

Deliverable 2.4

Report of on-farm research of innovative cropping systems

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List of Main Abbreviations

ABRV	Definition of the abbreviation
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LER	Land Equivalent Ratio
K	Potassium
N	Nitrogen
P	Phosphorus
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
WP	Work Package



Transition

1. INTRODUCTION

The natural resources are facing increasing pressures and degradation as a result of population pressures, intensification of agricultural and livestock activities, and unsustainable land use systems and management practices. Agroforestry has been seen as a viable alternative to conventional monocropping in the semi-arid Mediterranean environment due to the sustainable intensification of land and water use. The research approach of the TRANSITION Project aims to assess newer and sustainable agronomic strategies and resources that may or may not have received testing but have suffered from a lack of exploitation or inter-comparison and give evidence of the benefits of these practices.

To do so the project's on-farm research is distributed in five different countries and regions. The study regions are Catalonia (Spain), Sétif (Algeria), Sicily (Italy), the Behia and Kafr Elsheikh Governates of Egypt, and Southwest France. The three regions in the North Mediterranean and two in the South represent different pedo-climatic areas, cultures, and agricultural practices.

The strategy was to collect previous or underway agroforestry and mixed farming experiences in contrast with conventional systems, and then the implementation of novel agroforestry and mixed farming system strategies, monitored during two years of the project life in on-farm research programs in the five Mediterranean regions.

1.1. The context of the deliverable within the TRANSITION project and the related work package to this deliverable

The present document presents the results of the research activity conducted in the context of WP 2 "Testing and validation of innovative farming systems", and in particular within the framework of the Task 2.5 "On-farm research program for testing of innovative technologies and genetic resources", which aims to evaluate sustainable agronomic strategies for increasing productivity and diversify crop production, while decreasing the pressure on Mediterranean natural resources to improve the resilience of agroforestry and mixed farming systems.

Various practices and cropping systems (Table 1) have been studied with the aim of improving the resilience of the cropping systems while considering the heterogeneity of the several regions identified within the Mediterranean Basin with their different pedoclimatic, social, and economic conditions.



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The resilience of the cropping systems has been defined according to specific indicators of resilience that have been developed within the WP1, Task 1.3 “Establishment of resilience indicators”.

Different ecosystem service and socio-economical resilience indicators have been identified by each partner of the project, with a general agreement over some aspects.

Yield stability was identified as main indicator of resilience for a cropping system. Other important indicators related to the ecosystem services were the improvement and stability of the soil organic matter content, which influences the overall productivity of the system, the capacity of carbon storage, the soil water holding capacity and the local biodiversity, with consequent effects on pest control.

Considering the socio-economical aspects, several indicators have been identified concerning the farm income, the products offer, and the people involved in the farming activity.

Within the frame of the WP2, the on-farm research focused on the productivity and ecosystem service indicators.

This report aims to summarize the findings and outcomes of the on-farm research focused on innovative agroforestry and mixed farming systems over several cropping seasons. The following sections, therefore, describe the methodologies used in the study and the major findings. The methodology section, the result section and the discussion section describe separately each case study for all the regions that have been selected for the on-farm research. The case studies have been described separately to address the differences in the pedoclimatic, social, and economic conditions and the several resilient farming systems that have been identified to adapt to these conditions. The conclusion reports the main finding for the resilient farming systems at the Mediterranean basin level.

Table 1. Summary of the systems studied in the frame of the project

Country	Priority systems	Threes	Crops
SPAIN	Silvoarable	Olive	Cereal
SPAIN	Silvoarable	Olive & Forest	Sainfoins
SPAIN	Innovative culture	n/a	Kernza
SPAIN	Silvoarable	Vineyard	Cereal & cover crops
SPAIN	Mixed farming	Vineyard & Forest	Cover crops



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ITALY	Silvoarable	Olive	Cereal (wheat & rye)
ITALY	Silvoarable	Olive	Legumes
EGYPT	Silvoarable	Citrus & guava	Forage, vegetables, & cereals
EGYPT	Agrosilvopastoral	Fruit trees	n/a
EGYPT	Silvoarable	Fruit tree	Tomato
ALGERIA	Mixed farming	n/a	Cereal, forage, & vegetable crops
ALGERIA	Mixed farming	n/a	Durum wheat & barley
ALGERIA	Silvopastoral	Olive & Forest	n/a
FRANCE	Technology	n/a	n/a
FRANCE	Technology	n/a	n/a
FRANCE	Technology	n/a	n/a
FRANCE	Innovative culture	n/a	Persimmon
FRANCE	Innovative culture	n/a	Chayote
FRANCE	Management culture	n/a	Salad

2. SPAIN CASE-STUDY

2.1. Experimental site description and methodology

In the case-study of Spain, five farms were selected in different areas of Catalonia region. Those farms were chosen through the activities performed in the WP 1. Farms were described searching for general and crop-specific information. A brief description of each of them is set out below. Detailed information of each farm can be consulted in the Annex VII in the D1.2 Resilience indicators.

Along with the farms' selection, different ecosystem service and socioeconomic indicators (Table 2) were also selected through participatory approach with stakeholders (for further information, please refer to D1.2 resilience indicators).

Table 2. Ecosystem service and socioeconomic indicators to evaluate resilience in agroforest and mixed farming systems. Indicators are classified into State (ST) and Management-related (MR) indicators

No.	Ecosystemic service indicator	Type	Socioeconomic indicator	Type
1	Physic-chemical characterisation	MR	Self-consumption	MR
2	Soil organic matter content	MR	Product price	ST
3	Soil structure	MR	Production certificate	MR



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4	Soil water holding capacity	MR	Nature tourism	MR
5	Cultivated species richness	MR	Company structure	MR
6	Floristic richness	MR	Accumulated yield	ST

Data from **ecosystem service indicators** (Table 2) were collected during two cropping seasons: 2022-2023 and 2023-2024. Each farm was sampled after harvest period, during a convenient moment of the year, considering the different crops/trees combinations. Physic-chemical characterisation including soil organic matter, soil structure and water holding capacity were performed through soil sample analysis in the laboratory (Figure 1 left). Disturbed soil samples were collected from 00-30 cm depth from the soil surface. A composite soil sample was obtained from 3 sampling points distributed across the selected plot. Undisturbed composite soil samples were collected only for aggregates stability.

Cultivated species information was collected from the farmer. Floristic richness was evaluated in the field using sampling quadrats (0,25 m²). Three points were randomly selected along the field area (Figure 1 right). Floristic richness was expressed in terms of species and soil cover percentage was also considered in terms of soil protection.



Figure 1. Soil and floristic richness sampling in different farms.

Socioeconomic indicators listed in Table 2 were collected three times during the task execution. First in an initial interview during the summer period of 2022. Then, at the end of two consecutive cropping periods. In the case of the innovative crop (farm 04), the



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socioeconomic indicators were only considered in the first interview, as the field was given to the UVic-UCC to be used as an experimental site.

Protocols regarding cultivated species, floristic richness and socioeconomic indicators were discussed also with CTFC partners. It was helpful to consider different aspects regarding such indicators as well as to set the questions to obtain the data of interest.

Farm 01

The farm is located in the municipality of Argençola (Barcelona, Spain), at 650 m.a.s.l. It belongs to the ecoregion “Northeastern Spain and Southern, France Mediterranean Forests (PA20)” following The One Earth Bioregions Framework, with 479mm of rainfall per year and 19°C of mean annual temperature and dryland conditions. The farm is located in the "Central Depression of Catalonia", specifically in the "Central Baisin - High Segarra". The morphology is extensive plains with fluvic sediments from the Pleistocene. The highest influence is on erosive instead of the deposition processes (ICGC 2021). Soil classification: Xerorthent typic (USDA, 2014). Texture Clay loam. pH 8.4. Soil depth <1m. Field is organised in level terraces.

The studied system is a silvoarable system of olive trees and sainfoins surrounded by forest. Olive trees are arranged in lines with 15 m among olive trees, with sainfoins (*Onobrychis bicifolia*) between the rows established in 2017. The farm is managed with innovative practices such as no tillage, sainfoins used as cover crop to improve fertilisation, and the aim to recovery of abandoned plots.

The technical interest in the frame of the TRANSITION project is that the plots are part of the recovering work of field sites that were abandoned during the second half of XX Century, and where the forest was growth. The farmer use of sanfoins as a cover crop to improve the soil fertility and reduce soil erosion.

Farm 02

The farm is located in the municipality of Bràfim (Tarragona, Spain) at 243 m.a.s.l., and it is considered a nitrates contamination vulnerable zone. It belongs to the ecoregion “Northeastern Spain and Southern, France Mediterranean Forests (PA20)” following The One Earth Bioregions Framework, with 487 mm of annual rainfall and 16°C of mean annual temperature and dryland conditions. The soil is categorized as s57c (Soil Taxonomy, 2014). Petrocalcic calcirepts and typical carcixerepts. Soils developed from



Transition

the weathering deposits rich in calcium carbonate in the base of mountains and in slight sloping slopes with a xeric moisture regime. From superficial to very deep, well drained, with medium textures and a variable content of coarse elements. They present many secondary accumulations of calcium carbonate in the form of nodules and/or coatings of the coarse elements that give rise to a calcic and petrocalcic horizons. c: upon petrocalcic horizon. Slightly alkaline soil.

The studied system is a silvoarable system of olive trees combined with extensive winter cereal production established in 2006. The olive trees are older than 50 years old and are arranged in a line surrounding the crop field. The main innovative practice in the farm are the windbreaks (olive trees) in three out of the borders of the cereal plot.

The technical interest in the frame of the TRANSITION project is that the crop combination is the traditional cereal - olive tree. During the last decades, the trees have been eliminated to create bigger areas of cultivation, increasing the soil lost by wind and water erosion.

Farm 03

The farm is located in Riner (Lledia, Spain), at 813 m.a.s.l. and is considered as a nitrates contamination vulnerable zone. It belongs to the ecoregion "Iberian Sclerophyllous and Semi-Deciduous Forests (PA20)" following The One Earth Bioregions Framework, with 603 mm of annual rainfall and 13°C of mean annual temperature and dryland conditions. The soil is categorized as s50a (Soil Taxonomy, 2014). Typical Xerorthents and calcic Haploxerepts. Soils developed from rocks of different lithologies and the deposits from their weathering at the base of the mountains and in slight and moderate slopes with a xeric moisture regime. From shallow to deep, well drained, with medium textures and few coarse elements. They can present secondary accumulations of calcium carbonate in the form of nodules and/or coatings of coarse elements that give rise to a cambial horizon. a: on sandstones and shales. Moderately alkaline soil.

The studied system is a silvoarable system involving vineyards combined with cover crops. The vineyards are arranged in rows with cover crops in the aisles established in 2017. These crops are different mixtures of cover crops. The main innovative practices in the farm are organic farming, use of cultivated cover crops among the wine trees and reduced tillage.

The technical interest in the frame of the TRANSITION project is that changes in temperature and precipitation promote people looking for cropping areas in other



Transition

altitudes. That is the case of vineyards in the Catalan region. The crop rotation in cultivated rows is also of interest as a resilient practice.

Farm 04

The farm is located in Vic (Barcelona, Spain), at 476 m.a.s.l. and is considered as a nitrates contamination vulnerable zone. It belongs to the ecoregion “Northeastern Spain and Southern, France Mediterranean Forests (PA20)” following The One Earth Bioregions Framework, with 680 mm of annual rainfall and 14°C of mean annual temperature and dryland conditions. The soil is categorized as s29 (Soil Taxonomy, 2014). Calcic Haplustepts and typical Calcicustpts. Soils developed from sandstones, loams and deposits from their weathering in the wider valleys of the interior mountain ranges. Moderately deep to very deep, well drained, with medium textures and few coarse elements. They present secondary accumulations of calcium carbonate in the form of nodules and/or coatings that can give rise to a calcium horizon.

The system studied is the innovative crop Kernza® (*Thinopyrum intermedium*) established in 2020. This innovative crop is a perennial cereal and the innovative interest in the frame of the TRANSITION project is the evaluation of a perennial cereal in its establishment to the Mediterranean conditions and the evaluation of the benefits for soil health.

Farm 05

The farm is located in Sant Quintí de Mediona (Barcelona, Spain), at 425 m.a.s.l. It belongs to the ecoregion “Northeastern Spain and Southern, France Mediterranean Forests (PA20)” following The One Earth Bioregions Framework, with 548 mm of annual rainfall and 13.5°C of mean annual temperature and dryland conditions. The soil is categorized as s47o (Soil Taxonomy, 2014). Lithic Xerorthens and typical Calcirepts. Soils developed from rocks of different lithologies, rich in carbonates, and their weathering deposits at the base of the mountain. Superficial or very superficial, well drained, with medium textures and a variable content of coarse elements. Some profiles can develop petrocalcic horizons from the dissolution and precipitation of the rocks that make up the original material. Moderately alkaline soil.

The studied system is a silvoarable system (silvopastoral in some specific moments) established in 2014. This system involves olives with cover crops, vineyards with and without cover crops, multifunctional field margins, and forest. These are arranged in rows of vineyards with cover crop in the aisles and lines of olive trees combined with cover



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crop with multifunctional field margins and a patch of forest in one section of the farm. The cover crops are composed mainly by natural vegetation and during 2 months in winter sheeps graze the aisles between the vineyards. The innovative aspect is the combination of olive trees with natural cover crop, managed forest and natural mediterranean vegetation in the border of the vineyards. Moreover, the organic management of the vineyard.

The technical interest in the frame of the TRANSITION project due to the complexity of the system. It includes forest, olive trees, vineyards and natural shrub vegetation. Furthermore, the effect of natural cover crops in the olive trees and the vineyards are of interest. The vineyards have organic fertilisation plus the natural cover crop.

2.2. Results

Results from the indicators are shown separately by ecosystem service and socioeconomic indicators (Table 2). Then, they are described by each farm, within this section, results are shown only for soil organic matter, water holding capacity, aggregate stability, main nutrients (N-P-K) and floristic richness. Detailed information regarding the other physical-chemical parameters of soil analyses for each farm can be consulted in the Annex III

2.2.1 Ecosystem service indicators

Farm 01

In this case study, it was observed that the agroforestry systems have the capacity to increase the SOM (Figure 2, left). The rows of the oldest agroforestry parcel showed the highest SOM content (~3%), surpassing the SOM of the forest (~2,5%), the parcel that show the SOM in a natural context, with no management. The SOM of the rows of olive trees was similar to the forest while the SOM of the rows of sainfoin could vary among years, probably reflecting the vegetation stage influence in the SOM.



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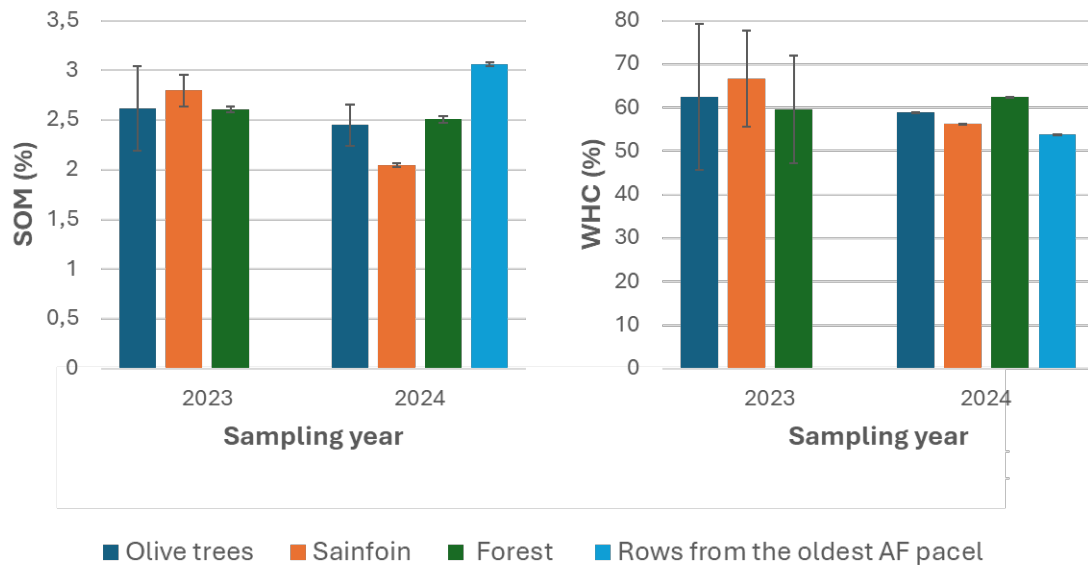


Figure 2. Average percentage of Soil Organic Matter (SOM) and Water Holding Capacity (WHC) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 01) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

The capacity of the agroforestry systems to increase the soil water holding capacity (%) was not clearly observed (Figure 2, right). The weight of the aggregates decreased with the particle size. In this case as the forest showed the higher value and the oldest agroforestry parcel did not show higher values than the rows with olive trees and sainfoin more recently established (2017). This positive effect could be observed probably in the long term.

Aggregate stability was evaluated as a parameter associated with soil structure. The results show similar outcomes for all agroforestry components as well as for the forest (Figure 3). Regarding large aggregates (>2000 μm), soils in the forest zone exhibited a high proportion of these aggregates, indicating good stability and structure compared to other areas. The areas of the oldest agroforestry parcel and the sainfoin also had similar proportion of large aggregates, suggesting that these systems promote stability.

For medium-sized aggregates (2000-250 μm), this fraction was more variable. The olive and sainfoin zones, along with the oldest agroforestry parcel, showed higher amounts of medium aggregates compared to the forest, which might suggest that these crops do not maintain as stable a structure as the forest.



Transition

Regarding small aggregates (250-53 μm) and fine particles (<53 μm), soils from the olive, forest, and sainfoin zones presented a similar amount of small aggregates. These smaller fractions are less stable and are often associated with lower soil cohesion, which could imply a higher risk of erosion or compaction if their proportion is high.

Overall, the forest zones and the oldest agroforestry parcel and the sainfoin seem to have a more stable soil structure with a greater proportion of large aggregates, which is beneficial for soil health and resistance to erosion. The zone under the olive tree, with higher proportions of medium and small aggregates, may have a less stable structure, especially in more recent systems or those with less vegetative cover.

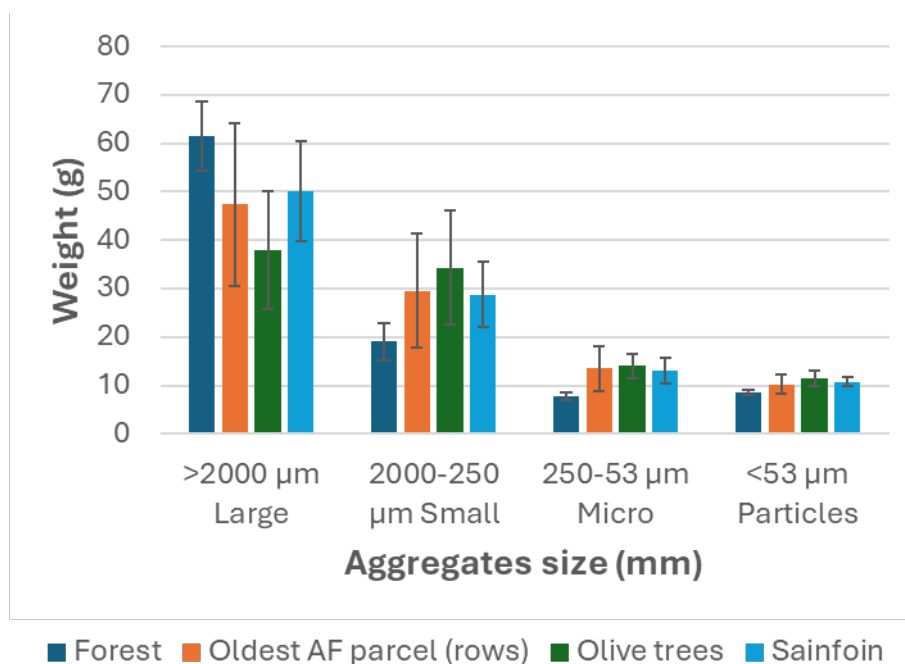


Figure 3. Aggregates stability and size distribution of the Farm 01 of Spanish pilot. Results showed the analysis of year 2024. Average values of 3 field replicates. Black vertical bars indicate standard deviation.

The total nitrogen soil content (ammonium and nitrate) was similar in the different agroforestry components (olive trees and sainfoin) and in the forest (5-10 mg/kg dm) (Figure 4, left). In the case of Olive trees, these are acceptable values after the yield period, meaning low risk of groundwater nitrates contamination. However, nitrogen was classified as strongly higher in the rows of the oldest agroforestry parcel (~30 mg/kg dm), indicating that agroforestry could increase nitrogen availability, probably associated to the increase of SOM.



Transition

The total phosphorus content of soil (mg/kg dm) varied among years in the agroforestry components while in the forest remain stable (Figure 4 middle). The availability of this macronutrient in the agroforestry system was higher than in the natural context (forest) reflecting the influence of trees and crops depending on their management and performance, such as the organic fertilisation.

Potassium content (mg/kg dm) was similar in the different agroforestry components and in the forest, as well as in the oldest agroforestry parcel (Figure 4, right). Values ranged between 4000 and 5000 mg/kg dm, which can be conserved as acceptable in accordance with the regional regulation.

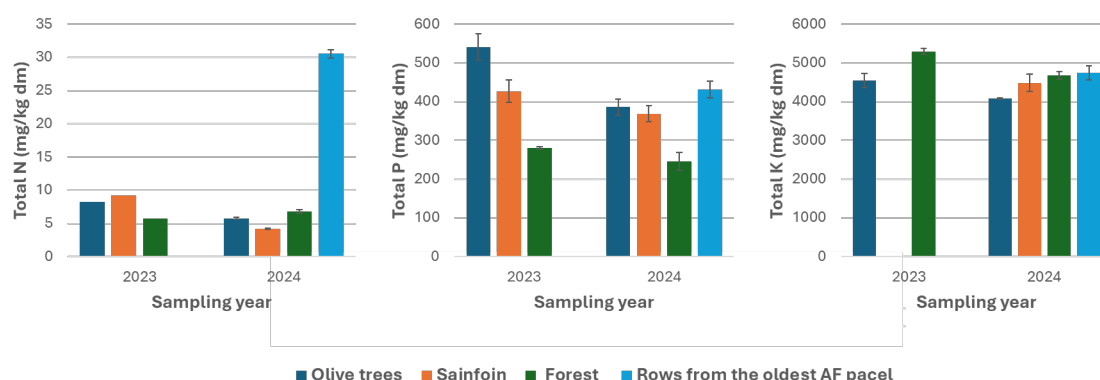


Figure 4. Average content of total nitrogen (N), potassium (K) and phosphorus (P) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 01) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation

Regarding floristic richness (Table 3), olive trees rows that are planted with sainfoin, showed the highest diversity in number of species. Lowest diversity was observed in the forest. However, soil surface was fully covered by natural mulch (needles, leaves and branches). On the contrary, olive trees which showed higher number of species, showed less surface cover than forest.

Table 3. Floristic richness for each component of the agroforestry system (pilot Farm 01) in Catalonia, Spain. Data obtained from two cropping seasons using three replicates per sampling

Floristic richness/ Component of the AFS	2023		2024	
	species number	family number	species number	family number
Olive trees	16	9	9	7
Sainfoin	24	6	12	7
Forest	4	2	7	5

Farm 02

Plot 2 from farm 02 was not sampled because it was already fertilised at the sampling time, thus no data was collected from such plot and period.

In this case study, the SOM (%) pattern reflected the effect of both the olive trees and the winter cereals in this parameter depending on their performance (Figure 5, left). The severe drought experienced during the study in this farm produced several alterations in crop performance, including the loss of harvest of the cereal. In this context, the SOM of the cereal field (nearly 3%) could be affected by the fact that in 2023 the cereal was not harvested and the crop remains in the field. In the case of olive trees, in 2023 the SOM decreased regarding the year before showing contents of 2,5%, probably due to the negative effects of drought in the soil fertility.

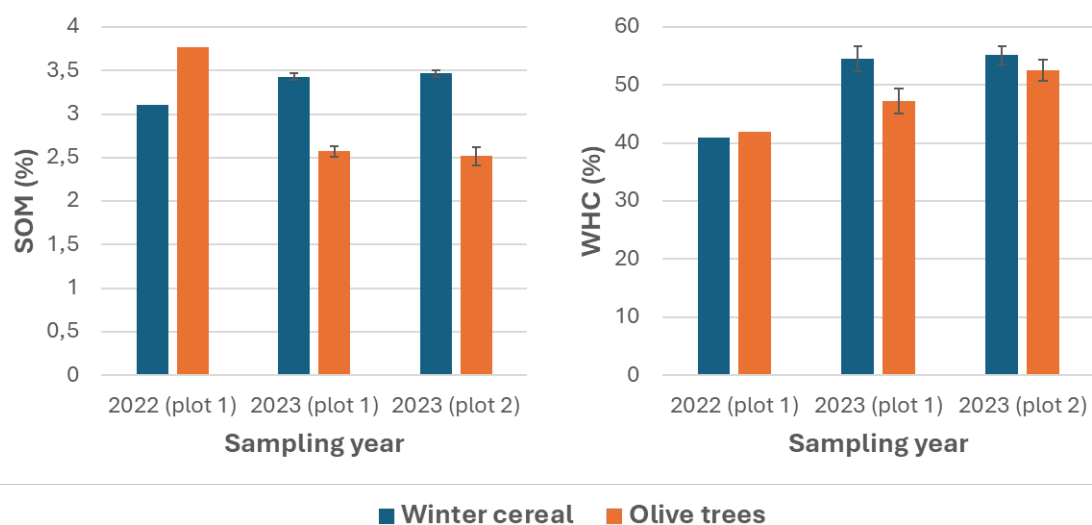


Figure 5. Average percentage of Soil Organic Matter (SOM) and Water Holding Capacity (WHC) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 02) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

The soil water holding capacity (%) was similar at the sampling period of the crop cycle 2022 for olive trees lines and cereal field (Figure 5, right). In the cropping cycle 2023 the values increased and showed a more pronounced increasing tendency in the case of winter cereal field. In this case it was expected higher in the olive trees lines with more



Transition

natural conditions and minimum soil management, but it could be probable that the soil compaction due to the severe drought negatively impact in this parameter.

Regarding aggregates' stability, samples were lost and no results are shown.

Total nitrogen content (mg/kg dm) was high (ranging 40 to 80 mg/kg dm) in the winter cereal field (Figure 6, left). It can be partially explained because the two sampling periods coincided with drought periods. It means that farmer sowed and fertilised the plot waiting for rain, but the drought experienced in the area produced the plant died. Then, N stayed in the upper part of the soil profile as no water moved it to deeper layers. On the contrary, in the olive trees lines, where the soil management was minimum, the total nitrogen content was low (ranging 5 to 20 mg/kg dm). In the same way, the patterns of the total phosphorus content (mg/kg dm) and the total potassium content (mg/kg dm) were similar (Figure 6, middle and right, respectively), except in year 2022 when the total potassium content was ranging between similar values both in the olive tree lines and in the cereal field.

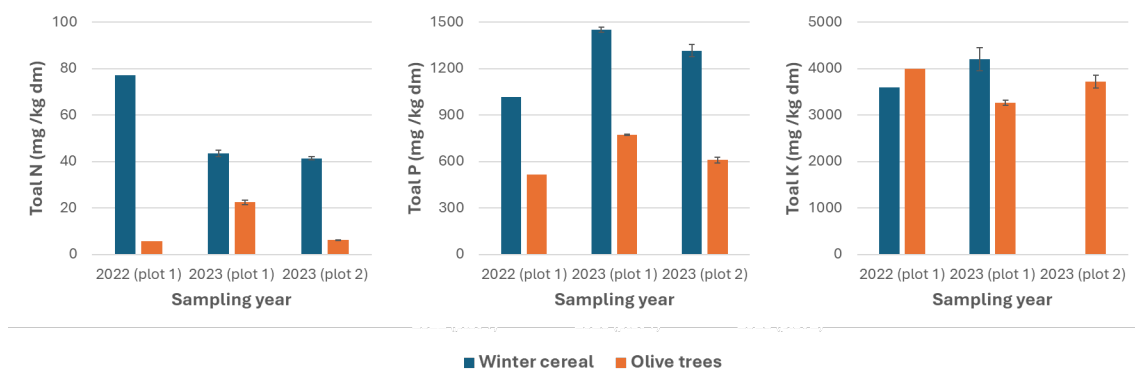


Figure 6. Average content of total nitrogen (N), potassium (K) and phosphorus (P) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 02) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

Floristic richness (Table 4) was evaluated only in the olive trees' plot. It showed few diversity. Probably, as a consequence of the severe drought faced in the area. In the case of winter cereal, at the sampling time, soil was tilled and floristic richness could not be assessed.



Transition

Table 4. Floristic richness for each component of the agroforestry system (pilot Farm 02) in Catalonia, Spain. Data obtained from two cropping seasons using three replicates per sampling.

Floristic richness/ Component of the AFS	2022		2023	
	species number	family number	species number	family number
Olive trees- plot1	7	1	3	3
Olive trees- plot2	N/A	N/A	6	3
Winter cereal	N/A	N/A	N/A	N/A

Farm 03

In this case study the SOM (%) pattern remained similar in the two years of the study (Figure 7, left). This pattern showed higher SOM content in the rows of conventional managed vineyard and in the rows between vineyard lines with spontaneous vegetation but values were similar to the vineyard rows in the agroforestry system (combined with cover crops and spontaneous vegetation) and in the rows between vineyard lines with sowed cover crops. SOM content increased in all components in year 2023, ranging between 2.7 and 3 %. The agroforestry components experienced a higher increase in SOM while the SOM in the rows with conventional managed vineyard increased slightly, reflecting the potential of agroforestry combination of vineyards with cover crops or spontaneous vegetation to increase the SOM.



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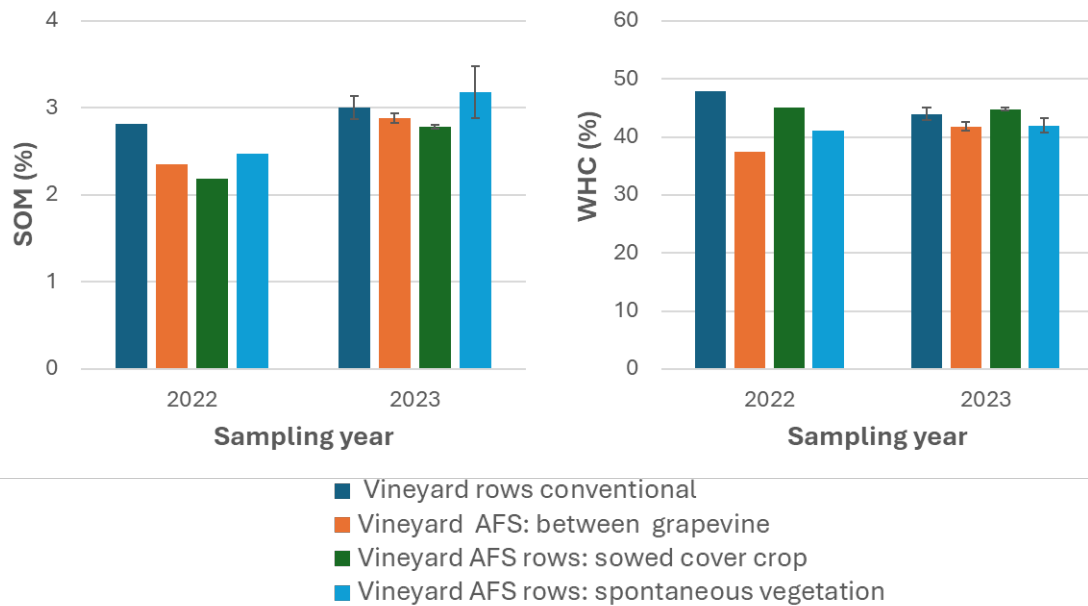


Figure 7. Average percentage of Soil Organic Matter (SOM) and Water Holding Capacity (WHC) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 03) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

Soil water holding capacity (%) was similar in the different components of the agroforestry system (Figure 7, right). These findings do not clear indicate the influence of the system into the increase of water retention. The system was established in 2017, indicating that significant changes in WHC could be observed probably in the long term.

A trend toward greater aggregate stability was observed in the vineyard rows of the agroforestry system. Regarding large aggregates (>2000 μm), the vineyard with spontaneous vegetation showed a higher proportion of these large aggregates compared to other practices (Figure 8). This could indicate that, in this specific case, the vineyard with spontaneous vegetation supports better formation of large aggregates, possibly due to specific management practices that enhance short-term soil stability. Conversely, rows with sown cover crops and newly planted vineyards showed a slightly lower but similar proportion of large aggregates.

For medium-sized aggregates (2000-250 μm), this aggregate size was predominant across all treatments, with similar values observed in all cases. Regarding small aggregates (250-53 μm) and fine particles (<53 μm), the different treatments exhibited a similar distribution of these smaller fractions, with slight differences.



Transition

Overall, the vineyard with spontaneous vegetation stands out for its higher proportion of large aggregates, while agroforestry practices with sown cover crops or conventional management tend to favour a greater prevalence of medium-sized aggregates. These differences could impact water infiltration and long-term soil structural stability, promoting a more durable structure due to higher organic matter content and greater biological diversity.

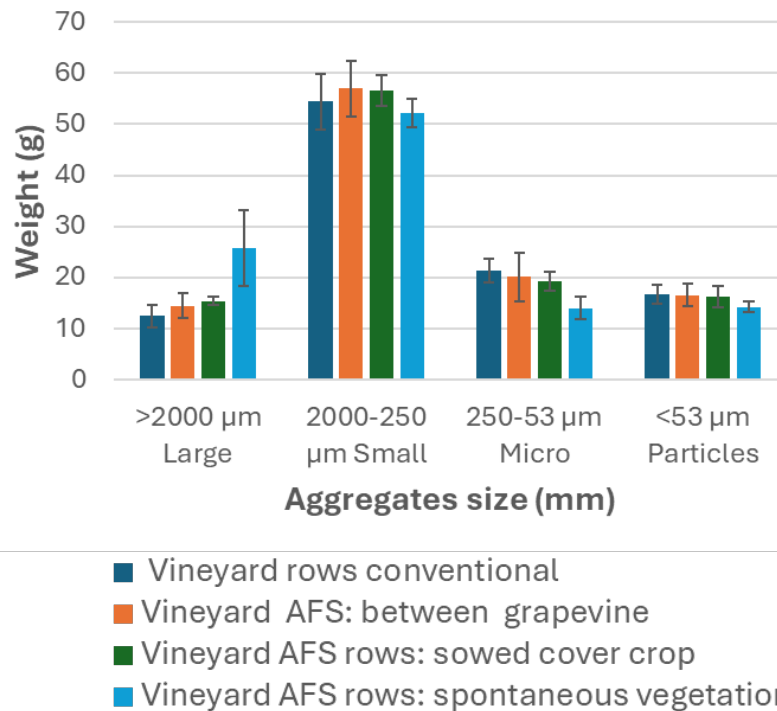


Figure 8. Aggregates stability and size distribution of the Farm 03 of Spanish pilot. Results showed the analysis of year 2023. Average values of 3 field replicates. Black vertical bars indicate standard deviation.

Total nitrogen content (mg/kg dm) were highly variable among years in the different studied components (Figure 9, left). Nitrogen content was very high in year 2022, overpassing the regional advised values for this crop and sampling period. Positively, nitrogen content decreased in the vineyard rows in combination with cover crops and spontaneous vegetation both in the vineyard lines and in the rows between them. However, values increased in the conventional managed vineyard rows. Between sampling time of 2022 and 2023, this named conventional plot was left under fallow, and the considerable decrease in nitrogen content was clearly observed, as fertilisation is nitrogen based.

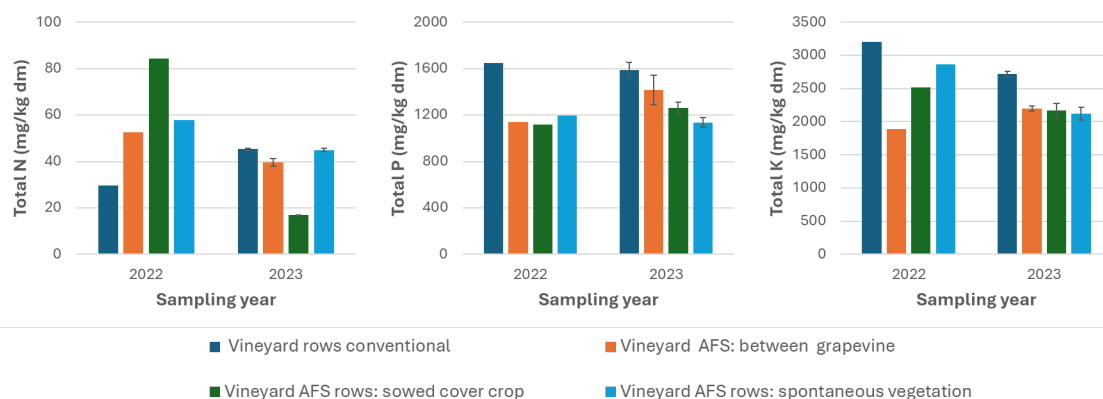


Figure 9. Average content of total nitrogen (N), potassium (K) and phosphorus (P) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 03) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

Total phosphorus content were high considering the low phosphorus requirements of the vineyard (Figure 9, middle). The components of the agroforestry system showed lower values than the conventional managed in the sampling year 2022. However, they increased inshoud an increase in the 2023, possibly as a result of the fertilisation.

In the case of the potassium content there was not found consistent results during the sampling year 2022 (Figure 9, right). The results from the second sampling year, showed higher values for the plot called “conventional” and all the other values, were similar.

Floristic richness showed higher values in the rows of vineyards (Table 5), as farmer clean the spaces between trees to reduce the nutrient competence. In the sowed rows, the floristic richness was higher than in the rows with spontaneous vegetation. It means that probably, a combination of this practice would increase the floristic richness with lower expenses.

Table 5. Floristic richness for each component of the agroforestry system (pilot Farm 03) in Catalonia, Spain. Data obtained from two cropping seasons using three replicates per sampling

Floristic richness/ Component of the AFS	2022		2023	
	species number	family number	species number	family number
Vineyard rows conventional	N/A	N/A	1	1
Vineyard AFS: between grapevine	0	0	0	0



Transition

Vineyard AFS rows: sowed cover crop	9	7	8	8
Vineyard AFS rows: spontaneous vegetation	5	5	6	5

Farm 04

In this case, the effect of the innovative crop showed a trend of SOM (%) increase over time (Figure 10). Despite the mean average results showed higher SOM in the plot with two year of stablishment (at the sampling time), the data variability indicates no differences when compared with a three-year established crop. Similar trend was observed in the case of total carbon content (%) (Figure 11, left). Total nitrogen content (%) showed the opposite trend, it reduced over time (Figure 11, right). It can be explained as no fertilisation was done during the last three years, and crop extracted the needed nitrogen from soil to its growth.

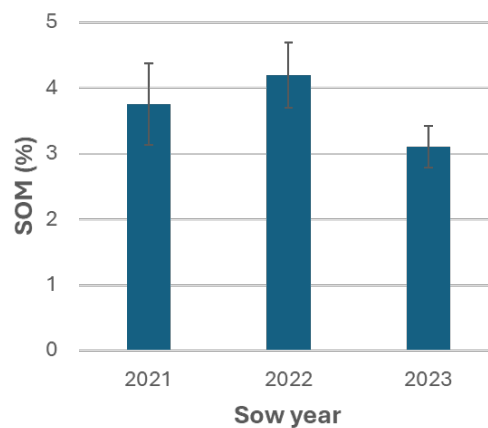


Figure 10. Average percentage of Soil Organic Matter (SOM) in soil samples (00-30 cm depth) collected from the kernza cereal (innovative crop, pilot Farm 04) in Catalonia, Spain. Samples were taken at the end of the cropping season 2022-2023. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.



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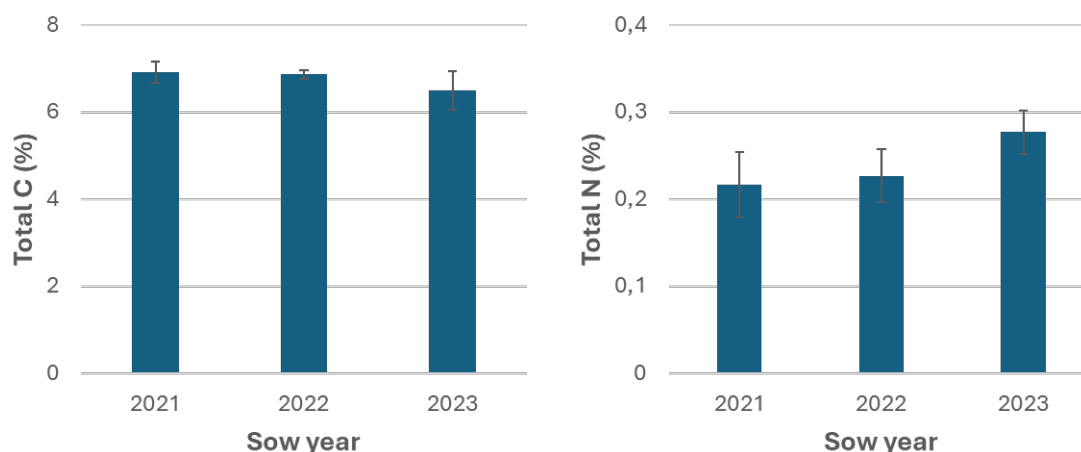


Figure 11. Average percentage of total content of Carbon (C) and Nitrogen (N) in soil samples (00-30 cm depth) collected from the kernza cereal (innovative crop, pilot Farm 04) in Catalonia, Spain. Samples were taken at the end of the cropping season 2022-2023. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

As kernza was evaluated as an innovative culture, crop diversity and floristic richness were not evaluated in this farm.

