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Carbon Farming CE

CE GUIDE FOR CARBON FARMING TECHNIQUES

DELIVERABLE D.1.2.2

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CONTENT

INTRODUCTION AND SCOPE OF THE TASK

This deliverable D.1.2.2 is created as a CE Guide for Carbon Farming Techniques. It consists of a step-by-step procedure for choosing and using 7 carbon farming techniques. It is thought to be used by farmers and agriculture advisors to mainstream carbon farming practices.

Often farmers or their consultants wish to implement an environmentally friendly way of agricultural technique, also in view of the raising awareness of possibilities to work against climate change and the excess of CO_2 in atmosphere by means of certain agronomic soil treatments. Therefore, this guide was elaborated.

This guide consists of a twin package:

- an Excel-tool as decision matrix, where scores of different criteria for each technique that is up to debate for the farmer can be entered. In the background these numbers are automatically further calculated and weighted. After all, result values are given, the highest final value displays the technique of choice.
- For further information, explanation and tips for implementing relevant techniques, as well as for considerations that must be taken into account before setting the scores in the decision matrix tool, this guide provides collected arguments and experiences for every criterion and every technique.

We provide information about seven techniques we followed over two seasons in at least two regions each. These techniques are:

- **A.1 Additional organic fertilizers**
- **A.2 Relocation of harvest residues**
- **B.1 Additional cover crops**
- **B.2 Diversification of crop rotation**
- **B.4 Agroforestry**
- **C.1 Reducing tillage**
- **C.4 Liming/gypsum effect**

The wording for the different techniques will be kept consistent throughout the two documents. The letters in front of the wording derive from the assignment of different ways of contributing to enhanced carbon stocks in soil:

A) adding external C to the soil
B) incorporating by plants through photosynthesis bound atmospheric CO_2 to the soil
C) avoiding loss of C/CO_2 from the soil

Missing numbers after the letters indicate that only selected techniques which we implemented in at least two countries of Central Europe are included in this guide.

Furthermore, we want to define the criteria used for evaluation of techniques to facilitate the choice:

- Feasibility is characterised by all criteria making it easy or hard for the farmer to implement the specific technique. The workload, the time of establishment, the need of detailed information, the lack of practicability or the time to get acquainted with the technique, the dependence on soil and climatic suitability of the site, the labour and other costs, the access to equipment, seed and other operating resources, etc. must be considered. If the feasibility is high, the technique is easy to implement, and the scores will be high.
- Impact means the estimated impact of the techniques on carbon sequestration, which also can be seen in the context of long-term humus accumulation. In this section some of our experiences of the project (2023-2024) so far are displayed to ease the evaluation for farmers. Still, it needs to be considered, that all remarks refer to one specific site in one specific climatic situation and region – which also explains the variability of discovered effects and their dependence on environmental conditions. If the carbon/humus storage is expected to be high, the score will be high, too.

  Besides, diverse techniques also can have an impact on biodiversity of flora and fauna, on above-ground biomass production, on yield, etc. Still, these impacts are not evaluated within this scoring but might be considered within the point of 'acceptance', and in case of good marketing chances, within the point 'feasibility'.
- The acceptance refers to perhaps occurring issues of outside reactions of neighbours, relatives, public, journalists, etc. or also to intrinsic doubts on the reasonability or fears to change usual methods. Furthermore, expected additional effects like long-term enhancement of soil micro- and macro-biome, like higher soil fertility and resilience or higher or lower yield can affect the internal acceptance of the method. As such aspects are similar for all techniques, the chapter ‘General aspects of acceptance’ is displayed as a separate and common section in this document. If there are no external or internal issues, the acceptance is high and so is the score.

At the end of the document, we will also provide an example of the use of the attached decision matrix calculation tool – for practice and demonstration.

CONSIDERATIONS FOR CHOSING AND USING DIFFERENT CARBON FARMING TECHNIQUES

A.1 EXTERNAL ORGANIC FERTILIZERS

External organic fertilizers include solid and liquid manure from different animals, biogas slurry, compost, and biochar for fertilization.

