. in the context of ‘Plan EcoPhyto’),
- Crop breeders trying to switch to new breeding schemes based on diversity and variety blends,
- The whole wheat sector, which may benefit from a more stable production both in time and space (note that our project will also evaluate constraints due to grain heterogeneity),
- Society as a whole, which may benefit from the ecosystem services provided by blends and subsequent increased sustainability and human health (fewer pesticides and fertilizer, more biodiversity...).

All results will be efficiently disseminated to the actors of the wheat sector, thanks to a tight collaboration with the Chambres d’Agriculture (their advisory services and farmer network), as well as through different meetings and workshops with stakeholders.

2.2. STATE OF THE ART

Intensive agriculture is both responsible for large greenhouse gas emission and is also extremely vulnerable to the subsequent change in climate. Worldwide impacts are expected to eventually reduce yields because of higher temperature, change in rainfall and increased drought and plant pathogen attack risks. Similarly, intensive agriculture is responsible for a decrease in agrobiodiversity at plot and landscape scales, which has negative feedback on some key services for agriculture as pollination or biocontrol of pests⁸. Producing crop varieties that will tolerate future global change remains challenging, because of increased climatic variability and new public policies that call for a lower use of chemical inputs⁹, whose impacts on future yields remain largely unknown. An alternative to be explored is the use of genetically diverse crops, in particular selected variety blends, which may be more resilient (on the short term) and more adaptable (on the long term) to changing environmental conditions and stress¹⁰.

Agroecosystem services and intra-specific genetic diversity – Evolutionary ecologists have long known that genetic diversity controls the ability of populations to adapt to environmental change. Species richness has been shown to be a key factor of ecosystem functioning that tends to increase the mean primary production and decrease variability in this production⁵. However, the ecosystem services provided by intra-specific diversity have only partly been explored, either in natural ecosystems or agro-ecosystems, despite early studies about the role of composite cross populations^{11,12} or blends on yields or disease resistance¹³. Except few studies of the effect of genotype mixtures on insect diversity or soil microorganisms^{14,15}, most studies have addressed production aspects. When surveying the abundant literature on the impact of blends on cereal yield, about 2/3 of blends are over-yielding the mean of parental performances¹⁶, demonstrating generally positive interactions between genotypes within blends. However, most studies analysing the origins of blend performance to better understand complementarity effects are focussing on disease control¹⁷⁻

¹⁹, disregarding other functional issues. Moreover very few studies are analysing genotype interactions in a proper agronomic level, disregard trait plasticity, and generally consider very few traits (often earliness and plant height). Major challenges are thus:

(i) to develop a broader characterisation of phenotypic/functional diversity among varieties, including both above- and below-ground traits, relevant for a range of services to be delivered in a global change context. Indeed, crop genetic diversity is likely to enhance the delivery of numerous ecosystem services, by favouring greater biodiversity² and enhancing interspecific interactions between crop pests and their predators²⁰. Similarly, varieties with different rooting and nutrient uptake patterns (e.g. main forms of N uptaken) and different influences on soil microbiota could allow complementarity effects and enhancement of soil fertility.

(ii) to study the plasticity of variety traits in single variety cultures and blends, using individual-based plant modelling. 3D plant models able to describe feedback loops that exist between resource acquisition (light, nitrogen²¹) and the development of plant organs²² could be major tools to explore trait plasticity according to environmental and management conditions.

From an agro-ecological to an agronomic and socio-economic assessment of the potential of intra-specific genetic diversity – In agro-ecology, a main hypothesis is that genetic diversity within a cultivated species could improve ecosystem functioning, the crop yield and its stability, and possibly other services through complementarity and insurance effects in the same way as species^{7,23–26}. However, to what extent the ecological potential of variety blend use can be jeopardized by technical, social and economic features of the agricultural sector is unclear and challenging.

Either for models²⁷ or for decision support²⁸, the participation of end-users during the step of design has been shown to be efficient for their future use outside the field of research. In the same way, the design of innovative cropping systems, based on a prototyping approach, is based on the mobilization of a collective and distributed knowledge, including the future users themselves²⁹.

In the case of participatory design of decision-aid tools, Cerf et al.²⁸ show the role played by the test of an innovation prototype by its future users. In the case of innovative cropping system design, its assessment is also a necessary step helping to adapt it so that it can reach the objectives targeted. Thus, the production of blends adapted to the needs and motivations of the main stakeholders of the wheat chain must result from a co-designing between geneticists, agronomists/agro-ecologists and end-users. In this context, the use of an ideotyping approach as proposed by Donald³⁰ is very pertinent. It consists in defining a plant model in terms of traits that allow the plant to reach some performance objectives³¹ and in selecting for those traits.

We must underline that, while mixing crop varieties is an old practice, it has so far never been fully assessed using a comprehensive approach crossing ecological, agronomic and socio-economic views.

The economic impact of variety blends has not been analysed in the (agricultural) economic literature. However, these impacts can be related to general economic issues or mechanisms. On the one hand, blend may affect competition and market interaction at different levels of the supply chain. One issue is related to firm strategies and product differentiation. On the seed market, blend can be considered as product bundle and may lead one or several seed companies to have different product lines and discrimination strategy³². On the commodity market, blend could be an opportunity for some grain merchant to adopt a differentiation strategy³³. Another issue is related to the management of the supply chain with this new kind of product. The operational research literature provides a set of interesting model to address issues related to the coordination among actors³⁴ as well as tractability of batches³⁵.

The diffusion of variety blends also raises interesting questions that are related to the economics of innovation. One issue is related to the accumulation of knowledge and the learning of the potential adopter. Many studies have emphasized the risk of lock-in in the agricultural sector: some innovations involving a lower use of inputs may not be adopted by farmers despite their positive impact on both economic and ecological performance of farms³⁶. This situation is partly due to the uncertainty that farmers face when adopting such innovations. This calls for new procedures between science and stakeholders for producing scientific and evidence-based knowledge about the effectiveness of such innovation compared to conventional technologies³⁷.

2.3. POSITION OF THE PROJECT

The forecasted climate changes and the ongoing changes in objectives assigned to agriculture by new public policies⁹ are of such a magnitude that there is a general agreement on the need for a re-evaluation of agricultural practices at the country scale^{38,39} particularly via renewed strategies for agroecology research⁴⁰. More specifically, the issue of increased climatic variability, including increased extreme climatic events, and decreased pesticide and fertilizer inputs, remains relatively unaddressed despite its crucial role for the environmental, agronomic and economic efficiency of farming systems. Both French and European agricultural policies, responding to an increasing concern of society for environmental questions, aim at limiting the negative impact of agriculture on environment and health. The joint action of a reduced use of inputs and an increased weather stochasticity leads to stronger environmental heterogeneity for the crops, both in time and space. There is thus a double need to secure crop production in face of changing climatic conditions and increasing environmental stochasticity, while protecting the environment, which is threatened by agricultural practices⁴¹ and emissions of greenhouse gases. A search for models of sustainable farming is therefore promoted ('Grenelle de l'Environnement'), which could rely on a better use of the ecological features of agroecosystems to ensure an ecologically sustainable functioning of productive ecosystems and a continued renewal of natural resources⁴². Different levers need to be mobilized to develop sustainable farming systems, as improving crop rotation, using inter-cropping cultures, and increasing the diversity of cultivated species^{9,43}. However, main crops such as wheat, maize or oilseed rape are dominant productions that presently structure the agricultural activity⁴³ at the farm and regional level. Considering the increasing world demand for bread wheat in the next years, improving the sustainability of such a key crop is required, and will have strong consequences. Moreover, wheat yield have reached a plateau since two decades in France and other countries, demonstrating how global change (evolutions in cropping practices and climatic change) is already impacting the wheat sector⁴⁴. **Exploring the potential of use of blends with high yield under low environmental predictability and low input is therefore a strategy deserving better attention.**

Therefore wheat within-field genetic diversity, which was greatly decreased by the widespread use of genetically homogeneous inbred lines, could play an essential role in new agro-ecological approaches, as a key element for future agroecosystem adaptation to global change. The presence of genetic diversity within fields is indeed likely to provide crucial ecological services:

(1) The commercial life expectancy of a wheat variety is ca. five years, partly due to breakdown of disease resistance. Combinations of varieties (blends) differing in their resistance to pathogens should increase the effectiveness of crop resistance^{17,45,46}.

(2) Crop varieties that were bred for intensive farming and optimal conditions are unlikely to be adapted to more variable and sub-optimal conditions (climatic variation¹, disease pressures) especially with limited chemical inputs^{13,47,48}. In contrast, crop genetic diversity is expected to stabilize production and favour adaptation to environmental change, which remains to be tested in practice⁴⁹.

(3) Crops are an important part of agroecosystem biomass; the genotypes of such "foundation" species can influence the composition of surrounding communities, trophic networks⁵⁰ and ecosystem functioning⁵¹. More genetic diversity within agroecosystems could therefore improve their ecosystem functioning and services (as pest control⁵², mycorrhizal symbioses⁵³ and soil fertility⁵⁴) and favour input reduction.

(4) Considering the need for innovative and low-input cropping systems, the expected phenotypic plasticity of blends, as well as the ability to customize their composition to fit a given environment, can increase/stabilize wheat yield and therefore contribute to the diffusion of new cropping practices.

Crop genetic diversity can thus be a major asset for a growing number of farmers who try to reduce chemical inputs, but also have to cope with climatic or parasitic risks. However, the shift towards more environmentally-friendly farming is slow, and there is an urgent need for additional research in this direction^{55,56}. The recent evolution of French variety registration rules, with Value for Cultivation and Use (VCU) criteria now considering the performance of varieties under low input conditions, is a first step toward a better use of genetic diversity. However, registration of wheat blends is not presently considered, even if allowed for other species (rapeseed, turfgrass). At the same time, there is a general consensus on the fact that blends are not adapted to present wheat sector, from seed breeders to processing industry. Though, many French farmers are presently using blends in their fields (30 identified in the Paris basin by C.A.

partners), finding a direct interest, despite the absence of advising services and specific grain gathering. Therefore there is a need for an in-depth analysis of strengths and weaknesses associated to blend introduction in wheat sector, in particular its actual potential to enhance the multifunctionality and sustainability of wheat farming, and for interdisciplinary research engaging key stakeholders. This could spur the emergence of models of agrobiodiversity.

Position regarding the AGROBIOSPHERE call – WHEATAMIX aims at assessing how intra-specific diversity can provide ecosystem services, and thus improve agroecosystem adaptation to global change. The project thus falls perfectly within the second theme of the AGROBIOSPHERE call “Stratégies d’adaptation innovantes”.

Regarding the **components of global change** considered, WHEATAMIX will focus on the two main constraints responsible for wheat yield stagnation in France: evolution of cropping practices, with specific attention to reduction in nitrogen and pesticide use, and climate change (weather stochasticity). It will also consider the evolution of public policies and regulations at French and World level (PAC, seed registration rules, Plan EcoPhyto...).

Concerning the **time frame** considered, one aim of the project is to provide timely solutions for the development of a sustainable and productive wheat sector: the time horizon of our study will thus range from present time to the next 30 years. About 5 to 10 years would be necessary to develop robust methods to combine varieties and evaluate blends, adapt seed registration/trading rules, and disseminate blends in French farmland. A horizon covering the next 30 years and considering various future climatic and economic contexts will allow us to consider higher weather stochasticity, and better assess the interest and limit of intra-specific crop diversity, as well as the development of specific blend-breeding programmes.

Regarding **spatial scales**, WHEATAMIX will consider and integrate a range of scales. We will focus on the field level to study the genetic, agronomic, and ecologic processes determining ecosystem (dis)services provision by blends. We will use experimental trials in 5 locations in France and study 50 farm fields in the Paris basin to account for agro-climatic variations and test the robustness of our results. In complement, we will focus on the level of farms and wheat sector in the Paris basin to study the potential of and lock-ins affecting the use of blends.

Consistently with the Agrobiosphere call text, we will develop scenarios for variety blend integration, considering various levels of the wheat chain. How multiple ecosystem services can be better delivered thanks to variety diversity in a context of low input agriculture, and how this can drive individual or local strategies for farmers and other actors of wheat sector (advisory services, processing, grain gathering...) will be a major concern for the project.

Position vis-à-vis other national or international projects – Our project will build on, and has strong connexions with current or recent projects on (1) the conservation and optimal use of genetic diversity (CESAB project ‘NETSEED’, involving I. Goldinger; ANR ‘BREEDWHEAT’, involving B. Andrieu, S. Lemarié and J. Enjalbert; EC-FP7 ‘SOLIBAM’, involving I. Goldringer and S. Lemarié) that focus on crop diversity management, genomics for elite breeding or breeding for organic agriculture, respectively, but do not consider blends; (2) the impact of climate change on agriculture (two INRA-ACCAF-Metaprogram: ‘Climagie’ project involving J. Enjalbert and I. Goldringer and ‘CLIFF’ project, involving S. Saint-Jean, C. Pope and J. Enjalbert), Climagie working on intra- and inter-specific diversity of turfgrass, while CLIFF do not address this question, focussing on evolution of epidemics under climate changes.; (3) the role of plant species diversity in agroecosystems (ANR ‘DISCOVER’ project, involving X. Le Roux and F. Poly) but that did not consider intra-specific diversity; and (4) ecological engineering to enhance agriculture sustainability (ANR ‘AZODURE’ project, involving X. Le Roux and F. Poly) that evaluates the potential of maize inoculation by *Azospirillum*. **The main originality of our project is to gather a range of up-to-date approaches and skills from a range of disciplines to examine how crop diversity can be an asset for a sustainable and multifunctional agriculture adaptable to global change.** In particular, link with BREEDWHEAT project will be made through both modelling approaches and phenotypic and genetic diversity descriptions. As within-field diversity is not studied in BREEDWHEAT, WHEATAMIX research will provide original and complementary results on yield stability and trait plasticity in blends. WHEATAMIX will also have some connections with PHENOME project, as V. Allard is heading the Clermont-Ferrand platform. The different phenotyping efforts planned in the project could benefit from ANR-GUI-AAP-06 – Doc Scientifique 2013

ongoing developments on high-throughput field phenotyping equipments. WHEATAMIX will be tightly linked to the Labex BASC, with 5 teams (EGC, BIOGER, Agronomy, GV, BIOEMCO) participating to its axes 2 & 3: “**Understanding and improving the adaptive capacity of agroecosystems through knowledge of genetics and evolution**” and “**Biodiversity enhancement and management for sustainable social-ecological systems**”. Some connections will be made with EC-FP7 project PROAKIS about advisory services and knowledge systems for agro-ecological transitions in Europe.

3. SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT ORGANISATION

3.1. SCIENTIFIC PROGRAMME AND PROJECT STRUCTURE

To address opportunities for a better management of genetic diversity within agroecosystems through the wheat blends analysis, we need a multidisciplinary and multi-actor approach. We thus structured our project around three workpackages based on cohesive groups of disciplines: in WP1 geneticists and eco-physiologists develop a mechanistic study of plant interactions in blends; in WP2 ecologists, epidemiologists and pathologists study how blends can affect the associated communities (biodiversity and functions); in WP3, agronomists, economists and management scientists analyze how blends development can be hosted by the actors of the wheat chain. WP4 is dedicated to a trans-disciplinary synthesis, strengthening the trans-WP exchanges due to the work based on shared experimental designs. WP0 is dedicated to the management of the project and the critical coordination of work between teams on common experiments. This general organisation is illustrated in Fig. 1.

