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Functional trait-based approaches applied to agricultural sciences

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Trait-based approaches applied to agroecosystems: Towards a better understanding of agroecosystem services

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AVERTISSEMENT

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Formation par la recherche, Projet de Fin d'Etudes en génie de l'aménagement et de l'environnement

La formation au génie de l'aménagement et de l'environnement, assurée par le département aménagement et environnement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme, de l'aménagement des espaces fortement à faiblement anthropisés, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir-faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

- Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,
- Accroître la capacité des ingénieurs en génie de l'aménagement et de l'environnement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de fin d'études (P.F.E.), situé en dernière année de formation des élèves ingénieurs. Cet exercice correspond à un stage d'une durée minimum de trois mois, en laboratoire de recherche, principalement au sein de l'équipe Dynamiques et Actions Territoriales et Environnementales de l'UMR 7324 CITERES à laquelle appartiennent les enseignants-chercheurs du département aménagement.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

- Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement
- Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne sur la base du Système Universitaire de Documentation (SUDOC), les mémoires à partir de la mention bien.

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CONTENTS

Introduction

Nowadays, there are more and more concerns about the environmental sustainability of intensive agriculture (soil degradation, loss of biodiversity, etc.) and its dependency on artificial inputs (pesticides and fertilizers) (Damour et al. 2018; Roucou et al. 2018). Modern cropping systems attempt to maximize one ecosystem service (food provision from a single crop), but this results in a reduction of biodiversity and ecosystem services related to ecosystem regulation (Santos et al. 2021). Over the past 30 years, alternatives to this system are widely discussed and sustainable agricultural management practices are set up around the world in order to create more resilient agroecosystems facing climate changes and less dependent on chemical inputs (Damour et al. 2018). Research in this field broadly focuses on understanding how more biologically complex systems may present short- and long-term environmental and socio-economic benefits, such as enhanced food security, ecosystem service provisioning and agricultural resilience to environmental change (A. R. Martin and Isaac 2015).

It becomes more and more important, especially in this time of climate change, to understand how biota and fauna respond to biotic and abiotic changes in a global way to enable us to create and arrange resilient systems (Wood et al. 2015, Garnier and Navas 2012). We imperiously need to predict changes in vegetation in response to global change drivers. Consequently, the scientific sphere searches for simplification of floristic complexity (Garnier and Navas 2012). For this purpose, trait-based approaches (quantifiable morphological, physiological, chemical or phenological property of a plant) are more and more applied to agroecological science, to understand the functional properties of agroecosystems and how the biota and fauna within these managed ecosystems impact the services or disservices they provide (Wood et al. 2015). Furthermore, one of the reasons for an increased number of research papers using the trait-based approach in recent years is the promise of its generality, synthesis and predictive ability (Santos et al. 2021).

Here comes the following issue: how functional trait-based approaches could help us to understand and to predict agroecosystem services in order to install more complex and resilient systems facing climate change and facing our dependence on inputs?

To answer this question, I carried out some research on the database Web of Knowledge with the three following word combinations:

- Functional trait, Agriculture, Ecosystem service, Resilience
- Functional trait, Agroecology
- Functional trait, Agroecosystem, Ecosystem service

For these combinations, 16, 68 and 54 papers were respectively displayed on Web of Knowledge. Considering this set of papers, I selected the ones that best fitted the previous issue.

1. Definitions

To understand what will be further depicted in the review, here are some definitions of the central terms.

1.1. Agroecology

Through the scientific literature, it came out that agroecology is currently defined as an approach that promotes environmental conservation, ecosystem health and social equality in the global food system (Lichtfouse 2016). Agroecology is the contraction of the words "agronomy" and "ecology". It is the science of ecology applied to agriculture (Monteduro et al. 2015). In agroecology, agroecosystems are considered as domesticated ecosystems, an intermediate between natural and fabricated ecosystems (Odum 1971). Agroecosystems are also recognised as functional ecosystems (Damour et al. 2018).

1.2. Functional trait-based approach applied to agriculture

Functional trait-based approaches are used to understand or predict the causes and consequences of biotic or abiotic species interactions, as a function of the physiological, morphological, chemical or phenological characteristics of organisms (A. R. Martin and Isaac 2015). These approaches are applied to diverse topics especially in ecology, such as the characterisation of community responses to environmental changes and how organisms participate to ecological processes. Trait-based approaches are less based on fine taxonomic knowledge than usual studies on biodiversity and ecosystems, and allow for more general and comparable conclusions than a species-by-species approach (Nock et al. 2016). The prospects to apply approaches based on traits in the field of agriculture are wide (Garnier and Navas 2012).

However, adapting trait-based to agricultural systems requires taking into account farmer's decision-making, which differs from trait-based approaches applied to the field of ecology, which involves considering:

- the farmer's control over community structure through the choice of planned species and their spatial organization
- the high degree of control of environmental filters via technical practices
- a shift in the relative importance of services considered, to account for the greater share of agricultural production in agroecosystems (Damour et al. 2018).

The application of ecological theory to agricultural systems, as the use of trait-based approaches in agroecology, needs to consciously take into account existing on-farm practices (Isaac et al. 2018).

1.3. Functional traits

Here is a common definition of a functional trait: 'functional traits are morphological, biochemical, physiological, structural, phenological or behavioural characteristics of organisms that influence how they respond to the environment and/or their effects on ecosystem properties. A trait is a feature measurable at the level of the individual, which does not require additional information from the environment or at any other organization level (Violle et al. 2007). These traits have varied scales of study: it goes from genetic and an individual perspective to habitats and global scales of integration (A. R. Martin and Isaac 2015).

The definition of a trait also emphasises the two main raisons d'etre for trait-based approaches: to quantify trait-ecosystem 'effects' and trait-environment 'response' relationships (Nock et al. 2016). Effect traits of a species are those that determine its influence on ecosystem properties and, in turn, the services or disservices that human societies derive from them. Response traits influence the abilities of species to colonise or thrive in a habitat and to persist in the face of environmental changes (Nock et al. 2016). This coupled 'response and effect' framework (Figure 1) has led to better predictions of several aspects of plant community structure and function in ecology, including many that are relevant to agricultural management such as plant resource requirements for growth and survival, plant responses to disturbance, plant invasion dynamics and ecosystem service provisioning (A. R. Martin and Isaac 2015).

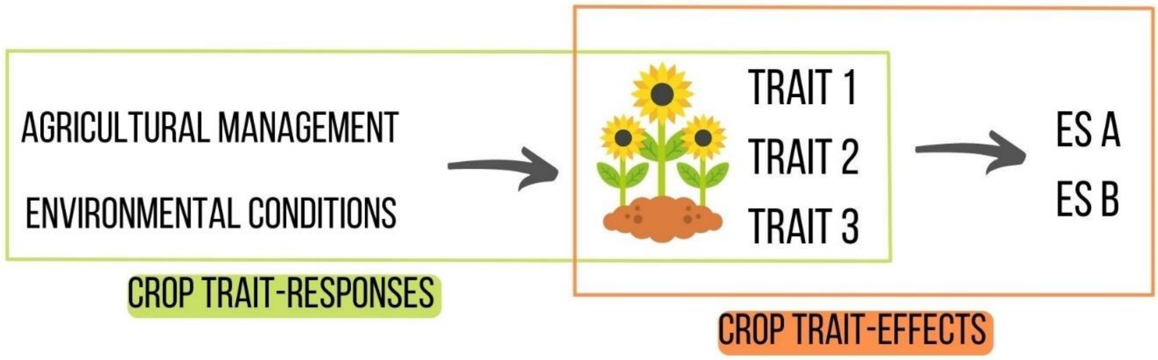

Figure 1 : 'response and effect' framework. ES = Ecosystem Service.