Feasibility

- Dependance on machinery: Applicability of external organic fertilizers, like compost or powdery matrices, depends on machinery used and can be difficult to distribute due to certain characteristics in size and shape.
- Complex logistics: Transporting, storing, and applying organic fertilizers require careful planning, adding logistical challenges for farmers, especially for small farms. The bulkiness of organic fertilizers may require more frequent applications, decreasing efficiency in large-scale operations.
- Higher costs: Specialized equipment for the application of organic fertilizers can be expensive, increasing initial investment costs, especially for farms without livestock, when organic fertilizers must also be transported over long distances. Certain requirements for adequate storage facilities may lead to additional high construction costs.
- Legal restrictions: In some cases, the use of organic fertilizers is legally restricted during certain periods (e.g., winter, requiring investments in storage facilities) or within narrow time slots after delivery (digestate), or in specific areas (e.g., water protection zones).
- Odors: the application of organic fertilizers can produce unpleasant odors, especially close to settlements.
- Potential contamination: If improperly processed, organic fertilizers may carry unwelcome weed seeds, or even pathogens that pose risks to plant health and food safety. They may also contain heavy metals and contaminants, such as plastics or glasses in composts.
- Reduced dependence on price fluctuation of chemicals: Organic fertilizers have a complex composition of nutrients, which helps reduce dependence on the purchase and use of mineral fertilizers and therefore dependence on fluctuating prices of mineral fertilizers.

- Alternative economic opportunities: The production, marketing, and distribution of organic fertilizers can open new income streams for farmers and businesses.

Impact

- Long-term reaction: Within 40 years of data collection on the same site (starting at appr. 27 t soil organic carbon (SOC)/ha), organic fertilizer addition showed positive effects on carbon storage. While agricultural treatment as such caused a slow decrease of carbon stocks (to <20t SOC/ha), incorporating crop residues could maintain SOC-level, and regularly added manure could even increase SOC (to >40T/ha).
- Correlation with plant growth: In some cases, an increase of soil organic matter depends on a better growth of plants, by providing new carbon via root growth and via above-ground plant residues which are incorporated into soil. This increase of biomass can in some cases be better achieved by using mineral fertilizers than by organic fertilizers. Therefore, the SOC increase can, in some cases, be rather fostered using mineral fertilizers instead of organic fertilizers.
- No change with compost: No significant results were observed following the use of compost (applied once at the start of the first crop cycle) on soil organic matter within two vegetation periods.
- Weather variability: Comparisons of sampling results from 2020 in 2023 showed the sensitivity of unstable SOC to weather variability.
- Humus quality change: Compost increased the quality of organic matter in terms of humic acid/fulvic acid (HA/FA) ratio, which suggests the formation of more stable, humified organic matter.
- Dependance on initial carbon stock: SOC increase in soils with higher initial SOC is smaller compared to SOC stock increase in soils with lower initial SOC stocks.

A.2 RELOCATION OF HARVEST RESIDUES

Relocation of harvest residues comprise the transfer of for animal nutrition not needed forage crops (clover-grass, alfalfa, etc) to another field (mostly humus degrading row crops), systems of 'transfer-mulch', and cut & carry systems.

Feasibility

- Logistics for harvesting and relocating harvest residues must be planned carefully to ensure economic efficiency. Farmer cooperations had a very positive influence on a successful conduction.
- High initial investment and operational costs: The implementation of residue relocation requires significant investment in equipment, such as machinery for residue collection and relocation, as well as additional labour costs. For small-scale or resource-constrained farmers, these upfront expenses can be challenging.
- Labor- and time-intensive: The process of collecting, relocating, and managing residues can be labour-intensive and time-consuming, particularly during busy harvest periods.
- High energy input: Transportation of fresh matter necessitates increased use of fossil fuel as high water contents in organic matter result in higher tonne-kilometres. Therefore, distances longer than 5 kilometres of transport should be avoided to justify carbon emissions.
- Lack of knowledge and technical expertise: There is often a gap in knowledge and technical expertise regarding the proper implementation of post-harvest residue relocation. Depending on C/N ratio of the residues, immobilization of nitrogen can occur, leading to a higher need for nitrogen fertilizers.
- High amounts needed: Calculations showed that approximately 2.5 to 3 hectares of alfalfa would be needed to cover 1 hectare of maize with the same thickness and amount used in the experiment. This significantly increases the costs associated with maize cultivation, especially considering the lack of yield benefit.
- Producing silage out of fresh biomass is an efficient way to make harvest residues storable for later relocation. Silage fertilizers proved to be spreadable by using common devices for solid manure

application. Its decomposition rate is comparable to those of strawless solid manure, commercial organic fertilizers or even cover crop biomass.

