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The FarmForward Project: Sustainable and Transformative Strategies for Climate-Resilient Agriculture in VET

WP2

Climate-Resilient Farming Handbook

Handbook 4

Understanding Climate Change & Its Impact

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QUALIFICATIONS AND
VOCATIONAL EDUCATION
AND TRAINING
DEVELOPMENT CENTRE



The FarmForward Project: Sustainable and Transformative Strategies for Climate-Resilient Farming in VET

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Table of Contents

Introduction	4
Learning Objectives.....	5
Climate System Essentials	7
Communicating Climate Science	10
Agro-Climatic Stressors & Pathways	15
Pests, Weeds & Diseases Under Change	18
Livestock Impacts	19
Soil & Water Implications	21
Farm Economics & Risk	24
Self-Assessment Questions.....	27
Annexes	28
Glossary	28
Abbreviations.....	30
References	31

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Introduction

Climate change is no longer a distant or abstract topic for agriculture. It is increasingly shaping everyday decisions on farms: when to plant, how to manage water, how to protect animals during heat, which varieties to choose, and how to cope with greater uncertainty in yields and costs. Across Europe, observed warming and changes in rainfall patterns are already influencing the timing of seasons, the frequency of heatwaves, the likelihood of drought and wildfire, and the intensity of heavy rainfall events (IPCC, 2023; EEA, 2024).

This module gives VET educators and trainers a shared and practical baseline on what climate change is (and is not), and how it affects farming systems through clear cause-and-effect pathways. The aim is to provide science that is accurate and credible, but also remain accessible for trainers who need to explain climate-related risks in agricultural education.

FarmForward recognises that climate-resilient farming requires not only new practices on farms, but also strong teaching materials and educator confidence. This module is designed to help trainers connect climate information to concrete decisions on the ground and to support learners in analysing risks using evidence rather than assumptions.

By the end of this module, educators should feel confident to:

- explain key climate concepts clearly (weather vs climate, greenhouse effect, greenhouse gases, trends, extremes, uncertainty);
- describe the main pathways of impact on crops, livestock, soils, water, pests/diseases, and farm finances;
- help learners practise analysing climate risks using evidence (records, observations, trusted summaries) rather than assumptions.

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The following modules build on this foundation: moving from what is happening to what might happen next, and what we can do about it.

Teachers are urged to generally start local in their approach, then zoom out. Begin with learners' lived experience (e.g., 'What has changed on farms in the last 10 years?'), then connect those observations to wider climate trends. Use local weather records or recent news headlines to make concepts concrete, but always distinguish weather events from long-term climate change. And most importantly, keep the tone optimistic and solution-focused: recognising risks is the first step towards adaptation and resilience.

Learning Objectives

The learning objectives below are written for educators and trainers.

- 1. Explain key climate drivers and concepts (weather vs climate, greenhouse effect, greenhouse gases, uncertainty, extremes).** Learners can define the terms in plain language, interpret a simple climate graph, and explain why a single extreme event does not 'prove' or 'disprove' climate change.
- 2. Describe major agro-climatic stressors relevant to European farming (heat, drought, heavy rainfall/flooding, frost risk, wind, wildfire).** Learners can link each stressor to at least two crop or livestock impacts and can identify which stressors are most relevant for their region.
- 3. Map direct and indirect impacts on crops, livestock, soils, water, pests/diseases, and farm economics.** Learners can draw a simple impact pathway from a climate hazard to farm outcomes and propose one monitoring indicator per pathway.
- 4. Link climate risks to key farm decisions (inputs, rotations, varieties/breeds, water planning, markets, labour).** Learners can analyse a short farm scenario

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and suggest optimal adjustments that improve resilience across multiple possible futures.

5. **Debunk common misconceptions and communicate climate evidence clearly to different audiences.** Learners can identify misleading claims, explain the evidence respectfully, and choose appropriate visuals or analogies for farmers, consumers, or policymakers.

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Climate System Essentials

A clear vocabulary creates a baseline of communication between trainer and learners, helping discussions related to climate headlines and ‘farm talk’. It is best for the trainer to strive for a balance between scientifically accurate and accessible to a wide range of learners:

- **Weather** is what happens day to day; climate is the long-term pattern of weather over decades. Agriculture is sensitive to both. A wet week can delay harvest (weather), while a long-term shift in rainfall seasonality can change which crops are viable (climate).
- **The Earth’s climate** is influenced by natural factors (such as volcanic eruptions) and by human activities. The dominant driver of recent global warming is the increase in greenhouse gases from burning fossil fuels, land-use change, and some industrial and agricultural activities (IPCC, 2023).
- **Key greenhouse gases** (GHGs) include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). These gases trap heat in the atmosphere. The heat-trapping effect is natural and essential for life; the problem is that human activities have increased greenhouse gas concentrations, strengthening the greenhouse effect: the trapped heat increases the earth’s temperature.
- For **agriculture**, it is useful to **separate**: (1) long-term trends (e.g., warming), (2) variability (good and bad years), and (3) extremes (events beyond typical conditions). Extremes can matter as much as averages: a short heat spike during flowering can reduce yield even if the seasonal average looks ‘normal’ (Hatfield & Prueger, 2015).
- **Uncertainty is not ignorance.** Climate projections use multiple models and scenarios to show a range of plausible futures. Even when the exact value is uncertain, the direction of key risks (e.g., warming and increased heat extremes)

