AGROMIX brings together farmers, researchers and policymakers to explore agroecological solutions for more resilient land use in Europe, developing tools to implement these practices.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

D3.7.1
Methodological approaches to assess climate resilience

Fig.1 Farm systems should be designed to align with Sustainable Development Goals such as achieving improved food security, responsible consumption and production, and enhanced life on land.

Understanding resilience

When developing approaches to assess climate resilience, it is helpful to have clear answers to six questions.

1. Resilience of what and for what reason?

Resilience is not always desirable as, for example, we should not seek the increased resilience of systems that sustain [illegible], poverty, and inequality. Hence any consideration of resilience should clearly define "the resilience of what?" The United Nations (2015) outlined 17 Sustainable Development Goals (SDGs) to enable "a shared blueprint for peace and prosperity for people and the planet, now and into the future". In the AGROMIX project we want to increase the resilience of farms and related value chains, to achieve goals such as zero hunger (SDG2), responsible consumption and production (SDG12), and enhanced life on land (SGD15) (Fig.1).

2. Resilience to what?

Until recent times, it was typically assumed that the climate in a location was relatively stable over human time-scales and the focus was often dealing with short-term shocks. However, the process of climate change is creating more extreme shocks and greater circumstances such as drought, high temperatures, and intense rainfall. The challenge of climate change requires systematic thinking and new responses. The focus of the AGROMIX project is on the resilience of farm and land management to climate change.

3. What attributes should be considered alongside resilience?

Building on a definition by Meuwissen et al. (2019), the resilience of a farming system to climate change can be defined as the "ability to ensure the provision of the desirable functions of the farming system to climate shocks and stresses".

However, it is important to remember that resilience should be considered alongside other attributes such as efficiency, stability and equitability (Fig.2) (Conway et al. 2019). One measure of efficiency in a farm system is the total quantity of food produced per unit input. The stated focus of the AGROMIX project is to drive the transition to efficient as well as resilient land use in Europe.

