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Benefits of HDLFs for on-farm adaptation to climate change

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Introduction – MOTIVATION

The Biodiversity Strategy 2030 objectives include a target for 10% of agricultural land to incorporate landscape features or non-productive areas (European Commission, 2020). In practise and under the proposed Nature Restoration Law (Directorate-General for Environment, 2022), that is currently in the process of political negotiation, these features are divided into four groups (woody, stony, grassy, and wet features), and among others include buffer strips, rotational or non-rotational fallow land, hedgerows, individual or groups of trees, tree rows, field margins, patches, ditches, streams, small wetlands, terraces, cairns, stonewalls, small ponds, and cultural features. Many of these features are perennial and are positioned in the agricultural landscape for longer periods. The longevity of features raises a question of their flexibility, adaptability, and long-term functionality in the scope of changing environments and climate changes. Woody features in agricultural landscapes have often been out of the interest of farmers and foresters in the past but better collaboration between the agriculture and forestry sectors is required. HDLFs are a typical example of joint knowledge and action that can mitigate climate change and provide other benefits.

Climate change is a fact, and as landscape management is changing and adapting to changes that are already happening and are envisaged to become even more pronounced in the next few decades (IPCC, 2018), extreme environmental conditions, such as high or low temperature extremes and increasing precipitation extremes with severe and prolonged drought periods, are occurring with increased frequency. Global climate change is already showing direct effects on the growth and production of both natural and agricultural ecosystems (United Nations, 2023), including the functioning and survival of **high-diversity landscape features (HDLF)**. The HDLFs should follow the changes and adapt adequately to retain (or even enhance) their ecological, economic, and other ecosystem roles. The high context-specifity of these aspects and landscape dimension need to be considered in planning, by inclusion of different actors (like farmers, local authorities, NGO) and disciplines (e.g. landscape planning).

Objectives of this mini paper, focusing on the potential directions of HDLF management for their adaptation and mitigation to climate change and for their future benefits to farmers and the environment, include: 1) reviewing adaptation and mitigation strategies of HDLFs for farmers and their environment benefits; and 2) exploring the potential and limits of the productivity, functionality, and existence of HDLFs under changing climate.

Different high-diversity landscape features: woody, stony, grassy, and wet features (Author: Jana Špulerová)

Threats to agriculture by climate change

Agricultural production faces an increasing production (yields) risk due to a changing climate and increased abiotic and biotic stress, including other factors (pests, diseases.etc.). The severe negative effects of climate change threaten our ability to ensure global food security, eradicate poverty, and achieve sustainable development. Climate change has both direct and indirect effects on agricultural productivity, including changing rainfall patterns, droughts, flooding, and the geographical redistribution of pests and diseases (FAO, 2023).

Climate change is having a big effect on agriculture, which is causing farmers a lot of problems and difficulties. Some of the major issues brought on by climate change include (Ang, 2022; Wheeler and von Braun, 2013):

- Changes in temperature and rainfall can affect the growth and production of crops. Higher temperatures or heat waves can cause heat stress in crops and for livestock and reduce the yield and quality of some crops, while changes in rainfall patterns can cause long dry periods – droughts, or heavy rainfall can lead to flooding or waterlogging, which can reduce crop yields.
- Frequent and severe flash floods can damage crops, increase erosion and nutrient runoff, leading to reduced soil fertility and lower crop yields. Soil erosion can also be the result of increased wind in open landscapes.
- Changes in temperature and rainfall patterns are causing shifts in the distribution and behaviour of pests and diseases. This is leading to the emergence of new pests and diseases, and the spread of existing ones into new areas.

Benefits of HDLFs for on-farm adaptation to climate change

The maintenance or implementation of HDLFs on their farms can bring farmers numerous benefits regarding climate change adaptation on local level, with impact on regional or global climate conditions.