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can be clear enough to support planning (IPCC, 2022). Simultaneously, knowing just how much you don't know something for certain can be useful information.

What climate change practically means for farmers is a change in the conditions within which farming takes place. Farmers have always dealt with variable weather, but climate change alters the background pattern behind that variability. This means that familiar risks may become more frequent, appear at different times of year, or combine in ways that are harder to manage. For agriculture, specifically, the difference is vital: a single dry month may be manageable within a normal season; a long-term rise in temperature, combined with less reliable rainfall and higher evaporative demand, can gradually change the suitability of land for certain crops or production systems.

Greenhouse gases differ in their sources, lifetimes, and effects, and this is useful for trainers to explain in simple terms. Carbon dioxide remains in the atmosphere for a long time and is strongly linked to fossil fuel use and land-use change. Methane has a shorter atmospheric lifetime but a strong warming effect, and agriculture is an important methane source, through the animals' digestive functions and management of their manure. Nitrous oxide is especially relevant to farming because it is associated with nitrogen fertilisers, manure, and soil processes. The abovementioned facts place agriculture in a special position: it contributes to emissions, but is also highly exposed to the consequences of warming (IPCC, 2023).

A useful theoretical distinction for this module is the difference between average change and threshold effects. Many agricultural systems do not respond to climate stress in a linear fashion, where for example the more you raise the temperature the more the crops are damaged. Rather what holds true is that agricultural systems display threshold effects. That is to say, a crop may grow normally until, during the flowering phase, a critical temperature is reached; research on wheat responses to rising temperatures shows how sensitive production can be around key development stages (Asseng et al., 2015). Or animals may cope with warm conditions, until a combination

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of humidity, night-time temperature, and poor ventilation suddenly becomes an obstacle to the animals' recovery. Or soil may absorb rainfall well, until an intense storm causes the rain to exceed the soil's infiltration capacity. Such threshold effect phenomena explain why small changes in climate averages can produce huge changes in agricultural outcomes. They also explain why extreme events receive so much attention in climate-risk assessment.

Uncertainty should be treated as part of climate knowledge rather than a shortcoming of science. Climate projections contain inherent uncertainty, because it is impossible to know exactly the conditions of the future, such as emissions, regional climate responses, and local data. Farmers already make most of their decisions under uncertainty: prices, pests, rainfall, labour availability, and input costs all vary outside of their control. Climate information helps farmers measure that uncertainty, so the information can still improve judgement. For trainers, the main point is that measured uncertainty is a tool for better, more flexible planning, especially where a decision has long-term consequences, such as investment in irrigation, drainage, buildings, orchards, or livestock housing (IPCC, 2022).

Regional differences also matter. A statement such as "Europe is warming" is too general: warming does not affect all farms in the same way. For instance, mediterranean areas may face stronger pressure from heat, drought, water scarcity, and wildfire; areas that are more continental may experience a mixture of warmer growing seasons, altered frost patterns, summer drought episodes, and intense rainfall; northern areas may see some new production opportunities, but these can be accompanied by new pests, wetter soils, or infrastructure challenges (Challinor et al., 2014). Climate change is a process that is far from uniform, and trainers should therefore present it as a set of uneven regional pressures.

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Communicating Climate Science

Teaching climate change in agricultural settings often involves strong opinions between students and/or information overload. A trainer should remain as neutral as possible: strive to cultivate climate literacy in learners so that they can make better decisions regarding their farming; at the same time, avoid tendencies that emerge in any debate, such as needing be right, wanting to always win the argument, or trying hard to prove that you are knowledgeable.

Three communication principles (especially useful in VET contexts)		
Connect to values and decisions!	Use clear visuals!	Address misconceptions respectfully!
Farmers care about: • reliability • risk • practicality. Frame climate information around decisions they already make, like decisions regarding irrigation scheduling, variety choice, housing ventilation.	Simple graphs of local trends, seasonal calendars, and risk matrices are more effective than technical model outputs. Visuals also help explain probability and uncertainty.	Common misconceptions: <i>'the climate has always changed'; 'CO₂ is plant food – more is always better'; 'one cold winter means warming stopped'.</i> Acknowledge the kernel of truth (e.g., natural variability), then add the missing context (rate of change, extremes, system limits) (IPCC, 2023).