1.4. Functional diversity and the multifunctionality associated

Considering the previous definition of functional traits, functional diversity represents the value, range, and relative abundance of the functional traits of the organisms in communities that respond to the environment and influence ecosystem functioning. Functional diversity also includes the richness of functional types, which refers to a non-phylogenetic group of species functioning similarly with respect to environmental variation or presenting similar effects on ecosystem properties. Functional diversity measures could bridge the gap between ecosystem functioning and community ecology (Faucon et al. 2017).

Functional diversity could lead to multiple ecosystem services that are defined as ecosystem processes which confer either direct or indirect benefits to humans. Here we talk about the goods that are directly used by humans (food, energy, and fibre) and the ecological processes affecting the provision of these goods (pollination, soil fertility, etc.) (Faucon et al. 2017). However, ecosystem services are still poorly described, or it is impossible to quantify them. They are often achieved through monetary evaluation, which requires many hypotheses that are mostly context dependent. In addition, quantifying ecosystem services as if they were independent of each other can be in vain. Instead, we focused on agroecosystem properties that were available in the literature and hypothesized as indicators of ecosystem services (Guiguitant et al. 2020). Agroecosystem properties can be defined as indicators, quantifiable this time, of a state of the ecosystem considered such as crop growth rate, crop

N acquisition, C: N ratio, etc. that can be measured/calculated with functional traits (Tribouillois et al. 2015).

Below, the study of agroecosystems under trait-based approaches is depicted as promising in allowing us to better understand the relationships between agrobiodiversity and ecosystem services, which for the moment remain misunderstood mechanisms in the scientific literature.

2. The role of functional diversity to increase ecosystem services (trait-effects)

Crop diversity management in agriculture is a fundamental principle of agroecology and a powerful way to promote resilient and sustainable production systems (Wagg et al. 2021). As seen above, functional diversity has the potential to drive multiple ecosystem services. However, to increase efficient diversity within cropping systems and to deal with multiple ecosystem services, choosing appropriate species is an important prerequisite (Guiguitant et al. 2021). The study of agroecosystems through functional traits allows us to better understand how to manage the diversity of our agricultural systems (associated species mixtures, choice of crop sequences for rotation, etc.) in order to generate multiple ecosystem functions. Several studies have been carried out, both field experiments and studies on existing trait data in the scientific literature to explain and predict combinations of traits for diverse ecosystem services. It appears that traits of crops can be good predictors of plant effects on ecosystem services and that functional traits of crops may be considered as an informative tool as to the potential of a crop to promote a desired agroecosystem service (Wagg et al. 2021; Navas 2012).

2.1. Crop traits are associated to ecosystem services and have trade-offs

Crops vary greatly in the traits by which they capture resources and influence the local ecosystem (Wagg et al. 2021). In their paper, Wagg et al. investigate the characteristics of cover crops and associated soil microbial communities that are linked to certain ecosystem services: above biomass production, nutrient capture, weed suppression, erosion control and building particulate organic matter. To measure ecosystem services, the authors used a set of agroecosystem properties that refer to specific ecosystem services. For instance, estimating weed cover and weed biomass can give an insight into the capacity of a crop to fulfil weed suppression ecosystem service (Figure 2).

Agroecosystem property	Ecosystem service
Standing crop N	Nutrient capture
Standing crop P	
Soil ammonium (NH4)	
Soil nitrate (NO3)	
Weed cover	Weed suppression
Weed biomass	
Crop cover	Erosion control
Winter cover	
Rooting density	
Particulate organic C	Soil building
Active carbon	
Particulate organic N	
Aggregate stability	

Figure 2: Agroecosystem properties associated with an ecosystem service measured on the field (Wagg et al. 2021)

Analysis of functional traits enable Wagg et al to identify full season cover crops that maximise specific ecosystem services. These results show that not all crops are equal in their abilities to promote various ecosystem services, some crops may promote agroecosystem services but may have a potential trade-off with another agroecosystem service. For instance, legumes were particularly effective at capturing more nutrients from the environment due to their symbiotic reliance on rhizobia and arbuscular mycorrhizal fungi. However, the residual NO_3 remaining in the soil at the end of the growing season was higher with legumes. It means that legumes can fix atmospheric nitrogen and make it available for the next crop, but can capture the nitrate residues applied by fertilisers to a lesser extent (Wagg et al. 2021). In another hand, a study conducted on 30 pulses varieties belonging to 10 species identified seven clusters of species based on their agroecosystem properties trade-offs (Guiguitant et al. 2021). For instance, the first cluster grouped species with high production (Grain Yield and Biomass Yield) as well as a high maximum soil cover and soil cover duration, but a low Ndfa (Nitrogen Derived from Atmosphere) and a low biomass and LAI (Leaf Area Index) at flowering. Thus, this group of species is well suited at giving food production service but not at the catch crop effect service. Afterwards, researchers identified the traits affiliated to these seven clusters to define trait syndromes corresponding to agroecosystem services. For instance, the cluster 1 varieties are characterised by a LNC (Leaf Nitrogen Content) between 2.7 and 3 $mg.N.g^{-1}$ offs (Guiguitant et al. 2021). In a similar perspective, Honvault et al. aimed to characterise the relationships among traits involved in P acquisition to explore trade-offs and the P-acquisition strategies. Trade-offs between thicker and thinner roots were observed, with thicker roots exhibiting greater P capture (Honvault et al. 2021). Bukovsky-Reyes et al also found some support for root trait trade-offs between hairy vetch and cereal rye (Bukovsky-Reyes et al. 2019)**.** Hence, considering ecosystem services at a species level, trade-offs always occur. Species differ in their ability to provide ecosystem services, and are often specialised in some of them, to the detriment of other ecosystem services (Figure 3).

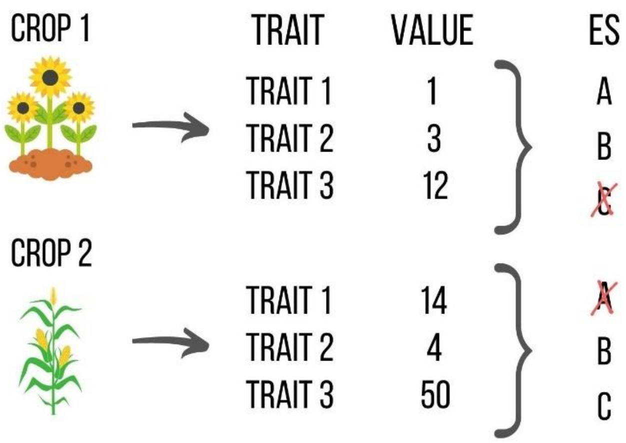

Figure 3 : Scheme of trade-offs occurring for each crop. ES = Ecosystem Service.

Finney and Kaye and Blesh found that at a community level, when functional diversity increases, an increase in the number of ecosystem services produced is observed (Finney and Kaye 2017; Blesh 2018). However, there are trade-offs among functions in which increasing functional diversity enhances some functions and decreases others (Blesh 2018). Therefore, agroecological services provided by functional diversity do not necessarily outperform the highest performing monocultures in the provision of individuals services. Still, polycultures may be beneficial if they perform better than monocultures at simultaneously providing multiple ecosystem services (multifunctionality) (Finney and Kaye 2017). These findings highlight the need to better understand competitive interactions in mixtures by deeply taking into account trade-offs in order to create efficient crop mixtures to increase the number of ecosystem services produced and at the same time increase their performance (Blesh 2018; Bukovsky-Reyes et al. 2019). Finally, Finney and Kaye also found that species-based indices have lower explanatory power compared to abundance-weighted functional diversity indices. It suggests that species abundances alone may not reflect the optimal functional trait distribution, an important consideration for designing multifunctional agroecosystems (Finney and Kaye 2017).

