DIVERFARMING

Crop diversification and low-input farming across Europe: from practitioners' engagement and ecosystems services to increased revenues and value chain organisation

GUIDELINES SHOWING THE FUTURE PATHWAYS FOR AGRICULTURAL MACHINERY INNOVATION IN EUROPE ADAPTED TO CROP DIVERSIFICATION TO INCREASE GLOBAL SUSTAINABILITY

Deliverable D5.2
Version 2.0
Issue date: 19/09/2021
Authors: Javier Calatrava, David Martínez-Granados, María Dolores Gómez-López

This project has received funding from the *European Union's Horizon 2020 Research and Innovation Programme* under grant agreement No 728003

DIVERFARMING

Document summary	
Document title	Guidelines showing the future pathways for agricultural machinery innovation in Europe adapted to crop diversification to increase global sustainability
Authors	Javier Calatrava, David Martínez-Granados, María Dolores Gómez-López
E-mail of principal author	j.calatrava@upct.es
Lead beneficiary	Universidad Politécnica de Cartagena
Deliverable No.	D5.2
Work Package	WP5. Environmental impact and delivery of ecosystem services by crop diversification
Dissemination type	Report
Dissemination level	Public
Deliverable due date	31/10/2020 (M42)
Release date	04/11/2020 (M43)
Copyright	© 2020 DIVERFARMING Project and Consortium

List of Diverfarming participants

No	Name	ACRONYM	COUNTRY
1	Universidad Politécnica de Cartagena (Coordinator)	UPCT	Spain
2	Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria	CREA	Italy
3	Agencia Estatal Consejo Superior de Investigaciones Científicas	CSIC	Spain
4	Universita degli Studi della Tuscia	UTu	Italy
5	Asociación Regional de Empresas Agrícolas y Ganaderas de la Comunidad Autónoma de Murcia	ASAJ	Spain
6	Consorzio Casalasco del Pomodoro Società Agricola cooperativa	CCP	Italy
7	Arento Grupo Cooperativo Agroalimentario de Aragón	GA	Spain
8	Barilla G.E.R. Fratelli SPA	Bar	Italy
9	Disfrimur Logistica SL	DML	Spain
10	Universidad de Córdoba	UCO	Spain
11	Wageningen University	WU	Netherlands
12	Firma Nieuw Bromo van Tilburg	NBT	Netherlands
14	Industrias David S.L.U.	InDa	Spain
15	University of Portsmouth Higher Education Corporation	UPO	United Kingdom
16	Universität Trier	UT	Germany
17	Eidgenössische Technische Hochschule Zürich	ETH	Switzerland
18	Weingut Dr. Frey	WDF	Germany
19	University of Exeter	Exeter	United Kingdom
20	Pecsi Tudomanyegyetem - University of Pecs	UP	Hungary
21	AKA Kft	AKA	Hungary
22	Nedel-Market Kft	NMT	Hungary
23	Luonnonvarakeskus	Luke	Finland
24	Paavolan kotijuustola	PK	Finland
25	Polven juustola	PJ	Finland
26	Ekoboerderijdelingehof	Eko	Netherlands

Executive summary

The activities within Diverfarming's task 5.6 (Benefits, drawbacks and limitations of machinery adapted to diversified cropping systems), which focuses on machinery innovation adapted to new diversified cropping systems, include an assessment of the advantages, disadvantages and limitations that the existing farm machinery has for the diversification of agricultural production, with the aim of identifying the actual needs and demands for innovation in new agricultural machinery to properly adopt intercropping in annual and tree crops. This report deals with such assessment, which was performed via a survey to farmers and experts on farm machinery from manufacturing enterprises, research centers and universities. Two separate questionnaires for annual and tree crops, respectively, were designed, tested and implemented by UPCT during 2019 and 2020. Surveys were divided into seven different needs for machinery: soil management, weed control, pruning, fertilization, foliar treatments, pesticides application and harvesting. This report presents the results of both surveys.