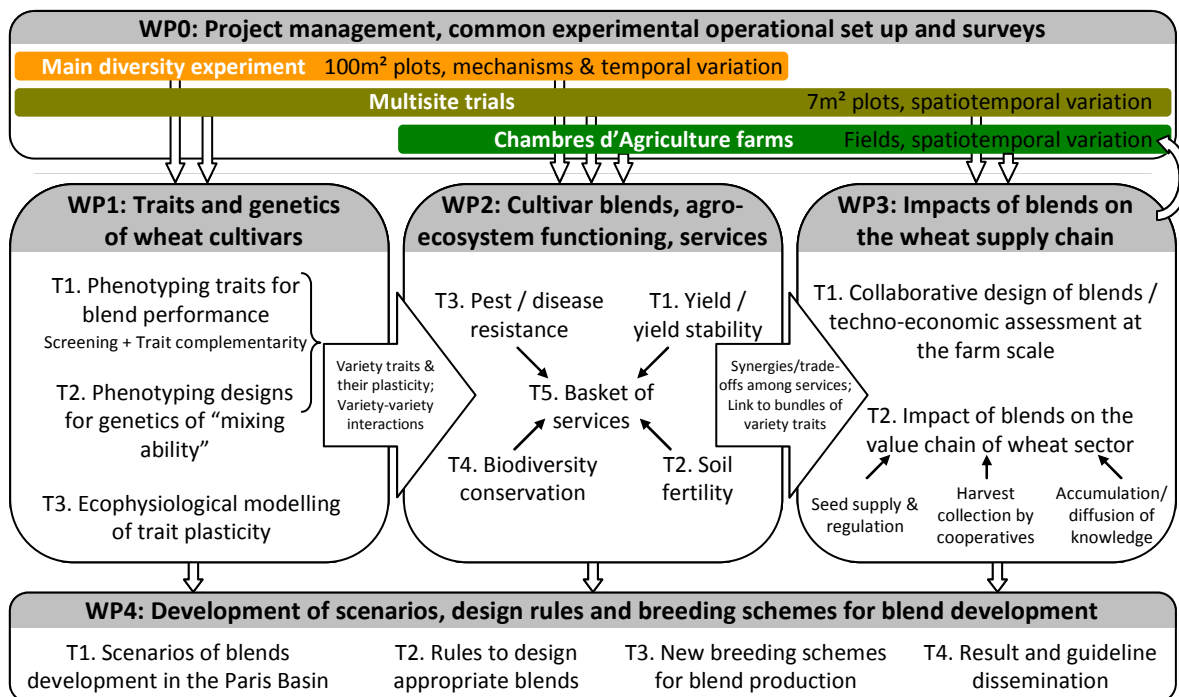


Figure 1: General organisation of the WHEATAMIX project.

Description of the three common experimental designs – Measuring ecosystem (dis)services associated with blends necessitates parallel work of the different teams on shared experiments. Three main designs will concentrate our experimental efforts: 1) one central diversity experiment, 2) a related multi-site experiment, 3) a network of on-farm experiments (Fig. 2).

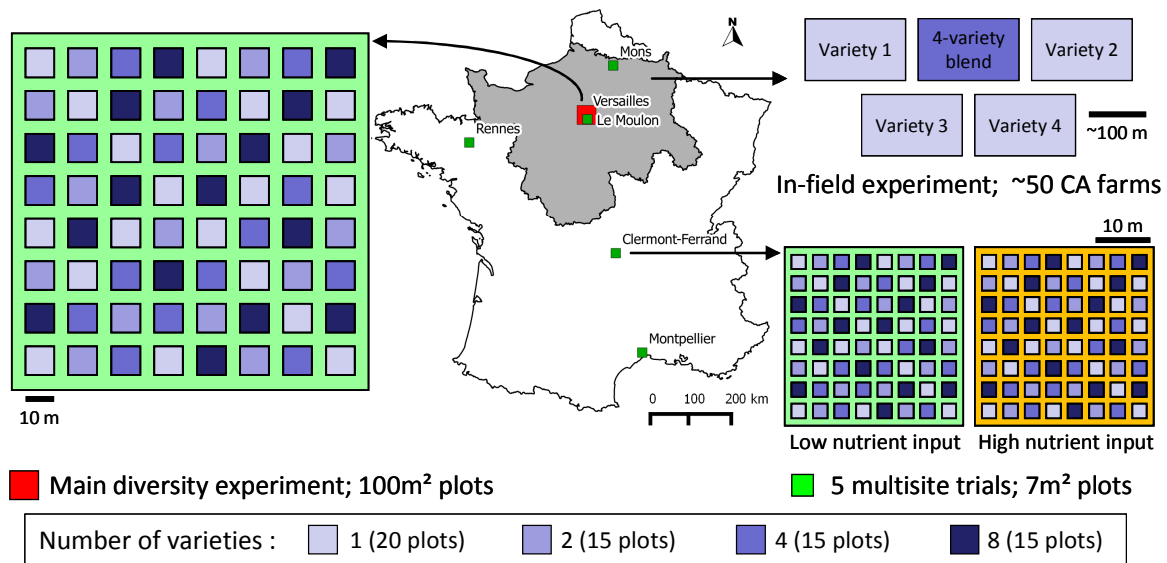


Figure 2: Description of the three common experimental designs. The grey area represents the Paris Basin, in which ca. 50 farms will be selected to evaluate 4-variety blends in the field. In the factorial experiments, plots will be separated by an interstitial crop. Note that in these experiments, only 19 (instead of 20) monocultures were plotted for graphical convenience.

1- Central diversity experiment - This experiment will analyse ecosystem services on large plots presenting contrasted levels of wheat diversity. The experimental area, located in INRA-Versailles experimental domain, will contain 65 large plots (10 x 10 m) sown with wheat at a density of 220 seeds/m². Wheat pure lines and blends of 2, 4 and 8 varieties (equal proportion for the varieties used in a given mixture) will be sown in mid-October of Year 1 & 2. Since variety traits will not be characterized before the end of year 1, blends will be randomly chosen from a pool of 20 varieties to determine blend composition, using a “broken stick” approach to minimize blend similarity at high level of variety diversity. The 20 varieties will be chosen 1) to maximize differences in their selection history, differences in selection targets being likely related to differences in key traits (height, N use,...) 2) to represent the main varieties cultivated in the Paris basin (7 varieties). Because the aim of this experiment is to identify diversity effects and associated causal mechanisms rather than to compare the performance of individual blends according to their composition, 15 replicates for each diversity level (i.e. blends with different compositions) will be used for levels 2, 4 and 8 varieties per plot. In addition, all 20 varieties will be also cultivated as monocultures (20 + 3*15 =65 plots). Furthermore, this experiment will concentrate on the effect of varietal diversity under low input crop management plan: the Nitrogen dose will be calculated using the balance sheet method (Azofert software) taking into account soil N availability for a 70% optimal yield objective. Fertilization will be provided at heading/flowering time. No fungicides/pesticides will be used, and chemical weeding will be done on demand, after scoring weed density per plot.

2- Multisite trials – The previous experimental scheme (65 plots) will be replicated, in year 1 and 2, in 5 locations (INRA centers) across France (Clermont-Ferrand, Mons, Montpellier and Le Moulon), albeit on smaller plots (7m²), to examine contrasted environmental conditions. In each site, the 65 plots will be observed under low and high input, defined according to local cropping system and targeted yields. Note that in year 2, plots will be added to allow the complete observation of all 2-variety-blends (28 plots) based on the most contrasted varieties present in the assay (year 1 result of WP1).

3- Chambres d’Agriculture Farm Network – An on-farm assessment of eco-systemic services linked to the use of wheat blends will be set-up. In year 1, CA will organise the farm network, based on 50 farmers spread out in the Paris basin (6 French departments: 18; 27; 36; 41; 45; 77), and presenting a range of cropping systems, intensification and “terroir” effects. Field trials will be carried out in year 2 and 3, in large plots (c.a. 1ha). In each farm, one 4-variety-mixture chosen by the farmer will be compared to its components in pure stand. CA will manage the techno-economic survey of blend performances as regards to the

corresponding monoculture/cultivar, while additional ecosystem analyses will be performed (see WP2). Blend composition as well as crop management and performances assessment will be defined during an “ideotyping” exercise (WP3.1).

3.2. DESCRIPTION BY TASK

WP 0: PROJECT MANAGEMENT

Task coordinator: Jérôme Enjalbert

Partners: **GV**, Agronomie, BIOGER, BIOEMCO, EGC, LEM, GAEL

Main objectives. Due to the multidisciplinary nature of WHEATAMIX, as well as the challenging experimental schemes deployed, its coordination will require specific attention and skills. WP0 therefore organises the project management in four tasks, in order to manage the necessary dialogue between the different partners, while keeping clear specific objectives, organising collective experimental schemes, and creating exchanges with the stakeholders of the wheat chain.

Task 0.1: Project supervision (J. Enjalbert + WP leaders): The core management of WHEATAMIX will consist, beside the administrative duties, supervision of experiments, and follow-up of progress of each task, in the organising of key events structuring Wheatamix partnership:

- a two-day early kick-off meeting, held right at the start of the project, allowing a first exchange between the different scientific teams and the CA partners. The aim of the meeting will be to fine tune the work plans of each task, as well as visit the Versailles site where the diversity experiment will be implanted,
- meetings at the end of each year, where partners present the progress of each task, with invited experts to provide feedback, and discuss improvements of the work plans.

Task 0.2: Coordination of the operational setup and survey of diversity experiment (S. Saint Jean - C. Pope): One engineer will be recruited (Year 1 and 2) and supervised to set-up the diversity experiment, and then plan, coordinate and participate to the various samplings and scorings performed by technician or scientists on this transversal experiment.

Task 0.3: Coordination of studies based on CA’s collaboration (Farm network). (I. Bonnin & A. Gauffreteau). One engineer will be recruited (Year 1, 2 and 3) and supervised to organize the exchanges with the Chambres d’Agriculture, and coordinate the studies conducted by the Farm network (surveys and data collection). In relation with the task 3.1, this engineer will set-up workshops on blend design (ideotyping) and will contribute to protocol dissemination, evaluation, result analyses of field experiments and reporting to the network.

Task 0.4: Information exchanges and dissemination. (I. Bonnin). Wheatamix will organize one scientific conference on the impact of intra-specific diversity on ecosystem services, three targeted meetings with stakeholders of different parts of the wheat chain (WP4), and a final meeting, broadly open to the public and private actors, where principal conclusions of the project will be debated with stake-holders and policy makers.

The quality of the management will be assessed by the capacity of the different partners to reach jointly the deliverables listed in each task, and to propose new research or development path.

WP 1: WHEAT TRAITS GENETIC VARIABILITY AND PLASTICITY IN RELATION TO NEIGHBOUR PLANTS

Task coordinator: Vincent Allard

Partners: **GDEC**, EGC, GV, LEM

Main objectives. WP1 will characterize functional and architectural traits of individual plants among wheat varieties, along with their plasticity according to intra- or inter-variety competition, and will explore how differences in traits between wheat varieties can produce complementarities for resource acquisition, and possibly better plant performance of the blends. WP1 will thus identify and quantify variety traits relevant for blend performance. To achieve this goal, we will (i) explore wheat genetic variability for key root and leaf architectural traits and functional traits, including their possible plasticity in response to plant-to-plant

interaction, (ii) evaluate the genetic bases of traits involved in mixing ability of varieties grown in mixtures, (iii) explore the role of trait differences and plasticity for potential mutuality effects using modelling approaches, and (iv) develop efficient phenotyping designs for traits of varieties to be used in blends. WP1 results will be used in WP2 to characterize the functional diversity that might explain changes in agroecosystem functioning and service delivery, and will help to propose new breeding schemes (WP4).

Task 1.1: Phenotyping traits of varieties relevant for blend performance [GDEC, EGC, GV, LEM]

T.1.1.1. Phenotypic variability screening

Objectives – Objectives – We will describe the genetic variability of root and aerial characteristics of wheat varieties in isolated/pure stand to (i) characterize variable traits potentially involved in blend performance, (ii) describe the architecture of each line studied, and (iii) classify the screened varieties according to plant architecture (light foraging), rooting depth and N form utilization.

Methods – A selection of 50 wheat genotypes will be screened at the single plant level in the field and in the lab, on years 1 and 2, to identify genetic variability of root and leaf architectural traits and key functional traits. This pool will include the 20 genotypes used in the WP2 diversity experiment and multisite trials (see WP2), as well as the most common elite genotypes used by farmers in Paris Basin (WP2&3).

Root architecture screening will be performed on year 1 on young wheat seedlings. Simple traits such as the number of seminal roots and maximum rooting angle will be measured under lab conditions, as they show a good correlation with wheat architecture at later stage (anthesis), in particular rooting depth^{57,58}. The methodology proposed, as developed by Bengough et al.⁵⁹, will use vertical chambers allowing a reproducible and high throughput screening. An existing facility hosted in CIRAD, Montpellier will be used to minimize development time and cost. This method has recently been used successfully to study the genetic determinism of root architectural traits.

Concerning root functional traits, ¹⁵N labelling will be used to characterize the main N forms used by 30 varieties including the 20 varieties in the blends studied in WP2. Ammonium-nitrate labelled either for ammonium or nitrate will be applied to roots of each variety under controlled conditions to characterize ammonium vs nitrate absorption by roots⁶⁰. We will also measure leaf N concentration, specific leaf area and total matter concentration, along with root specific length, nitrogen concentration and total matter concentration which are traits widely used to assess plant functioning and N economy⁶¹.

Screening of aerial architecture will be performed throughout plant development (emergence to flowering) for wheat individual grown in pure culture in the field so as to characterize the main traits that play a role for competition for light. In year 1 we will (i) use fast phenotyping methods to screen the whole set of genotypes in field conditions. This will involve the use of gap fraction measurements⁶² from which LAI and mean leaf angle will be estimated at several dates along the cycle. This will also involve measuring simple architectural traits at flowering (number of green leaves, plant height, tiller number) and taking silhouette photographs of individual plants. We will also test innovative methods for 3D digitizing: a FARO Photon 120 LIDAR will be rent to the Plateau Xylosciences from INRA-Nancy; a Microsoft Kinect will be tested for indoor measurements using FARO software <http://www.faro.com/scenect/scenect#main>). Based on these results a subset of around 10-20 genotypes representative of the observed variability in plant architecture, will be considered for additional measurements in year 2. Here we will characterize the size of mature leaves, sheath and internodes, the leaf and curvature and azimuth, the tiller number and position. The methodology for these measurements has been established in previous works performed at EGC (3D/Arvalis and ECHAP/MEEDAT), it involves the characterization of organ size by scans⁶³ and stature and leaf insertion from silhouette photographs⁶⁴ and 3D digitizing. For this we can use our 3D digitizer (Polhemus) or if possible more efficient LIDAR/Kinect alternatives. The collected data will be used parameterise organ size and leaf geometry as a function of position along the stem for the studied varieties.