Farm 05

In this case study, the potential of agroforestry systems to increase the SOM was observed as in most components of the system the SOM increased from year to year (Figure 12, left). However, it was also observed that these plots have high range of improvement to reach SOM of the natural area (the forest, with SOM of ~7-9 %). In general, the multifunctional field margins, the olive trees plot and the cover crop under the olive trees (maintained for more than 10 years) showed higher values than the vineyard plots reflecting the positive effect of the naturalization of some areas in the SOM and, in turn, in the soil fertility.



Transition

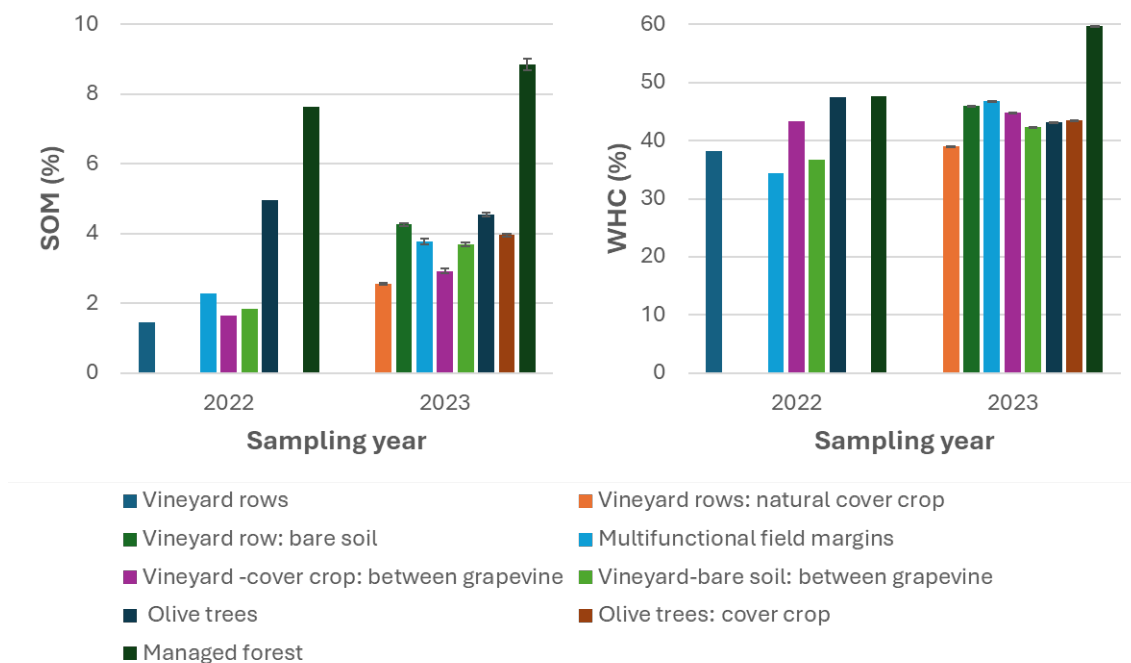


Figure 12. Average percentage of Soil Organic Matter (SOM) and Water Holding Capacity (WHC) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 05) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

On the contrary, the capacity of the agroforestry systems to increase the soil water holding capacity (%) was not clearly observed (Figure 12, right). The first sampling period, there were no consistent results, and some samples were lost during the laboratory analysis. The second sampling year, all the components showed similar average values, except managed forest. Furthermore, WH did not showed an increase from one year to another, which was expected as SOM did not change. In both sampling years, water holding capacity of the soil of the most natural area (the managed forest) was higher in than the cultivated areas. It can be said that SOM lost after 8 years of cultivated vineyards and 12 years of olive trees plantation, produced a decrease in 20% of soil water holding capacity.

The stability of soil aggregates was higher in the managed forest compared to the components of the agroforestry system (Figure 13). Regarding large aggregates (>2000 μm), the managed forest exhibited a high proportion of large aggregates, indicating a highly stable and resilient soil structure. This stability in the forest could be attributed to the high organic matter content and minimal soil disturbance. Multifunctional field



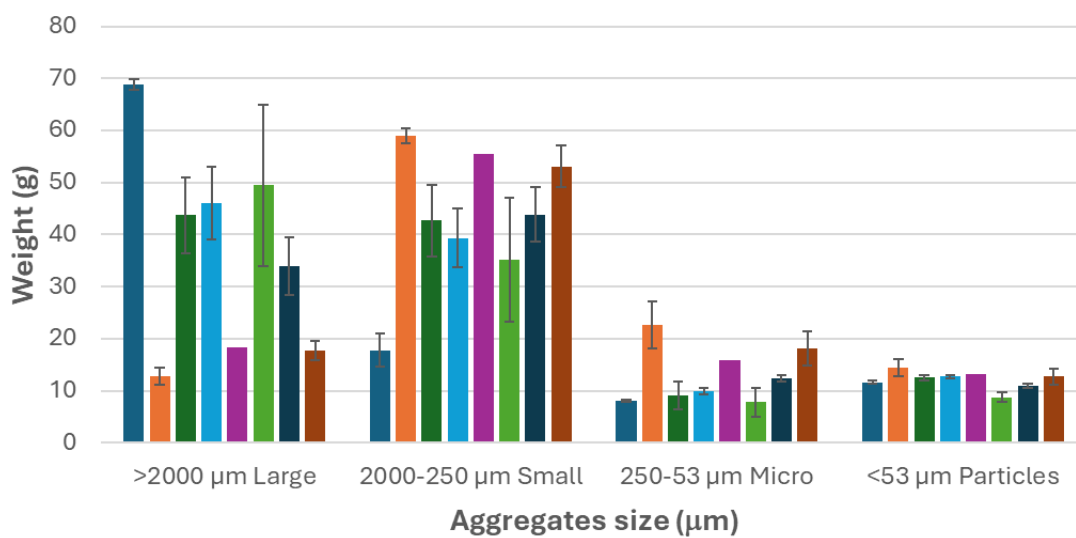
Transition

margins also showed a significant amount of these large aggregates, demonstrating that these areas can contribute to soil stability.

As for medium-sized aggregates (2000-250 μm), most treatments, including vineyards with natural cover and vineyards with sown cover between the vine rows, showed high proportions of medium-sized aggregates. This type of aggregate reflects a good soil structure, although less stable than that of the larger aggregates. In treatments such as olive trees with cover crops, a notable presence of these medium-sized aggregates was also observed.

Regarding small aggregates (250-53 μm) and fine particles (<53 μm), all treatments exhibited similar proportions of these small aggregates and fine particles, with slight differences. Overall, soils managed with cover crops (both natural and sown) and multifunctional margins tend to display a healthy balance of aggregates, offering stability and protecting the soil from erosion. The managed forest stands out for having a higher proportion of large aggregates, suggesting a very stable structure.

These results could indicate that: i) at this stage of development of the agroforestry system, aggregate stability was not as robust as that of the natural environment, and ii) soil management associated with vineyards negatively impacted aggregate stability, reducing the proportion of large aggregates.



- Vineyard rows
- Vineyard row: natural cover crop
- Vineyard row: bare soil
- Multifunctional field margins
- Vineyard -cover crop: between grapevine
- Vineyard-bare soil: between grapevine
- Olive trees
- Olive trees: cover crop
- Managed forest



Transition

Figure 13. Aggregates stability and size distribution of the Farm 05 of Spanish pilot. Results showed the analysis of year 2023. Average values of 3 field replicates. Black vertical bars indicate standard deviation.

In the case of total nitrogen content (mg/kg dm) differences among system components were observed (Figure 14, left). Plots growing vineyards showed the higher nitrogen values, indicating the positive effect of organic fertilisation when compared against field margins, olive trees and managed forest. The high values of nitrogen in soil for the sampling moment, aware farmer of a possible excess of nitrogen fertilisation and leaching risk.

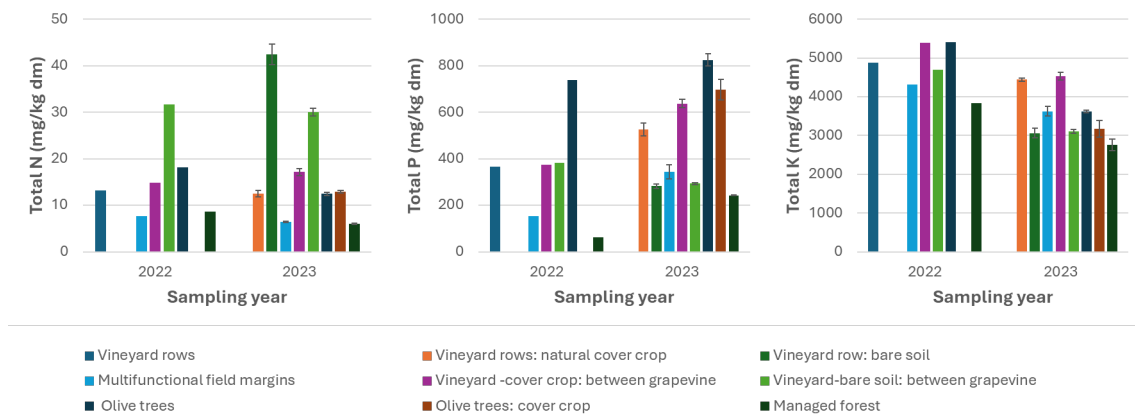


Figure 14. Average content of total nitrogen (N), potassium (K) and phosphorus (P) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 03) in Catalonia, Spain. Colour bars are the mean of 3 laboratory replicates of a homogenized field sample composed by three single field samples. Vertical bars indicate standard deviation.

In general, the total phosphorus content (mg/kg dm) was higher in olive trees with cover crop and in vineyards with cover crops (Figure 14, middle). They were specially higher in sampling year 2023, indicating that fertilisation could increase the presence of this macronutrient in soil. This increase should be controlled considering the regional regulation. Potassium content (mg/kg dm) in soil did not showed a clear pattern (Figure 14, right). Highest values were obtained in vineyards plots with cover crops.

Floristic richness was higher in multifunctional margins and managed forest (Table 6). The spaces between winegrapes did not showed floristic richness as farmer clean the spaces among trees to reduce the water stress. Similar situations happens in rows



Transition

without cover crop. In this case, the farmer strategy is wait until the tree is strong enough to compete with the cover crop.

Table 6. Floristic richness for each component of the agroforestry system (AFS, pilot Farm 05) in Catalonia, Spain. Data obtained from two cropping seasons using three replicates per sampling

Floristic richness/ Component of the AFS	2022		2023	
	species number	family number	species number	family number
Vineyard rows	N/A	N/A	N/A	N/A
Vineyard rows: natural cover crop	5	5	12	5
Vineyard row: bare soil	N/A	N/A	N/A	N/A
Multifunctional field margins	10	7	8	8
Between-Vineyard rows with sowed cover crop	N/A	N/A	N/A	N/A
Between-Vineyard rows without cover crop	N/A	N/A	4	4
Olive trees	N/A	N/A	10	7
Olive trees: cover crop	N/A	N/A	7	4
Managed forest	8	7	5	5

2.2.2 Socioeconomic Indicators

Farmers were asked what percentage of their production was for **self-consumption** (Table 7). Answers showed differences from 0 to 100% in the self-consumption. It was observed that it depends on the crops and trees they grow. Depending on the farm size, self-consumption is not enough to cover the family's needs (farm 02)

Farmers were asked if they knew the price difference between **production and retail price** (Table 8). Generally, they know roughly the differences but do not have a number in mind. Only Farm 05 could provide the price production, but the retail prices vary according to the diversity of obtained products-

Production certificates showed a diversity of opinions (Table 9). Three of the five selected farms reported to hold at least one certificate (Farms 02, 04, and 05). The two others do not believe in the certification process (Farms 01 and 03). One of them reported following the organic production rules but they are not interested in having any certificate. Farmers agree that in the current situation, local sales are more valuable than labelling,



Transition

partially because clients trust the product quality and avoid price increases by intermediaries and long-distance transport, as may happen with industrial production.

The product price increase by certification varies according to the product type and the global markets. In some cases, certificates are used for facilitating products exportation, independently the price increasing or not.

Nature tourism (Table 10) is an activity fully implemented in only two of the studied farms (farms 03 and 05). In the first case, the incomes reflect a third of the total company incomes, reflecting the importance of this activity to the farm. In the second case, nature tourism only counts for a tenth of the total income due to the size of the farm. Two more farms offer the tourism service sporadically (farms 02 and 04). The last farm does not offer this as the system is still in the installation period (farm 01), preferring to wait until the trees are in full production.

The **company structure** (Table 11) was evaluated through the type and workers involved in the project. The company type and labour resources are stable over time. Only farm 05 increased the number of workers during the period of the task execution. Companies vary in workers number from one to five, except one of them which has 43 workers (farm 05). Working hours also vary. Only one farmer (farm 01) has few working hours dedication as it is an extra income for the owner.

Farmers reported to know the annual **crop production** (Table 12). The 2022-2023 and 2023-2024 cropping seasons were the second and the third consecutive drought seasons. These conditions affected negatively the crops' productivity. Two farms lost full production (farms 01 and 02) while two others showed a 50% and 25% decrease in the main crop of the system (farms 03 and 04).

Table 7. Data collected regarding self-consumption percentage indicator.

Farm	Data period		Self-consumption percentage (%) from the products obtained from the farm
FARM 01	Interview	2022	100%
	Crop season	2022-2023	100%
		2023-2024	100%
FARM 02	Interview	2022	Almond and olive oil: 100% consumption of the production. It is barely the whole consumption
	Crop season	2022-2023	
		2023-2024	
FARM 03	Interview	2022	0%
	Crop season	2022-2023	0%



Transition

		2023-2024	0%
FARM 04	Interview	2022	around 60% (meat and milk)
FARM 05	Interview	2022	Residual. The entire production is transformed into wine, which is then commercialised.
	Crop season	2022-2023	
2023-2024			

*n/a: Not applicable

Table 8. Data collected regarding product price indicator.

Farm	Data period		Product production price vs retail price
FARM 01	Interview	2022	Not applicable at the moment
	Crop season	2022-2023	
		2023-2024	
FARM 02	Interview	2022	In general, they have positive balance
	Crop season	2022-2023	Cereal and olives were not harvested due to the low productivity as a drought consequence
		2023-2024	Peas cultivation for straw bales
FARM 03	Interview	2022	Direct sales are profitable for the company
	Crop season	2022-2023	Yes
		2023-2024	Yes
FARM 04	Interview	2022	The production price varies yearly. Achieving a cheap production cost is the key as the farmer doesn't have a brand. In consequence, the products they obtain have no added value
FARM 05	Interview	2022	1,80 €
	Crop season	2022-2023	2,20 €
		2023-2024	3,00 €





Transition

Table 9. Data collected regarding certificates and certification interests from farmers.

Farm	Data period		Hold any production certificate	Certificate/s name, if applicable	Interest in obtaining any certification	Product price increased by the certificate	Do consumers value certificates?	Turnover attributed to certification labelling (opinion) (%)
FARM 01	Interview	2022	No	n/a*	Not reported	Biodynamic certificate 10%	Generally speaking, yes	n/a
	Crop season	2022-2023	No	n/a	Farmer does not believe in certifications	n/a	Yes	n/a
		2023-2024	No	n/a		n/a	Yes	n/a
FARM 02	Interview	2022	Yes	Catalan Council of Organic Production, local sales (CCPAE and <i>Venda de</i>	n/a	Not reported	Generally, the origin is valued more than the certificate. Local sale	Almond and olive Olive oil: 100%. Cereal: n/a
	Crop season	2022-2023	Yes		n/a	Almond 100%		The certificate influences what



Transition

		2023-2024	Yes	<i>proximitat</i> , by its name in Catalan)	n/a	Almond 50% and olives 5-10%	certificate is valued as there is a price difference when compared with industry products	consumers buy, but trusting the project has a greater influence than the certificate itself.
FARM 03	Interview	2022	No	n/a	Farmer doesn't believe in certifications	n/a	In their case, consumers value the short-trade product	n/a
	Crop season	2022-2023	No	n/a	Not really. The most important is the local market instead of a certification label. They do organic management without certification	n/a		n/a
		2023-2024	No	n/a		n/a		



Transition

FARM 04	Interview	2022	Yes, but only for livestock, not for crops	Animal Welfare for meat; animal welfare to milk by Danone company	not reported	It does not increase it but helps sell. Certificates are needed to export	Yes, and it is increasing	Not important, but without the certificates, there are more restrictions on selling meat and milk
FARM 05	Interview	2022	Yes	Catalan Council of Organic Production (CCPAE), biodynamic, and wineries for climate protection	n/a	almond 25% olives 5-10%	Yes	Export 100%, in the other cases >50%
	Crop season	2022-2023	Yes		n/a	Biodynamic certificate 5%	Yes	Export 100%, in the other cases >50%
		2023-2024	Yes		n/a	Biodynamic certificate 10%	Yes	Export 100%, in the other cases >50%

*n/a: Not applicable

Table 10. Data collected regarding nature tourism indicator

Farm	Data period		Nature tourism on the farm	Nature tourism on the farm in the future	Income from nature tourism (%)
FARM 01	Interview	2022	No	Yes	n/a
	Crop season	2022-2023	No	Yes	n/a
		2023-2024	No	Yes	n/a
FARM 02	Interview	2022	No	Yes	n/a
	Crop season	2022-2023	No	The farm offers occasional tours of its agricultural system	Not reported
		2023-2024	No		Not reported
FARM 03	Interview	2022	Yes	n/a	25-30%
	Crop season	2022-2023	Yes	Yes	30-35%
		2023-2024	Yes	Yes, it has expanded and diversified	30-35%
FARM 04	Interview	2022	No	No, although they show the farm to anyone who asks. Sadly, they have more restrictions in this sense for health reasons	n/a
FARM 05	Interview	2022	Yes	n/a	10%
	Crop season	2022-2023	Yes	n/a	<10%
		2023-2024	Yes	n/a	<10%

Table 11. Data collected regarding company structure indicator

Farm	Data period		Company type	Workers number	Working hours per worker
FARM 01	Interview	2022	Self-employed	1	5%
	Crop season	2022-2023		1	5%
		2023-2024		1	5%
FARM 02	Interview	2022	Self-employed grouping	5	3 full-time, 1 part-time. During work peaks, 1 full-time and 1 part-time
	Crop season	2022-2023		3	3 part-time
		2023-2024		3	3 part-time
FARM 03	Interview	2022	S.A. Limited company (2 partners)	3	1 full-time, 1 sporadically, 1 for work peaks
	Crop season	2022-2023		2	1 full-time, 1 part-time
		2023-2024		2	1 full-time, 1 part-time
FARM 04	Interview	2022	Private limited company	40	All full-time



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FARM 05	Interview	2022	S.A. Limited company	43	all full-time, 4 technical farm assessment
	Crop season	2022-2023		43	all full-time, 4 technical farm assessment
		2023-2024		43	all full-time, 4 technical farm assessment

Table 12. Data collected regarding crop productivity of the system

Farm	Data period		Annual crop production records	Crops yield of the agricultural system
FARM 01	Interview	2022	Yes	n/a
	Crop season	2022-2023	Yes	Olives and sainfoins: not harvested due to the drought
		2023-2024	Yes	Olives and sainfoins: not harvested due to the drought
FARM 02	Interview	2022	cereal: no. Fruit trees: yes	n/a
	Crop season	2022-2023	Yes	Olives and cereal: not harvested due to the drought
		2023-2024	Yes	Olives and cereal: not harvested due to the drought
FARM 03	Interview	2022	Yes	n/a
	Crop season	2022-2023	Yes	2000kg/ha
		2023-2024	Yes	1000 kg/ha (drought)
FARM 04	Interview	2022	Yes	Not reported
FARM 05	Interview	2022	Yes	n/a
	Crop season	2022-2023	Yes	Grapes 40 000kg; olives 5 000kg; honey 0kg; Infusions 0kg
		2023-2024	Yes	Grapes 10 000kg; olives 500kg; honey 200kg; infusions 0kg

2.3. Discussion

Regarding the environmental indicators the different resilience strategies studied in the Spanish pilot showed the capacity of the different components of the agroforestry systems to increase the SOM. It was specially appreciated in plots older than 5 years. The influence of crop management, especially the fertilisation strategies and agroforestry system configuration indicated that these are key elements to reduce the nutrient excess and nutrient leaching risks. The capacity of the agroforestry systems to increase the soil water holding capacity (%) was not clearly observed so the positive effect of the agroforestry systems in this parameter could be observed probably in the long term. The



Transition

innovative crop was successfully implemented in the Mediterranean conditions and could be used as an element of the agroforestry or mixed farming system. However, special attention should be paid to the lower biomass production during the first years of growth and other economic aspects that are not considered in this study.

Furthermore, it was detected few or non previous information regarding the soil physico-chemical properties in the studied systems. Providing analytical data to farmers, helped to their understanding of their implemented systems and the benefits of agroforestry. These results, will also set a data basis for future collaborations with these farmers.

In the case of the socioeconomic indicators, it was observed a consciousness regarding the fertilisation strategies and land management as farmers do organic farming without the interest of commercial labelling. The crop diversity but also the implementation of nature tourism help farmers to overcome with expenses during the drought years. There are also a variety of company types, showing that agroforestry systems are not only for isolated and small farms, but also for bigger companies who bet on alternative growing systems.

3. ITALY CASE-STUDY

3.1. Experimental site description and methodology

The Italian partner of the project, based in Sicily, carried out the on-farm experimentation in three farms with an olive-cereals agroforestry system.

Winter cereals and olive are respectively among main herbaceous, and tree crops typical of the Mediterranean environment.

Solar radiation is one of the limiting factors in both cereals and olive yield, therefore the optimization of solar radiation interception by the agroforestry systems comprising olive trees and winter cereals has a considerable importance to enhance the system efficiency [3–6].

The study aims to evaluate the productivity and the solar radiation interception of an agroforestry systems comprising olive trees and herbaceous crops, namely durum wheat (*Triticum durum*), common wheat (*T. estivum*), rye (*Secale cereale*) and fava bean (*Vicia faba*).



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The field trials were carried out during the 2022-2023 and 2023-2024 growing season in a 4-year-old olive grove with trees spaced 5.5 m between the rows and 5 m along the row (Figure 15) located on a mountainous site (970m a.s.l.) in Sicily (Italy). The rows of trees were aligned along the East-West axis.

The olive grove has been plowed between the rows twice a year (end of autumn and end of spring) before the establishment of the trial to allow for weed control. During the trial, tillage has been performed before sowing (December) by harrow and after harvesting (August) by plow.



Figure 15. Trial layout

The winter cereals used for the trials were a durum wheat (*T. durum*) landrace (*Timilia*) a common wheat (*T. aestivum*) evolutionary population (Mixwheat) and rye (*S. cereale*) variety (Irmanu).

The herbaceous crops were sown on a 4.5 m strip between two adjacent rows of trees and in an adjacent field as monocropping control. The sowing of the herbaceous crops took place in January 2023.

The amount of photosynthetically active radiation (PAR) intercepted by the trees and the crops was measured using the ACCUPAR LP-80 PAR/LAI Ceptometer at two different heights above the ground (below the tree canopy and below the herbaceous crop canopy) in several positions between the rows of trees, described by two factors: position and strip.



Transition

The positions were

- On the North side of a tree (position Under)
- On the North side of the inter-row gap (position Between)

The strips were

- The 1.5 m wide strip on the South side of the row of trees (Strip 1)
- The middle 1.5 m wide strip (Strip 2)
- The 1.5 m wide strip on the North side of the row of trees (Strip 3)

Grain yield has been measured for all the combination of position and strips.

Beyond these common experimental designs, each farm had their singularities, specified in the following paragraphs.

Farm 01

Location: Nicolosi, Catania, Italy

- Climate eco-region: Adriatic Sea & Central Mediterranean Mixed Forests (PA19)
- Altitude: 660 m asl
- Rainfall: 1060 mm per year
- Soil main characteristics: Texture: sandy; soil classification: Xerandt typic (USDA, 2014)
- Type of system: agroforestry-silvoarable
- Trees on the farm: olive trees
- Crops on the farm: Wheat, rye, fava bean, vetch
- Innovative practices: cover crops

Farm 02

Location: Nicolosi, Catania, Italy

- Climate eco-region: Adriatic Sea & Central Mediterranean Mixed Forests (PA19)
- Altitude: 960 m a.s.l.
- Rainfall: 1200 mm per year



Transition

- Soil main characteristics: texture: sandy; soil classification: Xerandt typic (USDA, 2014)
- Type of system: agroforestry-silvoarable
- Trees on the farm: olive trees
- Crops on the farm: wheat, rye, fava bean, vetch

In the second year a third trial was also carried out in a farm located in the inner part of Sicily (Gagliano Castelferrato, Enna) but the results will not be presented because of the crop failure due to the extreme drought that affected the area.

3.2. Results

Farm 01 and Farm 02

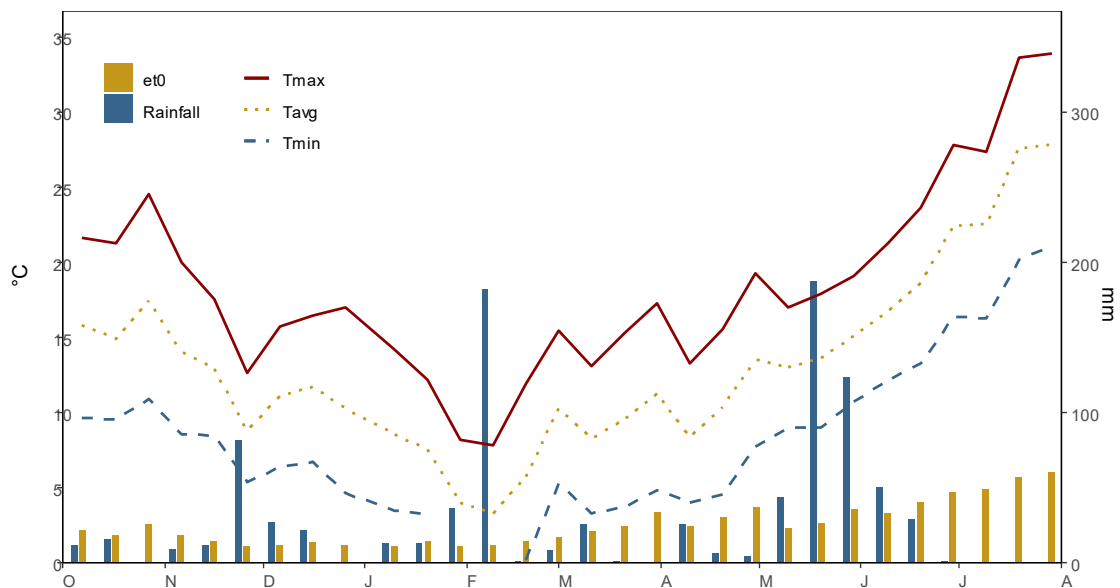


Figure 16. Meteorological variables (T_{max} = month average of daily maximum temperature, T_{avg} = month average of daily mean temperature, T_{min} = month average of daily minimum temperature, ET_0 = month sum of daily reference evapotranspiration according to [26], Precipitation = monthly precipitation) from October 2022 to August 2023 at the Farm 1.

3.2.1 Light interception by the agroforestry system

PAR interception by the trees was higher in the positions on the North side of a tree (position Under) and along the strips on the North side of the row of trees (Strip 3) (Figures 17 and 18). The middle strip (Strip 2) was the least affected by the shadow of the trees.



Transition

In the position closer to the trees, the interception of PAR by the cereal is higher, possibly due to a higher leaf area development in response to the shade or a different angle of insertion of the leaves.

The middle strip (Strip 2) had higher light availability for the cereal, independently of the position, while the strips closer to the tree lines are more affected, especially in the position under the tree projection.

Rye reached the highest values of PAR interception during 2023 in the middle strip, while it was highly affected by the shadows of the trees in the side strips (Strip 1 and 3); while mixwheat reached the highest values of PAR interception during 2024.

Among the species, rye and mixwheat had the higher leaf area and thus the higher rate of PAR interception.

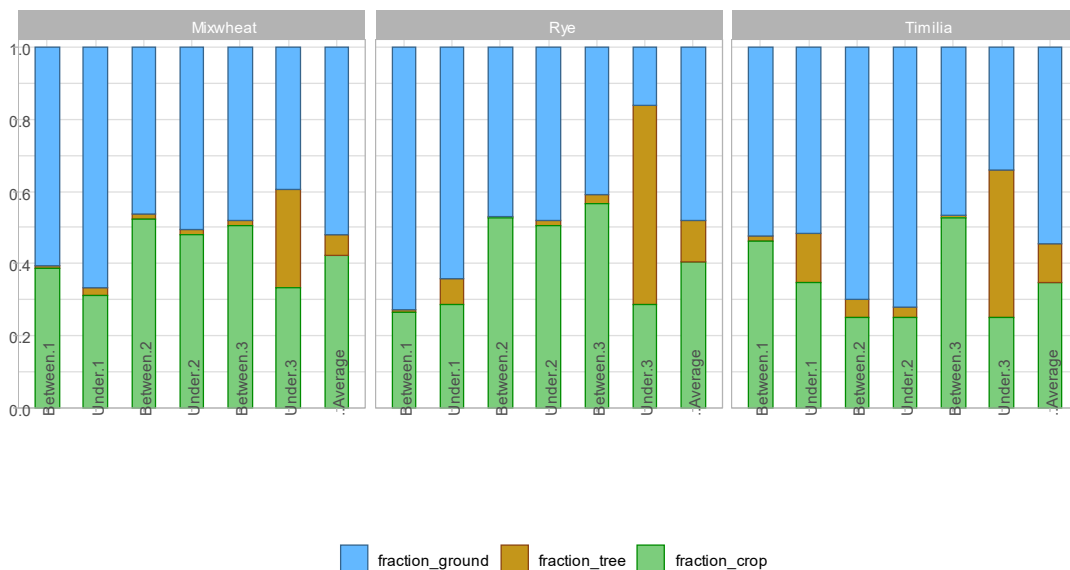


Figure 17. Combined light interception by the crop canopy (fraction_crop), olive tree canopy (fraction tree) and not intercepted by the system (fraction_ground) during the moment of maximum leaf expansion at the flowering stage of 2023 cropping season.

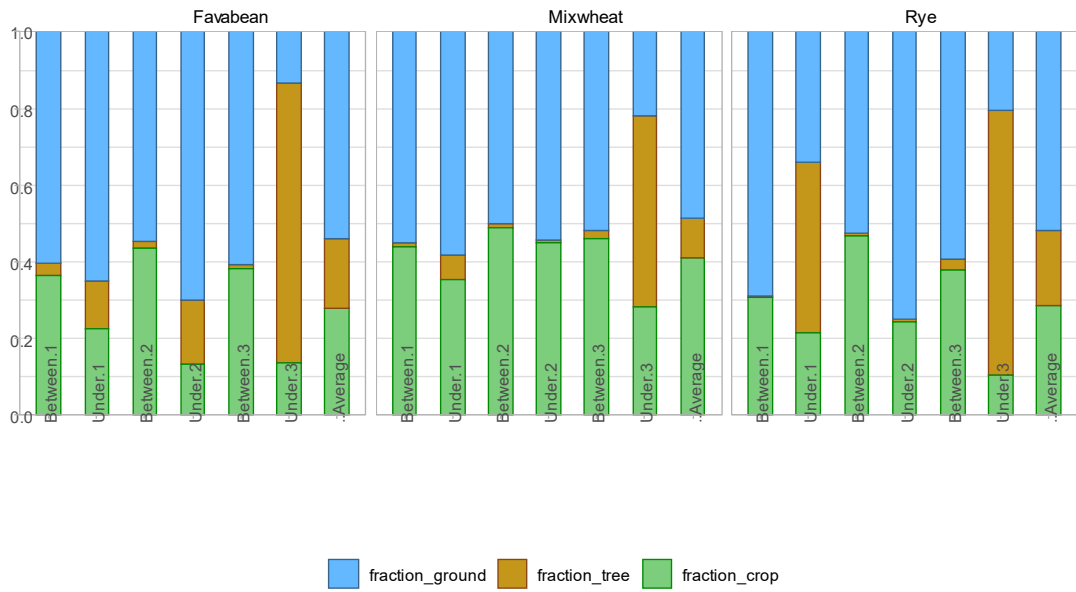


Figure 18. Combined light interception by the crop canopy (fraction_crop), olive tree canopy (fraction tree) and not intercepted by the system (fraction_ground) during the moment of maximum leaf expansion at the flowering stage of 2024 cropping season.



Transition

3.2.2 Biomass yield

The amount of PAR intercepted by the crop and the biomass yield were positively correlated and the highest values of biomass yield for each species were achieved in the position with the highest values of PAR interception (Figures 19 and 20).

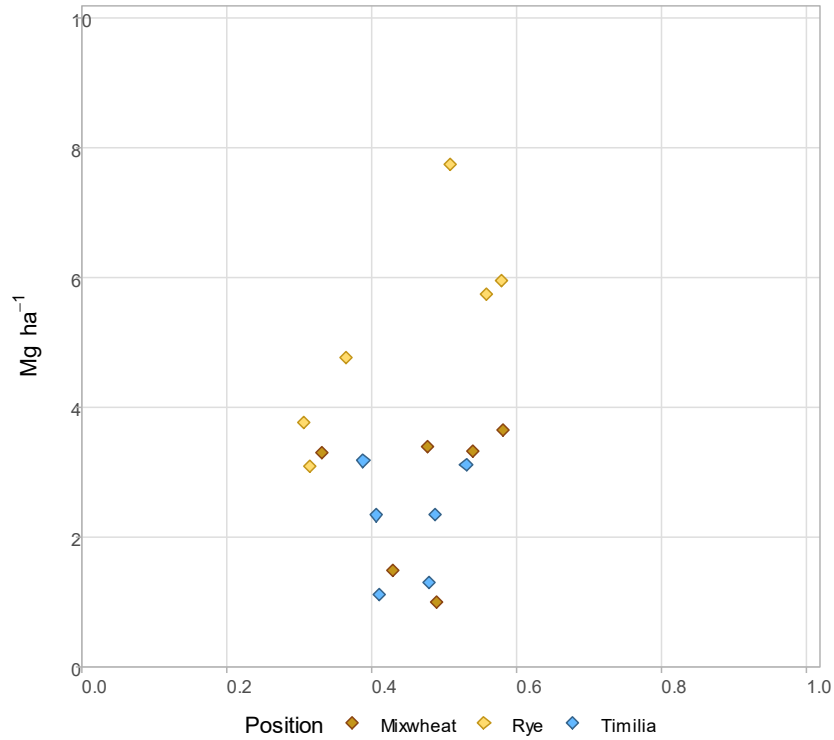


Figure 19. Relation between light intercepted by the crop (x axis) and biomass yield (y axis) during 2023.

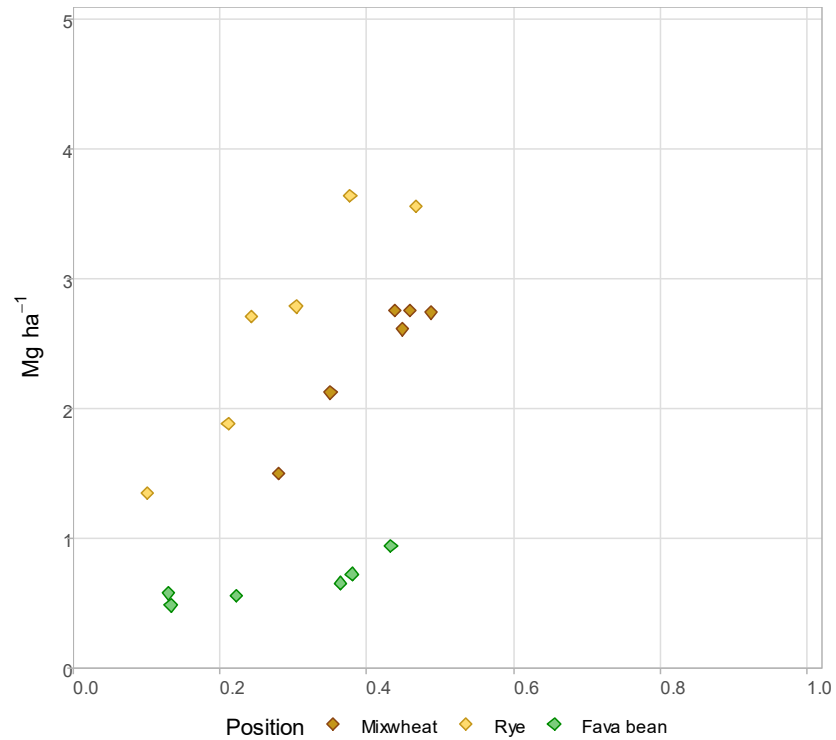


Figure 20. Relation between light intercepted by the crop (x axis) and biomass yield (y axis) during 2024.

Whitin each species there is a clear correlation between the amount of PAR available for the cereal (i.e. not intercepted by the olive trees) and the biomass productivity, as expected (Figures 21 and 22).

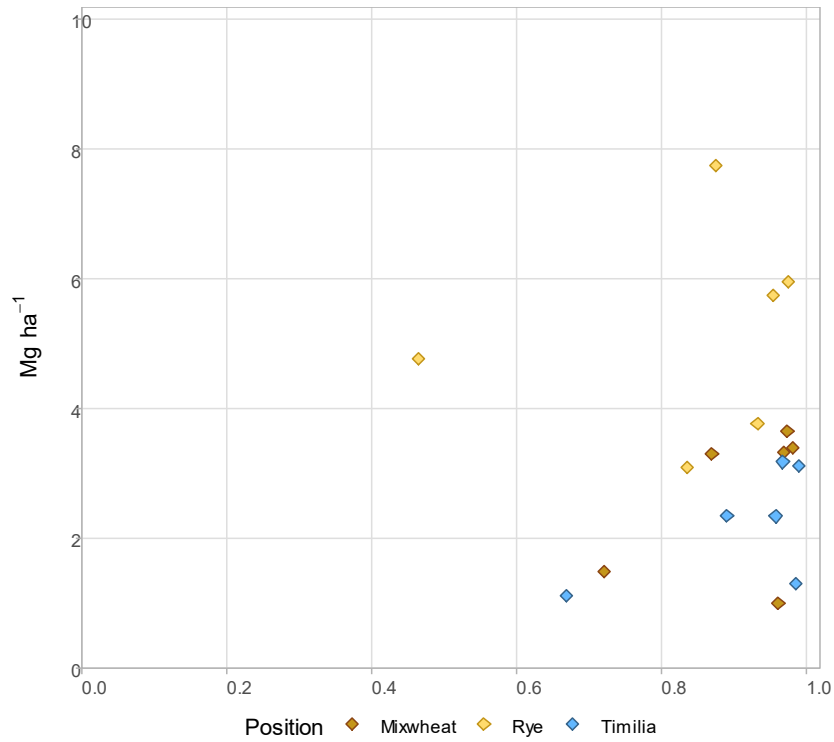


Figure 21. Relation between light available for the crop (i.e. not intercepted by the olive trees) (x axis) and biomass yield (y axis) during 2023.

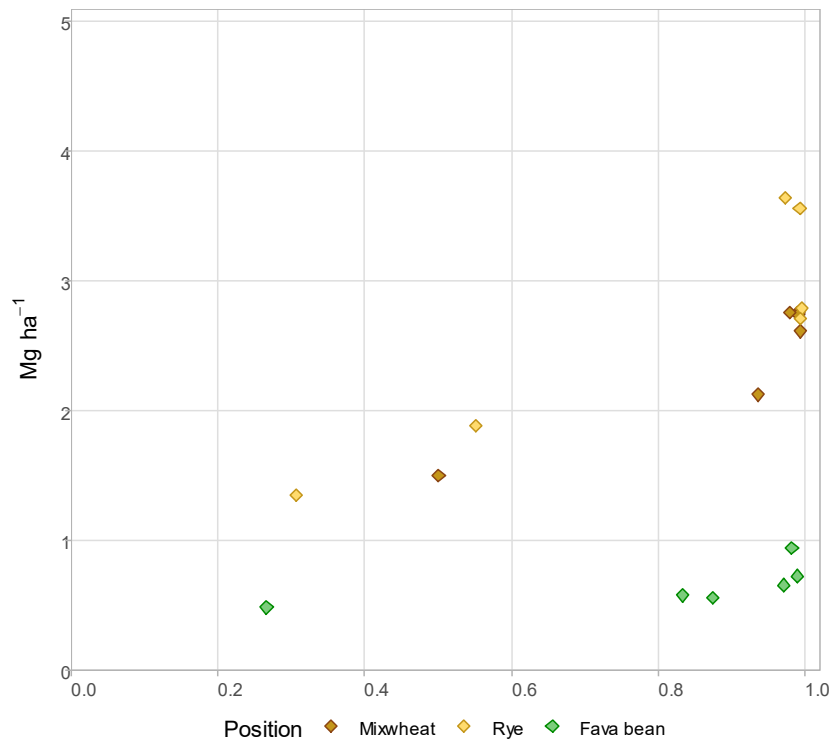


Figure 22. Relation between light available for the crop (i.e. not intercepted by the olive trees) (x axis) and biomass yield (y axis) during 2024.

