Seminar Paper

Carbon Farming in Germany – Potential and Feasibility

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1. Introduction

Since the pre-industrial age (-1850), human activities, especially the combustion of fossil fuels and land use management, led to an exceedance of greenhouse emissions compared to the natural GHG absorption potential (IPCC, 2021). The results of an increasing imbalance between GHG sources and sinks, is what we call the human driven climate change. To slow down the current trend of increasing atmospheric GHG concentrations or even reverse it and reach the goal of climate neutrality (net emissions = zero) by 2050 which is part of the so called 'Green Deal' of the European Union (EU), two approaches are followed (European Commission, 2021). On one hand, GHG emissions are to be avoided to the lowest possible amount without giving up current consumption standards. On the other hand, increasing GHG sinks by using technical or nature-based solutions should compensate the not mitigatable share of GHG emissions. As a contributor and victim of human driven climate change, the agricultural sector is assigned a double-sided role and is therefore of special interest when thinking about the need for action in terms of climate change. Besides a reduction in GHG emissions by lowering the application of synthetic nitrogen fertilizers, agricultural soils can be an important nature-based carbon sink (Freibauer et al., 2004). Adapted management practices, including elements often used in organic crop rotations, can lead to an increase in soil organic carbon, and therefore to a reduction of atmospheric CO_2 (Poeplau & Don, 2015). Within the framework of the climate conference in Paris 2015, a global initiative was adopted, aiming at an increase of soil carbon stocks by 0.4 % per year, which corresponds approximately to the annual emissions caused by humans (Minasny et al., 2017). An estimation of the carbon sequestration potential in agricultural used soils in Bavaria, Germany, revealed a great saturation deficit of soil organic carbon (Wiesmeier et al., 2017). This results in a considerable potential for soil carbon sequestration in the first place. Since an adaption of management practices in favour of an increase in organic matter means an additional effort for the farmer, the feasibility of the concept Carbon Farming is often doubted by economists, farmers and scientists. Including the fact, that higher organic matter contents in soils improve a wide range of soil parameters, a proper concept motivating farmers to implement appropriate practices could generate a double-sided benefit (Kögel-Knabner, 2018) From an economic point of view - turning around the perspective and representing the carbon sequestration as a positive externality of increasing soil fertility due to organic matter benefitting management - internalizing the positive externality "carbon sequestration" can ensure to reach the social optimum. Due to rising prices for CO_2

sequestered, the farmers' revenue from participating in programs rewarding carbon sequestration could increase within the next years (Krukowska, 2021).

This paper reviews the current state of the literature regarding the potential of carbon sequestration in agricultural soils in Germany. It introduces approaches for creating incentives for farmers e.g., business models which are independent of funds. It reflects possible implementation barriers for farmers and accordingly the overall feasibility of Carbon Farming approaches. Commonly criticised aspects like the permanency of sequestered carbon or leakage effects leading to a carbon loss on areas of a farm, which are not participating in such programs, will be described and discussed.

Taking these concerns into consideration, this paper will address the following research questions:

- Which barriers have prevented Carbon Farming from being implemented on a large scale so far?
- How must programs be designed, to make participation profitable for farmers?
- Could Carbon Farming become a common source of additional income for farmers in Germany in the future?

Besides basic literature about how to build up organic matter in soils, deepening literature about current carbon stocks and carbon dynamics in soils will be used to describe the state of knowledge – also with regard to the influence of climate change on carbon dynamics. To get insights into Carbon Farming, programs from different providers and their published methodologies will be analysed. If available, Farmer's statements about their motivations and barriers to participate in the respective programs will be reflected.

Research will mostly be conducted via Google Scholar. Common Databases for researching on agriculturally and environmentally related topics like Scopus, Cambridge Core, Research Gate, Science Director or Springer Link will be used.

