EUROPEAN CROP SYSTEMS: REGION-SPECIFIC RECOMMENDATIONS TO REDUCE ENVIRONMENTAL IMPACTS AND ENHANCE CLIMATE CHANGE MITIGATION

A visual guide

CLIMATE CROPPING

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EJP SOIL
European Joint Programme

ClimateCropping directly addresses Topic B outlined in the 2024 EJP SOIL Call Announcement by investigating soil management practices in the context of climate change, using data derived from long-term experiments. Its objectives are closely aligned with the national priorities on greenhouse gas mitigation in each partner country, and the project's outcomes have contributed to achieving both national and international climate goals, making it highly relevant to current climate change policies.

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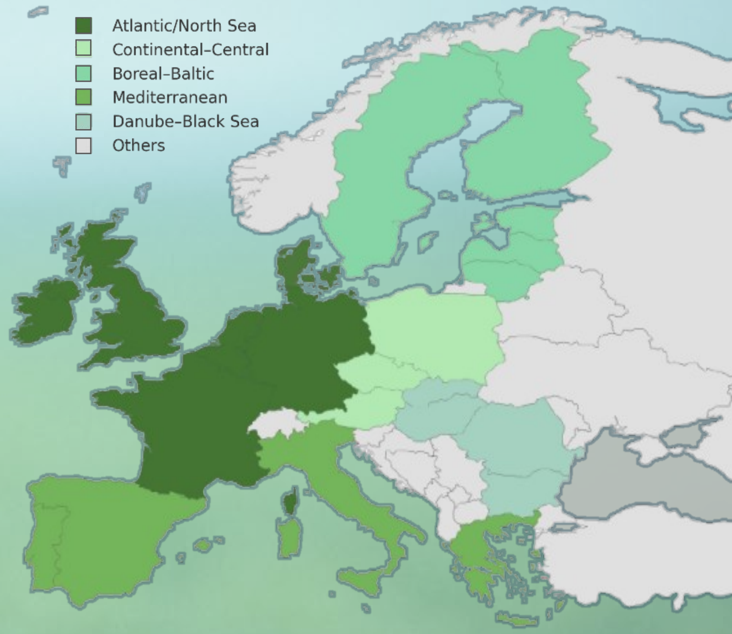
How to read this guide

Regions here presented reflect dominant European agro-climates and crops: Atlantic/North Sea, Continental–Central, Boreal–Baltic, Mediterranean, and Danube–Black Sea (SE Europe).

Key data by region: **Top 5 priority actions** (ranked), with indicative mitigation indicators, and co-benefits/trade-offs to manage.

Mitigation indicators are based on recent scientific syntheses (e.g., IPCC AR6, JRC, EEA, and major meta-analyses). These should always be validated through local trials and monitoring, reporting, and verification (MRV) systems before being applied at scale.



This map is a simplified approximation

Strengths of this scheme

- **Simplicity:** five clear categories, easy to map and explain.
- **Alignment with agronomy:** each zone really does have distinctive dominant crops and constraints (e.g. erosion in Med, peat soils in Boreal, high nitrogen inputs in Atlantic).
- **Overlap with EU Science:** similar clusters appear in FAO/EEA "agro-ecological zones" and in the EPPO/Eurostat regional groupings.

Limitations of this scheme

- **Not official:** EU and FAO generally use finer "Agro-ecological Zones" (AEZ), with 20+ classes based on climate + soil + terrain.
- **Borders are fuzzy:** transitions (e.g. from Atlantic to Continental across Germany/France, or between Continental and Danube) are gradual, not sharp.
- **Soil and altitude ignored:** mountain regions (Alps, Carpathians, Pyrenees) have unique agro-climates that don't fit neatly.
- **Regional crops overlap:** maize is grown in both Continental and Mediterranean; wheat is ubiquitous.

To access additional information, click on the "Read more" texts, the underlined texts, or the logos.

Some preliminary considerations

To meet its decarbonization commitment, the EU must accelerate action across all sectors to achieve climate neutrality by mid-century. This requires a rapid transition toward sustainable technologies, cleaner energy systems, and stronger coordination among Member States to ensure consistent progress. In agriculture, this involves promoting innovation, improving resource efficiency, and embedding climate action within rural development and the Common Agricultural Policy. Without more comprehensive and coordinated measures, progress toward the EU's long-term decarbonization objectives could slow, undermining both environmental ambitions and economic sustainability.