Rye achieved both the highest levels of light interception and the highest biomass yield during 2023 and 2024 cropping seasons (Figures 23 and 24).

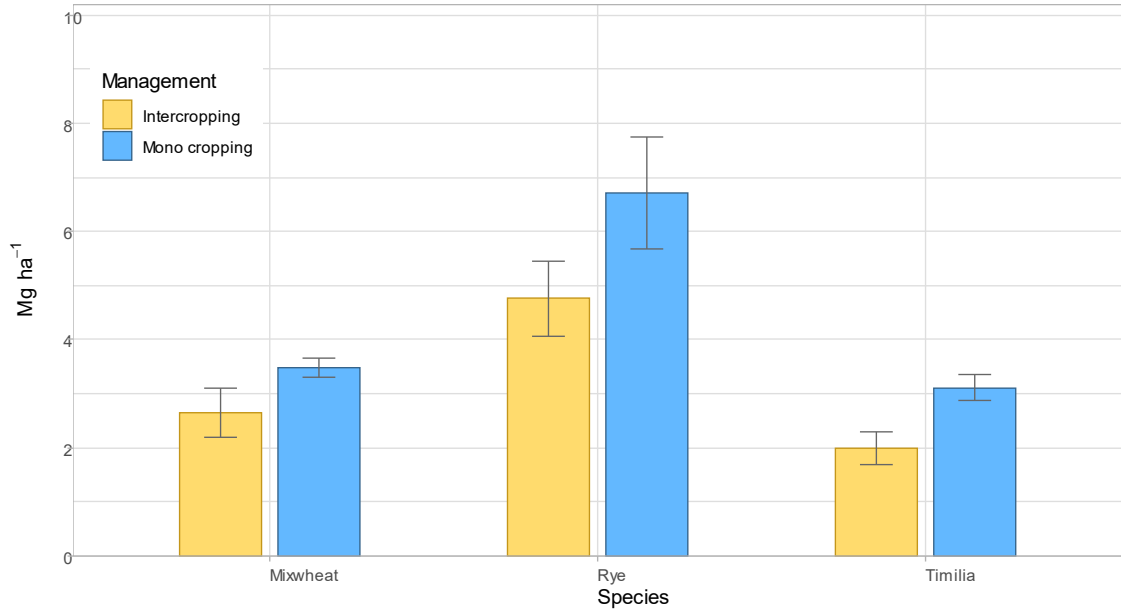


Figure 23. Crop biomass yield in agroforestry and monocropping systems in 2023.

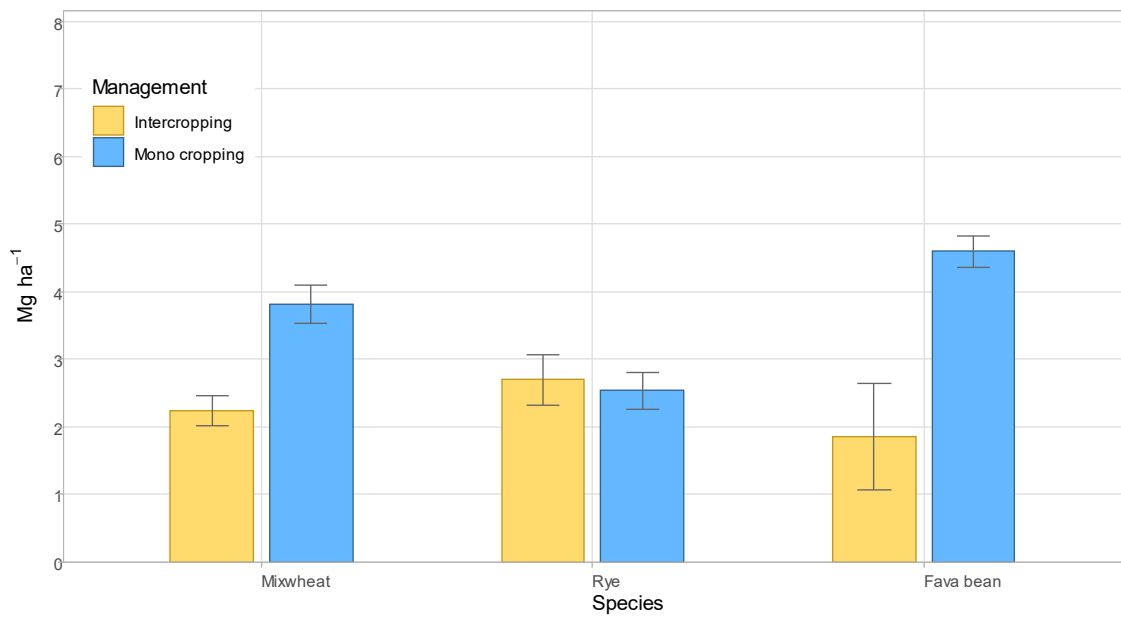


Figure 24. Crop biomass yield in agroforestry and monocropping systems in 2024.



Transition

The subplot at the north side of the trees (strip 3) in the *between* position had the same or higher biomass productivity as the middle strips, while the *under* position at the north side of the trees (strip 3) showed the lowest biomass productivity values (Figures 25 and 26). This suggests the ability of the herbaceous crops to take advantage of the protection offered by the trees and to limiting the suffering due to the competition for light.

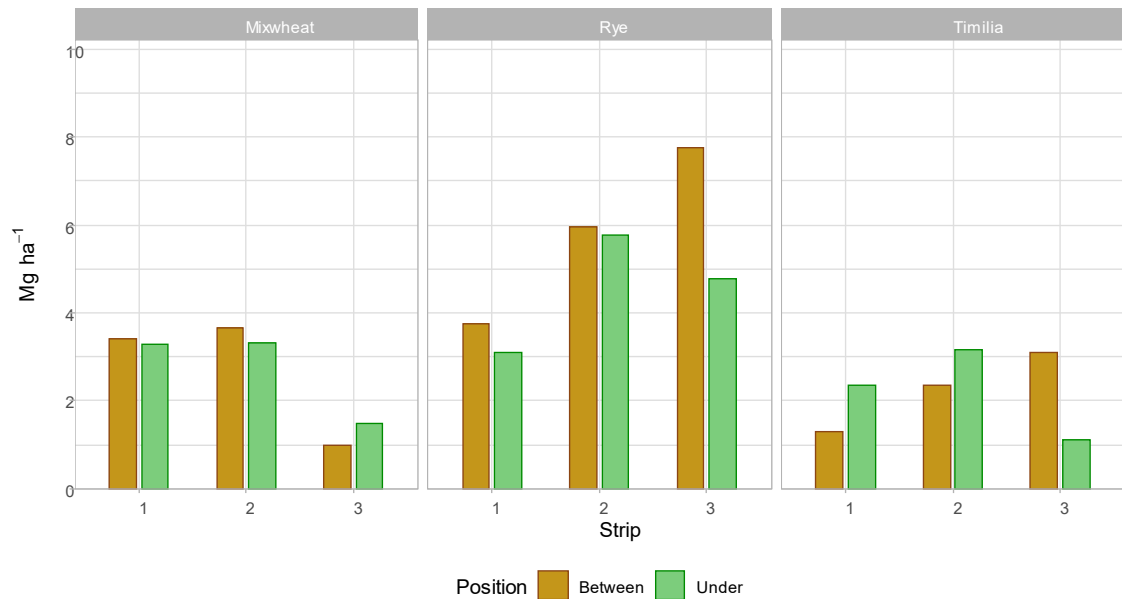


Figure 25. Crop biomass yield in agroforestry and monocropping systems in 2023 in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3).

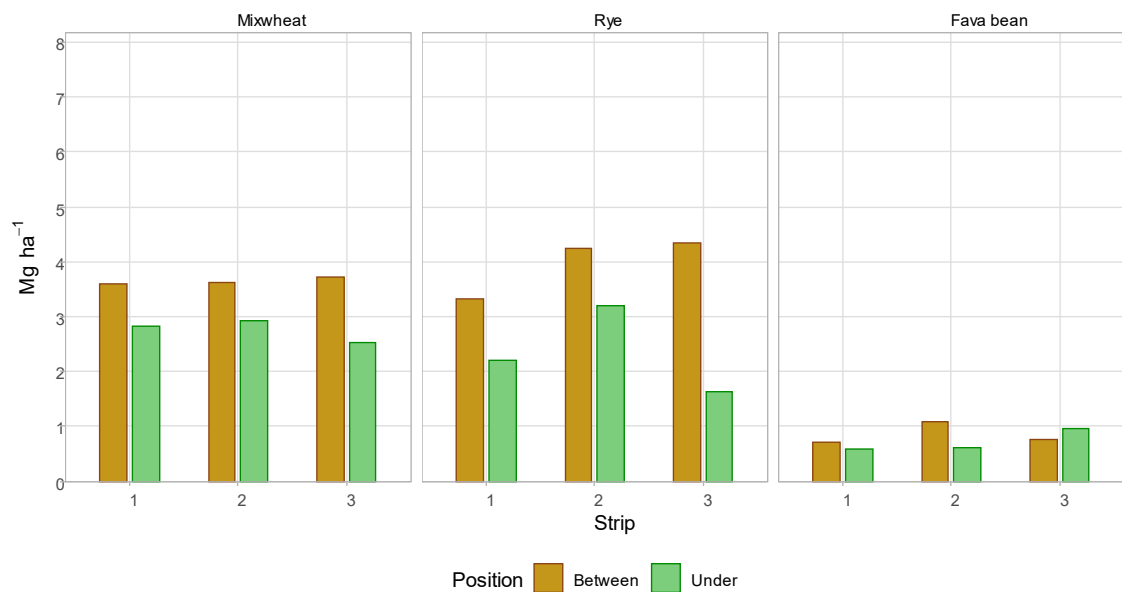


Figure 26. Crop biomass yield in agroforestry and monocropping systems in 2024 in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3).

3.2.3 Grain yield

As for the biomass yield, the amount of PAR intercepted by the crop and the grain yield were positively correlated and the highest values of grain yield for each species were achieved in the position with the highest values of PAR interception (Figures 27 and 28).

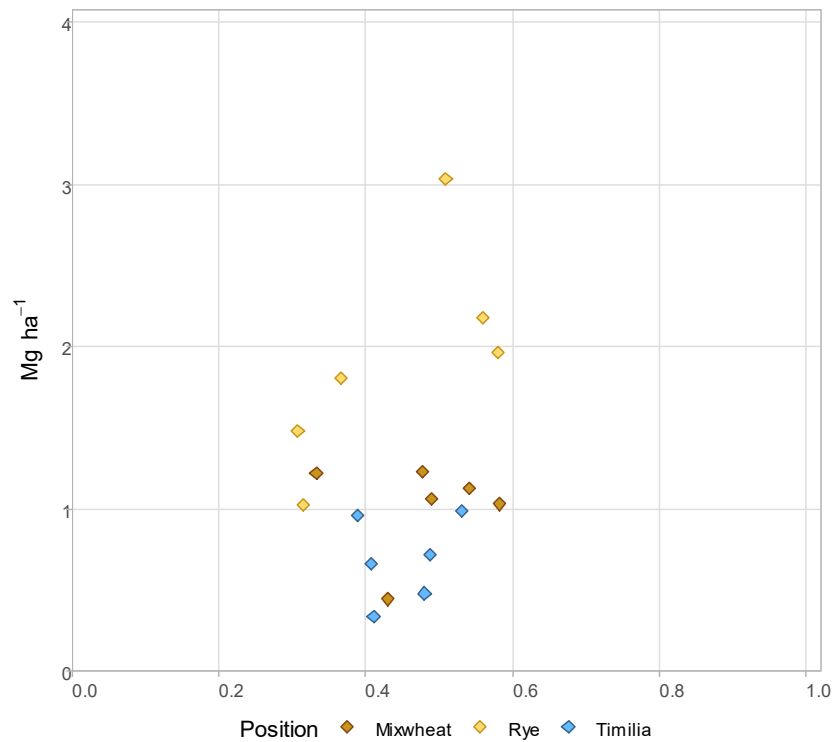


Figure 27. Relation between light intercepted by the crop (x axis) and grain yield (y axis) during 2023.

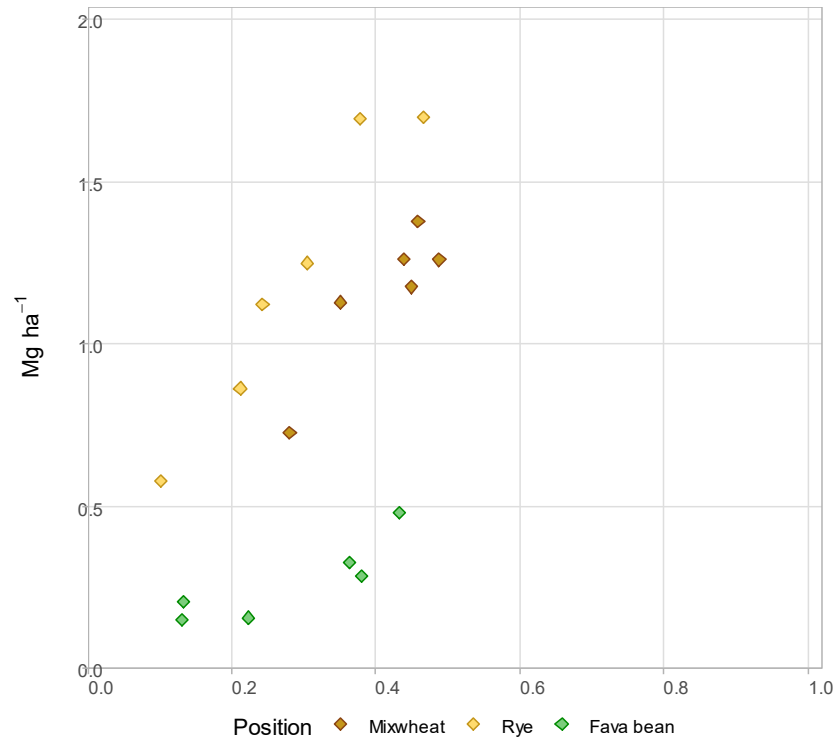


Figure 28. Relation between light intercepted by the crop (x axis) and grain yield (y axis) during 2024.

The amount of PAR available for the cereal (i.e. not intercepted by the olive trees) and the grain yield are positively correlated (Figures 29 and 30).

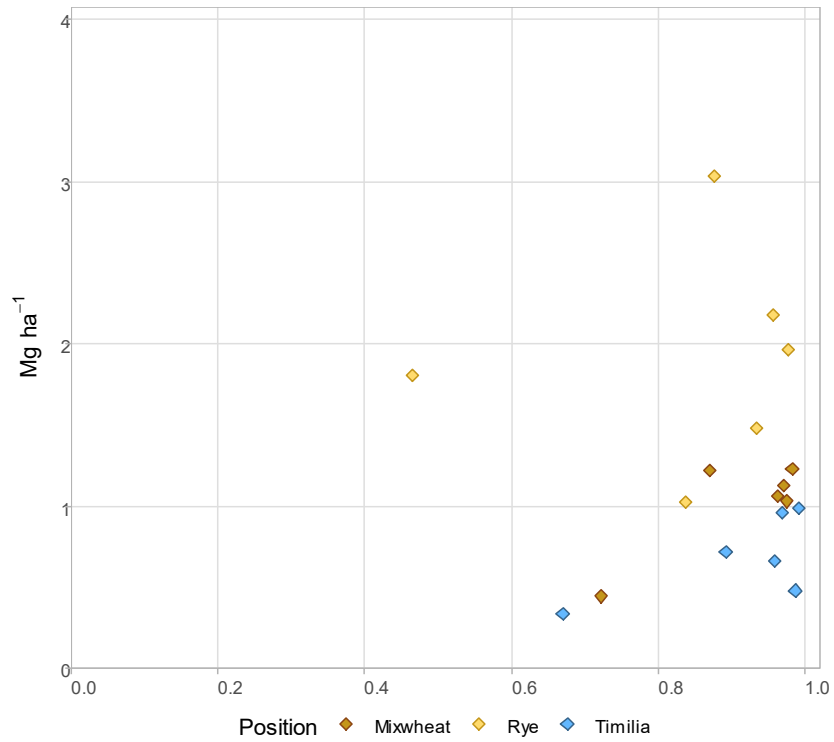


Figure 29. Relation between light available for the crop (i.e. not intercepted by the olive trees) (x axis) and grain yield (y axis) during 2023.

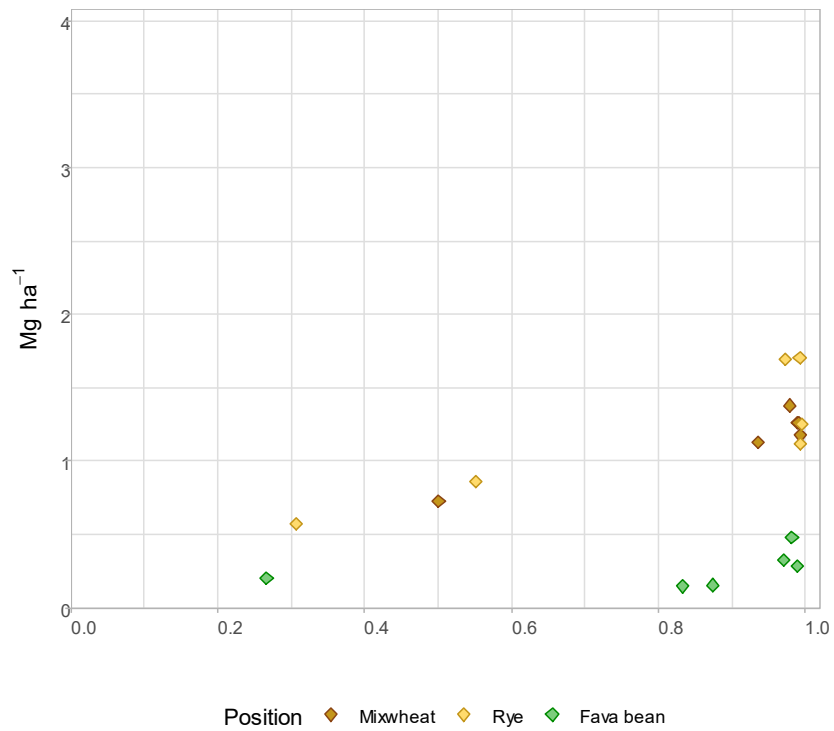


Figure 30. Relation between light available for the crop (i.e. not intercepted by the olive trees) (x axis) and grain yield (y axis) during 2024.

Rye was the most productive winter cereal in 2023 and 2024 with a grain yield of 2.5 t ha⁻¹ in monocropping and 1.7 t ha⁻¹ in intercropping during the first year and 2.05 t ha⁻¹ in monocropping and 1.05 t ha⁻¹ in intercropping during the second year (Figures 31 and Figure 32). Common wheat population Mixwheat had a mono and agroforestry production of 1.2 t ha⁻¹ and 0.9 t ha⁻¹ respectively. The lowest yield was achieved by durum wheat landrace Timilia with a production of 0.75 t ha⁻¹ in monocropping and 0.6 t ha⁻¹ in agroforestry.

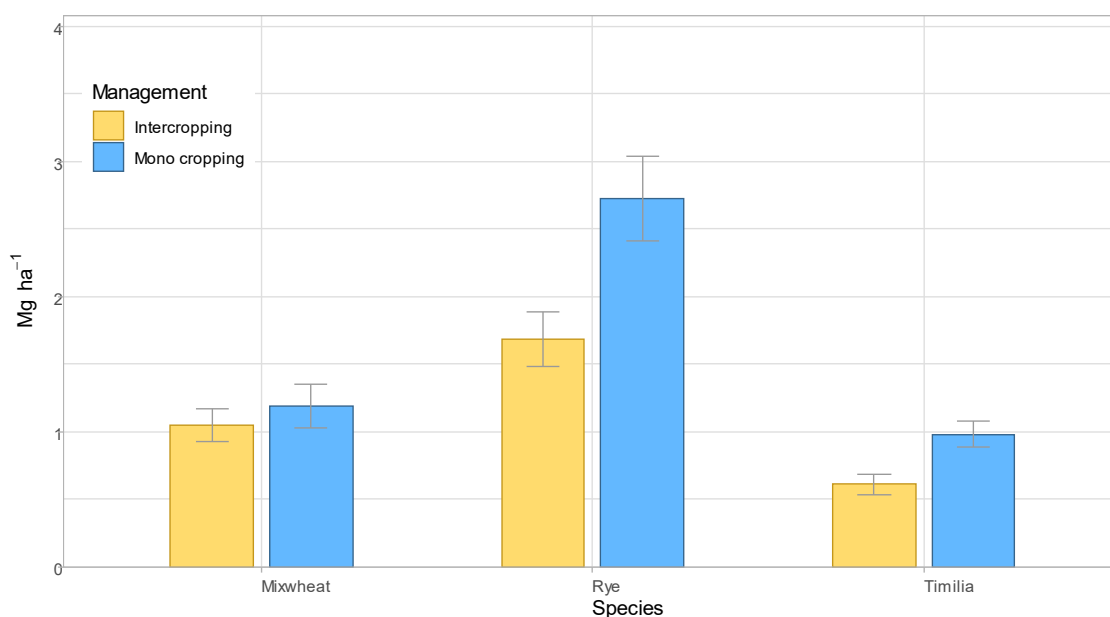


Figure 31. Crop grain yield in agroforestry and monocropping systems in 2023.

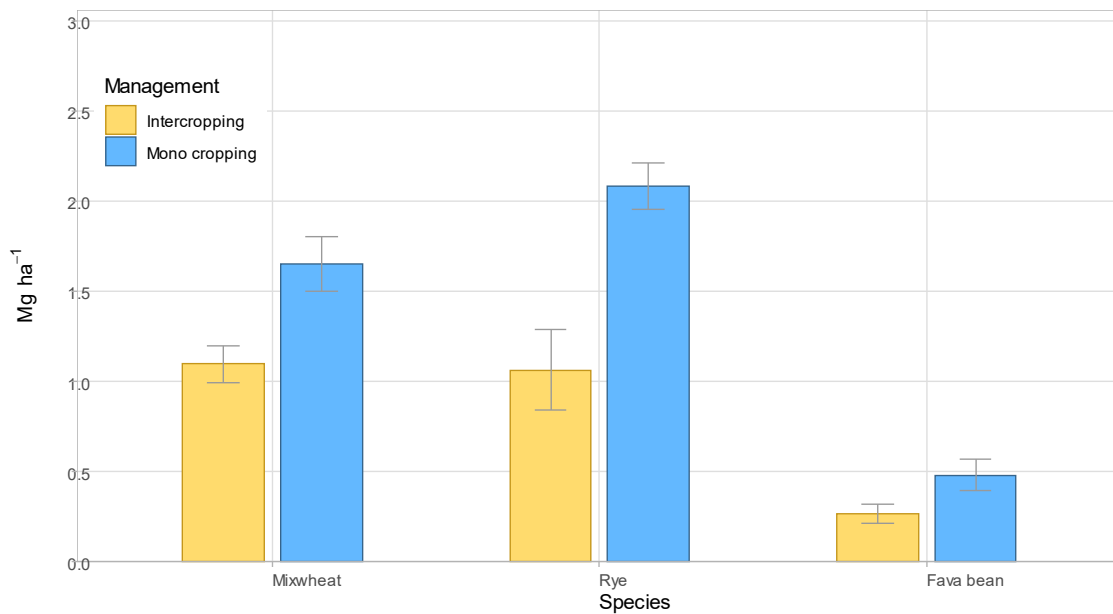


Figure 32. Crop biomass yield in agroforestry and monocropping systems in 2024.



Transition

The subplots at the north side of the trees (strip 3) in the *between* position had the same or higher grain yield as the middle strips, while the *under* position at the north side of the trees (strip 3) showed the lowest biomass productivity values (Figures 33 and 34). This suggests the ability of the herbaceous crops to take advantage of the protection offered by the trees and to limiting the suffering due to the competition for light.

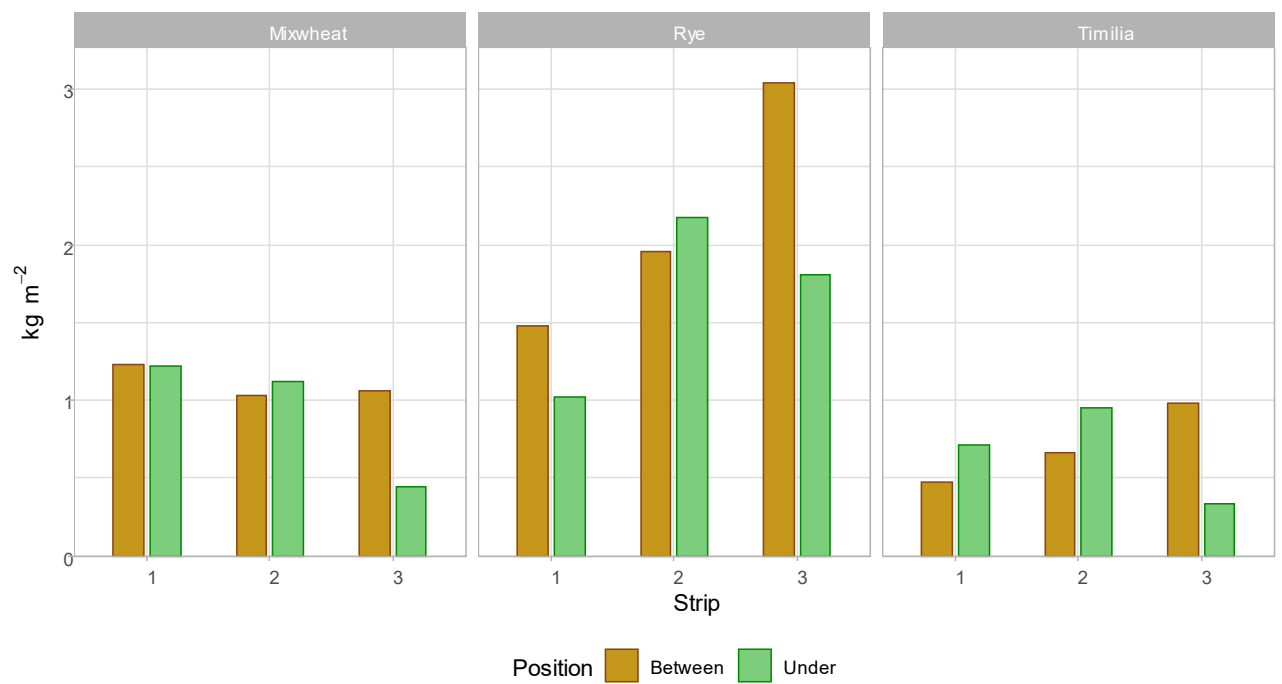


Figure 33. Crop grain yield in agroforestry and monocropping systems in 2023 in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3).

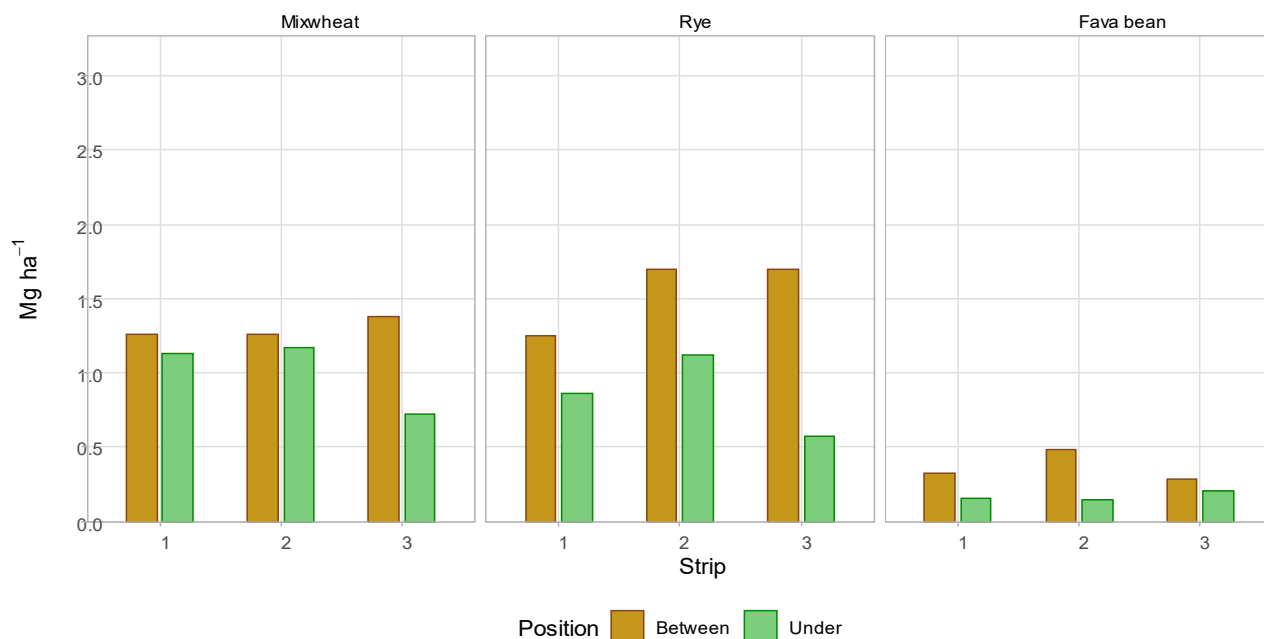


Figure 34. Crop grain yield in agroforestry and monocropping systems in 2024 in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3).

3.2.4 Land equivalent ratio (LER)

The agroforestry system achieved a higher combined yield than the equivalent monocropping systems. Average Land equivalent ratio (LER) in monocropping systems are equal to 1, while results from the agroforestry system varied among 1.2 and 1.6, during both 2023 and 2024 (Figures 35 and 36).

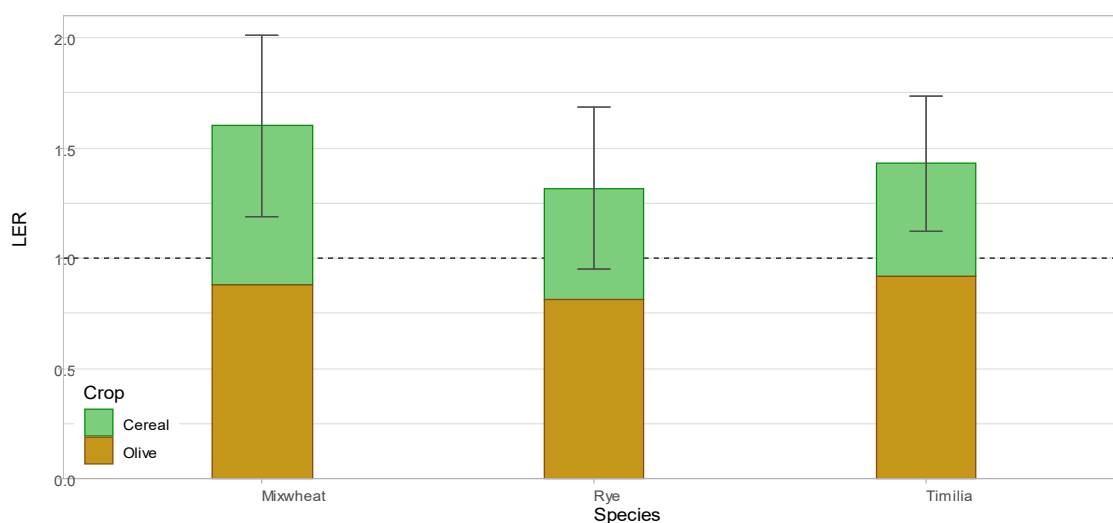


Figure 35. Land equivalent ratio (LER) of the agroforestry system (cereal-olive) in comparison with the cereal and olive monocropping in 2023.

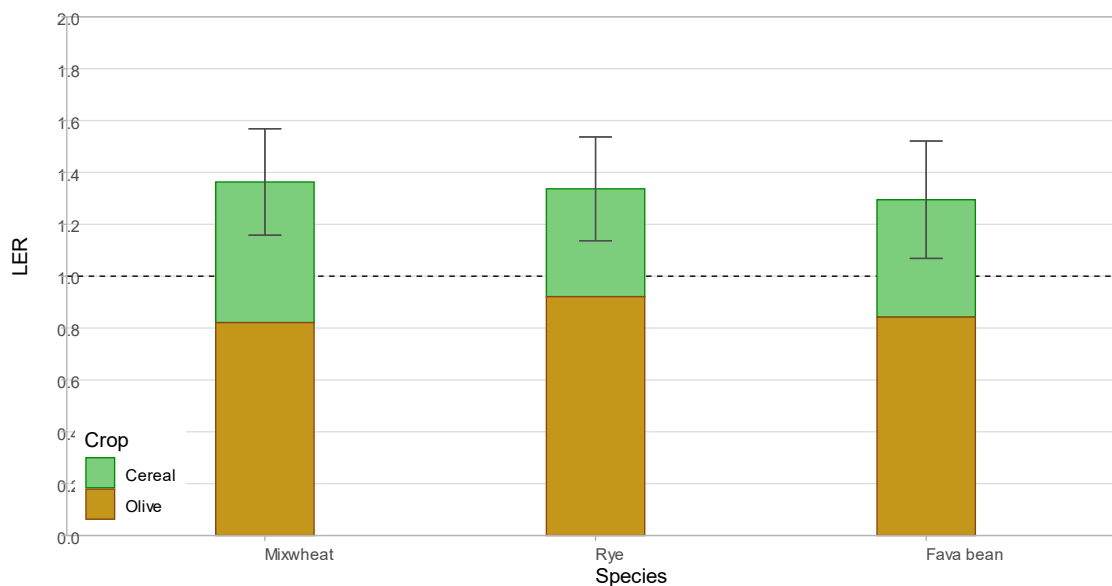


Figure 36. Land equivalent ratio (LER) of the agroforestry system (cereal-olive and fava bean - olive) in comparison with the crop and olive monocropping in 2024.

3.2.5 Soil organic carbon

After the first growing season, the presence of a cover offered by the herbaceous crop led to an increase of soil organic matter of more than 37% (Figure 37).

More years of observation would be necessary to describe the long-term trend on soil fertility under the agroforestry systems.



Transition

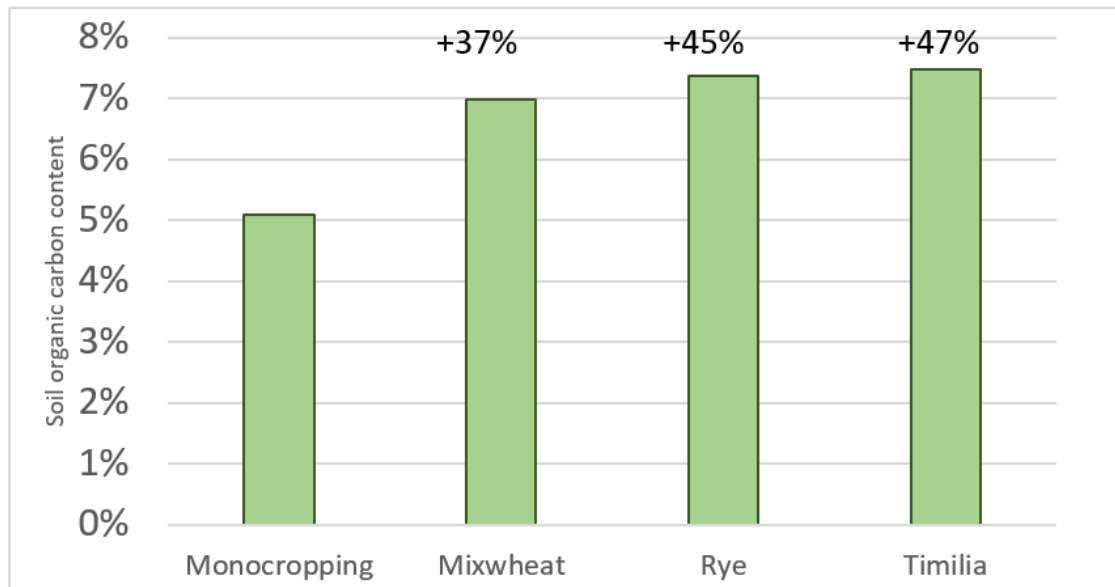


Figure 37. Soil organic carbon content after the first cropping season.

Farm 03

As reported in the methodology section, in the growing season 2023-2024 another farm was added to the Italian case-study. The low rainfall amount during the entire growth cycle did not allow the plants to grow and survive. As a consequence, it was not possible to obtain any data. In the graph below (Figure 38) rainfall and temperatures trend is reported from November 2023 to September 2024.

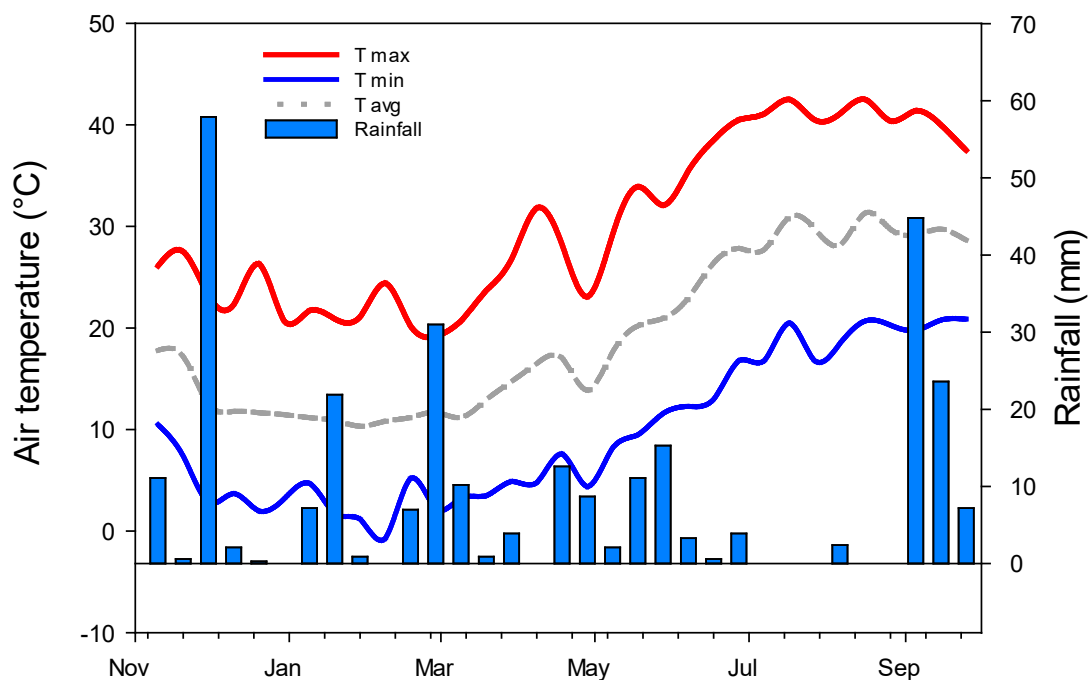


Figure 38. Meteorological variables from November 2023 to September 2024 grouped by decades for Farm 03 area.

3.3. Discussion

The agroforestry systems achieved higher combined yield (grain crop yield and olive tree yield) in comparison with the same extension of land under the monocropping systems, and therefore the agroforestry systems had Land Equivalent Ratios (LERs) higher than 1. Rye achieved the highest yields, being able to intercept the highest amount of PAR due to the high leaf area index. The yield of the herbaceous crops varied significantly according to the sampling site between the lines of trees. The shaded areas under the North side of the trees produced lower biomass and grain yield, while the partially shaded areas between two adjacent trees had higher biomass and grain yield, thus proving the beneficial influence of the tree-crop interaction.

Rye proved to be the most suited winter cereal for olive tree agroforestry in the condition of the experiment (Mediterranean mountainous environment).

