INTERCROP VALUES

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D3.2 Practical guides and videos presenting innovative machineries designed or adapted by farmers related to sowing, mechanical weeding, harvesting, cleaning and sorting, and dissemination of operational solutions

Document Summary

Deliverable Title	Practical guides and videos presenting innovative machineries designed or adapted by farmers related to sowing, mechanical weeding, harvesting, cleaning and sorting, and dissemination of operational solutions
Version	1
Deliverable Lead	ENSFEA
Related Work package	WP3 Managing intercrops in cropping systems: GHGs, soil health and agro-equipment studies
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Communication level

☒ PU – Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project’s page)

☐ SEN – Sensitive, limited under the conditions of the Grant Agreement

Grant Agreement Number	101081973
Program	HORIZON EUROPE
Start date of Project	01-11-2022
Duration	48 months
Project coordinator	CIRAD

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Preliminary information

About the authors and contributors

This deliverable is associated with task 3.4 (Leader: ENSFEA; Contributors: FNCUMA, SRUC, INRAe). However, SRUC was unable to participate in this work for two main reasons: (1) the funding they received from the UK government, a decision taken after the proposal was submitted, and (2) the fact that this task was not considered crucial by the relevant stakeholders in their context (Scotland). Consequently, this deliverable focuses on the French case study. Nevertheless, several presentations have been made with CIC leaders, and a webinar is planned for February 2026 as part of WP7, to ensure wider dissemination beyond the consortium of this work about agro-equipments for intercropping and species mixtures.

About the content of the deliverable

The initial objective was to present innovative agro-equipments designed or adapted by farmers for all aspects of crop cultivation, such as sowing, weeding, harvesting, cleaning and sorting. However, interviews with farmers revealed that sowing was a decisive operation and therefore most of the innovative agro-equipment identified concerned this operation. Consequently, the innovative agro-equipments presented in this deliverable mainly focus on sowing, reflecting the needs expressed by the interviewed farmers and justifying the focus of our work.

However, to provide a broader overview of agro-equipments for intercropping and species mixtures, this deliverable includes agro-equipments used for other operations (sowing, weeding, harvesting, cleaning and sorting) from four perspectives: (1) the "three management logics of the agro-equipment fleet", (2) the "management logic of the agro-equipment when introducing the first species mixture", (3) the "co-evolution of agro-equipment and species mixtures", and (4) the "three approaches to designing agro-equipment for growing mixtures in the long term". Regarding sorting and harvesting, we have used all material produced as part of the previous European ReMIX project to capitalise on acquired knowledge and provide information to stakeholders and farmers, in particular for all interested CICS (in close collaboration with WP1). All information available can be found in the IntercropVALUES project website (https://intercropvalues.eu/remix) and the specific document for farmers and advisors concerning harvesting and sorting grains with various agro-equipements at : https://intercropvalues.eu/wp-content/uploads/2023/07/Remix-2-Organic-Matters-Issue-146.pdf.

Please note that no videos are included in this deliverable at this stage. However, links to videos produced within the CICs on this topic, as well as links to relevant practice abstracts, will be added by the end of the project.

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Abstract

The transition to sustainable farming systems requires a thorough understanding of the diversity of farmers, their particular contexts and the fact that they often adopt new practices gradually. To date, the literature has not sufficiently addressed the relationship between intercropping with species mixtures and agro-equipments, in particular how the use of agro-equipments influences farming practices. In addition, access to appropriate agro-equipments is often seen as a barrier to the diversification of species mixtures, as existing agro-equipments may not meet local needs and may be prohibitively expensive.

This deliverable investigates how farmers manage their agro-equipments to implement suitable species mixtures, characterising innovative agro-equipments for key tasks of crop management with a particular focus on sowing. It also examines the open innovation processes that support the development of species mixtures, particularly those relating to agro-equipment sharing.

This deliverable is aligned with the project's tasks, which focus on analysing the collective organisations that promote the development of species mixtures and tracking innovative agro-equipments designed by farmers. Two complementary studies are presented: (1) farmers' management logic in terms of agro-equipments to grow and sort species mixtures, and (2) how farmers are progressively redesigning their agro-equipments fleets in connection with the adoption and development of species mixtures.

The results indicate that farmers are actively engaged in modifying, combining and repurposing existing agro-equipments to grow a diversity of species mixtures. A total of 21 species mixtures were identified among the 13 farmers interviewed, for which the spatial arrangement (species sown in the same vs alternated rows) and sowing depth (species sown at the same vs different depths) appear, in the farmers' view, to be critical factors influencing their effectiveness.

Three management logics aimed at optimising the use of agro-equipments were identified: (1) minimising mechanisation costs by repurposing existing agro-equipments, (2) adapting agro-equipments to the specific sowing requirements of each species and (3) aligning the choice of agro-equipments with local resources.