- Cost-effective fertilization: By repurposing post-harvest residues, as natural by-product of farming, this method reduces the need for expensive synthetic fertilizers.

Impact

- Smaller reduction of carbon loss: Cut-and-carry treatments, with using alfa-alfa straw showed a smaller reduction in organic carbon (Corg), with a 7.9% decrease in a two-year trial, compared to the 12.0% decrease in control plots. This suggests that the addition of biomass through the cut-and-carry practice helped mitigate some of the losses in soil organic carbon.

- Increase of C:N ratio: The C-N ratio increased in the control treatment by 0.9%, in the alfalfa $70m^3/ha$ treatment by 19.8% and in the alfalfa 140 m^3/ha treatment by 22.9%. Statistical significance in the increase of the C-N ratio was determined in the Alfalfa $70m^3/ha$ and Alfalfa $140m^3/ha$ treatments ($LSD=1.5634$, $p<0.01$). C:N ratios were calculated via total organic carbon and nitrogen.

- Increase of total organic carbon: Relocating post-harvest residues led to a noticeable increase in total organic carbon (TOC) content, rising from 0.81% in the control variant to 1.09% in the residue relocation variant. This 0.28% higher value in the residue relocation variant indicates that relocating crop residues enhances soil carbon sequestration, contributing to the long-term storage of carbon in the soil.

- No change of total organic carbon: The relocation of the harvest residues (grape leftovers and mulch) did not show any evident increase of total organic carbon content, if comparing the values from the control plot with the field being treated with residues.

B.1 ADDITIONAL COVER CROPS

Additional cover or catch crops cover the soil instead of fallow. Different cover crop mixtures might, due to different local suitability and different growing/rooting habitus, entail different impact on soil organic carbon.

Feasibility

- Cultivation time:
  - The right cultivation time is relevant for drought tolerant species.
  - Furthermore, the timing for terminating cover crops is crucial, and if weather or soil conditions delay certain operations (e.g. sowing or cutting the cover crops), the benefits could be lost, such as a reduction in soil moisture or difficulty in preparing the seedbed for the main crop. Termination of winter-hardy cover crops is more challenging than for freeze-killed cover crops.
  - Incorporating cover crops into the rotation requires careful planning and scheduling, which can complicate farm operations, especially if some unforeseen factor makes it necessary to carry out sub-optimal interventions. As the frequency of unpredictable weather patterns increases, this could pose a particular challenge.
- Sowing depths: A higher plant diversity in the mixtures showed positive effects, however, different sowing depths of various components must be considered to achieve optimum results. Some species might not emerge because of an inappropriate seed placement.
- Seed availability and costs:
  - A wide range of plant species can be cultivated as cover crops, many with different traits to target a site-specific main goal of cover crop cultivation.
  - Seed costs of valuable mixtures are considered too expensive for the majority of farmers
  - The accessibility of seeds can vary depending on the species. Many regions of Central Europe depend on imported seeds and have a very limited domestic seed production.
- Surface enhancement: Cover crops enhance the surface support of soils for farming machinery.
- Misinterpretation of workload: In the short term many farmers consider this technique as additional workload as they are not aware of the multiple positive effects, like improving soil fertility and

suppressing weeds, which often lead to net savings in costs and labour in the long term by reducing the need of fertilizers, pesticides and repeated field operations.

- Rigid CAP rules: Challenges arise with farms hunting for CAP funding and rules of intervention not in line with the best practices for the cultivation of cover crops.
- Reduction of herbicide costs: As cover crops are effective in suppressing weeds, reducing the need for chemical treatments and thus lowering associated costs.
- Reduction in fertilizer costs: Some cover crops can fix nitrogen or recycle nutrients from the soil.
- No or low investment costs: Technique can be implemented with common on-farm machinery to a sufficient extent. The cultivation of cover crops therefore is relatively simple, making them an accessible option for farmers. Some advanced management practices might still need special machinery and in some cases, there might be a lack of knowledge of advanced management practices to realize the full potential of cover crops.
- Calculating long-term returns: The difficulty of calculating long-term returns and the very different process from „normal" management practice can negatively affect farmers' attitudes.