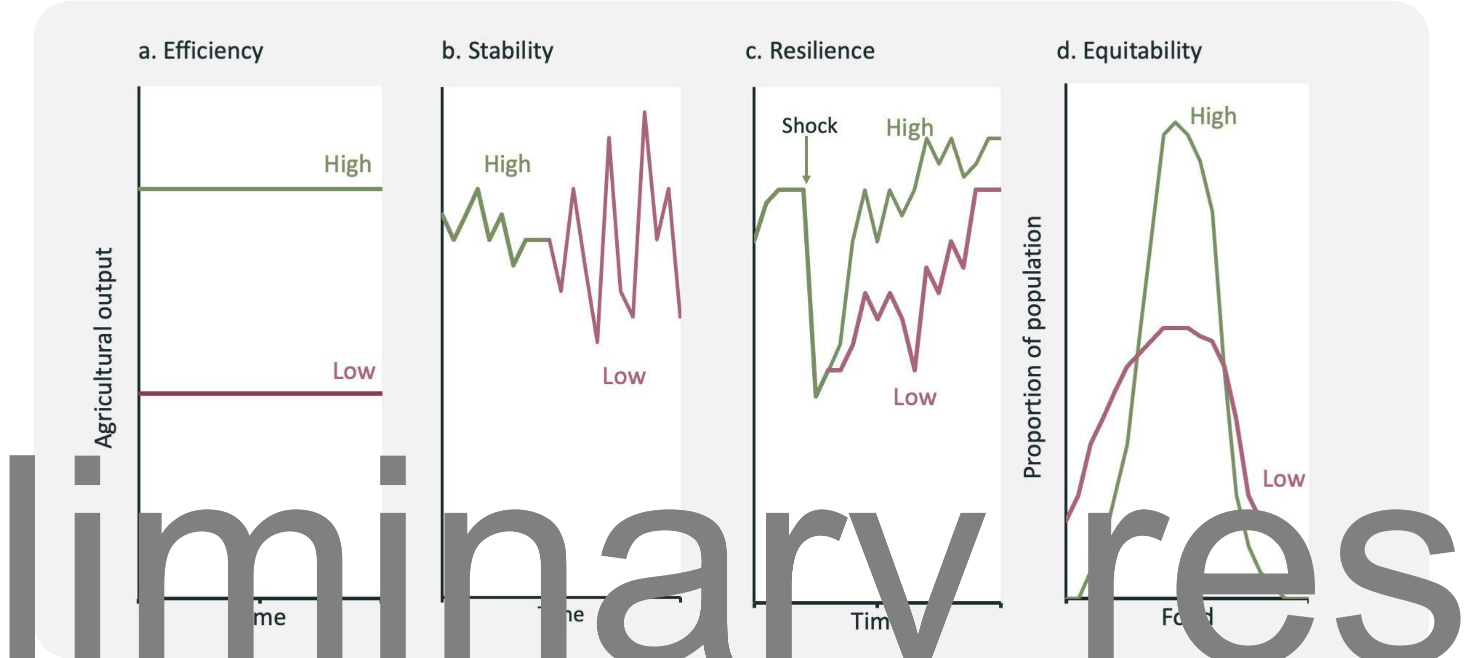


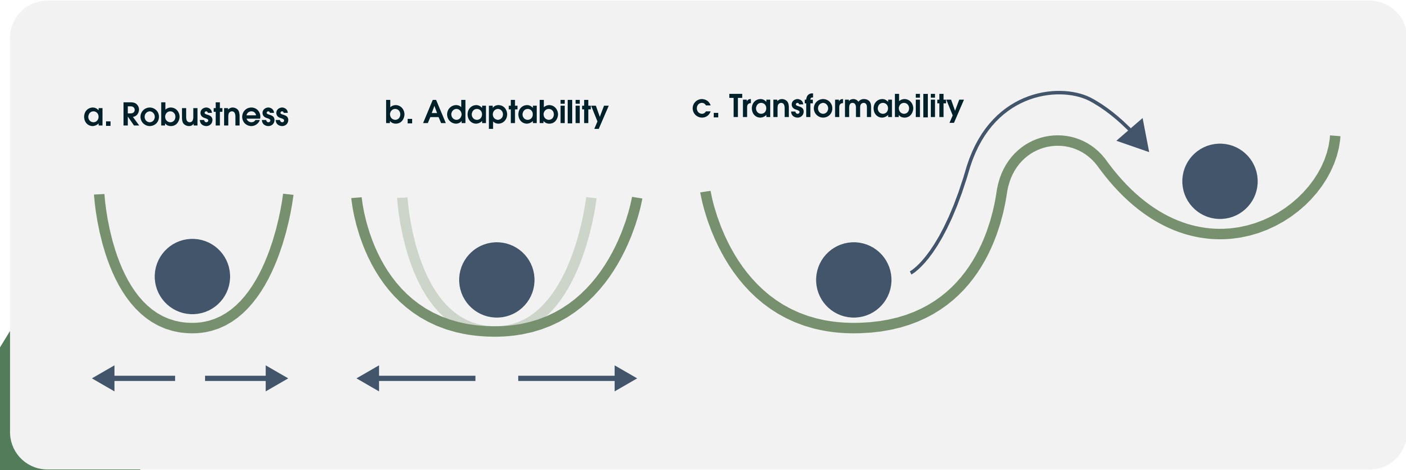
Fig.2 Resilience is just one attribute of a food system. The level of efficiency (or productivity), stability, and equitability can also be important (after Conway et al. 2019).

4. What are the forms of resilience?

There are different forms of resilience. Meuwissen et al (2019) outlines that resilience is achieved through "the capacities of robustness, adaptability and transformability" (Fig.3). The form of resilience, will partly depend on the intensity of the shock or stress.

- robustness - being able to absorb or resist shocks and stresses;
- adaptability - being able to adjust to the changes; and
- transformability - being able to move the existing system to a stronger one.

Fig. 3 Three forms of resilience – robustness, adaptability and transformability - illustrated schematically as a ball (the state of the farm) in a stability landscape (after Holling et al. 2002). The form of resilience needed may depend on the level of the shock.



5. At what scale do we measure resilience?

In addition to considering the outcomes sought, the shocks and stress, the different capacities, it is also important to consider the scale at which to measure resilience (Bullock et al. 2017). For example, resilience can be assessed at a field, a farm, a community, a regional, national, or global scale (Fig. 4). It is possible that feedback loops at a national scale can undermine or support the resilience of the farm system.

Fig. 4 Resilience of food production can be considered a field, farm, and regional/global scales. A systematic assessment of resilience should consider the impact of scales above and below the scale of interest (after Bullock et al. 2017)

6. What about the social and economic aspects of resilience?

The above analysis has largely focused on the technical and environmental aspects of resilience, but there are also social and economic aspects of resilience. AGROMIX has identified 17 indicators that may be associated with resilience that cross social, economic and ecological domains (Verstand et al. 2021). One way to visually present the resilience performance across such domains is to use an Amoeba diagram (Fig. 5). Accompanying fact sheets describe in more detail the measurement of resilience in terms of biodiversity, animal welfare, and the use of models.

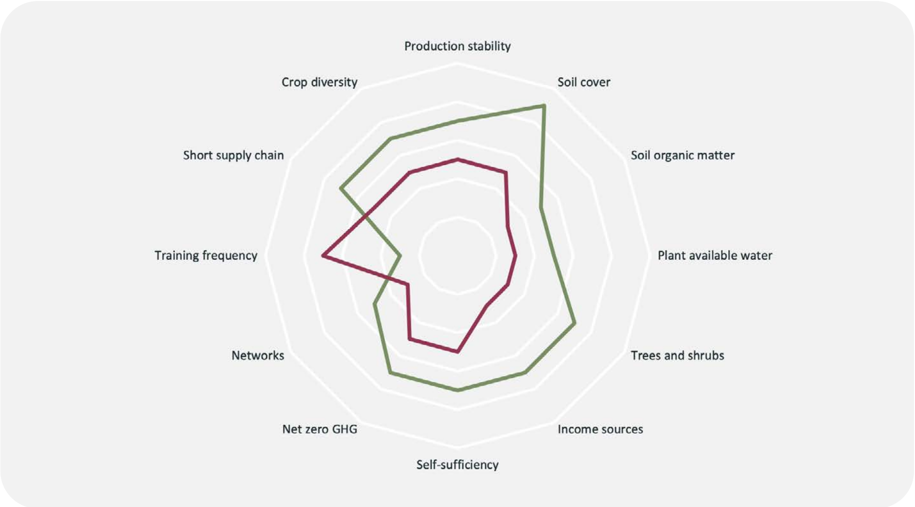


Fig. 5 An indicative AMOEBA diagram allows a qualitative (1-5 scale) comparison of two farm systems (black and red) across 12 indicators of social, economic and ecological resilience (after Verstand et al 2021).