Additionally, three strategies for designing agro-equipment for long-term cultivation of species mixtures were highlighted: (1) frugal design, which focuses on cost-effectiveness and allows experimentation without major financial investment, (2) standardised design, which aims to optimise large-scale production and improve efficiency and management, and (3) flexible design, which allows adaptable practices through the gradual acquisition of various agro-equipment in response to changing needs.

The findings highlight the importance of agro-equipment in the development of species mixtures, revealing that it acts as an enabler rather than a barrier. Farmers' approaches to the modification and collaborative purchase of agro-equipment demonstrate their commitment to innovation. The role of cooperatives for the use of agricultural agro-equipment (CUMA) in France should be strengthened, as should the development of training and collaboration with local entrepreneurs to support the adoption of species mixtures in various contexts.

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Introduction

1.1 Societal issue

The transition to sustainable farming systems requires taking into account the diversity of farmers, their unique farming contexts and their gradual appropriation of new practices over a long period of time. To date, the literature (Bellon and Huyghe, 2017; Kefi et al., 2023; Salembier et al., 2020) has paid only limited attention to intercropping with species mixtures from the point of view of agro-equipment and the interaction between changes in farming practices and the use of agro-equipment. Moreover, access to appropriate agro-equipment is often identified as a major barrier to the diversification and development of species mixtures (Morel et al., 2018; Bellon-Morel and Huyghe, 2017). Indeed, existing agricultural agro-equipment may not be adapted to local agricultural needs (Sims et al., 2017) and may be prohibitively expensive and time-consuming to maintain (Lucas et al., 2018).

1.2 Objectives

In the light of previous studies (Salembier et al., 2020; Kefi et al., 2023), this deliverable aims to explore how farmers manage their agro-equipment in order to implement various species mixtures adapted to their specific situation. In addition, it seeks to better understand how farmers (re)design their agro-equipment fleets as they progressively experiment with species mixtures. Thus, the primary objectives of this deliverable are:

1. To characterise innovative farm agro-equipment and its applications for the essential tasks involved in the management of species mixtures, with a particular focus on sowing;
2. To examine innovation processes that enable the development of species mixtures through interconnected innovations, including sorting organisations, agro-equipment sharing initiatives or new supply chains.

1.3 Articulation within the project tasks

This deliverable was produced in collaboration with WP1 with the aim of feeding ideas and knowledge into the co-innovation processes within the 13 CICS of the project through two project tasks (T.1.2 and T.3.4).

- **Task T1.2 "Analysis of existing innovative collective organizations and actions enhancing intercropping developments"**
  The aim of this task was to characterise innovation processes that facilitate the development of species mixtures, focusing on the emergence of interconnected innovations. To this end, the trajectories of machine design, adaptation and assembly by farmers were analysed in order to draw lessons on how to support the design and adaptation of agricultural agro-equipment in different contexts.

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- **Task T3.4 "Tracking innovative agro-equipment designed by farmers, and study of their uses for the production and for cleaning/sorting of grains after harvest"**
  Given that farmers in the EU have already developed species mixtures, this task aimed to explore the innovative machines that farmers use, design, adapt and tinker with for their own context, as well as their use, in order to produce references and to show the diversity of practices. This diversity was contextualised according to various situations of use, such as individual versus collective use, different species mixtures, time availability and consideration of the entire value chain, from sowing to post-harvest technology.

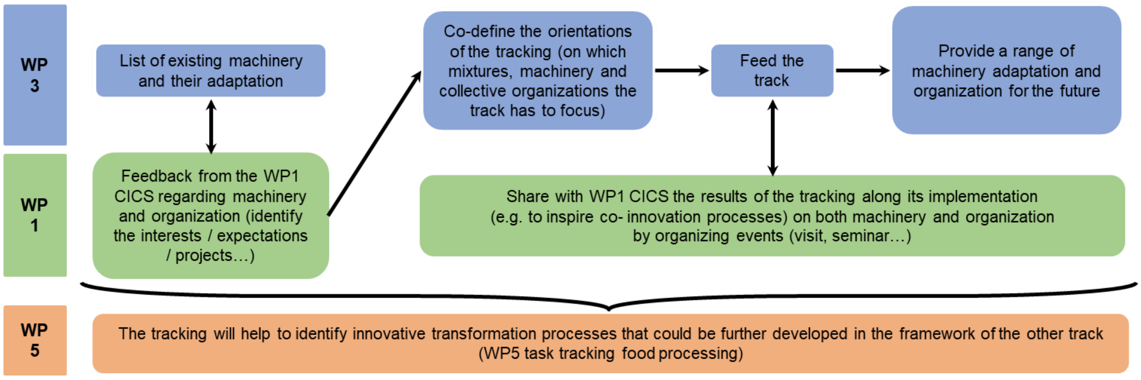

Figure 1: Relationships between the work carried out as part of tasks T1.2 "Analysis of existing innovative collective organizations and actions enhancing species mixtures developments" and T3.4 "Tracking innovative agro-equipment designed by farmers, and study of their uses for the production and for cleaning/sorting of grains after harvest" and the links with WPs1, 3 and 5.