T.1.1.2 Studying trait plasticity and the importance of trait complementarities for resource acquisition in a context of plant-plant interaction

According to trait values characterised for pure varieties, 8 varieties will be selected within the ones used in the diversity experiment (WP2), based on the variability of rooting depth, and contrasted light and N foraging strategies (T.1.1.1). All monocultures (8), all possible 2-variety-blends (28, including the ones

observed within the diversity design) and the blend of 8 varieties (1) will be grown in the field under high and low N supply in 3-4 locations of the multi-site trials. We will (i) measure the same plant traits under variety-variety interactions to evaluate trait plasticity, and (ii) finely analyse the mechanisms through which increased trait variability could allow more efficient light and nitrogen foraging, in particular under low N availability. The implantation of the blends in the multi-site trial will allow in situ characterization of trait plasticity according to environmental conditions, and fine mechanisms allowing complementarity and possibly better plant performance in blends, including grain production per plant. A subset of these 28 blends and the corresponding monocultures will be studied under controlled conditions in order to test more precise ecophysiological hypotheses. In particular wheat blends grown in rhizotrons will allow direct characterization of plant root profiles at adult stage and testing the effect of contrasted root traits on N acquisition.

Task 1.2: Phenotyping designs to study genetics of blend performance
[GV, EGC]

Objectives - We aim to (i) study the impact of functional and architecture traits on the fitness of individuals in a genetically heterogeneous crop, (ii) develop optimal experimental designs to characterize genetic variability for the response in mixed stand and (iii) analyse the genetic bases of traits involved in general and specific response to mixed stands (mixing ability).

Methods - We will compare different designs for large scale phenotyping of genotypes in pure and mixed stands. While a time-consuming approach (all pure + all binary mixtures) is necessary for the identification of key traits and their responses to plant-to-plant interaction, it raises limits for the study of a large set of genotypes such as those used during the breeding process for instance, which will be of major importance for WP4. We are thus investigating alternative blend phenotyping designs: precision sowing of individuals at fixed position with controlled neighbouring, alternate row (pure stand) plots with randomly chosen neighbours and mixed rows plots.

Using previous phenotyping design, we will evaluate in year 1 the set of 30-50 genotypes studied in T1.1., to assess the genetic variability on yield components and simple architectural traits (height, earliness, yield component, as well as LAI measures using EGC methods), in pure and mixed stands. If reliable, the method will be extended in year 2 and 3 to the study of 300 lines from a highly recombining and diverse population (MAGIC population developed by GV in coll. with NIAB). The phenotypic and molecular data produced in previous or on-going GV projects (Arvalis and BREEDWHEAT project) will allow for association mapping of mixing ability traits, as fine genotyping data (9K & 420K SNP array) are or will be shortly available (PhD S. Thepot, BREEDWHEAT project).

Further, Task 1.2 will characterize individual plant performance (biomass and grain yield) in mixed versus pure stands (mixing ability) using the most appropriate experimental design. Following Gallais⁶⁵ we will apply to blends the quantitative genetics concepts and define the general mixing ability (GMA) as the average performance of a genotype in blends including that genotype, and the specific mixing ability (SMA) as the deviation in performance of a blend from that predicted by the GMA of both components. For blends with a larger number of varieties, we will evaluate the relevance of the concept of ecological combining ability⁶⁶ that quantifies the difference in yield of all components when grown in a blend or separately in pure stands⁶⁷. This will allow us to detect which genotypes tend to favour neighbour genotypes within blends while being not significantly penalized (good mixing ability). The genetic bases of mixing ability will be analysed through association mapping as previously described. This approach will be complemented by the overall results obtained in WP1 and WP2 on the structure of correlations among traits, that will allow us to identify groups of genotypes with contrasted values for key traits. These groups, that can be viewed as analogs of the heterotic groups in hybrid breeding, would thus provide a functional basis for SMA

Task 1.3: Ecophysiological modelling of trait plasticity and resource capture [EGC, GV]

Objectives - This task will develop a model of plant-to-plant interaction, using results of T1.1, so as to simulate how the structure of the plants in a blend changes within one growth cycle, depending on the characteristics of blend components. The model will focus on competition and complementarity in resource capture for light and for nitrogen, between plant components, depending on their architectural/functional traits and plasticity, in absence of disease and weeds. It will make use on actions currently undertaken by the EGC partners (founded externally from this project):

- a. A 3D model of C and N economy within a wheat plant that simulates plasticity of plant architecture depending on light and nitrogen availability. This model is being developed in 2013-2014 within the Breedwheat project, extending the NEMA model to the vegetation cycle^{68,69}
- b. A dynamic, 3D model of wheat plant architecture expressing the plasticity in plant geometry for resource capture, extending the Adel-wheat model^{70,71}
- c. A model coupling ADEL based model of plant-to-plant competition for light in blends, with an individual-centred genetic modelling (PhD work co supervised by EGC and GV). This work is integrated in the ongoing ACCAF-Climagie project.

The models (a) and (b) consider a homogeneous crop in which all plants are supposed to perceive a same environment and develop identically, while model (c) considers competition between plants but is restricted to a simple process description (eg. plant plasticity only depends on competition for light).

The present task will incorporate the main results of (a) and (b) in order to improve the individual-based model of plant-to-plant interactions within a blend (c), incorporating N economy and adaptive aspects of plant geometry to neighbouring plants. This work will take place in Year 3 so as to benefit fully of the developments of actions a-c. Model simulation will be assessed through a comparison with the results of the multisite trial in T1.1 (Yield component and N acquisition), as well as individual plant monitoring performed by GV partner (BAP project). The model will then be used for sensitivity analysis in T1.3, focussing on the impact of trait variability on competition outcomes.

Direct links with other WPs: WP1 will determine key variety traits and their plasticity, which will be used in WP2 to compute bundles of traits associated within the trial plots studied (to be linked to ecosystem baskets: T2.5). Traits determined in WP1 will also be used in Tasks T2.1 to T2.4 to better understand the observed relationships between variety diversity and aspects of ecosystem functioning. Results from T1.2, and more generally WP1,2&3, will guide the search for new breeding systems adequate for the design and use of variety blends (WP4).

WP 2: IMPACT OF VARIETY BLENDS ON AGRO-ECOSYSTEM FUNCTIONING AND BASKET OF SERVICES

Task coordinator: Xavier Le Roux

Partners: **LEM**, Agronomie, BIOEMCO, BIOGER, CA, CERSP, EG, EGC, MNHN

Main objectives. WP2 will build on the characterization of the morphological and functional traits associated to wheat variety performed in WP1, with the following main objectives:

- analyse the relationships between the intra-specific wheat diversity used in fields and key agro-ecosystem services and associated key aspects of agro-ecosystem functioning. We will focus on six interconnected services which are likely to be important for variety blends use in a context of low input agriculture: (1) grain yield and quality, including their inter-annual variability, (2) maintenance of soil fertility, (3) regulation of important foliar diseases for wheat, i.e. rusts and septoria leaf blotch, (4) biological pest control, (5) regulation of weeds, and (6) maintenance of biodiversity at the level of wheat fields. This will allow better understanding of the role of wheat variety diversity for service (possibly disservice) delivery at plot to field scale, in particular if low input is used as promoted by recent initiatives, e.g. Plan EcoPhyto. Studying the impact on services at larger scales is not feasible in this project.
- study which services are compatible or not, especially with grain yield and quality, and what are the links between trait syndromes of wheat variety blends and bundles of services accounting for the observed trade-offs and possible synergies among the services. This will help us to evaluate to what extent we can, from an agro-ecology point of view, promote a basket (or a bundle) of biodiversity-based services in low-input wheat crop systems while preserving biodiversity, which will feed the socio-economic analysis of possible use of blends in the wheat sectors and scenarios of blend use in the next decades developed in WPs 3&4.

One challenge for WP2 is to both (i) properly explore the causal mechanisms explaining the relationships observed between wheat variety diversity and a range of ecosystem functions and services, and (ii) test the robustness of these relationships under a range of realistic conditions (climate, soil and high- and low-input agricultural practices in particular). A single field trial or situation can hardly allow us to reach these goals, and we will thus use 3 complementary approaches (Table 2.1):

- A main diversity experiment (INRA Versailles site located in the Parisian basin, see description in WP0) with 65 100m² plots including 1, 2, 4 or 8 varieties will allow analysis during two years of the causal relationships between variety diversity and ecosystem functioning and services.
- Multi-site field trials (5 French experimental sites: Moulon+Mons+Clermont+Rennes+Montpellier) will test the robustness of these relationships and allow analysis of the stability of key services over a range of climate and soil (according to site) and management (low or high input) conditions.
- A farm network in the Parisian basin will allow us to assess the impact of wheat variety diversity on the targeted services (including yield) and farmland biodiversity at the field scale in a range of environmental and realistic agricultural contexts for the production basin analysed in WP3 and 4.


		Ecosystem status & functions	Growth & primary production	Soil N dynamics	Rusts & septoria severity	Aphid load & predation	Weed density	Abundance of taxonomic groups
Capacity to analyse mechanisms		Services delivered	Grain yield & quality + stability	Maintenance of soil fertility	Regulation of plant diseases	Biocontrol of pests	Weed regulation	Maintenance of biodiversity
	Main diversity expe. (low input)	X	X	X	X	X	X	X
	Multisite trials (low & high input)	X	(X)	(X)	(X)	(X)	(X)	(X)
	CA farms (real farm fields)	X	(*)	(*)	(*)	(*)	(*)	(*)
Realism & range of environmental constraints								

Table 2.1: Synthetic view of the complementarity allowed by the 3 experimental and field-trial approaches used in WP2 and type of measurements planned for each. X: measurements of the different variables planned for all plots as presented in the text ; (X): measurements of these variables planned on selected plots and years ; (*): only measurements of proxies of services, no measurements of ecosystem status/functioning.

To build on the complementarity of sites and approaches, the following strategy and time frame are planned: (1) on years 1 & 2, grain yield and quality will be surveyed on all plots of the diversity experiment and multi-site trials (first column of Table 2.1); (2) throughout this period, a wide range of variables will be measured on the main diversity experiment plots to quantify key aspects of agro-ecosystem functioning and to characterize the levels of delivery of 6 services including yield (first line of Table 2.1). Yield data obtained during the first year on the main and multi-site trials will be used to identify the 2 variety blends that appear as the most generalists according to yield mean and variance observed across sites and management conditions, along with the 2 best blends and one blend performing poorly at each site and for each management (5 sites x 2 management, thus a maximum of 32 blends assuming lack of overlap among all the blends identified). The 32 blends will then be studied along with monocultures of the varieties included in these blends (maximum: 20) on year 2 on all multi-site trials to test the robustness (through soil, climate and management conditions) of agroecosystem multifunctionality and of the causal mechanisms underlying the diversity-services relationships identified with the diversity experiment. In addition, on each of the 50 CA farms, one 4-variety blend viewed as a potential good performer and suitable for cropping by farmers, and the 4 corresponding monocultures, will be studied at field scale using proxies of services on years 2 and 3. This will allow testing the robustness of the conclusions raised from the diversity experiment and multi-site trials in real conditions. WP2 is organised in 5 Tasks: the first 4 analyse relationships between variety diversity and ecosystem services, and Task 5 synthesises their results to analyse trade-offs and synergies between services and the dependence of bundles of services to trait syndromes of variety blends.

Task 2.1: Provisioning services: grain yield and quality, and their stability facing environmental variations (GDEC, Agronomie, CA)

Objective and working hypothesis – We aim to evaluate the effect of increased variety diversity within wheat fields on grain yield and quality, which provides information on processing (breadmaking) quality, and the robustness of the observed effect across a range of soil/ climate/ management conditions. We will also assess the inter-annual stability of this effect. Our working hypotheses are that (1) increased variety diversity will increase both grain yield and its stability particularly under low input management due to functional

complementarity among varieties (e.g. for nutrient uptake) and promotion of supporting and regulating services (see below), whereas monocultures of some varieties will perform better than blends under high input; and (2) high variety diversity will result in higher variability of grain quality due to different grain quality among varieties and their responses to environmental conditions from one year to another.

Methods– Grain yield will be measured on all years in the plots of the diversity experiment and the plots of the multi-site trials. Yield will also be recorded on years 2 and 3 on the fields of CA farms. For all plots of the diversity experiment on 2 years, and for the 32 selected blends and corresponding monocultures on the multi-site trials on year 2, plant vegetative dry mass at harvest and grain protein content will be measured.

Task 2.2: Supporting service: maintenance of soil fertility (LEM, BIOEMCO, CERSP)

Objective and working hypothesis – We will analyse the effects of wheat variety diversity on the activity, abundance and diversity of microbial functional groups involved in nutrient cycling and can induce feedback on plant growth and fitness, and ecosystem functioning^{72,73} as well as actual and time-integrated soil ammonium and nitrate concentrations, and plant N status, which provides information on soil fertility status. We will also evaluate the stability of these effects across a range of soil/climate/management conditions and between years. Our working hypotheses are that (1) variety diversity will influence soil fertility e.g. if varieties differ in their preference for N forms (assessed in WP1) and in their influence on key soil microbial groups (mineralizers, nitrifiers and denitrifiers), which ultimately determines the level of forms of mineral N available to wheat plants; and (2) high variety diversity will allow complementarity effects, e.g. through differences in root depth and mineral N preference, leading to higher total N uptake at blend scale.

Methods – For each of the 65 plots of the diversity experiment, soil will be sampled from the 0-20cm layer. Ten 8cm-diameter soil cores will be taken on each plot and pooled. Four sampling dates will be studied in the diversity experiment: early May, early June and harvest time during year 1, and one date for year 2 chosen according to the results obtained during year 1 (i.e. 65 plots x 4 dates over the project = 260 samples). Soil will also be sampled once on the 32 selected blends and the 20 monocultures for each of the multi-local sites on year 2 (5 sites x 52 = 260 plots). This will lead to a total of ca. 520 samples. Fresh soil sub-samples will be used for microbial activity/flux measurements and other sub-samples will be frozen. Resin bags⁷⁴ will be buried at 10cm during two-weeks-periods prior to each sampling campaign to assess the time-integrated soil ammonium and nitrate concentrations. For each fresh soil sub-sample, actual soil moisture and ammonium and nitrate concentrations will be determined. Nitrifying- and denitrifying-enzyme activities will be measured on fresh soil samples for 2 dates on year 1 and once on year 2 (195 samples) for the main experiment, and once on year 2 for the 260 samples from multi-site trials as described by Patra et al.⁷⁵. For 130 samples from the main diversity experiment (i.e. once per year), soil DNA will be extracted. An additional 130 soil samples from the multi-sites trials (year 2 sampling, likely selected only under low input) will be added. The abundance of key microbial groups will be measured by quantitative PCR targeting key genes on the 260 samples: *16S* for the total bacterial community ; *amoA*-AOB and *amoA*-AOA for ammonia oxidizers⁷⁶; and *nirK* and *nirS* for denitrifiers^{77,78}. The genetic diversity of 3 key microbial groups (i.e. 3 genes selected according to activity and abundance data) will be assessed on 65 samples (one date – diversity experiment) through pyrosequencing.

Task 2.3: Regulating services: foliar fungal pathogen regulation, weed regulation, and aphid biocontrol (BIOGER, CA, CERSP, EGC)

Objective – We will quantify the effect of variety diversity on foliar pathogen regulation, weed regulation, and aphid biocontrol, three important regulating services for wheat crops.

Task 2.3a: Foliar fungal pathogen regulation (BIOGER, CA, EGC)

Working hypothesis – We assume that the combination of varieties differing in their resistance to pathogens or the use of varieties with high genetic diversity should increase the effectiveness of resistance to major wheat pathogens in a context of low input of pesticides as promoted, eg. by the Ecophyto2018 plan⁹.