Impact

- No change due to cover crop mixtures: A higher diversity of species also means utilising the rootable space in soil as fully as possible. This might affect the effect of roots as soil organic matter sources as such and the effects of root exudates on carbon sequestration. However, the total carbon content in soil did not differ much between different cover crop mixtures.
- Necessary input of dry matter: A greater impact of different pea varieties (as cover crops) on soil C storage would probably be possible under more favorable weather conditions. Given that the year was extremely dry, peas in this experiment failed to develop the expected biomass. To get favorable results in increasing organic carbon in soil, it would be necessary to introduce at least 5 to 8 t/ha of dry matter into the soil.
- Higher organic matter content: Soil organic matter levels were relatively high across all cover crop variants, ranging from 2.2% to 2.5%, compared to an average organic matter content of less than 2% in soils of non-conservation farms in the same area.
- No difference between cover crops: No significant overall difference in soil organic carbon (in mg/kg soil dry matter) was observed between autumn 2023 and spring 2024 across various legume species as cover crops. Alsike clover and Sweet clover exhibited the largest increases in soil organic carbon, while Hungarian vetch, Hairy vetch, and Grass pea clover showed higher decreases. However, all changes were below 2 % of initial values.

B.2 DIVERSIFICATION IN CROP ROTATION

Diversification in crop rotation includes incorporation of diverse underutilised and varying crops in field rotation. This technique also considers undersowing, intercropping and mulching practices, leaving crop residues on the field, including crops with distinct root development and root exudate release.

Feasibility

- Fertilizer costs: The practice enhances soil nutrient levels by diversifying crop demands and incorporating nutrient-restoring plants, such as legumes. Utilization of green manure can lower fertilizer costs significantly
- Know-how intensive: Effective crop rotation requires a deep understanding of crop characteristics, soil needs, and pest dynamics, which can be challenging for farmers to master.
- Complexity of machinery and related investment: Different crops or cropping systems may require specialized machinery, increasing costs and operational complexity.
- Lower short-term financial return: Transitioning to a highly diverse crop rotation can lead to reduced income, increased working time and production costs in the short term as farmers adjust to new systems and markets.
- Challenging crop protection: It is more difficult to use plant protection agents, specifically herbicides, in intercropping systems because a herbicide for one crop can harm another crop.
- Variability across locations: Results may differ depending on soil types, climates, and agricultural practices at different sites. The generalisation for various regions or farming systems is to date not possible.
- Dependency on crop selection: The effectiveness of intercropping systems is dependent on selecting appropriate crop combinations.
- Synergy effects with other techniques: A combination with carbon farming techniques B.1 additional cover crops and C.1 reduced tillage can provide synergy effects, e.g. if a farm has a no-till seed drill, it is possible to do conservation tillage within this technique.

Impact

- Crop species make the difference: Different crops showed an overall significant influence on all carbon root exudates values (per ha and per root biomass), including the composition of organic acid root exudates. Furthermore, crops showed a significant influence on root biomass at the growth development stage BBCH 10-11.
- Increase of soil organic matter: By cultivating cover crops and leaving crop residues on the field, soil organic matter is boosted, which contributes to carbon sequestration. Intercropping also showed improved humus quality (humic acids/fulvic acids ratio).
- Positive impact of intercropping: It was found that intercropping maize with rye positively impacted the total organic carbon (TOC, %) content in the soil. The initial TOC content was 2.27% in February 2023, serving as the baseline before the experiment began. After one year, in October 2023, the TOC content increased to 2.38%, demonstrating that the interaction between maize and rye led to a higher accumulation of organic carbon in the soil.
- Legumes slower organic carbon decrease: In general, there was a slight decrease in total organic carbon (TOC) during experiment (average -0.15 TOC % DM of soil; maybe caused by warm, humid weather and in consequence, active micro-organisms and mineralization of C), but for lupines the decrease was significantly lower (-0.06 TOC % DM) than for summer-barley (-0.24 TOC % DM). Maybe we can see here a positive influence of legumes by providing additional N and supporting the maintenance of a certain C/N ratio of the soil.
- Certain legumes increase carbon level: Total organic carbon content increased in all treatments (corn -control, corn- alfalfa, corn -red clover in final soil state compared to initial soil state, but only in the Corn/red clover treatment was the increase statistically significant (LSD=0.3091, $p<0.05$, from 0,88% to 1,31 %).
- Best crop rotation version: Some differences in soil organic matter can be observed; in particular, the crop rotation version Barley (cv. Marjorie) + field bean (cv. Vesuvio) + horseradish (cv. Orca) (100 Kg/ha of seed) generated an increase of up to +1.5% compared to the pre-trial content. Without green manure there was a decrease of 0,2%.
- Fluctuation during vegetation period: Within one growing season total organic carbon values in soil might change due to external reasons like climate, moisture, temperature or the abundance of relevant micro-organisms, irrespective of the growing crop.

