HOLISTIC RESOURCE MANAGEMENT FOR
CLIMATE RESILIENCE OF FARMING

Farmer Handbook
Introduction and manual
ClimateFarming

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Target(group) and purpose of the farmer handbook (disclaimer)

Climate change confronts agriculture with diverse and fundamental challenges. In order to meet these challenges at the individual farm level, we also need new and innovative methods and tools. The aim of the ClimateFarming (ClimateFarming) project is to create and apply materials and training courses that equip advisors, agricultural experts, teachers and farmers with the necessary knowledge and skills. The farmer handbook is primarily aimed at farmers and agricultural holdings who search for guidance concerning farm-level adaptation planning.

In contrast to past projects in the area of individual farm climate change adaptation, the ClimateFarming project is not focussed on specific measures or outputs, but is process-oriented. This means that it is not only important which climate mitigation and adaptation measures are actually implemented on the farm, but above all how we organise the decision-making processes that lead to implementation. A partially standardised procedure has been defined for a resource-optimised process.

However, the farmer handbook only provides an entry point to farm-level adaptation. If the development of an elaborated climate farm strategy is considered, we highly recommend consulting a ClimateFarming advisor which supports and moderates the process.

Target image

At the end of the holistic decision-making process is the target image of a climate-resilient agricultural enterprise. The process is based on comprehensive data collection and analysis. This climate-resilient farm plans climate protection and adaptation together, while other effects on biodiversity, soil, etc. are taken into account. The farm combines various short, medium and long-term measures, maximises synergy effects and minimises conflicting objectives. When planning and implementing measures, the climate-resilient farm is characterised by the ability to learn, flexibility and the will to transform. This enables it to react quickly to new and unforeseen climatic changes and to continue to develop. In this way, the climate-resilient farm not only secures its long-term economic stability, but also has a positive impact on both its natural and social environment.

What is not processed in the ClimateFarming project?

It is important to emphasise that the specific implementation of climate change mitigation and adaptation measures does not fall within the scope of the ClimateFarming materials or the farmer handbook. In the best case scenario, practical implementation takes place in consultation with the respective technical advisors, who plan and carry out the farm-specific implementation together with the farmers.
The ClimateFarming project is also not aimed at simply providing climate protection and adaptation measures. The aim is not only to support farm managers in finding the right adaptation measures, but also to provide them with the tools they need to decide in favour of or against an adaptation measure. However, the Measure Sheets can serve as starting points and inspiration.

Furthermore, the identification of potential climate changes and climate change impacts that will affect agriculture in Europe and how this will affect different production systems will not be provided as part of the ClimateFarming project, but will be based on the results of previous projects and the expertise of external partners. Guidance where to find this information is given in the farmer handbook.

Material for practitioners (work package 4)

The practical results of the ClimateFarming project are summarised here. The main product is the Farmer Handbook. Methods and procedures for climate strategy development are summarised here in a correspondingly abridged form. It is important to emphasise that this material cannot replace comprehensive ClimateFarming consultation, but offers a low-threshold introduction to the topic of regenerative agriculture and climate change adaptation. This is rounded off with selected practical examples from ClimateFarming partner farms.

In addition to the Farmer Handbook, the handouts from the various on-farm workshops are also provided. These workshops dealt with farm-specific issues or adaptation measures that are implemented on the respective farm.

Components of the Farmer Handbook

- Introduction
- Background
- Analysing Farms
- Practice Examples
- Templates and Tools

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Agriculture in a changing climate

- Agriculture plays various roles in the context of climate change - as a **greenhouse gas emitter, as a potential greenhouse gas sink** and **as an affected party**.
- Global warming today is over 1°C and is expected to rise to well over 1.5°C in the course of the 21st[st] century.
- The indiscriminate use of detrimental agricultural practices such as continuous monocultures and intensive tillage have contributed to **widespread soil degradation**.
- Progressive soil degradation poses the risk that the soil will no longer be able to cope with climate disturbances such as drought and severe and frequent weather events.
- **Extreme weather situations** such as longer periods of drought or heat or heavy precipitation events will increase with climate change.
- Many farms are trapped in **dependence on external inputs** such as fertilizers and fuel. Agricultural soils have often been degraded over decades. An adapted fertilization strategy can only be implemented once cultivation has slowly restored a soil to its functional capacity.
- **The problems of animal welfare** will be exacerbated by climate change.
- Farmers are under great pressure to produce enough healthy food for everyone while maintaining healthy ecosystems as they face market demands, land use conflicts and changing environmental conditions.

Climate protection and climate adaptation

In this project, we use the terms **climate change mitigation** and **climate protection** interchangeably. They describe measures to reduce further climate change by reducing greenhouse gas emissions (and improving sinks).

Climate adaptation refers to the measures taken to adapt to the effects of actual and expected climate change. This can be done at many levels, e.g. through flood protection, drought-resistant crops or government measures to cope with the effects of climate change.

"Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change (IPCC AR6, 2023)".

Management of climate change

The following terms are used at farm level:

- **Climate impact**: includes climate hazards (e.g. new pests and diseases) and climate impacts (e.g. yield losses, higher veterinary costs, etc.)

- **Vulnerability (of agriculture)**: The propensity of a farm to be affected by actual or projected changes in climate parameters
- **Resilience (of agriculture)**: The ability of an agricultural operation to remain functional and meet operational objectives across a spectrum of different changes and disturbances, including the ability to learn and adapt following shocks or in response to new knowledge.

Climate protection and adaptation to climate change are both necessary to cope with climate change. At farm level, both must be taken into account and the corresponding measures should be planned together in order to exploit synergies

Adaptation refers to the planning and implementation of measures that mitigate the negative effects of climate change and take advantage of positive developments.

- Adaptation should enable a farm to **act preventively** (to reduce risks) and **react flexibly** in the face of abrupt and unforeseen climatic and non-climatic changes

Key challenge: Uncertainty about climate change and its effects

- **Uncertainties must be integrated** into the adaptation process
- **Adaptation** must be seen **as a continuous process** based on observation, preparation and learning.
- Inadequate planning can lead to maladjustments
  - **Maladaptation**: Negative consequences of adaptation decisions that impair the adaptability of a company or result in negative external effects

It is difficult to determine the success of the adaptation, as this depends on the temporal and spatial dimension of the observation. As a result, **there are no "one-size-fits-all" adaptation measures**

- At farm level, the **individual farm targets are crucial for monitoring the success of adaptation measures.**

Successful climate adaptation is a challenging task and therefore requires a comprehensive approach to be effective and successful in the long term. The ClimateFarming project combines approaches and methods from adaptation management and regenerative agriculture to provide a comprehensive approach for successful adaptation planning at farm level

Regenerative agriculture

Regenerative agriculture is an unprotected term that has **many different definitions**, which is why it is necessary to define it when it is used. As our understanding of **regenerative agriculture fits the requirements of transformative climate adaptation**, it is used as a conceptual framework within the ClimateFarming methodology.

The term "*regenerative agriculture*" was first coined in the 1980s, but its sole origin is not clear. It came back into use in 2015, and shortly afterwards various interest groups began to use the term, leading to misunderstandings, especially among consumers.

In our understanding, regenerative agriculture can be defined as "*an agricultural approach that uses soil conservation as a starting point for regeneration and contribution to* ***multiple*** *provisioning,* ***regulating and supporting services****, with the aim that this improves not only the* ***environmental*** *but also the* ***social*** *and* ***economic dimensions*** *of sustainable food production (Schreefel et al. 2020)*", or as
"*a* ***constantly evolving, complex*** *and* ***context-dependent*** *agricultural approach that aims to restore and regenerate degraded land and* ***contribute to climate change adaptation*** *with positive mitigation co-benefits. In RA [regenerative agriculture], soil is the starting point for* ***rethinking food systems with*** *the aim of improving* ***biological, physical, chemical*** *and* ***cultural ecosystem services*** *in response to ecological conditions and the climate crisis, both locally and globally (Daverkosen and Holzknecht et al. 2022)*".

In this sense, regenerative agriculture also largely overlaps with concepts such as permaculture, agroecology, organic farming, climate-smart agriculture or carbon farming. The practices promoted are often similar and could simply be considered *good agricultural practice*. While regenerative agriculture does not generally exclude synthetic inputs such as fertilizers, pesticides or herbicides, many proponents advocate organic principles or strive to minimize the use of synthetic inputs.

Soil health and soil carbon storage are considered central in many definitions and also correspond to the goals of climate change mitigation and adaptation. While it is scientifically controversial whether soil carbon can or should be quantified for carbon credits, many certification schemes have emerged in recent years. These must be critically evaluated.

Climate change mitigation and adaptation go hand in hand. Although their starting points are different - mitigation aims to prevent further climate change, while adaptation aims to address current or future change - their ultimate goal is the same: to enable a comfortable life for all in the face of climate change.

The table below lists some examples of practices and principles that can be regenerative when applied in an appropriate context:

Operational category	**Practical measures**
Administration and planning	- Holistic management - taking into account the operational context and regional conditions - Operational planning with a focus on water resources (keyline scale of permanence) - Community Supported Agriculture CSA
Inputs & material flows	- Circular economy at agricultural and regional level - Use of compost - Compost tea - Biochar, Terra-Preta - Fermentation products - Woody biomass and fresh branch cuttings - Targeted use of mycorrhiza - Soil analysis and fertilization according to Albrecht/Kinsey

Comprehensive land use	- Increasing plant diversity - Reducing the use of synthetic substances (sprays and fertilizers) - Horse work - Agroforestry - Management pattern according to the keyline design - Natural Sequence Farming - Rewilding
Arable farming and vegetable growing	- Wide crop rotations - Leave plant and root residues on the surface - Occasional plowing, direct sowing, minimal tillage, direct sowing - Permanent soil cover: cover crop, undersown crops, catch crops, mulch systems, green manure - Permanent living roots in the soil - Mixed crops - Use of perennial crops (e.g. perennial cereals) - Integration of animals in arable farming - Biointensive vegetable cultivation ("vegetable cultivation")
Animal husbandry	- Essential element - Animals as designers of ecosystems - Increasing the diversity of livestock - Holistic pasture management: adaptive rotational grazing management, graze mobbing, holistic planned grazing - Pasture cultivation

Table 1: *Overview of possible practical measures for a regenerative economy, classified according to possible areas of application within a company (own compilation and classification;. Sources: Brown 2018; Burgess et al. 2019; Fortier 2014; General Mills 2021; LaCanne and Lundgren 2018; Merfield 2019; Newton et al. 2020; Perkins 2019; Rodale Institute 2014; Savory and Butterfield 2017; Shephard 2013)*

Connecting: Regenerative agriculture and the ClimateFarming Cycle

Both the concept of regenerative agriculture and that of climate adaptation have similar starting points and premises, e.g.

- Recognizing climate change as a complex challenge that must be met with proactive measures,
- Assessment of the long-term effects versus the short-term benefits,
- Process orientation, feedback loops and continuous learning,
- They demand that we move away from the usual practice,

and similar needs:

- Contextualization and flexibility,
- Multifunctionality

and similar goals:

- holistic and systematic approach,

- Understanding the interdependencies.

We therefore see potential in the application of the ClimateFarming Cycle to transfer the principles of climate adaptation to the real conditions on farms.

Theoretical background: Methods and principles of the ClimateFarming Cycle

Strategic operations management (Barnard and Nix, 1979; Kay et al., 2016) is a cyclical process and consists of the following phases.

- Analysis (problem definition)
- Target formulation
- Planning
- Implementation
- Monitoring, control and replanning (target/actual comparison)

In principle, this process can be compared with approaches to adaptation planning (e.g. Adaptation Action Cycles; Park et al., (2012)), as key elements are similar.

- It is a continuous process of analysis, implementation, monitoring and reassessment. The focus is on learning, adaptability and flexibility.

Strategic operational management must be supplemented by DMDU (Decision-making Under Deep Uncertainty) approaches in order to counter the problem of increasing uncertainty.

Decision-making under great uncertainty:

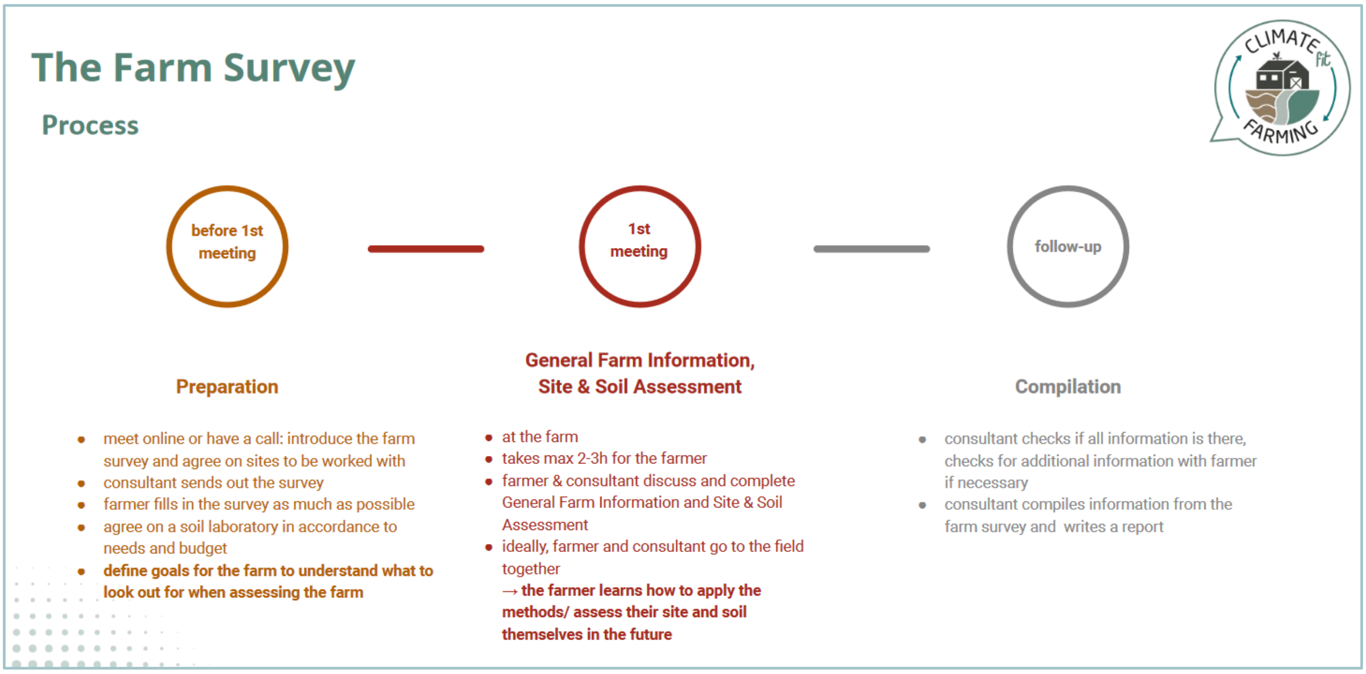
- Definition from the U.S. Climate Resilience Toolkit (2023):
  "*Deep uncertainty occurs when decision makers and stakeholders do not know or cannot agree on how likely different future scenarios are.*
    - *If there is no agreement or knowledge or confidence in these future scenarios.*
    - *When decision-makers or interest groups do not agree or do not know what consequences their decisions could have".*
- There are various approaches and methods that help decision-makers to make decisions in situations of great uncertainty, summarized under "Decision-making under Deep Uncertainty (DMDU)" (Marchau et al., 2019)

The **Dynamic Adaptive Pathways Approach (DAPP**) forms the methodological basis for the Climate Farming Cycle.