Regarding the need for specific machinery and equipment when intercropping in annual crops, stakeholders highlight that equipment must be adapted to different crop strips' width and, in the case of pesticides/herbicides, the equipment should allow the product to be applied differentiated per sprayer and facilitate a more localized application. However, the most important innovation needed is harvesting machinery, such as swath mowers, or adaptable harvesters that can work with different widths.

Concerning alley cropping between trees, stakeholders highlight the need for smaller, narrower and more adaptable machinery and equipment in terms of width to enter the alleys and do not disturb any present crop. Suggestions are developing multifunctional tillage and pesticide application equipment.

Table of Contents

1. Introduction and Methodology

Diverfarming's Task 5.6. (Benefits, drawbacks and limitations of machinery adapted to diversified cropping systems) focuses on machinery innovation adapted to new diversified cropping systems and addresses several issues. A first issue is the use of the farming practices and machinery selected in WP2 in the field experimental sites to assess, when possible, their benefits and limitations in terms of fuel consumption, greenhouse gas emissions, soil disturbance and labour time. For this purpose, within WP8, we are collecting labour time and fuel consumption data, and within WP5 soil quality properties to assess how machinery reduction is affecting these factors. We will come to this issue when we collect all these data, to be included in last deliverables (D10.2 to D10.5). A second issue of task 5.6 is the identification of needs and demands for new agricultural machinery to properly adopt intercropping in annual and tree crops, an issue addressed in the survey to farmers, machinery manufacturers and researchers. The third issue is the development and field validation of a prototype in case study 14, that is being performed by Industrias David partner.

This report deals with the second issue explained above and includes an assessment of the advantages, disadvantages and limitations that the existing farm machinery has for the diversification of agricultural production, with the aim of identifying the actual needs and demands for innovation in agricultural machinery to ease the adoption of intercropping in annual and tree crops. Such assessment is performed via a survey to farmers and experts on farm machinery from manufacturing enterprises, research centers and universities. This survey aims to evaluate the suitability of the existing machinery for its use in diversified cropping systems and to identify the needs for new and more suitable machinery for these cropping systems. Two separate questionnaires for annual and tree crops, respectively, were designed, tested and implemented by UPCT during 2019 and 2020. This report presents the results of both surveys plus some insights from *Industrias David*, a farm machinery manufacturer that is partner in Diverfarming, regarding the need for cooperative approaches for the development of new machinery that meets farmers needs regarding intercropping.

The questionnaire starts with a brief explanation of the Diverfarming project and the purpose of the survey and the consent form to be signed by the respondent, followed by several blocks of open-response questions:

- The first block of questions aims to identify and characterise the interviewee (name, gender, institution/enterprise, job position).
- The second block of questions asks the experts if they think that the currently existing farm machinery is compatible with establishing simultaneous crops between annual or tree crops. If the experts think that it is not compatible, they are asked to explain why and in which cases, and which possible technological solutions they would apply to solve such incompatibility. Questions are posed separately for different types of farm machinery (machinery for soil management, for weed control, for fertilizers application, for pesticides application and for harvesting).
- The last block of questions asks the experts if they think that it would be necessary to use some specific machinery, different to the currently used one, when growing simultaneous crops between annual or tree crops. If the answer is positive, the experts are asked to indicate which type of machinery that is not currently available would be necessary and for which specific farming practices.

The survey was implemented in a commercial online surveying platform (Survey Monkey) so interviewees can answer it online using a laptop/tablet/smartphone. The questionnaire was available for being answered both in Spanish and English. Survey answers can be downloaded in an Excel format template for its validation and analysis.

2. Survey participants

Diverfarming partners and the members of the Crop Diversification Cluster have cooperated to identify suitable experts to be surveyed. However, due to the difficultness to find really knowledgeable experts on the issue, only seventy-nine respondents were surveyed. Table 1 and Table 2 show the number of survey respondents per type of stakeholder and country. Forty-two are farmers or work in a farming enterprise, fourteen work at agricultural machinery manufacturing companies, fifteen work at agricultural machinery selling and repair companies and eight are academic/researchers. Most of them are from Spain.