It should be noted that a workshop was held with the WP1 CICS leaders at the beginning of the project to focus the work on what the case studies wanted to explore without however preventing us from broadening the scope of the study later on (by exploring new and interesting elements not mentioned). It should also be noted that at the very beginning of the project, we did not focus specifically on species mixtures, as some innovations were certainly made for another purpose, but could be useful for mixtures. The study was designed and conducted in close collaboration with the National Federation of CUMA.

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Materials and methods

1.1 Concepts and methods mobilized

To encourage the development of species mixtures, information is needed on the selection and use of appropriate agro-equipment for their management. This deliverable, aiming to explore how these practices are influenced by the design and use of agro-equipment, mobilised therefore : (1) knowledge from the design sciences (Hatchuel and Weil (2009) and Schön (1983)) to help us understand the dynamics of change through such situated design processes, and (2) concepts from systems agronomy (Willey (1981), Salembier et al. (2021), Quinio et al. (2021) and Meynard et al. (2001, 2003)) to analyse practices relating to species mixtures and their evolution in relation to agricultural agro-equipment.

Our methodology is based on and adapts the approach of tracking farmer innovation (Salembier et al., 2021) in terms of agro-equipment adapted, modified or designed by farmers to grow species mixtures. The main objectives were to identify innovative machines, such as changes in settings, reuse of existing agro-equipment, combination of different types of agro-equipment and creation of machines built by farmers themselves. In addition, we studied their use and examined their agronomic logics and trajectory of emergence over time, including the identification of the stakeholders involved. Following the methodology proposed by Salembier et al. (2020), the main research questions guiding our study relate to the types of agro-equipment used and their objectives, the conditions in which they are used, the species mixtures and value chains for which they are designed, and the way in which they have been adapted, designed or redesigned.

This study was carried out in France at the start of the project. It is important to note that our aim was not to design new machines, but to study existing adaptations and innovations. Initially, the focus was on agricultural agro-equipment and adaptations identified by French cooperatives, known as CUMA, a French network of around 10000 agricultural agro-equipment cooperatives.

1.2 Two complementary works for two specific questions

This deliverable presents two complementary studies focused on understanding the management of agro-equipment in the context of species mixtures practices. Together, these studies contribute valuable insights into the adaptive strategies of farmers in transitioning towards sustainable agricultural systems based on intercropping. These results should reveal that some problems identified in WP1 CICS could be already resolved and inspire farmers and their advisors engaging in the practice of species mixtures.

The first study addresses the following question: what are the farmers' agro-equipment management logics for growing different species mixtures in their situation? Through interviews with 13 farmers, we characterised the species mixtures they implement, the agro-equipment employed and their underlying logic of action (i.e. the reasons for their choices, conditions, performance, etc). This analysis enabled us to categorize their practices in

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terms of species mixtures, agro-equipment and action logics in various farming situations. An article detailing these results was submitted to Agronomy for Sustainable Development (Fouillet et al. accepted with revisions).

The second study examines how farmers gradually appropriate the practice of species mixing and how they (re)design their agro-equipment parks during this process. To this end, we interviewed 16 farmers in order to study the evolution of their practices and their farm agro-equipment along two axes: (1) the (re)design of the farm agro-equipment when they first adopted species mixtures and (2) the ongoing (re)design as farmers experiment with these species mixtures over time. An article based on this work is being prepared and will be submitted to the journal Agricultural Systems by the end of 2025.

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Results

1.1 Characterizing species mixtures through the lens of agro-equipment

In our study, we identified a total of 21 species mixtures, of which 18 comprise combinations of cereals and legumes. Notably, nine farmers are engaged in the cultivation of two or more species mixtures, highlighting a trend towards biodiversity in agricultural practices. According to the farmers surveyed, two characteristics significantly influence the effectiveness of species mixtures: spatial arrangement and sowing depth. These factors play a crucial role in how species mixtures interact with agro-equipment, affecting crop performance and sustainability.

Interestingly, our findings indicate that there is no specific type of agro-equipment associated with a given species mixture. For example, the combinations of wheat and faba bean appear in both types 5 and 6, demonstrating the flexibility and adaptability of agro-equipment in accommodating various species mixtures. This lack of a fixed species mixture suggests that farmers can tailor their agro-equipment usage to suit different mixtures, promoting innovation and efficiency in their farming practices.