Methods– The variety monocultures and blends will be evaluated for their level of resistance to *Septoriatriitici* blotch (STB) caused by *Mycosphaerella graminicola*, and yellow and brown rusts caused by *Pucciniastriiiformis* and *P. triticina*, which are the most damaging wheat fungal foliar diseases in Europe. Disease severity will be assessed 3 times during the season on 15 plants in monocultures and on 30, 48 and 64 plants in mixtures of 2, 4 and 8 varieties, respectively. Each notation consists of disease area per plant. The experiment will be conducted during the 2 years in Versailles and on one year on selected plots of the ANR-GUI-AAP-06 – Doc Scientifique 2013

multi-site trials. The experimental results analyzed and compared with a model (based on fungal pathogen dispersal within a variety blend, based on the 3D canopies built in WP1⁷⁹). Visual assessments of disease levels will be made by farmers in the common on-farm setup using a unified protocol.

Task 2.3b: Weed regulation (CERSP, CA, Moulon)

Working hypothesis – We expect that a higher diversity of wheat varieties will hamper weed growth, due to a better use of available resources (including soil nutrient as well as space and light), as already demonstrated with species diversity⁸⁰.

Methods– Soil coverage kinetics by wheat will be compared with weed diversity and coverage, which will be assessed twice on year 1 (May-June) in all plots of the diversity experiment and on the multi-site trials using respectively 5 1m² and 5 1/2 m² quadrats per plot¹⁴. If herbicide application is necessary on the plots of a given trial, a measurement will be taken just before application and herbicide input will be recorded. A more qualitative assessment of weed diversity and coverage will also be performed in the CA fields by farmers, with methods used for nation-wide weed monitoring⁸¹.

Task 2.3c: Aphid biocontrol (CERSP, CA)

Working hypothesis – We assume that increased variety diversity will increase both the abundance of prey⁵² (see also task 2.4) and the diversity of habitats (e.g. via contrasting plant architecture⁸²) available to invertebrate predators, thus increasing their abundance and diversity and the effectiveness of biological control on pests like aphids.

Methods– Aphid control will be assessed by placing live aphids on adhesive tape and recording a daily predation (removal) rate⁸³ and by estimating aphid abundance per plot. This will be done twice a year (May and June), during two years, in the 65 plots of the diversity experiment and in the 52 selected plots of the multi-site trials. For predation rate, ten adhesive tapes with 5 live aphids will be placed in each plot and aphid removal will be measured after 24 hours. A similar protocol will be used in CA sites by the farmers themselves, supervised by CERSP. Aphid abundance will be estimated by recording aphid numbers on a random sample of 50 tillers per plot⁸⁴.

Task 2.4: Agro-biodiversity preservation (CERSP, BIOEMCO, CA)

Objective and working hypothesis – We will quantify the effect of variety diversity on above- and below-ground macrofauna. We will focus on taxa that likely provide services but that are also mobile enough to move among experimental treatments and select their preferred habitat: (i) earthworms for belowground soil macrofauna, which contribute to soil aggregation⁸⁵ and dynamics of soil organic matter⁸⁶, and promote plant growth via increased mineralization⁸⁷, and (ii) key aboveground invertebrate communities that live in crops and include important pest predators. Our working hypothesis is that increased variety diversity will increase the total amount or diversity of resources (food sources or habitats) for a range of macroorganisms, thus increasing their diversity⁵².

Methods– Assessment of soil macrofauna (i.e. size>2mm) will be achieved once a year for each of the 65 plots of the diversity experiment, and once on year 2 for the 32 selected plots of the multi-local sites and corresponding varieties grown in monocultures (particular taxa could be targeted for the latter according to results obtained on year 1). We will apply the TSBF method⁸⁸ with 5 replicates per plot, which consists in extracting soil blocks (25x25x30 cm) and sorting out manually macrofauna. Densities of soil macrofauna sorted out in large taxonomic groups and as much as possible to family level will be determined. Earthworms will be identified to species level. Collembola diversity and density will be assessed using five 5cm diameter soil cores pooled for each plot and extraction by the Berlese method. Aboveground invertebrates (ground beetles and spiders) will be collected on the same plots using pitfall traps (3 replicates per plot) according to Chateil et al¹⁴. Earthworm and aboveground invertebrate diversity and abundance will also be conducted yearly in the CA fields by farmers, on a voluntary basis, using the simplified protocols of the “Observatoire Agricole de la Biodiversité” (<http://observatoire-agricole-biodiversite.fr/>) run by CERSP.

Task 2.5: Analysis of trade-offs and synergies between services, and identification of corresponding variety blend trait-syndromes (LEM, BIOEMCO, BIOGER, CERSP, EGC, GV)

Objective and methods – Whereas each of the Tasks 2.1 to 2.4 will analyse the relationships between variety diversity and particular aspects of agro-ecosystem functioning and a particular service, Task 2.5 will promote 3 types of synthetic analyses, using all the data obtained from Tasks 2.1 to 2.4:

- multivariate analysis⁸⁹ will be applied to key variables measured in tasks 2.1 to 2.4 (including variety trait diversity accounting for results of WP1, mean and variance of wheat yield, soil fertility, disease prevalence, aphid levels, weed levels, species composition and diversity of biological communities from micro-organisms to insects, along with soil/climate conditions) to statistically identify the best predictors of crop yield and stability. This will be complemented by GLMs and path analyses⁹⁰ to test for possible direct vs. indirect relationships between variety diversity and associated traits, diversity levels of key taxonomic groups, key aspects of agro-ecosystem functioning, and yield. All these analyses aim at a better understanding the determinants of yield as a key service, viewed as the variable to be explained and its dependency on variety diversity, agrobiodiversity, and supporting and regulating services.
- multivariate analysis of service levels reported on the different plots will be used to identify tradeoffs/synergies between the 6 services (possibly disservices) studied. This aims at identifying possible ‘baskets’ of services, with a particular attention to grain yield and its temporal stability.
- For either the main diversity experiment or multisite plots, we will test the congruency (e.g. with Spearman coefficient) between matrices of variety diversity (or variety trait matrices), matrices of variables characterising agro-ecosystem functioning, and matrices of service levels. We will also identify syndromes of traits at variety blend scale that would relate to particular bundles of services, using the framework proposed by Lavorel et al.⁹¹.

WP2 main outcome is to get a broad view of by which mechanisms variety diversity, through morphological and functional trait diversity, influences yield and its stability at plot/field scale in a land/management change context, and whether the resulting increase in farmland biodiversity is a mere by-product of increased crop diversity or can also favour crop yield via increased regulating and supporting services.

Direct links with other WPs: WP2 will use the determination of variety traits and their plasticity done in WP1 and available at the end of year 2 for data analysis; it will identify baskets of agro-ecosystem services and trade-offs among services/disservices that will be used by WP3 in years 3 & 4.

WP 3: ASSESSING BLEND PERFORMANCE IN FARM FIELDS, AND THEIR IMPACT ON THE WHEAT SUPPLY CHAIN

Task coordinator: Stéphane Lemarié
Partners: GAEL, SADAPT, Agronomie, GV, LEM

Main objectives Even if it has not been widely recognized in the economics literature on agricultural innovation⁹², the success of an innovation depends not only on its impact on productivity but also on whether it is in line with the strategy of various actors of the supply chain.. In some cases, the constraint of the economic system may lead to a lock-in situation that impedes the diffusion of the innovation³⁶. In the case of wheat blends, we have to consider an economic system, from the seed company to the miller, including the advisory services, the farmers, and the warehousing organisations (cooperatives, retailers...). Thus, the aims of WP3 are to (i) promote the collaborative design of blends between scientists and farmers accounting for agroecological blend performances (WP2) and farmers’ knowledge and expectations, (ii) assess the agronomic and economic performance of blends in farmer’s fields, and (iii) analyse the impacts (positive and negative) of variety blends for all the actors of the wheat supply chain, both in terms of economic interest and in terms of knowledge exchange and accumulation for this type of innovation.

WP3 is divided in two complementary tasks. T3.1 focuses on blend performance at farm level. Based on a participatory process, we will define the objective(s) targeted by farmers when they use blends, design blends in accordance with those objectives, and assess them experimentally in a network of 50 farms in the Paris basin (link with WP2). T3.2 will allow assessing the impact (opportunities and drawbacks) of blend use for the other actors of the wheat supply chain in the Paris basin. Based on a survey of a representative sample of actors, we will analyze the economic interest of these actors for blends and the process of knowledge accumulation and diffusion by advisory services.

Two main complementarities between these two tasks should be underlined. First, the needs of the downstream supply chain's actors (e.g. the quality of flour suitable for millers) that are analyzed in the second task will be important to define the type of blends that should be tested in the first task. Second, the participatory approach used in the first task will provide interesting inputs to the second one to better understand the heterogeneity of the demand for blends by different actors and the way blend-related knowledge should be created and circulated.

Task 3.1: Collaborative design of blends, and their techno-economic assessment at the farm scale (Agronomie, SADAPT, GV)

Objectives - This task aims at designing blends adapted to several requirements, and assessing them in farmers' fields, in comparison with pure line varieties. Mixing varieties in a same field is not a common practice in this area. The farmers need some rules to choose the right varieties to be mixed on their farm, which corresponds to particular environmental and socio-economic conditions. An ideotyping approach involving farmers and the main stakeholders who have an impact on the variety farmers' choice (customers, advisors...) will be implemented to design blends for a given context and given objectives.

Methods - In a first step, the farmers and other stakeholders will define a hierarchy of agronomic goals for the blends by clarifying their needs and motivations (environmental, economic, social, political...). This work will rely on individual interviews of the different actors and on collective working groups. A particular attention will be paid to the testimonies of farmers already using wheat blends in their farms.

The second step will consist in proposing strategies for blend design to meet the agronomic/quality goals previously listed. We will convert those strategies into target traits or bundles of traits of the varieties to assemble. This designing work will build up on results from the WP1&2 and will also rely on existing knowledge (scientific, technical, expert) in agronomy, ecophysiology and genetic extracted from literature, but also from interviews with farmers already using blends. Once designed, the blend ideotypes will be built with existing varieties.

Finally, the blends will be assessed in comparison with pure line varieties, in close link with farmers and advisors from CA, in the farm trial network (WP0.3). The field trials will be carried out over a two year period in around 50 farms spread out in the Paris basin, providing results obtained under highly contrasted conditions at a large regional scale. Whereas WP2 will characterize the blend performance as regards to the corresponding monocultures in an agroecological perspective only, WP3 will use a broader range of criteria (agronomic, socio-economic, and ecological). To improve the understanding of the performances observed in the different trials, some indicators will be calculated to quantify the main biotic and abiotic environmental conditions that may have hindered the crop development at each location. The calculation of those indicators will be based on observations and measurements made during the cropping period.

Two rounds (2 years) of design, building and evaluation of blends will occur during the project. The blends designed in the second round will be improved in light of the results obtained during the first round evaluation step.

Task 3.2: Impacts of blends on the value chain of wheat sector (SADAPT, GAEL)

Working hypothesis - The seed choice made by farmers depends on the range of products supplied by the seed companies, the knowledge related to the performance of blends, and the downstream valorisation of the production after the farm gate. Seed blends may also be favoured by particular policies dedicated to ecosystem services (e.g. agri-environmental schemes). The objective of this task is to conduct an integrated analysis of the multiple techno-economic determinants of the seed choices within the wheat supply chain. These determinants cover three main issues:

- The seed supply and seed regulation. A blend can be considered as a bundle of inbred line varieties. Is there an interest for a given seed company to develop and sale such bundles, or should the seed company continue to sell only inbred seed and let the retailers or the farmers make their own blends? If selling blend is interesting for some seed companies, how should seed regulation be adapted to let such a product be sold, knowing that the regulation has a direct effect on the competition between firms?
- The collect by cooperatives. The blends that are collected could be considered as equivalent to some other wheat production (and mixed with them) or, alternatively, they can represent an opportunity to develop new markets downstream. What are the circumstances and the commercial strategy of a given cooperative that

may favor this last alternative (new market)? If some new markets are opened, what is the efficient way to organize the separate collect of these blends? Is cooperation among collectors an interesting way to improve this efficiency?

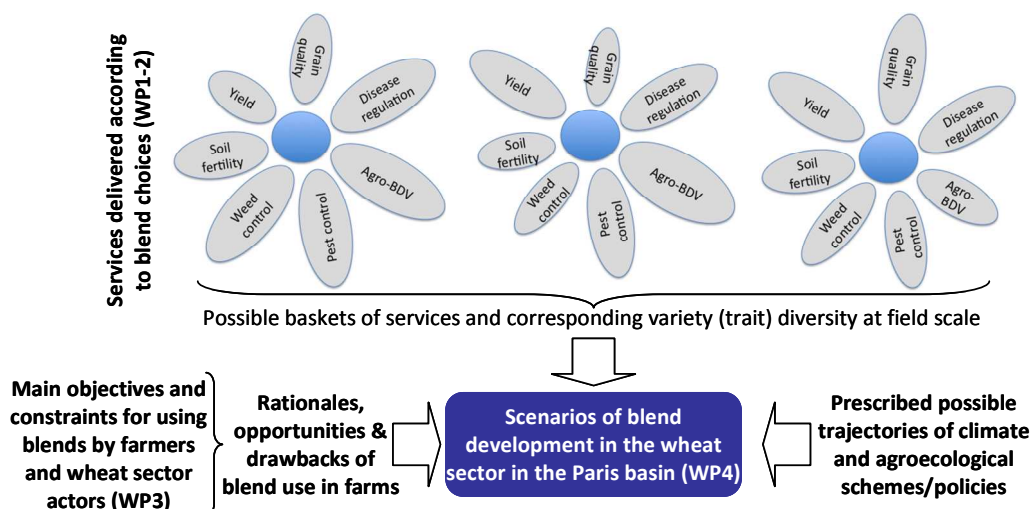
- The knowledge accumulation and diffusion. The knowledge on the performance of blends is based on multiple evidence, which can possibly be produced by advisory services, farmers, scientist, etc. Does blend introduction necessitate new forms of production and validation of such knowledge? What is the adequate organization among actors and should this organization be different compared to the current one that is adapted to inbred varieties?

Methods - These 3 issues will be addressed through a series of about 30 face-to-face interviews with principal actors of the wheat chain including: advisory services (chambers of agriculture, regional cooperatives), seed retailers and harvest collectors (e.g. farmers' cooperatives), seed companies, and regulatory institution (CTPS). We will also analyze experiences of blend introduction for wheat in foreign countries. Special attention will be paid to the Danish case, where a farmer-based advisory organization ("Danish Knowledge Center") has organized a knowledge system to create blends with farmers and assess their performance through experimental settings. In addition, economic modelling will be used to address two issues: the competition between seed companies with blends and the organization of a separate blend collect. Particular attention will be paid to analyze the determinants of possible diffusion of blends, paying much attention to (i) who develop the blends (a seed company, a seed retailer, the farmer), (ii) the heterogeneity of blend performance among farms in one region (cf. task 3.1) and (iii) the eligibility of farmers who adopt blends for some specific agricultural and environmental policy (e.g. Common Agricultural Policy, agri-environmental schemes (MAE), EcoPhyto).