2. Carbon Farming

2.1. Carbon Sequestration – Scientific basis

With an amount of 2500 Gt, soils contain almost 80% of the overall terrestrial C, which sums up to 3170 Gt (R. Lal, 2008). While around one-third of the stocks are inorganic carbon fractions, two-third and therefore more than 50 % of the overall terrestrial carbon, are stored mostly in form of dead organic compounds, but also living organisms. These huge quantities make it necessary to consider ways of preserving and expanding this carbon pool.

To understand Carbon Sequestration in agricultural soils and therefore its' dynamic and potential as a sink, basics from plant- and soil-science must be understood. Therefore, in this chapter, a small introduction is given.

Through the process of photsynthesis, CO_2 is assimilated in the form of organic carbon compounds in plant tissue. Accordingly, plants always represent a temporary CO_2-sink. Due to the harvest and human or animal consumption of most crops, C returns to the atmosphere as CO_2 through oxidation. Even though that's the lifecycle for the largest part of plant-bounded CO_2, certain pathways lead to an enrichment of organic carbon fractions in soils. Carbon compounds enter the soil through above- and below-ground plant residues and root exudates. Most of these compounds are transported back to the atmosphere through oxidation processes (e.g., mineralisation) when microorganisms feed on them. Being included in soil aggregates or bound to clay minerals, another smaller part of the carbon remains in the form of stable complexes in soils, protected against oxidation either short or long-term (Amelung et al., 2018).

The amount and stability of organic carbon, that can be sequestered and stored in soils, mostly and highly depends on the current carbon stock, input substrate, the quantity of organic materials supplied, soil characteristics and climatic conditions in the corresponding area and certain management practices (Chenu et al., 2019; Jacobs et al., 2018; Kolbe, 2012; Xu et al., 2020)

The development of carbon stocks under the continuation of current management practices on agricultural land shows a decrease in soil organic carbon (SOC) (IPCC, 2021; Jacobs et al., 2018; Riggers et al., 2021). The losses can be estimated on 0,1 - 0,2 t C_{org} ha^{-1} a^{-1} (0,36 – 0,72 t CO_2) (Jacobs et al., 2018). Therefore, Carbon Farming can be described as both an opportunity to reduce emissions and an actual reduction of atmospheric CO_2 (= sink).

2.2. Management Practices

As mentioned in the last chapter, several parameters influence the C-sequestration performance of soils. Since location factors like soil properties and climate conditions can only be slightly influenced, the idea of Carbon Farming is based on high carbon sequestration rates to be achieved primarily through adapted management practices. Therefore, this chapter will give an introduction into the most important management practices, that are considered as SOC enriching. Nevertheless, site factors including current carbon contents, must always be taken into account (Wiesmeier et al., 2020).

Due to the difficulty of sequestering C in soils with already high SOM contents, most Carbon Farming programs in Germany focusing on the implementation of measures on arable land instead of grassland. Conversely, the change of use from arable land to grassland or agroforestry, systems with very high SOC values in the long term, already represents a potential measure (Cardinael et al., 2017; Conant et al., 2001). While Carbon Farming initiatives usually aren't restricted on either conventional or organically managed farms, common practice in organic crop rotations already includes many elements that have been shown to increase organic matter and thus C-content in soils. The input of many organic fertilizers like manure or straw, which are essential for organic management, can lead to an increase in SOM. Keeping decomposition mechanisms in mind, the C/N-ratio of substrates significantly determines the C-sequestration rate that can be achieved by bringing out organic fertiliser. Another way to sequester C in soils is the more frequent and prolonged implementation of legumes in crop rotations. Either as single crops, or in the form of e.g. legumes cereals mixture, shifting the C/N ratio and benefits soil physical parameters through intensive rooting (Technologie und Förderzentrum, 2017). A significant increase in SOC can also be reached by using perennial crops, e.g. on less favoured locations (Ledo et al., 2020). While these measures focus on the input for organic C through different pathways, conserving C has a great significance for the long-term accumulation potential of C in soils. Low-tillage practices prevent the destruction of soil aggregates and therefore physically protect soil C (R. Lal, 2008; West & Post, 2002). Especially in intensive organic crop production systems, measures like mulching can help to keep weed pressure low making mechanical weed protection, thus C losses obsolete (S. Ahlgren, 2004). Another part of soil conservation is the prevention of erosion, which can often be managed by covering soils' surfaces permanently (Lugato et al., 2018).