Laying the groundwork for climate-smart farming

Across Europe's main crop systems, the biggest, most reliable climate wins come from:

- Managing nitrogen better (4R, precision, inhibitors, legumes).
- Keeping soils covered (cover and catch crops, residue retention).
- Minimising soil disturbance where it fits (controlled traffic, reduced or strip tillage).
- Rewetting organic (peat) soils and shifting them to productive wet uses.
- Smart irrigation changes (drip or fertigation, deficit irrigation, alternate wetting and drying in rice).
- Integrating trees and hedgerows (agroforestry, field margins).

Together, these practices cut non-CO_2 GHGs (N_2O, CH_4), increase soil carbon, and reduce co-impacts like erosion, nutrient loss and water demand. Meta-analyses and EU assessments demonstrate significant mitigation effects from these measures when they are adapted to local climate, soil conditions, and crop calendars, and evaluated through robust MRV systems.

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European framework: Policies and funding opportunities

- **CAP 2023–27 eco-schemes** can fund cover and catch crops, precision fertilisation, agroforestry, hedgerows and carbon-farming pilots. Each Member State designs its own CSP, using a national menu of measures and interventions.

Read more...

- **EU Carbon Removals Certification Framework** (CRCF) establishes EU-wide quality criteria for certifying carbon farming removals, including soil carbon, agroforestry and biochar, supported by monitoring and reporting rules to ensure credible claims and trustworthy markets.

Read more...

- **EEA tracking.** Since 2005, agricultural non-CO_2 emissions (mainly methane from livestock and nitrous oxide from fertilizer use) have declined only modestly. Although improvements in nutrient use efficiency and manure management have contributed to mitigation efforts, increasing agricultural output and the limited adoption of sustainable practices have constrained further emission reductions.

Read more...

Region-specific recommendations

Atlantic / North Sea

Ireland, United Kingdom, coastal Germany, NW France, Belgium, Netherlands, Denmark

Cereals–oilseed–maize rotations with grass–clover pastures, potato, sugar beet, peas and beans, linseed, short-cycle soybean, vegetables, and energy crops

Humid oceanic, high rainfall, mild winters, cool summers, cloudy and windy conditions

TOP ACTIONS

Over-winter cover and catch crops, combined with residue retention, help reduce nutrient leaching and enhance soil organic carbon (SOC) stocks, showing a strong positive SOC response under European conditions. Termination timing should be carefully managed to prevent spring N_2O emission peaks.

Read more...

4R nitrogen management and precision application (optimizing rate, source, time, and place), including enhanced-efficiency fertilisers (e.g., nitrification inhibitors) where suitable conditions apply. Meta-analyses indicate substantial average N_2O emission reductions (around 30–40% or more), although results vary depending on site and management conditions.

Read more...

Conservation or strip tillage and controlled traffic farming on well-drained mineral soils help protect soil structure and reduce fuel use. The magnitude of benefits is context-dependent, but these practices are supported by recent Europe-focused research syntheses.

Read more...

Phase out conventional cultivation on organic (peat) soils and promote rewetting or paludiculture where feasible. These actions rank among the most effective and low-cost agricultural measures for achieving immediate GHG emission reductions in the region, particularly in the Netherlands and northern Germany.

Read more...

Hedgerows, field margins and agroforestry strips to sequester carbon and curb wind erosion, while enhancing long-term carbon storage and biodiversity.

Read more...

CO-BENEFITS/TRADE-OFFS

Cover crops help reduce nitrate losses, though wet winters can hinder spring seedbed preparation, so plan termination timing carefully. On peat soils, short-term CH_4 emissions after rewetting are generally offset by the much larger avoided CO_2 losses; selecting productive wet-adapted crops helps maintain farm income.