Direct links with other WPs: WP3 will make use of the determination of baskets of agro-ecosystem services and trade-offs or synergies among services/disservices, including yield and grain quality, as key determinants that could influence farmers' motivation to use variety blends. WP3 results will be used by WP4 in years 3 & 4 to develop scenarios of blend development in the Paris basin during the next decades, along with guidelines to design adequate blends in this production basin.

WP4. DEVELOPMENT OF SCENARIOS, DESIGN RULES AND BREEDING SCHEMES FOR BLEND DEVELOPMENT

Task coordinator: Sébastien Barrot & Isabelle Bonnin
Partners: BIOEMCO, GV, BIOGER, BIOEMCO, CA, CERSP, EGC, GAEL, GDEC, LEM, SADAPT
Main objectives. WHEATAMIX will produce considerable data and information about wheat variety traits, the effects of blends on main ecosystem services, the underlying ecological mechanisms, and the economical, technical or organisational implications of such blends. Since the first 3 WPs of the project develop either ecophysiological, agro-ecological or socio-economical approaches, in WP4 we will build a transversal analysis and use other WPs' results to (i) develop scenarios for the use of wheat blends in the Paris Basin and (ii) synthesize and disseminate project results to key stakeholders.



Task 4.1: Scenarios of blends development in the Paris Basin (GAEL, Agronomie, LEM, and other partners)
Objective – Building on WP2&3 results, we aim at assessing plausible trajectories for blend use in the wheat sector, according to the ecosystem (dis)services they can provide including production, by **building scenarios of blend development in the Paris Basin over the next 3 decades**.

Methods – We will make use of the major constraints and opportunities associated to blend use identified along the wheat chain in WP3, and the agroecological benefits and drawbacks of using blends at field scale (yield, grain quality, multifunctionality potential, particularly under low input conditions) as revealed by WP2. The **yield stabilizing effect and its interest for risk management** will be analysed with specific attention to global change context, using external (prescribed) climatic scenarios and their consequences on yield instability (link with WP2 and with ACCAF metaprogramme and use of Climator results on impact of climatic scenarios on yield variations). **Scenarios of blends development in the Paris Basin will be built**. Such narrative scenarios will be based on a comprehensive list of socio-economic leverages and impediments identified by the WP3 at the individual farm level on the whole area of the Paris basin, accounting for possible baskets of services delivered identified in WP2, providing as much as possible concrete solutions to ease blend development in favourable contexts. A workshop with stakeholders will be organized to question how wheat blends could be traced in grain gathering network, or which adjustments in the processing industry could ease their economic development.

Task 4.2: Defining rules to design appropriate blends which should be transferred to stakeholders (GDEC, Agronomie, BIOEMCO, and remaining partners)

Objective – We will use outputs of WP1/2/3 to **sketch rules to design appropriate blends in the Paris basin** according to the targeted baskets of services to be delivered. In particular, we will assess what kind of advice/information need to be provided to farmers/cooperatives to choose the mixture of varieties adapted to a given situation (variety traits to be documented, tools to assess the complementarities and antagonisms of traits, seed registration rules, information provided in official seed catalogue...).

Methods – A specific workshop on rules to be built and refined will be organized with scientists, technical advisers, organisms in charge with registration and assessment of varieties, farmers, seed companies and food companies.

Task 4.3: Proposing new breeding schemes for blend production (GV, BIOEMECO, and remaining partners)

Objective – We aim at **developing new schemes specifically designed for breeding blend components**. Indeed, though WP1/2/3 consider existing varieties, varieties could be specially bred to optimize blends. WP1/2 outputs will determine key traits and their genetic bases that will have overall beneficial effects on agroecosystem functioning (e.g. traits favorable to N uptake) or particular baskets of services (e.g. production and its inter-annual stability, soil fertility and biocontrol of major pests). These WPs will also demonstrate to what extent and how the stability and multifunctionality of wheat cropping systems can be enhanced if varieties with contrasting trait values are mixed. WP1, and in particular Task 1.2 will also provide knowledge of the genetic bases of key traits involved in plastic response to plant to plant interactions, and characterize the genetic variability for mixing ability of genotypes.

Methods – We will apply to blends quantitative genetics concepts developed for breeding for hybrid value and explore different breeding strategies relying on general/specific mixing ability approach (cf Task 1.2), on more functional approach (groups of genotypes based on key traits), or on a mixed approach integrating both. The proposed breeding schemes will be discussed with public and private breeders during a specific workshop.

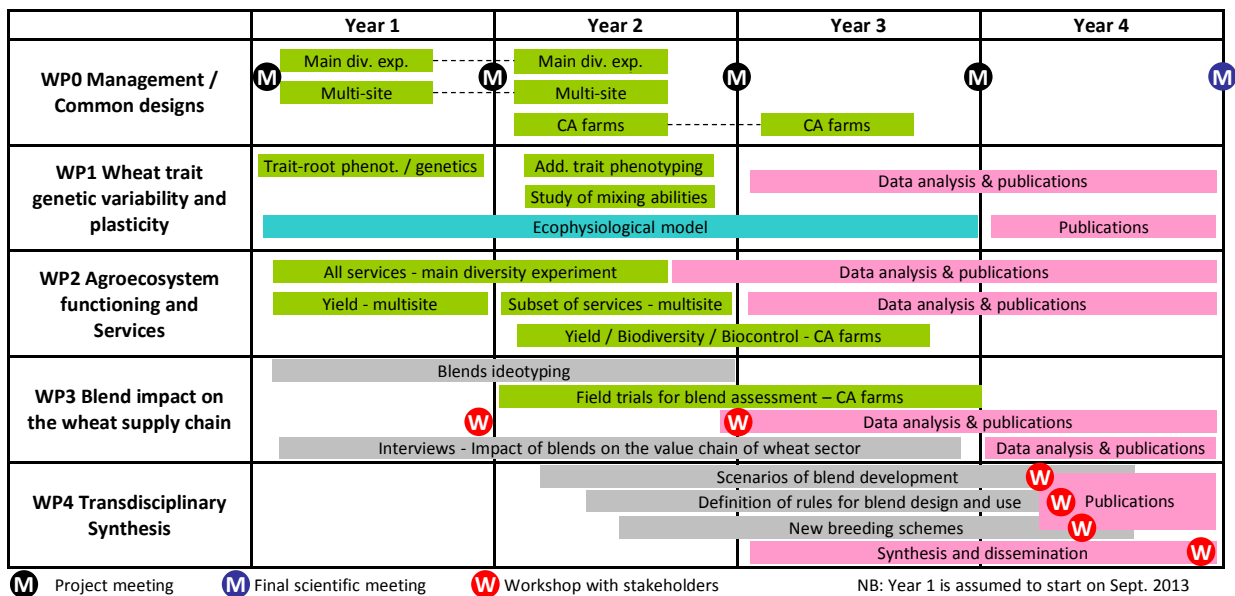
Task 4.4: Project results and guidelines dissemination (GV and remaining partners)

Objective – We aim at disseminating the results of the project to a broad range of professionals involved in wheat production (cooperative societies, seed companies...) and more generally to institutions involved in the development or the application of national/international agri-environment schemes (territorial institutions, ministries, etc.).

Methods – Scientists and a range of farmers/stakeholders will have intensively interacted throughout WHEATAMIX, especially thanks to the collective working groups set up in the WP3. Part of WP4, we will organize (1) a final WHEATAMIX symposium open to a wide audience including stakeholders from the

Paris Basin or relevant at national scale (FARRE, FNAB, ...), key scientists, heads of relevant research institutes (INRA, CIRAD...), and technical institutes (ARVALIS, ...), along with relevant policy makers (from the Ministry of Agriculture, of Environment...), and (2) a national congress on variety blends with international invited keynote speakers (complementary fundings will be sought). We will also produce a **methodological guide for blend design associated to particular baskets of services** (e.g. production and its inter-annual stability, soil fertility or biocontrol of major pests): this will be disseminated as paper copies to a wide range of stakeholders during events organized during the last year of the projects, through the actors mobilized in this project and more particularly Chambres d'agriculture. The guide will also be downloadable on the project web site.

3.3. TASKS SCHEDULE



LIST of DELIVERABLES per WP:

N°	Task	Date	Milestone – Deliverable	Partner resp.
D0.1	WP0	M1	Kick-off meeting of the project	1-GV
D3.1	WP3	M12	Results of the collaborative design of blends	2-Agronomie
D0.2	WP0	M13	2 nd annual scientific meeting of the project	1-GV
D1.1	WP1	M18	Report on the properties of designs for mixing ability assessment	1-GV
D1.2	WP1	M24	Phenotyping experiments of wheat varieties completed	9-GDEC
D2.1	WP2	M24	Wheat yield measured over the 2 yrs as a function of variety diversity	9-GDEC
D2.2	WP2	M24	Weed regulation is assessed as regards to variety diversity used	5 - CERSP
D2.3	WP2	M24	Effect of diversity on soil N availability and microbial activities quantified	10 - LEM
D0.3	WP0	M25	3 rd annual scientific meeting of the project	1-GV
D1.3	WP1	M30	List of key variety traits for smart blend design, and recommendation for a better variety description.	9-GDEC
D1.4	WP1	M30	Results and analysis of the experiments on the complementarity between varieties in resource use	9-GDEC
D1.5	WP1	M30	Assessment of genetic variability for plasticity of development / architecture traits and for mixing ability is completed	1-GV
D2.4	WP2	M30	Effect of diversity on foliar fungal pathogen regulation characterized	4-BIOGER
D2.5	WP2	M30	Variety diversity effect on aphid biocontrol quantified	5-CERSP
D1.6	WP1	M36	Conception, realization and analysis of the 3D model allowing to explore the consequences of plasticity for resource use in blends of varieties	7-EGC
D1.7	WP1	M36	Association mapping for the development and architecture traits, their plasticity, and for mixing ability is completed	1-GV
D2.6	WP2	M36	Variety diversity effect on the abundance and diversity of microbial communities is quantified	10-LEM
D2.7	WP2	M36	Variety diversity effect on soil macro-fauna and aboveground invertebrates is quantified	3-Bioemco

D2.8	WP2	M36	Effect of increasing biodiversity levels on diseases progression	7-EGC / 4-BIOGER
D4.1 a,b,c	WP4	M30-40	Three workshops allowing for transdisciplinary assessment with perspectives from stakeholders on scenario toward blend development	1-GV
D0.4	WP0	M40	4 th annual and last scientific meeting of the project	1- GV
D3.2	WP3	M40	Integrated analysis of the impact of blends on the wheat supply chain, based on interview and economic modelling	8-GAEL 11-SADAPT
D4.4	WP4	M40	Description and assessment of innovative strategies to breed blends components, to be proposed to breeders	1-GV
D3.3	WP3	M42	Techno-economic assessment of blends at the farm scale	2-Agronomie
D2.9	WP2	M42	Trade-offs and synergies between (dis)services characterized	10-LEM
D2.10	WP2	M42	Syndromes of traits at variety blend scale related to particular bundles of services are analysed	10-LEM
D4.2	WP0 WP4	M45	Final symposium with stakeholders and policy advisors	1-GV
D4.3	WP0 WP4	M48	International scientific conference	1-GV
D4.5	WP4	48	Methodological guide for stakeholders and policy makers summing up the results of the project	All partners

4. DISSEMINATION AND EXPLOITATION OF RESULTS. INTELLECTUAL PROPERTY

Dissemination and exploitation of results - The results of our study will be communicated (1) to farmers, agriculture stakeholders and policy makers, (2) to scientists from various disciplines, and (3) to the general public.

Our project only makes sense if results are disseminated to the entire farming community and to policy makers, so that they can be used for decision-making in agri-environmental public policies. A first and essential dissemination will occur thanks to the collaboration of Chambre d'Agriculture, and through the 50 farms involved in the Paris basin network. Additional audience will be reached through the production of leaflets and posters, and thanks to the final conference involving stakeholders, managers and decision makers (WP4).

Scientific publications will be privileged to communicate our results. Publications will target high-rank international journals, either within each discipline (e.g. *Ecology Letters*, *Ecology*, *Molecular Ecology*, *Genetics*, *Journal of Applied Ecology*, *Conservation Biology*) or, as much as possible, at the interface between disciplines (*Agriculture*, *Ecosystems & Environment*, *Human Ecology*, *World Development*, *Economic Botany*, *Renewable Agriculture and Food Systems*, etc.). Our work may also appear in books published as part of this project. The two-day workshop on diversity issues in agriculture, organized at the end of the first year, as well as the final meeting, will be good opportunities to communicate about this project. Finally, the project will be advertised on the BASC and partners websites, with a homepage hosted by GV. In addition, we will propose a scientific symposium, as a Eucarpia meeting or a side-event of another congress focusing on agro-ecology. Several partners of the project are involved in teaching, so that the results will also be disseminated to students enrolled in ecology, conservation biology or agronomy courses. Finally, some results will be presented to the public, during events such as the Science Festival (in which CERSP and UMR-GV take part each year) or as part of public lectures at Muséum national d'Histoire naturelle.

One indicator of success of WHEATAMIX dissemination will also be its ability to federate additional studies, and to take advantage of the shared experimental designs to develop complementary analyses (e.g. blends effect on genetic structure of specific pathogen or soil microorganisms, on mycotoxin production,...), attracting other scientists within related communities, as the BASC Labex.

Intellectual property - The results and methods developed during the project will be public, and made available to the scientific community as well as public and private actors of the wheat chain.

5. CONSORTIUM DESCRIPTION

5.1. PARTNERS DESCRIPTION, RELEVANCE AND COMPLEMENTARITY

Principal complementarities between the different teams have been developed in WP descriptions. In Brief, WHEATAMIX consortium is proposing a balanced contribution of geneticist, ecologists, eco-physiologists, agronomists, economists, management scientists, Chambre d'Agriculture members and farmers, to develop an integrated approach relevant for a better definition and development of agro-ecology. Our main challenge will therefore be to develop efficient collaboration and maintain close interaction between diverse partners with complementary skills. We are confident with this issue, as the work performed by the different communities on shared experimental designs as well as the dedicate transdisciplinary WP4 will allow efficient diffusion of concepts, fruitful brainstorming, and stimulate the birth of new ideas (as witnessed by the present document). Moreover most partners (UMR-GV, BIOGER, CERSP, GAEL...) have been collaborating fruitfully together in regional to European projects. Here follows the description of partners activities in relation with WHEATAMIX.

Partner 1-GV: The Plant Genetics laboratory (UMR 320 CNRS-INRA-UPS-AgroParisTech) studies the genetics and evolution of quantitative traits. Within this lab, the DEAP team (Diversity, Evolution and Adaptation of Populations, resp. I. Goldringer) analyses the evolutionary mechanisms involved in on-farm and experimental dynamic management of genetic resources, using innovative participatory approaches to promote sustainable and realistic agro-ecosystems. DEAP has expertise in quantitative and population genetics, as well as theoretical conservation biology (metapopulations). DEAP is partner of the Breedwheat project, as well as two INRA meta-programmes (ACCAF-Climagie and SELGEN-CropDL). DEAP has good experience of interdisciplinary work with partners CERSP, BIOGER, EGC and has a strong partnership with a national network of farmers involved in the management and use of agrobiodiversity (RSP). Such partnership ensures the development of socially and economically realistic research projects, which are funded by various European (SOLIBAM), national (FRB) and regional (PICRI) sources.