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Myths vs Facts (but respectfully)	
Misconception claim:	Respectful response:
<i>"This year was wet – so drought isn't a problem."</i>	Weather swings will continue, but climate change can still increase drought risk by raising evaporation and shifting rainfall patterns. Focus on long-term trends and seasonal distribution.
<i>"CO₂ helps plants, so climate change will boost yields."</i>	Some crops can respond to higher CO ₂ , but benefits are often limited by heat, water stress, nutrient limits, and pests. Also, in some cases, crop quality can decline under higher CO ₂ (IPCC, 2022).
<i>"Farmers can't do anything about climate change."</i>	Farmers can't control global emissions alone, but they can reduce risk and increase resilience through 'no-regrets' measures: soil cover, water efficiency, diversification, and better monitoring (FAO, 2013).
<i>"Models are unreliable, so projections are useless."</i>	Models are not perfect, but they consistently show the direction of key risks (warming, more heat extremes). Planning for a range of outcomes is standard risk management.

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Teaching technique: CER (Claim – Evidence – Reasoning)

Use the acronym 'CER' to remember this general teaching structure. CER is especially useful for debates, when you need to keep discussions evidence-based and constructive, and to avoid heated and unproductive exchanges.

Remember to always:

(C): **Claim:** Make a factual statement (e.g., 'heatwaves are becoming more frequent').

(E): **Evidence:** Present a chart, dataset, or trusted summary (e.g., IPCC/EEA).

(R): **Reasoning:** Explain why the claim is supported by the evidence, and what that means practically for farming.

Climate communication in agricultural education must be something more than the learning-by-heart of scientific facts. Trainers often work with learners who already have strong impressions of climate change, based on family experience, media narratives, political debates, or recent weather events. Some of these impressions may be accurate; others may be incomplete. A trainer's task is to create enough shared understanding for meaningful discussion. This requires careful language. Terms such as "risk", "trend", "projection", and "extreme event" should be explained before they are used to support larger arguments. Careful language is required since climate communication research shows that reception of information is shaped by audience, framing, and context (Moser, 2010).

One difficulty is that climate change is visible and at the same time invisible: the change hides in the form of invisible patterns of climate behind the visible everyday weather. Trainers must strike a balance between local experience and scientific data: while local examples make the issue credible for farmers, scientific summaries prevent discussions that depend only on memory, or anecdote, or simply emotion. A

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wet year, a cold week, or one successful harvest does not really change the pattern of a long-term trend.

Misconceptions are usually less effective when met with corrections, and more effective when addressed with explanations. The statement “the climate has always changed” contains an element of truth, since Earth’s climate has varied throughout history. The missing issue is the speed, cause, and present-day consequences of current warming. The statement “CO₂ helps plants” also contains a partial truth, since carbon dioxide can support photosynthesis in some conditions. The missing issue is that plant growth also depends on water, nutrients, temperature limits, pest pressure, and crop quality.

While there is a natural tendency in all of us to treat misconceptions as simple indicators of ignorance, trainers should remember that these misconceptions are made up of fragments of correct information placed in the wrong context (IPCC, 2022; IPCC, 2023). At the same time, climate-sceptical attitudes can become stronger when new evidence is filtered through existing beliefs (Corner et al., 2012). For these reasons it is preferable to work with the fragments of correctness rather than focusing on the ignorance; the latter often triggers emotional resistance in the learner.

Scientific confidence is another useful idea for trainers to explore. Climate science does not assign the same level of certainty to every claim. Some findings are very well established, such as the warming influence of greenhouse gases and the observed rise in global temperature; other findings, especially local changes in rainfall or pest behaviour, may be more variable. This does not make them useless. It means they should be discussed with appropriate caution and the corresponding level of uncertainty tied to each finding. Understanding that scientific data can have varying levels of certainty cultivates their critical thinking.

The tone of climate communication matters because climate change can easily produce defensiveness or fatigue. Understandably, agricultural learners may feel a

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personal emotional investment in the issue which can hinder discussions. It is more constructive to frame climate change as a complex issue, basing your arguments in agriculture science while simultaneously examining that science critically.

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Agro-Climatic Stressors & Pathways

Agro-Climatic Stressors are the climate-related conditions that directly affect farm production and the environment. The same amount of warming can produce different outcomes depending on soil type, water access, crop choice, and management. This section helps educators teach *impact pathways*, i.e., the chain from 'hazard' to 'biophysical process' to 'farm outcomes'.