These articles highlight the importance of crop mixtures and functional diversity in agroecosystems to provide multiple ecosystem services. Functionally diverse and not necessarily taxonomically diverse, plant communities are strongly correlated to positive ecosystem processes (Buchanan et al. 2020). It also emphasises the need to choose plant associations that provide complementary ecosystem services as each plant is characterised by ecosystem services trade-offs. This choice of association could be facilitated by studying functional traits as they are seen as predictors of ecosystem services. However, functional complementarity requires further detailed research, as competition among crops and lower densities of individual crops within mixtures may respectively interfere or dilute their abilities to enhance an ecosystem service (Wagg et al. 2021).

2.2. Understanding interspecific crop competition to enable complementary association of crops and weed regulation

To attempt a response to this question of the process of competition occurring among crops (Figure 4), Tribouillois et al developed a predictive model for agroecosystem nitrogen functions provided by cover crop species in bispecific mixtures. This study, which considers the competition between two crops (a legume and a non-legume species) developed a model that indicates the traits of the two plants that must occur in order to produce several complementary ecosystem services without interfering their abilities to enhance ecosystem services (Tribouillois et al. 2015). In this study, functional trait differences between the two species explain the interactions for resource use and the competition intensity. Functional trait also helped at explaining ecosystem services (catch crop effect and green manure effect) with positive or negative correlations between functional trait differences and agroecosystem properties (Tribouillois et al. 2015).

In addition, several papers highlight that functional traits can depict plant strategies in relation to their environment and the way they acquire resources. The analysis of the pulse crop put forward that functional traits can be classified in three ecological strategies, associated with life forms already described by Grime in ecology sciences (Guiguitant et al. 2020) : producers (associated to R-strategy), competitors (associated to C-strategy) and stress-tolerant species. In another hand, Honvault et al establish that crop species are split into four plant strategies for P acquisition (Honvault et al. 2021). The diversity of strategies demonstrates a potential for functional diversity benefits in cultivated plant communities via preferential access to different P pools leading to complementarities and reduced competition for resource acquisition (Honvault et al. 2021).

The process of crops-weeds competition and how to manage it is discussed in other papers, because weed regulation is one of the biggest issues in agriculture. For example, in 2010, Smith et al. created a new hypothesis called the Resource Pool Diversity Hypothesis (RPDH). It aimed at explaining how soil resource pool diversity may mediate competition for soil resources between weeds and crops. The better resource pool diversity elements such as NPK available under different forms and in different spaces in soil, the lesser weed-crop competition (Smith et al. 2010; Navas 2012). This hypothesis is based on the concept of niche and functional traits. At the origin, the concept of niche is used in ecological models to explain plant species coexistence and can be correlated to weed-crops interactions here. The niche concept implies that resources differ along some environmental axis and that species differ, however slightly, in their needs for and ways of acquiring these resources. In addition, this paper argues that the breadth of a species' soil resource niche is determined by species-specific functional traits for resource acquisition (such as roots length, ability to fix atmospheric nitrogen, association with soil microorganisms, tissue recalcitrance, etc.). Thus, functional traits related to resource acquisition (such as root traits) defined a niche for each species in an agroecosystem. It is also maintained that agricultural management (crop rotation, utilisation of fertilisers, etc.), in addition to soil type, is the main generator of resource pool diversity. Then, the more diversity in soil resources, the more weeds and crops will use different strategies to obtain nutriments (Smith et al. 2010).

In addition to developing different resource pool diversity to reduce crop-weed competition, some studies underline the fact that we could enhance weed regulation and reduce crop-weed competition by understanding weed trait syndromes (Gunton et al. 2011; Navas 2012; Pinke and Gunton 2014;

Mahaut et al. 2019). Weed trait syndromes differ in extensive and in intensive systems. In intensive systems, they are usually large plant height, short life cycle, low seed size, and have opportunistic phenology (longer potential flowering periods to cope with herbicide application). In extensive systems, weed are shorter, have divergent seed weights (very high or very low) and flower later than species found in more intensive systems and contain the highest proportions of rare and red list species (Navas 2012; Pinke and Gunton 2014). However, studies pointed out that phenological traits of weeds are the best predictors of weed proliferation, and that consequently, the strongest filter on weed traits is crop sowing date (Gunton et al. 2011; Mahaut et al. 2019; Ciaccia et al. 2020). Consequently, farmers may achieve better control of weed abundance and lesser crop-weed competition by increasing the diversity of crop sowing dates across the crop sequence of their rotation. Here trait-based approaches can provide useful information about the selection of crop phenological traits and the seedbank of the previous and subsequent crops in the rotation (Mahaut et al. 2019).

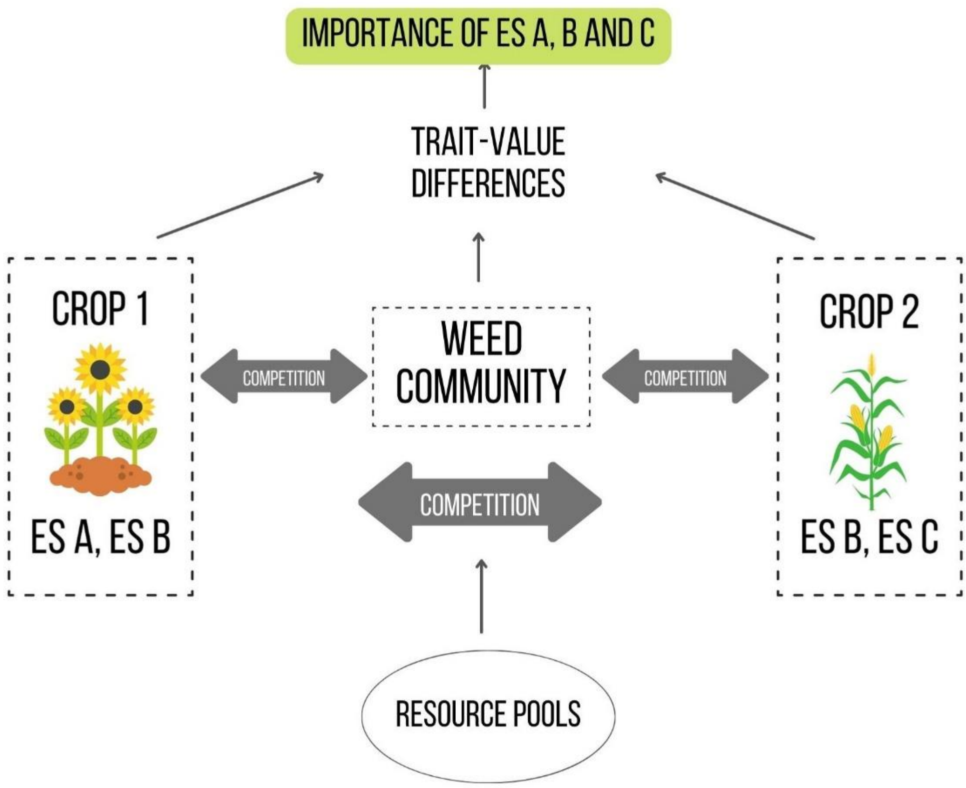

Figure 4 : Competition among crops and among crops and weeds. ES = Ecosystem Service.

Even though many research are conducted on weed regulation, the recent emergence of the concept of ecosystem services has led to the recognition of the positive impact weeds can have on the agroecosystem. To that aim, a framework recognising three categories of weeds, involved in the whole range of ecosystem services, has been recently proposed: species with high intrinsic conservation value or because of sheltered biodiversity, species contributing to the production of food for animals, or to services of regulation such as pollination or limitation of soil erosion and species with no intrinsic value but that are used as indicators of high-quality practices (Navas 2012). Thus, one of the objectives of functional trait-based approach for weeds is to understand how to manage weeds not to eliminate them but to reduce their impact on cash crops for farmers. In fact, farmers can enhance weed diversity in their fields by sequentially sowing crop species that differ in their competitive ability and sowing dates (Mahaut et al. 2019).