Partner 2-Agronomie – INRA-AgroParisTech UMR 211. The Agronomie research team aims at producing knowledge and methods to design and assess sustainable cropping systems. Research tackles four themes: (1) biologic regulation in agro-ecosystems, (2) interaction between genotype, environment and cropping practices, (3) methods for design and assessment of cropping systems and (4) global agronomy. Research programs have been conducted for a long time to design with models ideotypes of sustainable cropping systems and to develop tools coupling statistical and agronomic approaches to assess varieties and characterize their resistance to different environmental stress. In particular, researchers from the unit showed the interest of hardy varieties adapted to low input cropping practices to reduce the environmental impact of wheat production.

Partner 3-Bioemco – CNRS/ IRD/ UPMC/ UPEC/ ENS UMR 7618, Team “Biodiversity and ecosystem functioning” Bioemco is a large laboratory (mixed research unit) affiliated to the National Centre for Scientific Research (CNRS), Institute of Research for Development (IRD) and the University Pierre and Marie Curie. About 100 scientists, 50 technicians and 50 PhD are working in this laboratory. The general objective of the laboratory is to contribute to the emergence of the so-called “ecogeochemistry” in which the dynamics of energy and nutrients in the ecosystems is considered as the result of interactions between the chemical and physical components of the environment (hydrosphere, atmosphere, soil), the physiology of organisms, the diversity and organization of communities, the hierarchical structure of the ecosystem. Questions are studied on model ecosystems (cropfields, grasslands, savannas, fresh water ecosystems) in order to get both a general and theoretical understanding of ecosystem functioning and a predictive knowledge of ecosystem dynamics. Within BIOEMCO, the team “Biodiversité” aims more specifically at studying ecological interactions, networks of interactions and ecosystem functioning. The members of the project are particularly knowledgeable in soil ecology and soil macrofauna.

Partner 4-BIOGER UR - INRA Grignon (Biologie et Gestion des Risques en Agriculture). BIOGER is a leading French research institute in fungal plant pathology (<http://www.versailles-grignon.inra.fr/bioger>). This institute gathers teams working on major fungal crop pathogens using multidisciplinary approaches from functional genomics, evolution and population genetics to epidemiology and modelling. The team "Plant Disease Epidemiology" has a long-standing expertise in the following fields: qualitative epidemiology of wheat rusts and,

more recently, of septoria leaf blotch, virulence surveys on a national basis; quantitative epidemiology of airborne fungal diseases, analytical studies of sporulation, infection and dispersal in relation with weather factors; analysis of spatial-temporal spread of diseases; use of the host genetic diversity as a means of controlling disease and increasing the durability of resistance; theoretical ecology and spatial-temporal processes; spread of primary inoculum and early stages of epidemics.

Partner 5-CERSP – UMR MNHN-CNRS-UPMC 7204 Conservation des Espèces, Restauration et Suivi des Populations, team “Ecological Bases of Conservation” (BEC). CERSP consists of two research teams, which are interested in the study of the reciprocal interactions between human societies and biodiversity, with the aim to enhance the conservation of biodiversity and ecosystem services. Research at CERSP relies strongly on long-term nationwide participatory biodiversity monitoring programs, for which CERSP has international leadership (e.g. WP leader in the past FP7 programs EuMon and SCALES). The “BEC” team involved in the WheatAmix project focuses on understanding the fundamental ecological mechanisms underlying biodiversity changes and several researchers have already worked on the impact of agricultural practices on biodiversity. CERSP will therefore provide expertise in participatory monitoring (e.g. via the “Observatoire Agricole de la Biodiversité”), in the study of wild farmland biodiversity, in the assessment of ecosystem services and in multivariate statistics. The team has already worked with partners of the project (UMR-GV, BIOEMCO) and will complement the skills of LEM and BIOEMCO by expanding the number of taxonomic groups included in the project and allowing in-site participatory measurements of biodiversity by farmers.

Partner 6-CA – Five departmental extension services (“Chambres d’Agriculture” 27, 36, 41, 45, 77) and FDGEDA18 over 3 regions of the Paris Basin can relay the project in their regional coordination bodies. These six organizations work with groups of farmers (GDA, CETA) and identified farmers who practiced wheat varietal mixtures. For three years, each department has conducted at least one trial to compare mixtures of varieties with their components in pure stands in different pedoclimatic conditions and make these references available to the project.

Partner 7-EGC - UMR1091 INRA-AgroParisTech Environnement et Grandes Cultures has recognized expertise in the analysis and modelling of the relations between crops and their environment, focusing on the scientific questions raised by durability of agriculture in the context of global change. It has a total permanent staff of 105 and is organized in three research teams with complementary competencies in plant ecophysiology, agronomy, physics, chemistry and a strong experience in the development of process-based models to simulate these interactions. They have an extended experience both in modelling and in experimental work both in field and in controlled conditions. Wheat is an important model species for EGC, and specifically the modelling of interactions between wheat and foliar fungi, as modulated by climate, crop practices (including N fertilisation) and phenotypic traits. The laboratory has been working for a long time on particle atmospheric transfer in relation to biological contamination (aerial fungal diseases, gene flow by air-borne pollen transfer), on the understanding of the plant-pathogen interaction at plant and canopy scale.
(<https://www4.versailles-grignon.inra.fr/egc>).

Partner 8-GAEL – INRA/UPMF UMR1215. Grenoble Applied Economics Laboratory. GAEL was evaluated "A" by the AERES in 2010. GAEL involves 20 full time researchers on two main themes: the economics of innovation and the experimental analysis of consumer behaviours. A large part of these researches are applied to agriculture related sectors: innovation in seed and biotechnology, analysis consumption behaviour for food. Wheatamix is more particularly related to the researches on innovation. GAEL has a long experience in analyzing the drivers of innovation in the seed sectors (intellectual property rights, industry structure, seed regulation). Researchers from GAEL are involved in several multidisciplinary projects concerning crop genomics (Breedwheat, Amaizing, Rapsodyn, Peamust) as well as participatory plant breeding (SOLIBAM). (www.grenoble.inra.fr)

Partner 9-GDEC INRA UMR 1095, Clermont-Ferrand. UMR GDEC has a recognised expertise in wheat genomics, quantitative genetics and ecophysiology. The ABC team focus on wheat adaptation to abiotic stress using both ecophysiological and quantitative genetics approaches in particular within the context of increasing wheat nitrogen use efficiency (NUE). UMR GDEC leads the Breedwheat project and the ABC team is involved in several work packages. The Wheatamix project is an opportunity to extend our research

on ecophysiological and genetic determinism of wheat NUE to wheat blends. UMR GDEC and the ABC team were evaluated “A” by AERES in 2011.

Partner 10-LEM - CNRS/UCBL1/INRA UMR5557 USC1364, Microbial Ecology, Team Microbial functional groups and nitrogen cycle. The Center for Microbial Ecology of Lyon-Villeurbanne gathers researchers from several different governmental agencies (Univ. LYON 1, CNRS, INRA and ENVL). The LEM is composed of seven research groups, one of them being involved in the WheatAmix project. One of the main research axes of this team is the study of the mechanisms and environmental drivers that control the levels of the activity insured by model microbial organisms or functional groups involved in soil N cycle. The different possible regulation levels are taken into account, namely changes in the abundance, diversity and specific activity of the organisms, using up-to-date tools (qPCR, high-throughput sequencing...). This team has already worked on the effect of plant (species) diversity on soil microbial groups part of national (DISCOVER) and European (VITAL) projects, and has been involved in the large Jena Biodiversity experiment. It will also bring skills in complex data analysis through multivariate methods, GLMs and path-analyses for WP2. The expertise of this partner complements skills of other WheatAmix partners, in particular those of Bioemco on soil fauna ecology, of INRA Grignon on plant root growth and architecture and plant N economy, along with those of Bioemco and CERSP for ecological data analysis. X. Le Roux, who will coordinate the WP2, has experience of the coordination and management of projects and structures: in particular, he has coordinated a FP6 European project, and a FP7 project (BiodivERSA).

Partner 11- SAD-APT – INRA/AgroParisTech UMR1048. Sciences for Action and Development, Activities, Product, Territories. (<http://www6.versailles-grignon.inra.fr/sadapt>). SAD-APT involves together more than 80 researchers, teachers, PhD and Post-doc fellows from various academic disciplines: agronomy, ecology, animal sciences, economics, sociology, geography, management sciences... SAD-APT as a strong potential and experience in multidisciplinary research project about agriculture and environment, from various and complementary perspectives (modeling land-use and farm performance, analyzing public policies, understanding conflicts and innovation at territorial scales...). It is also well connected with many stakeholders potentially involved in the promotion of seed blends in the wheat supply chains (farmers' cooperatives, chambers of agriculture...)

5.2. QUALIFICATION AND CONTRIBUTION OF EACH PARTNER

Leader scientific qualification – J. Enjalbert is an INRA senior researcher specialized in population biology and genetics. In his former experience, in BIOGER and UMR-GV, he has developed with Claude Pope a European project on phylogeographic and worldwide adaptation of yellow rust to wheat, studying adaptation to environmental and host selective pressures, with a specific interest on adaptation to temperature. This project was based on five international collaborations, and has allowed the training of three PhD students in population genetics and molecular epidemiology. The work developed on host-pathogen interactions is of direct interest for the present project. He joined in 2009 the DEAP team of Isabelle Goldringer, and now develops studies on the genetic architecture of life history traits in wheat, with the aim of building a better understanding of plant competition and fitness in heterogeneous populations. His competences led him to be involved in reflexive INRA groups on ideotype definition and on the role of genetics and plant breeding for agro-ecology and ecosystem services.

JÉRÔME ENJALBERT (P1-GV; 44, CR1 INRA) is a population and quantitative geneticist (engineer in agronomy and PhD INA-PG), he has experience both in plant genetics and breeding and in epidemiology of plant fungi. He has developed research in diversity dynamics of wheat rust at BIOGER during 10 years and is now conducting projects on the analysis of the genetic bases of development and architecture traits in wheat and of evolutionary models. He has already worked or is currently working with BIOGER and EGC. He has been involved in many large scale european projects (BIOEXPLOIT 2005-2010, ENDURE 2005-2009 and SOLIBAM 2010-2014) and was WP co-leader in ANR project EMERFUNDIS (2007-2010). He has co-supervised 4 PhD, supervised 1 PhD and 5 MSc.

List of five selected publications out of 27 in peer-reviewed international journals

Mboup M, Bahri B, Leconte M, De Vallavieille-Pope C, Kaltz O & **J. Enjalbert**, 2012. Genetic structure and local adaptation of European wheat yellow rust populations: The role of temperature-specific adaptation. *Evol. Appl.* 5 (4): 341-352.

Enjalbert J, Dawson J, Paillard S, Rhoné B, Rousselle Y, Goldringer I, 2011. Dynamic management of crop diversity: from an experimental approach to on-farm conservation. *CR Biol.* 334: 458-468.

Ali S, Leconte M, Walker AS, **Enjalbert J** & de Vallavieille-Pope C, 2010. Reduction in the sex ability of worldwide clonal populations of *Puccinia striiformis f.sp. tritici*. *Fungal Genetics and Biology* 10:828-38

Bahri B, Kaltz O, Leconte M, de Vallavieille-Pope C & **Enjalbert J**, 2009. Tracking costs of virulence in natural populations of the wheat pathogen, *Puccinia striiformis*. *Bio Med Central Evol Biol*, 9: 26.

Bahri B, Leconte M, Ouffroukh A, De Vallavieille-Pope C & **Enjalbert J**, 2009. Geographic limits of a clonal population of wheat yellow rust in the Mediterranean region. *Mol Ecol.* 18(20): 4165-4179

ISABELLE GOLDRINGER (P1-GV, 44, HDR), DR2 INRA at UMR-GV Le Moulon, is a plant population and quantitative geneticist (engineer in agronomy and PhD INA-PG). She is head of the team “Diversity Evolution and Adaptation of Populations” and has supervised (or co-supervised) 10 PhD. She has coordinated 3 national projects and is WP leader in the 7th FP project SOLIBAM (2010-2014). She is interested in assessing, breeding and managing of crop diversity of farm.

List of 5 recent publications out of 39 publications in peer-reviewed international journals:

Thomas M, Demeulenaere E, Dawson JC, Khan A-R, Galic N, Jouanne-Pin S, Remoue C, Bonneuil C, **I Goldringer**, 2012. On-farm dynamic management of genetic diversity: the impact of seed diffusions and seed saving practices on a population-variety of bread wheat. *Evol. Appl.* 5(8): 779-795

Bonneuil C, Goffaux R, Bonnin I, Montalent P, Hamon C, Balfourier F, & **I Goldringer**, 2012. A new integrative indicator to assess crop genetic diversity. *Ecol. Indic* 23: 280–289

Dawson JC Serpolay E, Giuliano S, Schermann N, Galic N, Chable V & **I Goldringer**, 2012. Multi-trait evolution of farmer varieties of bread wheat after cultivation in contrasting organic farming systems in Europe. *Genetica* 140:1–17

Rousselle Y, Thomas M, Galic N, Bonnin I & **I Goldringer**, 2011. Inbreeding depression and low between-population heterosis in recently diverged experimental populations of a selfing species. *Heredity* 106: 289-299

Rousset M, Bonnin I, & **Goldringer I**, 2011. Deciphering the genetics of flowering time by an association study on candidate genes in bread wheat (*Triticum aestivum L.*). *Theor. Appl. Genet.* 123: 907-926

Isabelle Bonnin (P1-GV, 45, CR1 INRA) is a population biologist and geneticist, she has experience in plant population adaptation (conservation biology, spatial structure, heavy metal tolerance) and genetic diversity management. She was assistant professor during 5 years at the University of Lille before to join the INRA (UMR GV) 13 years ago. She has supervised 1 PhD and 4 MSc. During the 4 latest years, she was in charge of the stakeholders-scientists interactions at the FRB (Fondation pour la Recherche sur la Biodiversité) in Paris, supervising a team of three engineers.

List of 5 recent publications out of 22 publications in peer-reviewed international journals (h-index= 14):

Bérard A., M.C. Le Paslier, M. Dardevet, F. Exbrayat-Vinson, **I. Bonnin**, et al. **2009**. High throughput SNP genotyping in wheat (*Triticum* spp.). *Plant Biotechnology Journal* 7:364-374.

Rhoné B., R. Vitalis, I. Goldringer and **I. Bonnin**. **2010**. Evolution of flowering time in experimental wheat populations: a comprehensive approach to detect genetic signatures of natural selection. *Evolution* (7): 2110-2125.

Rousselle Y., M. Thomas, N. Galic, **I. Bonnin** and I. Goldringer. **2011**. Significant inbreeding depression and low between-population heterosis in a recently diverged experimental population of a selfing species. *Heredity* 106: 300-309.

Rousset M., **I. Bonnin**, et al. **2011**. Deciphering the genetics of flowering time by an association study on candidate genes in bread wheat (*Triticum aestivum L.*) *Theoretical and Applied Genetics*. 123: 907-926.

Bonneuil C., R. Goffaux, **I. Bonnin**, et al. **2012**. A new integrative indicator to assess crop genetic diversity. *Ecological Indicators* 23: 280-289.