Since Carbon farming initiatives usually reward real changes in the C content of the topsoil, the choice of measures applied is usually left to the farm. Nevertheless, most initiatives have a catalogue of measures that are included in the advice given to farmers.

Table 1 shows the expected C-sequestration potential of typical measures, that are proposed by Carbon Farming initiatives. The expected values for carbon sequestration rates differ by most of the initiatives. Therefore, Table 1 only serves the purpose of providing a brief overview about the selection and scale of some common measures.

Table 1: Expected C-sequestration rates for various measures

Measure	C-seq. expected (t C_{org} $ha^{-1}a^{-1}$; 0-30 cm)	Reference
Conversion arable land to agroforestry*	0.68	(Cardinael et al., 2017; Winans et al., 2015; Wotherspoon et al., 2014)
Conversion arable land to grassland*	0.73	(Conant et al., 2001)
Cover crops*	0.32	(Poeplau & Don, 2015)
Legumes in crop rotation (incorporation)	0.40	(Drinkwater et al., 1998)
Miscanthus	0.70	(Müller-Sämann & Hölscher, 2010)
Stable manure (t^{-1} manure C_{org})	0.32	(Carlgren & Mattsson, 2001; Körschens et al., 2014)
No tillage	0.57	(West & Post, 2002)
Enhanced rotation complexity	0.20	(West & Post, 2002)

*collected in (Wiesmeier M., Burmeister J., Treisch M., Brandhuber R., 2017)

To make them comparable e.g. with emissions of CO_2e, values of table 1 will be divided by 1000 to generate values in units of t SOC and multiplied by 3.6 to generate results in the typically comparative unit t CO_2. Measures are classified into 3 Levels of effort, which will be used for calculations in Chapter 2.3.

Table 2: Expected Carbon sequestration rates for different effort levels

Level	Effort	Example measures	+ t SOC $ha^{-1}a^{-1}$	+ ~t CO_2 $ha^{-1}a^{-1}$
1	Low	Improved crop rotations	0.2	0.7
2	Medium	Yearly cover crop	0.32	1.2
3	High	Land use change, miscanthus, no tillage	0.66*	2.4

* Average value calculated from the values for land use changes (arable land to forestry or grassland), Miscanthus, no tillage

In the following chapter, an estimate of the theoretical humus formation potential in Germany is made based on the expected values given in Table 1 & 2. Since this is only a rough estimate to classify the theoretical potential, the calculation made in the following chapter does not claim to be complete and exact. Estimated values are used and individual factors are neglected for simplification.

2.3. Theoretical Potential in Germany

The following information regarding land use in Germany is taken from current data from the Federal Statistical Office of Germany (Statistisches Bundesamt, 2021). Since saturation deficits and possibilities for carbon storage in soils under permanent grassland management are limited, only the arable area in Germany, which is around 70% of the total agricultural land, was considered in the following estimation The overall arable land was around 11.66 million ha in 2021. It is very difficult to implement humus-enhancing measures for a few special crops. Since areas with such a use exist only on a very small scale in Germany, they can be neglected without any major distortion of the values. Assuming implementation of measures that do not result in land use change, and using conservative values for this, a storage capacity of ~1 t CO_2 per hectare could serve as a realistic average value (deduced from Table 10). Implementing comparable measures and using these values for the entire arable area in Germany, an overall annual Carbon sequestration rate of 11.66 Mt CO_2 could be expected. To be able to classify this value, a look at the annual CO_2-equivalent (CO_2e) emissions per sector in Germany can be taken: In 2020, the annual emissions of Germany amounted to 729 Mt CO_2e (Umweltbundesamt, 2021). That means, that under the previously described assumptions, only around 1.6 % of the yearly annual emissions could be restored by carbon sequestration in soils.