- **Improving water management and flood control:** Hedgerows can help absorb water during heavy rainfall, reducing the risk of flooding. Ditches can help prevent flooding by directing excess water away from crops and towards storage areas like ponds or retention basins. This can help reduce soil erosion and prevent damage to crops.
- **Protecting crops from wind damage:** Dry stone walls can act as a windbreak, reducing the impact of strong winds on crops or pasture. This can be particularly beneficial in areas that experience high winds or storms due to climate change.
- **Reducing soil erosion:** The protection of soil against erosion caused by wind or water is an essential function of HDLFs related to the improvement of water management and wind break. For maintaining soil fertility and crop productivity, it is important to prevent the loss of topsoil. Roots of trees and the vegetation in hedgerows hold the soil in place and prevent it from being washed away; dry stone walls and terraces can act as a barrier to reduce soil erosion caused by heavy rainfall or wind. Field margins and buffer strips can reduce the impact of wind and water on fields by slowing down the movement of water and reducing the impact of heavy rainfall on fields.
- **Soil moisture retention and water storage:** HDLFs help to retain moisture in soil by different functioning mechanisms. Ponds and ditches can help retain and buffer moisture in the soil and can be used to store water during periods of heavy rainfall. This helps farmers to better manage their water resources and ensure that crops have access to water even during droughts or periods of low rainfall. Dry stone walls and terraces can act as a barrier to slow down and retain moisture within the soil, trap moisture and increase the amount of water available for crops or pasture. Hedges can also help retain moisture in the soil during dry periods, which can be particularly beneficial in areas that are experiencing more frequent droughts due to climate change.
- **Nutrient management:** Field margins and buffer strips can help maintain soil health on farms by retaining nutrients in soil and preventing nutrient loss from fields into the water. This is particularly important in areas experiencing heavy rainfall or flooding due to climate change. Depending on the trees and plants used for woody HDLFs, they can potentially contribute to nutrition management by nitrogen fixation or enhanced availability of nutrients as a result of mycorrhiza.
- **Microclimate moderation:** HDLFs contribute to the moderation of microclimate, e.g. ponds increase humidity and reduce temperature fluctuations. This can help create more stable growing conditions for crops and reduce the risk of frost damage.
- **Benefits in relation to animal welfare:** Trees and hedgerows can provide shade to livestock in the event of heat waves, which can help keep them cool and reduce heat stress. As temperatures rise due to climate change, this becomes increasingly important.
- **Natural pest control:** Different HDLFs provide different wildlife habitats for a wide range of species and therefore support natural pest control.

Effects of HDLFs on biodiversity, climate change adaptation and mitigation

As a general effect, HDLFs foster natural pest control and pollinators and hence help to reduce the impact of new pests and diseases or altered pest dynamics due to climate change. Furthermore, production systems which are diverse, are more resilient and can better cope with abrupt changes of conditions such as drought and high temperatures. This applies to any considered scale: field, farm, region or food system (Tilman, 1999; Renard & Tilman, 2021). Traditional agricultural landscapes with terraces, small woodlands, conservation tillage, and riparian buffers are an example for a land use strategy which supports climate change adaptation and mitigation. Increasingly, the agricultural sector is investing in practices that use HDLFs more wisely for sustainable production while at the same time enhancing the natural resource base.

Traditional agricultural landscapes protect the soil from erosion, improve stream water quality, and mitigate climate change (Hriňová, Slovakia; author: Jana Špulerová)

In addition to these general interactions of biodiversity and climate change, different HDLFs deploy specific effects regarding climate change adaptation and mitigation. Examples of specific effects of HDLFs on biodiversity, climate change adaptation and mitigation are presented in Table 1.