ARNAUD GAUFFRETEAU (P2-Agronomie, IR2 INRA), is engineer in agronomy. He is interested in understanding and predicting Genotype x Environment Interactions (GEI) in variety trials. He leads a

scientific network on GEI in INRA and contributes to the reflection about design and assessment of plant ideotype in the framework of the GIS GC HP2E (http://www.gchp2e.fr/gchp2e/le_gis_gc_hp2e).

C. Lecomte, L. Prost, **A. Gauffreteau**, 2009. Présentation d'une méthode pour améliorer la connaissance des aptitudes variétales, intérêt des modèles, besoins de développements nouveaux. *Innovations Agronomiques* 7, 105-119

A. Gauffreteau, C. Loyce, M.H. Jeuffroy. Is the Beta-var model able to identify the wheat varieties best suited to low-input crop management system? *Farming System Design Symposium – August 23-26, 2009 – Monterey. CA – Poster*

A. Gauffreteau, R. Marzouki, M.H. Jeuffroy. Does disease resistance have a cost in potential yield of winter bread wheat varieties? *Farming System Design Symposium – August 23-26, 2009 – Monterey. CA – Oral communication*

SÉBASTIEN BAROT (P3-BIOEMCO, DR2 IRD), is an ecosystem and soil ecologists. He is combining field work, experimentations in controlled conditions and mathematical modelling to analyse ecosystem functioning and belowground-aboveground interactions. He has particularly worked on soil macrofauna and plant-earthworm interactions.

List of five selected publications out over 54 publications in international journals:

Boudsocq, S., A. Niboyet, J.-C. Lata, X. Raynaud, N. Loeuille, J. Mathieu, M. Blouin, L. Abbadie, and **S. Barot**. 2012. Plant preference for ammonium versus nitrate: a neglected determinant of ecosystem functioning? *Am. Nat.* 180:60-69.

Boudsocq, S., J. C. Lata, J. Mathieu, L. Abbadie, and **S. Barot**. 2009. Modeling approach to analyze the effects of nitrification inhibition on primary production. *Func. Ecol.* 23:220-230.

Fontaine S., **Barot S.**, Barré P., Bdioui N., Mary B. & Rumpel C. 2007 Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature*, 450: 277-281

Fontaine, S., and **S. Barot**. 2005. Size and functional diversity of microbe populations control plant persistence and long-term soil carbon accumulation. *Ecology Letters* 8: 1075-1087

Laossi, K.-R., D. C. Noguera, A. Bartolomé-Lasa, J. Mathieu, M. Blouin, and **S. Barot**. 2009. Effects of endogeic and anecic earthworms on the competition between four annual plants and their relative reproduction potential. *Soil Biol. Biochem* 41:1668-1773.

Barot, S., A. Ugolini, and F. BekkalBrikci. 2007. Nutrient cycling efficiency explains the long-term effect of ecosystem engineers on primary production. *Func. Ecol.* 21:1-10.

CLAUDE DE VALLAVIELLE-POPE (P4-BIOGER, DR2 INRA), Grignon is a plant epidemiologist (Thèse d'état, University ParisXI). Former head of BIOGER epidemiology group, she has supervised 12 PhD theses and 20 masters. She directed different projects on epidemiology of foliar diseases on wheat and is a world recognised expert on wheat variety blends and airborne diseases.

List of five selected publications out over 50 publications in international journals

BelhajFraj M., Falentin-Guyomarc'h H., Monod H., de **Vallavieille-Pope, C.**, 2003. The use of microsatellite markers to determine the relative proportions of grain produced by varieties and the frequency of hybridisation in bread wheat mixtures. *Plant Breeding* 122, 385-391.

de Vallavieille-Pope C., BelhajFraj M., Mille B., Meynard J.M. 2006. Les associations de variétés: accroître la biodiversité pour mieux maîtriser les maladies. In: Gassel P., Clément O. (coord.). *Quelles variétés et semences pour des agricultures paysannes durables ?* Dossiers Env INRA n° 30, Paris, 186 p.

Mille B., BelhajFraj M., Monod H., **de Vallavieille-Pope, C.**, 2006. Assessing four-way mixtures of winter wheat varieties from the performances of their two-way and individual components. *Eur. J. Plant Path.* 114, 163-173.

Hau B., **de Vallavieille-Pope C.**, 2006. Wind-dispersed diseases. In: *The Epidemiology of Plant Diseases*. p. 387-416, Eds Cooke, & Kaye, Second Edition, Springer.

de Vallavieille-Pope C., Ali S., Lecomte M., Enjalbert J, Delos M., Rouzet J., 2012. Virulence dynamics and regional structuring of *Puccinia striiformis* f. sp. *tritici* in France between 1984 and 2009, *Plant Disease* 96, 131-140

EMMANUELLE PORCHER (P5-CERSP, 37, HDR), MCMu at CERSP (MNHN) and professor at Ecole Polytechnique, is a plant ecologist and population geneticist (PhD University ParisXI). She is head of the

“Bases écologiques de la conservation” team and has supervised 5 PhD and 3 postdocs. She is interested in combining population genetics and ecology and has already worked with UMR-GV on the impact of wheat genetic diversity on biodiversity.

List of five selected publications out of 27 in peer-reviewed international journals

Chateil, C, I Goldringer, C Kerbirou, I Le Viol, JF Ponge, S Salmon, S Gachet, **E Porcher**. 2013. Crop genetic diversity benefits farmland biodiversity in cultivated fields. *Agric. Ecosyst. Environ.* In press.

Coron, C, S Méléard, **E Porcher**, A. Robert. 2013. Quantifying the mutational meltdown in diploid populations. *Am. Nat.* In press.

Maurel, N, M Fujiyoshi, AMuratet, **E Porcher**, E Motard, O Gargominy, N Machon. 2013. Biogeographic comparisons of herbivore attack, growth and impact of Japanese knotweed between Japan and France. *J. Ecol.* 101:1 18-127.

Eckert, CG, S Kalisz, MA Geber, RD Sargent, E Elle, PO Cheptou, C Goodwillie, MO Johnston, JK Kelly, DA Moeller, **E Porcher**, RH Ree, M Vallejo-Marín, AA Winn. 2010. Plant mating systems in a changing world. *Trends Ecol. Evol.* 25:35-43.

Johannes*, F, **E Porcher***, et al. 2009. Assessing the impact of transgenerational epigenetic variation on complex traits. *PLoS Genet.* 5(6). (*Equal contributions)

DOMINIQUE DESCOUREAUX (P6-CA, 56 years, head of the crops and GDA division at “Chambre of Agriculture” of Loir-et-Cher): crop advisor in charge of the coordination of crop experimentation of the CA in the Centre Region (200 trials / year); coordinator of the "crop innovative technics" experiments of the CAP crop sector in the Centre Region (technical partnerships: Arvalis, Cetiom, ITB, 6 CA, FGEDA18, UCATA, CETA36, Biocentre and 6GAB, SCAEL, Axereal); territorial engineer DEPHY (link for the EXPE networks and the FARM networks) for arable crops (Regions: Centre, Ile de France, Bourgogne).

BRUNO ANDRIEU (P7-EGC, 57, HDR, DR INRA), is a plant ecophysiological and modeller. Former head of groups working in remote sensing and in plant modelling. He has supervised or co-supervised 12 PHD. He is a world recognized expert in the development of individual-based, structural-functional, crop models, with special focus on N economy and on plasticity in response to plant-to-plant competition

Selected publications (over 69, H index=22 https://www.researchgate.net/profile/Bruno_Andrieu/)

Bertheloot J., Cournède P.-H., **Andrieu B.** (2011). NEMA, a functional–structural model of nitrogen economy within wheat culms after flowering. I. Model description. *Annals of Botany*, 108, 1085-1096

Baccar R., Fournier C., Dornbusch T., **Andrieu B.**, Gouache D., Robert C. (2011). Modelling the effect of wheat canopy architecture as affected by sowing density on Septoria tritici epidemics using a coupled epidemic–virtual plant model. *Annals of Botany*, 108, 1179-1194

Bertheloot J., Martre P., **Andrieu B.** (2008). Dynamics of light and nitrogen distribution during grain filling within wheat canopy. *Plant Physiology*, 148, 1707-1720

Evers J.B., Vos J., Chelle M., **Andrieu B.**, Fournier C., Struik P.C. (2007). Simulating the effects of localized red / far-red ratio on tillering in spring wheat (*Triticum aestivum* L.) using a 3D virtual plant model. *New Phytologist*, 176, 325-336

Fournier C., **Andrieu B.** (1998). A 3D architectural and process-based model of maize development. *Annals of Botany*, 81, 233-250

SÉBASTIEN SAINT-JEAN (P7-EGC, 38, assistant prof. AgroParisTech) conducts research in Environmental Physics (PhD University ParisXI Orsay) and more particularly on the study of atmospheric transfer of biotic and abiotic particles of agricultural origin (dispersal of plant pathogens). Recently, he co-supervised projects and a PhD on the use of variety blends to prevent epidemic progression of wheat leaf blotch.

List of five selected publications out of a total 22 peer-reviewed one

Calonnec, A., Burie, J.-B., Langlais, M., Guyader, S., **Saint-Jean, S.**, Sache, I., Tivoli, B., 2013. Impacts of plant growth and architecture on pathogen processes and their consequences for epidemic behaviour. *Eur J Plant Pathol* 135, 479–497.

Gigot, C., **Saint-Jean, S.**, Huber, L., Maumené, C., Leconte, M., Kerhornou, B., de Vallavieille-Pope, C., 2013. Protective effects of a wheat variety blend against splash-dispersed septoria tritici blotch epidemics. *Plant Pathology* in press.

Marceau, A., **Saint-Jean, S.**, Loubet, B., Foueillassar, X., Huber, L., 2012. Biophysical characteristics of maize pollen: Variability during emission and consequences on cross-pollination risks. *Field Crops Research* 127, 51–63.

Saint-Jean, S., Kerhornou, B., Derbali, F., Leconte, M., de Vallavieille-Pope, C., Huber, L., 2008. Role of rain-splash in the progress of Septoria leaf blotch within a winter wheat blend. *Aspects of Applied Biology* 89, 49–54.

Saint-Jean, S., Chelle, M., Huber, L., 2004. Modelling water transfer by rain-splash in a 3D canopy using Monte Carlo integration. *Agricultural and Forest Meteorology* 121, 183–196.

STÉPHANE LEMARIÉ (P8-GAEL, DR2 INRA), Grenoble is engineer in agronomy and PhD in economics. He is involved in several multidisciplinary projects concerning the seed sectors. Stéphane Lemarié is responsible for the WP3 and will contribute to task 3.2 by analysing more particularly the impact of blends on the seed market. His most recent important publications are:

Bonroy, O., **Lemarié, S.** (2012). « Downstream labeling and upstream price competition » - *European Economic Review*, vol. 56, n° 3, pp. 347-360.

Aujas, P., Lacroix, A., **Lemarié, S.**, Reau, R. (2011). « Réduire l'usage des pesticides: un défi pour le conseil aux agriculteurs » - *Economie Rurale*, n° 324, pp. 18-33.

Lemarié, S. (2009). Les variétés hybrides vues par un économiste. *Le Sélectionneur Français* 60:101-108.

Ambec, S., Langinier, C., **Lemarié, S.** (2008). Incentives to reduce crop trait durability. *American Journal of Agricultural Economics*, vol. 90, n° 2, pp. 379-391.

Vincent ALLARD (P9-GDEC, 35, CR1 INRA) is a wheat crop physiologist. He studies the genetic and ecophysiological determinism of wheat nitrogen use efficiency. His approaches involve both experimental work (field and controlled conditions) and modelling. He is in charge of the Phenome platform of Clermont-Ferrand

Allard V., Martre P., Le Gouis J. 2013. Genetic variability in biomass allocation to roots in wheat is mainly related to crop tillering dynamics and nitrogen status. *European Journal of Agronomy* 46: 68-76.

Allard V et al. 2012. The quantitative response of wheat vernalization to environmental variables indicates that vernalization is not a response to cold temperature. *Journal of Experimental Botany* 63: 847-857.

Bogard M, **Allard V**, et al. 2010. Deviation from the grain protein concentration–grain yield negative relationship is highly correlated to post-anthesis N uptake in winter wheat. *Journal of Exp. Bot.* 61: 4303-4312.

Bogard M, Jourdan M, **Allard V**, (...) Le Gouis J. 2011. Anthesis date mainly explained correlations between post-anthesis leaf senescence, grain yield, and grain protein concentration in a winter wheat population segregating for flowering time QTLs. *Journal of Experimental Botany* 62: 3621-3636.

Gaju O., **Allard V.**, Martre P., (...), Foulkes M.J. 2011. Identification of traits to improve the nitrogen-use efficiency of wheat genotypes. *Field Crops Research* 123: 139-152.

Moreau D, **Allard V**, Gaju O, Gouis JL, Foulkes M. John, Martre P. 2012. Acclimation of Leaf Nitrogen to Vertical Light Gradient at Anthesis in Wheat Is a Whole-Plant Process That Scales with the Size of the Canopy. *Plant Physiology* 160: 1479-1490.

XAVIER LE ROUX (P10-LEM, 45, HDR, DR1 INRA) is a microbial and ecosystem ecologist. He is the co-leader with F. Poly of the Research Group “Groupes fonctionnels microbiens et cycle de l’azote” at LEM. He has skills in both ecosystem ecology and microbial ecology. His two main research topics are the response of the bacterial communities involved in soil N dynamics to global change factors (in particular changes in climate, land-use and plant diversity) and the analysis of biodiversity-ecosystem functioning relationships. As a Director of FRB during 2008-2012, he has also skills for developing links between biodiversity science and stakeholders ; as a Coordinator of the EC-FP7 project BiodivERsA, he has project coordination skills. He has been the scientific leader of the national scientific expertise on ‘Agriculture and biodiversity’ required by the French ministries of Ecology and Agriculture (Le Roux X. et al. (Eds) 2008. *Agriculture and biodiversity: promoting synergies*. National scientific expertise scientifique, QUAE, 75 pp.).

List of five selected publications out of 79 in peer-reviewed international journals (H factor = 30)

Attard E., Poly F., Laurent F., Commeaux C., Terada A., Smets B.F., Recous S & **Le Roux X.** 2010. Shifts between Nitrospira- and Nitrobacter-like nitrite oxidizers underlie the response of soil potential nitrite oxidation to changes in tillage practices. *Environ. Microbiol.* 12, 315–326.