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Region-specific recommendations

Continental - Central

Central and NE France, central Germany, Poland, Czech Republic, Austria

Typical rotation: winter wheat – oilseed rape – winter barley – maize (or sugar beet)

Temperate continental climate with cold winters, warm summers, and moderate rainfall concentrated in the growing season

TOP ACTIONS

Diversified rotations including legumes (grain and forage types) and cover crops lead to proven increases in SOC and lower mineral fertiliser requirements. Integrating these systems with targeted spring nitrogen applications further enhances nutrient efficiency and overall soil health.

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4R nitrogen management together with nitrification or urease inhibitors in high-risk situations (e.g., wet soils or heavy N applications) consistently reduces N_2O emissions. Monitoring the partial nitrogen balance provides a robust indicator of nitrogen use efficiency and environmental performance.

Read more...

Reduced or strip tillage combined with controlled traffic farming helps preserve soil structure and stability, particularly on loess-derived or clay-rich soils. When drainage is adequate, these practices typically maintain or slightly increase crop yields while improving soil resilience and long-term sustainability.

Read more...

Landscape features such as hedgerows, buffer strips, and grassy margins helps reduce soil erosion, enhance biodiversity, and contribute to carbon storage in both biomass and soil organic matter. These elements also improve landscape connectivity and resilience to extreme weather events.

Read more...

Targeted biochar produced from clean biomass sources (such as prunings or manure) can improve degraded soils, particularly where local feedstock supply is available. These practices enhance soil structure, water retention, and carbon sequestration potential, and may qualify under emerging CRCF methodologies as they are formalized.

Read more...

CO-BENEFITS/TRADE-OFFS

Residue retention and reduced tillage can support soil health and carbon gains but may also increase slug pressure or disease risks; integrating robust IPM strategies helps manage these trade-offs. Similarly, nitrogen inhibitors can reduce N_2O emissions but, if poorly matched to local soils or timings, may raise NH_3 volatilization; selecting site-specific products and application windows is essential to balance these effects.

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Region-specific recommendations

Boreal - Baltic

Finland, Southern Sweden, Estonia, Latvia, Lithuania

Spring cereals (barley, wheat, oats) and oilseeds (rape, turnip rape), complemented by grain legumes and forage crops in rotation

Cool, moist climate with short growing seasons; cold snowy winters and mild, bright summers

TOP ACTIONS

Rewet peat soils and shift to wetland crops to stop large GHG emissions from drained peatlands while allowing the cultivation of wetland plants such as reeds or cattails, achieving one of the most effective short-term climate actions in the region and improving biodiversity and water retention.

Read more...

Use legume and grass–clover leys in crop rotations to build soil carbon, improve structure, and supply natural nitrogen, especially in areas where the short growing season limits the use of cover crops.

Read more...

Plant catch crops after early harvests to capture leftover nutrients from cereals like oats or barley, reducing nutrient losses to the environment and protecting soil condition for spring planting by ending growth early.

Read more...

Apply nitrogen precisely and efficiently by using moderate fertilizer rates, targeted placement, and timing based on field conditions, improving nutrient efficiency and lowering emissions, while using inhibitors strategically on wetter fields to prevent nitrogen losses.

Read more...

Plant shelterbelts and hedgerows to reduce wind and soil erosion, store carbon, and create habitats for wildlife, helping fields become more resilient to extreme weather and maintaining favorable local microclimates.

Read more...

CO-BENEFITS/TRADE-OFFS

While some rewetted sites may experience short-term CH_4 pulses, the long-term avoidance of CO_2 emissions from peat oxidation greatly outweighs these effects. Well-designed water-level management and the development of productive wetland uses, such as biomass harvesting, grazing, or ecosystem service payments, can help balance climate mitigation goals with farm income and local livelihoods.

Read more...

Region-specific recommendations

Mediterranean

Spain, Portugal, Italy, Greece

Olive groves, vineyards, citrus, irrigated maize/ sunflower

Mild, wet winters and hot, dry summers, with seasonal rainfall and high evapotranspiration driving drought-adapted agriculture

TOP ACTIONS

Permanent or seasonal cover crops in orchards and vineyards, using grasses, legumes, or organic mulches combined with low-tillage inter-row management, provide strong evidence of increasing SOC while dramatically reducing erosion, provided that water competition is controlled through appropriate species selection and timely termination.

Read more...