- DAPP integrates uncertainty into the planning process by making it possible to change the plan over time if new findings or changed conditions arise (Marchau et al., 2019).

There are additional methods that can be integrated into the ClimateFarming Cycle to improve its results

- Additional methods 1: TOWS analysis (step 2)
- Additional methods 2: SWOT analysis and emergency measures (step 4)
- Additional methods 3: Adaptation tipping points and opportunity tipping points (ATP and OTP)



Analyzing Farms

The Farm Survey - Instructions

Some of the information may seem excessive to collect at this stage of the assessment but might become relevant in the process. You can skip parts of the survey now, and come back at a later stage when the strategy and goals become more tangible (e.g. ownership of specific fields). Some questions concern sensible farm information one might be reluctant to share with an external consultant. However, it is important to keep in mind that the consultation process will be more effective and overall successful if all involved parties have the same information level. As a guidance, you can follow the 🌱 base case scenario, if you want to collect the most necessary information only, and the ⭐ best-case scenario if you want to do a comprehensive farm analysis.

Icons

🏞 **On-site assessment**

💻 **Internet research, (online) maps or geodata**

You will find this symbol where (online) maps can support the collection of relevant information. Such can include aerial images, erosion maps, elevation profiles, contour maps, slope and exposition maps, precipitation and temperature maps, various soil maps, geological maps, drainage plans, and protection areas, among others. Here you can find a list of helpful online map services for Germany.

🚜 **This task can be done by the farmer**

💼 **This task should be done by the consultant (or an experienced farmer)**

📷 **Please take pictures** of everything that might be interesting or helpful for interpretation of the results (e.g. color changes within a soil horizon, a lot of soil attached to roots, compacted soil layers, a root is oriented in a different direction than all the others, etc.) and to track your progress! Ideally, photos should be standardized at **1m distance** from the targeted object, e.g. from the soil surface. It could also be helpful to establish fixed photo points to monitor changes. If possible, automatically link the pictures to GPS coordinates, or save them separately. For more information check out this document: CF_Taking Photos_in progress

⏰ **Time this task**

👫 **Should be done with at least 2 persons**
🌱 **Base-case scenario**
⭐ **Best-case scenario**
ℹ️ **Why do we look at these indicators?**

General farm information

🚜 🌱

Guiding questions:

- What is the total farm area?
- Which different production branches do you have on the farm?
- e.g. Feed production, Sheep herding, Market garden
- How many animals? Which cultures? etc.
- What is your farming practice?
- conventional, organic, conservation agriculture,
- Do you have any certifications?
- e.g. EU-organic, other organic, KAT, QS
- How do you market your products? What are your sales channels?
- e.g. direct marketing, own processing, regional/ interregional/ international partners, bulk purchasers from the agricultural sector, cooperatives, large-scale processers
- Which other establishments belong to the business? (e.g. affiliated restaurant)
- Are there any special geographical features?
- e.g. lee side of mountain range, viticultural climate, special bedrock
- How is the farm located regionally?
- e.g. proximity to villages/ cities, distributors, processors, storage units, etc.
- What is the main soil type and soil texture on your farm?
- Find site-specific questions below

Describe the regional climate around your farm:

- What is the main wind direction? What are peak velocities you experience?
- Precipitation (mean, min, max, per season)
- old and new long-term means, as well as personal estimations
- Do you get most of the precipitation in spring/summer/autumn/winter? Or is it equally distributed over the year?
- Temperature (mean, min, max, per season)
- old and new long-term means, as well as personal estimations
- How many days with temperatures below 0°C do you experience? When do you have temperatures below 0°C during the year? How low do temperatures go in the spring? Are there late frosts in the spring?
- Recall experienced and historic extreme weather events (strong rain, drought, etc.).
- Are there changes in weather patterns/ extreme events/ seasonal shifts in your farming area? Do you observe "new" patterns that have developed over the last year?

- e.g. earlier budding, increased pressure from invasive organisms, less rain events, higher peak temperatures
- Which of your sites are most vulnerable and how?

Farm overview

🚜 ⭐ Please fill in the area that is available on your farm for the different branches in the table, how much of it is your own property and how much is used under leasing agreements. How many different fields do you have per branch and what are their particularities?

Please state all crop rotations and their approximate output on the farm to get an overview. Specific information on the crop rotations for the concerned site(s) that you want to work with can be stated in the Site Assessment below.

- If you have livestock, please state species, amount, husbandry system, and what the outputs are. How do you source the animal feed?
- e.g. buying feed pellets, grazing your own/ rented land, buying/ making your own silage
- If you graze your animals, can you describe your grazing system?

Ownership structure and decision making

🚜 🌱 Guiding questions:

- Who are the legal owner(s) of the farmed areas?
- Are there existing lease agreements? What is the duration of such? What is the relation with the owner(s)?
- Are there past or upcoming generation changes/ farm transfers (on both owned and leased land)?
- Do you have partnerships, dependencies or other involved parties that necessitate inclusion in decision making?

Workforce, facilities and machinery

🚜 🌱 Guiding questions:

- How many people work in each production branch? (Indicate overlaps)
- What is the training and education of farm staff?
- Which special knowledge and skills are available from farm staff?
- Is additional workforce available if needed for workload peaks?
- Which facilities do you have at your disposal?
- differentiate between on-farm and contractors
- Which machinery do you have at your disposal? List your vehicles with their operating widths.
- differentiate between on-farm and contractors
- Do you use agricultural contractors, and if so which?

Economic background

🚜 🌱 Guiding questions:

- How would you describe the economic situation of your farm (e.g. stable, insecure, potential to grow, need to consolidate, etc.)?
- What is the average farm investment sum in a five-year period?

- Are there any major expenditures planned or necessary (e.g. replacement of machinery)?
- How is the relative contribution of the different production branches to the farm income (e.g. crop production: 70% + pig production: 30%)?

Climate change measures

🚜 ⭐ Guiding questions:

- Is a farm climate balance (carbon footprint) available? If not, is it planned to do one?
- Are measures implemented or planned which aim at improving the farm climate balance (mitigation; e.g. increasing soil organic carbon)?
- Are measures implemented or planned which aim at adapting the farm to climatic changes (adaptation; e.g. irrigation, undersowing, agroforestry)?

Formulation of goals and priorities

🚜 What is important to you as a farmer? What is the motivation behind your work? Which topics would you like to develop further on? Formulate your goals and try to order them according to your priorities.

Site Assessments

This part of the questionnaire concerns the site(s) on your farm that you would like to assess in more detail. Please copy this section in the documentation form and fill it out separately if you are assessing more than one site.

General information

🚜 💻
🌱 Guiding questions:

- Note the name, lot number, location, GPS coordinates, and area of this site.
- Who is/ are the current land manager(s) and what is the current land use and vegetation or crops?

- How far away is the concerned site from the main production building?
- Which means of transport do you use to get there?
- How long does it take to get there?
- How relevant is the concerned site within the farm? Is it a formerly merged site, high-yield site, etc.?
- How often is management and/or observation necessary/ reasonable?
- Why did you choose this site for new measures?

💼 🏞️ 🌱 Continue by checking the field for heterogeneity:

- Are there relevant differences within the field?
- e.g. in terms of weeds, harvest, soil quality, soil depth, water logging, compaction
- If so, **divide the field into different zones** according to these differences.
- Visualize zones on a map, note the respective GPS coordinates and possibly measure dimensions. Note what characterizes each zone and give them IDs.

💼 🏞️ 🌱 Continue with the assessment of the total area; or if zonation, then every zone respectively. Depending on the geometry of the field, chose according locations for soil sampling

- Walk through the field in an N or X-shape and sample in 4-5 locations
- Borders and irregular areas within the zone should be avoided

The goal for all methods is to get a **representative impression** of the respective zone/ area, but keep it pragmatic and don't divide it into too many subareas.

Management history

💼 💻 🌱
Tip: Use for example Google Earth (web application), or Google Earth Pro (desktop application with more functions) to determine e.g. cultivation borders, which can be seen especially well on winter imagery after seeding. Look at different seasons over several years to get a good impression of the conditions.

Guiding questions:

- How long have you been the farm manager? Do you know the previous farm manager/ have information on their management practices?
- What has been grown in the last 5-10 years?

- Have there been additions of fertilizers/ pesticides/ herbicides/ manure/ compost/ etc.? Which approximate amounts?
- e.g. fertilizers: pig slurry, farmyard manure, NPK fertilizer
- e.g. other amendments: soil improvers, biotite, liming
- Did you leave crop residues on the field?
- What was the tillage regime (frequency, depth)?
- Which machinery has been used on the site? Has work been done with heavy machinery?
- Have there been any other noteworthy management practices?
- e.g. soil cultivation/ harvesting under unfavorable conditions

Protection status

💼 💻 🌱

- Are any of the fields or nearby areas under special protection?
- E.g. Water protection area, Birds Directive, Habitats Directive
- How does the protection status influence your farming decisions?

Climate/weather

💼 💻

Describe the climate **specifically on the concerned site**. If it does not differ from what was noted in 1. General farm information, you can omit this step.

🌱 Guiding questions:

- What is the main wind direction? What are peak velocities you experience?
- Precipitation (average, min, max, per season)
- old and new long-term averages, as well as personal estimations
- Temperature (average, min, max, per season)
- old and new long-term averages, as well as personal estimations
- Recall experienced and historic extreme weather events (strong rain, drought, etc.).
- Which of your sites are most vulnerable and how?

Topography & Terrain

💼 🏞️/💻

🌱 Guiding questions:

- What is the altitude of the site (min-max)? Is there a lot of elevation change/ are there steep slopes?
- Where do you get the most sunlight/ shade/ rain?
- Which areas are prone to surface runoff or water erosion? Are there wide open areas that are exposed to high wind velocities?

⭐ Outline the terrain/ topography in min. 2 directions (e.g. N-S and E-W) on Google Earth Pro (free Desktop app) or GIS services.

Landscape elements, compaction, drainage & surrounding vegetation

💼 🏞️/ 💻

🌱 Guiding questions:

- Do you have areas/ zones in your field where puddles form easily after rain? How long does the water take to infiltrate?

- Are there any especially compacted areas in your fields? What causes the compaction?
- Do you have drainage systems in place? Which? Where?
- What is the regular water table on the site?

🌱 Describe shortly if / where you can find such elements on your fields:
    - Trees, shrubs and other perennials
    - Wetland areas or ponds
    - Depressions, hills
    - Power lines
    - Underground cables, pipes, power lines

⭐ Guiding questions:
- What is the usual time of budding of surrounding vegetation?
- compare with phenological calendar (e.g. flowering of forsythia), especially interesting over the course of several years
- What is the species composition on the site?
- Which plant communities do you find in the area?
- What is the growth rate of local plants (especially shrubs/ bushes/ trees)?
- What is the yield of local plants? How regular is it?
- (e.g. irregular yield of walnuts might indicate critically late frosts)

Existing cultures

💼 🏞️/💻

🌱 Guiding questions:
- Do you have an existing field journal of cultures and activities on the field?

🌱 Guiding questions:
- Describe the following elements on the concerned area:
    -
    - Are you struggling with diseases or pests?
    - Are there root or harvest residues left on the field?
    - What is the height of your culture? Is it uniform?
    - How high is/ was your yield?
    - Do/ did you observe any deficiency or excess symptoms on the culture?

⭐ Guiding questions:
    - Identify the phenological development stages of your culture using the BBCH scale.
    - For grasses: What are the tillering rates?
    - Use a refractometer to measure the Brix level (=sugar content; indicator for crop quality) of the leafsap.
    - Get micro- and macronutrients of leafsap checked.
    - or check in the field with e.g. Yara-N-Sensor, HORIBA plant sap device
    - Do you observe indicator plants indicating:
        - Nitrogen
        - Water

- Compaction
- Salt

→ You can e.g. use the Ellenberg indicator values, that can be found for various regions in Europe, for orientation
(e.g. http://botanik.mettre.de/alpha_liste.shtml (German))

Issues & Optimisation

💼 🏞️ 💻
🌱 Are there problems or optimisation needs currently, or have been in the past concerning e.g.:

- Microclimate: e.g. solar radiation/ shade, wind
- Weeds, pests
- Yields
- Erosion: water or wind
- Water balance/ management: Is there too much or too little water? Is it raining at the "wrong" time? Can all the water infiltrate or does it run off? Do you employ measures to keep water in the landscape?
- Biodiversity: Is your farming area genetically diverse? How many species grow on your fields? Are annual or perennial plants dominant? Are animals part of your rotation? Is the surrounding landscape heterogeneous and diverse (e.g. different trees/ forests, bushes, water areas, buffer stripes, wildlife habitat zones)?
- Wildlife: Do you experience game pressure? Are your fields located in proximity to a forest? Do you observe many (beneficial) insects?
- Others: Are there any other issues or optimisation potentials that have not been listed above? Please describe.

Soil Assessment

In the soil assessment we will collect information about the state of the soil before interventions, and regularly afterwards.

Timing: The ideal time to do the in-field assessment is in autumn or spring, at least two days after the last rain (depending on the quantity). More importantly, the sampling should be consistent, and always be repeated under similar conditions, ideally by the same person. If one year, you sample after harvest and before sowing, keep doing so in the next years (or at least document what activities have been carried out previously).
Don't assess during frost, in very wet or very dry conditions, as this will influence the results of soil health indicators. Wait for 6-8 weeks after tillage or slurry application to get unadulterated data. Record any information that may help to remember the sampling or interpret the results later on.

Frequency: Some soil tests like earthworm counts, spade analyses or infiltration tests can be carried out several times a year, to see the development e.g. at the beginning and end of the vegetation period or to get a feeling of the impact of certain interventions.