2.3. Intraspecific competition at a plot scale

The design of crop mixtures and intercropping systems could lay on resource-use complementary mechanisms and the choice of species and varieties displaying contrasting functional strategies (Roucou et al. 2018). However how intraspecific competition interfere in functional diversity is poorly documented and variation in intraspecific traits is generally considered of marginal importance compared to differences in interspecific traits at a plot level (Garcia et al. 2020). Guiguitant et al, in their study on pulse crops, found that interspecies variance explained 81% of the functional diversity, while intra-species explained 19% (Guiguitant et al. 2021). This low rate for intraspecific diversity could be partially explained by agricultural management and the domestication syndrome. In fact, the ITV (intraspecific trait variability) of plants growing in high-resource agricultural conditions does not express the same trade-offs compared to those observed among wild plants. It supports the hypothesis that artificial selection and high-resource agricultural environments lead crops to systematically deviate from trade-offs leaf traits observed across wild plant species and interspecific functional diversity (A. R. Martin et al. 2017). For instance, ITV in weeds plays a strong role in their functional diversity strategies. On average, ITV accounted for more than 50% of the total functional diversity (Borgy et al. 2016). To understand the process of the domestication of wheat, and shifts in plant functional strategies, Roucou et al gathered a collection of 39 genotypes representative of key steps during tetraploid wheat domestication and grew them in a common garden experiment and measured 13 functional traits. It came out that phenotypes of modern wheat varieties have converged towards a unique resource-use strategy due to homogenization and artificiality of the intensive cropping systems (Roucou et al. 2018).

Even though intraspecific functionality of domesticated plants at a plot level seems not to be really critical, intraspecific trait variation is more and more studied to understand crop trait variation and crop plasticity under environmental gradients at a larger scale (A. R. Martin et al. 2018; Hayes et al. 2019).

In fact, one of the challenges to manage ecosystem processes and services in agroecosystems based on a plant functional trait approach is to consider intraspecific trait variation and the plasticity of plant traits to understand these variations under various conditions. In fact, the capacity of a plant to provide some ecosystem services is also governed by climate, soil and agricultural practices (crop response) and not only on plant effect on its environment (Faucon et al. 2017). Even though previous studies underpin that functionally complementary multispecies crop design from a community-interspecific approach are a promising approach to design sustainable cultivated systems, it also seems essential to understand how environmental variables affect domesticated plants and how they respond under an environmental gradient, as it will affect plant trait-effects and consequently the importance of the ecosystem services provided (Garnier and Navas 2012).

3. Impacts of environmental and agricultural management on agroecosystems (trait-responses)

3.1. Intraspecific Trait Variation (ITV) of crops across environmental and agricultural management gradients: trait plasticity (crop trait-responses)

Through functional trait studies, researchers usually collect trait data from diverse environment and management contexts across organizational and spatial scales and seek to make generalizable predictions on these traits (Guiguitant et al. 2021). However, some studies have reported a significant effect of trait plasticity on the ranking of species and thus the ecosystem services provided by species across their developmental environment (Guiguitant et al. 2021; A. R. Martin et al. 2018; 2017; Borgy et al. 2016).

For instance, Guiguitant et al. collected data on pulse crops produced by 327 articles published around the world without considering climate or agricultural management variables (Guiguitant et al. 2020). They used simple aggregation functions (means, medians, etc.) to represent trait variations and correlations. However, some trait mean values from this study are different from trait values calculated in a field experiment which took place in France on pulse crops, especially for SLA (Specific Leaf Area) and LNC (Leaf Nitrogen Content) (Guiguitant et al. 2020; Guiguitant et al. 2021). According to the authors, environmental conditions and agricultural management explained these variations, meaning that traits should be studied in environmental and agricultural management gradients, to understand trait plasticity, intraspecific trait variation (ITV) and the consequences on the ecosystem services provided (Figure 5) (Guiguitant et al. 2021). How traits vary and respond with respect to environmental and management gradients is further depicted.

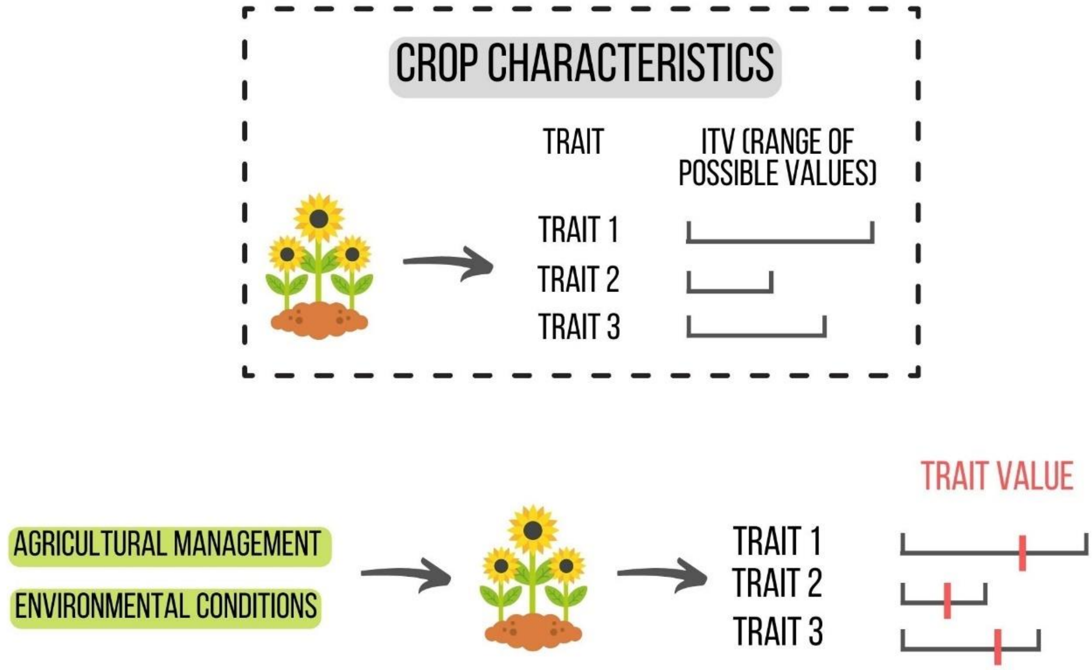

Figure 5 : crop trait-responses under specific management en environmental conditions. ITV = Intraspecific Trait Variation.

3.1.1. Crop plasticity according to soil properties

Several studies were conducted to understand the influence of soil properties (mainly P and N availability) on crop traits. In the first one, 13 species of diverse phylogenetic lineages were tested for P-acquisition trait strategies in two soil types: Calcaric Cambisol and a Retisol. They found that although expression of both P-mining traits and morphological traits are essential for P acquisition, their costs in a specific context may define how plants express and mix their functional traits. Reliance on either morphological or physiological traits and combinations thereof for P acquisition are strongly mediated by soil P forms. For instance, PME (Phosphomonoesterase) activity and carboxylate release were overall significantly lower in Calcaric Cambisol and root length density and surface area were higher overall in this soil than in Retisol, especially for Fabaceae and Brassicaceae (Honvault et al. 2021).

In addition to this paper, Tribouillois et al worked on a bispecific crop mixture, they found that soil environmental factors (water and N availability) were significant input co-variables on their own or in interaction for expressing the values of ecosystem services. In fact, environmental factors strongly interacted with functional trait differences. Thus, functional traits are impacted by growth conditions, thus it affects species competition and species ecosystem services (Tribouillois et al. 2015). In another hand Bukovsky-Reyes et al found support for the hypothesis that acquisitive traits for both species studied (rye and hairy vetch) would decrease in response to increasing soil N availability, with higher RL (root length) in more N limited conditions (Bukovsky-Reyes et al. 2019).

These studies highlighted the importance of considering environmental factors/plant interactions when attempting to improve our understanding of resource-acquisition strategies and traits developed by crops in order to associate the right ecosystem services they can provide to the right environment. Further studies on the impact of the environment and farm management on crop functional traits should help us select locally optimised crop services and facilitate species selection (Honvault et al. 2021; Tribouillois et al. 2015). This has been done by several authors, basing their studies on the variation of intraspecific traits of coffee crop (A. R. Martin et al. 2017; Fulthorpe et al. 2020; Gagliardi et al. 2015; A. R. Martin et al. 2018; Hayes et al. 2019).