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15 March 2022

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Methodological approaches to assess climate resilience

D3.7.2
Assessing the microclimate and animal productivity, welfare and behaviour in mixed farming and agroforestry systems

Introduction

Climate change alters the thermal environment of animals, affecting animal health, reproduction, and the feed conversion efficiency (Fig.1). In many cases this will reduce the productivity and stability of the farming system and thereby its economic resilience. Livestock stress across Europe can be caused by both cold and hot temperatures.

Agroforestry systems can help to alleviate the effects of environmental stress. The presence of trees can moderate day and night temperatures providing a source of shade or shelter and a more comfortable microclimate for animals raised in extensive conditions.

Resilience of animals to environmental change

The resilience of animals to environmental change can be defined as the ability of animals to ensure the provision of physiological, behavioural, cognitive, health, emotive, and production states over time when an environmental disturbance occurs. Hence useful indicators of resilience will describe the physiological, behavioural, cognitive, health, emotive and production states of an animal. Examples of useful resilience indicators are:

- Core body temperature.
- Heart rate and heart rate variability.
- Normality of circadian ethogram and expression of behavioural complexity.
- Feed intake
- Growth rate, or main production variable of the species, such as fertility, milk, or egg production.

It is helpful to select indicators that are easy to measure and which can be used to predict the adaptive response of animals to microclimate conditions. Such indicators can also be used in mathematical models to predict the resilience of animals in mixed farming and agroforestry systems across future climates.

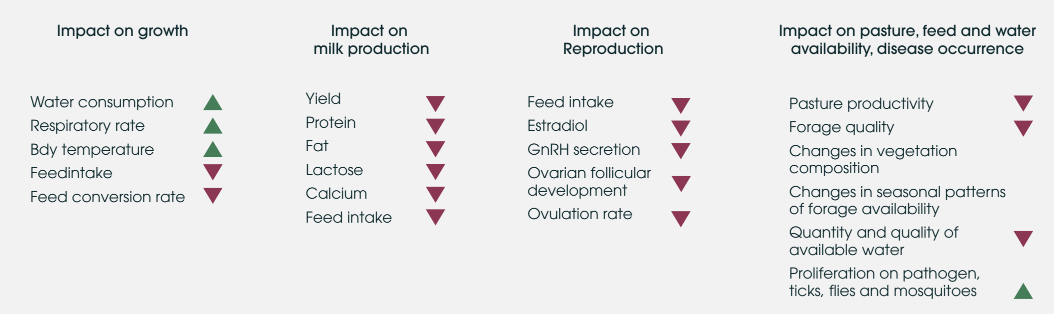

Fig.1 Anticipated impact of climate change on livestock production and reproduction traits in Mediterranean regions.

Experiments

In the AGROMIX project, three experiments have been set up across Italy (Fig.2), France (Fig. 3), and Northern Ireland (Fig.4). At each site, the microclimate and animal responses are being measured in agroforestry and open pasture systems.

Microclimate

At each site, we are using weather stations (Fig.5a) to measure:

- Solar radiation
- Air temperature and air humidity
- Rainfall
- Wind speed and direction
- Black globe temperature (Fig. 5b)

High temperatures and low water availability limit extensive livestock production in Mediterranean countries. Low temperatures, high wind speeds and rain can limit production at more northern latitudes.

Animal productivity

Adaptive responses of animals might be firstly measured using deviations from expected production levels over a period of time. In the AGROMIX project, variations in average daily gain of growing animals or in body condition score of adult animals are routinely being measured in the experiments.