In conclusion, the study underscores the importance of understanding the interplay between species mixtures and agro-equipment characteristics. By recognizing the significance of spatial arrangement and sowing depth, as well as the adaptability of agro-equipment, farmers can enhance their practices and contribute to more sustainable agricultural systems.

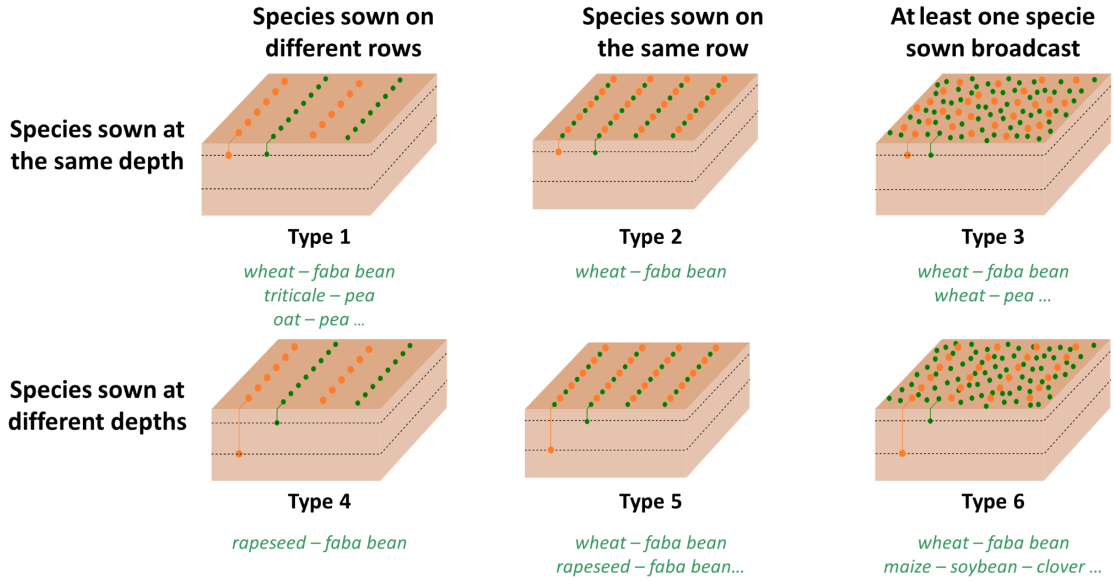

Figure 2: Schematic representation of the six categories of mixtures identified according to seeding depth and spatial arrangement of associated species.

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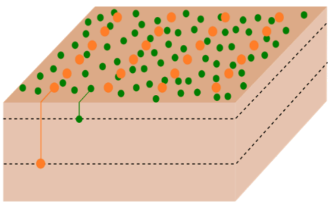
1.2 Which agro-equipment for species mixtures adapted to the situations and logics of farmers?

1.2.1 Repurposed agro-equipment for sowing cover crops with species mixture



Type 6

This example illustrates a repurposed agro-equipment, namely that of a micro granulator electric distribution initially designed for spreading fertilizer and repurposed here for sowing cover crops. In this case, the species mixtures include sunflower with alfalfa and clover, the latter two being sown with this front-mounted fertilizer spreader, while the sunflower is sown with a single-seed drilling system located at the rear of the tractor. This configuration allows the seeds to be sown simultaneously at an optimal depth while maintaining optimal row spacing for sunflowers. The integration of these two types of agro-equipment improves work speed because sowing can be done in a single pass. From an agronomic point of view, this mixture and sowing strategy maximizes ground cover, helping to reduce weeds and erosion.

Figure 3: Illustration of a repurposed agro-equipment, namely that of a micro granulator electric distribution initially designed for spreading fertilizer and repurposed here for sowing cover crops. Credit: E. Fouillet, INRAE.

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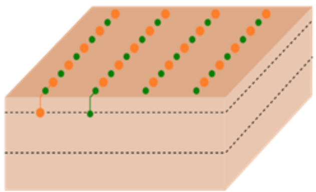
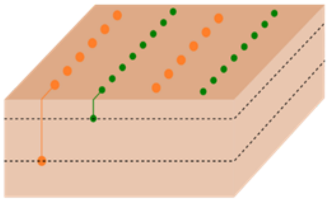
1.2.2 Tinkered agro-equipment to sow 2 species at 2 depths (or not)



Type 2



Type 4

This example illustrates the case of tinkered agro-equipment to sow two species simultaneously, here a wheat–faba bean mixture, and with the possibility of doing so at different depths. The agricultural agro-equipment used is a 20-year-old no-till seed drill, which has been modified with the addition of a hopper partition and a second distribution head. Each compartment is connected to a different distribution head (one for the front part and one for the back part of the drill), allowing each row to be fed with a different species and each species to be sown at its optimal depth.