3.1.2. Intraspecific Trait Variation across environmental and crop management gradients

Three studies have been conducted on coffee crop and its associated leaf traits in Central America across different gradients (management and environmental) (A. R. Martin et al. 2017; Fulthorpe et al. 2020; Gagliardi et al. 2015). In the first paper, the authors studied some leaf traits under four management treatments differing in shade-tree species composition (Gagliardi et al. 2015). In the second paper, four sites of coffee crops were studied:

- A hot and wet site
- A hot and dry site
- A cool and wet site
- A cool and dry site

There were two treatments for each site : full sun and intercropped with trees of N_2 fixing Fabaceae species (A. R. Martin et al. 2017). These papers highlight the following trends:

Table 1 : Trait trends in coffee crops (Martin et al. 2017; Gagliardi et al. 2015)

Trait type	ITV (Intraspecific	Particularities

	Trait Variation)	
Physiological traits	High	High plasticity and ability of coffee to acclimate leaf photosynthesis across light, temperature or moisture gradients
Morphological traits	Intermediary	Unstructured ITV, showing that these traits are highly responsive to localized environmental stimuli such as self-shading
Chemical traits	Low	ITV is highly structured according to management systems, in which leaves are sampled. It indicates that N2-fixing leguminous shade trees influence leaf N and C:N ratios traits

Gagliardi et al. found that there was no evidence that leaf traits covary systematically across the agricultural management gradient (shade tree treatment composition), but rather change in response to continuous variation in light levels that occurs irrespective of shade tree composition (Gagliardi et al. 2015). However, Martin et al. suggested that chemical coffee traits ITV changed with N2-fixing leguminous management (A. R. Martin et al. 2017).

In the last paper, the authors highlighted the fact that the expression of functional traits in coffee also depends on soil organisms, which in turn depend on environmental variables such as pH, soil C concentration, moisture, etc. Fungal communities stand out as the ones that vary most with these different variables compared to bacterial communities. Fungal communities were found to be the most variable with respect to these different variables compared to bacterial communities. The study also showed that root traits were not significantly related to variation in bacterial community composition. However, variation in bacterial communities was significantly correlated with two leaf physiological traits (mass-based photosynthesis and water use efficiency). Coffee root traits also varied significantly with fungal communities as did two morphological traits: leaf density and leaf mass per unit area (Fulthorpe et al. 2020).

The different coffee traits thus vary in a distinct way: physiological and morphological traits vary more in response to management and environmental factors than chemical traits. These trends are also confirmed for other crops such as wheat and maize or in willow agroforestry (A. R. Martin et al. 2018; Bukovsky-Reyes et al. 2019; Coleman et al. 2020). It also appears from all these studies that each trait has variable plasticity. However, the type of trait governs the trend. Indeed, for all the crops studied, the ITV of morphological traits appears globally more important, more plastic than chemical traits. Morphological traits also appear to be more influenced by localized environment and management. Physiological traits are also very plastic and depend on more global environmental such as precipitation and temperature on a site. This understanding of the plasticity of traits can help us understand how the environment modulates the ecosystem services provided by crops in a given system (A. R. Martin et al. 2017; Fulthorpe et al. 2020; Gagliardi et al. 2015; Bukovsky-Reyes et al. 2019; Coleman et al. 2020). These results show that if we want to create resilient ecosystems targeting specific ecosystem services, understanding the effects of functional diversity on a given environment is not enough. It is also necessary to take into account how this given environment (climate, agricultural management, biotic factors, etc.) impacts crop traits and how these in turn respond. The papers presented here provide insights into how the global environment of a crop affects it. Field studies or meta-analysis that evaluate ITV across key environmental gradients and management systems could make important contributions to our understanding of the functional ecology of many of the world’s most common crops (A. R. Martin et al. 2017).

Understanding crop ITV across environmental gradients could also enhance our agricultural adaptation facing future climate events. For example, understanding the ITV of crop traits under drought and water stress would allow us to adapt our systems in the future. Trait-based approaches help us to rapidly understand trade-offs and behaviours of plants facing these climate events. Traits syndromes enable us to put forward plant strategies that could quickly be interpolated to species with similar traits, and thus to design ideotypes of crops to ensure long-term sustainable production (Volaire et al. 2014).

Thus studies suggest that a better understanding of intraspecific variation in traits, can provide novel insights into the mechanistic linkages between environmental variables and management practices, and agroecosystem services (Gagliardi et al. 2015).

3.2. Impacts of agricultural management on arthropods communities (biological control and pollination services)

While management and environmental variables affect crop trait responses, they also influence trait responses of spontaneous biodiversity that occurs in agroecosystems such as arthropod communities which provide ecosystem services as biological control and pollination thanks to pest enemies and pollinators. In fact, landscape composition and configuration, and agricultural management gradient have important impacts on arthropod biodiversity, which are significant communities responsible of several ecosystem services as seen previously (Potapov et al. 2020). Changes in land use and management intensification, especially on agriculture, have led to alarming declines in arthropods populations and the important ecological services they provide (Odanaka and Rehan 2019). The relationship between the loss of taxonomic diversity of arthropods and ecosystem functions in agricultural landscapes can be disentangled with functional traits, meaning characteristics of individuals that are relevant to their role in ecosystem and govern their response to environmental changes and their effect on ecosystem functioning (Potapov et al. 2020; Gallé et al. 2019). In this way, trait syndromes can be identified and associated with agricultural management practices and landscape organisation, to understand how vary arthropods functional traits and then understand the alteration of ecosystem services they provide (E. A. Martin et al. 2019).

To enable biological control, the provision of diversified trophic resources and appropriate physical habitats are necessary to converse functional diversity of arthropods (Gardarin et al. 2018). For instance, it has been shown that management practices that increase habitat-structural complexity and plant diversity such as mulching, reduced weeding, and intercropping monocultures with other plants may contribute to maintaining functional diversity of and predation services provided by ground invertebrate communities in plantations (Potapov et al. 2020). Another study put forward that reduced management intensity (organic agriculture) and higher landscape heterogeneity (small-scale agriculture) promote functional diversity of carabids. (Gallé et al. 2019). Several attempts have been made to point out trait syndromes and trait metrics to use to understand how arthropods communities interact with their environment, however, this topic stays largely non explored (Gardarin et al. 2018; E. A. Martin et al. 2019) and generalization by trait-based approaches may be not appropriate for some interactions highly specific, between arthropods and plants for instance (Gardarin et al. 2018).

Concerning pollination service, Pisanty et Mandelik identify the differences in pollinator (especially bees) species composition between agricultural and surrounding habitats and which response trait may predict species tendency to cross the ecotone (transition between semi-natural habitat/agricultural land) and enter in agricultural field. They distinguish crop from non-crop pollinators based on a set of life history traits (nesting, lecty, sociability, body size) linked to habitat preference and crop visitation ; crop and non-crop pollinators are distinguished by behavioural and morphological traits (Pisanty and Mandelik 2015). Agricultural affinities of pollinators were strongly associated with nesting guild trait; aboveground nesters being largely confined to the seminatural habitat and the ground-nesting being more likely to be found in agricultural lands. Crop affinities strongly depend on the sociality of pollinators, which can also be related to lecty, as social species tend to be broadly polylactic. Thus, the delivery of crop pollination services will ultimately be determined by the behavioural and morphological traits of pollinators, and not by their presence in nearby (Pisanty and Mandelik 2015). Another study revealed that bee communities respond negatively to grazing pressures. However, even though the abundance and the richness of bee communities are reduced, functional diversity is conserved in the observed ecosystems (Odanaka and Rehan 2019). Nevertheless, the lack of functional redundancy can make these ecosystems vulnerable and non-resilient to further management or environmental changes (E. A. Martin et al. 2019).