Key stressors for agriculture include heat stress, drought and soil moisture deficits, heavy rainfall and flooding, shifting frost risk, windstorms, and wildfire risk (IPCC, 2022; EEA, 2024). Examining some stressors in more depth:

- **Heat stress** affects crops through reduced photosynthesis, accelerated development, poor pollination, and lower grain or fruit filling. Critical windows (flowering, fruit set) are often the most sensitive (Hatfield & Prueger, 2015). In livestock, heat stress reduces feed intake and productivity and can compromise welfare (Renaudeau et al., 2012).
- **Drought** means lack of accessible water to the crops, but that is not caused only by low rainfall. In higher temperatures, evapotranspiration increases, which means that crops can experience water stress even in years with average rainfall if evaporation is high. Teaching learners to think in terms of soil-water balance (inputs, storage, losses) is more useful than focusing on rainfall totals alone.
- **Heavy rainfall** can cause erosion, nutrient losses, and waterlogging. Waterlogged soils reduce root oxygen and can increase disease pressure. Intense downpours can therefore harm farms both in the moment (flooding) and later (soil structure decline) (Panagos et al., 2015).
- **Phenology shifts** (changes in timing) can affect the whole farming calendar: earlier budburst can raise spring frost damage risk; changing flowering time can create mismatches with pollinators, machinery availability, or labour.

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Impact Pathway Maps

(example templates)

Biophysical process →	Farm outcome!	← What to monitor
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scenario: *Heatwave during flowering*

Reduced pollen viability; faster development	Lower yield; quality loss	Heat days; flowering dates
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scenario: *Long dry spell & high temperatures*

Soil moisture deficit; high evapotranspiration	Yield variability; irrigation costs	Soil moisture; ET; allocations
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scenario: *Intense rainfall event*

Runoff and erosion; waterlogging	Soil loss; delays; nutrient loss	Rain intensity; cover; infiltration
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scenario: *Milder winter*

Higher overwinter survival of pests	Earlier/larger outbreaks	Traps/scouting; degree-days
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Agro-climatic stressors rarely occur in isolation. For instance, a heatwave may coincide with low soil moisture; heavy rainfall may arrive after a long dry period, when soil surfaces are less able to absorb water; milder winters may increase pest survival, while warmer springs can bring crops and pests into sensitive stages at different times. Such combinations of stressors are often called *compound risks*. They are important in farming because damage possibly done is based on both timing and stressor interaction alike. Practically speaking, the same rainfall total can be helpful or harmful depending on when it falls, how quickly it falls, and what condition the soil is in.

Heat stress in crops is closely linked to growth stage. During vegetative growth, high temperature may accelerate development and reduce the time available for biomass accumulation. During flowering, heat can interfere with pollen viability, fertilisation, and fruit or grain set. During grain filling or fruit development, heat may shorten the filling period and affect quality. Trainers should emphasise this timing issue because annual averages can hide the real risk: a season may appear acceptable in broad climate terms while still containing a damaging heat episode during a sensitive crop window (Hatfield & Prueger, 2015).

Drought should be explained as a relationship between water supply and water demand. Rainfall is only one side of the problem. Some factors that influence how quickly water is lost from the soil-plant system include the following: higher temperatures, stronger winds, solar radiation, soil texture, rooting depth, crop stage; which is why agricultural water management in Europe is increasingly treated as a climate-adaptation issue (Iglesias & Garrote, 2015). This is why a farm can experience drought stress even when annual rainfall does not look extremely low. The concept of evapotranspiration (see Glossary) is useful here, because it connects atmospheric demand with crop water use, and it also helps trainers explain why warming can intensify water stress even without a dramatic drop in rainfall.

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Heavy rainfall affects farms through several pathways. Surface runoff can remove topsoil, organic matter, fertilisers, and pesticides from fields. Waterlogging can reduce oxygen around roots, delay field operations, and increase the risk of some diseases. Flooding can damage infrastructure, contaminate water sources, and create animal-welfare risks. In many European regions, the concern is not simply the quantity of rain, but the patterns of rainfall quantity within a time period: for instance, longer dry spells interrupted by more intense downpours (EEA, 2024; Panagos et al., 2015).

Phenology is one of the clearest ways to show that climate change affects the farming calendar. Warmer conditions can bring earlier budburst, flowering, pest emergence, and crop development. Earlier development may appear beneficial at first, especially where it lengthens the growing season. Yet it can also expose crops to late frosts, disturb synchronisation with pollinators, or shift harvest and labour needs. Trainers should present phenology as a timing system. When climate changes, the timing of biological events changes too, and farm management has to interpret those changes carefully.

Pests, Weeds & Diseases Under Change

Changing temperatures and rainfall can alter conditions regarding pests, weeds, and diseases. Warmer conditions can allow some pests to survive winters that previously limited them, extend breeding seasons, and support additional generations per year. Many crop pests and pathogens are shifting their ranges polewards as climates warm (Bebber et al., 2013).

Weeds can also respond strongly. Higher CO₂ can favour some fast-growing weeds, and warmer conditions may support invasive species. At the same time, stress-weakened crops are often more vulnerable to competition and infection.