Table 1. Number of survey respondents by type

	Woody crops	Annual crops	Total
Farmers/producers	11	31	42
Agricultural machinery manufacturers	13	1	14
Agricultural machinery sellers/repairers	15	0	15
Academic / Researchers	2	6	8
TOTAL	**41**	**38**	**79**

Table 2. Number of survey respondents by country

	Woody crops	Annual crops	Total
Spain	37	34	71
The Netherlands	0	3	3
United Kingdom	2	1	3
Israel	1	0	1
Greece	1	0	1
TOTAL	**41**	**38**	**79**

3. Compatibility of the existing machinery with implementation of intercropping

3.1 Machinery for soil management

Almost all the respondents think that the existing tillage machinery is compatible with intercropping in annual crops. However, some of them point that it might be necessary to use different machinery for each crop in the diversification. For example, in diversifications with cereals, legumes and oilseeds, the same machinery could be used, but different machinery could be required for aromatic or vegetable crops. Some stakeholders also indicate that a problem might arise if the productive cycles of both crops do not coincide, as it would be difficult that the soil management needs for each crop could be met with the same operations for both ones. In such case, there would be a problem if the crop strip width is not adapted to the existing tillage machinery.

Precisely, a few respondents think that the existing tillage machinery should have a smaller size and be more versatile to be used in intercropping, but other respondents indicate that smaller tools are available in the market.

Regarding intercropping in woody crops, respondents agree that the currently existing tillage machinery is compatible with establishing alley cropping, but different tillage tools should be used for each crop, as the soil management needs for a tree crops are quite different than those for an annual crop that has more superficial root systems. Additionally, intercropping would require that the characteristics of the tractors available are considered when deciding the distance between rows and the way the alley crop is grown. Respondents agree about the lack of commercial tillage machinery prepared for working with alley crops and tree crops at the same time.

3.2 Machinery for weed control

In the case of intercropping in annual crops, respondents think that mechanical weeding would not be a problem if the crop strips are wide enough (at least 3 meters). An intercropping width smaller than normal machinery working width would require adapting the existing tools. For chemical weed control, normal working widths are greater, as herbicide application equipment cover a range of 12 to 18 meters, what would require even larger strips width. A solution could be designing application equipment with lower ranges adapted to more narrow crop strips, what could not be economically efficient, as it would increase operation time, or machines that are adaptable to different widths. One respondent indicates that adaptable machinery for herbicides application is increasingly available. In any case, there is an additional complication resulting from the incompatibility of weed control treatments for different species (e.g. for dicotyledons and monocotyledons). Application equipment can incorporate anti-right systems, such as protection screens, but they are not fully effective to avoid damages in the adjacent crop. Solutions are developing equipment that can differentiate the product applied per sprayer using protection screens.

Moving to woody crops, the vast majority of respondents think that the compatibility of the existing machinery for mechanical weed control exists but that it would depend on the suitability of tractors and tools for the distance between tree rows, the way alley crops are planted and its strip width. In the case of chemical weed control, there is a major drawback. As commented, existing equipment for weed control in non-woody crops require wide crop strips that are wider than the standard distance between tree rows. One solution is developing specific equipment for more narrow crop strips. However, a few respondents point out that intercropping is a weed control practice in itself and that the need for weed control in tree crops would be largely reduced.

3.3 Machinery for pruning

In the case of pruning, respondents think that the existing machinery is compatible with intercropping in woody crops, as far as the tree density and the configuration of the intercrop permits the access to the trees. If they do not, manual pruning would be necessary.

3.4 Machinery for fertilization

All respondents think that the existing machinery for fertilization is compatible with intercropping in annual crops, even if each crop has different fertilization needs. In this latter case, the only constrain would be, again, the compatibility of machinery with the width of crops' strips. However, there a significant number of farmers (nine) that think that more precise tools are required for a more localised application of fertilizers in order to take into account the different needs of each crop, and that these are usually expensive, especially for smaller farms.

In the case of woody crops, respondents think that the existing machinery for fertilization is compatible with alley cropping. If fertilization is applied non-locally and on the soil's surface, without burying it, the same

fertilization equipment could be used. On the contrary, the localised fertilization and the burying of the fertilizer would require having different equipment for the tree crop and the alley crop. Alternatively, in irrigated crops fertilization could be done using fertirrigation systems.