Smart irrigation strategies, integrating drip systems and fertigation (including microfiltered slurry where available) with regulated deficit irrigation, can maintain maize and sunflower yields while significantly lowering N_2O emissions and overall water footprints, especially when coupled with nitrification inhibitors in high-risk conditions.

Read more...

Methane mitigation in rice systems of the Po Valley and Ebro Delta could be achieved through alternate wetting and drying, which reduces CH_4 emissions by approximately 30–70% without yield penalties when irrigation cycles are carefully monitored and managed.

Read more...

Legume rotations and organic amendments, including composted pruning residues and targeted biochar, contribute to SOC stabilization, improved nutrient cycling, and enhanced drought buffering capacity, thus supporting long-term soil health.

Read more...

Erosion control on sloping lands through contour farming, terracing, and hedgerow establishment prevents soil loss, consolidates carbon gains, and strengthens both fertility and landscape resilience.

Read more...

CO-BENEFITS/TRADE-OFFS

In dry years, cover crops may compete with the main crop for water, requiring flexible, season-specific management based on rainfall balance, soil depth, and irrigation access. Early termination can minimize competition while preserving soil structure and carbon gains. Recent Mediterranean research highlights the need for precise, site-adapted cover crop management supported by soil moisture monitoring and adaptive scheduling to balance ecosystem benefits and yield stability.

Read more...

Region-specific recommendations

Danube - Black Sea

Romania, Bulgaria, Hungary, Slovakia

Barley, rapeseed, soybeans, sugar beet, potatoes, alfalfa, and clover

Wheat, maize, sunflower, barley, rapeseed, soybeans, sugar beet, potatoes, alfalfa, and clover

TOP ACTIONS

Diversified rotations, including pulses and summer cover crops after early-harvest cereals, improve soil protection, enhance biological nitrogen fixation, and reduce nutrient losses. Such rotations extend the period of soil cover, limit erosion and fallow exposure, and increase overall system resilience to drought and climatic variability.

Read more...

Reduced or strip tillage with residue retention helps conserve soil moisture, protect SOC, and sustain microbial activity. Combining this with controlled traffic farming minimizes compaction, optimizes infiltration, and maintains root zone structure, key to improving water-use efficiency and long-term soil health.

Read more...

4R nitrogen management, together with nitrification or urease inhibitors, is recommended in maize and sunflower systems where fertilizer rates and N_2O emission risks are high. Monitoring through partial nitrogen balance allows adaptive fine-tuning of applications, improving nitrogen-use efficiency while minimizing environmental losses.

Read more...

Drip irrigation and fertigation, or regulated deficit irrigation in areas with existing infrastructure, enable precise nutrient and water delivery, improving yield per unit of water and reducing leaching. Upgrading to modern, water-saving systems should be prioritized as a climate adaptation measure in regions with recurrent droughts.

Read more...

Shelterbelts, hedgerows, and riparian buffers reduce erosion, enhance biodiversity, and act as long-term carbon sinks through woody biomass and soil organic matter, while improving microclimate and landscape connectivity in open farmlands.

Read more...

CO-BENEFITS/TRADE-OFFS

Measures that enhance soil cover, optimize nutrient and water use, and integrate landscape elements build resilience and reduce emissions. However, they also require adaptive management, investment, and sometimes changes in crop choices or markets. Balancing short-term economic pressures with long-term soil and ecosystem health remains a key challenge. Overall, these transitions strengthen both farm productivity and regional climate resilience.

Read more...

Crop-system specific highlights

Cereals / Oilseed rotations *(Temperate Europe)*

Use winter cover crops and legume breaks to protect soils and add nitrogen; apply 4R nutrient management with inhibitors on wet, high-risk fields; adopt strip or slot tillage to retain residues; establish hedgerows or field margins for erosion control and biodiversity.

Long bare fallows and unnecessary spring tillage, especially on wet or compact-prone soils.

JRC and EU syntheses show consistent SOC gains and 10–30% lower N_2O emissions under diversified, reduced-tillage systems.

Irrigated maize and *sunflower (Mediterranean/SE Europe)*

Implement drip fertigation with synchronised nitrogen delivery (including microfiltered slurry where feasible); consider regulated deficit irrigation (75–85% of full irrigation) to enhance water-use efficiency; combine with nitrification inhibitors in high-risk conditions.