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For this reason, Integrated Pest Management (IPM) becomes even more valuable under climate uncertainty. IPM emphasises monitoring, thresholds, prevention (healthy soils and crops), biological control, and targeted treatments – reducing over-reliance on a single control method (FAO, 2013).

For teaching, it helps to distinguish three drivers of change:

- **Climate suitability** (temperature, humidity, rainfall patterns).
- **Host/Crop changes** (new varieties, earlier planting, different rotations).
- **Management pressure** (pesticide use, resistance, landscape diversity).

Livestock Impacts

Livestock systems are affected by climate through heat stress, water availability, feed supply, and disease. Heat stress is particularly important because animals have physiological limits: productivity can decline rapidly once conditions pass certain thresholds (Renaudeau et al., 2012). Heat stress can lead to reduced feed intake, lower milk yield, poorer fertility, higher mortality in extreme events, and increased veterinary costs. Heat can also affect housing (ventilation needs) and labour safety. These effects form part of a wider livestock-system risk, since climate change can ultimately influence forage availability, feed costs, animal health, and reproduction (Nardone et al., 2010).

A practical way to teach heat risk is the Temperature-Humidity Index (THI), which combines temperature and humidity into one indicator of ‘heat load’. High humidity makes it harder for animals to cool themselves by evaporating moisture. The THI is a useful tool for trainers to explain why some hot days are much harder on animals than others. In short, temperature alone does not tell the full story, because high humidity makes it more difficult for animals to lose heat (i.e., to cool down). In a training session, THI can be linked to everyday farm decisions: when to open or improve ventilation,

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when to provide extra water checks, when to reduce handling, or when to move feeding to cooler parts of the day. It is useful to urge learners to compare two forecast days with the same temperature but different humidity levels, then discuss which day creates greater risk for dairy cows, poultry, pigs, or other locally relevant animals.

Adaptation options against heat stress include shade and shelter, improved ventilation, sprinklers or evaporative cooling (where appropriate), adjusted feeding times, genetic selection for heat tolerance, and improved water access. Trainers can frame these as a hierarchy: first reduce heat load (shade and airflow), then support the animal (water and diet), then adjust management (timing, stocking density).

Pest, weed, and disease pressure depends on the interaction between climate, host availability, and management. Temperature affects survival, reproduction, development speed, and the number of generations that some pests can complete in a season; pests and pathogens also affect the gap between potential crop yield and actual yield (Gregory et al., 2009). Rainfall and humidity influence many fungal and bacterial diseases. Crop choice, planting date, variety, landscape structure, and pesticide use then shape whether a potential problem becomes an outbreak. This complexity of stressor relations shows why climate change is presented as a risk multiplier and not as a simple singular cause.

Warmer winters are especially important for organisms that were previously limited by cold conditions. If more individual organisms survive the winter, pest populations may begin the season at a higher level. Warmer springs can also allow earlier activity, which may bring pests into contact with crops at more vulnerable stages. Over time, some species may expand into areas where they were previously rare or absent. Evidence already shows poleward movement in many crop pests and pathogens, although local outcomes differ by species and farming system (Bebber et al., 2013).

Disease pressure can change in ways even more complicated than pest pressure. Some diseases are favoured by warm and humid conditions; others may decline where

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conditions become too dry. Irrigation can also alter disease risk by changing humidity around the crop canopy or by creating wet leaf surfaces. As with all other stressors so with disease, trainers should avoid presenting climate change as producing a single direction of change. For this reason, trainers can explain to farmers that climate change makes disease calendars, risk periods, and monitoring routines less reliable if they are based only on past experience.

Weeds deserve attention because they compete directly with crops for resources, such as sunlight, nutrients, and water. The growth of some weed species may benefit from higher carbon dioxide concentrations, longer growing seasons, or disturbed conditions after drought or flood events. Weed control may become more difficult if crop establishment is weakened by drought or heavy rainfall. Generally, a climatically stressed crop canopy leaves more space for weeds to establish themselves.

The aforementioned concept of Integrated Pest Management (IPM; see Glossary) remains relevant because it is based on observation, prevention, and threshold-based decisions. Under climate change, fixed calendars become less dependable. Then climate uncertainty, by reducing the reliability of routine treatment schedules, increases the value of monitoring-based pest management (FAO, 2013).

Soil & Water Implications

Soil is simultaneously (a) a foundation for growth, (b) a buffer against climate stress. Good soil structure and organic matter help store water, reduce runoff, and generally support resilient crops. Climate change can threaten these functions through more intense rainfall (erosion of soil), longer dry spells (reduced biological activity and cracking), and higher temperatures (faster organic matter decomposition) (IPCC, 2019).