Figure 4: Illustration of a tinkered agro-equipment to sow two species simultaneously. Credit: E. Fouillet, INRAE.

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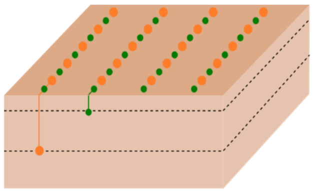
1.2.3 Tinkered combined agro-equipment to sow 2 Species at 2 depths



Type 5

This example illustrates modified combined agricultural agro-equipment that can sow two species at different depths in a single pass. In this case, it is used to sow a mixture of rapeseed and faba beans. It includes a strip-till system with seed drop tubes added by the manufacturer for sowing the faba bean, as well as a field cultivator with a distribution head for sowing the rapeseed at a shallower depth in the same row. This combination of agro-equipment enables both species to be sown at their optimal depth while tilling the soil, all in a single pass and without the seeds needing to be mixed beforehand.

Figure 5: Illustration of a modified combined agricultural agro-equipment that can sow two species at different depths in a single pass. Credit: E. Fouillet, INRAE

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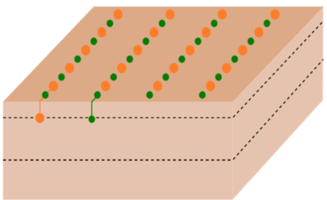
1.2.4 Development of a no-till drill for sowing cover crops with species mixture



Type 2

This example illustrates the construction of a no-till drill to sow several species simultaneously, in this case a pea–vetch–faba bean–oat mixture and a faba bean–phacelia mixture. The project aims to achieve operational efficiency through the use of high-volume hoppers, enabling extended sowing operations without the need for frequent refills and without the need to mix the seeds beforehand. To achieve this, the farmer bought two hoppers with a capacity of 1.2 tonnes and 0.6 tonnes, which he installed on a self-built robust frame. He also built the ploughshares for the direct seed drill designed to penetrate the soil effectively while minimizing disturbance. Finally, to ensure optimal seed-to-soil contact he added chains followed by plough wheels into the drill's design. These components will press and cover the seeds, improving germination and establishment of the cover crops.

Figure 6: Illustration of the construction of a no-till drill to sow several species simultaneously. Credit: E. Fouillet, INRAE

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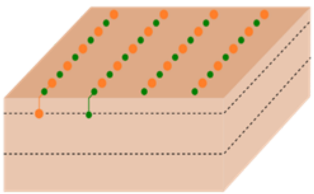
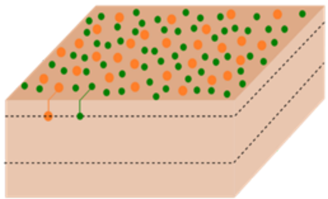
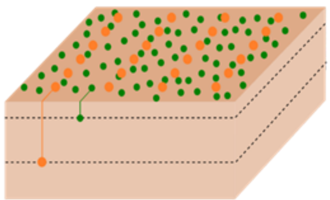
1.2.5 Construction of a Seed Drill for Sowing Species Mixtures



Type 2



Type 3



Type 6

This example illustrates the construction of a seed drill to sow several species simultaneously, quickly, in different spatial arrangements and with effective depth control. The 6 m wide seed drill has been designed to be compatible with low-power tractors while maintaining a high working speed. The construction of the seed drill involves several key components: (1) a compartmentalised hopper to avoid having to mix seeds from upstream species, (2) two distribution heads, each connected to one of the two compartments, (3) a field cultivator with tines to prepare the soil, on which some of the seed drop tubes are fixed for row seeding, (4) several distribution systems for dispersing seeds in broadcast, located behind the cultivator tines, and finally (5) a Y-shaped connector that can be used, if required, to connect the two hopper compartments to the same distribution head in order to sow the two species identically (in row or broadcast). This design makes it possible to sow mixtures of species where one or more species are sown in rows (wheat–faba bean, triticale–pea or rye–lentil) as well as mixtures where one or more species are broadcast and finally mixtures combining both broadcast sowing and sowing in rows (barley–clover, barley–alfalfa, rapeseed–faba bean–clover–buckwheat).