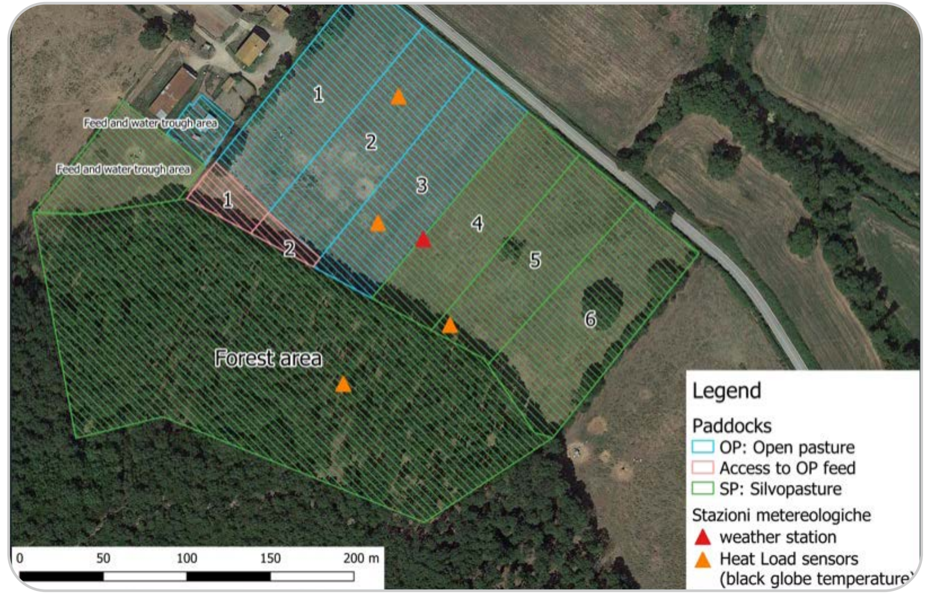

Figure 2. Experimental set up of the grazing trial at Tenuta di Paganico core site, Italy

Preliminary results

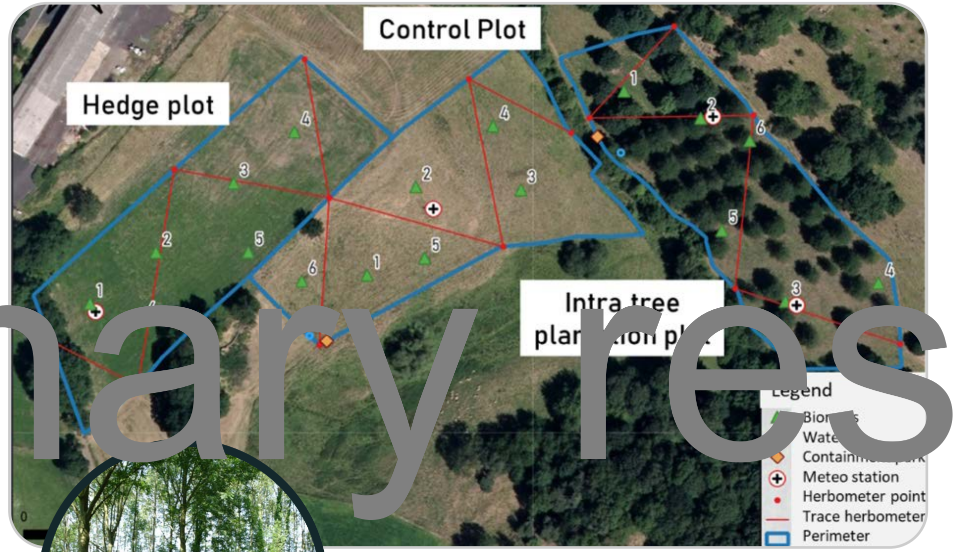

Fig.3 Experimental set-up of the sheep grazing trial at the Lamartine site in Saint Genès Champanelle, France

Fig.4 Sheep grazing at silvopastoral system in long-term silvopastoral system in AFBI Loughgall, Northern Ireland UK

Fig.5.a

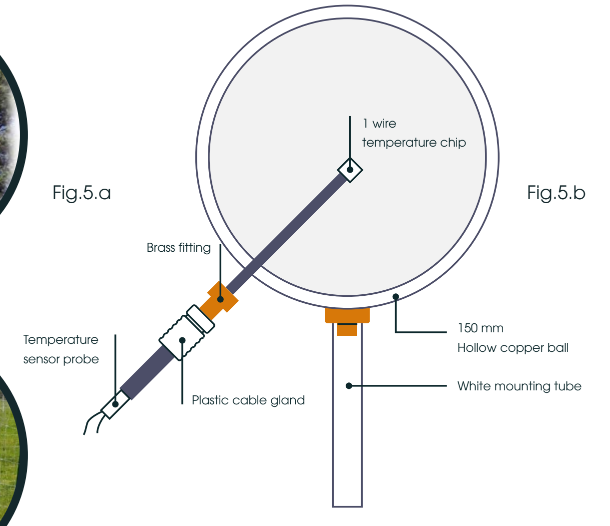

Fig.5.b

Fig.5.c

Fig.5 Black globe: a simple device to predict the heat load of animals

Animal welfare and behaviour

Animal behaviour is monitored by applying smart collars equipped with sensors (Fig.6) able to continuously collect individual parameters without disturbing animals:

- Body temperature
- Animal activity
- Animal positon in the grazing area

We are using sensors that do not disturb animals to study behaviour responses.

In the AGROMIX experiments, animal responses to climate conditions are also monitored by periodically collecting individual hair and blood samples to evaluate cortisol concentration, an useful indicator of cronic stress in animals. We are also measuring the seasonal variation of herbage availability, the time spent by animals on pasture, and the impact on animal feed intake and behaviour using, for example, exclusion cages (Fig.7).