B.4 AGROFORESTRY

Agroforestry includes different silvo-pastoral (trees and animals) and silvo-arable (trees and arable field crops) systems with interactions of the agricultural and the forestry part.

Feasibility

- High initial costs: Establishing and maintaining an agroforestry system within its first years can be costly
- Need for large land areas: To establish agroforestry systems, where forestry parts are included in lines or in islands within pastures or fields, large areas must be available.
- Ownership structures: Issues can appear if land or fields are leased

Impact

- No difference between crop/tree species: Measures, i.e. different tree species (poplar, Robinia), field between rows or clover-grass in non-agroforestry system did not exhibit any differences in total organic carbon values at any time, nor in slopes of the trendline.
- Perennial systems advantageous: The non-agroforestry system with perennial clover-grass had a higher mean value (1.77 %DM) than the agroforestry system (mean 1.57 %DM) at the end of a two years measuring period. There is a tendency for the trendline of carbon development in the agroforestry system (mean slope -0.09) to show a steeper decrease during time elapse than the non-agroforestry system (mean slope-0.003). Probably, the only explanation can be found in the lower tillage in a perennial system (only mowing of clover-grass), than in the agroforestry system, where the field between the tree rows bore winter rye in the year 2023, and summer wheat and later cover crops in the year 2024.
- No difference between crop/tree species: The carbon content of the soil was very low, ranging from approx. 0.1% or less for the trees stand to 0.39-0.51% for the control site at 60 cm depth, and from 0.44-0.46% for the trees stand to 0.72-0.73% for the control stand at 30 cm soil depth. No statistical differences were observed between wooded sites and grass strips in the inter-rows.
- Long maintenance advantageous: Agroforestry seems highly valuable for carbon sequestration due to long-lasting maintenance, deep rooting systems, and shedding foliage.

- Seasonal fluctuations: Total organic carbon levels between seasons (mean values between 1.76 and 1.51 % soil DM) are significantly different, with the lowest value in spring, probably due to higher activity of organic matter metabolizing micro-organisms in a warm and moist environment. Therefore, the seasonal effect might exceed the effect of the agroforestry technique as such.

C.1 REDUCING TILLAGE

The technique ‘reducing tillage’ includes all kinds of reducing conventional, deep ploughing tillage. That means, shallow ploughing to different extents, any kind of non-inversion tillage with a cultivator or similar device, strip-till versions, special innovations like the Turiel-technique, up to no-tillage treatments.

Feasibility

- Problematic weed control: Mechanical weed control may be unable to destroy over-wintering legumes, which can become competitors for main crops under strip tillage.
- Special equipment needs: The adoption of reduced tillage often requires the purchase of specialized machinery, such as no-till drills, which are costly.
- Cost of technical adaptation: Transitioning to reduced tillage involves expenses related to training, equipment, and changes in farming practices.
- Learning curve: Farmers may need time and guidance to master the new techniques and adapt them effectively to their specific conditions.
- Different specific needs of subsequent crops: Reduced tillage techniques are not always in line with specific needs of subsequent crops, especially for those which need a well-prepared seedbed, like sunflower, rapeseed or sugar beet. If operations are not correctly planned, delays can accumulate, making subsequent activities like sowing and transplanting difficult to manage.
- Time management of external services: The use of cover crops combined with minimum tillage or no-till practices requires timely and technical management of agronomic operations. This is often difficult to combine with the involvement of agricultural subcontractors, who may not be able to follow such a precise schedule.
- Dependency on specific soil types: Reduced-tillage methods may not be suitable for all soil types or climates. They are easier to implement on lighter, sandy soils, where reduced tillage also

achieves more and different beneficial results than on heavy clay soils. Therefore, it is important to adapt no-till practices to specific local conditions.