Depth: For some assessments below (like the Extended Spade Analysis), specific sampling depths are given. If you are specifically sampling for soil organic matter/ carbon analysis, sampling at greater depths e.g. 0-15 cm, 15-30 cm, >30 cm is advisable. Check which specifications for sampling (depth, sampling frequency and distribution, separate or aggregated samples) are required, for example by your chosen soil laboratory and/ or carbon credit scheme.

You can choose between two scenarios: If you have little time and want to make a basic soil assessment, please follow the 🌱 base case scenario, which includes a analyses of surface, aggregate structure, water stability, and roots. If you want an in-depth field assessment with added indicators for a more thorough understanding of the state of the soil, please first follow the base case scenario and then proceed to the ⭐ best-case scenario. It includes counting earthworms, a lime test, infiltration measurements, and noting some more soil characteristics.

For comparison you could also perform one test in an undisturbed area, e.g. a grass strip next to the field. This can be comparable to "natural conditions" and may help to understand the site-specific soil development under undisturbed, permanently vegetated conditions.

⏰ Please time how long it takes you to assess every method and one zone/ field. It is interesting for both the farmer and the advisor to know the amount of time needed.

👫 You should be **two persons** to carry out the soil assessment.

Visual Soil Assessment and Extended Spade Test (according to Beste 2003 and Junge)

💼 🏞️ 🌱 This is a standardized in-field soil assessment that allows us to calculate an overall soil score at the end.

ℹ️ Aggregate stability is a major indicator for soil health. Soil minerals stick together with organic materials like fungi, bacterial cells, roots and their exudates, to form small and large aggregates. A well-aggregated soil will enable healthy root growth, water infiltration, and soil aeration, and decrease the chances of soil erosion, among others. Aggregation is also the most important process in soil organic carbon stabilization, as it protects organic matter from biodegradation. Disturbances like tillage and heavy machinery, and bare soil (and thus erosion) decrease aggregation.

ℹ️ Roots supply plants with water, nutrients and oxygen. They stabilize the soil against erosion and compaction, are a primary material for the formation of humus and habitat for many soil organisms. Root exudates stimulate microbial growth and are important carbon inputs to the soil. Root-fungi symbioses are important for nutrient acquisition. The space close to the roots is called the rhizosphere.

Required material: *spade, soil probe, hydrochloric acid, tweezers, 3 ice cube trays, distilled water, stopwatch, camera, cardboard, sieves 3 mm and 5 mm*

Surface analysis, organic matter, root and harvest residues

Describe what the surface looks like:
Do you see pores, crumbs, aggregates, algae, organic residues, crusting, cracks, etc.? Is the surface dry/ wet/ do you see surface ponding? Do you see signs of erosion (rills/ gullies/ sheet erosion)?

Horizon	Description	Score
Surface (0-1 cm)	rough surface, single aggregates are visible, not platy, worm castings, no slaking, no crusting	100
	transition	75
	aggregates are slaked, platy, no/ little worm castings, initiating crusting (cracks)	50
	transition	25
	platy aggregates, crusts, cracks, slaking, sealing	0

Soil organic matter is material like microbial, plant and animal residues that is alive and in various stages of decomposition. It is an important indicator for soil health as it feeds microbial activity, influences soil physical and chemical properties and all soil ecosystem services like carbon and nutrient cycling, infiltration, and water holding capacity.

Do you find any organic materials or residues on the soil surface? Describe which & how much.

Soil sampling

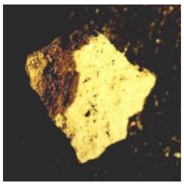
Sample a soil block of about 30 cm depth with a spade. Mark at 15 cm depth, as we will analyze the block from 0-15 cm and 15-30 cm separately.
Take a picture of the sample.

Soil structure assessment

Term	Diameter	Surface	Shape	Emergence
fine crumb	few millimetres	rough surface	round	mainly biologically built structure
polyhedron	few millimetres	smooth surface	angular	swelling-shrinking cycles, mechanical cultivation
fragments	**general term for aggregates in centimeter and decimetre range**			
large crumbs	=< 5 cm	rough, round edges, fracture surface rough	round	built up structure

clumps (also called clods)	> 5 cm	rough or smooth	rather round, very compact	swelling-shrinking cycles, mechanical cultivation

Polyhedron: smooth surface, no pores



Sub-polyhedron: smooth surface, few pores

Fine crumb: rough surface, lots of pores

Horizon	Description	Score
Topsoil (0-15 cm)	more than 80% fine crumbly structure, at high clay content also small polyhedra, loose, few crumbs	100
	transition	75
	(after slight pressure disintegration in) mixed structure of differently sized aggregates, small polyhedra and single particles, disintegrates easily with low pressure	50
	transition	25
	dominated by large crumbs and sharp-edged fragments or clumps with smooth surface or unaggregated structure, only a few crumbs	0

Horizon	Description	Score
Subsoil (>15-30 cm)	(after slight pressure disintegration in) mixed structure of differently sized aggregates, small polyhedra and single particles	100
	transition	75
	Large crumbs and dense, large fragments/ clumps, with partially smooth surfaces, disintegrate with low pressure	50
	transition	25
	more than 80% sharp-edged fragments/ clumps, larger and distinctively smooth surfaces, coherent structure	0

Root assessment

Detailed pictures are especially interesting for documentation/ evaluation over several years and consultation.

Horizon	Description	Score
Topsoil (0-15 cm)	high root penetration, many roots and fine roots, strongly branched, evenly distributed and glued together with small soil aggregates (large contact area between roots and soil)	100
	transition	75
	moderate root penetration, few fine roots, slightly branched, partially in irregular tufts, growing in coarse pores of larger fragments and large crumbs	50
	transition	25
	very irregular root growth, tufts and partly horizontal root felts, growth mainly in large pores through (or on the surface of) larger, angular fragments and large crumbs	0

Horizon	Description	Score
Subsoil (>15 - 30 cm)	high root penetration, many roots and fine roots, strongly branched, evenly distributed and glued together with small and large soil aggregates (large contact area between roots and soil)	100
	transition	75
	moderate root penetration, few roots and fine roots, poorly branched, partially: several roots grow in parallel in coarse pores through (or on the surface of) larger angular fragments and large crumbs	50
	transition	25
	very irregular root growth in tufts, partially: several roots grow in parallel in large pores through (or on the surface of) larger angular fragments and crumbs, partially horizontally kinked and flattened	0

Aggregate sampling

Sample aggregates from different locations in the soil block 0-15 cm and >15-30 cm. Aim at getting a representative sample. Sieve the aggregates, first through a 5 mm- sieve and then through a 2 mm-sieve to obtain aggregates of size 2-5mm. Count 45 aggregates from both soil blocks respectively. If you are short on time in the field, you can store the sieved aggregates in a small jar or closable test tube and continue with the aggregate stability test later (but the aggregates should still be field fresh).

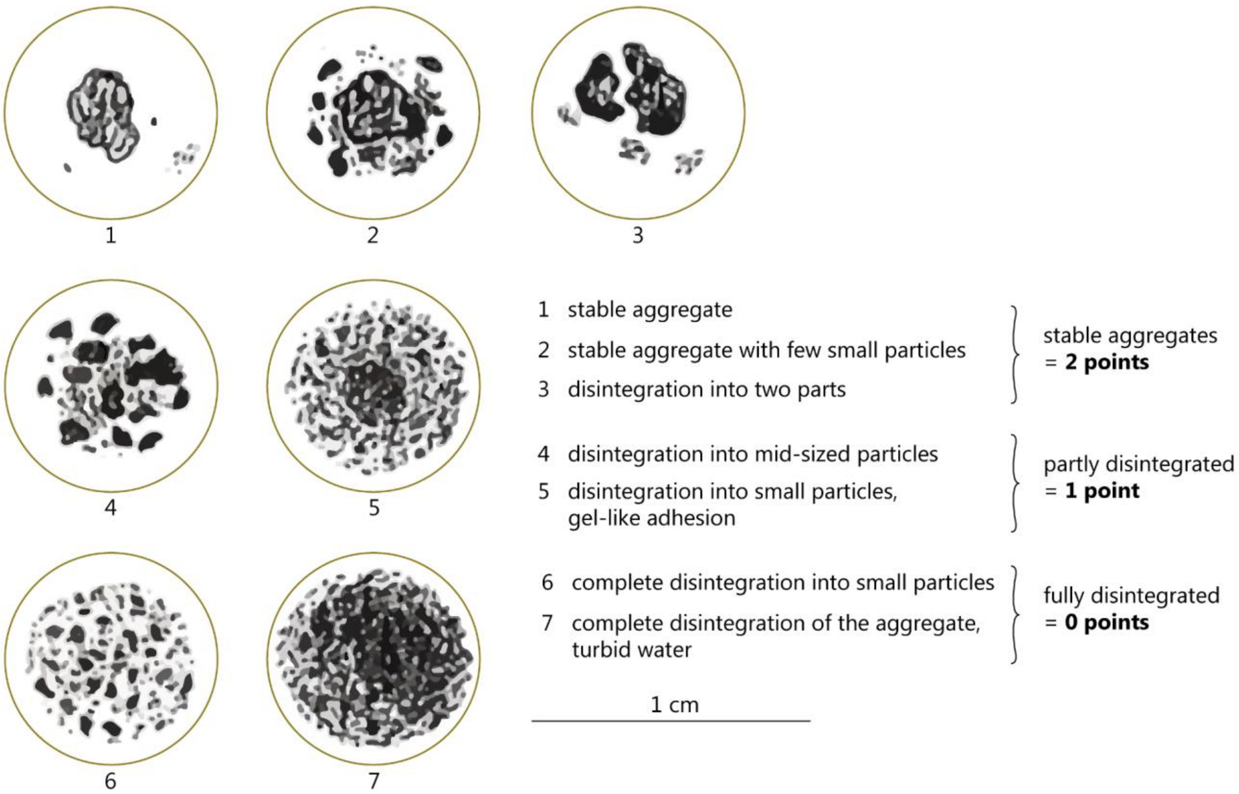
Aggregate stability test / Slaking test

Distribute the aggregates in the ice cube trays: two aggregates per small compartment. Carefully pour deionized water in the trays, wait for *one minute* and then tap the individual compartments repeatedly. Did the aggregates disperse? Check the figure below to score the slaking of the aggregates.

Calculation of the Assessment score

$$\begin{aligned} \textit{Soil structure index} &\\ &= \left(\frac{\textit{soil score}_{topsoil} \times \textit{aggregate stability}_{topsoil}}{2}\right) \\ &+ \left(\frac{\textit{soil score}_{subsoil} \times \textit{aggregate stability}_{subsoil}}{2}\right) \end{aligned}$$

→ Score: 0 - 100 points for topsoil and subsoil together. However, it is important to also look at the results from topsoil and subsoil separately. They might develop differently, or there may be a specific problem in one horizon, which is not represented in the total score.



Root indicators:

💼 🏞 🌱

Root tips: Are no/ few/ many/ all root tips white?

ℹ️ Root tips are especially important for water, oxygen and nutrient uptake and thus are essential for sound plant growth. Active and healthy root tips are white.

Soil attached to roots: Is there no/ little/ moderately/ a lot of soil attached to the roots?

ℹ️ Root exudates are substances that are secreted from living and active plant roots and are one of the major driving force for interactions between plants and microorganisms in the soil. The more exudates, the more soil is attached to the roots, even when shaking strongly.

Smell: Smell the roots. Do you smell anything distinct? Is it a foul or putrid, fungal or pleasant smell?

Root nodules on legumes: Do you see nodules (little bulbs) on the roots? How many? What is their colour? Actively N-fixing nodules are reddish/pink inside, indicating that the bacteria are alive and active. Dead or inactive nodules are greyish green or brown inside.

ℹ️ Roots of legumes (and a few other plants like alder) form small bulbs, called nodules, that are in a symbiotic relationship with nitrogen-fixing bacteria, called rhizobia (or frankia in the case of alder). Rhizobia (or frankia) bacteria convert atmospheric nitrogen to plant-available forms of nitrogen. In exchange, the plant root supplies sugars to the rhizobia (or frankia).

Root orientation: Are all roots oriented in the same direction? Do you see one or a few roots that are growing in a different direction? Is there a visible obstacle (mechanical/ chemical) they avoid?

ℹ️ Roots grow in response to resource availability and constraints like compaction. Thus, limitations in the soil can often be recognized looking at root orientation and depth.

Root depth: How deep are most of the roots reaching? How deep are the very deepest roots reaching? Do you see a layer/ area that is prohibiting root growth? E.g. compaction, water logging, rocks.

Mycorrhizae: Do you see mycorrhizae? How much?

ℹ️ Mycorrhizae are symbiotic associations between plant roots and fungi that play an important role in plant nutrition. The plant root supplies sugars to the fungus which in return acquires nutrients and water for plant uptake by exploiting a larger soil volume than the plant roots alone.

🌱 **If you are doing the base case scenario, you have finished the Soil Assessment and can proceed to 3.7. Soil sampling.**

⭐ **For best-case scenario, continue:**

Soil texture

💼 🏞 ⭐ Use the flow diagram "Determine Soil Texture by the Feel Method" (= Soil Ribbon Test) at the end of this document.

Other soil indicators

💼 🏞 ⭐

Carbonate testing with Hydrochloric acid: Add hydrochloric acid dropwise to different depths on the spade sample.

If you see foaming or bubbling, there is are carbonates in your soil, which usually means that the soil is well buffered against acidification and thus the pH is naturally higher than in soils without carbonates.