3.5 Machinery for foliar treatments

All respondents think that the existing machinery for foliar treatments is compatible with intercropping in tree crops, as long as tree density and the configuration of intercrops does not impede the access of machinery. Some respondents highlight that, in the case that alley crops also require treatments, it must be considered that the equipment would be different (atomizer for the tree crop and bar sprayers for the intercrop). Both could be installed jointly but the different needs of each crop would require separate applications in different moments.

3.6 Machinery for pesticides application

Similarly, respondents think that the existing machinery for pesticides application would be compatible with intercropping in annual crops, as long as strip width is compatible with the width ranges of commercial equipment. Otherwise, the existing equipment could be easily adapted. Another concern relates to the different needs of each crops what could require separate applications for each crop and the use of anti-right systems. Precisely, a significant number of farmers/producers (ten of them) think that the tools for pesticides application can be used but that are not fully adapted to the different needs of each crop. However, responses suggest that this is not perceived as difficult to solve.

3.7 Machinery for harvesting

Harvesting is the farming operation where respondents find the major difficulties. In annual crops, respondents think that the suitability of existing harvesting machinery would depend on the specific combination of crops considered. A major problem is each crop's harvest date. Ideally, both crops should be harvested in a single operation to prevent unitary harvest costs from increasing, but this may not be possible as both crops are likely to have different harvesting dates. There are combined harvesters for grain crops and legumes that could be used. However, for other crop combinations, even if they could be harvested at the same date, they should have to be harvested separately using different harvesters specifically for each crop. In any case, as the size of most commercial harvesters is perceived as a problem, the width of crop strips should be adapted to the existing machinery or new more narrow harvesters should be developed.

In the case of intercropping between tree crops, the fact that each crop is harvested differently impedes thinking on integrating harvest operation in a single operation or, moreover, using the same machine. With this in mind, respondents point at the size of harvesters as the major problem for harvesting the alley crop, as there are not commercial harvesters with small widths to fit between the usual distance between tree lines. In the case of mechanical vibrating tree harvesters, the respondents think that the alley crop might be a problem for its functioning, not in the case of hedge-formed plantations.

Table 3. Summary of compatibility of the existing machinery with implementation of intercropping

Mechanical labors	Annual crops	Woody crops
Soil management	Compatible, but need to use different implements and machinery types for each group of crops	Not compatible: alley cropping needs different tillage tools than trees
Weed control	Compatible only if crop strips are wide	Compatible only if alleys are wide
Pruning	Not applicable	Compatible
Fertilization	Compatible only if crop strips are wide	Compatible if application is not local and it is superficial. Not compatible if it is local and buried in the soil
Foliar treatments	Compatible only if crop strips are wide	Compatible, but with different sprayer tools for alley and row crops
Pesticides	Compatible only if crop strips are wide	Compatible if application is not local. Not compatible if it is local
Harvesting	Not compatible if crops are different in harvested product and timing, and strips are narrow	Different machinery needed for alley and row crops. Challenge: alley width

4. Need for specific machinery in intercropping systems

Half of respondents think that there is a need for new machinery or the adaptation of the existing one to respond to the needs of intercropping systems. In the case of annual crops, they point at the need for new harvest machinery that is suitable for harvesting mixed cropping systems, such as swath mowers, or adaptable harvesters that can work with different widths. A significant number of respondents also indicate the need for adaptable equipment for fertilization and pesticides application that can apply products locally to different crops.

In the case of alley cropping between tree rows, the most commented needs relate to three main issues. The first one is developing cultivators that can be adapted to different widths and to the different tillage needs of tree crops and annual alley crops, i.e. multifunctional hybrid equipment for soil management. The second one relates to the need for adaptable and smaller harvesters for the intercrops that can work with different widths or even with single crop rows. The third one relates to the need for multifunctional hybrid shredders for mechanical weed control and herbicide application equipment that can work in-row and that are adaptable to different widths. Some respondents also point at the need for adaptable fertilization equipment and for foliar treatment hoods that can be adapted to each type of plantation.