- Reduced fuel costs: Fewer passes over the field with machinery significantly lower fuel consumption and operational expenses.
- Simplifying logistics: Reduced tillage may simplify logistics for cultivation and sowing on larger plots, streamlining farm management.

Impact

- Seasonal carbon fluctuation is smaller in reduced tillage: Conventional tillage initially led to a decline in organic carbon due to accelerated decomposition caused by soil disturbance (-1.4%), followed by significant recovery in autumn 2024 (+9.3%), likely due to increased root biomass and crop residue inputs. Strip tillage, on the other hand, showed a slight increase in organic carbon from autumn 2023 to spring 2024 (+1.2%), indicating that reduced soil disturbance helps retain organic carbon, though the overall recovery by autumn 2024 was lower than in conventional tillage (+4.6%). However, these changes are likely to represent changes only in the labile soil organic carbon (SOC) pool, while the effect on more permanent SOC increases is likely smaller than indicated here.
- Carbon decrease with minimum tillage: In the initial sampling, the control variant showed a total organic carbon (TOC) content of 0.99%, while the minimal tillage variant had a higher starting value of 1.30%. By October 2024, the TOC content in the control variant had risen to 1.17%, marking a significant increase, while the minimal tillage in fact showed a decrease of TOC to 1.23%.
- No differences: Eight weeks after cultivation of soybeans no significant differences were found for organic or total carbon between variants of early strip-till, late strip-till, and shallow overall tillage.
- Long-term no-till increases carbon: Within a long-term no-tillage experiment, the humus content increased from 2.37 % to 5.17 % within the observed period.
- Promising combination of techniques: The combination of minimal tillage practices with a diverse range of cover crops has shown promising effects in enhancing soil carbon sequestration, which shows a possible positive effect of synergies with other techniques.
- Not significant carbon increase: The analysis of soil Corg content over 18-year experiment indicates a clear higher increase in soil Corg content in the no-till system (5.4% increase) compared to the ploughed system (2.3% increase). At the end of the experiment, no-tilled soil Corg content was 1.32%, while ploughed soil Corg content was 1.36%.

- Ploughing increased carbon: The carbon content analysis revealed that ploughing technology resulted in higher carbon content in the soil. This can likely be attributed to the mixing effect of ploughing, which incorporates organic material from deeper layers into the surface.

C.4 LIMING/ GYPSUM EFFECT

This technique includes the use of lime ($CaCO_3$), gypsum ($CaSO_4$) and other agents (like basalt meal, filter dust) to provide positively charged Ca-ions to enhance the complexation of organic carbon of humus and clay minerals:

Feasibility

- Way of application of different lime agents:
  - **Gypsum:** As far less $CaSO_4$ than $CaCO_3$ is needed per ha (recommendation of 50-60kg S/ha), the better way of application can be reached with granulated gypsum in a centrifugal spreader. With an average of 60 kg S/ha and a 20% content of sulphur (S) in granulated gypsum, you would apply about 300 kg per ha. In the powdery original form of gypsum, the application will not work evenly, as a minimum of 1000 kg is necessary to receive a good scattering.
  - **Lime:** This can be far better reached with lime ($CaCO_3$) fertilization with a broad acre spreader, as you need a far higher amount of it.
  - **Filter dust carbocalc:** The liming agent carbocalc is fine dust, so in the case of humid air during application, the product may clump, which makes it extremely difficult to distribute the product evenly on the soil surface. In addition, farmers do not have adequate machinery for applying the liming agent. In the case of the application of some granulated agent for liming effect, the application itself becomes easier, but this raises the cost of liming.
- Carbon effect needs time: The full effects of lime and gypsum on carbon sequestration may take years to manifest, making short-term carbon farming goals harder to achieve.
- High initial costs: Both lime and gypsum, can be costly to apply, especially on large-scale farms, with transportation and application costs adding to the financial burden.
- Periodicity: Liming and gypsum applications may need to be repeated periodically, adding to the long-term cost and maintenance.