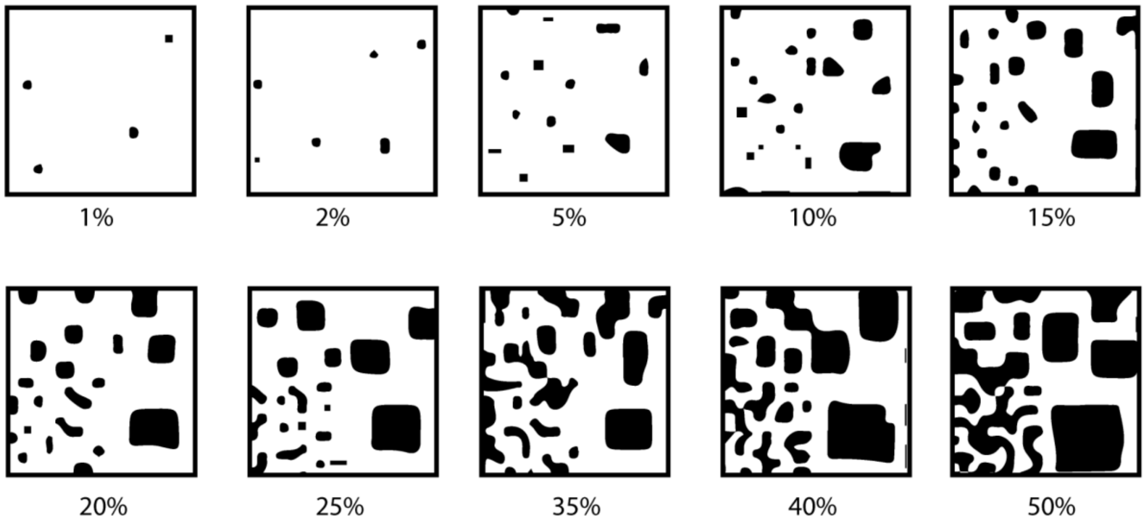
Moisture: Assess the soil moisture by looking at and possibly squeezing some soil in your hand.

Smell: Take a handful of soil and smell it. Do you smell anything distinct? Is it a foul or putrid/ fresh forest soil smell?

Color, color gradient: Note: dark/ light brown, gray, greenish, white, other (describe). You can also compare your sample with a handful of soil from an undisturbed area (e.g. grass strip next to the field). Do you see any difference in color, is it paler/ darker than the undisturbed soil?
Typically, a darker soil contains a higher amount of organic matter. Gray or greenish colors indicate disturbed soil respiration, poor drainage or water logging.

Mottles: Describe the color and percentage (compare with percentage chart below) of mottles (=spots with distinctly different color than the surrounding soil).
They are a good indication about whether a soil is well- drained and aerated. Mottles can also indicate poor soil structure and compaction with a lack of soil pores.

Percentage chart (own representation after FAO)



Soil pit: Horizon formation, Soil depth, Bedrock depth, Groundwater depth: Do you see distinct layers in your soil profile? These can be characterized by differences in color, texture or other soil attributes. Describe and make a sketch. Note how deep the A-horizon reaches in several locations. Do you know how deep you can dig until you reach bedrock? Is groundwater coming up when digging deeper?
Usually, we find a distinct “A-horizon” at the top with a darker color because of its higher organic matter content.

Compaction: Penetrate the soil with a soil probe in several locations and note if you feel higher resistance at a specific depth.
Compaction is promoted by the use of heavy machinery, overgrazing and intensive tillage. It impairs root growth and thus plant development, reduces water infiltration, and soil aeration. Often

a plough pan (= compacted layer) can be detected at around 25-40 cm depth. Does the soil on the spade break open "like a book" at specific depths?

Volumetric stone content: Determine the percentage occupied by stones in the A-horizon of the soil. You can compare with the percentage chart below.

Earthworms

💼 🏞️ ⭐ To get a feeling of the population in your soil, dig out a pit of 20cm x 20cm x 20cm and count the number of earthworms, in this volume of soil , ideally in several locations on your field. This is especially interesting to do repeatedly over the season/ years. You can also work with this more detailed method:
https://ahdb.org.uk/knowledge-library/how-to-count-earthworms (attached in the end of this document).

ℹ️ Earthworms provide essential services like improving soil structure by burrowing, mixing, aerating and recycling nutrients. They are excellent indicators of soil health and the presence of accessible organic materials, acting as feed for the worms.

Infiltration test

💼 🏞️ ⭐ *Required material: piece of wastewater pipe, ~10L water, stopwatch, possibly mallet and piece of wood*

- Note some information about the place where the infiltration test is done. Is there a slope? On bare ground or vegetation? Is the surface crusted?
- The wastewater pipe is smacked into the soil (~5 cm), so no water runs out on the side of the ring.
- Mark a distance of 10 cm from the ground on the pipe.
- Pour water into the ring up to the 10 cm- mark and time how long it takes for all the water to infiltrate (no more visible water puddles on the surface).
- Repeat 3 times around the sampling plot, note all 3 results and calculate the mean value.

ℹ️ In the infiltration test we estimate the infiltration rate, i.e. how well the soil can take up precipitation. This depends highly on soil texture, but can also be influenced by organic matter content, nutrient content, soil fauna, rooting systems, surface crusting etc..

The infiltration rate is often given in mm (e.g. weather reports), but can also be expressed in liters / m^2. Thus, **mm / hour = L / m^2 / hour**. We measure how long it takes for a 10cm (=100mm) water column to infiltrate, thus we can calculate the infiltration rate:

$$infiltration\ rate\ (mm/hour) = \left(\frac{water\ column\ (mm)}{infiltration\ time\ (sec)}\right) \times 3600$$

Soil sampling for laboratory analysis

💼 🏞️ 🌱 We are sampling soil for analysis in soil laboratories. You can also easily estimate bulk density and soil moisture of the sampling day yourself.

Please attach any available soil results from earlier analyses.

<u>Required material</u>*: shovel/ soil auger, sampling rings of known volume, sealable plastic bags (~2L), sharpee*

Note on each bag: farm, field, sample ID, date, which horizon/ depth, purpose of sample (e.g. for SoilBalancing, for freezing, for BD). Note the sample IDs under 2.1. General information.

<u>Per homogenous area/ zone:</u>

🌱 **One or several (composite) sample(s), depending on soil laboratory requirements**

⭐**Three samples with sampling ring**: for bulk density in the A-horizon (top horizon, below vegetation). The bag with the three samples should be weighed field moist, then dried until constant weight (at 105°C, e.g. in an oven for 2 hours) for a few days and weighed again. Like this, we can calculate bulk density and volumetric soil moisture on the sampling day.

$$Bulk\ Density\ [g/cm^3] = \frac{mean\ weight\ of\ air - dried\ soil\ [g]}{sampling\ ring\ volume\ [cm^3]}$$

$$Volumetric\ Water\ Content\ [\%] = \frac{mean\ weight\ of\ moist\ soil\ [g] - mean\ weight\ of\ air{-}dried\ soil\ [g]}{sampling\ ring\ volume\ [cm^3]} * 100$$

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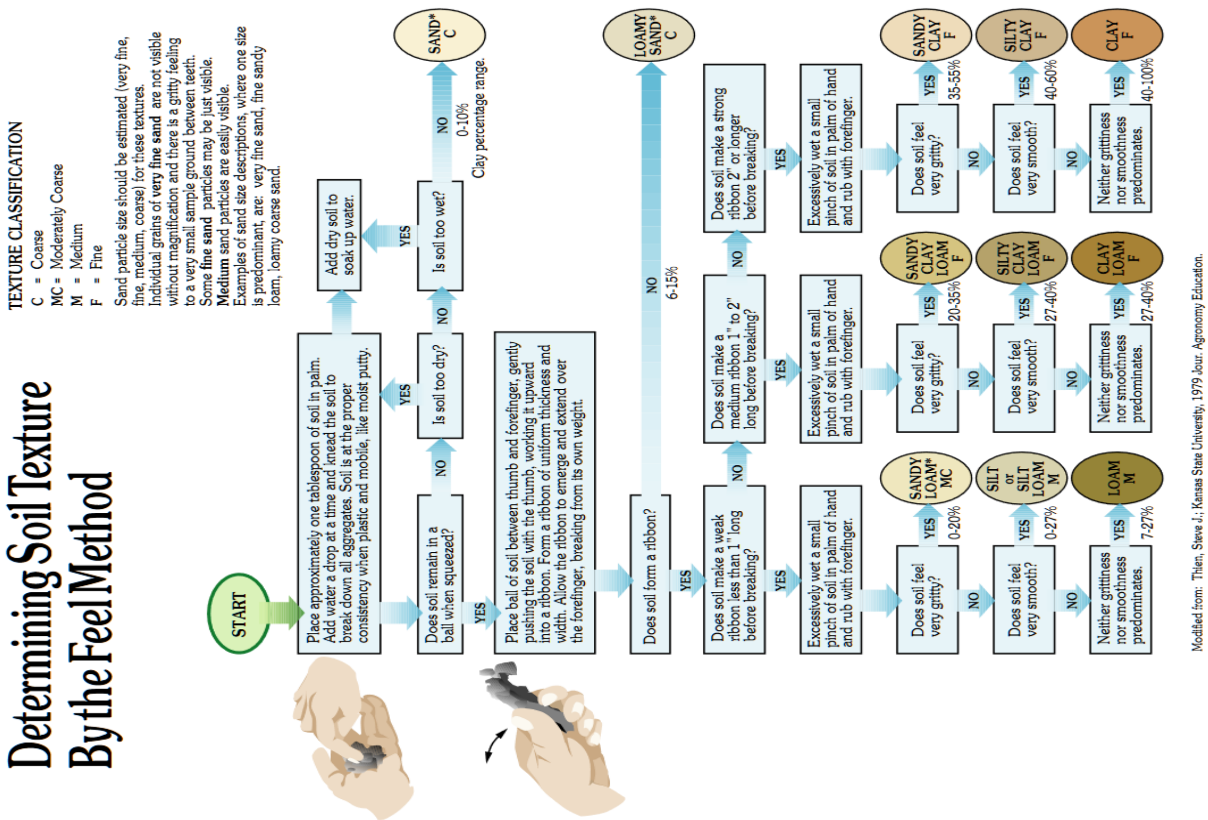

Identifying adults and juveniles

Adult earthworms have a clearly developed **saddle** (reproductive ring) and juveniles do not.

You may need to rinse worms with water to determine if a saddle is present.

Size is not a good indicator of maturity as adult earthworms typically range in size from 2cm to 15cm, depending on species.

Assessing earthworm populations in just 60 minutes

When is it best to count earthworms?

Spring and autumn are the best times to carry out earthworm assessments.

Timing the sampling after warm, wet conditions often provides the best earthworm population estimates.

How to assess the earthworm populations

Tools: Spade, pot, bottle of water, mat and a record sheet available to download at **ahdb.org.uk/greatsoils**

Procedure: Dig 10 soil pits per field following a standard W-shape field-sampling pattern. Aim to spend five minutes hand-sorting the soil from each pit.

1. Dig out a soil pit (20cm x 20cm x 20cm) and place soil on mat
2. Hand-sort the soil, placing each whole earthworm into the pot
3. Count and record the total number of earthworms
4. Separate earthworms into adults and juveniles (see above)
5. Return juveniles to the soil pit
6. Count and record the number of each type of adult earthworm (see overleaf)
7. Return earthworms to the soil pit and backfill with soil
8. Repeat steps 1–7, until 10 soil pits per field have been assessed

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Identification of Climate Adaptation & Mitigation Strategies: The Measure Catalogue

This catalogue contains a number of measures that can be used to respond to the effects of climate change. It does not claim to be exhaustive.

	Category	Measures
Field structural	Field restructuration/ reorganisation/ habitat connectivity	Plot arrangement
		Controlled trafic
		Greening of tractor lanes
		Contour line parallel management
		Tractor lane positioning
		Headlands/ buffer strips/ flowering stripes
		Reduced field size (max 3 ha)
		Agriphotovoltaik
	Irrigation	Drip irrigation
		Underground irrigation
		Rainwater harvesting
	Agroforestry	Tree intercropping
		Tree crops
		Multistrata agroforestry
		Silvopasture
		Perennial cropping
	Digitalisation	Precision agriculture
		Smart farming
Land management (Crop- and Grassland)	Machinery	Cutter bar
	Soil maintenace & Soil cover	Mulching
		Liming
		Stubble working
		Retaining harvest residue
		Undersowing
		Green manure
	Crops	Leguminous species
		Cover crops
		Crop rotations
		Intercropping
		Catch crops
		New cultivars
		Diversification of crops
		Assollement
		Perennial plants
	Fertilisation/ Nutrient management	Manure management
		Nutrient management
		Balanced plant nutrition
		Biochar

	Soil amendments/ additions of organic matter	Terra preta
		Addition of organic matter
		Mycorrhizal inoculation
		Compost
		Green manures
		Rottelenker
Cropland-specific	Minimized soil disturbance	No-till
		Reduced tillage
		Conservation agriculture
		Subsoil loosening
		Mechanical weeding
	Specialized crop cultivation	Market gardening
		Tractor lane positioning
		Protected gardening
		Ornamental plants
		Herbs
		Hops
		Nuts
		...
		Energy crops
Grassland-specific	Adapted seed mixtures	
	Increased plant diversity	
	Grazing management	Multi-paddock grazing
		Mob grazing
		Silvopasture
		Rotational grazing
		Pasture cropping
		Holistic grazing
Animal Husbandry	Animal management	Chaptel size
		Species diversification
		Adapted species/race
		Bruderkalb
		Pastured poultry
		Improved cattle feed
	Double use species	Meat + Milk
		Wool + Meat
		Eggs + Meat
Spezialized production	Waterflow agriculture	Hydroponic agriculture
		Aquaonic agriculture

Autarky / Self-sufficiency	Water management	Retention pools
		Keyline design/ swales
	Heating	Biogas
		Biomass heap
	Electricity	Agriphotovoltaik
		Solar
		Wind
	Organic ressources, fertilizer	Compost
		Wood cuttings
		animal husbandry
		Biochar
	Weather	Hay dryer
		Protected gardening
		Irrigation
	Additional income	Farm café
		On-farm vacation
		Other touristic activities
		Event location
		Boarding horses
		Cleaning, conditioning of grains, seeds, etc. with own machinery for others
	Other	Seeds, seedlings
		Fuel
Management	Labour	Co-ownership
		Co-management
	Consultation	Tools
		Spezialized offers
	Finances	Community-supported agriculture
	Marketing	Direct marketing
		Farm shop
		Restaurants, cantines
		Supply chain partners
		Producer associations
	Cooperations	
		Fodder-manure-cooperation
		Machinery ring
		Research institutions
		NGOs
	Reduce harvest losses	

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Meassure Sheets

AGROFORESTRY

multifuncional | timber, fuel, fruits, nuts | small- & large-scale

Description: Agroforesty (AF) is the systematic integration of woody plants on agricultural land. This multifunctional form of land use can induce a variety of positive interactions. The agriculturally produced products are extended by stem wood, energy wood, fruits, nuts or also fodder foliage. Overall, this can lead to an increased productivity.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Drought: Less susceptible to drought conditions (optimized microclimate)

Heat: Lower temperatures in the cultivation (optimized microclimate)

Water: More water in the ecosystem. Irrigation is possible.

Diversification: Can diversicate income and increase economic stability. Often direct marketing.

Ecosystem: Improving biodiversity and robustness of agro-ecosystems

Customizable: Suitable for many locations and farms.