In any case, several respondents indicate that the use of guiding GPS systems is required to optimize farming operations and avoid problems, especially in annual crops. A summary of needs is included in Table 4.

Table 4. Summary of needs for specific machinery in intercropping systems

Annual crops	Woody crops
Implements to select strip width	Implements to select strip width
Sensorised machinery for precision farming depending on crop type, crop damage/infection and soil fertility	Soil preparation machinery adapted to alley cropping (multifunctional hybrid equipment)
Tools than differentiate fertilizers/pesticides locally	Sensorised machinery for precision farming depending on crop type, crop damage/infection and soil fertility
	Fertilizers/pesticide application tools adapted to both trees and alley crops

5. Concluding remarks

In general, survey respondents think that existing machinery is, in principle, compatible with intercropping. A major factor to be considered is the compatibility of crop strips width and distance between tree rows with the width ranges of commercial equipment, usually between 3.0-3.5 m. Obviously, adapting the width of crop strips to the characteristics of existing machinery is easier in the case of intercropping between annual crops, but far more complex in the case of intercropping between tree crops, especially in Mediterranean woody crops, such as citrus, vines, almond, where tree rows are narrower. Moreover, in the latter case, the distance between tree rows can even be a problem for the access of machinery (e.g. machinery for pruning, vibrating harvesters, …) itself.

This potential compatibility is less clear in the case of equipment for the application of chemical inputs, such as herbicides, which usually cover wider working ranges than machinery for mechanical operations (shredders, cultivators, etc.). Respondents highlight the need for such equipment to be adaptable to different widths/products.

Another relevant factor to assess the compatibility of existing farm machinery with intercropping is the farming requirements of each crop within the diversification. For example, the same machinery could be used (or a different one would be required) depending on the type of tillage to be implemented on each crop or the type and dosage of fertilizers, herbicides and pesticides required by each crop. Moreover, even if these coincide, their timing might not. If the timing of farming operations do not coincide, they should be implemented separately, thus increasing working time and costs.

In the case of harvesting, which is perceived by respondents as the most complicated issue, it might not be a problem in annual crops if they can be harvested at the same time and using the same machine, which basically depends on the type of crops in the diversification. In the case of intercropping between tree crops, it is impossible to harvest using the same machine.

Regarding the need for specific farm machinery and equipment when intercropping in annual crops, respondents point at the need for fertilization and pesticides application equipment that can apply products locally to different crops, and for herbicides application equipment that can be adapted to different crop strips' width or that can differentiate the product applied per sprayer and facilitate a more localized application of herbicides. However, the most relevant need highlighted is that of harvesting machinery that is suitable for mixed cropping systems, such as swath mowers, or adaptable harvesters that can work with different widths. However, it should not be forgotten that, in many cases, harvesting might not dates coincide, so it might not be worth developing specific solutions for combined harvesting.

In the case of alley cropping between tree crops, the survey responses suggest that the need for smaller, narrower and more adaptable machinery and equipment is basic, including:

- Soil management equipment that can be adapted to different widths and to the different tillage needs of the tree crops and the intercrops, i.e. multifunctional tillage equipment.

- Shredders for mechanical weed control and herbicide application equipment that can work between rows and that can be adapted to different widths.
- Equipment for herbicides application that can be adapted to more narrow crop strips.
- Adaptable and smaller harvesters for the intercrops that can work with different widths or even with single crop rows, similar to the single-furrow harvesting devices that exists for some tuberous crops.

However, it must not be forgotten that the survey results highlight paths for machinery innovation on a fairly generic way. The needs for specific machinery innovations can differ significantly between different types of intercropping systems and also between farms. This variety of requirements makes developing new machinery for diversified cropping very challenging, as technical solutions should be usable in different cropping systems and farms. According to *Industrias David*, machinery manufacturer and partner in Diverfarming, and considering how the different farming operations must be implemented in diversified cropping systems, farmers most often demand relatively simple machines that are robust, preferably easy to maintain and to be fixed at the farm, and relatively inexpensive, and this is, in general, not supplied by manufacturers. Developing new machinery for diversified cropping requires significant targeted research and innovation efforts, but also the cooperative interaction between farmers and machinery developers.