Excessive irrigation or surface flooding that triggers N_2O losses and nutrient leaching.

Multiple Mediterranean studies show 20–40% N_2O reduction and stable yields under optimised fertigation schedules.

Vineyards and olive groves *(Mediterranean)*

Maintain inter-row cover crops or mulches with minimal tillage; compost and reincorporate pruning residues; build contour hedges or terraces on slopes; and apply spot-drip irrigation for efficiency.

Continuous bare soil management and deep tillage that accelerate erosion and SOC loss.

Long-term European trials report strong SOC accumulation and up to 80% erosion reduction; adaptive termination of cover crops prevents water stress.

Rice systems *(Italy, Spain, Greece)*

Apply alternate wetting and drying with water-tube monitoring; coordinate irrigation schedules at district level; and adjust nitrogen fertilisation timing to minimise N_2O peaks.

Continuous flooding without monitoring, which increases CH_4 emissions.

Controlled alternate wetting and drying typically cuts CH_4 by 30–70% with no yield penalty.

Crop-system specific highlights

Cropland on organic soils *(Northern / Baltic Europe)*

- ✔ Implement rewetting combined with paludiculture (e.g. reed, cattail, sphagnum) to stop CO_2 losses while maintaining productivity; use CAP or national restoration funds for water-level regulation.
- ✘ Partial drainage or continued cropping on oxidised peat.
- ☞ Rewetting rapidly lowers CO_2 emissions (>20 t CO_2-e ha^{-1} yr^{-1}) compared to drained status quo.

Root Crops - sugar beet, potato
(Central / Northern Europe)

- ✔ Integrate cover crops post-harvest to prevent erosion; use controlled traffic farming to limit compaction; and adopt precision N and irrigation scheduling.
- ✘ Late autumn tillage or leaving soils bare during wet periods.
- ☞ Trials across Germany, France and Poland show 15–25% SOC improvement with winter cover and improved traffic management.

Grasslands and forage systems
(Temperate / Continental Europe)

- ✔ Maintain permanent grass cover with optimized grazing intensity; reseed degraded swards with legumes; and apply targeted organic amendments to stabilise SOC.
- ✘ Overgrazing or frequent ploughing of long-term grasslands.
- ☞ SOC accumulation rates of 0.3–0.6 t C ha^{-1} yr^{-1} observed under improved grazing and fertilisation balance.

Case study: Conservation agriculture transition in the Po Valley

In the Po Valley (northern Italy), a region characterized by intensive maize and wheat cultivation, long-term field trials conducted by the University of Padova examined how different tillage intensities and soil cover management practices influence key physical soil properties. These experiments provide valuable insights into the long-term sustainability of conventional versus conservation-oriented soil management systems under the temperate continental climate of northern Italy.

More precisely,, they compared three systems: i) **conventional ploughing**, ii) **strip tillage**, and iii) **no-tillage**, combined with cover crops and residue retention, as part of a multi-year transition to conservation agriculture.

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A significant improvement

The study found that reducing tillage intensity led to significant improvements in soil structure and stability:

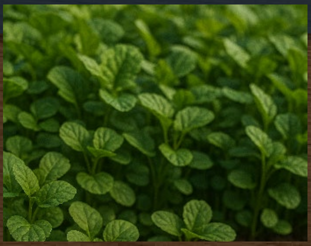
- **Aggregate stability increased**, reducing soil erosion risk.
- **Bulk density decreased**, improving aeration and root penetration.
- **Water infiltration and storage capacity improved**, enhancing drought resilience.
- **Soil organic matter content increased**, especially in the topsoil layer (0–30 cm).

Conservation agriculture improves soil quality and physical resilience, helping farms adapt to Mediterranean–continental climates. While GHG emissions weren't directly measured, the observed gains in organic matter and soil structure suggest greater carbon sequestration and lower emissions from fuel use, aligning with similar studies in the region.

Several authors have estimated that long-term conservation agriculture practices in the Po Valley can increase SOC by 0.3–0.4 t C ha^{-1} yr^{-1} and reduce soil erosion by 60–70%.

Together, these findings confirm that transitioning to conservation agriculture in the Po Valley contributes to both climate mitigation (through SOC build-up and lower energy use) and climate adaptation (through improved water and soil structure), aligning with the goals of the EU Green Deal and Soil Mission.