Key soil-related risks include:

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- **Erosion by water and wind** – especially when the soil is bare and rainfall is intense (Panagos et al., 2015).
- **Compaction and poor structure** – which reduce infiltration and increase runoff.
- **Salinisation in irrigated or coastal areas** – where water quality and evaporation pressures are high.
- **Nutrient losses** – leaching after heavy rain; volatilisation in heat; affect both costs and water quality.

Water availability is a cross-cutting issue: it affects cropping, livestock, processing, and local ecosystems. Trainers can help learners think in terms of water demand (crops, animals, cleaning), supply (rainfall, groundwater, surface water), and governance (allocations, restrictions, local rules).

Soil resilience depends strongly on structure. A well-structured soil contains pores that allow water to enter, roots to grow, and air to circulate. Organic matter helps bind soil particles into aggregates, which improves infiltration and reduces surface sealing; soil aggregation is affected by the amounts of organic carbon, soil biota, and clay, as well as by management (Bronick & Lal, 2005). When soil structure is weak, rainfall is more likely to run off the surface, carrying soil and nutrients with it. This explains why climate change and soil management are closely connected. More intense rainfall creates greater erosion pressure, but the level of damage depends partly on the condition of the soil when the rain arrives.

Water erosion is a major concern in European agriculture because it removes the most fertile part of the soil profile. Loss of topsoil reduces productive capacity, but it also affects water quality when sediment and nutrients enter ditches, streams, or reservoirs. Erosion can be gradual enough to escape attention in the short term, yet serious enough to reduce long-term farm productivity. Trainers should make clear that erosion is both an environmental issue and a production issue. Worst of all, soil

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erosion represents the loss of a resource that took a long time to form, so in turn it will take a long time to be remedied (Panagos et al., 2015).

Compaction (see Glossary) becomes more problematic under unstable rainfall patterns, since wet soil is more vulnerable to damage from machinery and livestock traffic. Once compacted, soil often absorbs water less effectively, which increases runoff during storms and restricts root growth during dry periods. This creates a cycle in which the same field can be more flood-prone in wet periods and more drought-sensitive in dry periods. Such links are useful for trainers because they explain and demonstrate how soil condition can influence more than yield in a single season.

Salinisation is another risk in some irrigated and coastal areas. When evaporation is high and drainage is poor, salts can accumulate in the root zone of plants. This makes it harder for them to take up water, even where water is physically present in the soil. Salinity risk may increase where the quality of irrigated water declines, or where groundwater levels change, or where coastal aquifers are affected by saltwater intrusion. This issue will not be equally relevant in every partner country, but it is important enough to be included in all countries' climate-resilience education (IPCC, 2019).

Water availability should be understood as a question not of weather but of resources. Farms depend on rainfall, soil storage, groundwater, surface water, infrastructure, and local allocation rules. Naturally, during drought, agriculture may compete for resources with other sectors of society, such as domestic supply, ecosystems, industry, or tourism. During heavy rainfall, the issue may become drainage, runoff, and water quality. Trainers should stress that studying rainfall totals alone is a simplistic approach to water availability, which is actually a matter of supply, demand, storage, access, and governance. This wider view is especially relevant in European regions where adaptation choices are already shaped by water scarcity, irrigation demand, and competing uses (Iglesias & Garrote, 2015).

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Farm Economics & Risk

Climate impacts matter because they change risk: yield volatility, quality penalties, animal health costs, and the probability of bad years – these factors can all increase. But these biophysical risks interact with market risks such as fluctuating prices, input costs (energy, fertiliser, feed), and insurance availability (OECD, 2016).

From a trainer's perspective, climate-resilient farming is not only about 'doing the right thing' environmentally but also about keeping the business viable. Educators can introduce the idea of resilient Return on Investment (ROI), which is to say: some measures save money every year (e.g., improved water efficiency), while others mainly pay off in extreme years (e.g., drainage upgrades). The ROI is a useful concept for helping learners judge whether a climate-resilience measure is worth the cost that will be invested into acquiring it. In farming, the benefit of the investment, called "return", may be direct savings (resulting e.g. from lower water or energy use) but it may also include avoided losses during difficult years. For example, an irrigation upgrade may reduce bills every season, while shade structures or improved drainage may prove their value mainly during heatwaves or heavy rainfall. Trainers can implement the concept of ROI by asking learners to compare the upfront cost of an action with the benefits it could bring over several years (such as steadier yields, fewer animal-health problems, less soil loss, lower input waste, or reduced damage after extreme weather). ROI is especially helpful for comparing adaptation measures whose value is partly financial and partly protective.

Useful concepts for learners include:

- Exposure: what assets are in harm's way (fields, barns, irrigation pumps).
- Sensitivity: how strongly production changes when a hazard occurs.
- Adaptive capacity: resources, knowledge, and flexibility to respond.