Since each sector also develops its own solutions, it makes sense to focus on the comparison with emissions from the agricultural sector. With a carbon sequestration of 11.66 Mt COe, almost 20% of the 60.4 Mt CO_2e emitted by the agricultural sector can be offset. Wiesmeier (2017) found out, that soils in Bavaria are on average only 50 % carbon saturated and almost no soils are fully saturated, which means, that at least for Bavaria such a carbon increase can be maintained over decades, before a new steady state is created. Considering the carbon content and classification of arable soils nationwide, we can also assume large deficits in most cases and thus comparable potentials (Jacobs et al., 2018). In addition, increased humus content enables savings in mineral N fertiliser (Schjønning et al., 2018). An analysis of possible emission reductions through savings in mineral fertiliser can be achieved above all through the increased inclusion of legumes in crop rotations. The Potential is considerable, but beyond the scope of this paper and usually not focus of existing Carbon Farming programs in Germany, while there's a corresponding Methodology in the American Carbon Registry (ACR, 2012; Farzadfar et al., 2021).

Table 3 & 4 give a quick overview about some potential scenarios for 3 effort groups in the context of different scales of implementation in Germany. Table 3 shows the C-sequestration in total numbers:

Table 3: C-sequestration rates for different effort groups and scales of implementation in Germany

C-sequestration in Mt CO_2 a^{-1}		**Implementation on x % of the arable land in Germany**				
		10%	25%	50%	75%	100%
Effort Level	1	0.84	2.10	4.20	6.30	8.40
	2	1.34	3.36	6.72	10.07	13.43
	3	2.77	6.93	13.85	20.78	27.70

Table 4 shows the percentage of emissions caused by the agricultural sector in Germany that could be offset under each scenario:

Table 4: Relationship between C-sequestration rates and annual emissions from the agricultural sector in Germany

C-sequestration /total emissions agr. sector in %		**Implementation on x % of the arable land in Germany**				
		10%	25%	50%	75%	100%
Effort Level	1	1.4	3.5	6.9	10.4	13.9
	2	2.2	5.6	11.1	16.7	22.2
	3	4.6	11.5	22.9	34.4	45.9

After presenting carbon sequestration mechanisms, certain measures which are suitable for generating CO_2-sinks on agriculturally used soils and the theoretical potential for carbon sequestration in Germany, Carbon Farming initiatives will be introduced in the upcoming chapter. Organizational forms, methodologies, and current providers will be introduced.

2.4. Carbon Farming programs in Germany

The idea of convincing farmers to adapt their management in favour of increased carbon storage in soils by creating economic incentives can be pursued in several ways. Until now, the most important tool has been the subsidy of farmers in Germany as a member state of the EU within the framework of the CAP (European Commission, 2020). (European Commission, 2020, 2022)In addition, a number of initiatives have been launched in Germany in recent years to organize climate certificates for the voluntary market. While the subsidy approach of the EU relies on measure-based payments, voluntary certificates are largely issued result-based, which means that the actual measured carbon gains achieved rather than the mere implementation of measures is rewarded. The public interest for efforts beyond the previous subsidies was initiated by the '4-promille initiative' in 2015, picked up by some non-political programs and underlined by publications like the 2021 released technical paper of the European Commission for setting up result-based Carbon Farming programs in the EU (European Commission. Directorate-General for Climate Action et al., 2021). The EU Commissions' paper provides guidance on standardizing methods to create a framework that could be used by both small and large private initiatives, as well as in the form of policy programs. Existing methodologies from Verra and Gold Standard, which already provide a general framework for soil carbon sequestration projects, are comparable with the applied methodologies of initiatives in Germany (Gold Standard, 2022; Verra, 2021). Nevertheless, probably because of the demanding and costly process of verification as well as the preferred suitability for projects in less developed countries, programs in Germany are not Verra or Gold Standard certified yet.