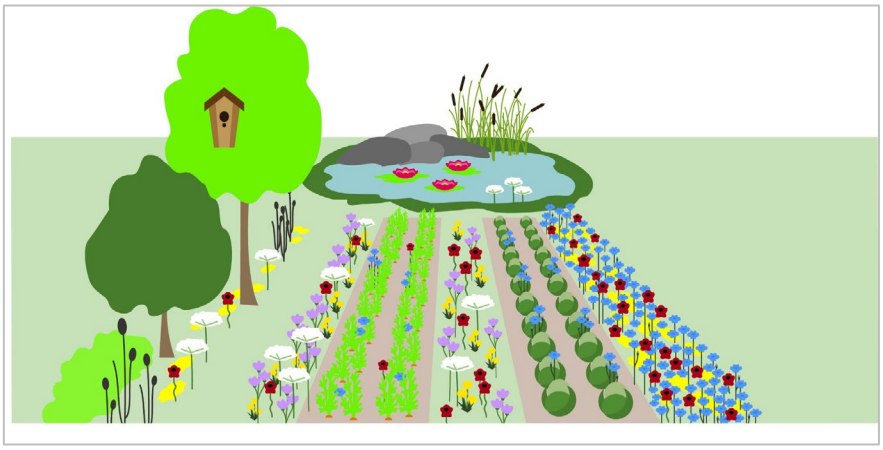
Table 1: Specific effects of HDLFs on biodiversity, climate change adaptation and mitigation

HDLF classes	Example for HDLF	Biodiversity	Adaptation	Mitigation
Woody features	Hedges in arable land	providing habitats, feeding sites, refuges, and corridors between habitats for invertebrates, birds, mammals, reptiles and amphibians, soil macro-and microorganisms	reduction of wind erosion, wind breaking, reduced evaporation of soils, shading	carbon sequestration in soils and wood

	Trees lines in permanent crops / Agroforestry systems	providing habitats, resources and corridors between habitats for birds and generalist invertebrates, lichens, fungi	reduction of erosion (wind/water), shading, efficient water use due to hydraulic redistribution	carbon sequestration in soils and wood, a potential could be the fixation of nitrogen by some trees resulting in a reduced nitrogen input
	Solitaire trees/ Group of trees on pastures and agropastoral systems	providing habitats, and resources for birds and bats, lichens	Shading for livestock and ground-vegetation, reduced heat stress	carbon sequestration in soils and wood
Grassy features	flower strips in crop cultures	retreat space and habitat for insects, reptiles, amphibians, …	Promotion of beneficial insects: they can help with the rising risks of disease and mass calamities	When done as perennial cultures, they can help build up humus and carbon sequestration.
	old grass strips on meadows	retreat space for insects, reptiles, amphibians, …	Parallel to the slope, they can have a positive impact on water retention in dry periods directly after mowing. Shadowing.	carbon sequestration through plant photosynthesis
	grassy terrace slopes	species rich habitats	water retention	carbon sequestration through plant photosynthesis
Wet features	Wetlands	Supporting aquaculture and grazing Providing habitat for harvestable (or not) plants and animal species Water supply for livestock	water retention providing shade, wind buffering, protection from floods assist in drought resilience, a key challenge for farmers	carbon sequestration through plant photosynthesis and by acting as sediment traps for runoff
	water drainage, ditch	habitats for dragonflies, amphibians, plants, underwater fauna, etc.	Water retention and regulation	cycling of nutrients
	Paludiculture	Increase in biodiversity; Probability of shift from xerophilic to hydrophilic species	Suppress further oxidation and prevent fires	Greenhouse gas emission savings, carbon storage
	Ponds	habitat for freshwater invertebrates and amphibians	water retention, reduction of erosion, feeding groundwater	less irrigation necessary, less energy/water input for irrigation
Stony features	stone walls	habitat for reptiles, spiders, others	Water retention and regulation, reduction of erosion; in future, crops may shift to colder climate regions. Stone walls can help to adjust the microclimate.	barriers/ slowing down the runoff

	terracing	Embankments often are meagre and offer habitats to rare plant species. Open floor spaces can be habitats for ground-breeding insects. Holes for mammals.	water retention and regulation, reduction of erosion	barriers/ slowing down the runoff

Sources : updated Boian et al., 2015



Some possible HDLF`s on a farm: woody, grassy and wet features (FiBL Suisse, Brigitta Maurer).