4. EGYPT CASE-STUDY

4.1. Experimental site description and methodology

Arid regions, characterized by limited water availability and extreme climatic conditions, face significant challenges in maintaining sustainable agriculture. Innovative approaches are necessary to ensure the resilience and sustainability of agriculture systems in these fragile ecosystems. Mixed farming systems integrate crops and trees, offering a promising solution for arid regions. By combining different elements of agriculture, these systems can create synergies that enhance productivity, improve soil health, and conserve water resources. On the other hand, the design of mixed farming systems must have the ability to improve soil organic carbon, ensuring the resilience of the system. The Egyptian case presents the potential of mixed farming systems to improve soil organic carbon (SOC) management in arid regions.

The intersection of agricultural systems and environmental sustainability has increased attention at the policy-making level in Egypt, with carbon farming and mixed farming emerging as promising approaches to address the challenges of arid regions. The relationship between carbon farming, mixed farming, and the circular economy is essential for sustainable development. The circular economy, which minimizes waste and maximizes resource efficiency, aligns with the principles of both farming approaches. By adopting circular practices, such as recycling organic waste, farmers can contribute to a more sustainable future.

The on-farm experiment conducted in Egypt aligns closely with the broader objectives of the TRANSITION project. By focusing on innovative and economic soil organic carbon management and climate resilience, the experiment contributes directly to the project's goals of promoting sustainable agriculture and strengthening the resilience of Mediterranean agroecosystems. The findings from this experiment provide valuable insights into the potential of mixed farming systems to enhance soil health and sequester carbon in arid environments.

The on-farm research, conducted within the context of the TRANSITION project in Egypt, aimed to assess the effectiveness of combining vermicompost and biochar with mineral fertilizers (N, P, K) in mixed farming systems as a climate resilience strategy in arid regions. This approach, evaluated over two seasons, represents a pioneering effort in



Transition

Egyptian agriculture. The study aimed to enhance soil health, nutrient retention, and crop productivity by examining the synergistic effects of these soil amendments.

The field experiments were conducted in the SRTA-City research farm, Borg Al-Arab, Alexandria, which spans longitudes 29°32'46.41"E to 29°32'46.19"E and latitudes 30°53'35.06"N to 30°53'32.96"N (Figure 39). In general, the experiment area has Mediterranean climatic features of mild, with less than 200mm of rainfall in winter and warm summer lasting from May to September. Soil is recognized by shallow depth to bedrock or permanent water table, hardpans, and fragipans, coarse-textured soils exhibiting low water holding capacity and fertility levels, along with the hazardous accumulation of salts and alkalis.



Figure 39. The geographic location of the SRTA-City research farm located in Borg Al-Arab, Alexandria, Egypt

The on-farm experiment was carried out in 2700m² in two seasons. The first season experiment was carried out in split plots design with three replicates in the summer (May 2023). Tomato plants (variety 0186) were cultivated under the 8-year-old *Jatropha* tree (*Jatropha curcas*, Mexican non-toxic species). The soil was prepared for cultivation by dividing the area into 32 plots measuring 2.8m by 30 m. Within each plot, there were an



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average of 10 *Jatropha* trees positioned along the center line, 90 tomato seedlings on either side of the *Jatropha* tree row (45 seedlings on each side) were rooted, resulting in a total of 2930 tomato seedlings, and 320 *Jatropha* trees across the entire area. Before the seedling process, the soil was prepared using manure and superphosphate, and then a drip irrigation network was installed. The second season of the experiment (February 2024) potato plants (variety Diamond) were cultivated instead of tomatoes as both crops are heavily nutrient-consuming and sensitive to climatic conditions; using the same experiment design and pre-soil management, 200 potato tubers on either side of the *Jatropha* tree row (100 tubers on each side in 2 lines) were planted, resulting in a total of 6400 plants (Figure 40 & Figure 41).

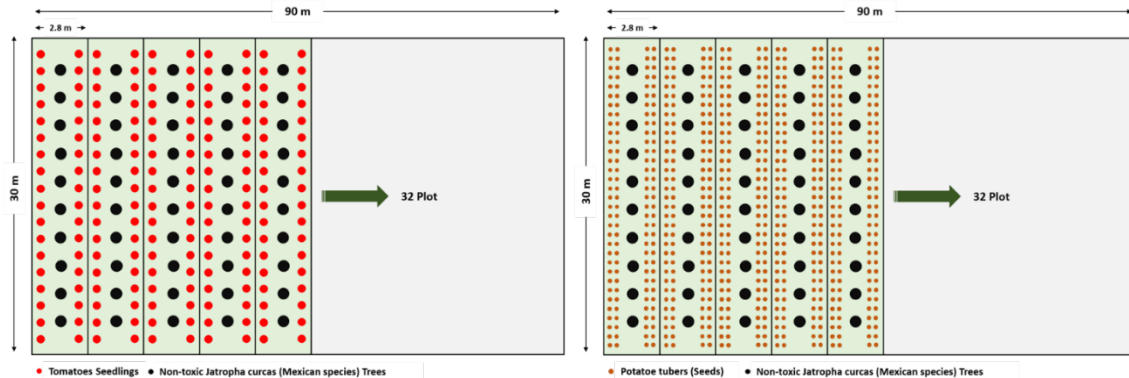


Figure 40. Farm design for the on-farm experiment: (A) Tomatoes, season 2022; (B) Potatoes, Season 2024

The experimental design for both seasons included 21 soil treatments, each representing a unique combination of vermicompost and corn cob biochar. Five levels of vermicompost (0.375, 0.750, 1.5, 2.25, and 3 ton/acre) and five levels of corn cob biochar (0.375, 0.750, 1.5, 2.25, and 3 ton/acre) were applied to the soil. Five levels of mineral fertilizers (12.5, 25, 50, 75, and 100%) were incorporated. Mineral fertilizer and organic amendment dosages were determined independently for each component based on the official recommendations of the Egyptian Ministry of Agriculture, which are typically provided for individual components rather than mixtures (Khedr et al., 2023).

Soil samples were collected during the cultivation of tomatoes and potatoes and in each growing stage for chemical analysis. The treatments were applied to plants before cultivation for organic fertilizers; however, mineral fertilizers were added in three batches, and the ratio of a combination of minerals and organic fertilizers is represented in Table 13.



Transition

After the experiment, soil samples were collected in triplicates, air-dried, ground, and sieved at 2 mm for the subsequent soil analyses following the manual proposed by Ryan et al. (2001). Soil pH and electrical conductivity (EC) were measured in 1:2.5 w/v and 1:1 w/v soil aqueous suspension, respectively. SOC was oxidized using the wet oxidation method. Total nitrogen (TN) was determined using the Kjeldahl method. Soil cations and anions were determined from the saturated soil paste extract.

After harvest (120 days), tomato and potato plants were randomly chosen to assess crop yield by measuring plant height (cm), number of leaves/plant, number of flowers/branches, number of fruits/plant, fruit length (mm), fruit width (mm), fruit yield (kg/plot), and fruit yield (ton/acre) for tomatoes. For potatoes plant height (cm), number of tubers/plant, weight of tubers (g)/plant, average tuber weight (g), Tuber diameter (cm), total yield/plot, total yield (ton/acre). The organic amendments were analyzed before their addition to the soil. Their pH, EC, SOC, total nitrogen, and C/N ratio were 7.42, 6.58 dS m⁻¹, 31.12%, 1.69%, and 18.41, respectively, for vermicompost and 8.01, 4.26 dS m⁻¹, 70.09%, 0.78%, and 89.58 for biochar, respectively.

A



B



Figure 41. Farm preparation for cultivation: (A) Tomatoes, season 2022; (B) Potatoes, Season 2024



Table 13. Soil treatments of vermicompost (VC), biochar (BC), and mineral (M) fertilizers

No.	Treatments
1	100 M
2	75M+ 12.5 VC + 12.5 BC
3	25 VC+ 75 BC
4	25 BC + 75 VC
5	50 M + 25 VC +25 BC
6	50 VC + 50 M
7	50 BC +50 M
8	25 M+ 37.5VC +37.5 BC
9	25 M+75BC
10	100BC
11	25VC+ 75 BC
12	75 BC+ 12.5 VC +12.5 M
13	25 BC+ 37.5VC +37.5 M
14	50 VC + 25 BC +25 M
15	50 VC+ 50 BC
16	50 BC+ 25 VC +25 M
17	100VC
18	75 VC+ 25 BC
19	75 VC + 25 M
20	25 VC + 37.5 BC+ 37.5 M
21	75 VC +12.5 BC+ 12.5 M

4.2. Results

4.2.1 Soil and crop performance

The soil chemical characteristics showed significant variation ($P < 0.05$) within and between the different treatments in the two seasons. The pH values were moderately alkaline and decreased after each season by 0.4 on average among the treatments. Implementing 25% mineral fertilizers, +37.5% vermicompost, and +37.5% biochar was the best treatment for TOC, total N, available P, and K along the two-season stages.

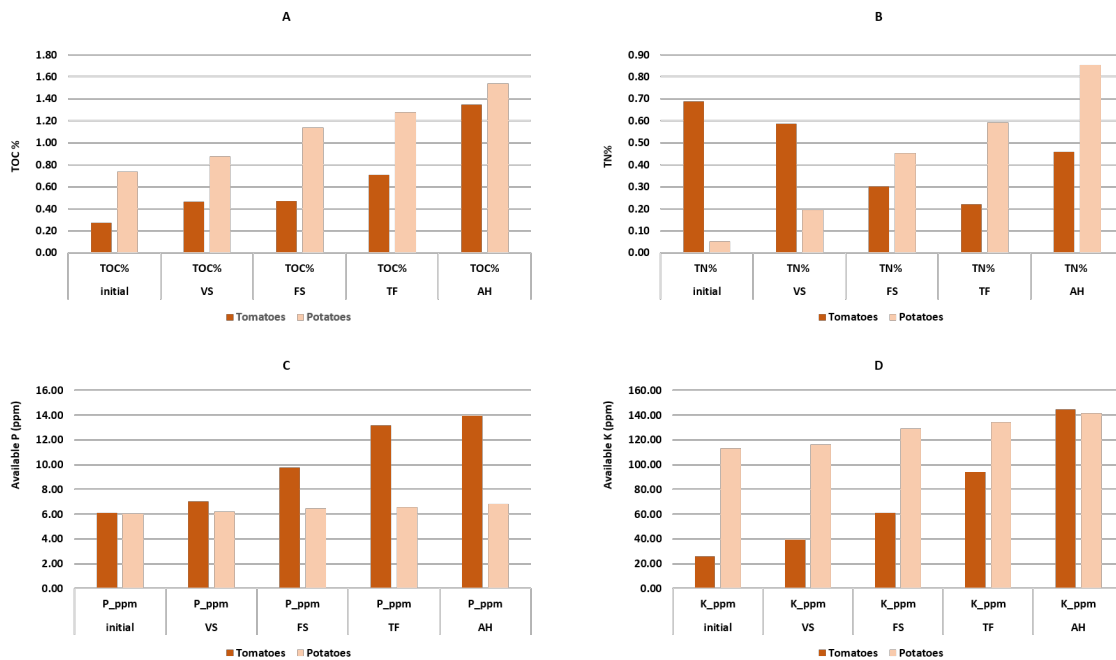


Figure 42. Changes in Soil Chemical Properties During the two seasons (Tomato and Potato Cultivation) – A: Soil TOC%, B: Soil TN%, C: Soil available P (ppm) and D: Soil available K (ppm)

As illustrated in Figure 42, the soil fertility characteristics reveal significant changes, including alterations in total organic carbon (TOC), total nitrogen (TN), available phosphorus (P), and available potassium (K), for different stages of the growing season: initial, vegetative (VS), flowering (FS), and fruiting (TF) stages, as well as after harvest (AH). Both crops' soil TOC increased significantly by 4-fold, indicating improved soil organic matter content, while total nitrogen increased significantly in potato cultivation; it fluctuated in the tomato case, indicating different crop consumption and the effect of climate on nitrogen processes in soil. In general, it's evident in the post-harvest soil samples, suggesting that not only the crops contributed to the enrichment of soil organic matter but also the resilience of the fertilizer mix in the soil. While soil available P increased for both crops, the changes were more noticeable for tomatoes. This suggests that tomatoes have a higher demand for phosphorus compared to potatoes. Soil available K increased significantly for both crops, indicating that tomatoes and potatoes require substantial amounts of potassium.

The application of various organic amendments and mineral fertilizer treatments significantly influenced tomatoes and potato growth, yielding at $p < 0.05$. In the first season, tomatoes' maximum plant height of 125.5 cm at harvest was observed by mixing 75% vermicompost + 12.5% biochar and 12.5% mineral fertilizer treatment, reflecting the high nitrogen concentration supported by vermicompost percentage. At the same time,



Transition

the minimum plant height was recorded with the treatment of 100% mineral fertilizer treatment. However, the treatment of 25% mineral fertilizer, +37.5% vermicompost, and +37.5% of biochar treatments remain also with the highest effect on the soil characteristics and plant growth as tomatoes yielded the highest values for the number of leaves per plant (105), flowers per branch (12), fruits per plant (12), fruit length (71 mm), fruit width (55 mm), fruit yield per plot (72 kg), fruit yield per acre (32 tons), and fruit yield per hectare (80 tons). Conversely, the 100% mineral fertilizer treatments exhibited the lowest values for these parameters (Figure 43 A&B).

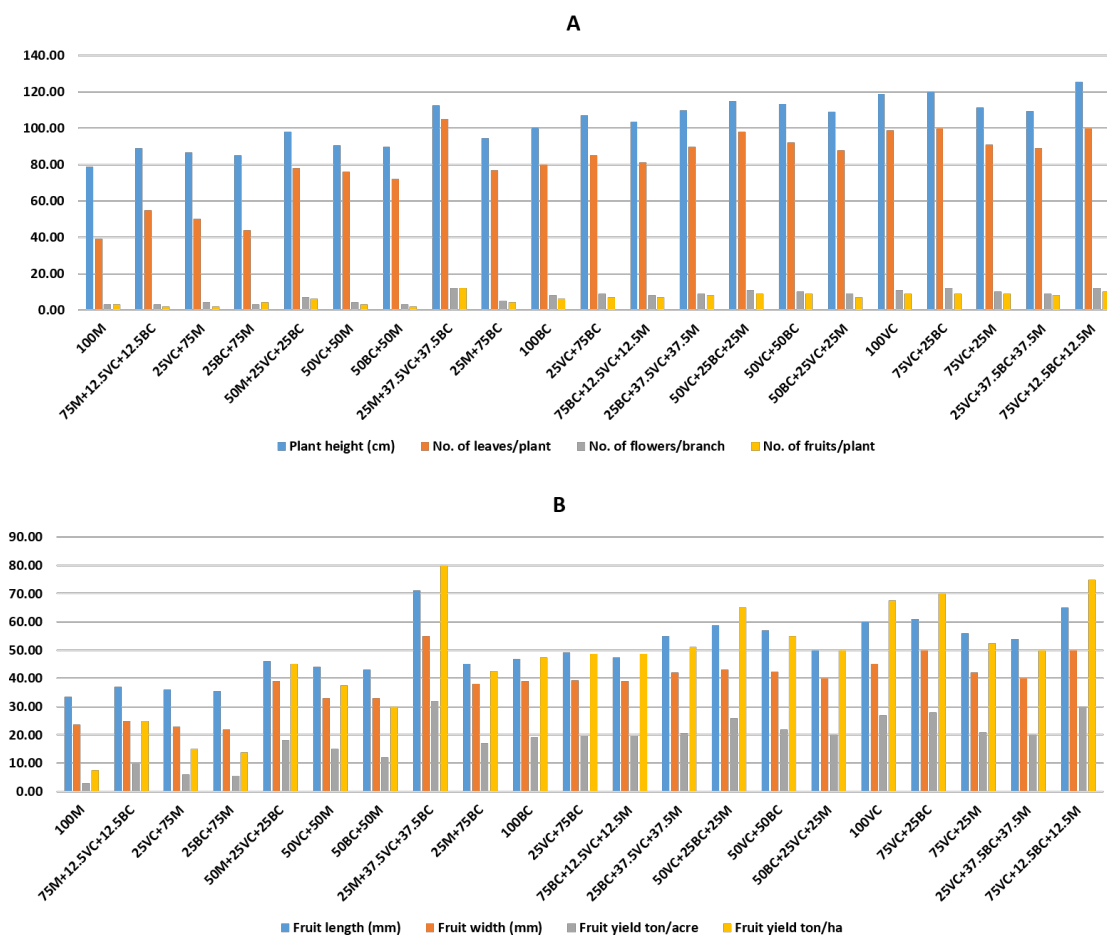


Figure 43. Tomatoes crop (A) vegetative and (B) yield parameters

In the second cultivation season for potatoes, the parameters evaluated included plant height (cm), tuber yield per plant (number, weight, average weight, diameter), and total yield per plot, acre, and hectare. The treatment of 50% mineral fertilizer + 25% vermicompost and + 25% biochar yielded the maximum plant height of 86.4 cm at



Transition

harvest, while the treatment of 100% mineral fertilizer exhibited the minimum. However, the treatment of 25% mineral fertilizer, + 37.5% vermicompost, and + 37.5 of biochar remains also demonstrated superior performance in terms of tuber yield, with the highest values for number of tubers per plant (10), weight of tubers per plant (986 g), average tuber weight (98.6 g), tuber diameter (7.8 cm), total yield per plot (197.2 kg), total yield per acre (12.62 ton), and total yield per hectare (31.55 ton). Conversely, adding 100% mineral fertilizer exhibited the lowest values for these parameters (Figure 44 A, B&C).

In addition to the previously mentioned parameters, Jatropha seed production was monitored throughout the two experiment seasons. Seed yield remained relatively consistent, averaging approximately 120-140 kg of seeds per tree.

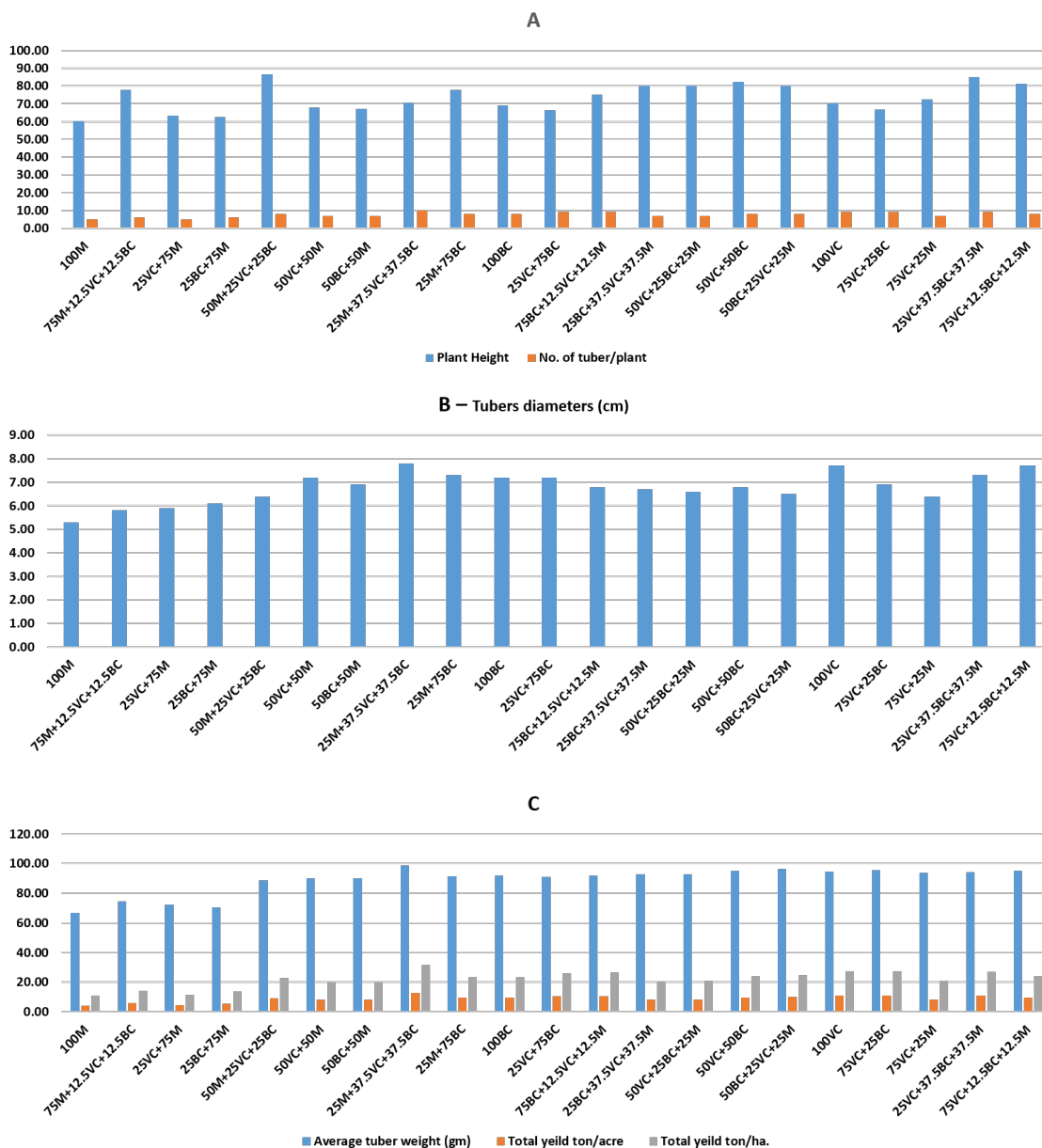


Figure 44. Potatoes parameters (A) Potato plant height and tubers no. /plant, (B) Tuber diameter (cm), and (C) Potato crop parameters

4.3. Discussion

Applying organic amendments and mineral fertilizers significantly enhanced soil chemical conditions over two growing seasons. Notable improvements were observed in soil pH and organic matter reserves. The release of microbial metabolites likely influenced these changes. Compared to biochar, Vermicompost demonstrated superior conservation of nitrogen, phosphorus, and organic carbon. This can be attributed to its nutrient content and beneficial metabolites produced during composting. The organic



Transition

treatments, particularly those involving Vermicompost, significantly decreased soil alkalinity and increased organic reserves due to introducing low-pH organic and carboxylic acids. Organic amendments effectively increased nutrient stocks in the soil over two seasons. Microbial activities were important in stabilizing these nutrients, contributing to their long-term availability. Also, adding organic amendments led to a significant decrease in soluble sodium (Na) compared to NPK-treated soils. This reduction may be attributed to the introduction of fulvic and humic acids, which can decrease the solubility of soil nutrients. Combining organic amendments with mineral fertilizer (NPK) additions yielded the highest values for the tomato and potato crop assessment parameters. At the same time, Jatropha seed production remains the same due to weather complications. This enhancement was primarily due to the improved availability of macro and micronutrients, which positively impacted plant growth, general health, and productivity. The organic amendments also acted as plant nutrient sources, improving soil biological properties.

The on-farm research not only presented the potential of mixing two organic amendments with mineral fertilizers in a mixed farming system but also in terms of the resilience indicators identified in the WP1 of the project journey. The designed system regarding the soil organic matter content significantly increased along the two cultivation seasons. In the tomato growing season, the extreme weather in 2022 showed that temperatures during the tomato germination, flowering, and fruit set stages exceeded optimal levels by 1°C, 4°C, and 8°C, respectively (Figure 45). Despite these challenges, the experiment yielded 32 tons/acre, slightly below the optimal 40 tons/acre production. In comparison, potatoes that did not face any climatic challenges reached 12 tons/acre, above the Egyptian average in the same soil and water conditions by 4 tons/acres. Regarding the crop period, there were no noticeable changes, but regarding the economics, the system design achieved a 29% decrease in the total cost of tomato cultivation and 32% for potato cultivation.

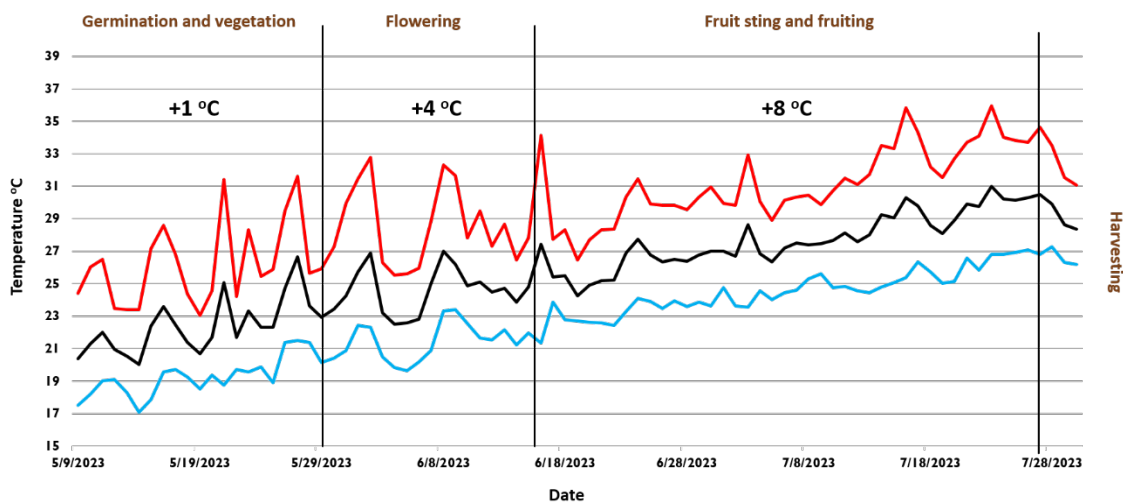


Figure 45. Air temperature conditions during tomato and potato cultivation season

The on-farm research highlights the potential of mixed farming systems as a sustainable and resilient agricultural approach for arid regions. By integrating crops and trees under the framework of carbon farming. These systems can improve soil health, conserve water resources, and mitigate the effects of climate change. Future research of organic matter stability and integrated irrigation systems under different mixed farming systems and policy support are necessary to promote the widespread adoption of mixed farming systems in arid regions.

5. ALGERIA CASE-STUDY

5.1. Experimental site description and methodology

The dominant cropping systems in Algeria and more particularly in the semi-arid region of Sétif are systems based on monoculture (cereals - fallow). Cereal farming is conducted by adopting the conventional system (deep plowing), the use of chemical fertilizers, and post-harvest, crop residues are grazed by the herd. However, the agroforestry systems are less developed except for mountainous areas where agricultural land is reduced. For this reason, there was an attempt of introducing a fodder crop into agroforestry systems in order to reduce the harmful effects of climate change as well as improve the quality of the soil and crops yields at the same time provide feed for livestock. At the beginning of the project 8 farms were selected for the experiments and their main features are listed below.



Transition

Farm 01

- Location: Mezloug, Sétif, Algeria
- Altitude: 915 m asl
- Rainfall: 150 mm per year
- Soil main characteristics: light and stony (poor in OM)
- Type of system: silvo-pastoral/mixed farming
- Trees on the farm: forest trees (poplar, ash trees)
- Crops on the farm: meadows; cereal and forage crops
- Animals on the farm: cattle

Farm 02

- Location: Bir Haddada, Sétif, Algeria
- Altitude: 950 m asl
- Rainfall: 180 mm per year
- Soil main characteristics: light, stony and calcareous (poor in OM)
- Type of system: agropastoral/mixed farming
- Trees on the farm: olive, almond, apple, plum
- Crops on the farm: barley, oats, triticale, durum wheat
- Animals on the farm: sheep, bees

Farm 03

- Location: Ain Arnet, Sétif, Algeria
- Altitude: 1009 m asl
- Rainfall: 300 mm per year
- Soil main characteristics: heavy, clayey (0,5% of OM)
- Type of system: agropastoral/mixed farming
- Trees on the farm: forest trees (ash trees, Aleppo pine and cypress)



Transition

- Crops on the farm: durum wheat, bread wheat, barley, oat, field peas, lentil and chickpeas
- Animals on the farm: cattle

Farm 04

- Location: El Eulma, Sétif, Algeria
- Altitude: 980 m asl
- Rainfall: 220 mm per year
- Soil main characteristics: clayey and sandy-clayey and calcareous soil (poor in OM)
- Type of system: agropastoral/mixed farming
- Trees on the farm: olive and forest trees: Aleppo pine and cypress
- Crops on the farm: durum wheat, bread wheat, barley, oat, triticale, Alfa-Alfa, lentil, olive tree, natural grassland
- Animals on the farm: cattle, broiler

Farm 05

- Location: Beni Fouda, Sétif, Algeria
- Altitude: 843 m asl
- Rainfall: 250 mm per year
- Soil main characteristics: clayey
- Type of system: agropastoral/mixed farming
- Trees on the farm: olive and forest trees: aleppo pine and cypress
- Crops on the farm: durum wheat, bread wheat, barley, green barley, oat, lentil and chickpeas, triticale, vetch-oat, maize, sorghum
- Animals on the farm: cattle, sheep, broiler

Farm 06

- Location: Ain Roua, Sétif, Algeria
- Altitude: 966 m asl



Transition

- Rainfall: 500 mm per year
- Soil main characteristics: clay-loam (OM: mean)
- Type of system: agroforestry-silvopastoral /mixed farming
- Trees on the farm: olive tree, almond trees, apricot, apple, pear, peach, walnut, vine,
- Crops on the farm: durum wheat, bread wheat, barley, green barley, oat, lentil and chickpeas, triticale, vetch-oat, vetch-triticale, alfa-alfa
- Animals on the farm: cattle, sheep, broiler

Farm 07

- Location: El Ouldja, Sétif, Algeria
- Altitude: 905 m asl
- Rainfall: 100 mm per year
- Soil main characteristics: light, stony, calcareous and saline
- Type of system: agropastoral/mixed farming
- Trees on the farm: olive trees
- Crops on the farm: barley, oat, lentil,
- Animals on the farm: sheep

Farm 08

- Location: Sétif, Sétif, Algeria
- Altitude: 965 m asl
- Rainfall: 300 mm per year
- Soil main characteristics: loamy + calcarous
- Type of system: agropastoral/mixed farming
- Trees on the farm: forest trees (poplar, eucalyptus)
- Crops on the farm: durum wheat, association (triticale-oat, vetch-field peas), alfa-alfa, corn (silage)
- Animals on the farm: cattle



Transition

Due to unforeseen problems mainly related to adverse meteorological conditions only the experiments of Farm 02 will be reported.

The experiment was conducted at the pilot farm Sersour Salah (Bir Haddada and Ain Lahdjar, Setif) focusing on the sowing of fodder peas (*Pisum sativum* L. variety Sefrou), as an alternative to fallow, under olive trees in an agroforestry system.

The experimental plot (Figure 46) was made of 3 blocks, each block divided into sub-blocks and each sub-block had 4 elementary plots of 30 m² with a space of 2 m² between plots and 1 m² between sub-blocks (criss-cross). The trials compared two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure) with a seeding rate of 12.5 g/m². The sowing date was 03/01/2024 (Table 14). The type of fertilizer used was Northweat (10, 30, 10, and 9), the manure was sheep type.

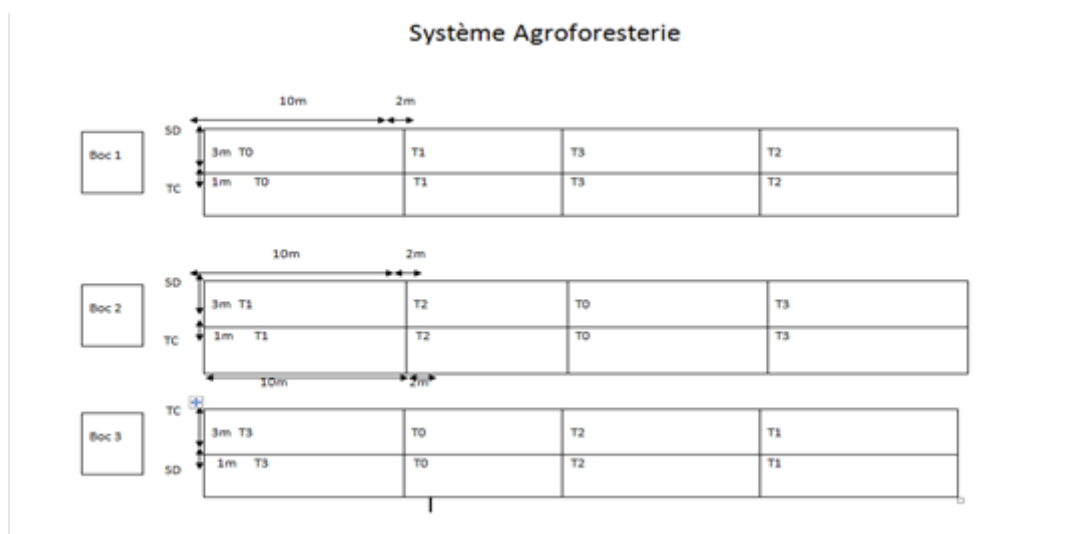


Figure 46. Experimental design of the trial

Table 14. Trial site and respective sowing and harvest dates

Salah Sersour pilot farm site	
Site coordinates	35.9687201N, 5.5436826E, Altitude: 949m
Agroecological zone	Semi-arid
Soil	Light, stony and calcareous
Prevailing cropping systems	Cereal-fallow and olive trees
Average rainfall (last 10 years)	Around 300mm



Transition

2022-2023		Because of severe drought and high rainfall in Mid- may- mid-june 2023 (164mm), this trial could not survive
2023-2024	Sowing date:	03/01/2024
	Harvesting date:	19/06/2024

The measurements performed were plant height, plant biomass at full maturity, seed yield, plant density at emergence, number of ramifications and number of pods per plant.



Figure 47. Experimental trial: a) tillage, b) sowing, c) plot design, d)&e) plant measurements f) plants at flowering stage.

5.2 Results

5.2.2 Season 2023-2024

The sowing date of the trials for the season 2023-2024 at Salah Sesrou pilot farm was 29-Dec-2023. The 2023-2024 season was very dry. Despite the trial received enough rain for germination but later, the crop started to experience the water stress condition at the time of maximum growth. The total amount of rain received from January to end of May was 102mm (Figure 48). More than a half of the rain was recorded on February.

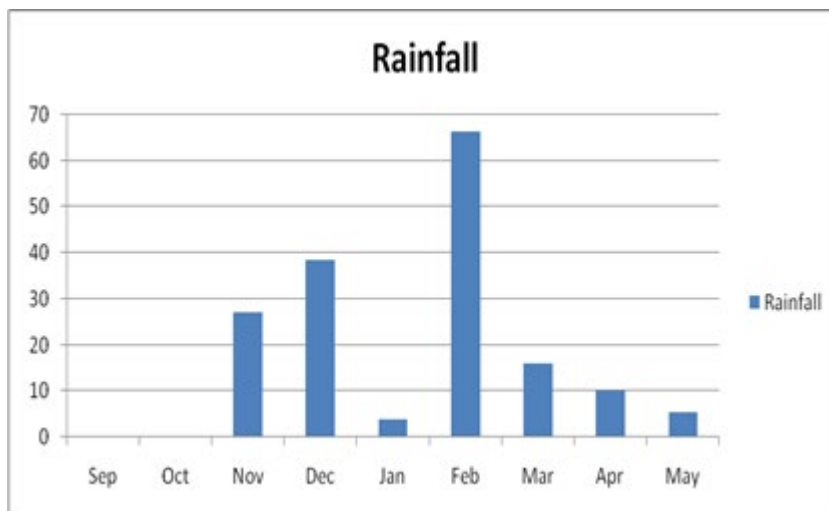


Figure 48. Rainfall in the month between September 2023 and May 2024 in Bir haddada, South of Sétif.

The analysis of data from the trial conducted at Pilot Farm site revealed that no tillage (SD) had significant effect on variability on density at emergence than conventional tillage (TC) (Figure 49). However, for all the rest of parameters measured (plant biomass, seed yield and, number of pods and ramifications per plant and height of plant), the TC showed best result than SD. For the fertilisation strategies, for grain yield, the density and number of ramifications, T2 recorded the best results than others, for the plant height and number of pods per plant, the T3 which has the higher performance. However, for the biomass, it is the T1 which obtained the best results than others (Figures 50, 51, 52, 53, 54).