In addition to estimating the functional diversity among arthropods and the services they provide, some authors recognised that the use of certain functional species as bioindicators is a valuable tool to measure how land use and environmental change affects arthropods communities. For instance, Odanaka et Rehan have determined potential bio-monitors for grazed landscapes and different levels of land use management, mostly based on behaviour and nesting biology traits. This type of functional bioindicator species could be used as a conservation tool to assess the effects of agricultural management and land use change on arthropods communities. This provides an insight into how landscape alteration can change the functionality of ecosystems, and how pollinators respond to these changes (Odanaka and Rehan 2019). Functional bioindicators can either measure land use and agricultural management changes or measure quality of functional restoration of damaged habitats. In fact, as functional trait-based approaches help us to associate species characteristics to ecosystem services, it could help us to restore or reinforce functionalities of the spontaneous biodiversity, or to adapt agricultural landscapes and management (Pisanty and Mandelik 2015). It can be the establishment of flower strips adapted to the ecosystem service that we want to restore. With careful selection of plant species, flowering strips can provide floral resources for both pollinators and natural enemies of crop pest in orchards for example, and enhance predator activity (Campbell et al. 2017).

Nevertheless, if data on crop traits and associated spontaneous biodiversity traits were all centralised and publicly available, there would be more opportunities to test hypothesis and models of trait variations to understand their responses and effects on the environment (Garnier and Navas 2012).

4. Centralization of data to test global hypothesis to enhance ecosystem services of agroecosystems

4.1. Trait-based approach potential for global predictive models

As we have seen above, we have the keys to understand crop-effects in a given environment through their traits and ecosystem services. This understanding, if further developed, would allow us to develop functional diversity in agriculture that would account for various ecosystem services. In addition, we also begin to understand how traits of different crops vary along environmental and farm management gradients (crop-responses). This knowledge can lead to global conceptual models to establish resilient agroecosystems, regarding climate, and environmental outputs (A. R. Martin and Isaac 2015; Garnier and Navas 2012). In fact several studies have suggested that functional diversity metrics could predict the multifunctionality of agroecosystems and then we could improve agricultural management (Finney and Kaye 2017; Bukovsky-Reyes et al. 2019; Blesh 2018). In another hand, Tribouillois et al developed a predictive model for agroecosystem nitrogen functions provided by cover crop species in bispecific mixtures using functional traits and environmental factors. Based on a bispecific mixture consisting of legume and non-legume species, the authors develop a conceptual model for the following indicator of agroecosystem functions (AEF): crop growth rate (CGR), crop N acquisition rate (CNR) and the C:N ratio. The magnitude of these services (CGR, CNR and C:N ratio) provided by cover crops can be used as indicators of agroecosystem functions (catch crop effect and green manure effect). CGR and CNR were used to measure the catch crop effect and the CNR and C:N ratio used to evaluate the green manure effect. This conceptual model aims to predict the growth of the non-legume and legume species to be sown in a field, to achieve a growth which is optimising the catch crop and green manure effects (ecosystem services) (Figure 6) (Tribouillois et al. 2015).

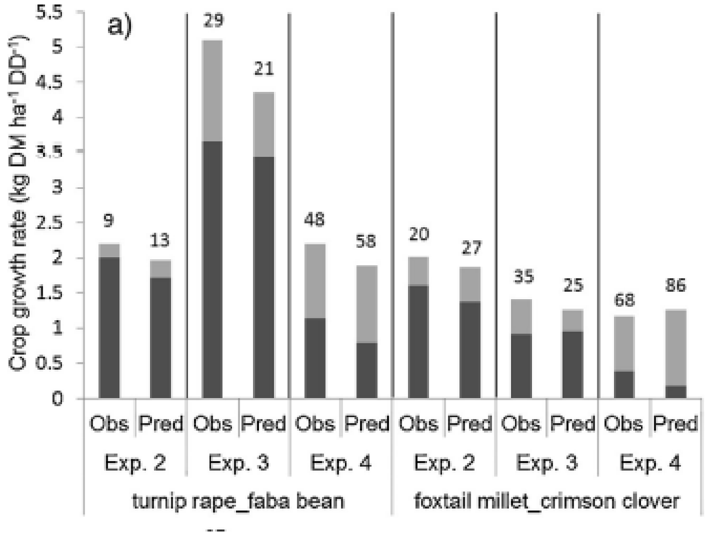

Figure 6 : Observed vs. predicted values for crop growth rate (CGR) of each species of turnip rape/faba bean and foxtail millet/crimson clover mixtures at three experimental sites and years (Experiments 2–4). Legume species are in gray and non-legume species in black. Numbers correspond to legume proportion in percentage (%) in the whole bispecific mixture (Tribouillois et al. 2015)

An interesting point is that this conceptual model was also able to predict AEF for species that were not used in calibration. It means that one application of the three AEF models could be to predict the behaviour of any given species, in a bispecific mixture, knowing its Leaf Functional Traits, the values of the potential AEFi of this species (Tribouillois et al. 2015). Even though Tribouillois et al based their studies on field experiments, other studies are based on peer's data and databases such as the TRY database, and attempt to interpret and predict interactions between crops and their environment (Guiguitant et al. 2020; A. R. Martin et al. 2018; Smith et al. 2010). They all show that there are possibilities to design and test trait-based predictive/conceptual models using existing data. These data sets of plant traits allow us to address general questions pertaining to plant functioning and evolution, as well as the effects and responses of plants on their environment (Garnier and Navas 2012).

According to Wood et al, spatial scales should also be integrated into modelling of trait-based ecosystem service predictive approaches. In fact, most of the studies focus on fine-scale ecosystem services. Yet, the authors sustain that we should first identify the landscape patches importance to the provisioning of certain ecosystem services. Services, key functional traits, and abiotic properties could then be measured in each of the components of the spatially structured landscape. Spatial configuration metrics could then be calculated to determine how space influences functional trait control of ecosystem services. Combining such spatial metrics with data on traits and abiotic characteristics would enable the development of spatially explicit models of ecosystem services that use point data to predict the landscape distribution of ecosystem services. Such a spatially explicit representation of traits and ecosystem services would also be important because functional traits, and associated services, can vary through the farmscape over time. For instance, plant matter of N2- fixing plants is often relocated from one field to another to improve soil fertility. Sampling vegetation and soil nutrient status in single plots would fail to identify the effect of N2 fixation on soil nutrient availability in the broader farmscape by ignoring this transfer of plant matter between farm fields (Wood et al. 2015).

Also, most research on biodiversity–ecosystem functioning has been conducted on single trophic scales. However, the ecosystem services provided by agriculture often depend on activity within multiple trophic levels and interactions across trophic levels. For instance, for pest control, consumptive predator activity traits (level 1) affect pest populations (level 2), which in turn affect crop yields. Thus, it is crucial not only to apply traits to understudied trophic levels, but also to understand the interactions among multiple trophic levels by quantifying effects and responses of each trophic level in an agroecosystem to know how they regulate ecosystem services (Wood et al. 2015).

4.2. The development of trait databases

4.2.1. Towards a data formalisation

Despite the growing interest of the scientific community on trait-based approaches to agricultural systems, it lacks structured available data (A. R. Martin et al. 2018) as it has been recognised four decades ago in molecular biology. Nowadays, there is no generally accepted format for trait databases (Garnier and Navas 2012).

Although the datasets constitute an invaluable resource for the scientific community as a whole, their compatibility, accessibility and further dissemination remain problematic. Some data sets are available as appendices to original or as ecological archives, and several attempts have been made to develop publicly accessible crop trait databases. However, it concerns only a small proportion of the data potentially available, and a comprehensive approach to data storing, management and retrieval for crop-based research is currently lacking. This involves devoting specific efforts to data integration, whose aim is to organise and structure the data currently stored in distributed repositories and in heterogeneous formats and make them available in easily and widely usable format. Beyond integration, such efforts would provide substantial added value to the data, which could then also be used in contexts different from those in which these were initially collected for, to address more general questions or simply different questions (Garnier and Navas 2012).