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Risk management strategies include diversification (crops, varieties, markets), improved monitoring and early warning, flexible contracts, savings and credit strategies, and insurance where available.

The concept of exposure risk is useful because, through decision-making, it bridges climate science and business. A hazard, i.e., the possibility of damage (such as with a drought or a flood) starts to matter economically when valuable assets or production processes are involved.

The idea of sensitivity explains why two farms facing the same hazard may experience different losses. Concepts like robustness, adaptability, and transformability, are widely used in climate-risk education because they separate the external event from the internal conditions of each farm. Adaptive capacity explains why one farm may recover faster than another, a topic often studied in resilient farming-systems research (Meuwissen et al., 2019).

Return on Investment (ROI) is a practical financial concept which, in climate adaptation, needs to be interpreted over a longer time frame than a simple purchase decision. The return may include lower input costs, steadier production, fewer losses, improved animal welfare, reduced repair needs, or better access to insurance and finance. Some measures, such as water-efficient irrigation, may create visible savings in ordinary years; others, such as drainage improvements or shade infrastructure, may show their value mainly when extreme weather occurs. This makes ROI useful for comparing adaptation options, as long as learners remember that avoided damage is also a form of return.

A narrow view of ROI can undervalue resilience. If a measure is judged only by whether it increases profit in the next season, many protective investments will look weak. A wider view asks how the measure affects risk in the short term, but also in the long term, across several years. For example, improving soil cover may not produce a dramatic short-term gain, yet it can reduce erosion, protect moisture, support soil

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biology, and lower vulnerability to both drought and heavy rainfall. The value of resilience, essentially, is the benefit of reducing the chance that a difficult year becomes a damaging year.

Climate risk also interacts with markets and institutions. A drought may reduce yield, but its financial effect can depend on factors like market prices, contracts, storage capacity, debt, insurance, and access to emergency support. Heat stress may reduce animal productivity, but the impact will vary according to feed costs, veterinary support, and housing investment. This is why climate adaptation cannot be separated from farm business planning. OECD guidance on droughts and floods in agriculture stresses the importance of risk management approaches that combine prevention, preparedness, response, and recovery (OECD, 2016).

Trainer should present climate change risk management as a basis for solid critical thinking when it comes to business planning in agriculture. Some responses reduce exposure (e.g. avoiding high-risk locations for sensitive infrastructure); some reduce sensitivity (e.g. improving soil water-holding capacity or selection of more tolerant varieties); other responses increase adaptive capacity (e.g. better records, access to advice, financial reserves, or flexible marketing arrangements). Agricultural adaptation often requires a mixture of immediate management adjustments and longer-term strategic changes (Howden et al., 2007). Trainers are encouraged to use these categories to explain why climate resilience is broader than any singular adaptive measure.

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Self-Assessment Questions

Trainers can use these questions to check understanding and to stimulate discussion; different subsets are available depending on time and learner level.

Self-Check Questions

1. Explain, in one sentence, the difference between weather and climate.
2. Name the three greenhouse gases highlighted in this module.
3. Give one example of why extremes can matter more than averages for a crop.
4. What does THI stand for and what is it used for?
5. Name two soil functions that help farms cope with drought.

Knowledge-Based Questions

1. Why can a normal rainfall year still lead to drought stress for crops?
2. List two direct and two indirect pathways by which heatwaves can affect crop yields.
3. Explain why milder winters can increase pest pressure in some regions.
4. Describe two adaptation options for reducing livestock heat stress in housed systems.
5. Explain how intense rainfall can increase both erosion and nutrient losses.
6. What is meant by 'uncertainty' in climate projections, and why is it still useful for planning?

Application-Based Exercises (mini-cases)

1. Choose one climate hazard relevant to your region and explain how it may affect crops, livestock, soils, water use, and farm income.
2. Explain how a trainer could use the concepts of exposure, sensitivity, and adaptive capacity to analyse the vulnerability of a farm system.

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Annexes

Glossary

Adaptive capacity: The ability of a farm or community to adjust to climate impacts, reduce damage, and take advantage of opportunities.

Climate normal: A long-term average used as a reference, commonly calculated over 30 years.

Climate variability: Natural ups and downs in climate from year to year or decade to decade.

Compaction: The compression of soil particles, usually caused by heavy machinery, livestock traffic, or working soil when it is too wet; it reduces pore space, making it harder for water, air, and roots to move through the soil.

Drought: A period of abnormally dry conditions; in farming often understood as a soil water deficit relative to crop needs.

Evapotranspiration (ET): Water loss from soil evaporation plus plant transpiration; often rises with temperature and wind.

Extreme event: An unusually severe weather event (e.g., heatwave, intense rainfall) outside typical conditions.

Greenhouse effect: The natural warming of Earth caused by gases that trap heat; human emissions have strengthened this effect.

Greenhouse gas (GHG): A gas that traps heat in the atmosphere (e.g., CO₂, CH₄, N₂O).