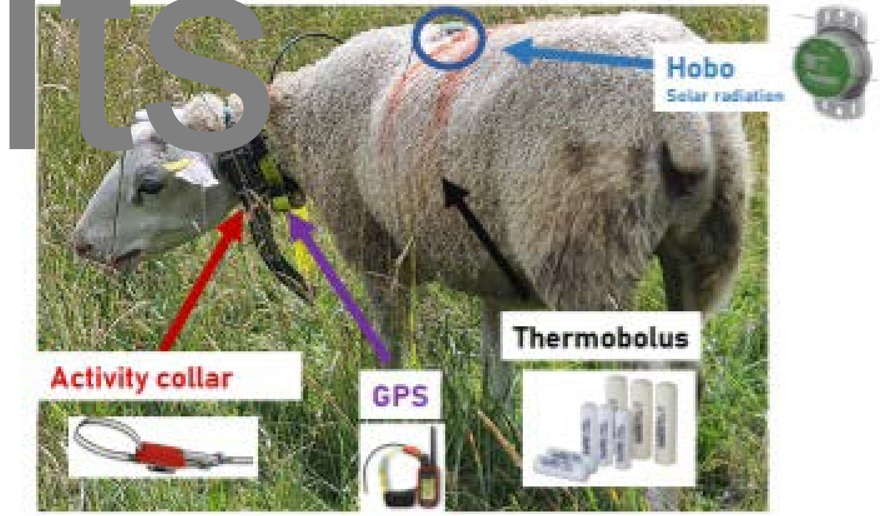

Fig.6 A monitored ewe equipped with sensors

Fig. 7 Exclusion cages are being used at the Italian and French sites

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Methodological approaches to assess climate resilience

D3.7.3
Methods to assess Biodiversity in Agroforestry Systems

Introduction

Wild species play important roles in food production. Insects pollinate many important crops, wild plants support animals and stabilize soils, and soil microorganisms recycle nutrients for the growth of our crops. Higher numbers of beneficial organisms support natural pest control, and every species has an intrinsic value that we should preserve for the future (Fig.1).

Biodiversity also contributes to the resilience of ecosystems to climate change: once conditions become unsuitable for certain species, a high species richness increases the chance that other species can take their role. Thus, there is a need to transform farming systems to reverse the decline of biodiversity observed in agricultural landscapes during recent decades.

Aim

By combining crops or livestock grazing with trees, agroforestry is one method to reconcile biodiversity and food production. In the AGROMIX project, we are quantifying the benefits of agroforestry systems to biodiversity. We do so by recording the activity of birds and bats, herbaceous plants, pollinating insects (Fig.2), spiders and beetles on the ground surface as well as microorganisms in the soil. We then compare agroforestry with non-agroforestry systems.

Fig.1 Birds like the Yellowhammer (*Emberizia citrinella*) have declined in Western European agricultural landscapes. They depend on a combination of trees and open ground for breeding. Photo: Steven Falk.

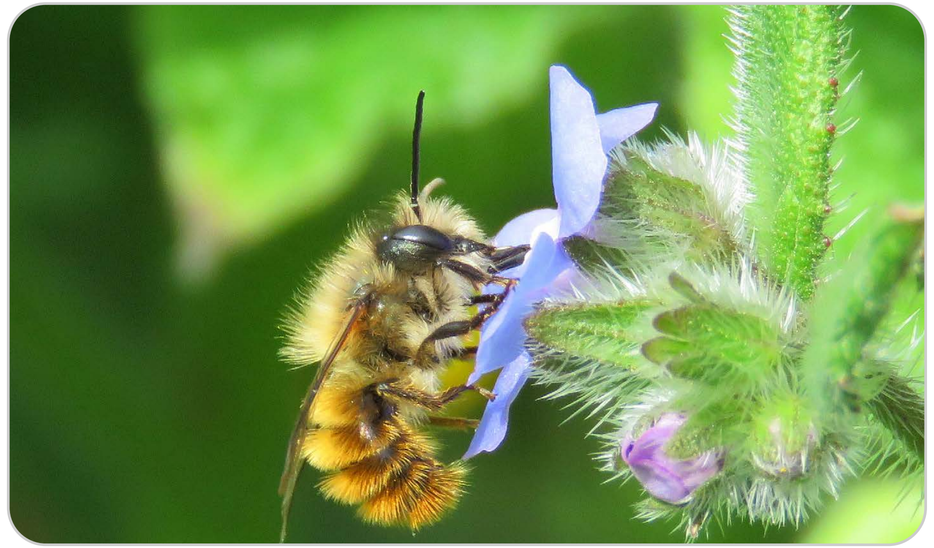
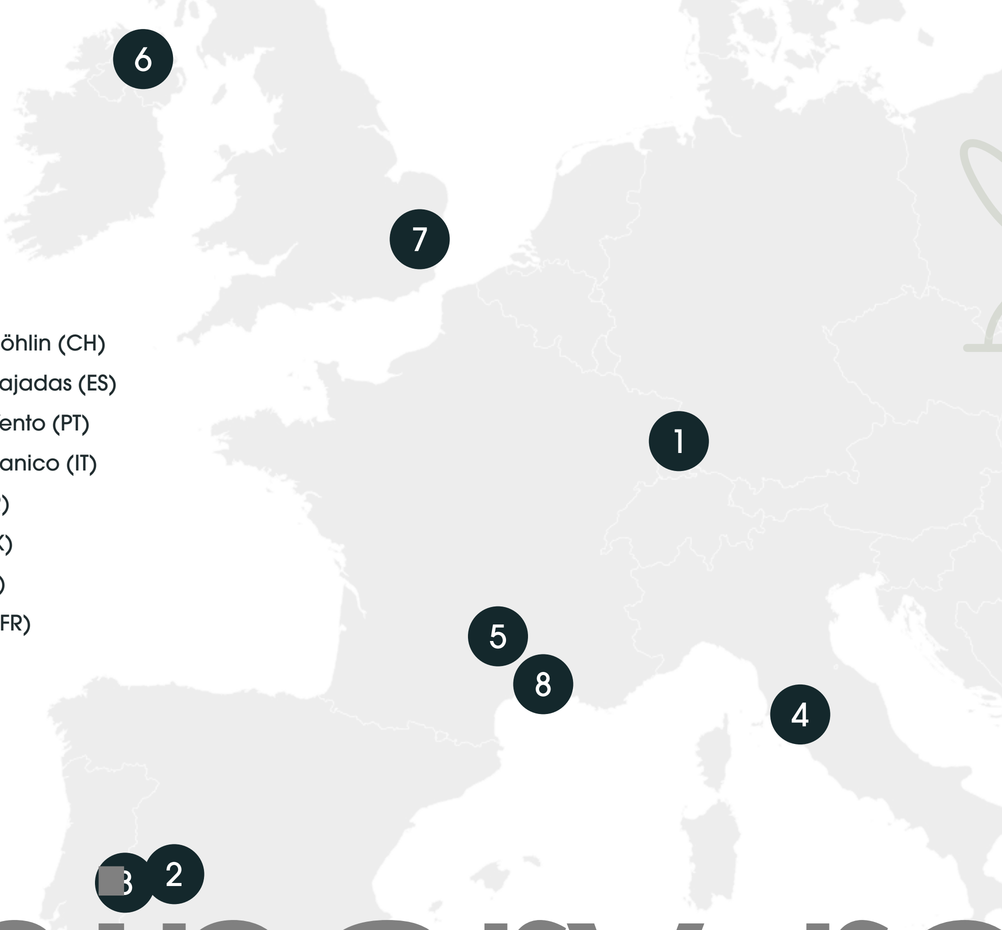