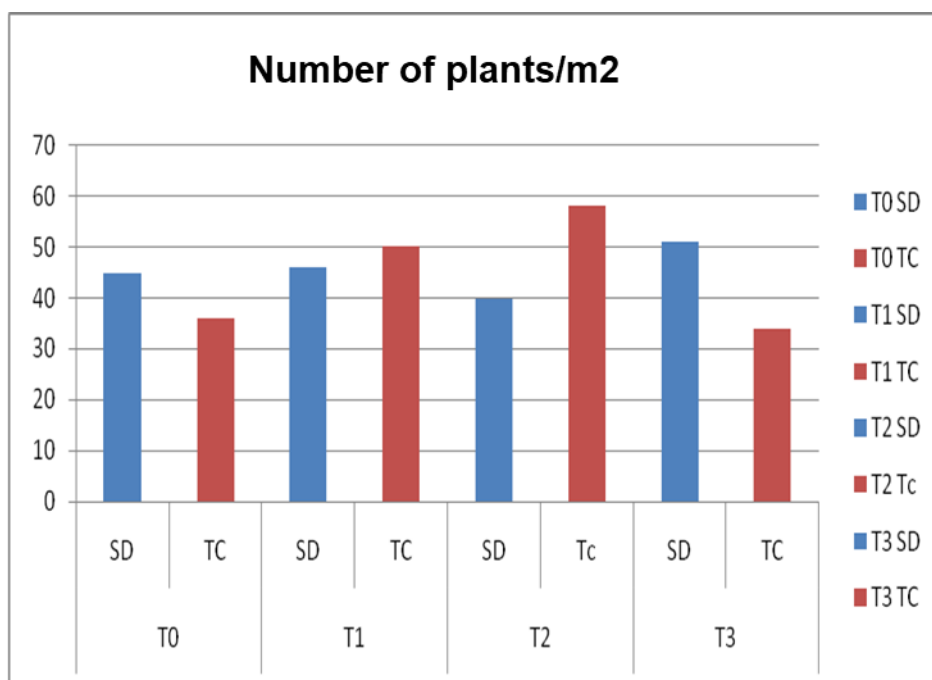


Figure 49. Number of plants on m² for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

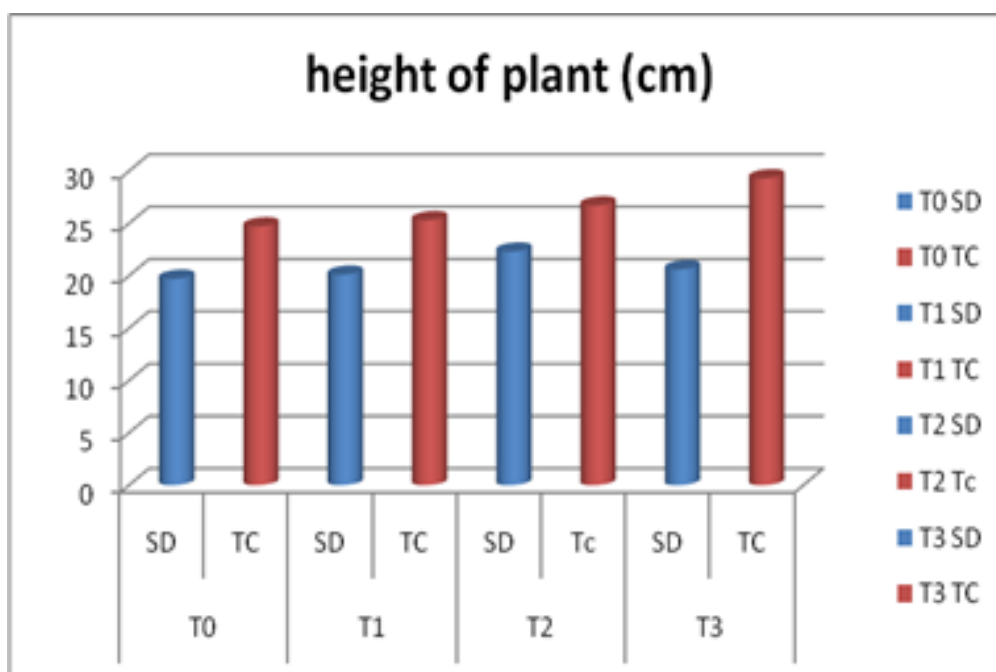


Figure 50. Height of plants for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

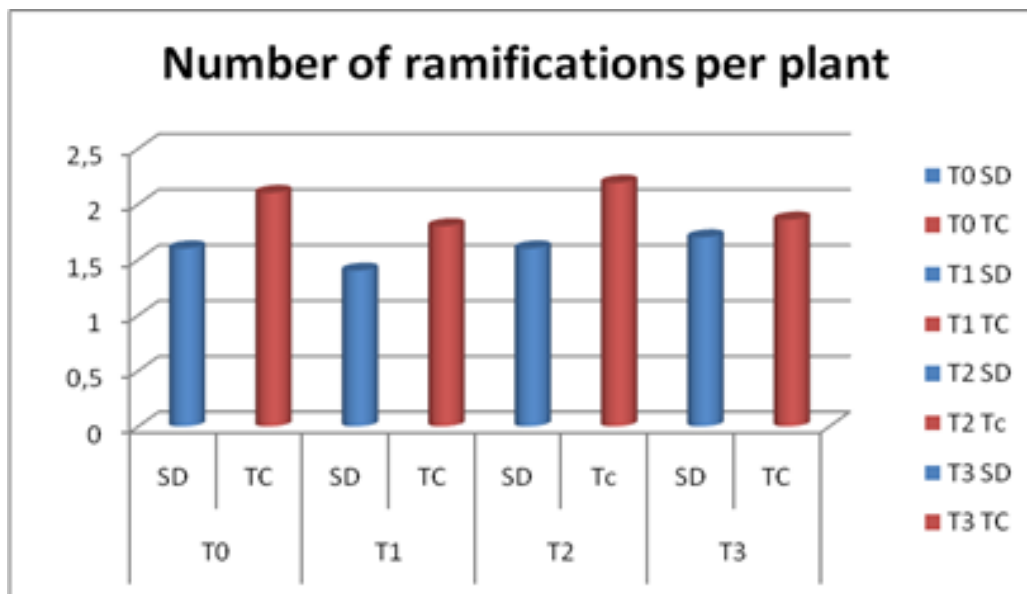


Figure 51. Number of ramifications per plant for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

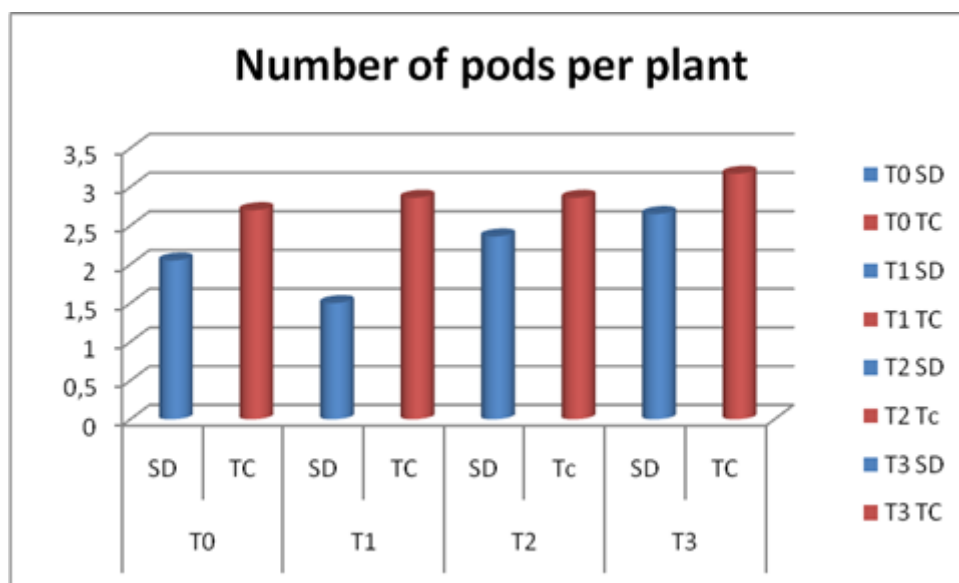


Figure 52. Number of pods per plant for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

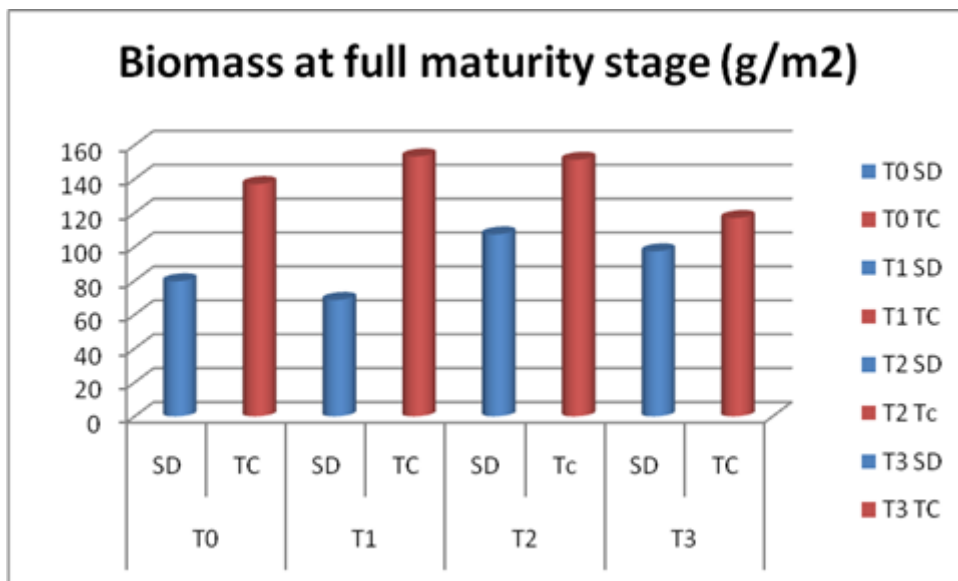


Figure 53. Weight of biomass at full maturity stage for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

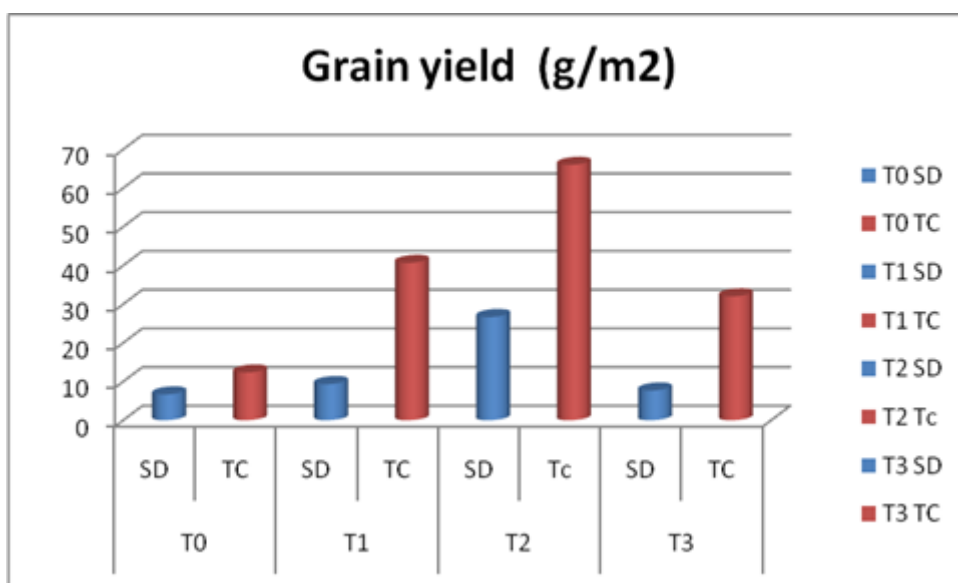


Figure 54. Grain yield for different treatments for two tillage systems (conventional TC and no-till SD) and different levels of fertilization (T0: no inputs, T1: mineral fertilization, 30g/m², T2: organic fertilization, 2kg/m² and T3: integrated fertilization: 15g/m² and 1kg of manure).

5.3 Discussion

From the results, given this year is dry, and the quality of soil in the region, we observed that the no tillage system has lower results than tillage system which indicates the soil is poor in MO.



Transition

For the fertilization strategies, the results indicated the importance of fertilization, especially the organic manure in that region most exposed to drought.

Based on the results of season 2023-2024, we conclude that under unfavourable environments such as south of Sétif, no-tillage system has great advantages under agroforestry system on plant density of crops as cover crop, but the results for other growth and productivity parameters cannot appeared in one cropping season. For this, the trail must be repeated for at least 4 seasons so that to allow the soil to build its OM stock.

Also, it is recommended to use the minimum tillage to minimize the problem of weeds in the field.

For the fertilization strategies, the use of combined fertilization (mineral and organic) is needed to improve the quality and the structure of the soil and improve the growth and productivity of the crops.

6. FRANCE CASE-STUDY

6.1. Experimental site description and methodology

For a better understanding of this document, it is recommended to read the article (Garreau et al., 2024) which was published in agroforestry systems that sums up the first part of the work carried in the TRANSITION project and presents the farmers interviewed. In the article, it is possible to find a notion of satisfactory states used here. As a second step of the project, a set of 17 farm resilience indicators were measured. These measures aimed at exploring two questions: (i) how close is the current state of the farm to the satisfactory state? (ii) which parameters can be improved to buffer disturbances?

Thanks to the semi-structured interviews of the first phase of the project a list of resilience indicators based on farmers' interests was established. These indicators were classified according to the five components of satisfaction that were outlined in the first phase of the project. These components were: (i) global organization of the farm; (ii) agroecological management of the plot; (iii) economic performance; (iv) provision of



Transition

ecosystem services; and (v) belonging to a knowledge-producing community. It was not possible to collect all the indicators for all the farms, and for some indicators, data that the farmer had already measured previously thank to collaborations with other organizations were used. It results in a heterogeneity of the data on some dimensions. The complete list of indicators is presented in Table 15. with the different sources of data mobilized.

Table 15. List and description of the resilience indicators evaluated in the farms

Indicator	Group	Complete name	Unit	Way of collecting the data
1	Organization	Number of farm activities	No unit	Semi-structured interviews and telephone survey
2	Organization	Minimum full-time equivalent observed at least once during the year	No unit	Telephone survey
3	Management	Number of fruit tree species	No unit	Semi-structured interviews and telephone survey
4	Management	Number of vegetable species	No unit	Semi-structured interviews and telephone survey
5	Management	Total soil organic matter	%	Soil analysis data supplied by farmers who have carried them out and wish to share them.
7	Management	Soil cation exchange capacity	Cmol+/kg	Soil analysis data supplied by farmers who have carried them out and wish to share them.
8	Management	C/N	No unit	Soil analysis data supplied by farmers who have carried them out and wish to share them.
9	Economy	Shannon index of share of sales per activity	No unit	Telephone survey



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10	Economy	Shannon index of sales share per selling point	No unit	Telephone survey
11	Economy	Standard deviation of sales share over 4 seasons	No unit	Telephone survey
12	Economy	Number of seasons in which products are sold in their entirety	No unit	Telephone survey
13	Services	Number of linear metres of hedges and forest edges per hectare of UAA	m/ha	Field campaign by Clémence Vershave and Léa Garreau
14	Services	Total number of woody species inventoried in the plot's hedgerows	No unit	Field campaign by Clémence Vershave and Léa Garreau
15	Services	Number of birds	No unit	Field campaign carried out by Federico and Yanina Benedetti and fauna data provided by farmers who have carried out surveys and wish to share them.
16	Services	Number of bats	No unit	Fauna data provided by farmers who have carried out surveys and wish to share them.
17	Knowledge	Number of organizations with which the farmer has been or is linked	No unit	Semi-structured interviews

Semi-structured interviews were conducted with 18 farmers from 16 different farms. Telephone surveys were conducted with 12 different farms. The survey outline is available in Annex 1. In addition, six farms provided soil analysis.



Transition

The field campaign on hedgerow was performed in the 16 farms and a detailed report on it entitled “Etude qualitative des haies dans les vergers-maraîchers et jardins-forêts méditerranéens” was written and it is available in the Teams folder of the project.

The field campaign on birds was performed on 4 farms. A detailed report on it is available in Annex 2.

This document aims at providing a global overview on the results of the different indicators. To accomplish it, the data were transformed in order to make it more friendly for visualization. As presented in Table 6, the different raw values of indicators vary in ranges that differ a lot depending on the considered indicator. The range of variation between 0 and 100 was standardized for all of them. For this purpose, a threshold value was set, considered as very high at 100. It may therefore result in some standardized indicator values being above 100 for extremely high values of the raw indicator. The justification of the value is presented in Table 16 .

Table 16. Key figures on the resilience indicators

Indicator	Min observed	Max observed	Max_100	Justification of the value 100	Details
1	2	5	14	Total number of different farming activities in the sample	Market gardening, arboriculture, training, food transformation, visits, laying hens, laying quails, research, hosting, caterer, salaried employee in another vegetable garden, design office, cereals.
2	1	5	5	Maximum farming activities for one farm (one person per activity).	
3	1	35	18	Average of the sample is 9 and considered as 50%	
4	9	160	68	Average of the sample is 34 and	

				considered as 50%	
5	2,4	6	12	Above 12-15% biological activity decreases	https://archinats.hypotheses.org/files/2023/02/QUE-SE-PASSE-T-IL-DANS-LE-SOL-03-03-31.pdf
6	269	366	400	Arbitrary	
7	5,7	19,9	40	Above 40 Cmol+/kg, the soil reservoir is considered large.	https://agriressources.fr/fileadmin/user_upload/Auvergne-Rhone-Alpes/177 Eve-agriressources/fertisols/Fiches_FERTISOLS/Fiche_IL.09.pdf
7	100	100	100	Maximum index value	
8	9,5	15,4	25	Value above which nitrogen hunger is observed	https://www.supagro.fr/ressources/pepites/sol/co/1_2_8def_c_sur_n.html
9	0,1	0,51	1	Maximum index value	
10	0	0,62	1	Maximum index value	
11	0,6	1	1	Maximum index value	
12	3	4	4	4 seasons in the year	
13	28	422	400	One-hectare perimeter	
14	10	45	143	Total number of species inventoried	
15	6	36	47	Total number of species inventoried	
16	3	18	34	Number of bat species in France	Figure given by Asellia in the report on the study carried out.



Transition

17

0

4

10

Total number of organizations mentioned

GRAB, Adept, agroof, Métropole, autres fermes, PNR, CEN, agribus

Civam, SAFER,

A description of all the farms is given below.

Farm 01

- Location: Avignon, Vaucluse, France
- Altitude: 30 m asl
- Rainfall: 752 mm per year
- Soil main characteristics: Fluvisol; Argilolimoneuse
- Type of system: Agropastoral/mixed farming
- Trees on the farm: Apple tree; plum tree; pear tree; cherry tree; peach tree; apricot tree; persimmon tree; mandarin tree; nectarine tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: ducks

Farm 02

- Location: Vézénobre, Gard, France
- Altitude: 102 m asl
- Rainfall: 949 mm per year
- Soil main characteristics: Fluvisol; Argilolimoneuse
- Trees on the farm: Peach tree; persimmon tree; apple tree; pear tree; plum tree; cherry tree; apricot tree; pawpaw tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: ducks

Farm 03

- Location: Pernes les fontaines, Vaucluse, France



Transition

- Altitude: 100 m asl
- Rainfall: 713 mm per year
- Soil main characteristics: Calcisol; Argileuse
- Trees on the farm: Apple tree; fig tree; olive tree; plum tree; hazel tree; cherry tree; walnut tree; peach tree; oak truffle tree; persimmon trees; others
- Crops on the farm: Diversified vegetables
- Animals on the farm: ewes

Farm 04

- Location: Le val, Var, France
- Altitude: 222 m asl
- Rainfall: 735 mm per year
- Soil main characteristics: Fluvisol; Argileuse
- Trees on the farm: Apple tree; peach tree; apricot tree; fig tree; plum tree; pistachio tree; mulberry tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 05

- Location: Le thor, Vaucluse, France
- Altitude: 49 m asl
- Rainfall: 759 mm per year
- Soil main characteristics: Reductisol; Argilolimono-sableux
- Trees on the farm: Apple tree; hazel tree; pear tree; fig tree; plum tree
- Crops on the farm: Diversified vegetables

Farm 06

- Location: Peyrolles en provence, Bouches du Rhône, France
- Altitude: 205 m asl



Transition

- Rainfall: 694 mm per year
- Soil main characteristics: Fluvisol
- Trees on the farm: Apricot tree; cherry tree; fig tree; plum tree; apple tree; pear tree; persimmon tree; olive tree; cold-resistant citrus tree; pawpaw tree; service tree; serviceberry tree; quince tree; jujube tree
- Crops on the farm: Diversified vegetables

Farm 07

- Location: La treille, Bouches du Rhône, France
- Altitude: 143-170 m asl
- Rainfall: 602 mm per year
- Soil main characteristics: Fluvisol; Argileuse
- Trees on the farm: Plum tree; apricot tree; fig tree; olive tree; persimmon tree; hazel tree; cherry tree; feijoa; almond tree; jujube tree; nashi tree; peach tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 08

- Location: Mirmande, Drôme, France
- Altitude: 212 m asl
- Rainfall: 966 mm per year
- Soil main characteristics: Rendosol; Limonoargileux
- Trees on the farm: Medlar; peach; quince; apple; pear; cherry; hazel; apricot; plum; persimmon; walnut; almond; nectarine; fig
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens and horses

Farm 09

- Location: Die, Drôme, France



Transition

- Altitude: 407 m asl
- Rainfall: 894 mm per year
- Soil main characteristics: Fluvisol ; Argileuse
- Trees on the farm: Plum tree; apple tree; goumi; eleagnus; walnut tree; catalpa; yuzu; sichuan pepper, quince; elderberry; tea tree; fig tree; hawthorn; nashi; timut pepper; lemon
- Crops on the farm: Diversified vegetables

Farm 10

- Location: Tourves, Var, France
- Altitude: 265 m asl
- Rainfall: 735 mm per year
- Soil main characteristics: Fluvisol
- Trees on the farm: Honey locust; elm; eleagnus; plum; molinia
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 11

- Location: Ansouis, Vaucluse, France
- Altitude: 245 m asl
- Rainfall: 746 mm per year
- Soil main characteristics: Fluvisol
- Trees on the farm: Walnut trees; hackberry; rowan; bohemian olive
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 12

- Location: Pernes les fontaines, Vaucluse, France
- Altitude: 50 m asl



Transition

- Rainfall: 713 mm per year
- Soil main characteristics: Fluvisol; Limonoargileuse
- Trees on the farm: Apricot tree; peach tree; plum tree; apple tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 13

- Location: Correns, Var, France
- Altitude: 306 m asl
- Rainfall: 735 mm per year
- Soil main characteristics: Calcisol; Argilo calcaire
- Trees on the farm: Pear tree; olive tree; apple tree; peach tree; almond tree; plum tree; pomegranate tree; cherry tree; hawthorn tree; strawberry tree; pistachio tree; black mulberry tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens and quails

Farm 14

- Location: Marseille, Bouches du Rhône, France
- Altitude: 165 m asl
- Rainfall: 602 mm per year
- Soil main characteristics: High in limestone
- Trees on the farm: Cherry tree; plum tree; apricot tree; fig tree; apple tree; pear tree; strawberry tree; elderberry; hazelnut tree; nashi tree; peach tree; olive tree; pepper tree; feijoa tree
- Crops on the farm: Diversified vegetables
- Animals on the farm: chickens

Farm 15



Transition

- Location: Forqualquier, Alpes de haute provence, France
- Altitude: 407 m asl
- Rainfall: 804 mm per year
- Soil main characteristics: Calcisol
- Trees on the farm: Apple tree; cherry tree; hazel tree; serviceberry tree; plum tree; peach tree; fig tree; olive tree; pepper tree; eleagnus; quince tree; walnut tree
- Crops on the farm: Diversified vegetables

Farm 16

- Location: Mallemort, Bouches du Rhône, France
- Altitude: 121 m asl
- Rainfall: 682 mm per year
- Soil main characteristics: Fluvisol
- Trees on the farm: Cherry tree; plum tree; apricot tree; peach tree; fig tree
- Crops on the farm: Diversified vegetables

6.2 Results

We list below the 18 figures synthesising the data gathered for all the farms. For each figure 3 graphs are displayed. (i) On the top right-hand corner is presented the number of satisfaction criteria per component of satisfaction mentioned by the farmer. (ii) On the bottom left-hand corner is the number of disturbances per category mentioned by the farmer and (iii) on the bottom right hand corner is the graph presenting the standardized values of the indicators.



Figure 55. Results for Farm n° 1 – Farmer n° 1 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

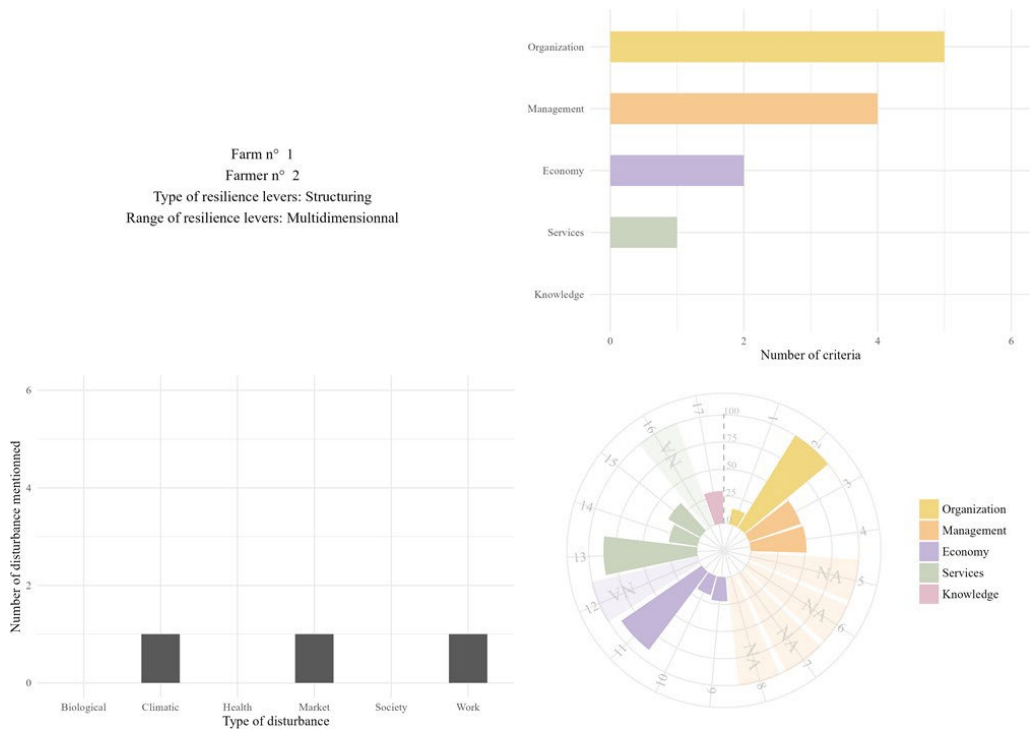


Figure 56. Results for Farm n° 1 – Farmer n° 2 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.



Figure 57. Results for Farm n° 1 – Farmer n° 3 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.



Figure 58. Results for Farm n° 2 – Farmer n° 4 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 3
Farmer n° 5
Type of resilience levers: Piloting
Range of resilience levers: Multidimensionnal

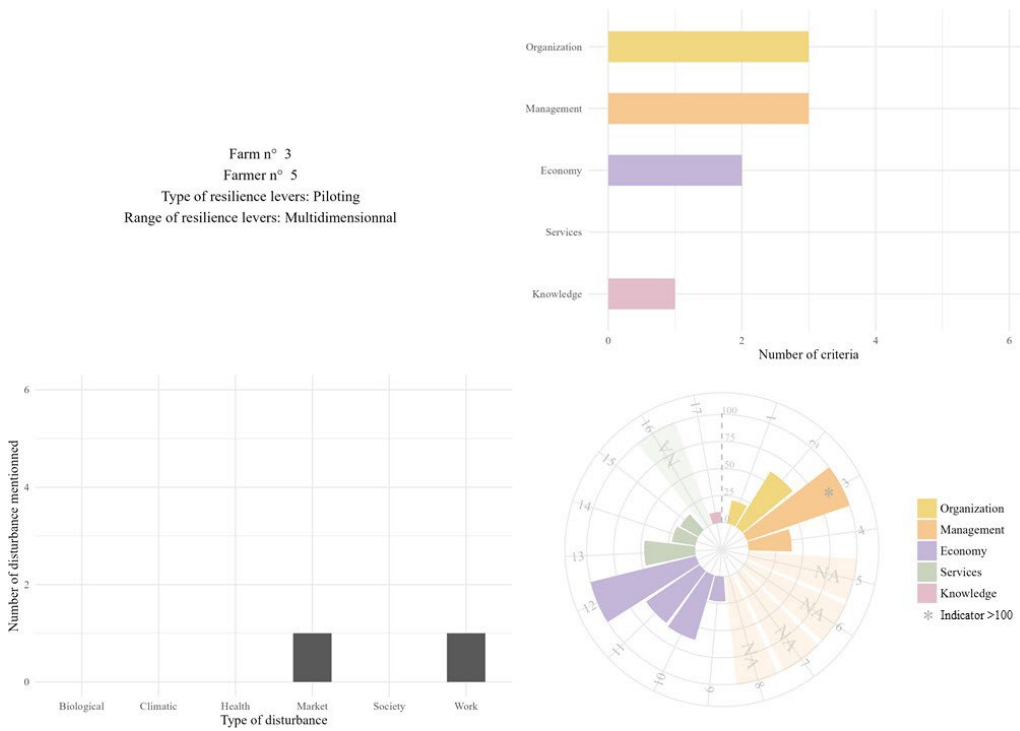


Figure 59. Results for Farm n° 3 – Farmer n° 5 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 4
Farmer n° 6
Type of resilience levers: Piloting
Range of resilience levers: Multidimensionnal



Figure 60. Results for Farm n° 4 – Farmer n° 6 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the



Transition

bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.



Figure 61. Results for Farm n° 5 – Farmer n° 7 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

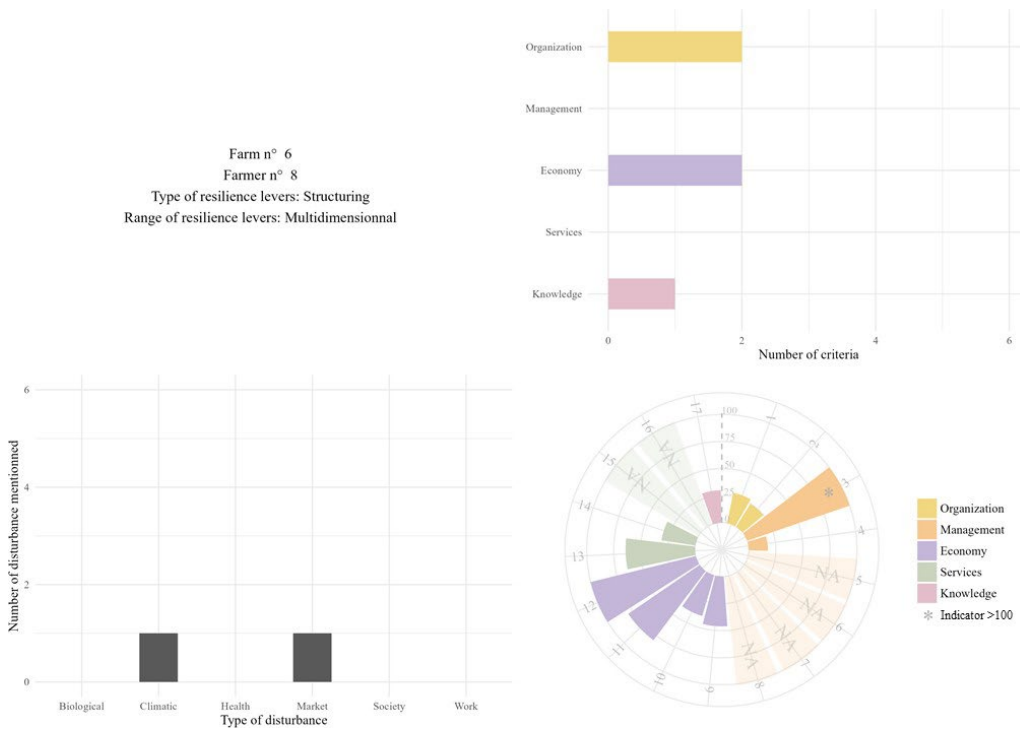


Figure 62. Results for Farm n° 6 – Farmer n° 8 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

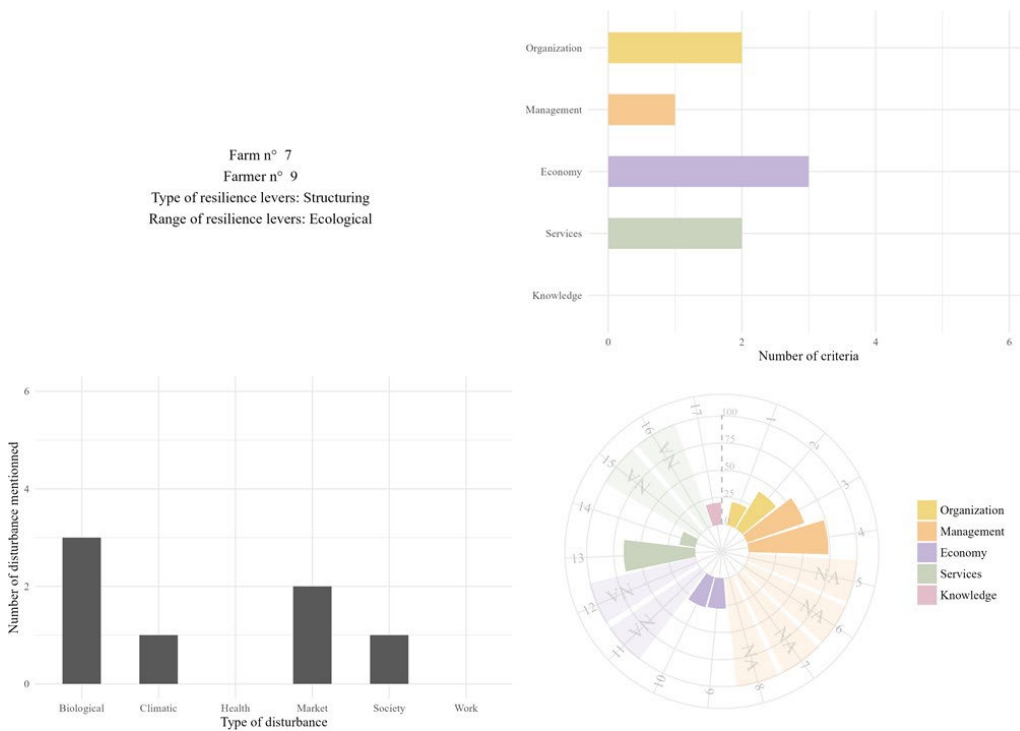


Figure 63. Results for Farm n° 7 – Farmer n° 9 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the



Transition

bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.



Figure 64. Results for Farm n° 8 – Farmer n° 10 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

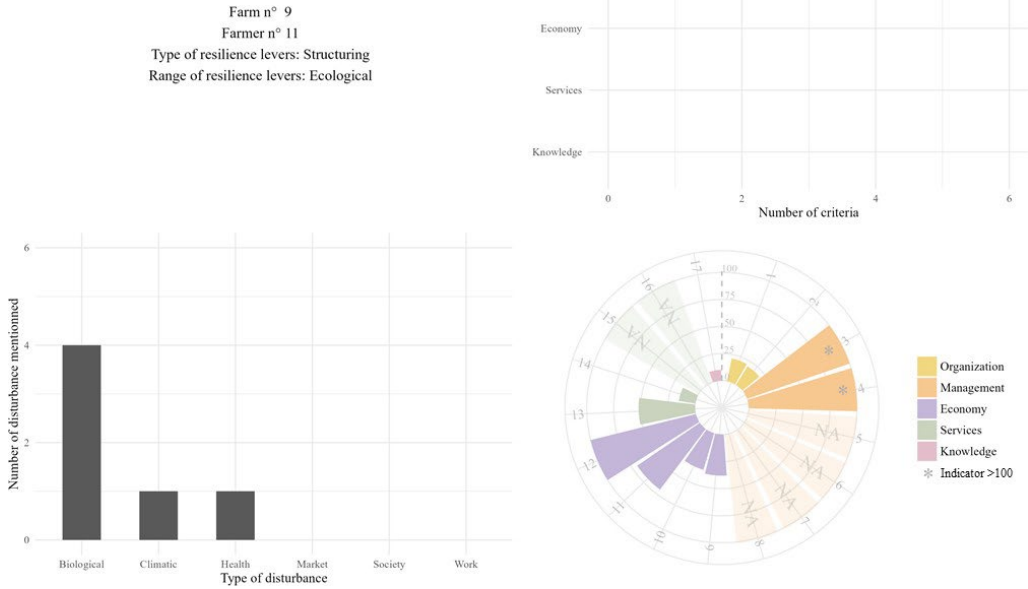


Figure 65. Results for Farm n° 9 – Farmer n° 11 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

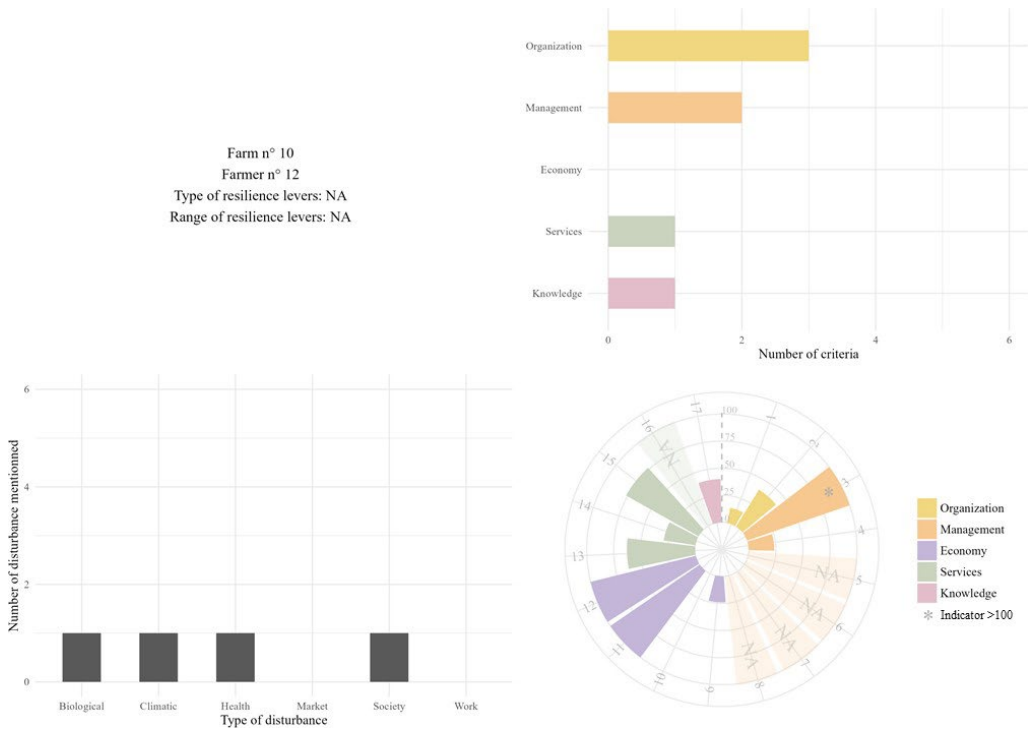


Figure 66. Results for Farm n° 10 – Farmer n° 12 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the



Transition

bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

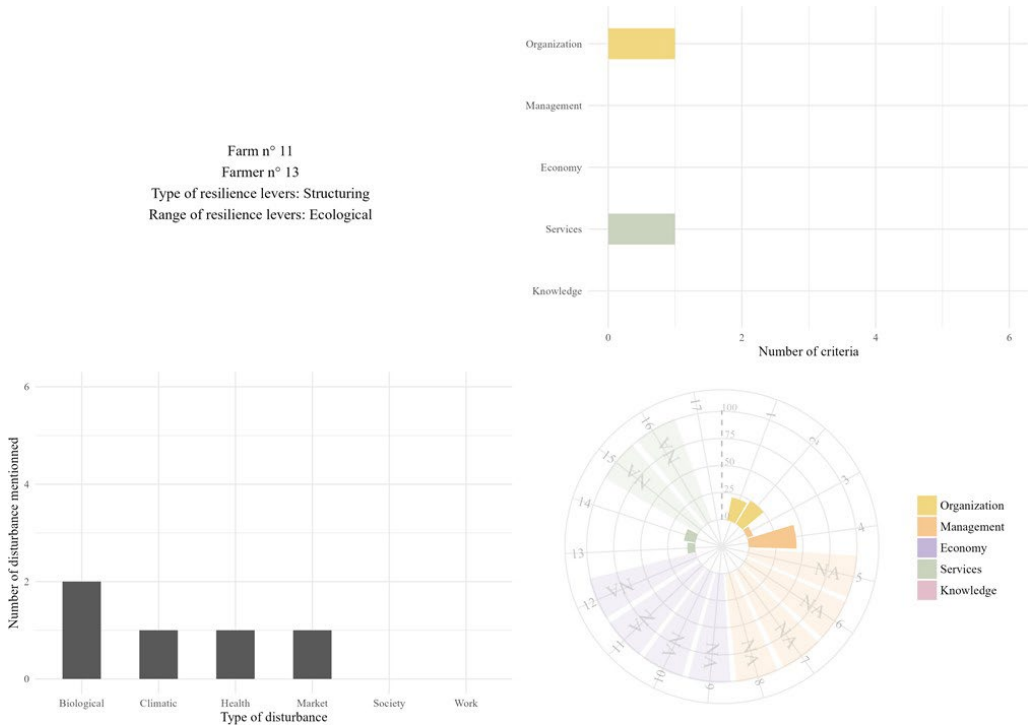


Figure 67. Results for Farm n° 11 – Farmer n° 13 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 12
Farmer n° 14
Type of resilience levers: Structuring
Range of resilience levers: Ecological

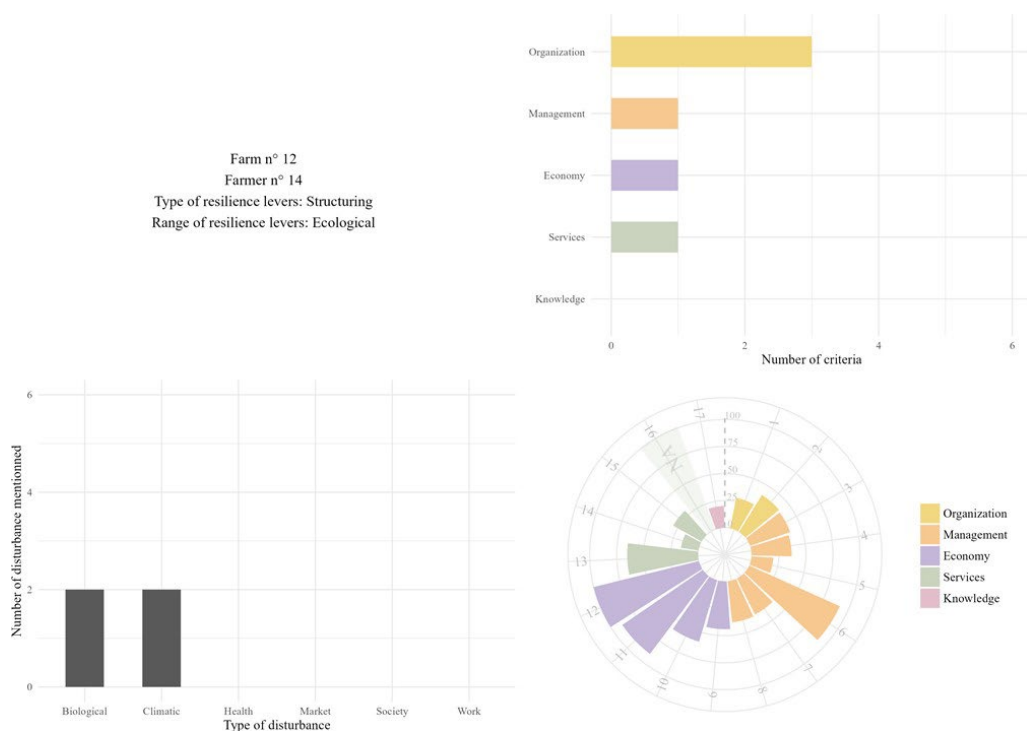


Figure 68. Results for Farm n° 12 – Farmer n° 14 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 13
Farmer n° 15
Type of resilience levers: Piloting
Range of resilience levers: Multidimensionnal