Impact

- Gypsum: Fertilization with gypsum (vs. liming and control) did not show any negative effects. If any, the effects of gypsum fertilization were positive on the measured traits, even after only one year of treatment:
  - Total organic carbon (TOC, % of soil DM) difference values of 2023 and 2024, both calcium-carbonate and gypsum, showed far higher increases (0.197 and 0.213 %) than control (0.057 %).
  - Cation exchange capacity (CEC) difference values, gypsum exhibited the highest value (1.423 cmol/kg soil) vs. calcium-carbonate (0.350) and control (0.826)
  - Base-cation saturation rate (BCSR) showed a statistical tendency (p-Value < 0.1) to increase with gypsum within one year, far more than with the other variants. The BCSR-Difference showed for treatment with gypsum a mean value of 10.99 % (mean in 2023: 69.94 %, in 2024: 80.92 %), whereas the control and the calcium carbonate treatment showed differences of 1.46 and 1.35 respectively.
- Increase of available Ca: Supporting this hypothesis might be an increase of the mean specified Ca_{eff} CEC in gypsum plots by 1.92 cmol/kg (from 5.90 in 2023 to 7.81 in 2024), whereas the total mean increase overall variants was only 0.94 cmol/kg. This shows that the gypsum fertilization derived increase of BCSR really depended on the increased Ca-share.
- Higher carbon levels with higher liming level: In the treatments filter dust (FD) 70 kg and FD 80 kg (from variants no liming, 50,70, 80 kg filter dust/ha), where the soil pH was high (end pH final (2024) mean values were 5.8, 6.4, 7.8 and 8.5), there was a slightly higher value of humus content in the soil (1.96; 2.25 vs. 1.78; 1.73), which is not statistically significant. Due to the high pH reaction of the soil, significant decomposition of organic matter could not occur. Like humus, mean TOC values were higher in the FD 70 kg and FD 80 kg treatments.

GENERAL ASPECTS OF ACCEPTANCE

Besides external influence of acceptance of a new technique, like rumours of the neighbourhood, inquiry of journalists and press, opinion of family members, etc., also the farmer himself may have doubts or see assets on the implementation. He/she might be aware of expected side-effects of implementation, which influence his/her acceptance. Such possible, and in farmer interviews or in trials realised side effects are collected and mentioned here:

- Focus: Alternative methods should not primarily focus on yield quantity, but other parameters of the production, like sustainability or environmental health.
- Limitation of available nutrients: Using slowly degradable organic fertilizers, the supply of readily available nutrients for the crops is sometimes limited compared to the use of mineral fertilizer.
- Lower yields: Crop competition in intercropping systems or inappropriate crop sowing for innovative crops can result in lower yields. Moreover, no-till systems can lower yields, particularly in high yielding crops like vegetables in heavy soils.
- Weed surpression: Mulching relocated residues succesfully prevents the growth of weed, which would compete with crops for nutrients and water.
- Soil prevention:
    - Soil **c**overage with relocated harvest residues reduces soil erosion and improves soil conditions by balancing surface temperature during extremely hot periods.
    - Reduced tillage additionally improves conservation of organic matter, encourages biodiversity, and prevents nutrient losses, including carbon.
    - Easily available Ca2+ from lime or gypsum is always good for the formation of an optimal soil structure and helps to build up permanent humus.
- Retaining soil moisture: Several carbon farming approaches help to retain soil moisture, ensuring that crops have a steady supply of water even during dry periods.
- Yield stability: Rotating crops helps maintain consistent yields over time by reducing soil depletion and pest build-up.
- Plant protection: Alternating crops disrupts the life cycles of pests and diseases, reducing the need for chemical interventions.