These issues have led to the recent development of ecoinformatics and the realisation of the importance of metadata (information about data, Table 2) and ontologies (formal models of knowledge covering a specified discipline in which each element is precisely defined and each possible relationship between data elements is parameterised or constrained) as applied to the field of ecology and that could be also applied to the field of agriculture. Ecoinformatics are a field of research and development focused on the interface between ecosystem-functioning, computer science, and information technology (Garnier and Navas 2012).

Table 2 : Examples of metadata of crop trait datasets (A.R. Martin and Isaac 2015)

Site characteristics	Management characteristics	Crop-level
quantitative characteristics such as geospatial information, altitude, atmospheric CO2 concentrations, monthly or annually resolved solar irradiance, temperature and precipitation rate, vapour pressure deficit, potential evapotranspiration, qualitative data on soil classification, prior land use	qualitative information on crop composition: monoculture, polyculture, presence/absence and identity of non-commercial species, and the presence of crop or non-crop N2 fixing species // quantitative measures: crop-specific planting densities, soil fertility and fertilizer application rates,	taxonomic information like subspecies, variety and or cultivar identity

	soil pH, soil water-holding capacity and irrigation rates	

These ideas are a first step towards a formal database such as those currently used for gene sequences and protein data (Garnier and Navas 2012). In addition to these ideas of Garnier and Navas, Martin and Isaac suggest that we should first focus on elaborating databases on the most widespread crops that account for most of the world's agricultural production and area. Based on FAO rankings, the authors suggest to base the research on 65 species across 36 agricultural groups, which represent the most common crops used around the world (based on area and yield) (Figure 7) (A. R. Martin and Isaac 2015).

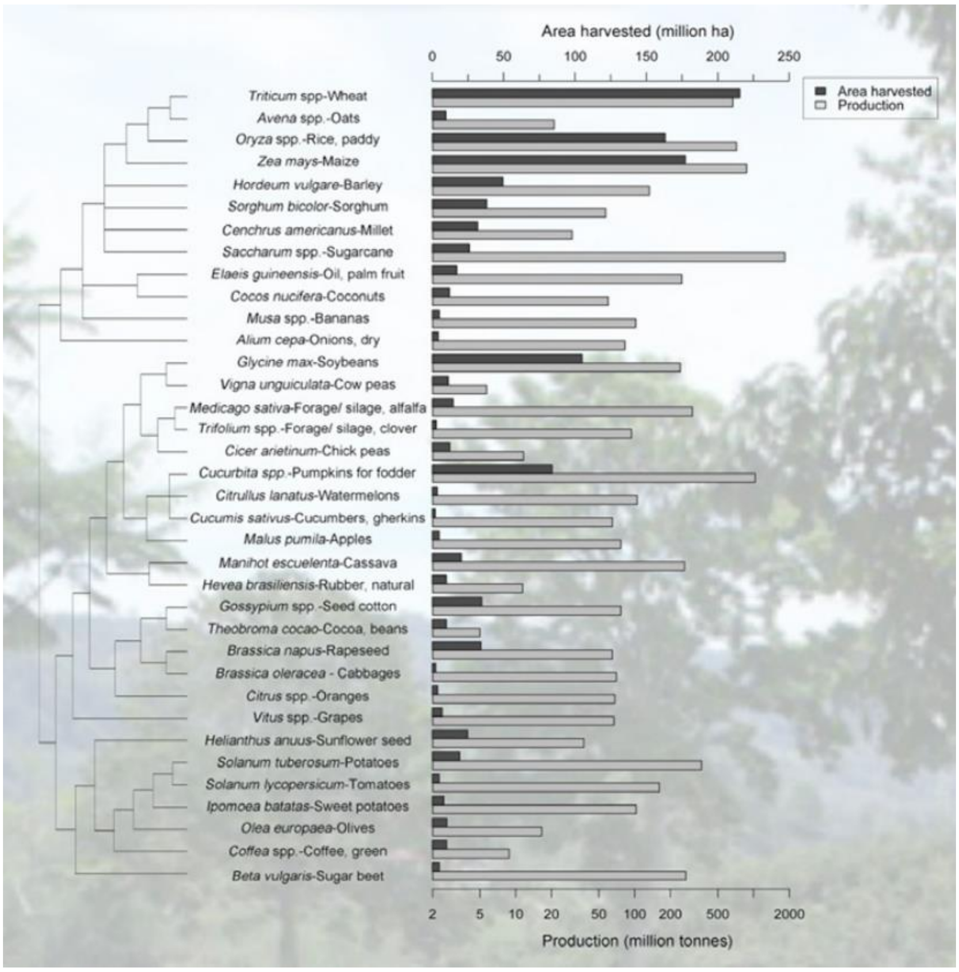

Figure 7 : The world's main agricultural groups (A. R. Martin and Isaac 2015)

4.2.1. Existence of multiple databases

Despite a lack of general agreement on trait data formalism, some databases have been created, especially in ecology research, allowing the detection of broad relationships among traits and trade-offs at various levels of organisation, the phylogenetic signal on traits, and the relationships between plant traits and environmental factors at continental or global scales (Garnier and Navas 2012). In particular the TRY database (https://www.try-db.org/TryWeb/Home.php) initiative has resulted in the compilation of more than 11 million trait records of 2100 functional traits across more than 160 000 plant species. This initiative is a huge step for consolidating functional trait data for plant species in natural systems, however it has not been focused on the world's most widespread crops as this database focused on ecological research. There is also a number of agricultural research organisations house crop data bases, which initially suggests that consolidated sources of functional trait data already exist in non-academic sources (A. R. Martin and Isaac 2015). For instance, there is the Crop Ontology Project (www.cropontology.org). This program was designed to compile germplasm as well as physiological, morphological and agronomic trait data that are important for understanding yield of commercially important crops. Similarly, the International Maize and Wheat Improvement Center (www.cimmyt.org) provides data on phenology and yield of wheat and maize varieties, but little information on other functional traits (A. R. Martin and Isaac 2015). Finally, different data sources are likely to be more or less effective in providing information on different traits. Agronomic institutions and databases (such as the Crop Ontology Project) are likely to house large amounts of data related to reproductive traits and potentially whole plant traits such as maximum height, while primary literature is more likely to be a main source of leaf economics and root functional trait data (A. R. Martin and Isaac 2015).

It is also suggested that databases might be housed as a module of ecological database. For instance, an agricultural module of the TRY database would also enable us to understand interactions between crops and natural biodiversity (A. R. Martin and Isaac 2015) because planned diversity usually creates conditions that promote associated biodiversity which plays a role in the ecosystem (Damour et al. 2018). For instance, FlorealData is a regional database which enables the management of both ecological and agronomical grassland issues in Pyrenees (Theau and Prud'homme 2021). This database gathers life traits of grassland species which make possible the calculation of agro-ecological indices. 768 species are listed and are characterised by 9 attributes (life form, functional group, specialisation index, biological type, flower dominant colour, size class, precocity class, temperature at flowering, type used in varietal selection) (Theau and Prud'homme 2021). Agroecological indicators can be calculated automatically when a vegetation survey is carried out, giving an idea of the quality of the grassland ecosystem. These indicators enable the characterisation of different grassland types. The use of these indicators by environmental managers and forage advisors provides a basis for discussion with farmers to adapt their practices towards more ecological conservation and protection (Theau and Prud'homme 2021). Here trait-based approaches provide a support for local farm management and decisions.