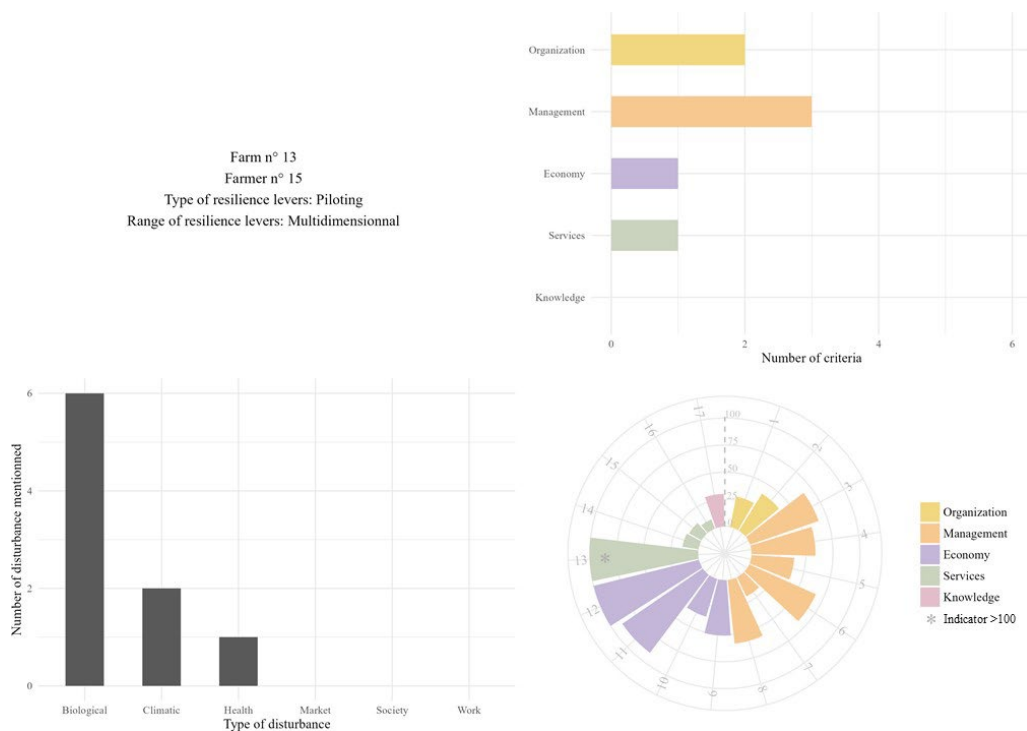


Figure 69. Results for Farm n° 13 – Farmer n° 15 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 14
Farmer n° 16
Type of resilience levers: Structuring
Range of resilience levers: Multidimensionnal

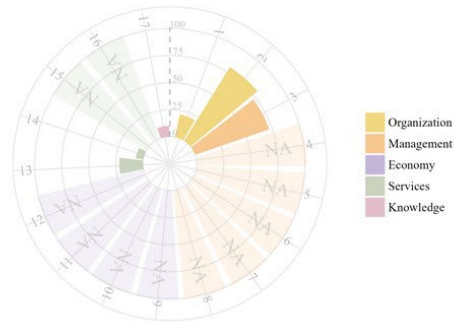
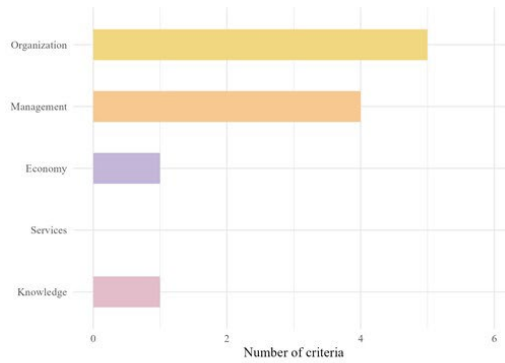
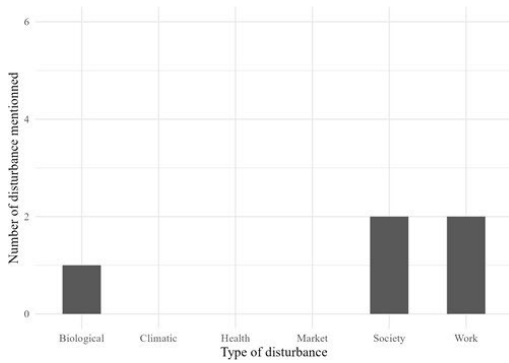


Figure 70. Results for Farm n° 14 – Farmer n° 16 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

Farm n° 15
Farmer n° 17
Type of resilience levers: Structuring
Range of resilience levers: Ecological

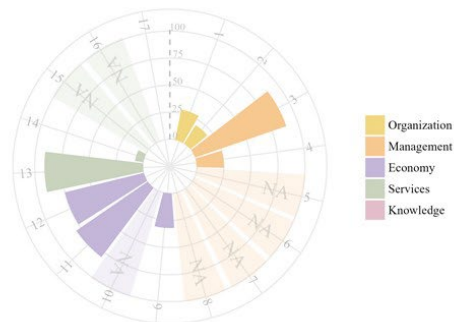
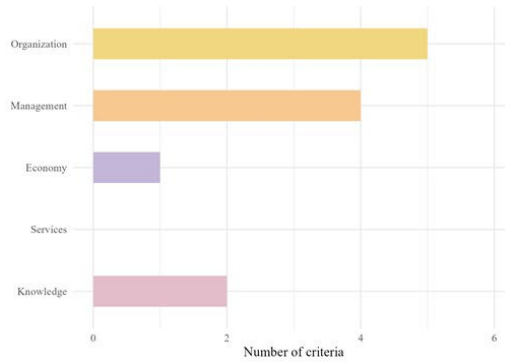
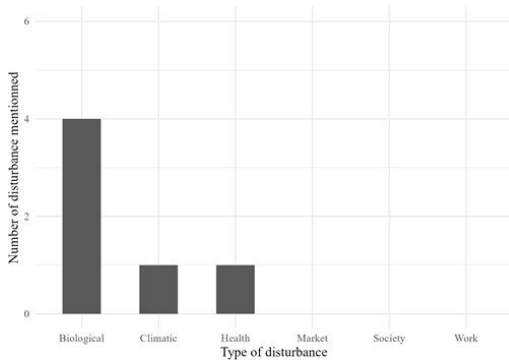


Figure 71. Results for Farm n° 15 – Farmer n° 17 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

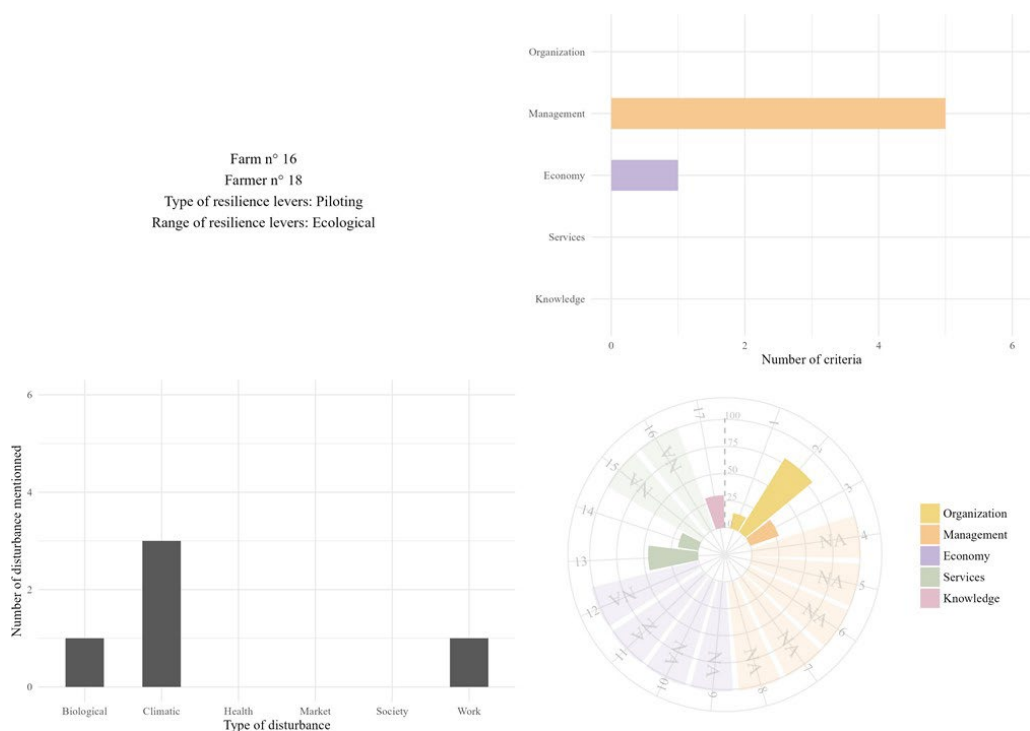


Figure 72. Results for Farm n° 16 – Farmer n° 18 represented by 3 graphs: (i) on the top right-hand corner the number of satisfaction criteria per component of satisfaction mentioned by the farmer, (ii) on the bottom left-hand corner the number of disturbances per category mentioned by the farmer and (iii) on the bottom right-hand corner the standardized values of the indicators.

6.3 Discussion

Due to the high heterogeneity of the data and the little time available for the analysis, it was not possible to perform an in-depth analysis of these figures. Nevertheless, concerning the two questions raised at the beginning of this document, the following observations were made:

1) How close is the current state of the farm from the satisfactory state?

A high number of satisfaction criteria in a component of satisfaction does not seem to be linked to a greater performance on the related resilience indicators. A great performance can also be observed on indicators that are not part of the satisfaction criteria.

2) Which parameters can be improved to buffer disturbances?

- High economy score seems to be associated with little mention of market disturbances;



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- Sometimes a high number of disturbances is associated with a low score of the related resilience indicator. It is the case for the farm 15 which witness a lot of biological disturbances and have little performance on ecosystem services provision indicators;

- Past disturbances can have been the source of improvement of some specific indicators. For instance, for the farm 1 a great score is observed on indicators related to collective organization and this farm had a great number of disturbances on this aspect in the past. These disturbances are now solved.

Therefore, this data would require a deeper analysis to be fully relevant. As such it can be used individually by farmers to identify how close is the current state of the farm from the satisfactory state and which parameters can be improved to buffer disturbances. It would have been very interesting as well to use this data as a basis for workshops about how to react to disturbances.



Transition









+37%

+45%

+47%

7. CONCLUSIONS

This deliverable has developed and applied a harmonized framework to compare innovative agroforestry and innovative cropping systems across 30 systems distributed in five Mediterranean regions.

Despite the agricultural, environmental and pedoclimatic differences among the five regions involved in the on-farm research, a general agreement emerges regarding the effects of agroforestry and innovative cropping systems on both system productivity and the provision of ecosystem services. In line with the resilience indicators defined in D1.2, soil-related indicators proved to be particularly sensitive to management and system complexity. Increases in soil organic matter content, identified in D1.2 as a core resilience indicator, were consistently observed in agroforestry and diversified systems, notably in the Spanish, Italian and Egyptian case. These results confirm the positive role of diversified systems in enhancing soil fertility, nutrient cycling and water-related soil functions.

Soil structure, aggregate stability and soil water holding capacity, also highlighted in D1.2

as key ecosystem service indicators, showed improvements or more stable values in systems with higher structural and biological complexity. Although some of these effects are expected to become more pronounced in the long term, the observed trends indicate an increased capacity of agroforestry and mixed systems to buffer climatic variability and reduce degradation processes, particularly under Mediterranean conditions.

With respect to productivity related indicators, yield stability and land use efficiency emerged as central elements of resilience. Generally, the more complex farming systems led to higher combined productivity compared to monocropping systems, as reflected by land equivalent ratio (LER) values above 1 in several case studies, particularly in Italy. These results demonstrate that agroforestry systems can maintain or enhance productivity while simultaneously delivering ecosystem services. In more constrained environments, such as the Algerian case studies, diversified systems showed a higher capacity to cope with adverse environmental and climatic conditions, supporting resilience through improved system robustness rather than yield maximisation alone.



Transition

Biodiversity related indicators, including floristic richness and cultivated species diversity, further reinforced the resilience potential of complex systems. Field assessments across French farms showed that the presence of cover crops, perennial species, trees and semi-natural elements increased plant diversity and soil cover, contributing to erosion control, biological regulation and long-term system stability, in accordance with the resilience framework defined in D1.2.

While the primary focus of WP2 was on biophysical and productivity indicators, the results also reflect key socio-economic resilience dimensions identified in D1.2, such as farm autonomy, product diversification and adaptive capacity. These aspects complement the measured ecosystem service indicators and highlight the systemic nature of resilience as the interaction between ecological functioning and farm-level decision-making.

Overall, the increased complexity of the observed agroforestry and mixed farming systems led to measurable improvements in soil fertility and land use efficiency, which are expected to contribute to greater stability of farm productivity over time. These findings highlight the relevance of diversified crop–tree combinations as adaptation strategies to climate change in the Mediterranean basin. However, further research based on long-term experiments is needed to consolidate observed trends and to quantify significant changes in soil properties and resilience indicators over extended time scales.

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9. ANNEXES

ANNEX 1. TELEPHONE SURVEY (INRAE)

Nom :

Date :

Questionnaire complémentaire

1. Avez-vous déjà fait des suivis des espèces d'oiseaux ?

Oui	Non
-----	-----

 Si oui, accepteriez-vous de nous les communiquer ?

Oui	Non
-----	-----

2. Avez-vous fait des suivis de chauves-souris ?

Oui	Non
-----	-----

 Si oui, accepteriez-vous de nous les communiquer ?

Oui	Non
-----	-----

3. Avez-vous des informations sur la quantité de matière organique contenue dans vos sols (mesures déjà réalisées par exemple) ?

Oui	Non
-----	-----

 Si oui, accepteriez-vous de nous les communiquer ?

Oui	Non
-----	-----

4. Concernant la diversité cultivée, indiquez le nombre de chacune des espèces que vous cultivez :

	Espèces maraichères	Fruitiers	Autres arbres (hors fruitiers)
202 1			
202 2			
202 3			

5. Liste exhaustive des activités source de revenus et % du revenu total provenant de cette activité :

Activité	% du revenu provenant de cette activité
é	



Transition

Maraichage	
Arboriculture	

6. Pouvez-vous nous indiquer combien de personnes travaillent avec vous selon les périodes de l'année et leur temps de travail approximatif (temps plein, mi-temps etc.)

Printemps
s : Mars
avril mai
Eté :
Juin
juillet
août
Automne :
septembre octobre
novembre
Hiver :
Décembre janvier
février

	Printemps	Eté	Automne	Hiver
Personne 1 (vous)				
Personne 2				
Personne 3				
Personne 4				
Personne 5				
Personne 6				
Personne 7				
Personne 8				

7. Concernant vos points de vente :

	Nom	Localisation	Loin ?	% de la production vendue par ce biais
1				
2				
3				
4				
5				



Transition

8. Concernant vos revenus au cours de l'année

	Printemps	Eté	Automne	Hiver
Répartition du revenu				
Est-ce suffisant ?				
Ecoulez-vous 100% de votre production ?				

9. Quelle part de vos revenus est dédiée au remboursement d'un prêt bancaire réalisé pour investirdans l'activité agricole ?

10. A quels ravageurs avez-vous été confronté ces 3 dernières années ?

11. Etes vous d'accord pour que les informations de ce formulaire soient diffusées de façon nonanonymisées ou préférez-vous qu'elles soient anonymisées ?



Transition

ANNEX 2. BIRDS SURVEYS (INRAE)

Liste des oiseaux entendus sur la ferme 1

Relevé effectué par Federico et Yanina Benedetti le 4 mai 2023 à 6h22 et 6h40

Nom français	Habitat	Nid	Régime alimentaire	Statut de protection enPACA en 2020
Bruant zizi	Milieux ouverts	Buissons	Granivore	Préoccupation mineure
<i>Chardonneret élégant</i>	Milieux ouverts	Buissons	Granivore	Préoccupation mineure
Choucas destours*	Milieux ouverts et anthropiques	Sous les toits	Omnivore	Préoccupation mineure
<u>Corneille noire</u> *	Généraliste	Arbre	Omnivore et opportuniste	Vulnérable
<u>Étourneau sansonnet</u> *	Généraliste	Cavernicole	Omnivore	Préoccupation mineure
<i>Fauvette à tête noire</i>	Généraliste	Buissons	Insectivore et frugivore	Préoccupation mineure
Fauvette grisette	Milieux ouverts	Buissons	Insectivore et frugivore	Préoccupation mineure
Merle noir	Généraliste	Buissons	Insectivore et frugivore	Préoccupation mineure
<i>Mésange charbonnière</i>	Généraliste	Cavernicole	Granivore	Préoccupation mineure
Pic épeichette	Forêts et haies	Cavernicole	Insectes du bois	Préoccupation mineure
<u>Pigeon ramier</u>	Généraliste	Buissons	Granivore	Préoccupation mineure
Pinson des arbres	Généraliste	Buissons	Granivore	Préoccupation mineure
<i>Rossignol philomèle</i>	Milieux fermés bas	Buissons	Insectivore	Quasi menacée
<i>Rougegorge familier</i>	Généraliste	Buissons	Insectivore	Préoccupation mineure
Serin cini	Milieux ouverts	Buissons	Granivore	Quasi menacée
<i>Tourterelle turque</i>	Milieux anthropiques	Buissons	Granivore	Préoccupation mineure

Souligné : espèce pouvant être problématique car peut être présente en grand nombre et occasionner des dégâts.

* : Espèce intéressante car consomme en grand nombre des ravageurs de culture.

Italique : espèce présente dans au moins 3 des 4 fermes étudiées.

Liste des oiseaux entendus sur la ferme 7

Relevé effectué par Federico et Yanina Benedetti le 5 mai 2023 à 6h42 et 7h05 et 8h07

Nom français	Habitat	Nid	Régime alimentaire	Statut de protection en PACA en 2020
<i>Chardonneret élégant</i>	Milieux ouverts	Buissons	Granivore	Préoccupation mineure
Choucas destours*	Milieux ouverts et milieux anthropiques	Sous les toits	Omnivore	Préoccupation mineure
<u>Corneille noire</u> *	Généraliste	Arbre	Omnivore et opportuniste	Vulnérable
<u>Étourneau sansonnet</u> *	Généraliste	Cavernicole	Omnivore	Préoccupation mineure
<i>Fauvette à tête noire</i>	Généraliste	Buissons	Insectivore et frugivore	Préoccupation mineure
Geai des chênes	Forêts et haies	Arbre	Omnivore	Préoccupation mineure
Huppe fasciée	Milieux ouverts	Cavernicole	Insectivore	Préoccupation mineure
Martinet noir*	Ciel	Sous les toits	Insectes volants	Quasi menacée
Merle noir	Généraliste	Buissons	Insectivore et frugivore	Préoccupation mineure
<i>Mésange charbonnière</i>	Généraliste	Cavernicole	Granivore	Préoccupation mineure
Milan noir*	Milieux ouverts	Arbre	Rongeurs et gros insectes	Annexe 1



Transition

Moineau domestique	Milieus anthropiques	Sous les toits	Granivore	Préoccupation mineure
Pic épeiche	Forêts et haies	Cavernicole	Insectes du bois	Préoccupation mineure
Pic vert	Forêts et haies	Cavernicole	Fourmis et larves du sol	Préoccupation mineure
Pie bavarde*	Milieus ouverts avec haies	Arbre	Omnivore	Préoccupation mineure
<u>Pigeon ramier</u>	Généraliste	Buissons	Granivore	Préoccupation mineure
Pouillot de Bonelli	Forêts et haies	Buissons	Insectivore	Préoccupation mineure
Rollier d'Europe*	Milieus ouverts	Cavernicole	Insectivore	Quasi menacée et annexe 1
Rosignol philomèle	Milieus fermés bas	Buissons	Insectivore	Quasi menacée
Rougegorge familier	Généraliste	Buissons	Insectivore	Préoccupation mineure
Serin cini	Milieus ouverts	Buissons	Granivore	Quasi menacée
Verdier d'Europe	Milieus ouverts	Buissons	Granivore	Vulnérable

Souligné : espèce pouvant être problématique car peut être présente en grand nombre et occasionner des dégâts

* : Espèce intéressante car consomme en grand nombre des ravageurs de culture.

Italique : espèce présente dans au moins 3 des 4 fermes étudiées.

Annexe 1: Liste des **espèces d'oiseaux portant désignation d'un site Natura 2000 en ZPS** (Zone de Protection Spéciale) et pour lesquelles il est **interdit leur mise à mort** ou leur **capture intentionnelle**, la **destruction ou le déplacement des nids et des oeufs** (même vides), leur **perturbation intentionnelle**, notamment en période de reproduction et de dépendance, leur détention.



Transition

ANNEX 3. SPANISH PILOT DATA COMPILATION

Apart from the results showed in the main text, further characterisation was done within each system. Such information helped to interpretate the results, to understand the system and to assess the global fertilisation state of the soil. Data was collected over two cropping seasons. During the first season, a full characterisation was performed, while in the second season some parameters were added or excluding according to the interest of evaluation compared to the first year.

Texture and density were intentionally done once as no changes were expected over two cropping seasons.

A3.1. Farm 01

Here below are placed the tables related to i) olive trees, ii) rows among olive trees cultivated mainly with sainfoins, iii) forest, and iv) rows among fruit trees (oldest part, offered to be sampled on the second cropping season).

i) Olive trees

Table 17. Average results from soil analysis under the canopy of olive trees (Farm 01) of the Spanish pilot at the end of the winter season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	---- YEAR 2023 ----		---- YEAR 2024 ----	
		Average	SE	Average	SE
pH	-	8.42	0.11	8.68	0.04
Electrical conductivity	µS/cm	185.78	24.88	99.05	3.39
Oxidable carbon	g/kg	5.23	0.21	12.30	0.60
Soil Organic Matter	%	2.62	0.43	2.45	0.21
Nitrate nitrogen	mg/kg	2.86	1.14	3.21	0.07
Ammonium-nitrogen	mg/kg	5.42	0.89	2.57	0.08
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	8.27	0.00	5.78	0.15
Soluble phosphorus	mg/kg	20.41	5.51	7.50	0.30
Total phosphorus	mg/kg	540.82	34.03	386.04	20.33
Interchangeable potassium	mg/kg	185.06	19.91	126.67	1.79
Total potassium	mg/kg	4546.85	175.52	4084.70	16.16
Calcium Carbonate Equivalent	%	35.11	3.78	31.68	0.53
Calcium	g/kg	129.75	6.47	150.46	3.66
Magnesium	g/kg	26.37	0.72	30.45	1.54
Sodium	g/kg	0.26	0.02	0.22	0.00
Copper	mg/kg	15.34	0.95	14.81	0.15
Zinc	mg/kg	42.85	2.02	44.29	0.52
Boron	mg/kg	33.68	7.47	-	-
Iron	g/kg	13.18	0.33	-	-
Manganese	g/kg	261.5	9.37	-	-



Transition

Sulphur	mg/kg	303.76	6.94	-	-
Water holding capacity	%	62.48	16.78	59.00	1.00
Density	g/cm ³	-	-	1.34	0.11
Texture	-	-	-	clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	2.75	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

ii) Rows among olive trees cultivated mainly with sainfoins

Table 18. Average results from soil analysis in rows among olive trees cultivates mainly with sainfoins (Farm 01) of the Spanish pilot at the end of the winter season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	YEAR 2023		---- YEAR 2024 ----	
		Average	SE	Average	SE
pH	-	8.54	0.18	8.58	0.08
Electrical conductivity	µS/cm	161.85	16.33	90.06	3.56
Oxidable carbon	mg/kg	13.81	1.84	10.59	0.29
Soil Organic Matter	%	2.80	0.16	2.05	0.02
Nitrate nitrogen	mg/kg	6.01	1.13	1.28	0.04
Ammonium-nitrogen	mg/kg	3.21	0.17	2.92	0.1
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	9.21	0.00	4.2	0.09
Soluble phosphorus	mg/kg	5.79	1.88	4.62	0.45
Total phosphorus	mg/kg	426.95	28.65	369.15	20.15
Interchangeable potassium	mg/kg	177.62	17.45	138.16	11.04
Total potassium	mg/kg	5.41	0.19	4487.34	225.54
Calcium Carbonate Equivalent	%	33.50	1.93	23.91	0.44
Calcium	g/kg	127.47	6.24	117.68	3.09
Magnesium	g/kg	26.84	0.88	27.89	0.80
Sodium	g/kg	0.25	0.01	0.19	0.00
Copper	mg/kg	18.44	2.18	21.25	0.4
Zinc	mg/kg	44.12	1.13	44.9	0.82
Boron	mg/kg	40.32	9.77	-	-
Iron	g/kg	15.08	0.57	-	-
Manganese	g/kg	304.83	12.37	-	-
Sulphur	mg/kg	262.52	31.28	-	-
Density	g/cm ³	66.68	11.04	1.41	0.06
Water holding capacity	%	-	-	56.00	1.00
Texture	-	-	-	clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	2.85	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

iii) Forest

Table 19. Average results from soil analysis in forest terraces (Farm 01) of the Spanish pilot at the end of the winter season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2023 ---		--- YEAR 2024 ---	
		Average	SE	Average	SE
pH	-	8,63	0,10	8,73	0,01
Electrical conductivity	µS/cm	150,13	7,94	100,48	4,53
Oxidable carbon	g/kg	6,25	0,06	13,46	0,55
Soil Organic Matter	%	2,61	0,03	2,51	0,03
Nitrate nitrogen	mg/kg	0,44	0,01	0,36	0,02
Ammonium-nitrogen	mg/kg	5,29	0,36	6,48	0,30
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	5,73	0,00	6,83	0,28
Soluble phosphorus	mg/kg	2,48	0,16	2,15	0,16
Total phosphorus	mg/kg	280,47	3,11	245,98	23,49
Interchangeable potassium	mg/kg	205,48	3,76	152,39	2,74
Total potassium	mg/kg	5293,05	75,34	4,68	0,10
Calcium Carbonate Equivalent	%	28,63	0,18	20,37	0,43
Calcium	g/kg	110,37	1,76	115,31	0,77
Magnesium	g/kg	28,62	0,28	32,44	1,47
Sodium	g/kg	0,30	0,03	0,23	0,01
Copper	mg/kg	16,40	0,24	17,59	0,53
Zinc	mg/kg	39,05	0,25	42,09	0,08
Boron	mg/kg	60,39	17,56	-	-
Iron	g/kg	13,52	0,17	-	-
Manganese	g/kg	271,86	4,21	-	-
Sulphur	mg/kg	242,71	0,41	-	-
Density	g/cm ³	59,56	12,31	1,14	0,11
Water holding capacity	%	-	-	62,00	1,00
Texture	-	-	-	sandy clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	2,89	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

iv) Rows among fruit trees (oldest part, offered to be sampled on the second cropping season)



Transition

Table 20. Average results from soil analysis in rows among fruit trees (Farm 01) of the Spanish pilot at the end of the winter season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	---- YEAR 2024 ----	
		Average	SE
pH	-	8.45	0.08
Electrical conductivity	µS/cm	118.90	12.38
Oxidable carbon	g/kg	16.03	1.06
Soil Organic Matter	%	3.06	0.02
Nitrate nitrogen	mg/kg	26.49	0.81
Ammonium-nitrogen	mg/kg	4.06	0.17
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	30.55	0.64
Soluble phosphorus	mg/kg	9.83	0.58
Total phosphorus	mg/kg	431.28	21.04
Interchangeable potassium	mg/kg	141.01	3.17
Total potassium	mg/kg	4745.40	183.00
Calcium Carbonate Equivalent	%	18.94	0.14
Calcium	g/kg	107.53	1.81
Magnesium	g/kg	27.85	1.58
Sodium	g/kg	0.22	0.01
Copper	mg/kg	21.40	0.22
Zinc	mg/kg	49.30	1.06
Density	g/cm ³	54.00	0.00
Water holding capacity	%	1.19	0.24
Texture	-	clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	2.62	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated



Transition

A3.2. Farm 02

Here below are placed the tables related to i) winter cereal, and ii) olive trees.

i) Winter cereal

Year 2022, plot 2 was not sampled as it was fertilised at the sampling time. Floristic richness and soil density were not evaluated as field was plough at sampling time.

Table 21. Average results from soil analysis in the winter cereal plots (Farm 02) of the Spanish pilot at the start of two autumn cropping seasons. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	----- YEAR 2022 -----		----- YEAR 2023 -----			
		PLOT 1		PLOT 1		PLOT 2	
		Average	SE	Average	SE	Average	SE
pH	-	8.45	0.02	7.94	0.11	8.03	0.03
Electrical conductivity	μS/cm	246	7.00	254.37	4.16	253.17	2.66
Oxidable carbon	g/kg	17.35	1.82	18.24	0.67	19.52	0.44
Soil Organic Matter	%	3.11	0.33	3.43	0.04	3.46	0.04
Nitrate nitrogen	mg/kg	17.80	0.66	41.62	1.41	39.73	0.65
Ammonium nitrogen	mg/kg	2.87	0.27	1.87	0.06	1.7	0.07
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	20.67	0.93	43.48	1.35	41.43	0.67
Soluble phosphorus	mg/kg	82.3	1.70	92.5	1.02	-	-
Total phosphorus	mg/kg	1019	91.00	1453.06	15.90	1317.32	38.45
Interchangeable potassium	mg/kg	461.7	2.30	-	-	-	-
Total potassium	mg/kg	3749.81	98.91	3603.19	245.59	4204.00	62.16
Calcium Carbonate Equivalent	%	42.70	4.70	46.72	2.49	34.23	0.89
Copper	mg/kg	56.5	0.50	73.34	0.21	49.98	0.42
Zinc	mg/kg	80.8	0.30	94.26	1.59	110.89	2.38
Boron	mg/kg	17.16	4.17	-	-	-	-



Transition

Manganese	g/kg	22.07	8.08	-	-	-	-
Water holding capacity	%	41	0.00	54.52	2.18	55.12	1.51
Texture	-	-	-	Sandy Clay Loam	n.a.	Sandy Loam	n.a
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	1.94	-	2.76	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

ii) Olive trees (under the canopy)

Table 22. Average results from soil analysis in olive tree plots (Farm 02) of the Spanish pilot at the start of two autumn cropping seasons. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	----- YEAR 2022 -----		----- YEAR 2023 -----			
		PLOT 1		PLOT 1		PLOT 2	
		Average	SE	Average	SE	Average	SE
pH	-	8.41	0.06	8.14	0.05	8.36	0.06
Electrical conductivity	µS/cm	198	1.00	172.9	3.18	135.87	8.23
Oxidable carbon	g/kg	1.83	0.15	14.94	0.36	14.62	0.60
Soil Organic Matter	%	3.77	0.03	2.57	0.06	2.52	0.10
Nitrate nitrogen	mg/kg	3.01	0.01	20.88	0.87	4.91	0.09
Ammonium nitrogen	mg/kg	2.66	0.07	1.61	0.15	1.22	0.08
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	5.67	0.06	22.49	1.00	6.13	0.04
Soluble phosphorus	mg/kg	31.3	2.50	47.11	3.92	34.12	1.42
Total phosphorus	mg/kg	517	10.00	774.21	5.00	609.81	17.41
Interchangeable potassium	mg/kg	216.9	0.80	-	-	-	-
Total potassium	mg/kg	3997.67	38.99	3270.48	58.51	3719.01	135.64



Transition

Calcium Carbonate Equivalent	%	34.10	0.20	41.86	1.38	38.35	0.76
Copper	mg/kg	110.3	1.30	85.06	0.88	68.44	1.73
Zinc	mg/kg	57.5	0.30	56.5	1.60	58.71	0.93
Boron	mg/kg	25.33	3.66	-	-	-	-
Manganese	g/kg	14.93	0.06	-	-	-	-
Density	g/cm ³	-	-	1.42	0.02	1.37	0.08
Water holding capacity	%	42.00	0.00	47.31	2.15	52.59	1.82
Texture	-	-	-	Sandy Loam	n.a.	Sandy Loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	2.65	-	1.35	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated



Transition

A3.3. Farm 03

Here below are placed the tables related to i) vineyard rows managed on conventional; ii) vineyard agroforestry system (VAFS), sampled between grapevine; iii) VAFS sampled rows sowed with cover crop; and iv) VAF sampled rows with spontaneous vegetation.

i) vineyard rows managed on conventional

Table 23. Average results from soil analysis in vineyard agroforestry system (Farm 03) of the Spanish pilot at end of autumn season. Samples were collected from grapevine rows. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.49	0.02	8.36	0.05
Electrical conductivity	µS/cm	225.00	14.00	204.27	2.73
Oxidable carbon	g/kg	1.71	0.31	17.34	0.65
Soil Organic Matter	%	2.82	0.17	3.00	0.14
Nitrate nitrogen	mg/kg	-	-	43.79	0.39
Ammonium nitrogen	mg/kg	-	-	1.52	0.10
Total nitrogen	mg/kg	29.60	0.96	45.31	0.46
Soluble phosphorus	mg/kg	65.08	5.86	71.06	1.93
Total phosphorus	mg/kg	1648.00	106.00	1586.80	64.26
Interchangeable potassium	mg/kg	369.00	8.00	144.16	4.07
Total potassium	mg/kg	3202.44	338.75	2714.43	43.73
Calcium Carbonate Equivalent	%	26.60	0.30	23.71	0.64
Calcium	g/kg	-	-	135.27	5.21
Magnesium	g/kg	-	-	9.17	0.13
Sodium	mg/kg	-	-	353.69	5.02
Copper	mg/kg	35.10	1.30	26.00	1.73
Zinc	mg/kg	127.70	5.70	118.64	0.71
Boron	mg/kg	15.49	3.07	-	-
Manganese	g/kg	21.75	0.71	-	-
Density	g/cm ³	-	-	1.32	0.06
Water holding capacity	%	47.9	0.02	43.97	1.11
Texture	-	-	-	Clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	0.9	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated



Transition

ii) Vineyard rows managed on conventional

Table 24. Average results from soil analysis in vineyard agroforestry system (Farm 03) of the Spanish pilot at end of autumn season. Samples were collected from vineyard rows managed on conventional. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.33	0.05	8.38	0.05
Electrical conductivity	µS/cm	298.00	5.00	212.73	3.70
Oxidable carbon	g/kg	14.90	0.39	15.45	0.91
Soil Organic Matter	%	2.36	0.15	2.88	0.05
Nitrate nitrogen	mg/kg	51.44	2.15	38.46	1.75
Ammonium nitrogen	mg/kg	1.83	0.26	1.13	0.10
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	52.57	1.91	39.59	1.69
Soluble phosphorus	mg/kg	67.80	3.80	60.82	0.67
Total phosphorus	mg/kg	1137.00	62.00	1415.99	124.68
Interchangeable potassium	mg/kg	297.90	10.00	396.00	12.55
Total potassium	mg/kg	1887.15	1353.62	2198.82	39.38
Calcium Carbonate Equivalent	%	36.28	1.20	17.18	1.26
Calcium	g/kg	-	-	139.10	5.10
Magnesium	g/kg	-	-	8.89	0.27
Sodium	mg/kg	-	-	298.14	7.19
Copper	mg/kg	30.30	0.50	21.12	1.01
Zinc	mg/kg	85.10	4.20	93.13	0.99
Boron	mg/kg	12.50	9.65	-	-
Manganese	g/kg	13.42	9.51	-	-
Density	g/cm ³	-	-	1.45	0.05
Water holding capacity	%	37.40	0.01	41.82	0.74
Texture	-	-	-	Sandy clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	0.33	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

iii) Vineyard rows sowed with cover crop

Table 25. Average results from soil analysis in vineyard agroforestry system (Farm 03) of the Spanish pilot at end of autumn season. Samples were collected from the rows sowed with cover crop. Average and Standard Errors (SE) values were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8,34	0,01	8,58	0,07
Electrical conductivity	µS/cm	365,00	28,00	152,20	4,16



Transition

Oxidable carbon	g/kg	15,75	1,58	15,39	0,45
Soil Organic Matter	%	2,18	0,38	2,78	0,02
Nitrate nitrogen	mg/kg	-	-	15,98	0,23
Ammonium nitrogen	mg/kg	-	-	0,96	0,12
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	84,44	0,74	16,95	0,12
Soluble phosphorus	mg/kg	53,90	1,77	65,89	3,11
Total phosphorus	mg/kg	1115,00	65,00	1262,71	50,48
Interchangeable potassium	mg/kg	323,90	7,30	315,76	3,21
Total potassium	mg/kg	2512,50	150,62	2166,82	111,93
Calcium Carbonate Equivalent	%	31,90	0,10	31,33	0,34
Calcium	g/kg	-	-	136,16	6,82
Magnesium	g/kg	-	-	9,66	0,27
Sodium	mg/kg	-	-	302,89	1,51
Copper	mg/kg	28,00	0,30	28,72	0,52
Zinc	mg/kg	88,60	2,60	95,97	1,38
Boron	mg/kg	7,98	1,64	-	-
Manganese	g/kg	20,28	0,10	-	-
Density	g/cm ³	-	-	1,40	0,09
Water holding capacity	%	45,00	0,00	44,75	0,26
Texture	-	-	-	Loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	0,66	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated

iv) Vineyard rows with spontaneous vegetation.

Table 26. Average results from soil analysis in vineyard agroforestry system (Farm 03) of the Spanish pilot at end of autumn season. Samples were collected from the rows covered with spontaneous vegetation. Average and Standard Errors (SE) values were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8,36	0,04	8,67	0,05
Electrical conductivity	µS/cm	294,00	14,00	188,27	4,29
Oxidable carbon	g/kg	15,48	1,03	14,80	0,29
Soil Organic Matter	%	2,47	0,14	3,18	0,29
Nitrate nitrogen	mg/kg	-	-	43,19	0,79
Ammonium nitrogen	mg/kg	-	-	1,78	0,08
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg		0,38	44,96	0,72
Soluble phosphorus	mg/kg	78,23	0,28	55,96	1,48
Total phosphorus	mg/kg	1196,00	106,00	1134,95	41,08
Interchangeable potassium	mg/kg	350,70	2,60	370,19	9,55
Total potassium	mg/kg	2865,08	96,43	2121,83	95,82
Calcium Carbonate Equivalent	%	33,60	0,50	30,19	0,43



Transition

Calcium	g/kg	-	-	133,59	6,77
Magnesium	g/kg	-	-	9,04	0,12
Sodium	mg/kg	-	-	306,88	19,49
Copper	mg/kg	29,20	0,70	28,53	0,97
Zinc	mg/kg	88,30	2,20	91,83	1,96
Boron	mg/kg	17,43	5,18	-	-
Manganese	g/kg	20,24	0,36	-	-
Density	g/cm ³	-	-	1,42	0,07
Water holding capacity	%	41,00	0,01	41,94	1,25
Texture	-	-	-	Sandy clay loam	n.a.
Basal respiration (MBRA)	µgCO ₂ /g h	-	-	0,49	-

n.a. not applicable to the analysis

MBRA: Microbial Basal Respiration Accumulated



Transition

A3.4. Farm 04

Here below are placed the tables related to the innovative crop the perennial cereal Kernza®.

Table 27. Average results from soil analysis in the innovative crop the perennial cereal Kernza® (Farm 04) of the Spanish pilot at the beginning of summer season. Average and Standard Errors (SE) values were obtained from three replicates and composite samples.

Parameter	Units	- sowed 2022 -		- sowed 2021 -		- pre-sowing 2021 -	
		Average	SE	Average	SE	Average	SE
pH	-	7,53	0,83	8,18	0,09	8,13	0,22
Electrical conductivity	µS/cm	139,17	21,52	200,18	18,51	291,38	13,36
Oxidable carbon	g/kg	18,04	1,84	24,40	2,88	21,83	3,62
Soil Organic Matter	%	3,10	0,32	4,20	0,50	3,75	0,62
Nitrate nitrogen	mg/kg	46,69	23,39	21,40	1,54	46,75	35,00
Ammonium nitrogen	mg/kg	4,43	0,90	5,42	2,43	4,67	1,99
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	51,12	23,35	26,82	3,51	71,72	15,48
Soluble phosphorus	mg/kg	97,46	16,78	77,79	8,75	68,93	17,88
Total phosphorus	mg/kg	1077,31	208,09	-	-	-	-
Interchangeable potassium	mg/kg	426,95	65,24	-	-	-	-
Total potassium	mg/kg	-	-	2781,59	240,53	2983,01	226,75
Total Carbon (CHN)	%	6,50	0,44	6,87	0,09	6,92	0,25
Total Nitrogen (CHN)	%	0,28	0,02	0,23	0,03	0,22	0,04
C/N ratio	-	23,61	2,74	30,57	3,79	32,50	4,90
Density	g/cm ³	1,23	0,04	1,32	0,14	-	-
Biomass	g/m ²	-	-	1069,52	34,48	982,64	176,68
Grain yield per spike	g grain/g spike	-	-	-	-	0,51	0,02
Productivity	kg grain/ha	-	-	-	-	765,60	122,04



Transition

A3.5. Farm 05

Here below are placed the tables related to the different components of the farm i) vineyard without cover crop; ii) vineyard rows without cover crop (bare soil); iii) vineyard with cover crop; iv) vineyard rows with natural cover crop; v) multifunctional field margins; vi) managed forest; vii) olive trees under canopy; and viii) olive trees in the cover crop out of the canopy.

i) Vineyard without cover crop

Table 28. Average results from soil analysis in vineyard without cover crop (Farm 05) of the Spanish pilot at end of autumn season. Samples were collected from grapevine rows. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.47	0.01	8.48	0.04
Electrical conductivity	µS/cm	271	16.00	223.33	6.67
Oxidable carbon	g/kg	18.1	1.85	19.49	0.51
Soil Organic Matter	%	1.84	0.08	3.69	0.06
Nitrate nitrogen	mg/kg	-	-	26.88	0.86
Ammonium nitrogen	mg/kg	-	-	3.10	0.03
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	31.69	0.54	29.99	0.83
Soluble phosphorus	mg/kg	38.03	2.28	8.16	0.19
Total phosphorus	mg/kg	383	14.00	293.01	3.87
Interchangeable potassium	mg/kg	349.8	7.70	142.03	6.13
Total potassium	mg/kg	4701.99	57.51	3106.74	53.86
Calcium Carbonate Equivalent	%	57.9	0.80	50.88	0.64
Calcium	g/kg	-	-	236.47	3.38
Magnesium	g/kg	-	-	3.47	0.16
Sodium	mg/kg	-	-	715.84	90.94
Copper	mg/kg	44.6	0.60	26.11	1.53
Zinc	mg/kg	31.6	0.30	43.46	0.75
Boron	mg/kg	39.54	8.87	-	-
Manganese	g/kg	13.08	0.17	-	-
Density	g/cm ³	-	-	1.21	0.04
Water holding capacity	%	36.7	0.01	0.42	0.01
Texture	-	-	-	Sandy clay loam	n.a.

n.a. not applicable to the analysis

ii) Vineyard rows without cover crop (bare soil)

Table 29. Average results from soil analysis in vineyard without cover crop (Farm 05) of the Spanish pilot at end of autumn season. Samples were collected from the rows without cover crop (bare soil). Averages and Standard Errors (SE) were obtained from three replicates and composite samples.