Old grass stripes during the hay season (author: Simona Moosmann)

Practical applications of HDLFs and good practice examples

Enhance water retention and regulation in agricultural landscape
Possible measures to improve the natural water retention in agricultural landscapes are: ponds, water retention reservoirs, ditches, landscape structuring, keyline design, and structures across the fall lines (e.g., hedges, greening stripes). The German Landcare Association collected best practice examples for water retention projects in Germany and their success factors (DVL, 2022).

In south-west Germany, there was a tradition called “Wuhren”: water ditches taken from a brook uphill and led parallel over meadows or pastures when needed. They were dammed to water the grassland in the spring to melt snow. This historic example could be revived as a good measure during dry periods.

Wetlands
Many current agricultural practices are reducing the need to use water from wetlands. Examples include the planting of drought resistant crop varieties, reusing water, including wastewater, and implementing more efficient irrigation.
The use of floodplains and rice fields has proven to be sustainable through millennia, as long as the degree of intensification and fertiliser and pesticide use remain within limits. Floodplain systems could be considered for growing flood-tolerant crop varieties.

Green infrastructure
The green infrastructure (GI) is being used as a tool to mitigate stormwater runoff by restoring natural ground cover, which allows precipitation to infiltrate into the soil. The green infrastructure tool mitigates stormwater runoff, increases the nutritional health of soil, and provides greenspaces. Currently, farmers consider implementation costs to outweigh potential—and often unknown benefits.

Paludiculture
Another essential nature-based solution is the rewetting of peatlands (that emit 25% of the total agricultural GHG emissions) combined with site-adapted land use, so-called paludiculture. Paludiculture produces biomass from wet and rewetted peatlands under conditions that maintain the peat body, facilitate peat accumulation, and can provide many of the ecosystem services associated with natural, undrained peatlands. The biomass can be used for a wide range of traditional and innovative food, feed, fibre, and fuel products (Lahtinen et al., 2022; Tanneberger et al., 2022).

The benefits of agroforestry for climate mitigation
A lot of HDLFs, such as shrubs, hedges, trees, and so forth, could also be part of agroforestry systems. When used as part of agroforestry systems, HDLFs can have multiple economic uses, including: timber, energy wood, the production of fruits, honey, nuts, mushrooms, etc. These multi-functional benefits are only recently becoming recognised among farmers. In the meantime, woody plants offer habitat to lots of organisms and can have a significant influence on microclimate and water management. The use of, e.g., trees as valuable timber or energy resources is a good mitigation strategy. Further recent information on HDLFs and their economic benefits is available in Final report of the EIP-AGRI Focus Group on Agroforestry (EIP AGRI FG on Agroforestry, 2017). There are also a variety of ecosystem services that HDLFs provide to agriculture. Sustainable farming practices that promote productivity while

maintaining ecosystem services recognise the interdependency between agriculture and healthy HDLFs and the potential for mutual benefit (EIP AGRI FG on Agroforestry, 2017).

Quantifying, modelling, and collecting data on carbon sequestration to better understand the benefits of HDLF

One of the good examples of quantifying carbon sequestration is the CarboCert project (CarboCert, 2023), which focuses on financing CO2 reduction in agricultural land. It offers the opportunity to offset CO2 footprint locally and has set itself the goal of using regional climate protection solutions (e.g., humus building, agroforestry, or climate-stable forest conversion) to strengthen and stabilise soil fertility, the resilience of agricultural habitats, and to use agriculture as a solution path to actively counteract climate change by creating carbon sinks.