- Attard E., Recous S., Chabbi A., De Berranger C., Guillaumaud N., Labreuche J., Philippot L., Schmid B. & **Le Roux X.** 2011. Soil environmental conditions rather than denitrifier abundance and diversity drive potential denitrification after changes in land-uses. *Global Change Biol.* 17: 1975–1989.
- Salles J.F., **Le Roux X.** & Poly F. 2012. Relating phylogenetic and functional diversity among denitrifiers and quantifying their capacity to predict community functioning. *Frontiers Microbiol.* 3: article 209.
- Le Roux X.**, Schmid B., Poly F., Barnard R.L., Niklaus P.A., Guillaumaud N., Habekost M., Oelmann Y., Philippot L., Salles J., Schloter M., Steinbeiss S. & Weigelt A. 2013. Soil environmental conditions and buildup of microbial communities mediate the effect of grassland plant diversity on nitrifying and denitrifying enzyme activities. *PLOS One* (in press)
- Lavorel S., Storkey J., Bardgett R.D., De Bello F., Berg M.P., **Le Roux X.**, Moretti M., Mulder C., Diaz S., Harrington R. & Pakeman R. 2013. Linking functional traits of plants and other trophic levels for the quantification of ecosystem services. *J. Veg. Sci.* (in press)

PIERRE LABARTHE (P11-SAD-APT, CR1 INRA) is engineer in agronomy and PhD in economics. He is involved in several multidisciplinary projects concerning farm advisory services in Europe. He will contribute to the task 3.2 by analysing the role of advisory services for producing evidences about the performance of blends. Short relevant selection of publications:

- Labarthe P., Laurent C. 2013. Privatization of agricultural extension services in the EU: Towards a lack of adequate knowledge for small-scale farms? *Food Policy*, 38, pp. 240-252.
- Labarthe P. 2010. Services immatériels et verrouillage technologique. Le cas du conseil technique aux agriculteurs, *Economies et Sociétés, Série Economie et Gestion des Services*, 11(2/2010), pp. 173-96.
- Labarthe P. 2009. Extension services and multifunctional agriculture, Lessons learnt from the French and Dutch contexts and approaches, *Journal of environmental management*, 90(2), pp. 193-202.

Main Partners involvement in other projects:

Partner	Name of involved people	Project name, financing institution, grant allocated	Start and end dates
N°1;8	I. Goldringer/ J. Enjalbert S. Lemarié	SOLIBAM, EU, 60k€	2009-2013
N°3	S. Barot / J.C. Lata	SAVARID, ANR CEP, 950 k€	2011-2014
N°3	S. Barot	PULSE, ANR CEP 1300 k€	2011-2014
N°4	C. Pope	LCP FP7 KBBE, Pure, 9 k€	2011-2014
N°4	C. Pope, S. Saint-Jean	Biodiv. intraparcellaire- CTPS-MAAF 4.2 k€/ 34 k€	2011-2013
N°4	C. Pope, S. Saint-Jean	Les champs de biodiversité FRB-LU 5.5 k€	2011-2014
N°4	C. Pope	Rustfight, projet danois 45 k€	2012-2014
N°4	C. Pope	FSOV Stabilité de la résistance à la rouille jaune 31 k€	2013-2015
N°5	PORCHER Emmanuelle	SCALES - FP7 Cooperation 225 k€	2009-2014
N°7,1,8	B. Andrieu/ S.Lemarié/ A Gauffreteau/J.Enjalbert	BREEDWHEAT, ANR Biotech & Bio Ressources, 300 /150 /230 K€	2012-2019
N°7	B Andrieu/S.Saint-Jean	ECHAP, MEEDAT, 200 K€	2010-2014
N°7	B Andrieu	ARCHIBLE, Arvalis; 77K€	2012-2015
N°8	Stéphane Lemarié	Rapsodyn, ANR, 150K€	2013-2019
N°8	Stéphane Lemarié	VESPA, MinAgri, 30K€	2013-2015

N°11	Pierre Labarthe	PROAKIS, EU, 250 K€	2013-2015
N°11	Pierre Labarthe	Bip-Pop, ANR, 10 K€	2010-2013

6. SCIENTIFIC JUSTIFICATION OF REQUESTED RESSOURCES

Our budget slightly exceeds the recommended maximum amount (140 k€), and the ratio of CCD PM/permanent PM (38%) due to the large number of partners (11), the multiple field experiments, and the labour intensive experiments. A large fraction (40%) of non-permanent PM are master students; we believe that their involvement in large scale projects is key to their scientific training. The presented budgets have been tightly adjusted to the tasks, and we will look for complementary funding (INRA/region/Labex), to support our two meetings (scientific and stakeholders), as well as develop connected analyses..

6.1. PARTNER 1: GV

Equipment

One node to the GV-computing cluster and a phenotyping CCD camera: 12 000€

Staff

Two master students, working o phenotyping experiments and genetic anayses 5 240€

An engineer will be recruited during 24 months (Yr2-3) to organise the experiments in the farm network, and between Wheatamix partners, collect, cure, analyse data and disseminate the results 88700€

A PostDoc will be recruited during 12 months (Yr3) to i) assess the genetic variability of yield components and simple architectural traits in pure and mixed stands of the 50 common genotypes and 300 MAGIC lines, ii) association mapping of mixing ability traits using the available SNP data 44 350€

Operating costs

- Travel

Project management – T0.1 coordination – farm-network visits 10 000€

Participation of the team to Wheatamix project meetings 6 000€

- Others

Final scientific and stakeholders meetings organisation 15000€

Field consumables, publication costs 19 500€

Total 200 790

6.2. PARTNER 2: AGRONOMIE

Equipment

Two computers and small equipment related to computer use: 4000€

Staff

A funding of 5240€ is asked for the grants of two master students who will assist us to: i) Organize and analyze the available data produced by the partners in previous projects, and prepare a first list of rules for ideotyping, ii) analyze the first year trial results and prepare the second ideotyping exercice.

An engineer will be recruited during 12 months in the first year of the project to design and build blends through an ideotyping approach with the partners: 44350€

Operating costs

Travel: The abundant exchanges with stakeholders (interviews, working groups) and the visits on the field trials need a substantial budget for travels: 10000€

We are also asking for 4000 € to allow the membersof the projects to attend an international conference.

Plant and soil analysis:

Nitrogen rate of the crop at the harvest and at the flowering period: 5.5€ x 2 years x 50 trials x 3 repetitions x 2 varieties x 2 stages = 6600€

Soil characterization for a dynamic characterization of water and nitrogen available for the crop (mineral and organic nitrogen, structure, carbonate): 11.5€ x 2years x 50 trials x 3 repetitions = 3400€

6.3. PARTNER 3: BIOEMCO

Staff

The funding (5800 €) of the grants for two master students (M2°) is necessary to allow the very time-consuming identification of the soil macro-fauna (WP2).

Operating costs

Travel: To achieve the sampling of soil macrofauna and collembola (WP2) 9000 € are necessary to go to the field site, extract blocks of soil and sort out the fauna. We are also asking for 3600 € to allow themembers of the projects to attend an international conference.

Consumables: A part from the necessary small field equipment and consumables (2000 €), 2000 € are necessary to buy ¹⁵N labeled ammonium (65 plots X 2 years X 15.3 €), 900 € are necessary for ¹⁵N measurements (4 measurements X 65 plots X 2 years X 19 €), and 6000 euros for the identification of soil fauna by international experts.

6.4. PARTNER 4: BIOGER

Equipment

2 data acquisition pads for collecting field data for 2 binomes during 2 days per scoring mainly in the diversity trial and also the multisite trials 3 000 €

Staff

AJT 3 months (WP2) 6 689 €
will participate to the analysis of resistance to major foliar diseases as the function of diversity of plots in the factorial experiment” (65 plots for 2 years, 3 scorings per cropping season on individual plants).

Travel

Field sampling travel for following the diversity experiment during all the cropping season, going to do the scoring and the third year to travel in the multisite plots (1 000 € x 4 years) 4 000€
Meetings between partners of the project & one international colloquium 3 000 €

Other expenses

A sample of some blends will be identified using microsatellite markers to assess the contribution weight of varietal component to disease reduction, Microsatellites analysis for variety identification (3 years) 5 000 €
Additional analyses 5 000 €

Total

23 000 €

6.5. PARTNER 5: CERSP

Post-doctoral researcher 24 months (24 x 4500)= 108 000€

The postdoctoral researcher will be in charge of the study of below- and aboveground biodiversity (months 6-30): collection of samples in the field, species identification (highly time-consuming) and data analysis. He/she will be sharing his/her time equally between CERSP and BIOEMCO and will be supervised jointly by E. Porcher and S. Barot. He/she should be familiar with the taxonomy of at least one arthropod group (training for other groups will be provided by hosting labs) and have strong skills in uni- and multivariate statistics. He/she will be helped by CERSP and BIOEMCO technicians and master students (see below) for sample sorting and identification.

Master students 12 months (12 x 483) = 5 800€

Two master students (year 1 and 2) will be studying the relationship between wheat diversity and species diversity of specific taxonomic groups (springtails and carabids), under the joint supervision of E. Porcher and the postdoc researcher. They will assist the postdoctoral researcher in the field, help with species identification (for which they will receive training) and analyze their own dataset.

Operating costs

1000 pitfall traps and other field material 4 000€
Stereo zoom microscope for invertebrate identification 2 000€
Travel to experimental sites (6 sites in France, 2 to 4 times a year) 7 500€

Travel to national and international meetings	5 000€
Grand total CERSP	132 300€

6.6. PARTNER 6: CA

The work of the CA is relying on a network of 6 Chambres d'Agricultures, headed by D. Descoureaux, Loir-et-Cher, CA41. For sake of simplicity, CA41 is the only declared partner, who will distribute the funds to the 5 other partners. This explains why the budget is charged with important subcontracting costs.

• *Operating costs:*

Coordinator:

Travels: Meetings and visits for the coordination of CA: 3 days x 2 years, and project meetings in year one for the ideotyping exercise = **3 000 €**

Travels and consumable for field experiments identification and monitoring in 8 farms (2 yrs) and dissemination = **12 000 €**

Subcontracting with the 4 CA and FDGEDA18 for the rest of the farm network (2 yrs):

Identification and validation of the 47 case studies (diversity of management practices, diversity of soil and climatic conditions); implementation and monitoring of the experiments; data analysis and synthesis = **61 000 €**

Travels for the subcontractors: project meetings in year one for the ideotyping exercise = **5 000 €**

Total CA: **81 000 €**

6.7. PARTNER 7: EGC

Equipment

High resolution camera and telelens (T1.1°) + Weather station and computer 10 000 €

Staff

IE 25 month 70 700 €

“Coordination of the operational setup and survey of diversity experiment” (all partners IE based at INRA-Versailles-Grignon) .The engineer will be in charge of the setting up and coordination of diversity experiment at INRA-Versailles (65 plots for 2 years) follow the agronomical status of the crop, and asses field measurements in collaboration with the partners of WP2.

IE 9 Months (T1.1) 26 600€

“Design of novel methods and use of novel instruments for phenotyping plants indoor and outdoor. (running the Faro Lidar for 3D imaging of wheat canopies in the field and analysing the data the compute light penetration, and characterize leaf geometry and (ii) defining protocols for indoor phenotyping,

Post Doc 12 Months (T1.2) 50 900€

Designing a 3D, structural-functional, individual-based model, of wheat simulating plant to plant interactions for light and N capture in a wheat association. This will results in an individual-based model of a wheat plant growing in a field, implementing and assessing model in which the genotype differs between plants.

PhD 3 years half grant 18 month 46 720 €

“Influence of the levels of wheat biodiversity on spore dispersal of fungal pathogens” He/she will be co-supervised by EGC(S.SJ) & BIOGER, and will develop by the means of biophysical approaches and field experiments, criteria for limiting spread of fungal aerial diseased within blends. A model will be developed to describe the pathogen splashing within a heterogeneous virtual plant canopy (3D plant models developed in WP1) in order to rank different criteria of the design of wheat variety blend (proportion, level of resistance and number of varieties). The half of the grant will be asked to other funding.

Operating costs

T1.1 3D Faro lidar, rental and consumable to build a mobile carrying platform 6 000 €

T1.1 building a system of indor2D and 3D image acquisition (consumableand software): 3 000 €

T1.1&T2.3 Field plot rental and consumable and analysis for agronomic experiments: 5 000 €

Travels

T2.3 Mission to Nancy & Field sampling 4 000€

T1.3, T2.3 & T3.3 National and international meetings 11 000 €

Grand total EGC

233 920 €

6.8. PARTNER 8: GAEL

Equipment

- Small equipment related to computer use: 500€

Staff

- Two months of technician level temporary employment is necessary for assisting the survey preparation and treatment of the task 3.2: 5000€

- Part of the task 3.2. will be made within a 6 month master student work: 2620€

Operating costs

- Travel for WP meetings and task 3.2. survey are necessary for 5500€

- Software licence and documentation: 1000€

6.9. PARTNER 9: GDEC

Research technician (2 x 3 months = 13 377 euros). The technician will be a support for the WP1 task held in Clermont-Ferrand. 3 months are needed for the root trait genetic screening in year 1 and three months are needed to support permanent technician with the controlled conditions experiment planned in year two of the project.

Master students (2 x 6 months = 5800 euros). One master students will be allocated to the screening of root trait genetic variability in year 1 and the second will be in charge of the year 2 controlled conditions experiment.

Operating costs

Field plot rental (54KE). Field experiments will be dispatched over INRA experimental units in 3 or 4 sites. Experiments will include 100 blends, 2 N treatments, 3 replicates and will be held two successive years. Estimated plot price is 15 euros.

Controlled conditions experiment (10 KE). Cost for the controlled condition experiment includes controlled chamber fluids, cost or irrigation systems and small equipment related.

Subcontracting

Genetic variability screening experiment (10 KE). This experiment will be held in CIRAD Montpellier.

Travel: Travel to meetings and multi environment trial supervision. (4 KE).

6.10. PARTNER 10: LEM

Equipment

Incubator: 8 520€

Staff

Casual staff: Technician 4 months (4 x 2900.25)=11 601€

Casual staff: Post-doctoral student 24 months (24 x 3875)= 93 000€

Competencies: Analysis of the in situ effect of wheat variety diversity on soil microbial activity, abundance and diversity implies a huge amount of work and high number of samples, and the ability to use ANR funding is thus requested for a post doctoral fellow for 24 months (years 2 and 3). He/she will be responsible for the analysis of the impact of variety diversity on the abundance and diversity of key soil microbial functional groups involved in N cycling: use of a range of molecular tools to characterise the copy numbers of target functional genes, and the diversity of functional groups of interest. He/she will be supervised by X. Le Roux and A. Cantarel. He/she will benefit from other measurements performed by different project participants (WP1 and tasks 2.1 to 2.4 mainly). He/she will have a solid background in microbial ecology and the ecology of N-related groups, and experience in advanced, molecular ecology such as environmental DNA extraction, quantitative PCR and pyrosequencing. He/she will have to lead the study of the relationships between variety diversity levels and the activity, abundance and diversity of key soil functional groups part of Task 2.2, and will also participate in the field campaigns and microbial activities measurements on year 3.

Operating costs

Travel: Tasks 1.1, 2.2, 2.5 and WP2 coord. Costs cover travel to field-sites for measurement campaigns/sampling: 4 dates for Lyon-Versailles, plus 5 travels to multi-site trials ; travel costs to Task meetings and project annual meetings. Total: 8 000€

Consumables (WP1 & 2). Funding is requested to cover for:

- 15N assays on wheat varieties = (40 varieties x 25)= 1 000€

- measurements of mineral nitrogen by resin bags = (520 samples x 7)= 3 640€

- measurements of mineral nitrogen extracted from soil = (520 samples x 6)= 3 120€

- measurements of nitrification and denitrification (455 samples x 17) = 7 735€

- for 260 samples, DNA ext.+ qPCR for 5 functional genes (36 € per sample) = 9 360€

- for 65 samples, analysis of the diversity of 3 target genes = 19 500€

Total LEM:

165 476 €

6.11. PARTNER 11: SAD-APT

Equipment

- Small equipment related to computer use: 3000€

Staff

- Part of the task 3.2. will be made within two 6 month master student works: 5240€

Operating costs

- Travel for WP meetings and task 3.2. survey are necessary for 7500€

- Software licence and documentation: 2000€

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