Fig.2 Mason bees (*Osmia bicornis*) become active in early spring to pollinate numerous plant species. They depend on wood for nesting. Photo: Steven Falk.



1. Sursee and Möhlin (CH)
2. Dehesa de Majadas (ES)
3. Moinhos de Vento (PT)
4. Tenuta di Paganico (IT)
5. Lamartine (FR)
6. Loughgall (UK)
7. Wakelyns (UK)
8. Restinclières (FR)

Fig.3 Location of nine field sites being used to compare the biodiversity of agroforestry with non-agroforestry systems.

An approach to measure biodiversity

Agroforestry systems are attracting increasing interest from farmers, researchers and policy. Unfortunately, newly planted systems need decades to develop their full potential, and mature systems are still scarce. Thus, our study sites are spread out over distant parts of Western Europe, including Portugal, Spain, Italy, France, Switzerland, Germany and the United Kingdom (Fig.3). For one individual to collect data at these separated locations is a challenge, especially during the COVID-19 pandemic. Hence local site managers are following detailed sampling protocols at each location.

Fig.4 Installing invertebrate traps in an apple-strawberry agroforest near Sursee, Switzerland. Photo: Manon Edo.

Agroforestry systems are highly diverse. Trees are grown for fruit, nuts, energy or timber. Between trees, cereals, vegetables or soft fruit are grown (Fig.4 and Fig.5), or livestock is grazed. Thus, every agroforestry system needs to be compared with several reference areas, such as orchards, tree plantations, horticultural and arable fields, or vineyards.

Techniques

To collect data in a standardized manner, we are using techniques that are as independent of the operating person as possible. For example, we use autonomous audio recorders to store bird vocalizations and use the ultrasonic calls of bats. These are identified centrally with the help of experts and modern software. Soil organisms are identified using DNA sequencing techniques and plant biodiversity is recorded using a standardized sampling protocol.

Next steps

The initial results are suggesting that agroforestry can help to increase biodiversity in agricultural landscapes. For example, agroforestry systems had more breeding birds than orchards or grassland, and different species than forest, indicating real added value to existing land-use systems.

Fig.5 Sampling the tree understorey in an apple-strawberry agroforest near Sursee. Photo: Manon Edo

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Methodological approaches to assess climate resilience

D3.7.4
Numerical models to assess resilience in Mixed Farming and Agroforestry systems