The positive influence of HDLF can be observed immediately (Author: Simona Moosmann)

RESEARCH NEEDS

The integration of various HDLFs needs further research and innovative ideas focused on cost/benefit analysis; need for demonstration sites, research on precise effects of HDLFs on water retention, soil and microclimate. An overarching dimension relevant to all the sub-sections is the high context-specificity of these aspects (e.g., same tree/bush species can give good results in a given region, but perhaps not just a few kilometres further away). It is also important to consider the landscape dimension, including cooperation between farmers and the involvement of other actors (e.g., local authorities) and disciplines (e.g. landscape planning).

1. The cost/benefit analysis of HDLFs with regards to on-farm climate change adaptation

There are many general sources of information on various HDLFs and their benefits, as well as financial tools for greening the landscape through RDP, in the form of an eco-scheme or support for Agri Environment-Climate measures. However, implementation of these measures by farmers is very slow due to concerns about losing productive land and other management costs. The **challenge for further research** is the need for a cost-benefit analysis of HDLF with respect to on-farm adaptation to climate change and, in this way, to disseminate knowledge on the eco-economic benefits of HDLFs and eco-schemes and thus motivate farmers to adopt and be involved in eco-schemes through the CAP. Implementation of climate change adaptation or mitigation measures can provide multiple co-benefits to farmers. The **need for this research** is especially acute in intensively managed landscapes with a low proportion of HDLFs, e.g., lowland areas with highly productive soils at a **pan-European level**.

2. A need for demonstration sites/examples/good practices

Related to the previous issue, **the challenge for future research** is a lack of evidence for HDLF long-term benefits to ecosystem services and demonstration sites/examples/good practises (new ones, studying existing ones, establishing a "HDFL best practises" network or an "Innovation path of future HDFLs". The research study of future HDLFs has to focus on different benefits addressed to farmers in the yields, resilience, water balance, soil/below ground benefits and structures, impact of HDLFs on microclimate. There are estimations on ecosystem benefits but mainly for past scenarios, not really for future scenarios; in scope of climate changes, therefore the models needed. The **need for this research** is especially acute in intensively managed landscapes, with a low proportion of HDLFs – e.g., lowland areas with highly productive soils at a **pan-European level**.

3. Research on the exact effects of HDLFs on water retention, soil and microclimate

Probably not all of the effects of different HDLFs on water, soil and microclimate are well known and explored. Correlations between HDLFs regarding microclimate are yet not well known. In very dry conditions e.g. it may be hard to establish the first wooden features, but they themselves influence the water conditions and the second step might be easier. Some research results might not be well known among farmers. The **challenge for a scientific team** is to identify knowledge gaps and do more research as an interdisciplinary team. The results could be communicated to the farmer in a suitable way (see mini paper knowledge transfer). This way, farmers would know about the potential positive effects in the first place. This research can be conducted at a **Europe-wide level** and is **relevant** mainly to production farms facing water problems, soil destruction and droughts.

4. Research and an innovative idea for the integration of HDLFs in existing production systems

The integration of individual or combinations of HDLFs, including agroforestry elements, in existing production systems can potentially have positive effects regarding climate change adaptation, such as higher water holding capacity, erosion reduction, shading, and a reduction in heat. On the other hand, also trade-offs are conceivable, for example, competition for nutrients or effects on plant health. Furthermore, farmers are facing challenges regarding mechanisation possibilities, rising workloads, and costs without reliable data on economic benefits. The **challenge for further research** is to provide information on the practical implementation, including, e.g., suitable varieties for treelines or hedges, options to maintain mechanisation, effects on nutrient management and economic viability. For permanent crops, also the analysis of long-term effects of agroforestry on product quality is an important topic. The **need for research** is especially relevant for crops with specific production systems, such as permanent crops and vegetables and can be conducted **in different regions of Europe** or at a **Europe-wide level**.