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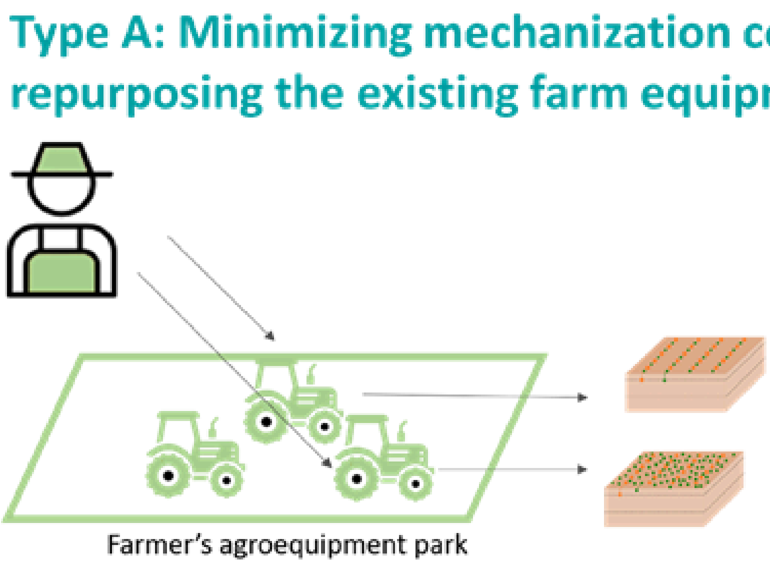
1.3 Three management logics for the agro-equipment park

The work carried out on the management of agro-equipment reveals three distinct management logics, each focusing on different strategies for optimising the use of agro-equipment and the management of species mixtures: (1) type A (minimising mechanisation costs by repurposing the existing agro-equipment), (2) type B (sowing mixtures based on species characteristics by adapting agro-equipment) and type C (choosing species mixtures and agro-equipments according to resources available locally).

1.3.1 Minimizing mechanization costs by repurposing the existing agro-equipment



With this action logic, farmers aim to minimise mechanisation costs by repurposing existing agro-equipment. This is often the case for farmers with a large and often ageing fleet of agro-equipment.

In this management approach, the choice of the layout of species mixtures aims to respect the crop physiology by making the most of the agro-equipment available. To achieve this, farmers reuse agro-equipment they have for new functions, combine different types of agro-equipment and sometimes make structural changes to the agro-equipments to better meet the needs of the crops. These changes make it possible to limit investment, thereby reducing mechanisation costs.

These farmers use fixed crop rotations and mixtures of species that can be adapted to different stand structures. In this case, we find the sunflower–alfalfa–clover mixture sown by diverting the use of a micro granulator (see 1.2.1 Repurposed agro-equipment for sowing cover crops) in which only the sunflower, which is the main crop, is harvested, thus simplifying the post-harvest process by not requiring sorting.

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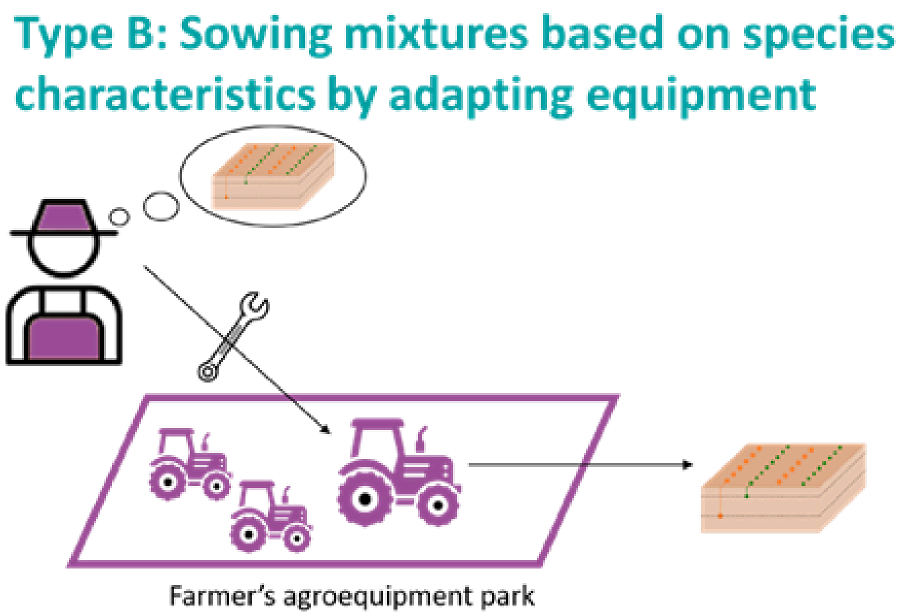
1.3.2 Sowing species mixtures based on species characteristics by adapting agro-equipment



In this type, farmers choose species mixtures and sowing methods that respect the physiological characteristics of the crops by adapting existing agro-equipment. The farmers concerned show varying levels of investment capacity and a certain amount of DIY skill, which characterises their ability to modify existing agro-equipment, ranging from modifying the structure to self-building bespoke agro-equipment to meet specific requirements in line with the desire to respect the physiological characteristics of the crops.