Impact pathway: A chain linking a climate hazard to biophysical processes, farm outcomes, and management responses.

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Integrated Pest Management (IPM): A strategy combining monitoring, prevention, biological control, and targeted treatments to manage pests sustainably.

Phenology: The timing of biological events such as flowering, budburst, or pest emergence.

Return on investment (ROI): A financial term, used to measure and compare the benefits of an investment to its costs.

Salinisation: Accumulation of salts in soil, which can reduce crop growth; often linked to irrigation, poor drainage, and high evaporation.

Scouting: The regular and systematic monitoring of fields to assess crop health and identify pests, diseases, weeds, and nutrient deficiencies; it involves inspecting plants – from roots to leaves – to detecting problems early, enabling timely and precise interventions.

Soil organic matter: Decomposed plant and animal material in soil that supports structure, water holding, and nutrient cycling.

Temperature-Humidity Index (THI): An index combining temperature and humidity to estimate heat stress risk for animals.

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Abbreviations

CO₂ – Carbon dioxide

CH₄ – Methane

N₂O – Nitrous oxide

EEA – European Environment Agency

ET – Evapotranspiration

GHG – Greenhouse gas

IPCC – Intergovernmental Panel on Climate Change

IPM – Integrated Pest Management

ROI – Return on Investment

THI – Temperature-Humidity Index

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References

- Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., Kimball, B. A., Ottman, M. J., Wall, G. W., White, J. W., Reynolds, M. P., Alderman, P. D., Prasad, P. V. V., Aggarwal, P. K., Anothai, J., Basso, B., Biernath, C., Challinor, A. J., De Sanctis, G., ... Zhu, Y. (2015). Rising temperatures reduce global wheat production. *Nature Climate Change*, 5(2), 143-147. <https://doi.org/10.1038/nclimate2470>
- Bebber, D. P., Ramotowski, M. A. T., & Gurr, S. J. (2013). Crop pests and pathogens move polewards in a warming world. *Nature Climate Change*, 3, 985–988. <https://doi.org/10.1038/nclimate1990>
- Bronick, C. J., & Lal, R. (2005). Soil structure and management: A review. *Geoderma*, 124(1-2), 3-22. <https://doi.org/10.1016/j.geoderma.2004.03.005>
- Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change*, 4(4), 287-291. <https://doi.org/10.1038/nclimate2153>
- Corner, A., Whitmarsh, L., & Xenias, D. (2012). Uncertainty, scepticism and attitudes towards climate change: Biased assimilation and attitude polarisation. *Climatic Change*, 114(3-4), 463-478. <https://doi.org/10.1007/s10584-012-0424-6>
- European Environment Agency. (2024). *European climate risk assessment* (EEA Report No. 01/2024). European Environment Agency. <https://doi.org/10.2800/8671471>
- Food and Agriculture Organization of the United Nations. (2013). *Climate-smart agriculture sourcebook*. Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/i3325e/i3325e.pdf>
- Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. I. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Botany*, 60(10), 2827-2838. <https://doi.org/10.1093/jxb/erp080>

Project Partners

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, 10, 4–10.
<https://doi.org/10.1016/j.wace.2015.08.001>

Howden, S. M., Soussana, J.-F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences*, 104(50), 19691–19696. <https://doi.org/10.1073/pnas.0701890104>

Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, 155, 113-124. <https://doi.org/10.1016/j.agwat.2015.03.014>

Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, 155, 113-124. <https://doi.org/10.1016/j.agwat.2015.03.014>

Intergovernmental Panel on Climate Change. (2019). *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.
<https://www.ipcc.ch/srccl/>

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press.
<https://doi.org/10.1017/9781009325844>

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report: Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, H. Lee, & J. Romero,

Project Partners

Eds.). Intergovernmental Panel on Climate Change.

<https://doi.org/10.59327/IPCC/AR6-9789291691647>

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., de Mey, Y., Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., ... Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, 176, Article 102656. <https://doi.org/10.1016/j.agsy.2019.102656>

Moser, S. C. (2010). Communicating climate change: History, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change*, 1(1), 31-53. <https://doi.org/10.1002/wcc.11>

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*, 130(1-3), 57-69. <https://doi.org/10.1016/j.livsci.2010.02.011>

Organisation for Economic Co-operation and Development. (2016). *Mitigating droughts and floods in agriculture: Policy lessons and approaches* (OECD Studies on Water). OECD Publishing. <https://doi.org/10.1787/9789264246744-en>

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54, 438–447. <https://doi.org/10.1016/j.envsci.2015.08.012>

Renaudeau, D., Collin, A., Yahav, S., de Babilio, V., Gourdière, J. L., & Collier, R. J. (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, 6(5), 707–728. <https://doi.org/10.1017/S1751731111002448>

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