Existing private Carbon Farming initiatives in Germany have so far tended to take on a kind of pilot role. As the biggest providers in Germany, 'Carbocert' issued certificates in the overall amount of around 10 000 t CO_2, mostly stored in soils of the Lake Constance area (Carbocert, 2022). The big US Company 'Indigo Ag', which already implemented Carbon Farming programs on a big scale in the US already, so far only operates in Germany in the form of pilot projects (Indigo Ag, 2022). In Austria, the initiatives 'Ebenrain' and 'Kaindorf' already issued certificates (Baselland, 2022; Ökoregion Kaindorf, 2022). Other providers, like 'CO_2-Land e.V.' in Freiburg or 'Stiftung Lebensraum' in Rheinland-Pfalz are still working on their exact methodology (CO_2-Land, 2022; Stiftung Lebensraum, 2022). All of them primarily act as an intermediary between certificate customers (companies, municipalities, private individuals) who wish to offset their CO_2 emissions and farmers, generating CO_2 sinks through their management. A typical result-based program flow (derived from the carbocert methodology), after farmers and clients have been convinced to participate, so far usually look like this:

Year 0: Division of the participation areas and entering the contract

Year 0: GPS soil sampling and analysis – SOC & optional further parameters

Year 0-10: Implementation of the measures

Year 2-5: First comparison sample – Payout according to the SOC increase

Year 7-10: Second comparison sample – Payout according to the SOC increase

If we take a look at the most important steps of the program, it becomes clear that a functioning monitoring system is indispensable. Data collection through soil sampling and analysis and solid data management, especially in terms of scaling, play a key role in developing a reliable methodology. Without examining the individual monitoring elements in detail, it should be noted that the process must be clearly defined and reproducible. In order to have the necessary capacities available for this, 20-30 % of the certificate price is retained by the provider, while the remaining 70-80% represents the revenue for the farmer. In order to be economically viable, providers require farmers to pay a proportionate share of the costs of soil sampling and analysis. While many of the organisations that have made a great effort to develop a methodology for this purpose, there is much criticism of the feasibility of the approach just described. Voices from business, politics and science generally do not doubt the SOC storage potential of agricultural soils. Rather, the criticism focuses on the suitability of the climate certificates tool for achieving the goal of SOC storage in soils (Häusling, 2020; WWF, 2021).

In the next chapter, common criticisms of the Carbon Farming approach via climate certificates are presented. Here, an attempt will be made to address criticisms from agriculture, business, science, politics, and society in general. Where possible, appropriate solutions and ideas for optimization are proposed. Finally, an assessment of the overall feasibility is made.

2.5. Acceptance and Concernments

In 2021, the EU published a technical manual for Carbon Farming, which is also to be understood politically as a statement in the direction of climate certificates via humus growth. Nevertheless, opinions on climate certificates are controversial, and even former advocates and even drivers are now critical of the approach. The topic is also being critically discussed by politicians: A position paper by (Häusling, 2020) agricultural policy spokesperson of the Greens/EFA group in the European Parliament, on climate certificates through carbon storage in soils was published in 2020. Shortly afterward, another position paper was published, this time by WWF and signed by former supporters of climate certificates (WWF, 2021). As the above-mentioned papers take up and summarise the common points of criticism, they will be used as a basis for the following discussion of the meaningfulness of CO_2 certificates via CO_2 storage in soils. Some of the arguments of criticism presented by Häusling (2020) and WWF (2021) are supplemented by common critical statements with which certificate providers are confronted. The following points of criticism are addressed in statements by the CO2-Land association, Wiesmeier (2020) and the European Commission's Guidance Handbook (2021).