These farmers' cropping systems show rotations with varying degrees of flexibility, enabling them to make adjustments according to weed pressure, for example. Among the mixtures encountered, we can cite the example of the wheat–faba bean combination described in part 1.2.2 (Tinkered agro-equipment to sow 2 species at 2 depths (or not)) in which the two species are harvested and then sorted using a rotary cleaner-separator. Ultimately, this management logic underlines the importance of the adaptability of both species mixtures and agro-equipments.

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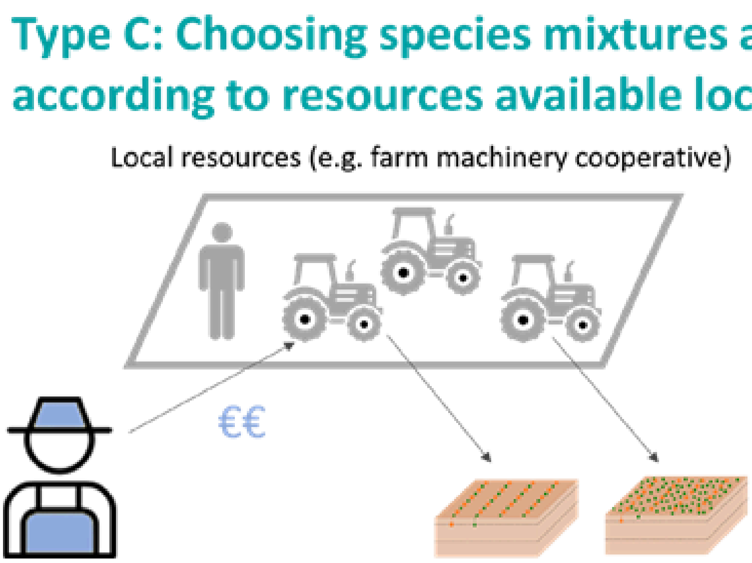
1.3.3 Choosing species mixtures and agro-equipments according to resources available locally



In this type, farmers choose species mixtures and agro-equipment based on the resources available in their environment. These farmers benefit in particular from the presence of nearby service providers who can supply them with essential services and agro-equipment, whether for harvesting or sorting, as well as reusing existing agro-equipment. This allows them not only to minimise investment costs, but also to customise agro-equipment to meet the specific needs of their crops.

By taking advantage of locally available resources, this gives them greater flexibility in crop management. Decisions on crop selection can be based on current field conditions, such as weed pressure, as well as market conditions. This adaptability allows farmers to react dynamically to changing circumstances, resulting in species mixtures that are modified from one year to the next. Take, for example, the case of a farmer growing barley–lentil or buckwheat–clover mixtures. For harvesting, he calls on a contractor with a range of harvesters to use the right model for each type of species mix. Then he calls in another service provider with a sorting chain ranging from rotary cleaner-separators to optical sorters. This guarantees an efficient harvesting-sorting process that optimises quality, and enables the products to be recycled for human consumption. This approach means that informed decisions can be made according to the resources available, with the emphasis on profitability and the farmer's specific objectives.

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1.4 Agro-equipment management logic when introducing the first species mixture

In the context of our study, it appears that none of the farmers interviewed had invested heavily in agro-equipment for their first trials of species mixtures. This suggests that farmers initially rely on existing resources or alternative methods to experiment with species combinations. Furthermore, farmers systematically indicated that agricultural agro-equipment was not perceived as an obstacle to the development of species mixtures.

An analysis of the composition of the species mixtures grown for the first time by the farmers reveals considerable diversity. With thirteen different combinations, cereal–legume mixtures are the most common among those grown for the first time (e.g. wheat–alfalfa or barley–lentil). It should be noted that some farmers have started to use mixtures through oilseed/legume combinations (e.g. rape/alfalfa with clover in some cases).

Several reasons are given for growing species mixtures for the first time. One of the main motivations is the desire to develop the use of cover crops, known for their ability to improve soil health and prevent erosion. Another key motivation is to optimise the performance of a particular crop through mixture with another species. For other farmers, the primary motivation is to manage and limit the risks associated with the improved resilience afforded by species mixtures. Lastly, some farmers chose to experiment with species mixtures in response to observations made in their fields, where mixtures had grown spontaneously due to the presence of regrowth from the previous crop.

The agro-equipment used to grow these first species mixtures was characterised by three main factors: (1) the physical properties of the agro-equipment, which played an essential role in the choice of species and their arrangement, (2) the specific uses of drillers and sorters so that they could meet the characteristics of the mixtures grown and harvested in connection with their marketing, and finally (3) the ownership structure of the agro-equipment (private, individual or collective), which could a priori influence the way in which farmers approached growing species mixtures for the first time.