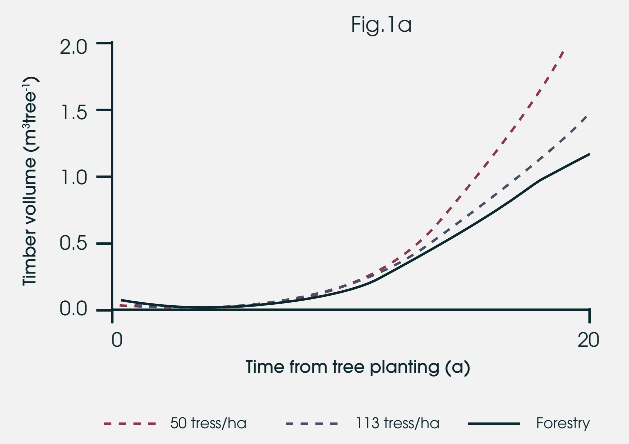
Introduction

The introduction of trees on farms can provide economic and environmental benefits such as tree products, shelter for animals and crops, water purification, and improvements to biodiversity (Fagerholm et al., 2019). An additional benefit of trees is their ability to sequester carbon from the earth's atmosphere to counter the impacts of climate change. Because quantifying these benefits through field experiments is extremely time consuming (since trees live for many decades) researchers have developed numerical computer simulation models of how trees interact with their environment. This provides researchers with the opportunity to undertake "virtual" computer experiments to obtain insights on the effects of incorporating trees on farms. In AGROMIX, these models are being used to predict how trees and crops in agroforestry systems will respond to future climate change, how trees can help provide benefits for crops and livestock, and how resilience in agricultural systems can be improved.

Computer simulation models currently being used on the AGROMIX project include Yield-SAFE, Hi-sAFe, and Farm-SAFE, as well as novel research using machine learning.

Yield-SAFE

Yield-SAFE (van der Werf et al., 2007; Giannitsopoulos et al., 2020) is a relatively simple daily time-step model that can be used to provide long-term predictions of tree and crop growth in mixed systems for a variety tree and crop species. It has been used over the last 20 years to predict tree and crop growth for many land use systems in Europe and globally (Fig.1a and Fig.1b). Over the years, it has been upgraded to include soil carbon impacts, livestock carrying capacity, and microclimatic effects (Palma et al., 2016, 2017). In the AGROMIX project, it is being used to examine how future tree, crop, and livestock growth develops in agroforestry systems, for example, by examining how trees can be used to provide productive benefits to livestock through shade and shelter provision, what the best densities are for future climates to ensure greater resilience in agro-ecosystems, and to what extent competition for light and water between trees and crops will become problematic under future climates.



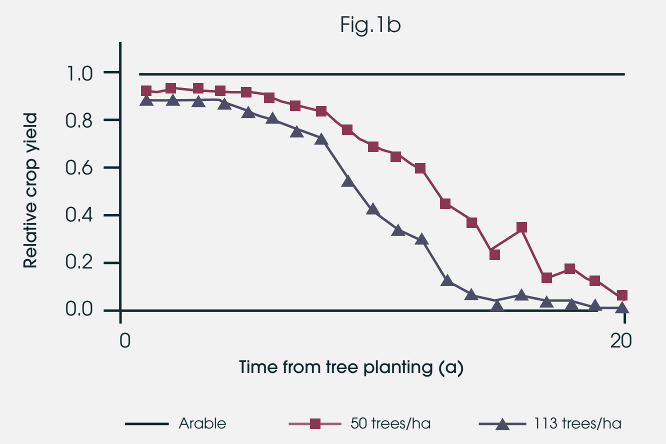
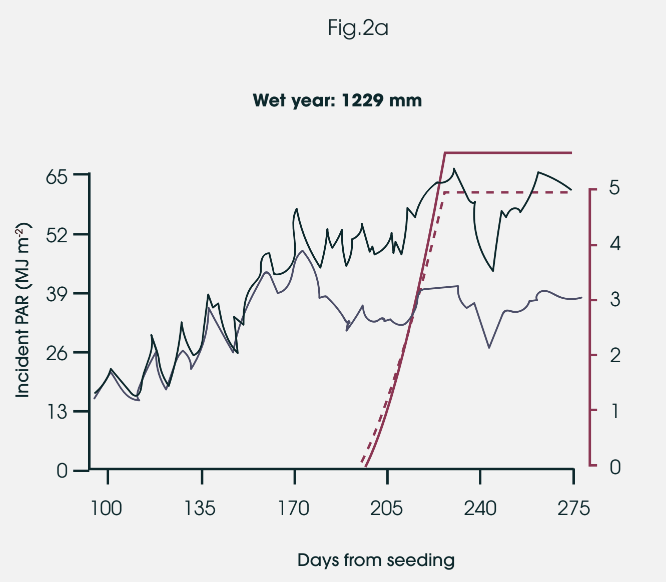


Fig.1a and Fig.1b: Yield-SAFE predictions showing a) individual poplar timber volumes in agroforestry systems at two different tree densities and for a poplar forestry system and b) agroforestry intercrop yields relative to an arable crop.

Hi-sAFe

Hi-sAFe (Dupraz et al., 2019) is a complex 3-D model that simulates crop and tree growth in agroforestry as well as forestry and arable systems. The trees are represented as geometric shapes above-ground and as a 3D representation of coarse root structure below-ground. Hi-sAFe allows predictions of tree-crop interactions in agroforestry systems to be made on a daily time step, and incorporates the effect of tree density, pruning and thinning, and crop species and variety, ploughing, fertilization, and irrigation. It is being used to undertake "virtual" experiments to identify how trees and crops will respond to climate change and determine how agroforestry systems might provide solutions to future environmental stresses (Reyes et al., 2021).