Transition

Parameter	Units	--- YEAR 2023 ---	
		Average	SE
pH	-	8.36	0.04
Electrical conductivity	µS/cm	266.07	2.79
Oxidable carbon	g/kg	23.01	0.22
Soil Organic Matter	%	4.26	0.04
Nitrate nitrogen	mg/kg	40.55	2.46
Ammonium nitrogen	mg/kg	1.94	0.32
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	42.49	2.19
Soluble phosphorus	mg/kg	6.69	0.57
Total phosphorus	mg/kg	281.68	9.10
Interchangeable potassium	mg/kg	143.73	2.63
Total potassium	mg/kg	3061.59	128.66
Calcium Carbonate Equivalent	%	40.4	0.52
Calcium	g/kg	223.96	6.84
Magnesium	g/kg	3.55	0.08
Sodium	mg/kg	639.04	27.74
Copper	mg/kg	25.21	0.36
Zinc	mg/kg	43.52	2.05
Density	g/cm ³	1.26	0.05
Water holding capacity	%	0.46	0.01
Texture	-	Sandy loam	n.a.

n.a. not applicable to the analysis

iii) Vineyard with cover crop

Table 30. Average results from soil analysis in vineyard with cover crop (Farm 05) of the Spanish pilot at end of autumn season. Samples were collected from grapevine rows. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.42	0.05	8.57	0.04
Electrical conductivity	µS/cm	220.00	22.00	201.87	0.49
Oxidable carbon	g/kg	1.23	0.36	15.56	0.36
Soil Organic Matter	%	1.64	0.08	2.93	0.07
Nitrate nitrogen	mg/kg	7.90	6.84	14.03	0.46
Ammonium nitrogen	mg/kg	-	-	3.10	0.31
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	10.74	6.95	17.13	0.76
Soluble phosphorus	mg/kg	26.06	2.70	32.40	2.88
Total phosphorus	mg/kg	374.00	8.00	637.63	18.91
Interchangeable potassium	mg/kg	459.10	6.10	465.63	6.30
Total potassium	mg/kg	5392.97	96.56	4529.00	105.74



Transition

Calcium Carbonate Equivalent	%	48.40	0.50	39.10	1.32
Calcium	g/kg	-	-	196.73	2.82
Magnesium	g/kg	-	-	6.24	0.08
Sodium	mg/kg	-	-	772.38	50.79
Copper	mg/kg	35.30	1.40	47.20	1.44
Zinc	mg/kg	34.00	0.40	51.82	1.31
Boron	mg/kg	44.22	9.88	-	-
Manganese	g/kg	15.55	0.46	-	-
Density	g/cm ³	-	-	1.26	0.06
Water holding capacity	%	43.30	0.01	45.00	0.00
Texture	-	-	-	sandy clay loam	n.a.

n.a. not applicable to the analysis

iv) Vineyard rows with natural cover crop

Table 31. Average results from soil analysis in vineyard rows with natural cover crop (Farm 05) of the Spanish pilot at end of autumn season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.57	0.03	8.53	0.04
Electrical conductivity	μS/cm	188.00	5.00	176.07	5.46
Oxidable carbon	g/kg	10.68	0.65	12.86	0.13
Soil Organic Matter	%	1.45	0.23	2.56	0.03
Nitrate nitrogen	mg/kg	-	-	9.64	0.16
Ammonium nitrogen	mg/kg	-	-	2.86	0.48
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	13.15	0.13	12.50	0.63
Soluble phosphorus	mg/kg	20.36	1.08	21.85	1.32
Total phosphorus	mg/kg	365.00	16.00	525.82	26.94
Interchangeable potassium	mg/kg	288.60	0.80	314.35	9.22
Total potassium	mg/kg	4886.45	246.40	4441.41	39.63
Calcium Carbonate Equivalent	%	52.30	1.20	39.30	1.27
Calcium	g/kg	-	-	198.82	4.72
Magnesium	g/kg	-	-	5.91	0.16
Sodium	mg/kg	-	-	781.50	15.71
Copper	mg/kg	43.10	0.70	47.41	1.50
Zinc	mg/kg	34.80	0.80	49.23	1.53
Boron	mg/kg	42.00	11.90	-	-
Manganese	g/kg	14.95	0.25	-	-
Density	g/cm ³	-	-	1.17	0.18
Water holding capacity	%	38.20	0.01	39.00	0.00
Texture	-	-	-	clay loam	n.a.

n.a. not applicable to the analysis



Transition

v) Multifunctional field margins

Table 32. Average results from soil analysis in multifunctional field margins (Farm 05) of the Spanish pilot at end of autumn season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.32	0.03	8.56	0.03
Electrical conductivity	µS/cm	184.00	22.00	128.37	0.67
Oxidable carbon	g/kg	17.53	0.40	20.91	0.41
Soil Organic Matter	%	2.27	0.43	3.78	0.08
Nitrate nitrogen	mg/kg	2.68	0.16	1.80	0.01
Ammonium nitrogen	mg/kg	4.97	0.38	4.57	0.14
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	7.65	0.26	6.37	0.14
Soluble phosphorus	mg/kg	4.95	0.34	2.58	1.32
Total phosphorus	mg/kg	154.00	8.00	344.19	31.07
Interchangeable potassium	mg/kg	217.70	10.60	136.83	17.64
Total potassium	mg/kg	4308.60	82.20	3622.98	122.35
Calcium Carbonate Equivalent	%	52.50	1.50	44.33	0.78
Calcium	g/kg	-	-	234.83	10.38
Magnesium	g/kg	-	-	4.05	0.15
Sodium	mg/kg	-	-	689.33	35.05
Copper	mg/kg	37.00	1.20	35.72	1.16
Zinc	mg/kg	32.40	0.70	45.54	3.01
Boron	mg/kg	27.89	4.84	-	-
Manganese	g/kg	15.13	0.18	-	-
Density	g/cm ³	-	-	1.12	0.08
Water holding capacity	%	34.40	0.02	0.47	0.01
Texture	-	-	-	sandy clay loam	n.a.

n.a. not applicable to the analysis

vi) Managed forest

Table 33. Average results from soil analysis in managed forest (Farm 05) of the Spanish pilot at end of autumn season. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.22	0.01	8.25	0.06
Electrical conductivity	µS/cm	302.00	5.00	233.63	2.14
Oxidable carbon	g/kg	51.40	0.70	47.09	1.60



Transition

Soil Organic Matter	%	7.64	1.19	8.85	0.17
Nitrate nitrogen	mg/kg	-	-	2.01	0.07
Ammonium nitrogen	mg/kg	-	-	3.94	0.20
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	8.65	0.44	5.96	0.15
Soluble phosphorus	mg/kg	-	-	4.46	0.28
Total phosphorus	mg/kg	60.90	0.00	242.69	2.43
Interchangeable potassium	mg/kg	133.00	3.30	135.01	4.89
Total potassium	mg/kg	3666.50	117.82	2752.56	148.15
Calcium Carbonate Equivalent	%	39.90	1.80	32.83	0.14
Calcium	g/kg	-	-	202.49	16.61
Magnesium	g/kg	-	-	3.14	0.03
Sodium	mg/kg	-	-	734.51	72.96
Copper	mg/kg	19.40	0.20	14.12	2.44
Zinc	mg/kg	40.40	0.70	48.53	0.67
Boron	mg/kg	26.33	0.47	-	-
Manganese	g/kg	24.19	4.28	-	-
Density	g/cm ³	-	-	0.72	0.08
Water holding capacity	%	47.70	0.01	0.60	0.02
Texture	-	-	-	sandy loam	n.a.

n.a. not applicable to the analysis

vii) Olive trees with cover crop (under canopy)

Table 34. Average results from soil analysis in Olive trees with cover crop (Farm 05) of the Spanish pilot at end of autumn season. Samples were collected under the tree canopy. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	----- YEAR 2023 -----	
		Average	SE
pH	-	8.58	0.03
Electrical conductivity	µS/cm	165.00	7.37
Oxidable carbon	g/kg	21.49	1.94
Soil Organic Matter	%	3.96	0.04
Nitrate nitrogen	mg/kg	11.25	0.21
Ammonium nitrogen	mg/kg	1.66	0.07
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	12.92	0.27
Soluble phosphorus	mg/kg	53.24	2.63
Total phosphorus	mg/kg	697.15	45.01
Interchangeable potassium	mg/kg	261.57	5.78
Total potassium	mg/kg	3166.56	212.96
Calcium Carbonate Equivalent	%	44.40	1.93
Calcium	g/kg	225.19	7.85
Magnesium	g/kg	4.17	0.16





Transition

Sodium	mg/kg	694.96	26.40
Copper	mg/kg	51.95	0.84
Zinc	mg/kg	56.82	3.30
Density	g/cm ³	0.99	0.11
Water holding capacity	%	44.00	0.00
Texture	-	Sandy clay loam	n.a.

n.a. not applicable to the analysis

viii) Olive trees with cover crop (out of the canopy)

Table 35. Average results from soil analysis in Olive trees with cover crop (Farm 05) of the Spanish pilot at end of autumn season. Samples were collected out of the tree canopy. Averages and Standard Errors (SE) were obtained from three replicates and composite samples.

Parameter	Units	--- YEAR 2022 ---		--- YEAR 2023 ---	
		Average	SE	Average	SE
pH	-	8.36	0.08	8.49	0.03
Electrical conductivity	µS/cm	254.00	10.00	172.03	6.77
Oxidable carbon	g/kg	28.60	2.05	24.26	1.57
Soil Organic Matter	%	4.95	0.78	4.54	0.06
Nitrate nitrogen	mg/kg	-	-	7.56	0.31
Ammonium nitrogen	mg/kg	-	-	4.92	0.52
Total nitrogen (NO ₃ -N + NH ₄ -N)	mg/kg	18.19	0.15	12.48	0.35
Soluble phosphorus	mg/kg	57.06	1.99	57.62	3.46
Total phosphorus	mg/kg	739.00	81.00	825.00	26.16
Interchangeable potassium	mg/kg	443.70	10.30	383.71	60.65
Total potassium	mg/kg	5401.86	26.82	3618.17	37.17
Calcium Carbonate Equivalent	%	43.20	1.10	45.31	0.94
Calcium	g/kg	-	-	207.25	3.68
Magnesium	g/kg	-	-	4.10	0.05
Sodium	mg/kg	-	-	689.82	6.52
Copper	mg/kg	90.10	0.80	93.96	0.63
Zinc	mg/kg	49.70	0.40	57.84	1.96
Boron	mg/kg	32.00	3.68	-	-
Manganese	g/kg	16.44	0.23	-	-
Density	g/cm ³	-	-	0.97	0.08
Water holding capacity	%	47.40	0.02	43.00	0.00
Texture	-	-	-	sandy clay loam	n.a.

n.a. not applicable to the analysis



Transition

ANNEX 4. Modelling results (UNICT)

A4.1. Modelling of productivity in AF systems

Materials and methods

The study aims to evaluate the productivity and the solar radiation interception of an agroforestry systems comprising olive trees and herbaceous crops, namely durum wheat (*Triticum durum*), common wheat (*T. estivum*), rye (*Secale cereale*) and fava bean (*Vicia faba*).

The field trials were carried out during the 2022-2023 and 2023-2024 growing season in a 4-year-old olive grove with trees spaced 5.5 m between the rows and 5 m along the row (Figure 1) located on a mountainous site (970m a.s.l.) in Sicily (Italy). The rows of trees were aligned along the East-West axis.

Location: Nicolosi, Catania, Italy

- Climate eco-region: Adriatic Sea & Central Mediterranean Mixed Forests (PA19)
- Altitude: 660 m asl
- Rainfall: 1060 mm per year
- Soil main characteristics: Texture: sandy; soil classification: Xerandt typic (USDA, 2014)

The winter cereals used for the trials were a durum wheat (*T. durum*) landrace (*Timilia*) a common wheat (*T. aestivum*) evolutionary population (Mixwheat) and rye (*S. cereale*) variety (Irmanu).

The herbaceous crops were sown on a 4.5 m strip between two adjacent rows of trees and in an adjacent field as monocropping control. The sowing of the herbaceous crops took place in January 2023.

The amount of photosynthetically active radiation (PAR) intercepted by the trees and the crops was measured using the ACCUPAR LP-80 PAR/LAI Ceptometer at two different heights above the ground (below the tree canopy and below the herbaceous crop canopy) in several positions between the rows of trees, described by two factors: position and strip.



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The Leaf Area Index (LAI) has been calculated on the basis of the amount of intercepted PAR.

The positions were

- On the North side of a tree (position Under)
- On the North side of the inter-row gap (position Between)

The strips were

- The 1.5 m wide strip on the South side of the row of trees (Strip 1)
- The middle 1.5 m wide strip (Strip 2)
- The 1.5 m wide strip on the North side of the row of trees (Strip 3)

Biomass and grain yield has been measured for all the combination of position and strips.

A subset of the observed data concerning LAI, biomass and grain yield has been used to calibrate the crop parameters of a model developed using R CRAN software (R Core Team, 2021).

Results

Observed and predicted Leaf Area Index (LAI) values for Mixwheat and rye showed clear spatial variability within the olive-based agroforestry system, associated with both position relative to the tree row (Under vs. Between) and strip location (south, middle, and north of the tree line) (Figure 1).

For Mixwheat, the highest observed LAI values were generally recorded in the *Between* positions, particularly in Strip 1 (south side) and Strip 2 (middle strip), where LAI exceeded 2.5. In contrast, LAI was consistently lower in the *Under* positions across all strips, with the strongest reduction observed in Strip 3 (north side). This pattern suggests a progressive decrease in canopy development moving from the south-facing to the north-facing side of the tree row, likely reflecting increasing shading intensity. Predicted LAI values closely followed the observed trends, although a slight underestimation was apparent in the highest LAI conditions, especially in the *Between* positions of Strips 1 and 2.



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In rye, LAI values were overall higher than those observed for Mixwheat, particularly in Strip 2, where both observed and predicted LAI reached their maximum in the *Between* position. Unlike Mixwheat, rye maintained relatively high LAI values even in *Under* positions of Strips 1 and 2, indicating a greater tolerance to reduced light availability. However, as observed for Mixwheat, LAI declined in Strip 3, especially under the tree canopy. Model predictions for rye showed a good agreement with observed data across most positions, with minor discrepancies in the *Under* position of Strip 1, where predicted LAI exceeded observed values.

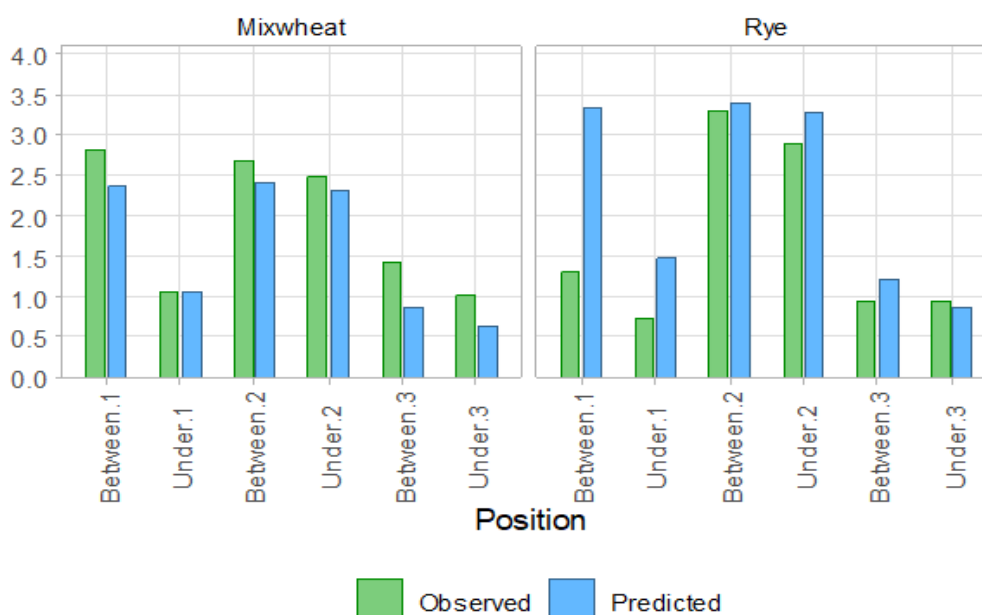


Figure 1 Observed and predicted values of Leaf Area Index (LAI) during 2023 for Mixwheat and rye in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.

In 2024, both Mixwheat and rye exhibited marked spatial variability in Leaf Area Index (LAI) across strips and positions within the agroforestry system (Figure 2). For Mixwheat, observed LAI values were generally higher in the *Between* positions compared with the *Under* positions across all strips. The highest LAI values were recorded in Strip 2 (middle strip), whereas a pronounced reduction was observed in Strip 3 (north side), particularly under the tree canopy. This confirms a strong negative effect of proximity to the tree row combined with the north-facing orientation on crop canopy development. Predicted LAI values captured the overall spatial pattern but tended to slightly overestimate LAI in the



Transition

Between positions of Strips 1 and 2, while underestimating the reduction observed in the most shaded *Under* positions.

For rye, LAI values were consistently higher than those of Mixwheat across most spatial configurations. Observed LAI peaked in the *Between* position of Strip 2, while remaining comparatively low in *Under* positions, especially in Strip 3. The difference between *Between* and *Under* positions was more pronounced for rye than for Mixwheat in 2024. Model predictions reproduced the relative ranking of strips and positions but systematically overestimated LAI for rye, particularly in the *Between* positions, indicating a tendency of the model to overpredict canopy development under higher light availability.

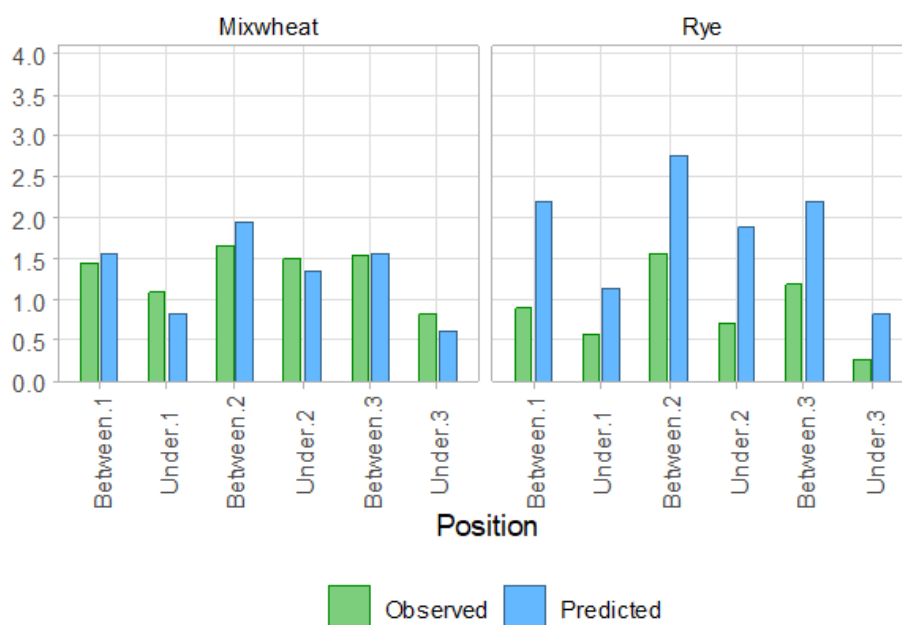


Figure 2
Observed and predicted values of Leaf Area Index (LAI) during 2024 for Mixwheat and rye in the strip at

the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.

Overall, the results highlight a strong interaction between crop species, distance from the tree row, and canopy position, confirming that tree-induced light gradients significantly influence crop canopy development. The close correspondence between observed and predicted LAI values across species and spatial configurations indicates that the calibrated model adequately captured the effects of spatial heterogeneity in light interception within the agroforestry system.



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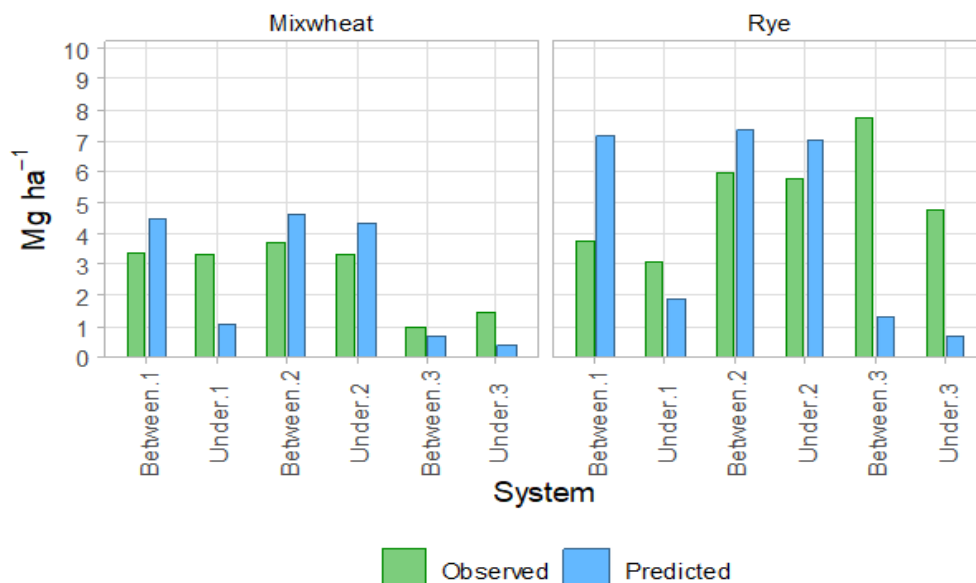
Biomass yield showed strong spatial variability in response to position and strip for both crops (Figure 3), reflecting the combined effects of light interception and crop species characteristics.

For Mixwheat, observed biomass yield was highest in the *Between* positions of Strips 1 and 2, reaching values close to 4 Mg ha⁻¹, while yields declined sharply in Strip 3, particularly under the tree canopy. Biomass production in *Under* positions was consistently lower than in *Between* positions across all strips, indicating a clear negative effect of tree proximity. Predicted biomass generally followed the same spatial trends but tended to overestimate yields in high-performing positions and underestimate yields in the most shaded conditions, especially in Strip 3.

In rye, observed biomass yields were substantially higher than those of Mixwheat, particularly in Strip 3, where rye maintained relatively high productivity even in *Under* positions. The highest observed biomass values were recorded in *Between* positions of Strip 3, suggesting a greater ability of rye to exploit available resources under agroforestry conditions. However, predicted biomass yields for rye showed large discrepancies in some positions, notably underestimating observed biomass in Strip 3, while overestimating yields in *Between* positions of Strips 1 and 2.

Predicted biomass yields were in line with the observed values for Mixwheat during 2023 and 2024, with the exception of the position under of the Strip 1 (Figure 3 and 4). The predicted biomass yields for rye were in line with the observed values in 2024, while in 2023 the differences were higher. The predicted values tend to be over-estimated for the *Between* positions, while they tend to be under-estimated for the Strip 3.

Figure 3



Observed and predicted values of biomass yield during 2023 for Mixwheat and rye in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.

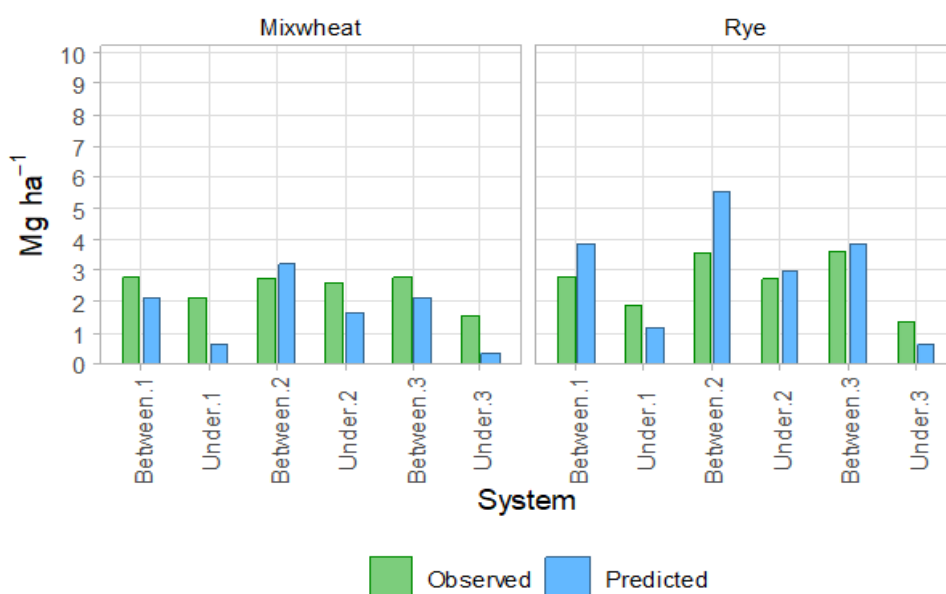


Figure 4
Observed and predicted values of biomass yield during 2024 for Mixwheat and rye in the strip

at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.

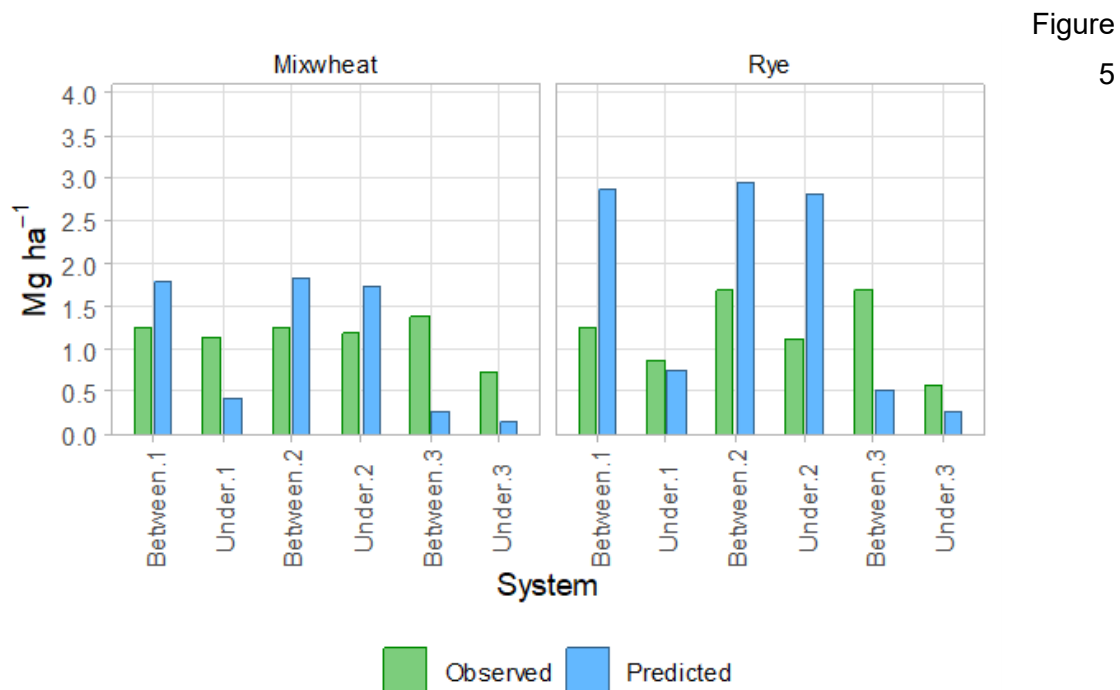
Overall, biomass yield patterns mirrored those observed for LAI, with reductions under tree canopies and on the north side of tree rows, although rye showed a greater resilience to these constraints than Mixwheat. The model successfully reproduced the



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general spatial structure of biomass production but exhibited crop- and position-specific biases, particularly for rye in shaded environments.

Predicted grain yields were in line with the observed values for both Mixwheat and Rye during, while the predicted values tend to be higher than the observed during 2023, with the exception of the Strip 3 (Figure 5 and 6).



Observed and predicted values of grain yield during 2023 for Mixwheat and rye in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.

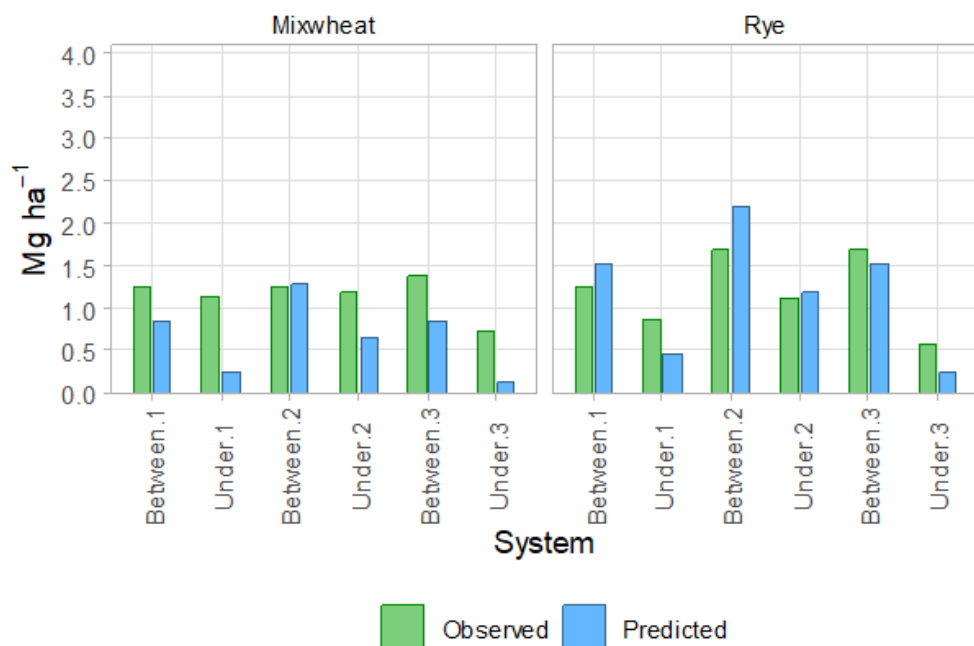


Figure 6

Observed and predicted values of grain yield during 2024 for Mixwheat and rye in the strip at the south side of the tree line (strip 1), the middle strip (strip 2) and the strip at the north side of the tree line (strip 3) and in Under or Between position.



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A4.2. Modelling of Soil organic carbon in AF and MF systems

Materials and methods

The farm is located in the municipality of Bràfim (Tarragona, Spain) at 243 m.a.s.l., with 487 mm of annual rainfall and 16°C of mean annual temperature and dryland conditions.

The studied system is a silvoarable system of olive trees combined with extensive winter cereal production established in 2006. The olive trees are older than 50 years old and are arranged in a line surrounding the crop field. The main innovative practice in the farm are the windbreaks (olive trees) in three out of the borders of the cereal plot.

The observed data (reported in Deliverable D.2.4) concerning soil organic matter has been used to validate the Hi-sAFe model (Dupraz et al., 2019).

Results

The Hi-sAFe model validation highlights the combined influence of olive trees and winter cereals on soil organic matter (SOM) dynamics in a agroforestry system established in 2006. The system consists of mature olive trees (older than 50 years old) arranged as windbreaks along the borders of a winter cereal field, with trees spaced at 15 m.

The SOM (%) pattern reflected the effect of a severe drought experienced in 2023: the cereal field SOM (nearly 3%) could be affected by the fact that in 2023 the cereal was not harvested and the crop remains in the field. In the case of olive trees, in 2023 the SOM decreased regarding the year before showing contents of 2.5%, probably due to the negative effects of drought in the soil fertility.





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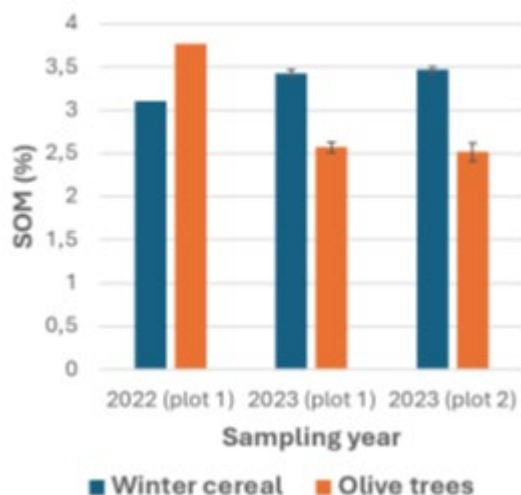
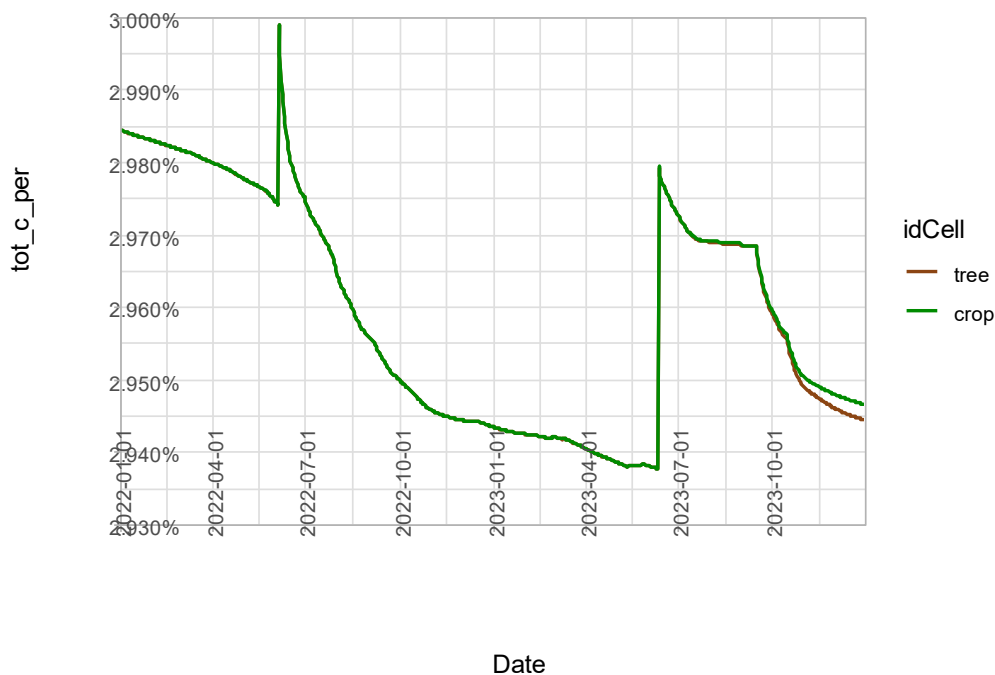


Figure 1 Average percentage of Soil Organic Matter (SOM) in soil samples (00-30 cm depth) for each sampling year and part of the agroforestry system (pilot Farm 02) in Catalonia, Spain as reported in the Deliverable D2.4.

Overall, SOM predicted values remain close to 3%, indicating a relatively stable soil carbon pool throughout the study period. However, distinct temporal patterns emerge that reflect the contrasting contributions of trees and crops, as well as the strong influence of climatic stress.





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Figure 2 illustrates the temporal evolution of simulated soil organic carbon in proximity to olive trees (brown line) and in the center of the plot under cereal cultivation (green line).

During the severe drought affecting the study period, marked alterations in crop performance were observed, including the loss of cereal harvest in 2023. In this context, the SOM content in the cereal field remained close to 3%, likely influenced by the absence of harvest and the retention of crop residues on the soil surface. The presence of unharvested biomass may have partially compensated for reduced plant productivity by increasing organic inputs to the soil.

In contrast, SOM levels in the vicinity of olive trees decreased in 2023 compared to the previous year, reaching values around 2.5%. This decline is likely linked to the negative effects of drought on soil fertility and organic matter turnover, potentially exacerbated by reduced litterfall quality and altered microbial activity under water stress conditions.

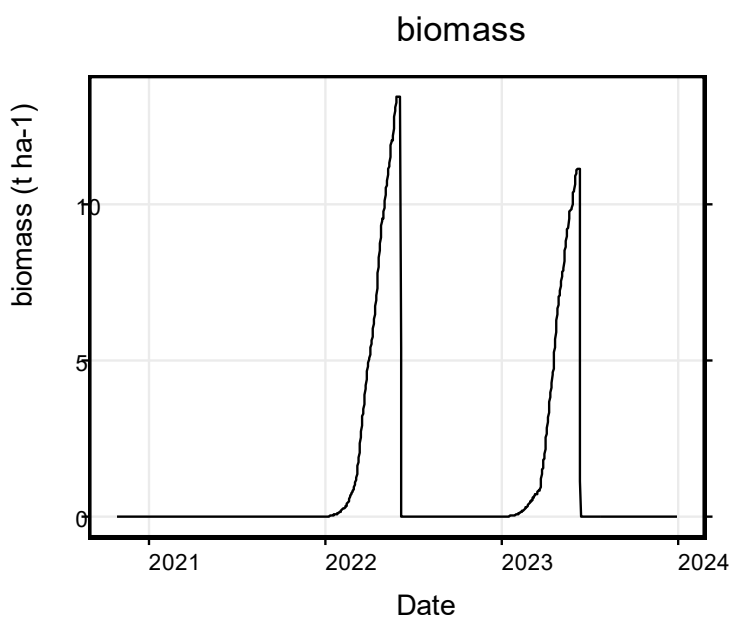


Figure 2 shows the simulated crop biomass production for the two study years.

Although the impact of drought is evident in the reduced biomass accumulation, the simulated reduction is less pronounced than that observed in the field. This suggests that the model may underestimate the severity of drought effects on annual crop growth under extreme conditions.

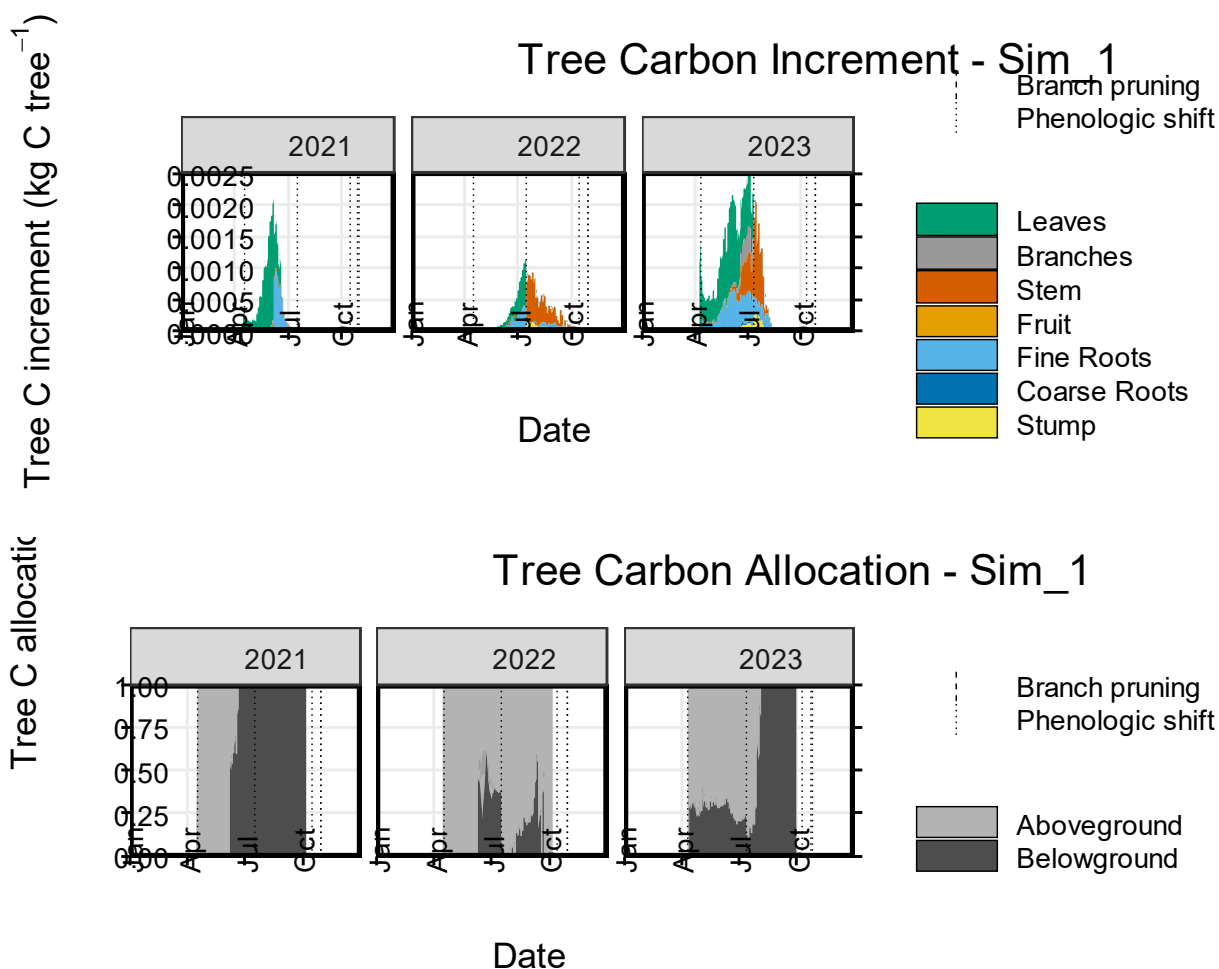


Figure 3 presents the simulated tree biomass production and its allocation among different compartments (leaves, branches, stem, fruits, fine roots, coarse roots, and stump).