- Microclimate: Agroforestry can avoid wind erosion, reduce the impact of drought and extreme rainfall, and enhance biodiversity.
- Reducing soil compaction: Minimum tillage or no-tillage techniques facilitate the transit of machinery through the field and consequently reduce soil compaction because the bearing capacity of the soil is better than that of tilled soil.
- Promoting soil microorganisms: Reduced soil disturbance and increased organic matter promote the diversity and abundance of soil microorganisms.
- Soil pH regulation: $CaCO_3$ (Lime) raises soil pH, neutralizing acidic soils, which improves plant growth and enhances microbial activity in acidic soils that contributes to carbon sequestration.

EXAMPLE OF USE OF THIS GUIDE

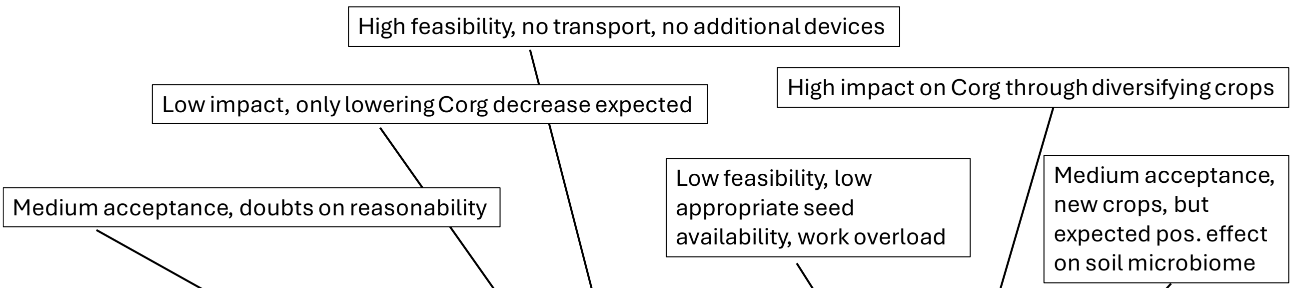
The use of this guide and the accompanying decision matrix will be demonstrated using a practical example.

<u>Example</u>:

A farmer wants to know whether he should use technique “A.2 Relocation of harvest residues” or “B.2 Diversification in crop rotation.” For the coming season, he has a field with perennial clover-grass and wants to grow maize alongside. Instead, he could also start with a highly diverse crop rotation that includes under-utilized crops such as buckwheat, lentils, and freezing-off mixed crops over the winter.

Step 1:

In the decision matrix, the farmer could enter scores between 1 and 10 for the criteria of feasibility, impact, and acceptance for the two techniques in question as follows. For guidance, he can look up all aspects of the respective techniques in the text document of the CE guide for carbon farming techniques.



Carbon Farming Techniques[2] / Criteria of decision[1]	Scores from 1(very bad)-10(very good)							Weig
	A.1 External organic fertilizers	A.2 Relocation of harvest residues	B.1 Additional cover crops	B.2 Diversi-fication of crop rotation	B.4 Agro-forestry	C.1 Reducing tillage	C.4 Liming effect	
Feasibility		8		4				
Impact		2		9				
Acceptance		5		5				
SUM		15		18				

Carbon Farming CE

Step 2:

The decision matrix automatically calculates the decisive final values for both techniques using an underlying weighting system validated by experts. The higher value determines the decision. This also works when comparing several techniques simultaneously

	Scores from 1(very bad)-10(very good)								Values						
Carbon Farming Techniques[2] / Criteria of decision[1]	A.1 External organic fertilizers	A.2 Relocation of harvest residues	B.1 Additional cover crops	B.2 Diversi-fication of crop rotation	B.4 Agro-forestry	C.1 Reducing tillage	C.4 Liming effect	Weighting	A.1 External organic fertilizers	A.2 Relocation of harvest residues	B.1 Additional cover crops	B.2 Diversi-fication of crop rotation	B.4 Agro-forestry	C.1 Reducing tillage	C.4 Liming effect
Feasibility		8		4				60		480		240			
Impact		2		9				22		44		198			
Acceptance		5		5				18		90		90			
SUM		15		18				100		614		528			

The simple sum of the decision criteria would suggest that “B.2 Diversification” is the technique of choice.

Nevertheless, the calculated values show 614 for “A.2 Relocation of harvest residues” and528 for “B.2 Diversification of crop rotation.”
➡ The technique of choice is
A.2 Relocation of harvest residues