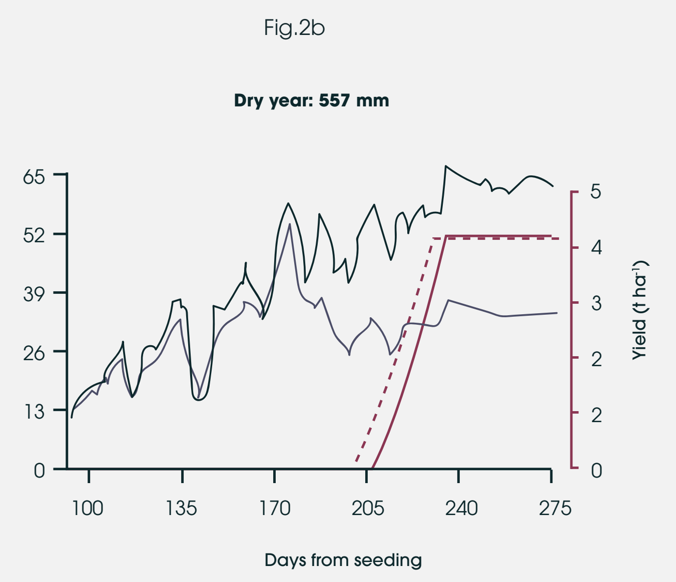


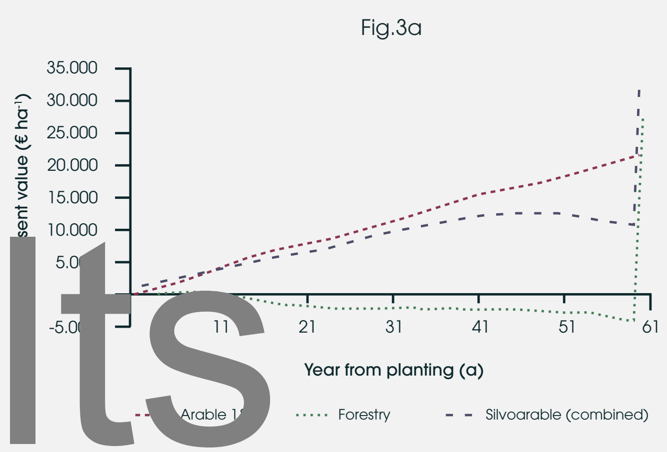
Fig.2a and Fig.2b: Examples of Hi-sAFe outputs: showing the daily dynamics of photosynthetically active radiation (PAR) reaching the crop (black) and yield accumulation (red) in a pure crop (solid line) and agroforestry plot (dotted line), during a wet year (a) and a dry year (b).

Farm-SAFE

Farm-SAFE (Graves et al., 2011) is a cost benefit analysis model that can be used to compare the performance of different types of land use systems. It can be operated at the plot, farm, and regional scale and uses discounted cash flow analysis to provide a summary of future revenue and costs transformed to a net present value (Fig.3a and Fig3b). Initially it operated purely as a financial model. More recently it has been developed to include life cycle assessment data to calculate the net greenhouse gas balance, nitrogen and phosphorus balance of arable, forestry, and agroforestry land use options to provide indicators for environmental valuation (Giannitsopoulos et al., 2020; García de Jalón et al., 2018a). Farm-SAFE is being used in the AGROMIX project to look at the financial and economic implications of the effects of climate change.

Can machine learning be applied to predict resilience?

In the AGROMIX project, we are also examining the potential of machine learning to investigate resilience. In machine learning, computers are programmed to identify new patterns in data without those patterns being known to begin with. AGROMIX will develop a qualitative classification of resilience using a machine learning technique known as discriminant analysis. The classification rule will provide researchers with a means of deriving qualitative resilience classifications and estimating the probability of a farmland belonging to a particular resilience class. The results from the classification model will then use commonly available data to assess the resilience of particular types of agricultural land.



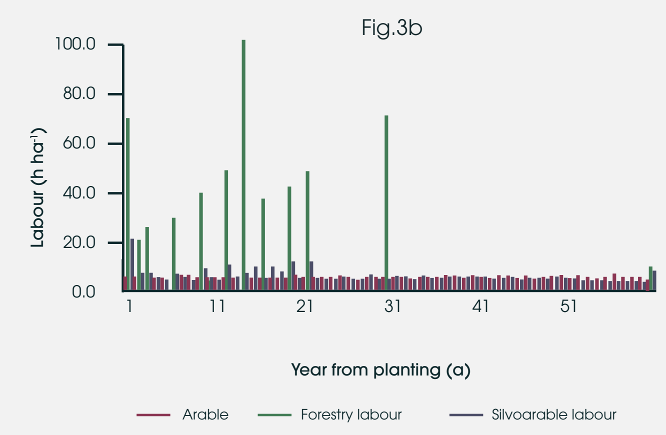


Fig.3a and Fig.3b Farm-SAFE predictions of; a) future net cash flows for an arable, forestry, and agroforestry system, and b) labour requirements for an arable, forestry, and agroforestry system

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