4.3. Trait-based approaches to help farmer's decisions and policy makers

As the example above shows, trait-based approaches and associated databases are essential to deeply improve our understanding of response-effect traits of agroecosystems but are also intended to help in the decision-making process for policy makers and farmers to develop multiple agroecosystem services (A. R. Martin and Isaac 2018). For example, understanding the ITV of different crops in relation to management and environmental gradients would allow rapid selection of species or varieties for specific targeted agroecosystem services provisioning under specific conditions (Guiguitant et al. 2021; Pinke and Gunton 2014; Lohbeck et al. 2018). In addition, identifying agroecologically meaningful functional groupings could serve as simplified decision tools for the choice of crop and intercrop compositions (Santos et al. 2021). For instance, trait-based approaches could enable farmers to adjust sowing rates of crop mixtures or crop sowing date in order to regulate weed proliferation (Blesh 2018). In addition to take into account agroecosystem services, decision rules result from production and service delivery objectives, biophysical constraints, market demand and economic, social and cultural references and constraints related to the farmer's knowledge (Damour et al. 2018). All these parameters must be taken into account in global models not only to model idealistic agroecosystems but to create models that consider farmers field reality, and that are economically achievable. Finally, Wood addressed another issue which is and will continue to be a challenge for policy implications: it is about how to include human nutrition into assessments of agroecosystem function and services. Wood developed a new metric, the potential nutritional adequacy (PNA), by employing principles of functional trait diversity, which could be paired with other indicators of environmental outcomes as a mean to assess the joint benefits of the provisioning of food security and sovereignty and other ecosystem services in agroecosystems (A. R. Martin and Isaac 2018).

Conclusion

The study of crop functional traits as well as its associated biodiversity traits such as arthropods or weeds, are important variables that allow us to better link agroecosystems and ecosystem services. In fact, it appears that functional diversity metrics are more strongly correlated with ecosystem services than species-based metrics (Finney and Kaye 2017). The trait approach allows us to better understand the responses induced by environmental changes and the type of agricultural management on agroecosystems. It also allows us to understand what effects these crops will have on their environment and what types of ecosystem services each crop can provide within an agroecosystem. The functional trait approach makes it possible to generalise trends and syndromes of traits that characterise agro-ecosystem services. It has been shown that the trait approach can predict the ecosystem services provided by an agroecosystem in a given environment and farm management at a given time (Tribouillois et al. 2015). Given the generalisability and predictive nature of functional traits, more and more research is highlighting the need to gather all existing data on crop traits, and formalise them in a database in order to test global hypotheses (Garnier and Navas 2012). The trends provided by trait-based approaches can subsequently serve as a decision aid for farmers who want to establish multifunctional agroecosystems adapted to their environment while limiting the addition of inputs and soil labour for example. This information could also help decision-makers to adapt quickly to the climatic and environmental changes that are likely to be faced in the coming years (Volaire et al. 2014). However, the management of agroecosystems also depends on other variables such as socio-economic criteria, which also play an important role in decision-making process.

Even though this review can give useful insights in designing functionally performant agroecosystems, I have only read about fifty articles for this review, consequently this study could be deepened by further reading. Notably, even though agroecosystems are not natural and are man-made, some studies have suggested that much has been done in functional ecology and that some of it could surely be applied to agriculture (Lohbeck et al. 2018; Hayes et al. 2019). There are also limits to the generalisation and prediction of ecosystem services by traits, as some interactions are species-specific. It appears specifically true for soil microbial communities which are often highly plant species-specific (Smith et al. 2010) or some plant-insect or insect-insect interactions (Gardarin et al. 2018). Furthermore, making predictions from crop functional traits is equivalent to modelling the effects and responses of crops and associated spontaneous biodiversity in a given environment. However, there are many possible interactions and many variables to consider in an agroecosystem, and the more multifunctional agroecosystem, the more difficult modelling it. It may be complicated to establish all the possible links between each component of the agroecosystem and to measure all the trade-offs and competition that occur in the interactions. It is therefore important to be aware that modelling agroecosystem services using functional traits represents a simplification of reality that simply allows us to test global hypotheses and advance our understanding of how agroecosystems function, to reveal gaps and to discover variables and ways of functioning. However, it may lack in the precision required for the description of detailed, small-scale mechanisms (Damour et al. 2018). Moreover, there is no general consensus on the most informative metric of functional diversity and relationships between diversity and ecosystem services remain largely unexplored even though some studies found that trait studies were good predictors, usually better than species-based metrics for ecosystem services (Finney and Kaye 2017). Furthermore, there is no global consensus for on indicators that represents and quantify agroecosystem services.

Finally, the functional trait approach seems promising because it is simplifying in a world where everything evolves very quickly. It makes possible to link the functional diversity of an agroecosystem to the ecosystem services it can provide, links that are relatively little estimated and quantified in the scientific literature. Trait-based approaches may be appropriate in a context where food objectives must be met in order to feed growing populations while limiting as much as possible the degradation and erosion of biodiversity that agricultural areas can create. However, modelling interactions between functional traits and ecosystem services remains a simplification of the interactions that can exist between organisms and in particular in agroecosystems for this study. It can be a complementary approach to other more traditional approaches, species-based metrics mostly, which also try to develop a sustainable agricultural system.

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Trait-based approaches applied to agroecosystems: Towards a better understanding of agroecosystem services

Abstract: Nowadays, there are more and more concerns about the environmental sustainability of intensive agriculture (soil degradation, loss of biodiversity, etc.) and its dependency on artificial inputs (pesticides and fertilizers). In addition, we imperiously need to predict changes in vegetation in response to global climate change drivers. Consequently, the scientific sphere searches for simplification of floristic complexity and a better understanding of agroecosystem functionalities. For this purpose, trait-based approaches (quantifiable morphological, physiological, chemical or phenological property of a plant) are more and more applied to agroecological science, to understand the functional properties of agroecosystems and how the biota and fauna within these managed ecosystems impact the services or disservices they provide. This review gives an overview of what has been proven in the last year in agricultural sciences, on trait-effects and trait-responses of crops and its associated spontaneous biodiversity. This study highlights the general and predictable aspect of trait-based approaches applied to agroecology, which would allow us to test global hypotheses if a common and public database on crop traits was established. Trait-based approaches could also help us to better understand and take into account the ecosystem services provided by agroecosystems in decision-making processes.

Mots Clés : Trait-based approach, functional trait, agroecology, agroecosystem, functional diversity, ecosystem service

Approche fonctionnelle des agroécosystèmes : Pour une meilleure prise en compte des services écosystémiques

Résumé : Aujourd'hui, la durabilité environnementale de l'agriculture intensive (dégradation des sols, perte de biodiversité, etc.) et sa dépendance aux intrants artificiels (pesticides et engrais) suscitent de plus en plus de préoccupations. De plus, nous avons impérativement besoin de prévoir les changements de la végétation en réponse aux facteurs de changement climatique mondial. Par conséquent, la sphère scientifique cherche à simplifier la complexité floristique et à mieux comprendre les fonctionnalités des agroécosystèmes. À cette fin, les approches basées sur les traits (propriété morphologique, physiologique, chimique ou phénologique quantifiable d'une plante) sont de plus en plus appliquées à l'agroécologie, afin de comprendre les propriétés fonctionnelles des agroécosystèmes et la façon dont la faune et la flore au sein de ces écosystèmes modifiés par l'homme ont un impact sur les services qu'ils fournissent. Cette revue donne un aperçu de ce qui a été prouvé l'année dernière en agroécologie, sur les effets et les réponses des traits des cultures et de la biodiversité spontanée associée. Cette étude souligne l'aspect général et prévisible des approches basées sur les traits appliqués à l'agroécologie, ce qui nous permettrait de tester des hypothèses globales si une base de données commune et publique sur les traits des cultures était établie. Les approches basées sur les traits pourraient également nous aider à mieux comprendre et à prendre en compte les services écosystémiques fournis par les agroécosystèmes dans les processus décisionnels.

Mots Clés : Approche basée sur les traits, trait fonctionnel, agroécologie, agroécosystème, diversité fonctionnelle, service écosystémique