IDEAS FOR INNOVATIONS

1. Create a cluster/network of farmers, scientists and policy makers

As climate change is one of the most significant megatrends because it targets whole continents and not just one country or farm, it is necessary to approach this issue on a national and global level and share knowledge between farmers, policymakers, and scientists. Therefore, this networking can bridge policy-practice-science and support knowledge sharing about “HDFL best practises" or an “innovation path of future HDFLs”, including new innovations as well as traditional ecological knowledge, such as the reactivation of traditional and reasonable measures such as the “Wuhren”.
The design of locally adapted green infrastructure conservation and development policies could be pursued.

2. Interdisciplinary network for agroforestry species in different farming systems

Agroforestry is an important technique when it comes to HDLFs on farmland and its positive effects on buffering climate change effects. But experts in forestry and agriculture often are not very well interconnected. Knowledge is very much bound to the different topics. Forest boundaries often lead to disputes over competence. As a result, agriculture experts often establish agroforestry systems without retrieving the existing forestry knowledge. A scientific network could bring existing knowledge together and make basic recommendations from different perspectives on tree and shrub species as well as on important planning issues. A network with forest scientists could build up on these results of the focus group on agroforestry (EIP AGRI FG on Agroforestry, 2017) with a focus on the species available in Europe. At the same time also the impact of agroforestry on the environment, especially underground water, and soil should be monitored.

3. A tool catalogue for water management measures for farmers, based on scientific results

When it comes to climate change adaptation, a lot of farmers first think of the water problems that have increased. The long dry periods in spring and summer affect all farming systems: grassland, cultivation of crops, water supply for animals, and so on. Also, long wet periods are a problem, for example, with fungi in plant cultivation or with trampling damage on pastures in animal keeping. A tool catalogue with measures to balance these effects under different farming circumstances could be a helpful tool for farmers to take action. New innovative methods of water retention in the landscape need to be explored and developed. HDLF can be effective as a measure, as shown in the table above. Farmers could test the measures and the catalogue to ensure a good practical implementation.

4. Implementation of HDLFs on a regional scale to improve water retention for example in flooding or very dry areas

An innovative cluster could bring together farmers in areas with only a few HDLFs and plan their establishment on a larger scale, together with experts on water balance, ecology, and biodiversity. Maybe it is possible to improve the water retention potential of larger areas than one farm if the group is able to include, for example, all farms along a small valley, brook, or on a mountain. The measures taken by single farms can add to each other and may strengthen the effect for the whole region.
In addition, tools could be developed to predict and model the period of inundation in riverine floodplains - the growing season could be geared toward the best performance given their waterlogging tolerance properties.

5. Living laboratory for testing of a reward system for climate change mitigation on farms

HDLFs might be interesting for farmers because they can help adapt to climate change effects. But is it possible to create a system that rewards mitigation? How would that work? How would effects be calculated, and how would farmers react to that offer? A group of farmers, scientists, officials, and advisers could test a rewarding system and identify the potentials and misleads of such a system on a local scale. This could be a template for a larger implementation of such a system, e.g., in the CAP.

HDLF can structure the landscape and therefore offer habitats for different species (Author: Simona Moosmann)

Conclusions

The interaction of HDLFs with biodiversity and climate change, especially the benefits regarding climate change adaptation and mitigation show that HDLFs can significantly contribute to climate change mitigation and adaptation in agriculture.
HDLF and the green infrastructure within agricultural landscapes strengthen the supply of ecosystem services, especially those relating to biodiversity, water, and climate targets. Climate, along with biodiversity, should be added as a major controller of population and ecosystem dynamics and structure, impacting species composition, disturbance, and nutrient supply (Tilman, 1999). Increasing HDLF and reforestation continues to be among the fastest and most affordable ways of removing atmospheric carbon (NFW, 2020).
The multiple performances of HDLF can also be evident for economic, agronomic, and social ecosystem services from different types of HDLF, including aesthetic and spiritual values, education, and recreation. Therefore, one of the research needs that we identified is the cost/benefit analysis of HDLFs with regard to on-farm climate change adaptation.

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