Permanency

The lack of permanence, thus the reversibility of carbon sequestration in soil is probably the biggest criticism. It's subject of almost all publications from basic soil science literature to publications that specifically focus on the issue of climate certificates (Kögel-Knabner, 2018; Smith et al., 2020; Wiesmeier et al., 2020). While it takes a long time and positive humus net balances for organic matter to accumulate in significant amounts in the soil, it can be degraded in a very short time if the management practices are changed (Wiesmeier et al., 2016). The recorded carbon storage capacity can therefore not be guaranteed over the term of the contract.

This assumption cannot be disputed and seriously questions the approach of climate certificates via humus build-up. However, if one considers the contract duration of usually at least 8-10 years, a noticeable and measurable improvement in operationally important parameters such as water storage capacity of the soil or yield can be assumed due to the increase in organic matter (Rattan Lal, 2020a, 2020b). The argumentation of certificate providers is that farmers become aware of these benefits over the course of the contract period, thereby motivating them to implement the measures either with or without re-participation in the program beyond the term of the contract. The European Commission's Guidance Handbook (2021) encourages providers moreover to use risk buffers to avoid over-issuance of certificates due to non-permanence in some areas – an approach, that already takes place in practice. It proposes that if one is participating in a program by applying land use changes, a long-term determination on the maintenance of the land use can be helpful. Furthermore, it can be argued to some extent that the creation of in some areas only temporary reductions leads to decreased GHG levels in the atmosphere. Even if the storage capacity is not permanently guaranteed in all areas, carbon sequestration in soils could be used as a bridge solution until the switch to more climate-friendly technologies or the development of new climate protection solutions.

Leakage

The increase in soil carbon stocks could be increased on one area at the expense of the other. Increased biomass removal and application on another area only results in carbon displacement and thus does not add value to the CO_2 reduction target. Areas participating in the project could be favoured, while excluded areas are neglected. The conversion of an area participating in the program from arable land to grassland could be compensated by farmers by changing the use of the other area back to arable land. The accounting of stored CO_2 through the change of use to grassland would be a pure shift.

One way of counteracting the risk of displacement effects is a contractual agreement that the external purchase of e.g., compost may not be used as a valid and therefore rewarded measure. Another way to prevent leakage could be the participation of farmers with the entire land of the farm. Farmers would therefore not neglect the humus content on individual plots. Individual areas where there is hardly any potential for humus build-up due to soil conditions, very high initial values, or other influencing factors could be excluded from the project. In case of agroforestry, the use of the wood could be designed according to a long-lasting storage, for example as a substrate in the wood construction sector (Kuittinen, 2013).

Additionality

Another problematic aspect of certificate expenditure through Carbon Farming is the determination of the additionality of measures. This means that they would not be applied without the corresponding program. On one hand, some measures are already rewarded through Common Agricultural Policy (CAP) support, so private operators would count towards already guaranteed sink performance (European Commission, 2020). Another part of measures, depending on the legislation in the corresponding area, can be obligatory by law anyway (Karl & Noleppa, 2017).

The common approach to tackle this issue is the historical view. The Gold Standard and Verra Methodologies propose to develop a reference scenario representing conventional management in the corresponding region over the last 10 years, for example (Gold Standard, 2022; Verra, 2021). Providers must prove that the rewarded measures deviate from the defined reference scenario. Since humus stocks to a certain extent reflect the management of the past years (decades), the C-dynamics, starting from the status quo, already represent an effect, the cause of which is the implementation of the measures. Nevertheless, the European Commission admits that free-riding and deadweight cannot be completely avoided.

Disadvantage with high start values

As mentioned in chapter 2.1, an important factor influencing the carbon saturation deficit and thus storage potential is the current carbon content of soils. Farmers who have already been farming for years in a humus-promoting manner and therefore enter the program with higher starting values must make greater efforts than farmers who have not previously placed any value on humus-rich soils.