Law: Subsidy and technical law often an obstacle. Case-by-case reviews helpful.

Experience and data: Knowlege-intensive. Currently there is little experience with modern agroforestry systems which leaves space for pioneer work.

Inputs and Invest: Depending on the system, but increasing demand for investment and working time

Path dependency: Reversibility possible but associated with costs and effort

Implementation Example

On 12 ha of the lighthouse farm **Werragut** in Central Germany a trial plot was established on the farm for testing 15 fruit species in combination with different substrates, tree protection systems and irrigation systems. The area is monitored and regular guided tours are arranged. **More Infos: werragut.de**

AGROFORESTRY

Assessment

FIELD LEVEL

Soil: AF can potentially be established on all soils, but the quality of the soil will influence the system's development and attainable yields. Waterlogging greatly limits the possibilities.
Temperature: A high variety of woody perennials are possible and planting times can be adjusted to the temperature. However, the colder the site, the shorter the growing season. Excessive irradiation can be a problem.
Frost: AF is vulnerable to (late) frost events. The systems should be planned accordingly.
Wild animals can cause great damage. There are different protection systems.

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- The positive effect of AF on GHG emissions is well researched
- Increase of soil carbon
- Carbon fixation in woody biomass (above and below ground)
- Renewable resources replace fossil fuels
- Reduced pressure on land (increased productivity per m^2)
- Reduced fossil fuel consumption possible (decreasing fertilization and plant protection)
- Optimized microclimate supports soil properties between woody plants
- Long-term effectiveness

ENVIRONMENTAL IMPACTS

- Highly beneficial for enhancing biodiversity
- Adaptation to climate change
- Soil and (ground)water protection
- Improving the microclimate

SOCIAL IMPACTS

- Provide new and interesting jobs in rural and urban areas
- Improvement of the level of local self-suffiency and food sovereignty
- Can increase joy and contentment about working in agriculture, many young farmers establish AF systems

INVESTMENT AND WORKLOAD

Investment:

- Wide range possible; **Minimum: 1.000-15.000 €/ha, depending on the system and own performance**
- Only occupies small amount of land (low opportunity costs)
- Can be tested with low investment approach and scaled up with time

Path dependencies:
Low risk: land can be converted back but needs money

Workload:

- Knowledge-intensive system: learning, implementation and management
- Labour-intensive system: depending on the system and scale
- Innovative system: interesting for integrating new persons in the farm business

ROBUSTNESS (MALADAPTATION CHECK)

- [x] **Multifuncional**
- [x] **Long-term measure. In some cases over several decades.**
- [x] **No negative externalities**
- [x] **Supports diversification**
- [ ] **Measure can be tested**
- [x] **No increase of dependencies**

Comments:
Depending on the system, a successful outcome for AF is highly dependent on professional planning and advice because it is very knowlege intensive.

SYNERGIES (TOP 4)

Within agroforestry systems, the combination with many other measures on field-scale are possible to provide soil, water and climate protection and further support biodiversity. Here are some examples for possible synergy effects at the farm level:

1. **Local energy supply:** Woody perennials can be planted for thermal use (e.g. woodchip heating).
2. **Compost production:** Biomass from trees/ shrubs can be used for composting which can be given back to the soil for nutrient supply and structural enhancement.
3. **Direct Marketing:** Many products from AF systems like fruits, nuts, berries are great for direct marketing. The positive impact on the landscape and long-term systems also helps to increase customer loyalty.
4. **Biochar production:** Biomass from trees/ shrubs can be used for biochar production.

AGRIPHOTOVOLTAIC

Energy | Diversification | Integrated Land-Use

Description: Agro- or agriphotovoltaic (APV) systems aim at integrating food and energy production on the same piece of land with photovoltaic (Weselek et al., 2019). APV aims at increasing the land productivity due to combined production of food and energy and usage of potential synergistic effects. The overall relevance for adaptation is dependent on the specific system.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Drought: Shading of PV-modules could reduce evapotranspiration

Heavy Precipitation and Hail: Depending on the crop (e.g. fruit shrubs), PV-modules can provide protection

Heat: Shading of PV-modules could reduce heat stress in crops and livestock - but can also reduce crop productivity

Planning: Complicated planning procedure with potential barriers (local administration, public acceptance)

Diversification: Can moderate income losses during drought/heat events - good addition to climate sensitive farm business

Investment: Irrigated APV installations encompass generally a large investment need

IMPLEMENTATION

Hofgemeinschaft Heggelbach: combination of arable crop production and PV:

hofgemeinschaft-heggelbach.de

Overview of running **research projects** and general information concerning APV technology:

https://agri-pv.org/de/

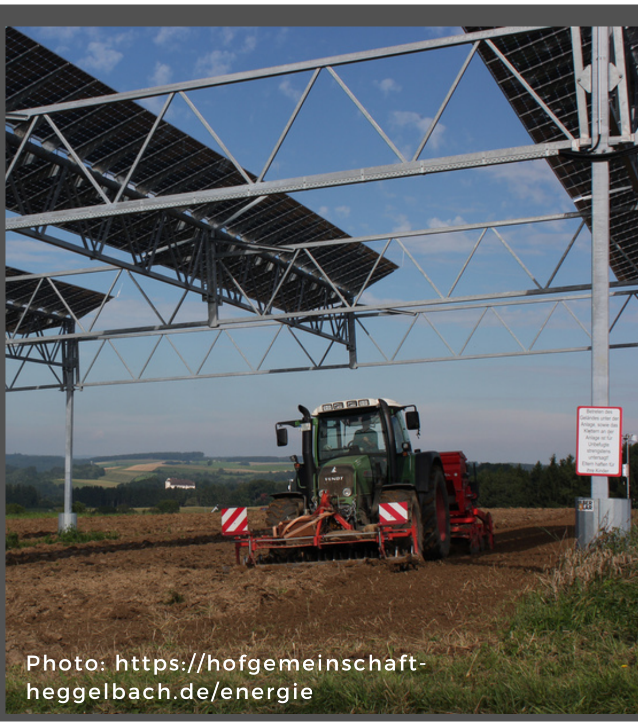


Photo: https://hofgemeinschaft-heggelbach.de/energie

FIELD LEVEL

Soil: APV should be focused on soils with a lower production potential in order to minimize conflicts with food production and optimize productivity of fields with lower soil quality
Sun hours: The higher the number of sun hours in the specific location, the higher the potential yield of the PV installation
Field exposition and sourrounding vegetation: In the best-case, the concerned field is able to catch sunlight during the whole day - however, this is not a neccesary condition for a productive APV system

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- Replacing fossil fuel based energy production
- In case of on-farm usage: provides an incentive to switch to electric vehicles
- Depending on the subconstruction, the installation of APV-systems will entail more GHG-emissions than a comparable installation on a roof or open-field

ENVIRONMENTAL IMPACTS

- The influence on the broader agroecosystem is uncertain and comprehensive research is lacking
- Main positive impact is the reduced land-use due to the integrated production of energy and food
- Room between the mounting poles could be used for the cultivation of hedges or other perennial biomass, what can improve habitat diversity of the agricultural land
- Practice reports show that especially during heat events, the shade of the PV-modules provides shelter for insects and birds

SOCIAL IMPACTS

- Can improve local availability of clean energy, e.g. a charging station for electric vehicles
- APV is a new and innovative concepts which largely changes the aesthetics of the landscape. This could entail disapproval by the local administration or public.

INVESTMENT AND WORKLOAD

Investment:
- **Minimum: ~ 500.000€**
- Rentability of an APV installation increases with scale due to high fix-costs. This makes a certain minimum area/investment necessary.
- Investment costs vary depending on the specific APV system
  - Rule of thumb: the higher the modules must be mounted, the higher the price per kWp installed capacity
- Investment costs are also dependent on the existing infrastructure (e.g. availability of a feed point)

Workload:
- High workload during planning and installation due to partly complicated legislative processes
- After installation, workload is relatively small - but depends on the specific system
- For example, dynamic modules need more maintenance than static modules

ROBUSTNESS (MALADAPTATION CHECK)

- [x] **No-Regret Measure**
- [ ] **Reversible and flexible**
- [ ] **Reduced time horizon**
- [x] **No negative externalities**
- [x] **Supports diversification**
- [ ] **Measure can be tested**
- [x] **No increase of dependencies**

Comments:

APV entails high investment costs and is only reversible in the mid- to long-term. This will partly impair the financial felxibility of the farm. However, APV is not sensitive to climatic changes and can provide a stable and reliable income source, which largely reduces its potential to be maladaptive.

SYNERGIES (TOP 3)

1. **Fruit Production:** Certain permanent crops (especially berries) grow better when partly shaded
2. **Energy intensive farms:** The production of on-farm energy can largely decrease energy costs and vulnerability to network failures
3. **Rainwater harvesting:** APV-modules can also be used to collect rainwater. However, the sufficient wtaer-supply of the crops beneath the modules must be ensured

COVER CROPS

Carbon farming | Soil management | Crop rotation

Description: Cover crops are a form of crops integrated in a crop rotation. Their main goal is to create a soil cover preventing bare soil (f.ex., between growing seasons). Their compositon out of different species serves to improve the soil, by diminishing weeds, controling diseases and pests, increasing biodiversity and increasing water uptake (water absorption capacity). Cover crops help to limit erosion and nutrient loss and in combination with leguminous species even add to the nutrient balance.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Climate resistance: Soil is less susceptible to drought conditions , helps increasing water holding capacity

Soil and fertility management: Promotion of soil life, increase in infiltration capacity and erosion protection

Pest management: Cultivar choice, placement and timing of cover crops can reduce infestations by insects, diseases, nematodes and weeds

Ecosystem service: Various different seed mixtures and varities are added to the crop rotation. Offering needed habitat for many species

Sun: Utilises the full photosynthetic potential of a field

Knowledge and research: A thorough understanding of cover crops and the relation and benefits of different species in regard to the soil and it's proprieties are needed

Implementation: Wrong implementation practices may lead to increased passage of machinery on the field, leading to soil compaction and fuel usage

Inputs/ Workload: Needing more workforce and time to add another culture to the farm production

Implementation Example

The **Oekozenter** leads a trial with 5 different cover crop species to demonstrate implementation and development of different mixtures and varieties in the condition of Luxemburg.

COVER CROPS

Assessment

FIELD LEVEL

Soil: Effective soil conservation practice by reducing runoff and water erosion. Cover crops raise soil fertility, increase soil organic matter and raise the aggregate stability of the soil.
Fertilization: Adding leguminous species to the cover crop mixtures allows to fix atmospheric nitrogen in the soil due to their root's capacity through the symbiotic relation with bacteria. Incorporation of cover crops after growing season functions as green manure.
Pests and diseases: Covering bare soil with cover crops provides direct competition to weeds. And adding various species to the crop rotation limits diseases and pests.
Frost events: A distinction is made between overwintering and freezing off, the choice should be made on the basis of the following crop and planned soil cultivation.
Crop rotation: If, for example, oilseed rape is part of the crop rotation, crucifers should not be used as catch crops.

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- Cover crops absorb CO2 and store carbon in the soil
- Sustainable agricultural practices combined with cover crops reduce the emissions of vehicles used in soil management.

ENVIRONMENTAL IMPACTS

- Raising soil's ability to absorb intense rain events, holding moisture.
- Increase organic matter, improving the soil structure preventing soil erosion.
- Breaking pest, disease and weed cycles.
- Providing diverse species on generally bare soils, creating a habitat for a multitude of species and promoting soil life.

SOCIAL IMPACTS

- Diverse crops with flowers present a better image than bare soil.

COVER CROPS

Assessment

INVESTMENT AND WORKLOAD

Investment:

- **150-300 €/ha**
- Costs are limited in the seeds, manpower and fuel/machinery.
- Main investment is time and work, during a busy period.
- Low risk: land will not be influenced negatively by the implementation of cover crops.

Workload:

- Knowledge-intensive system: The right crops and varieties must be found in regard of the soil proprieties and the crop rotation.
- Not very much time consuming only need planting once and either yielding or mulching once.

ROBUSTNESS (MALADAPTATION CHECK)

- ☑ **No-Regret Measure**
- ☑ **Reversible and flexible**
- ☑ **Reduced time horizon**
- ☑ **No negative externalities**
- ☑ **Supports diversification**
- ☑ **Measure can be tested**
- ☑ **No increase of dependencies**

Comments:

Depending on the soil, cover crops is highly dependent on the encountered conditions and the benefits wanted. A wide variety of seeds can be adjusted to fit every scenario.

SYNERGIES (TOP 3)

1. **Reduction of fertilization:** Due to the characteristics to enhance soil fertility, less fertilization is needed.
2. **Crop rotation:** Additional element in the crop rotation reduces weed, pest and diseases pressures.
3. **Soil properties:** Cover crops enhance soil structure, health and overall quality. Raising the growing potential of following crops.

FURTHER INFORMATION

https://www.fabulousfarmers.eu/en/get-fabulous/fab-measures/begruenung

FIELD BLOCK OPTIMIZATION

Economic efficiency | Lower soil compaction | Ecological stability

Description: Field block optimization (FBO) is one of the approaches of precision agriculture. The goal is to design the optimal shape and size of the land block resulting in the establishment of productive and non-productive areas that serve environmental-technical-social purposes. The correct shape and size of the soil block saves time, fuels, fertilizers and seed. And it also reduces soil compaction through mechanization.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Ecosystem: Non-production areas increase ecosystem stability, retain water and increases biodiversity. Reduction of water and wind erosion.

Legislation: Absence of assessment of benefits and non-production functions of environmentally technical areas in legislation.

Prevention: Of soil compaction by mechanization.

Duration: Time consuming preparations.

Inputs: Consumption of fuels, fertilizers, seeds and time is reduced.

Consultancy: Lack of counseling support.

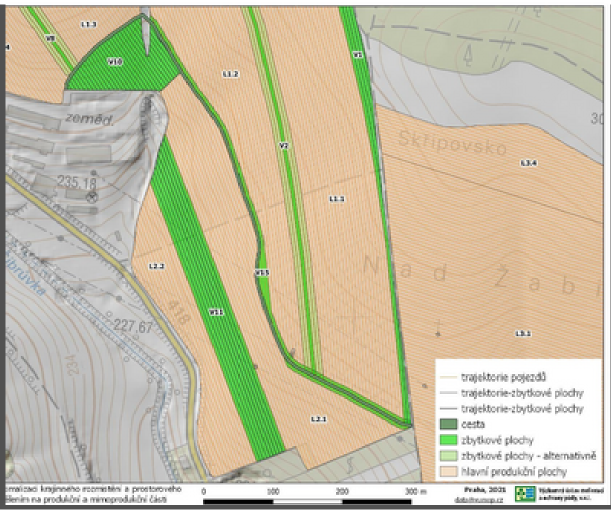
Time savings: More efficient crossings after optimizing crossing trajectories.