Despite the drought conditions, overall tree biomass productivity remains relatively high. This response is largely driven by an increased allocation to root biomass, particularly fine and coarse roots, which reflects an adaptive strategy of olive trees to enhance water uptake under drought stress. This belowground investment contributes to maintaining tree carbon stocks but does not fully offset the negative impacts of drought on soil organic carbon near the trees.

Overall, the model captures the contrasting responses of crops and trees to drought and their combined effects on SOM dynamics. While crop residue retention under failed harvest conditions appears to stabilize SOM in the cereal field, drought-induced stress on olive trees leads to localized declines in SOM, highlighting the importance of spatial heterogeneity in agroforestry systems.



Transition

Reference

Dupraz, C., Wolz, K. J., Lecomte, I., Talbot, G., Vincent, G., Mulia, R., ... & Van Noordwijk, M. (2019). Hi-sAFe: a 3D agroforestry model for integrating dynamic tree–crop interactions. *Sustainability*, 11(8), 2293.





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A4.3

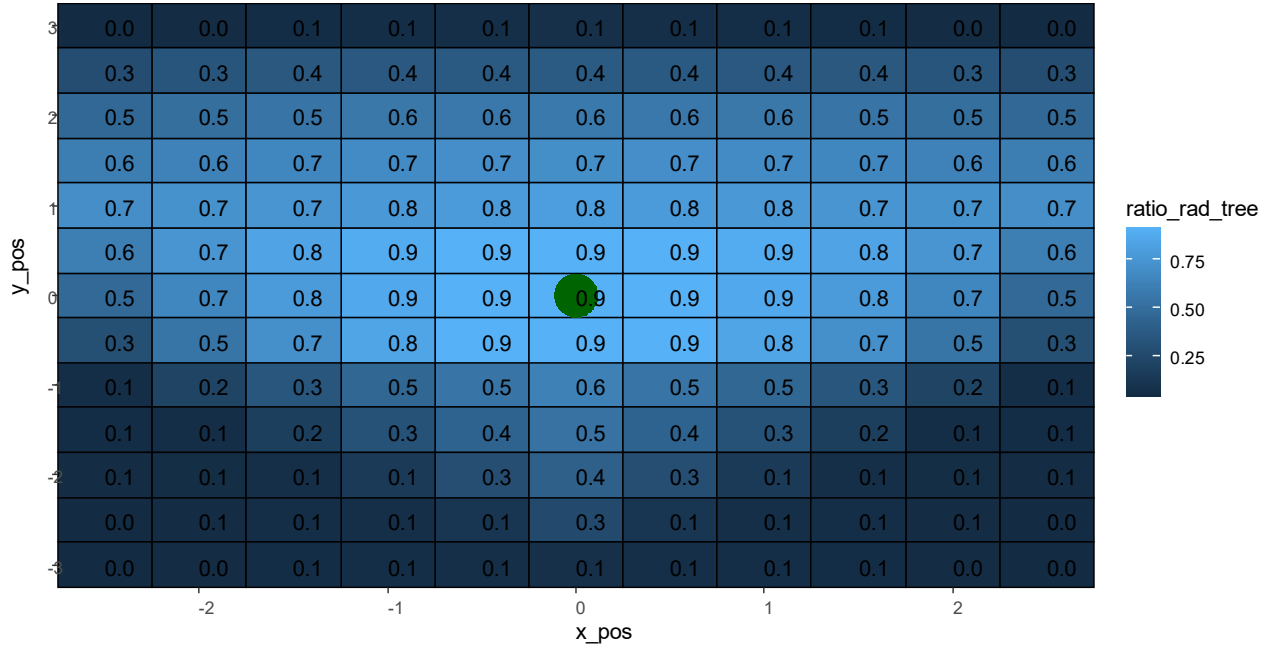


Figure 1A – Tree PAR interception in 2023. The position of the tree is represented by the green circle.

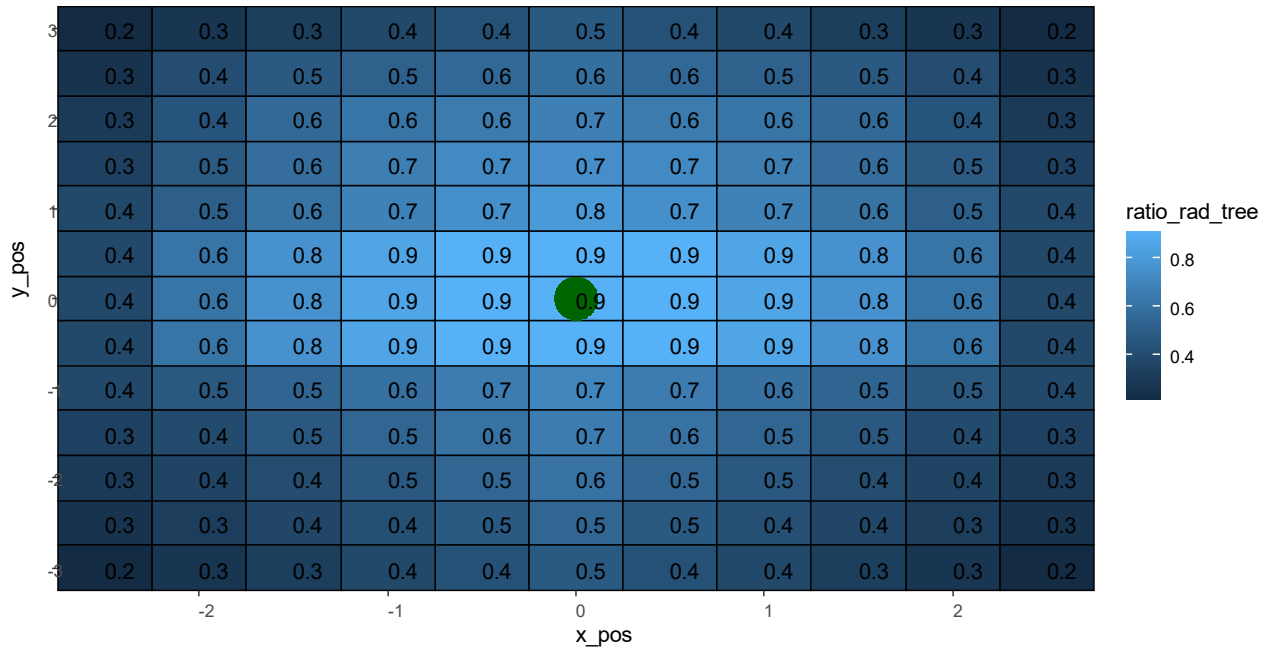


Figure 2A – Tree PAR interception in 2024. The position of the tree is represented by the green circle.

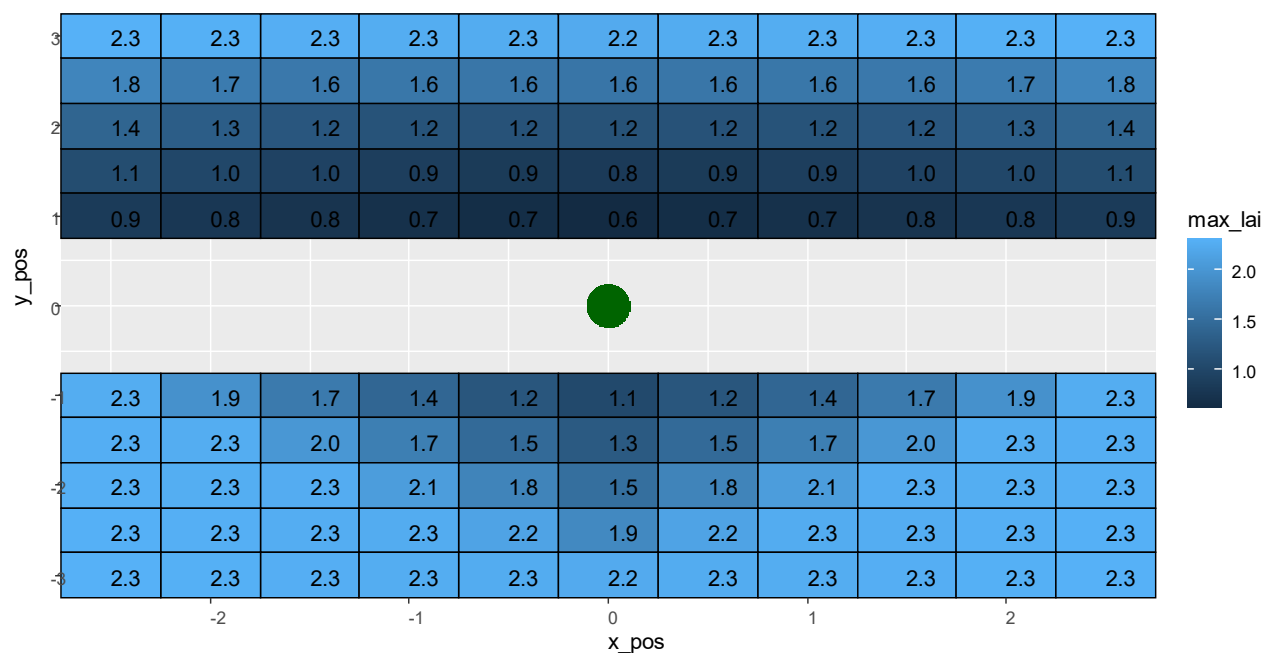


Figure 3A – Mixwheat maximum LAI expansion during 2023. The position of the tree is represented by the green circle.

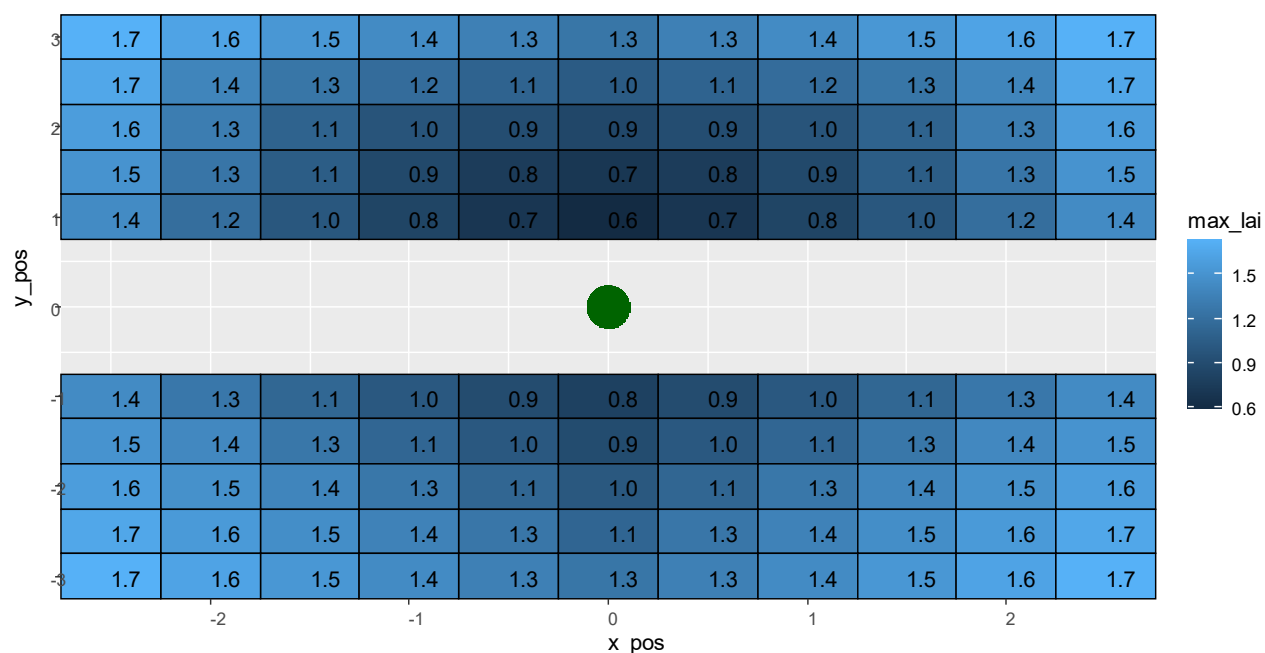


Figure 4A – Mixwheat maximum LAI expansion during 2024. The position of the tree is represented by the green circle.

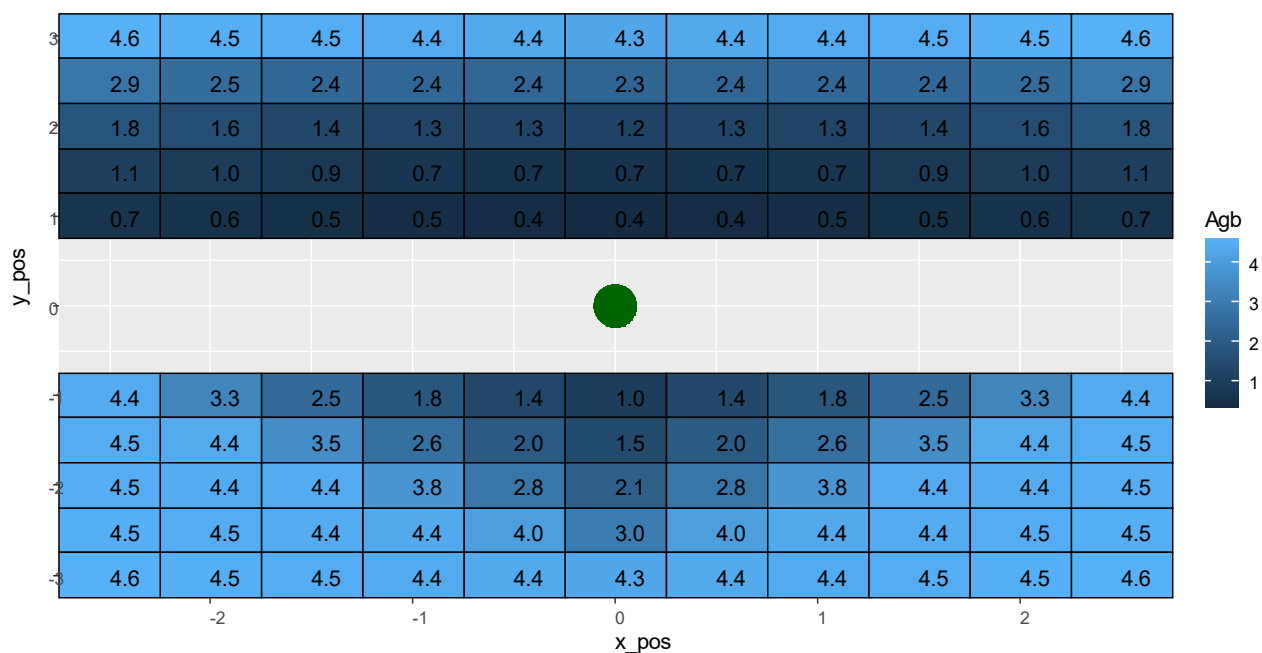


Figure 5A – Mixwheat aboveground biomass (AGB) yield during 2023. The position of the tree is represented by the green circle.

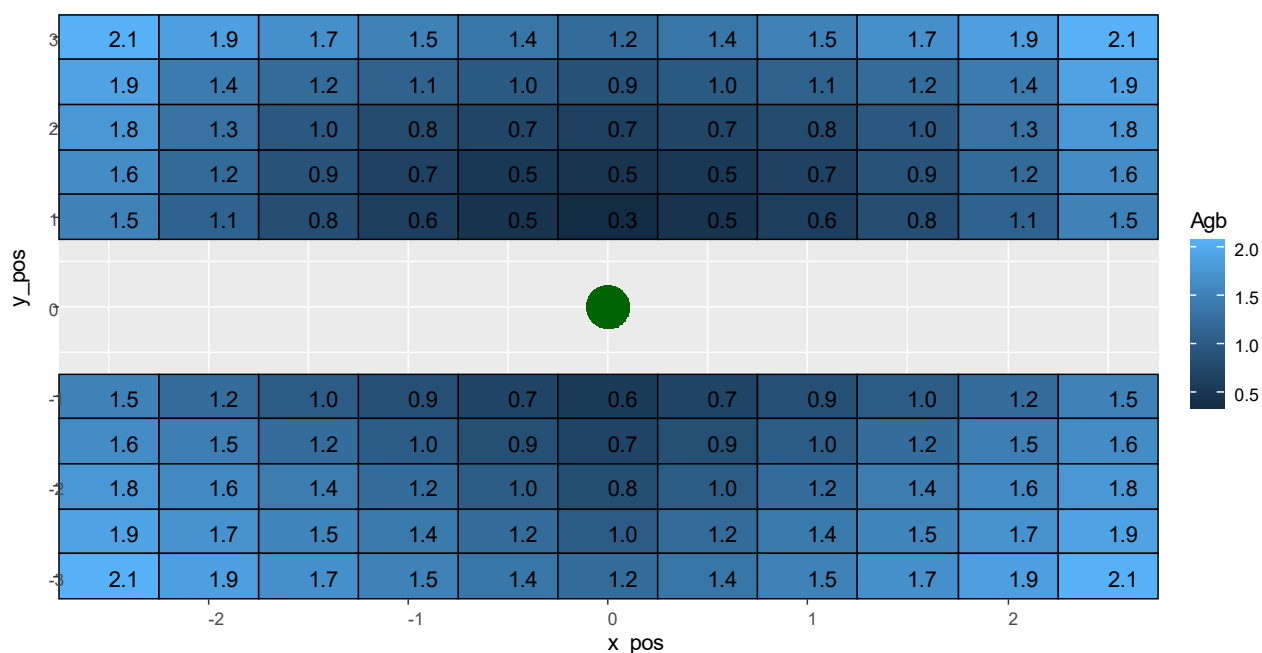


Figure 6A – Mixwheat aboveground biomass (AGB) yield during 2024. The position of the tree is represented by the green circle.

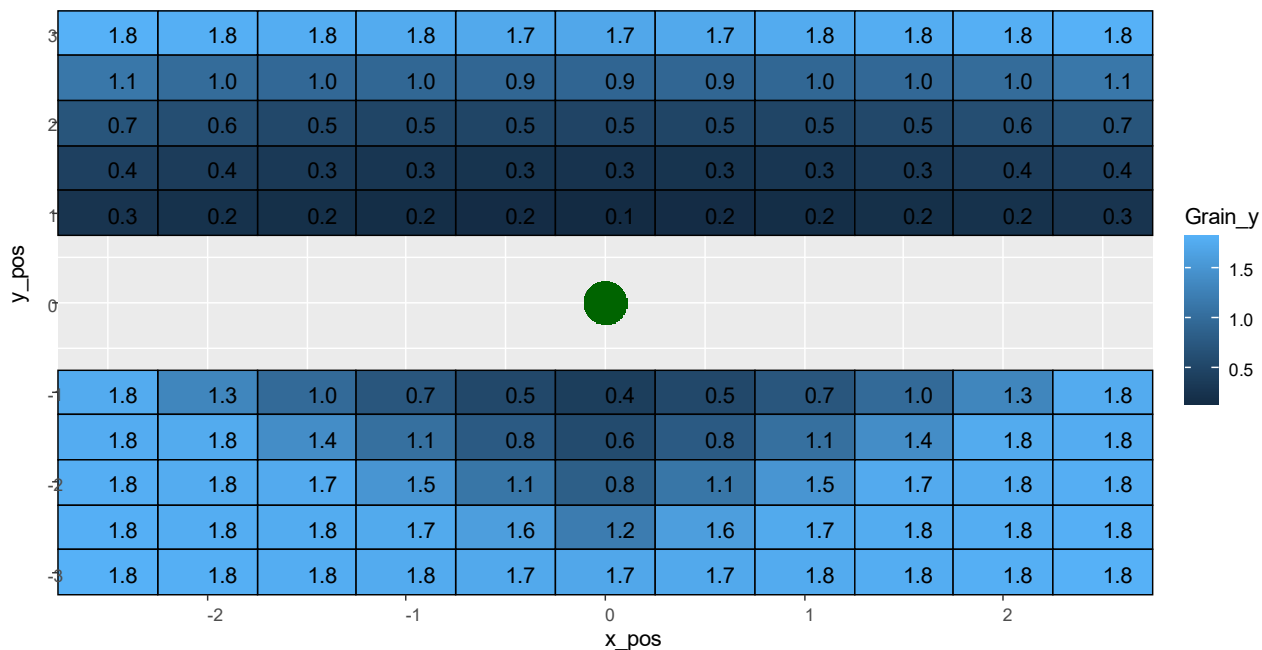


Figure 7A – Mixwheat grain yield during 2023. The position of the tree is represented by the green circle.

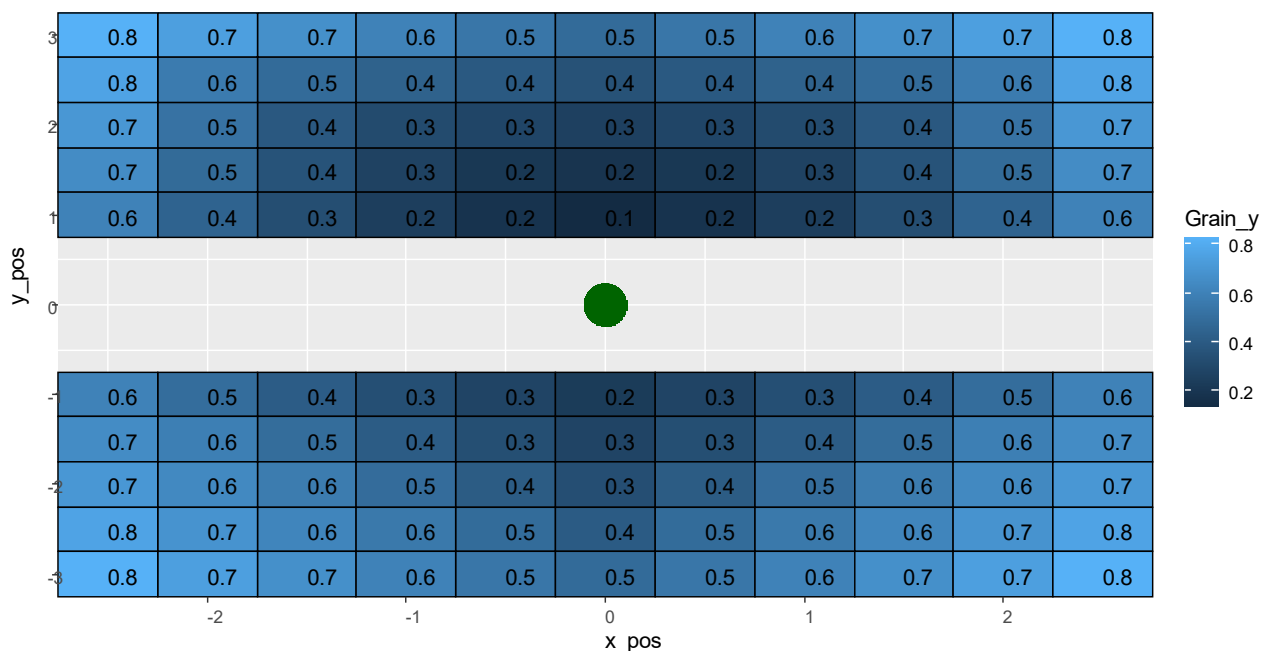


Figure 8A – Mixwheat grain yield during 2024. The position of the tree is represented by the green circle.

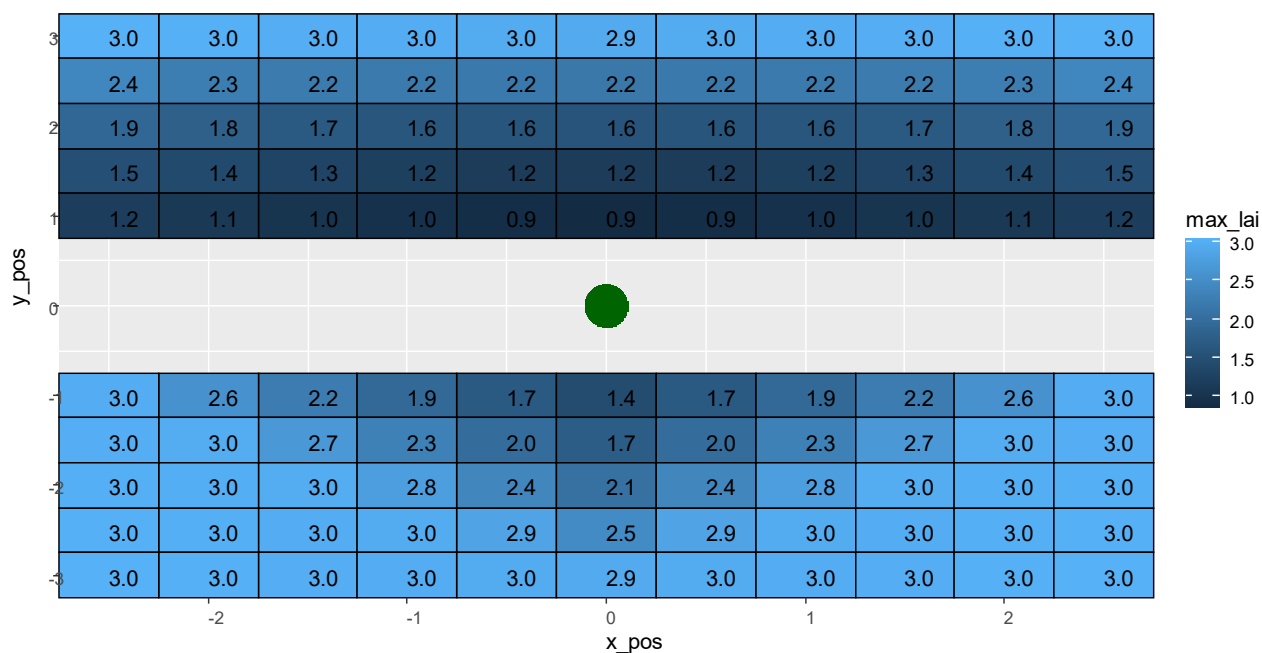


Figure 9A – Rye maximum LAI expansion during 2023. The position of the tree is represented by the green circle.

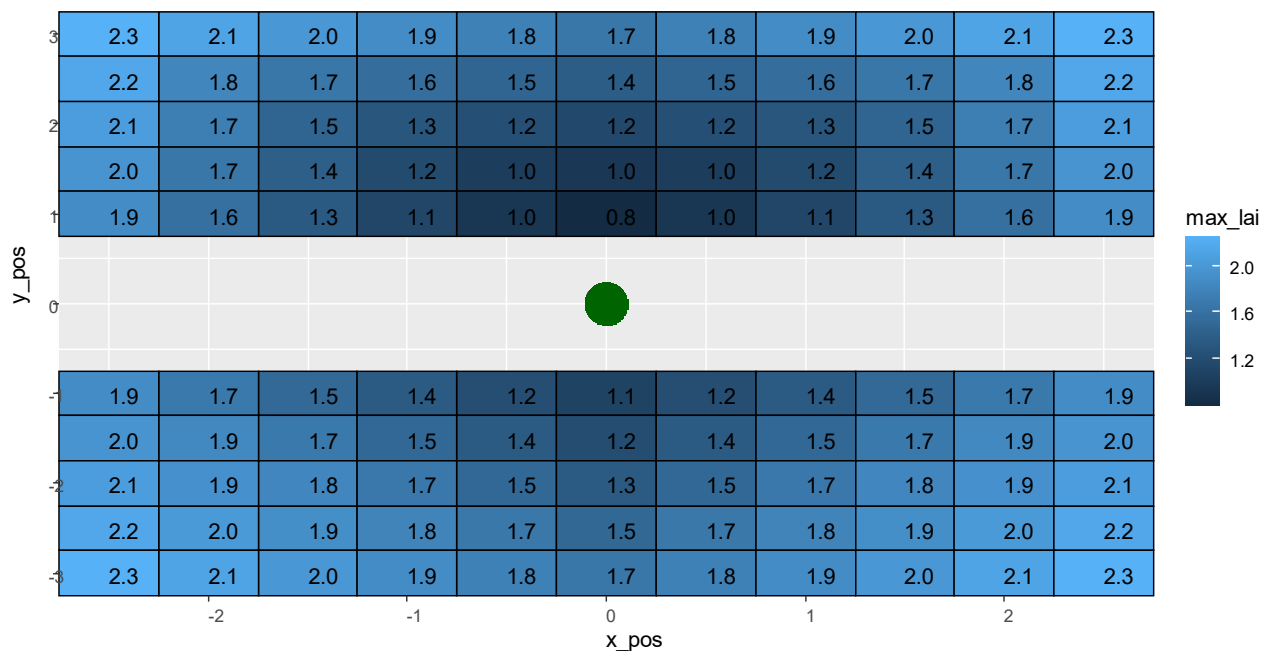


Figure 10A – Rye maximum LAI expansion during 2024. The position of the tree is represented by the green circle.

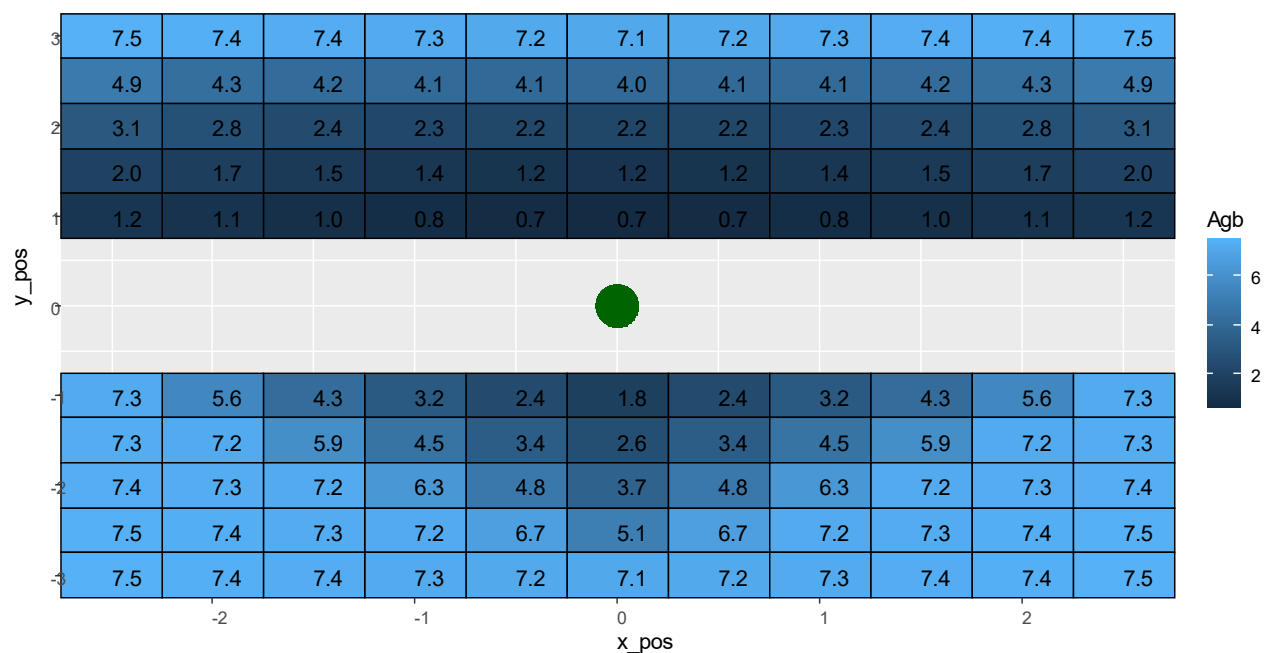


Figure 11A – Rye aboveground biomass (AGB) yield during 2023. The position of the tree is represented by the green circle.

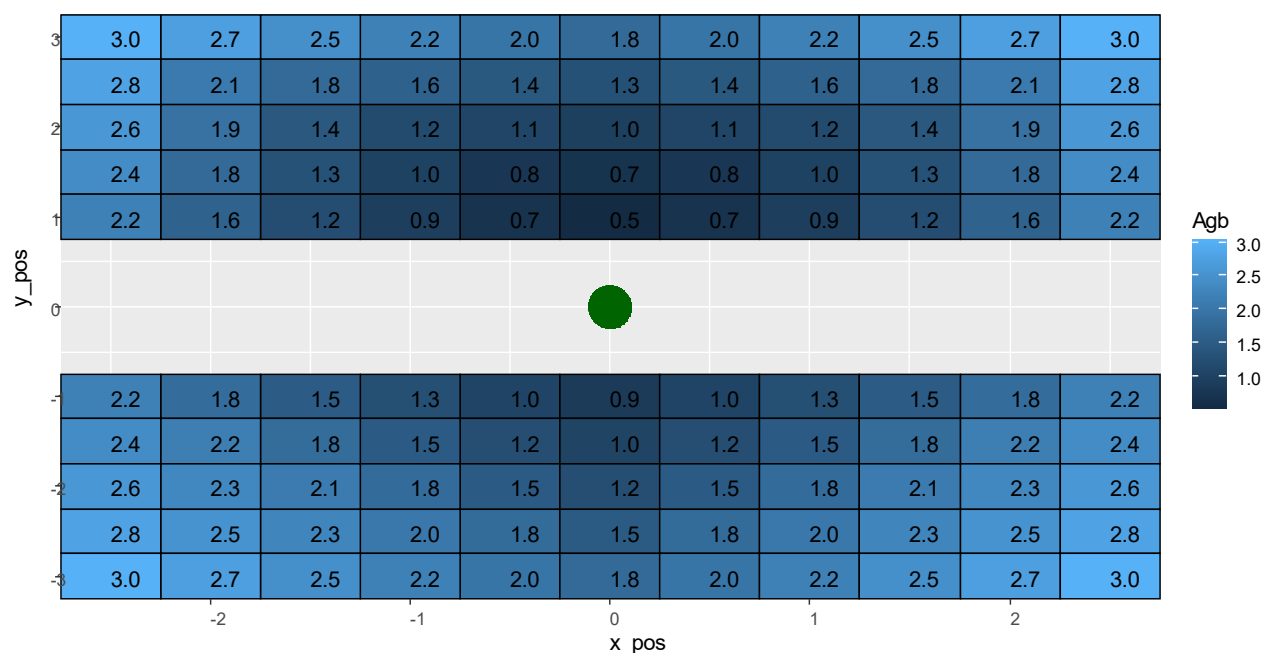


Figure 12A – Rye aboveground biomass (AGB) yield during 2024. The position of the tree is represented by the green circle.

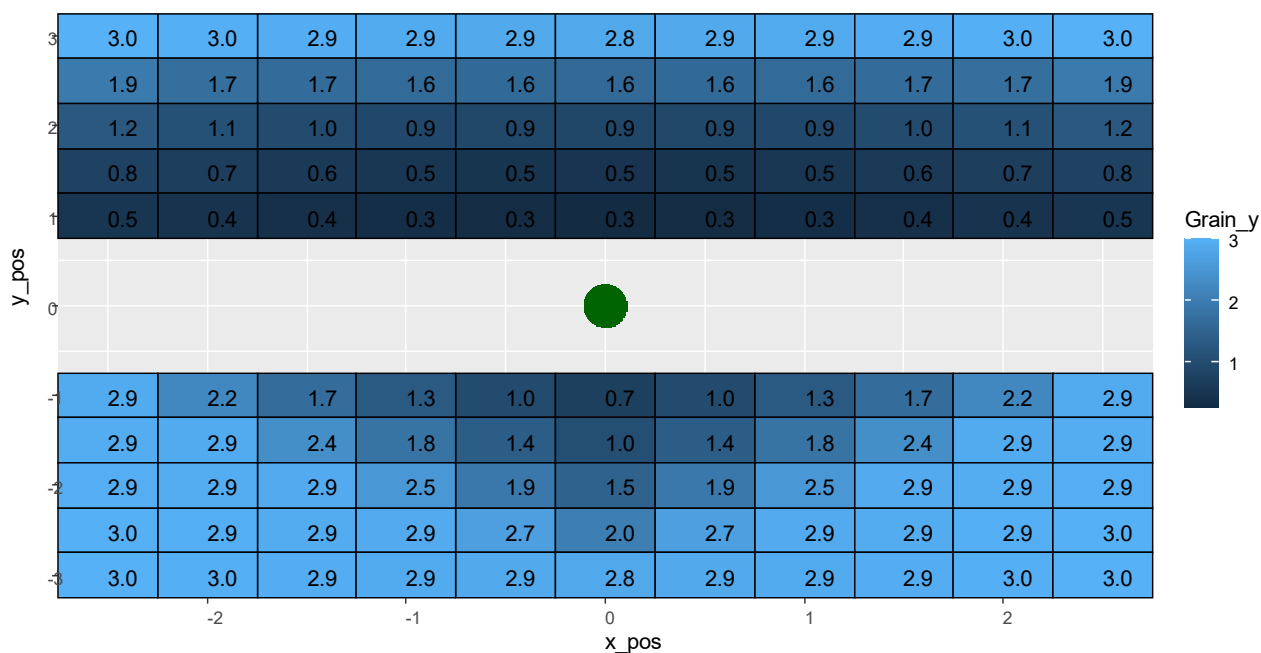


Figure 13A – Rye grain yield during 2023. The position of the tree is represented by the green circle.

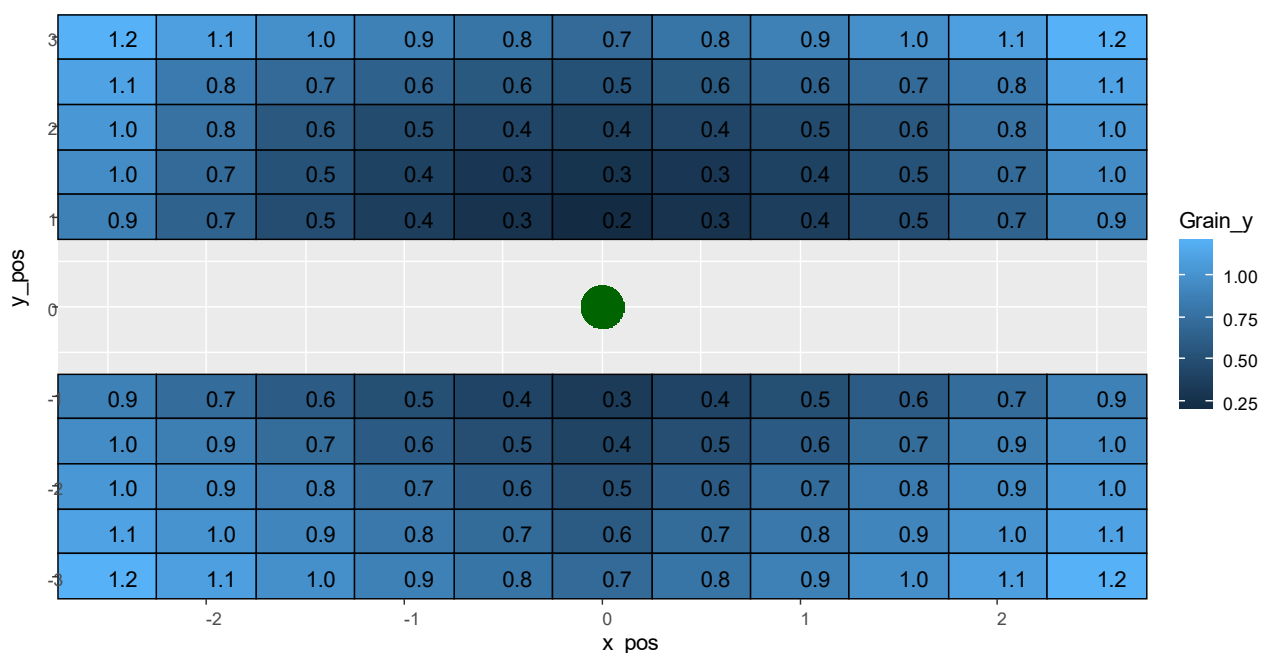


Figure 14A – Rye grain yield during 2024. The position of the tree is represented by the green circle.