Indicative mitigation strengths
(what the evidence says)



Cover and catch crops consistently increase SOC across European climates by improving root biomass inputs, reducing erosion, and extending vegetative cover. A JRC meta-analysis estimates average sequestration rates of 0.32 t C ha^{-1} yr^{-1} (1.2 t CO_2e ha^{-1} yr^{-1}), with wide variability depending on soil type, rainfall, and management intensity. The practice is most effective where bare fallow is replaced and cover crops are terminated at appropriate times to minimize water competition.

Read more…

Nitrification inhibitors and enhanced-efficiency fertilisers. Meta-analyses report 30–40% reductions in N_2O emissions compared with conventional nitrogen fertilizers, primarily through delayed nitrification and improved synchronization with crop uptake. Their performance depends strongly on soil temperature, moisture, and timing of application. Integration within 4R nutrient management and targeting high-risk zones maximizes mitigation potential while maintaining yields.

Read more…

Conservation and strip tillage. European syntheses show measurable reductions in CO_2 emissions and gains in SOC when practices are well adapted to local soil–climate conditions. The benefits are greatest on well-drained, erosion-prone soils, where residue cover protects against carbon loss, whereas outcomes are less consistent under cool or waterlogged conditions. Controlled traffic systems further enhance carbon retention and soil structure stability.

Read more…

Agroforestry, shelterbelts, and hedgerows provide durable carbon storage in woody biomass and belowground pools, while delivering co-benefits such as biodiversity, erosion control, and microclimate buffering. Recognised across the EU as a high-value, multi-benefit mitigation option, these systems are particularly suited for field margins, riparian zones, and wide-row crops (orchards, vineyards). They align with CAP greening and EU biodiversity strategies.

Read more…

Alternate wetting and drying in rice has demonstrated CH_4 emission reductions of 30–70% relative to continuous flooding, with negligible yield loss when water control is precise. Potential trade-offs include temporary N_2O increases and arsenic mobilization, but these can be mitigated through timing adjustments and field monitoring. Effective primarily in controlled irrigation schemes such as the Po Valley and Ebro Delta.

Read more…

Rewetting of cropland peat soils offers large and immediate CO_2e reductions compared to drained peatland management, by halting oxidation of organic matter. However, rewetting can increase CH_4 emissions, making paludiculture (productive wetland crops such as reed, cattail, or sphagnum moss) a preferred option to balance mitigation and continued land use. Long-term monitoring is needed to ensure net GHG benefit and hydrological stability.

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Practical implementation notes

Plan–Do–Check–Act with MRV

Implementing mitigation practices requires a continuous Plan-Do-Check-Act cycle. As emphasized in IPCC AR6, robust MRV systems are essential to ensure credibility and to avoid overestimating soil carbon gains. This means setting harmonised baselines, carrying out depth-explicit soil carbon sampling (since carbon content can vary significantly with depth), and collecting accurate activity data on management type, duration, and intensity. Transparent MRV not only strengthens data reliability but also supports access to carbon markets and climate-finance incentives.

Target the hotspots first

Mitigation efforts should focus first on emission hotspots, where climate benefits are largest per unit area. These include:

- Wet soils with high nitrogen inputs, which drive N_2O emissions.
- Drained organic soils (cropland peatlands), major sources of CO_2 through oxidation of soil organic matter.
- Flooded rice systems, key emitters of CH_4.
- Erodible slopes, where SOC losses are high.

European Environment Agency inventories and JRC emission factors can help identify and prioritise these critical zones to maximise mitigation efficiency and resource use.

Use CAP eco-schemes to de-risk adoption costs

CAP eco-schemes provide an important mechanism to reduce the upfront costs and financial risks of adopting sustainable practices. These payments can support:

- Cover crop and legume seeding to enhance soil fertility and structure.
- Precision agriculture technologies for efficient nutrient and water use.
- Hedgerow establishment, shelterbelts, and agroforestry systems, which deliver long-term carbon storage and biodiversity benefits.

Actions should be designed in line with national CAP Strategic Plan rules to ensure consistency with EU climate and sustainability objectives.

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