Investment requirement: To achieve the maximum effect, the use of a satellite navigation system is necessary.

Implementation Example

One of the example locations is EKOFARMA PROBIO Velké Hostěrádky (Czech Republic). The farm operates in an organic farming system approximately on 360 hectares of arable land, where the vast majority of land consists of areas at risk of erosion. Field block optimization helps reduce the risk of erosion.

https://www.ekofarmaprobio.cz/



FIELD BLOCK OPTIMIZATION

Assessment

FIELD LEVEL

- Increasing the efficiency of agrotechnical operations based on optimizing the shape and size of production parts.
- Elimination of technogenic soil compaction on vulnerable production areas.
- Creation of framework conditions for the full application of navigation systems.
- Increasing the competitiveness of plant production even while ensuring non-production functions of agriculture.
- Increasing the permeability of the landscape for equipment ensuring the maintenance of distribution networks, roads, etc.

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- Reduces GHG emissions because of lower fossil fuel and fertilizer consumption
- Reduces soil compaction (increased productivity per m^2)

ENVIRONMENTAL IMPACTS

- Elimination of erosion, soil compaction, and reduction of nutrient losses.
- Increasing the ecological stability of the landscape.
- Limitation of greenhouse gas production.
- Stabilization of the energy balance.
- Reduction of the import of substances used in agricultural production.
- Supporting food chains and migration routes.
- Connection of stable components of the landscape matrix.
- Increasing the water retention potential of the landscape.
- Protection of water bodies, reducing the risks of eutrophication and silting with sediments.

SOCIAL IMPACTS

- Prevention of material damage to property (flooding).
- Increasing the permeability of the landscape for leisure-time purposes of the public in nature.
- Targeted action to change the landscape character and support the aesthetic appearance of the landscape.
- The emergence of transition zones between agricultural production and other parts of the landscape.

INVESTMENT AND WORKLOAD

Investment:

- **Consultancy: 15-30 € /ha designing**
- It is recommended to contact experts to achieve optimal settings
- **Satellite navigation system: 10 000 - 25 0000 €**
- It is recomended use satellite navigation system to achieve maximum efficiency
- Can be tested on the part of soil blocks but when satellite navigation system is used, is better to have more optimized soil bloks
- Main investment is time which is important for good site analysis

Workload:

- Expert-intensive system: for a good setting and quality site analysis experts are needed
- Knowledge-intensive system: learning with satellite navigation system can take up an amount of time
- Innovative system: interesting for streamlining work processes and saving the costs

ROBUSTNESS (MALADAPTATION CHECK)

- ☑ **No-Regret Measure**
- ○ **Reversible and flexible**
- ☑ **Reduced time horizon**
- ☑ **No negative externalities**
- ☑ **Supports diversification**
- ☑ **Measure can be tested**
- ○ **No increase of dependencies**

Comments:

The measure (SBO) makes it possible to effectively set aside parts of land for Environmental-Technical Areas. These areas support diversity, retain water and create a more stable ecosystem.

INVESTMENT AND WORKLOAD

Investment:

- **Consultancy: 15-30 € /ha designing**
- It is recommended to contact experts to achieve optimal settings
- **Satellite navigation system: 10 000 - 25 0000 €**
- It is recomended use satellite navigation system to achieve maximum efficiency
- Can be tested on the part of soil blocks but when satellite navigation system is used, is better to have more optimized soil bloks
- Main investment is time which is important for good site analysis

Workload:

- Expert-intensive system: for a good setting and quality site analysis experts are needed
- Knowledge-intensive system: learning with satellite navigation system can take up an amount of time
- Innovative system: interesting for streamlining work processes and saving the costs

FURTHER INFORMATION

Comments:

The measure (FBO) makes it possible to effectively set aside parts of land for Environmental-Technical Areas. These areas support diversity, retain water and create a more stable ecosystem.

SYNERGIES (TOP 3)

1. **Environmental-Technical Areas + agricultural land:** effective division of land will make it possible to set aside part of the land to ensure environmental functions
2. **Lower vulnerability:** FBO will reduce the land's susceptibility to water and wind erosion, as well as soil compaction
3. **Costs:** optimization will bring cost savings - lower consumption of fuels, fertilizers, seeds

IMPLEMENTATION PLAN

How to implement this measure:

1.Site analysis
Identification of critical sites from the point of view of water and wind soil erosion, inclination, susceptibility to consolidation, slope variability and analysis of existing documents such as land use plan, etc. Analysis of geometric characteristics.

2. Field block optimization
Optimizing the shape and size of plots, availability to the plot, optimizing crossings and transplanting and implementing other principles of precision agriculture and quantifying their benefits.

3. Draft measures
Agrotechnical and organizational recommendations. Evaluation of DZES conditions. Design of crop structure and design of sowing and management of environmental-technical areas.

4. Digitization
Digitization of all underlying layers and land block optimization proposals, including land raids into an online browser or LPIS.

FIELD MARGINS

(HEADLAND, HEDGEROWS, FLOWERING STRIPES)

Field structure | Crop Production | big scale

Description: Field margins (Headlands....) and other non-crop vegetation structures in agriculture respond directly to climate caused challenges. These covered surfaces are limiting soil erosion and enhance water absorption. Additionally, headlands and field margins play an important ecosystem role (pest regulation, pollination and nutrient cycle) as well as enhancing biodiversity and creating habitat for a multitude of animals.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Eroision: Covered soil and enhanced soil structure lead to reduced soil erosion. Protection of the bare soil.

Flooding + Water erosion: Field margins located at strategic locations, at the end of a field slope and near waterflows can avoid flooding and contamination of waterways

Connectivity: Field margins act as ecological corridors, supporting habitat restoration

Ecosystem: High diversity of plants - improving biodiversity and robustness towards pests and diseases

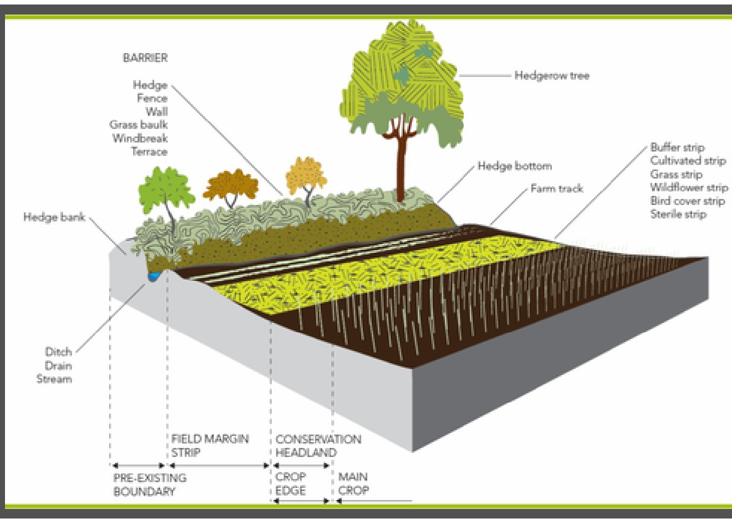
Environmental pressures: Headlands can promote weed infestations, disease induction and pest infestations.

Outputs/production: Less area can be cultivated, reducing overall production

Inputs: Reduces use of herbicides, pesticides and fungicides. It creates multiple habitats and promotes pollination.

Health: increases well-beeing, as part of recreation

Implementation Example:
Field margins can be found in numerous different forms with related specific ecological benefits for fauna and flora. Additionally at the right location field margins take part in the adaptation of the agricultural practices to climate change.



FIELD MARGINS

Assessment

FIELD LEVEL

Soil: Multifunctional field margins increase soil abundance and less invasive crop management systems in general increase survival and thriving of soil organisms. Therefore soil structure and fertility are improved and promoting soil pore structure, soil aggregation and the decomposition of organic matter.
Important: use a seed composition of native species.
Water: Perennial field margins play an important role in preventing water pollution, and water erosion combined with flood attenuation and water retention by regulating the capture, infiltration, regulation, retention and flow of water across landscapes.
Temperature and Frost events: With regard to flowering field margins, it is important whether a perennial or annual flowering strip is planted. Perennials should be sown in autumn and annuals in spring. In the case of spring sowing, this should be done early in order to be attractive to beneficial insects but not to suffer frost damage.

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- Carbon sequestration potential increases with increasing margin width and depends on plant diversity
- Increases soil health
- Reduced input and fossil fuel consumption
- Can create windbreaks, reducing wind speed, therefore lowering the risk of wind erosion
- High genetic diversity allows faster adaptation to climate change
- Reduces flood risks and nutrient run-off into water bodies

ENVIRONMENTAL IMPACTS & ECOSYSTEM SERVICES

- Field margins promote genetic diversity,
- Pools for pollinating and pest controlling species.
- Multifunctional field margins increase soil abundance of soil macro fauna, including earthworms, woodlice and beetles.
- Food source and nesting site for mammals and birds.
- Creating migration corridors between biodiversity hotspots.
- Reduces use of herbicides and pesticides
- Promotes rare native plants

FIELD MARGINS

Assessment

SOCIAL IMPACTS

- Farms can better promote their produce, field margins are visually pleasing for costumers.
- Field margins may be combined with recreational opportunities and tourism.

INVESTMENT AND WORKLOAD

Investment:

- Mechanical soil cultivation and seeding 100-200 €/ha
- Mechanical cutting with or without salvage of the cut material 40-100 €/ha
- Seeds: 40-700 €/ha
- Main investment is the loss of productive area
- Low risk: land can be converted back to arable production (laws may vary between countries)

Workload:

- Easy to understand and little knowledge needed
- Minimal and occasional work needed
- Good implementation in function of criteria (location, problems, waterfloods, biodiversity, connectivity...)
- Visual measure, easy to communicate to population

ROBUSTNESS (MALADAPTATION CHECK)

- ☑ **No-Regret Measure**
- ☑ **Reversible and flexible**
- ☑ **Reduced time horizon**
- ☑ **No negative externalities**
- ☑ **Supports diversification**
- ☑ **Measure can be tested**
- ☑ **No increase of dependencies**

Comments:

The correct implementation depends on a lot of different criteria, including diversity of species, topography of the field, crop produced in the field. But the measure is easy and fast to implement and can bring a lot of benefits for a small investment.

FIELD MARGINS

Assessment

SYNERGIES (TOP 3)

1. **Pollinated crops:** FM create areas with high count of pollinators, essential for the pollination process of a large number of crops.
2. **Extensive agriculture :** Auxiliary insects provide functions in pest management, no pesticides needed if FM are correctly placed.
3. **Agroforestry:** Integration of trees and shrubs can be essential in field margins installed in flooding areas.

HOW TO IMPLEMENT THIS MEASURE:

- IDENTIFICATION OF LOW YIELDING AREAS IN FARMS, CAN BE PLACED ALONG HEDGES, BANKS, FOREST FRINGES, DITCHES AND WATER COURSES.
- FIELD MARGINS ARE LONG-TERM STRUCTURAL ELEMENTS OF A FARM. BEST INTEGRATED WHEN CONNECTING ECOLOGICAL INFRASTRUCTURES.
- PREPARATION: PREPARE SEED BED, SOWING AND MANAGEMENT IN THE FIRST YEAR WITH CUTTING/MOWING TO LIMIT ANNUAL WEEDS AND PERMIT DEVELOPMENT OF FLOWERS AND SOWN SEEDS.
- MANAGEMENT IN FOLLOWING YEARS: CUTTING THE MARGINS 50% EVERY YEAR AT THE END OF THE FLOWERING SEASON, ALTERNATING EVERY YEAR TO GUARANTEE OVERWINTERING HABITAT FOR SPECIES.

SOURCE: MFFM-ASSESSING-THE-BENEFITS-FOR-NATURE-SOCIETY-AND-BUSINESS.PDF (SYNGENTA.COM)

FURTHER INFORMATION

MFFM-Assessing-the-benefits-for-nature-society-and-business.pdf (syngenta.com)

https://www.fabulousfarmers.eu/en/get-fabulous/fab-measures/field-margin-management/webinars-5

GREEN MANURE

Soil protection and improvement | Organic matter | Nitrogen

Description: There are many reasons why to implement green manure into the sowing processes. From improving soil quality to nitrogen fixation. For farm without cattle is the green manure the best solution how to nourish the soil and to produce organic matter. There are many types seeds and mixtures. Farmers have to decide what they want to achieve. It is possible to use a mixture with grasses if the green manure is used for fodder.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Soil improvement: green manure is a carbon that breaks down quickly. The main function is to feed microorganisms, mainly bacteria, and provide a quick flush of nutrients to soil life and the next crop.

Easy implementation: if you follow the basic recommendations.

Soil protection: against the erosion, heat and frost, lower evaporation.

Biodiversity support: habitat for pollinators and wild animals.

Recommendation: it is necessary to choose a suitable mixture of seeds for the chosen purpose

Climate problem: Green manures that are incorporated after they have been killed by frost, or those that are rich in biomass and winter-hardy, can release more climate-damaging gases (especially nitrous oxide) into the atmosphere during freezing and thawing cycle in winter.

Inputs: incidental costs are needed (seeds, cultivation)

Implementation Example

One of the example locations is EKOFARMA PROBIO Velké Hostěrádky (Czech Republic). The farm operates in an organic farming system approximately on 360 hectares of arable land, where the vast majority of land consists of areas at risk of erosion. They use green manufe for erosion protection and for improving soil structure.

https://www.ekofarmaprobio.cz/

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- reduction of evapotranspiration due to soil cover

ENVIRONMENTAL IMPACTS

- Elimination of erosion during the winter season
- Soil protection against the heat or frost
- Increasing the water retention
- Nutrition for the soil organisms and bacteria
- Impact on increasing of insects, pollinators and wildlife

SOCIAL IMPACTS

- Prevention of material damage to property (flooding).
- Maintaining or improving soil quality = property quality

INVESTMENT, WORKLOAD AND FIELD LEVEL

Investment:

- Seeds, fuel, time and mechanization for sowing

Workload:

- It is important to choose appropriate plants (seeds, mixtures) for your objective:

1. **Improving of the soil structure - production of organic matter**

- For this reason is the best solution grass-clover mixtures which will grow on the field at least 1,5 years. Their roots grow through the soil deep and intensiv. Regular mowing is recommended. The last mowing can be processed into mulch. Cattle-free farms can use lucerne-clover mixtures. But include grasses is an advantage. Grasses are better in organic matter production and have more stable release of nitrogen.