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1.5 Co-evolution of agro-equipments and species mixtures

The farmers surveyed have shown ability to adapt by transforming both their farming agro-equipment and the species mixtures grown. This transformation often begins with the acquisition or design of specific agro-equipment adapted to various species. For example, the acquisition of a sorter has enabled two farmers to successfully grow a wide variety of species mixtures, illustrating how targeted investment in agro-equipment can facilitate agricultural diversity.

Optimising the management of species mixtures appears to be made possible by the acquisition and design of new agricultural agro-equipment. A notable example is that of a farmer who switched from sowing alfalfa in a wheat crop to sowing wheat in an alfalfa crop, a change that required the design of an adapted seed drill.

Adapting the use of agro-equipment is crucial to the success of new species mixtures. However, farmers are committed to iterative optimisation, fine-tuning both the management of species mixtures and their agro-equipment. For example, over a period of four years, one farmer adjusted both sowing densities and tested different types of agro-equipment and combinations.

As farmers increase the diversity of species mixtures grown, they may find themselves replacing their agro-equipment with more flexible or higher-performance alternatives. For example, one farmer replaced a triple-hopper disc seed drill with a centrifugal seed drill for greater precision in sowing density, while offering greater adaptability to different soil conditions and increased throughput.

Conversely, farmers sometimes abandon certain species mixtures or certain agro-equipment for various reasons: (1) unsuitability of a particular species for the production situation, (2) poor management of interactions between species or (3) disappearance of commercial outlets for certain species. In all cases, agro-equipment was never cited as a reason for abandoning species mixtures, which indicates that the obstacles lie above all in the agronomic and commercial aspects and that farmers are capable of finding technical solutions.

In conclusion, the interaction between, on the one hand, the transformation of agricultural agro-equipment, through acquisitions, adaptations and iterative improvements and, on the other hand, the management of species mixtures is a dynamic process that reflects farmers' innovation and enables cropping systems to be improved.

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1.6 Three approaches to the design of agro-equipment to grow species mixtures over long term

The first approach can be described as "frugal design for testing different species mixtures". It is characterised by the transformation of existing agro-equipment, the purchase of second-hand agro-equipment and the use of services that make it possible to limit investment costs while at the same time multiplying experiments with mixtures of species.

The second approach can be described as "standardised design to optimize large-scale production". This approach is characterised by the acquisition of a wide range of agricultural agro-equipment and by their transformation, particularly for sowing, sorting and harvesting, enabling large-scale production of a diversified range of species mixtures. This standardisation not only rationalises production processes, but also ensures that farmers can manage and grow diversified mixtures efficiently.

The third approach is known as “flexible design for diverse mixture practices”. This approach is characterised by the gradual acquisition of various agro-equipments that enable autonomous and adaptable management of species mixtures over the long term. It is also characterised by the gradual transformation of agro-equipment, particularly existing seed drills. By designing flexible seeding agro-equipment, these farmers can respond to their changing needs and optimise their practices for a diversified range of species mixtures, enabling them to adapt to various agricultural contexts.

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Conclusion

The integration of intercropping with species mixtures into cropping systems is increasingly recognised for its potential benefits, but the role of agro-equipment in this process has been little explored. This study highlights the importance of agro-equipment in the development of species mixtures, proposes a framework for better understanding their management and design, and enriches our understanding of species mixtures by proposing a typology that complements existing typologies (Gardarin et al., 2022; Verret et al., 2020). In this study, we introduce the concept of 'agro-equipment management logic', which helps us to understand the motivations underlying farmers' decisions on agro-equipment use in relation to species mixtures. In addition, we studied design processes, i.e. how farmers design and adapt agro-equipment to support the long-term cultivation of species mixtures.

The management of agro-equipment enables farmers to achieve their objectives while promoting the sustainability and resilience of their farming practices. Contrary to popular belief, agro-equipment is not an obstacle to the development of species mixtures, as farmers get round these difficulties by using various alternatives: (1) modifying, reusing and building agro-equipment to meet their specific needs, and (2) collaborative purchases to complement individual ones, enabling them to experiment and gradually rethink species mixtures. By recognising and strengthening the role of agricultural agro-equipment in the development of species mixtures, in particular by taking greater account of agro-equipment in agronomic studies devoted to this subject, we can support and promote the appropriation of innovative practices such as species mixtures.

From a prospective point of view, the results of this research are of interest for action because of the implications for the different stakeholders involved in promoting the appropriation of species mixtures in various contexts. Cooperatives for the use of agricultural agro-equipment (CUMA) and the strengthening of collaborations with local entrepreneurs can play an essential role by: (i) providing access to agricultural agro-equipment adapted to species mixtures, and (ii) organising training and workshops focusing on agro-equipment modification and maintenance to improve farmers' skills.

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