2. Erosion protection during winter

- To protect the soil against erosion is recommended the timely seeding of winter-hardy green manure. Grass-clover mixture, ryegrass after cereals, forage rye, vetch rye, winter turnips after potatoes or maize.

3. Nitrogen supply for following crop

- Legume crops are the best nitrogen suppliers (peas, field beans, clover-lucerne mixtures). During the long term dense cultivation (left standing until flowering) they can furnish 70-140 kg nitrogen per hectare. For a shorter cultivation period is summer vetches or Egyptian-Persian clover suitable. Grain legumes (lupine) are able to bind phosphorus.

4. Conservation of nitrogen for the following crop

- For nitrogen conservation is recommended to use fast growing plants like green oats, forage rye, mustard, turnip and oil (fodder) radish. They are also tested new fast growing and drougt-resistant varieties of crops like Sudangrass and lyme grass.

5. Subsoil loosening

- For this purpose it is needed deep-rooting plants. It can be used oil (fodder) radish, perennially cultivated lucerne, lupines, field beans. It is recommended to loosen the soil with cultivator before the sowing. The plants may access the deeper soil layers more easily. Cultivation period is recommend at least 3 months.

6. Prevention of pests and deseases

- The main recommendation for prevention of pests and diseases is not to cultivate the green manure that is closely related to the main crop (e.g. mustard with rapeseed).

7. Weed supression

- For suppressing of seed-propagated weeds it is needed fast growing green manures which are amenable to a cut soon after growth to 10-15 cm in height and than they form a densely closed stand. For suppressing of perennial weeds it is needed to use perennial stands of grass-clover.

GREEN MANURE

Assessment

PLANTS AND THEIR EFFECT

Green manures and their effect

Green manure/ mixture	Production of organic matter	Gain of nitrogen for following crop	Subsoil loosening	Erosion protection during winter	Prevention of pests and diseases [1]	Weed suppression	Comments
Grass-clover 1,5 years	●●●○	●●●○	●●○○	●●●●	●○○○	●●●○	Suppresses thistles and bindweed, promotes docks/sorrels. Risk of wireworms for following crop. Thorough rooting of the deeper soil with lucernes.
Pure grass seeds (up to 9 months)	●●●○	●○○○	●●○○	●●●○	●●●○	●●●○	Non-host for root-knot nematodes and many crop-rotation diseases of root crops and vegetables.
Clover-lucerne mixture (up to 9 months)	●●●○	●●●●	●●●○	●●●○	●○○○	●○○○	Suited as a green manure between cereals and maize, little 'depth effect' given an over-year-long cultivation. Longer periods of cultivation maybe applicable.
Lupines, field beans (until flowering)	●○○○	●●●●	●●●○	●○○○	●○○○	●○○○	Susceptible to nematode varieties, few problems with wireworms in following crop. Lupines need warmth. Rather unsuitable when legumes are part of the main crop.
Peas, vetches (until flowering)	●○○○	●●●●	●○○○	●○○○	●○○○	●●○○	Pea is less warmth-dependent, also suitable for winter cultivation. Vetches depending on type. Peas are unsuitable if the same are part of the main crop. Vetches only limitedly.
Phacelia (until flowering)	●○○○	●○○○	●○○○	●○○○	●○○○	●●●○	Not related to crop types. 'N-gain' via prevention of washing out.
Oil (fodder) radish	●○○○	●○○○	●●●○	●○○○	●●●○	●●●○	Not in a crop rotation with cruciferous plants, subsoil loosening only when cultivated for a longer period. 'N-gain' via prevention of washing out. Recovery effect depending on variety (nematodes).

Key: ○○○○ no effect; ●●●● = very strong effect; [1] Focus on diseases with a wide range of hosts, and nematodes

MARKET GARDENING

Diversification | Vegetable Production | Small-Scale

Description: Market gardening (MG) is a novel concept in agriculture, mainly focused on high-value cash crops (vegetables). MG employs a small amount of land, uses direct-marketing channels and cultivates a high variety of plants while minimizing mechanization and financial investment needs.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Drought: Less susceptible to drought conditions (irrigated system)

Heat: Vegetables are planted set-wise - can be adjusted to changed patterns. Heat waves in spring can be problematic (early flowering)

Diversification: Can complement existing production structures but dependent on direct marketing

Ecosystem: High diversity of plants - improving biodiversity and robustness towards pests and diseases

Heavy Precipitation and Hail: Ususally open air production - susceptible to heavy rain and hail events

Health: Constant exposition to heat and sunlight can cause health issues and impair productivity

Water: Irrigated system - need to secure sustainable supply of irrigation water

Inputs: Depending on the soil, MG is highly dependent on the availability of high quality compost

Implementation Example

On the **Hof Tolle**, all production branches were susceptible to drought . The irrigated vegetable production can balance losses in drought periods. The market gardening was established by two external persons which were interested in the Market Gardening system - **more Infos: hof-tolle.de**

FIELD LEVEL

Soil: MG can potentially established on all soils, but the quality of the soil will influence the amount of compost needed to establish the vegetable beds
Temperature: A high variety of vegetables are deployed and planting times can be adjusted, the temperature. However, the colder the site, the shorter the growng season
Frost events: MG is vulnerable to (late) frost events. Cultivars selection should be planned accordingly. Various protection measures exist

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- The effect of MG on GHG emissions is not well researched yet
- Reduces pressure on land (increased productivity per m^2)
- Reduced input and fossil fuel consumption
- Indirectly, the availability of local, high-quality vegetables could increase the consumption, which in turn could reduce the consumption of other products, which produce higher GHG emissions
- Uncertain factor: GHG-emissions of compost production

ENVIRONMENTAL IMPACTS

- Depending on the design of the MG, the production mode can be highly beneficial for enhancing local biodiversity and improving the microclimate
- Higher availability of local food can reduce need for import and indirectly reduces negative impacts of intensive production systems in other parts of the world
- Potentially negative is the usage of plastic foils and nets for plant protection and the consequent

SOCIAL IMPACTS

- MG can provide new and interesting jobs in rural and urban areas
- Improvement of the level of local vegetable self-suffiency and food sovereignty

INVESTMENT AND WORKLOAD

Investment:

- **Minimum: <1.000€**
- Only occupies small amount of land (low opportunity costs)
- Can be tested with low investment approach (< 1.000€ is possible) and easily scaled up with time
- Main investment is time and work
- Higher investments will be necessary if production is complemented by greenhouse production
- Low risk: land can be converted back to arable production, active market for used tools and tunnels

Workload:

- Knowledge-intensive system: learning and implementation will take up a high amount of time
- Labour-intensive system: depending on the system and scale, labour-cost can constitute 75-90% of the overall costs
- Dependent on direct-marketing channels: due to higher prices compared to conventional vegetable production, direct marketing will be in most cases necessary
- Innovative system: interesting for integrating new persons in the farm business in order to reduce workload

ROBUSTNESS (MALADAPTATION CHECK)

- ✔ **No-Regret Measure**
- ✔ **Reversible and flexible**
- ✔ **Reduced time horizon**
- ✔ **No negative externalities**
- ✔ **Supports diversification**
- ✔ **Measure can be tested**
- ○ **No increase of dependencies**

Comments:

Depending on the soil, MG is highly dependent on the avaiability of high quality compost. Diversification of sourcing or internal compost production should be considered

SYNERGIES (TOP 3)

1. **Rainwater Harvesting:** MG is dependent on irrigation - need to secure sustainable water supply
2. **Composting:** Main input for MG - producing on-farm compost could make the farm more independent from external sources
3. **Agroforestry:** Integration of trees and shrubs can improve natural regulation mechanisms (pest and diseases) in MG and enhance the variety of products

REDUCED TILLAGE

Erosion Control | Soil Structure | Arable Cropping

Description: Reduced or no tillage (often referred to as/ similar to no-till, zero tillage, minimum tillage, conservation tillage or direct drilling) practices have the goal of reducing soil disturbance during field operations like weed management or seeding. Crop residues are left on the soil surface as mulch. Tillage has adverse effects on soil organic matter, soil structure and other environmental factors. Reduced or no tillage can be paired with cover cropping and crop rotations for best results.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Water storage: Reduces soil water loss by evaporation or runoff from the soil surface.

Water infiltration and quality: Can improve water infiltration and retention. Can improve water quality adjacent to agricultural land. However, if not implemented well, can also cause compaction.

Soil erosion and nutrient loss: Reduces soil loss by water and wind. Also decreases nutrient losses and pesticide leaching from surface runoff.

Soil organic matter (SOM): May contribute to increased amounts of SOM in top soil, and with it soil carbon levels.

Soil life: Increases diversity and amounts of soil fauna like earthworms, which have positive effects on soil quality.

Economics: Saves labour and fuel required to power machinery during tillage operations.

Soil structure: Can prevent soil compaction caused by heavy machinery. However, if not implemented well, can also cause compaction.

Weeds: No weed control through tillage. Often, herbicides are used instead, but alternative options exist.

Pests and diseases: Crop diseases can be harbored in surface residues. Pests that need additional management may arise.

Complexity: May require more complex ecosystem management to increase predator populations and improve biological pest/disease control.

Implementation Example:
No-till in organic agriculture: Werragut

- Shallow full-surface soil cultivation
- Clover and diverse cover crops in crop rotation
- Machine options: cultivator, rotary tiller, disc plow, power harrow
- Challenges include weed pressure, mineralization in spring

REDUCED TILLAGE

Assessment

FIELD LEVEL

Soil type: The benefits of reduced tillage depend on the soil type and are highest in well-drained coarse or medium-textured soils, i.e. sandy and loamy soils. Excessive tillage can lead to poor aeration and water infiltration. Sandy soils are prone to soil structure depletion.

Soil moisture and temperature: In regions with cold temperatures in spring, poorly drained soils potentially warm up slower without tillage. This may result in delayed planting. However, conventional tillage destroys soil structure, leading to decreased aeration and water infiltration which reduces resilience in terms of flooding and droughts in the long term.

Occasional or strategic tillage: Eliminating tillage in the long term may result in a compaction layer which can be broken by so-called sub soiling every 5-10 years. This practice is also referred to as occasional or strategic tillage and may also be helpful for weed management, incorporating soil amendments like lime, manure or crop residues, or transporting SOM to greater depths.

Occasional tillage does not usually have large negative effects on soil properties and productivity that have been built up by no-till, if well-planned. It is however important to simultaneously establish a cover crop with strategic tillage to avoid erosion [5].

Soil life: Soil disturbance through tillage harms soil micro- and macrofauna, and thus reducing it will increase their abundance and diversity, which in turn supports plant growth. For example, earthworms are essential builders of soil structure and digersters of nutrients and their abundance is directly correlated with higher soil fertility. Introducing beneficial insects and other animals can help fight pests and diseases, e.g. lady beetles to eat aphids.

REDUCED TILLAGE

Assessment

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- Reduced fossil fuel consumption.
- Reduced carbon losses from soils.
- The amount of additional SOC unter no-till is relatively small and often overestimated. Apparent increases in SOC result from altered depth distribution [1], as no-till often simply avoids the mixing of higher C topsoil with deeper soil layers. SOC increases in the uppermost soil layers with no-till, but these gains are offset by decreases of SOC in deeper soil layers. The C sequestration potential of no-till with respect to climate change is thus likely to be overvalued [2]. However, a larger C concentration in the topsoil following no-till is generally favourable for other soil properties that translate into better crop growth [1].

ENVIRONMENTAL IMPACTS

- Use of herbicides instead of mechanical weeding, leading to negative impacts on soil biodiversity and the surrounding environment, e.g. decreasing earthworm populations. However, reduced or strategic tillage can also be employed in organic farming systems.
- Less nutrient leaching and pesticide run-off from bare soil.
- Increased soil fauna and habitat for birds [1].
- Improved overall soil quality, resulting in higher climate adaptation and food security.

SOCIAL IMPACTS

- Lower workload.
- Lower costs of machinery use.

REDUCED TILLAGE

Assessment

INVESTMENT AND WORKLOAD

Investment:

- Initial cost for special equipment needed for mechanical weed control or direct seeding machines. Large market for used equipment.
- Costs can be alleviated over time through labour and fuel savings, possibly old tillage machinery can be sold. Some sources also claim increased yields.
- Low risk: land can be converted back to conventional tillage.

Workload:

- Employing reduced or strategic tillage may necessitate a more holistic rethinking of field management to counteract the emergence of weeds, pests and diseases and soil compaction or soil hardening by farm machinery traffic.
- Soil microbiota that improve plant defenses, encourage colonization of beneficial predators and parasitoids, and reduce pest abundances and the need for insecticides can be encouraged through no-till combined with crop rotations, pest-resistant crop varieties, adjustment of planting and harvest dates, retention of crop residues, and intercropping [3].
- Compaction can be alleviated by subsoiling in combination with cover crops, diversified crop rotations and controlled traffic [4].

ROBUSTNESS (MALADAPTATION CHECK)

- [x] **No-Regret Measure**
- [x] **Reversible and flexible**
- [ ] **Reduced time horizon**
- [x] **No negative externalities**
- [ ] **Supports diversification**
- [x] **Measure can be tested**
- [x] **No increase of dependencies**

Comments

Dependencies may arise if specific machinery is aquired. However, many machines can be borrowed and the second hand market is usually good.

REDUCED TILLAGE

Assessment

SYNERGIES (TOP 3)

1. **Cover cropping:** To provide mulching material and supress weeds, to protect the soil surface in times when no crop is grown, to decrease erosion and water evaporation, to fertilize, to stabilize/ prevent compaction after occasional tillage.
2. **Diversified crop rotations:** For soil fertility management, pest and disease control.
3. **Controlled traffic:** To prevent compaction.

FURTHER INFORMATION/ SOURCES:

[1] Soil Association (2018): To plough or not to plough. Tillage and soil carbon sequestration. https://www.soilassociation.org /media/17472/to-plough-or-not-to-plough-policy-briefing.pdf

[2] Meurer, K. H., Haddaway, N. R., Bolinder, M. A., & Kätterer, T. (2018). Tillage intensity affects total SOC stocks in boreo-temperate regions only in the topsoil—A systematic review using an ESM approach. Earth-Science Reviews, 177, 613–622.

[3] Murrell, E.G. (2020). Challenges and Opportunities in Managing Pests in No-Till Farming Systems. In: Dang, Y., Dalal, R., Menzies, N. (eds) No-till Farming Systems for Sustainable Agriculture. Springer, Cham. https://doi.org/10.1007 /978-3-030-46409-7_8.

[4] Peralta, G., Alvarez, C.R., Taboada, M. A. (2021): Soil compaction alleviation by deep non-inversion tillage and crop yield responses in no tilled soils of the Pampas region of Argentina. A meta-analysis,
Soil and Tillage Research, Vol 211, https://doi.org/10.1016 /j.still.2021.105022.

[5] Wortman, C. (2020): Strategic Tillage for the Improvement of No-Till Cropping Systems. https://cropwatch.unl.edu /2020/strategic-tillage-improvement-no-till-cropping-systems (last access: 27.2.23)

UNDERSOWING

Increasing the resilience of agricultural systems | Environment

Description: Undersowing is a process where a second crop is sown together with the main crop or the second crop is sown when the main crop is bigger. The reason why is the second crop sown is erosion control, improving the health of the soil, improving the soil retention capacity, weeds regulation, reduction of pests and deseases, increasing biodiversity and more benefits for the farmers and environment.

ADAPTATION, VULNERABILITY AND UNCERTAINTY

Soil: improving of soil structure, retention capacity, soil organic matter increasement.

Prevention: of soil erosion, soil compaction, weeds, insetcs and deseases.

Mechanization: adjustment of sowing machines is necessary.

Fertility: It can bind atmospheric nitrogen to the soil or bind excess nitrogen from the previous crop to the biomass of the catch crop.

Investing into the future: healthy soil → healthy agricultural system. Undersowing and catch crops increase the profitability of the main crops.

Aditional costs: seeds of plants for undersowing, fuels, time.

Implementation Example

One of the example locations is EKOFARMA PROBIO Velké Hostěrádky (Czech Republic). The farm operates in an organic farming system approximately on 360 hectares of arable land, where the vast majority of land consists of areas at risk of erosion. Undersowing helps reduce the risk of erosion.

https://www.ekofarmaprobio.cz/

UNDERSOWING

Assessment

FIELD LEVEL

There are two option when to implement undersowing:

- sowing together with the sowing of the main crop (narrow-row crops)
- sowing after the main crop is bigger (broad-row crops)

It is important not to sow deeply (1-2 cm).

Undersowing is used to control the **soil erosion**. Broad-row crops are particularly susceptible to water and winter erosion. Cover crops in maize can serve as a protective layer/mat for the soil during harvest. Maize is usually harvested later in the season when the soil is wet and prone to compaction by heavy machinery and cover crops can **protect the soil from compaction**. Undersowing is also recommend for the cereals.

Another advantage of underseeded cover crops is the ability to **nourish the soil** after the flowering of the cash crop (especially cereals). At this stage, the cash crop transfers most of its energy to grain production, which limits the flow of sugar to the roots. The roots stop producing root exudates that normally feed soil microorganisms. Cover crops can subsidize cash crops and nourish soil biology to maintain high activity. Grasses are exceptionally good at this, but clover can provide more nitrogen to the soil.

Crops from the **leguminous grou**p are able to use atmospheric nitrogen with the help of symbiotic fixation. This includes, for example, red clover, purple clover, sown alfalfa, Pannonian vetiver or bushy vetch, peas, lupine and broad beans. Annual species are capable of binding 50 to 200 kg/ha of organic nitrogen per year. Perennial species such as clover and lucerne can set up to 300 kg/ha per year. It is one of the most important sources of nitrogen in the ecological farming system.

Crops that are **unable to bind atmospheric nitrogen** include rye, oats, triticale, grasses - for example ryegrass; buckwheat, safflower, sunflower, sorghum, mustard and other cruciferous vegetables.

UNDERSOWING

Assessment

This is a group of crops that are used to capture available nutrients in the soil, reduce soil erosion, suppress weeds and produce a high volume of biomass that can contribute to the formation of soil organic matter. If there is a surplus of nitrogen on the land after the main crop has been harvested, catch crops sown in autumn are able to bind 15 to 30 kg of residual nitrogen per hectare. If a catch crop is sown in the summer after the main crop, the catch crops are able to fix up to 75 kg of residual nitrogen per hectare, taking into account previous organic nitrogen fertilization management.

MITIGATION, ENVIRONMENTAL AND SOCIAL IMPACTS

MITIGATION

- reduction of evapotranspiration due to soil cover

ENVIRONMENTAL IMPACTS

- Elimination of erosion during the winter season
- Soil protection against the heat or frost
- Increasing the water retention
- Nutrition for the soil organisms and bacteria
- Impact on increasing of insects, pollinators and wildlife

SOCIAL IMPACTS

- Prevention of material damage to property (flooding).
- Maintaining or improving soil quality = property quality

INVESTMENT AND WORKLOAD

Investment:

- Seeds, fuel, time and mechanization for sowing

Workload:

- It is important to choose appropriate plants (seeds, mixtures)

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Templates & Tools for practical adaptation of Own-Farm Climate Strategy

Farm Survey

Documentation form

Alena Holzknecht[1], Nils Tolle[1], Janos Wack[1]

Contact

Name	
Address	
E-Mail	
Telephone	

General farm information 🌱

Total farm area [ha]	
Production branches	
Farming practice	
Certifications (EU-organic, other organic, etc.)	☐ yes ☐ no if yes, please specify:
Marketing / sales channels	
Other on-farm establishments	

Farm location within region	

[1] kontakt@triebwerk-landwirtschaft.de
TRIEBWERK - Regenerative Land- und Agroforstwirtschaft UG
Im Rothenbach 49, D-37290 Meißner
https://www.triebwerk-landwirtschaft.de/

Main soil types & textures	

Wind (direction, peak velocities)	
Precipitation [mm] (mean, min, max, per season, peaks)	
Temperature [°C] (mean, min, max, per season)	
Average amount of days < 0°C per year	
Experienced/ historic extreme weather events	☐ yes ☐ no if yes, please specify:
Personal estimation of future climatic tendencies	
Vulnerable sites within farm	

Farm overview ⭐

Farm areas	Own property [ha]/ leased [ha]	Total [ha]	Number of fields	Remarks
Arable land				
Grassland				
Vegetables				
Orchards				
Other perennials				
Forestry				

Cropping

Culture(s)/ Rotation	Area [ha]	Yield [t/ha]	Marketing/ Use

Animals

Species	Amount	Husbandry system	Output	Marketing/ Use

Source of animal feed:	

If applicable, grazing system:	

Ownership structure & decision making 🌱

Legal owners	
Lease agreements, generation changes or farm transfers	
Other involved parties for decision making	

Workforce, facilities and machinery 🌱

Staff per production branch	
Training and education of persons involved at the farm	
Special knowledge and skills	
Additional workforce	
Facilities	
Machinery	
Agricultural contractors	

Economic background 🌱

Economic situation	
Average farm investment sum (5-year period)	
Planned/ necessary expenditures	
Relative contribution of branches to income	

Climate change ⭐

Farm climate balance	☐ available ☐ planned ☐ neither
Observed climatic changes	

Climate mitigation measures	
Climate adaptation measures	

Formulation of goals and priorities

How important are…	Very Important	Important	Positive side effect	Not important
Economic performance				
Providing a livelihood for yourself/ family/ employees				
Diverse product range				
Self-sufficiency				
Higher yields				
Local/ heritage varieties				
Processing				
Biodiversity				
Biotope connectivity				
Promoting beneficial insects/ animals				
Wind protection				
Improving soil health/ soil quality				
Preventing soil compaction				
Improving water balance (on landscape level)				
Preventing nutrient leaching				
Reducing greenhouse gas emissions / climate mitigation				
Carbon storage				
Climate adaptation				
Shade for animals				

Fodder quality				
Scenery/ landscape design				
Independence from external inputs				
Other:				

Site Assessment

General information

Site name	
Lot number / Site ID	
Site location	
GPS coordinates	
Site area [ha]	
Land manager	
Current land use	
Vegetation/ crops	

Distance from main production facilities [km]	
Means of transport & time needed	
Relevance of site within farm	
Reasonable intervals for management/ observations	
Reasons for choosing this site	
Zonation short explanation: (Please attach sketch with GPS coordinates of zones)	

Per zone:

GPS coordinates/ Zone map:	
Characterize zone:	Zone ID:
Sample IDs:	

Management history

Previous farm manager(s)	

Crops /-rotations	
Amendments, incl. crop residues	
Tillage regime	
Machinery use	
Other practices	

Protection status 🌱

Any/ which protection status?	
Influence on farming decisions	

Climate/weather 🌱

Wind (direction, peak velocities)	
Precipitation [mm] (mean, min, max, per season, peaks)	
Temperature [°C] (mean, min, max, per season)	
Average hours of sunlight per year	
Average amount of days < 0°C	
Local climate projections	
Experienced/ historic extreme weather events	
Personal estimation of future climatic tendencies	
Vulnerable sites within farm	

Topography & terrain 🌱 (⭐)

Altitude [m a.s.l.]	
Slope inclination, exposition	
Sunlight, shade, rain	
Surface runoff, erosion areas	

Landscape elements, compaction, drainage & surrounding vegetation 🌱 (⭐)

Waterlogging / Infiltration	
Compacted areas	
Drainage structures	
Water table [m]	

Trees, shrubs, other perennials	
Wetland areas, ponds	
Depressions, hills	

Power lines, pipes, underground cables	

⭐ Phenological indicators	
⭐ Species composition	
⭐ Plant communities	
⭐ Growth rate, yield	

Existing cultures 🌱 (⭐)

Field journal	☐ yes ☐ no
Diseases, pests	
Root or harvest residues	
Height & uniformity of cultures	
Yield	
Deficiencies, excesses	
⭐ Phenological development stages	
⭐ Grasses: tillering rates	
⭐ Brix level of leafsap	
⭐ Micro-, macronutrients of leafsap	
⭐ Indicator plants: - nitrogen - water - compaction - salt	

Issues & optimisation 🌱

Microclimate (e.g. late frosts)	
Weeds or pests	
Erosion (water/ wind)	
Water balance/ management	
Biodiversity	
Wildlife	
Others	

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Soil Assessment

Date & Time:
Authors:
Weather: ☼ ☁ 🌧 🌫 💨 Air temperature: _____________ °C

Visual Soil Assessment and Extended Spade Test 🌱

Surface analysis

☐ wheel tracks ☐ wind erosion ☐ water erosion (rills/gullies) ☐ surface ponding ☐ crusting ☐ cracks 📷

Ground cover: ☐ <30% ☐ 30-70% ☐ >70%

Organic matter, root and harvest residues

☐ none ☐ little ☐ moderate ☐ many

Describe: ____

Soil structure assessment

Horizon	Score	Notes
Surface (0-2) cm		📷
Topsoil (0-15 cm)		📷
Subsoil (15-30 cm)		📷

Root assessment:

Horizon	Score	Notes
Topsoil (0-15 cm)		📷
Subsoil (15-30 cm)		📷

Aggregate stability test / Slaking test

Horizon	# stable aggregates	# completely slaked aggregates	% stable aggregates	Notes
Topsoil (0-15 cm)				
Subsoil (15-30 cm)				

Assessment Score

$$Soil\ structure\ index = \left(\frac{soil\ score_{topsoil} \times aggregate\ stability_{topsoil}}{2}\right) + \left(\frac{soil\ score_{subsoil} \times aggregate\ stability_{subsoil}}{2}\right)$$

Zone ID	Horizon	Root score	Soil structure score	% stable aggregates	Overall soil structure index
	Surface (0-1 cm)				
	Topsoil (0-15 cm)				
	Subsoil (15-30 cm)				
	Total (=Topsoil + Subsoil)				

Root indicators

- **White root tips:** ☐ none ☐ few ☐ moderate ☐ many ☐ all

- **Soil attached to roots:** ☐ none ☐ little ☐ moderate ☐ a lot

- **Smell:** ☐ pleasant/earthy ☐ foul/putrid/rotten eggs☐ fungal/ fresh forest soil ☐ like the plantation (e.g. carrots) ☐ no smell (also not earthy) ☐ other, describe: _____________________

- **Root nodules on legumes (per plant):** ☐ none ☐ few ☐ moderate ☐ many ☐ on every

root → **nodule colour on the inside:** ☐ reddish/pink ☐ greyish green or brown ☐ other, describe: ________________ - **Root orientation/ root barriers (mechanical/ chemical):** ____ - **Root depth:** most roots: _______________ cm, deepest root: ________________ cm - **Visible Mycorrhizae:** ☐ none ☐ few ☐ moderate ☐ many
Space for additional notes:

📝 **Remember to:**

- draw a map of zones within every field
- take pictures of the soil pits with a measuring tape
- take soil samples and note sample IDs

⏰ **Time needed to assess this zone:** _____________________

🌱 **If you are doing the base case scenario, you are done with the Soil Assessment. Well done!**

⭐ **For best-case scenario, continue:**

Soil texture (Soil Ribbon Test) ⭐

Coarse: ☐ sand ☐ loamy sand ☐ clayey sand Medium: ☐ sandy loam* ☐ silt or silt loam ☐ loam Fine: ☐ sandy clay loam ☐ silty clay loam ☐ clay loam ☐ sandy clay ☐ silty clay ☐ clay *moderately coarse

Other Soil indicators ⭐

- **Carbonate testing:** ☐ no bubbling ☐ only audible ☐ slight bubbling ☐ strong bubbling

- **Moisture:** ☐ dry ☐ slightly moist ☐ moist ☐ very moist ☐ wet

- **Smell:** ☐ pleasant/earthy ☐ foul/putrid/rotten eggs ☐ fungal/ fresh forest soil ☐ like the plantation (e.g. carrots) ☐ no smell (also not earthy) ☐ other, describe: ____

- **Colour:** ☐ dark brown ☐ light brown ☐ grey/blue/greenish ☐ white ☐ reddish/orange ☐ other, describe: ____

- **Mottles:** ☐ none ☐ gray/blue/greenish ☐ orange/red; **if present, how many?** _____________ %

- **Soil pit:** describe and sketch:

____
____
____
____
____
____
____

depth of A-horizon:_______ cm

- **Compaction:** ☐ yes ☐ no; if yes, at which depth: _____ cm/ _____ cm/ _____ cm

- **Soil depth:** ___________ cm, **Bedrock depth:** ___________ cm, **Groundwater depth:** ___________ cm

- **Volumetric stone content:** ________________ %

Space for additional notes:

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Earthworms ⭐

Earthworm number in 20cm x 20cm x 20cm of soil:

Infiltration test ⭐

Infiltration time #1:	Infiltration time #2:	Infiltration time #3:
Infiltration rate:		

⏰ **Time needed to assess this zone (base+best-case scenario):** __________ + __________ min.