This is a justified and scientifically logical point of criticism that cannot be denied (Wiesmeier et al., 2020). Consideration can be given to a surcharge or discount factor depending on the initial carbon level at the start of the program. While this could be considered a fair solution, it creates a discrepancy between the number of certificates issued and the corresponding revenue received by farmers. Nevertheless, climate protection concepts should not be discarded just because actors benefit to different degrees. Every tonnage of CO_2 stored benefits society, which is why the net increase in soil organic carbon is the appropriate measurand. Climate protection measures such as subsidizing the purchase of new electric cars aren’t less effective because some customers have already been driving an electric car for years. However, it is important that the selection of measures is made appropriately with regard to the humus starting values.

Neglect of other climate efforts

Offsetting the carbon footprint of companies could negatively affect efforts to reduce emissions. Relying on non-permanent sinks as a substitute for reduced emissions could lead to long-term misjudgements and, in the broadest sense, greenwashing. Incorrectly offsetting sink performance against emissions caused could put the brakes on quantitatively more significant climate protection measures.

This assumption, which is presented as a contradiction, can be overcome by appropriate political tools (subsidies for more efficient technologies, CO_2 tax, emission restrictions, cap and trade), which could be placed upstream of compensation through voluntary climate certificates. In a functioning economy, there will always be a certain level of emissions that cannot be avoided or completely stopped. Therefore, nature-based solutions should generally be seen as a complement to emission reduction efforts and should also be legally classified accordingly.

This compilation of some points of criticism and possible conceptual proposals for certificate programs can be supplemented by further problems, which, however, would go beyond the scope of this paper. Instead, the next section provides a brief insight into the farmers spectrum of opinions on Carbon Farming and farmers' climate certificates. Since no surveys have been conducted to date on farmers' acceptance of participation in Carbon Farming programs, the following only refers to aspects derived from discussions with farmers in the context of the work of the non-profit association 'CO_2-Land e.V.', who will be issuing climate certificates on carbon sequestration for the first time in 2021.

2.6. Farmer's viewpoint

As the sink creator, farmers are the most important stakeholders in the Carbon Farming approach. Furthermore, demand for carbon offsets is increasing, which is why Carbon Farming models need to focus on attracting farmers (BloombergNEF, 2022; Hodgson & Noonan, 2022). The sums paid out are usually not sufficient, to cover the additional expenditure for the implementation of measures (e.g., labour costs for bringing out mulch, costs for catch crop seeds and sowing), even with an increasing CO_2 price (DSV, 2022). Therefore, participating farmers mostly refer to the positive effects that an increase in humus content has on crucial soil parameters and production targets. Frequent reference is made to adaptation to climate change, such as improved water storage capacity of soils and general stability of yields. Therefore, it can also be assumed that farmers, if they decide to participate, are seriously interested in positive humus developments in the soil in the long term. Farmers have often been considering making more efforts to build up humus for some time. Participation in the program is often the final impulse that motivates them to realize measures. It is very important to work out measures together with the farmer according to the conditions and production goals of the farm. The opinion of many farmers makes it clear that bureaucratic hurdles must be as low as possible. Apart from the long duration of contracts, the bureaucratic burden is usually the main reason why farmers do not participate in programs. Participation in Carbon Farming programs is also an opportunity for farmers to engage in dialogue with society. Farmers are often condemned for the environmental damage of their actions. Not only reducing emissions but actively contributing to climate protection by creating CO_2 sinks could be benefitting for the relationship between farmers and society.

In summary, farmers are often neither completely averse to Carbon Farming programmes nor completely convinced by them. The design of the program, especially in terms of the bureaucratic and organisational burden on farmers, is crucial to convincing farmers to participate.

3. Conclusion – Feasibility and potential evaluation

The potential of Carbon Farming in Germany in terms of potential carbon storage is much lower than emission reduction strategies. Carbon Farming is particularly suitable for achieving a better overall CO_2 balance and more stable yields in the long term within the scale of the agricultural sector. Since humus-rich soils are necessary anyway in view of climate change, efforts in this direction should be made as soon as possible. Higher SOC contents increase yields and reduce the need for synthetic fertilizers, the price of which is currently rising enormously (Oldfield et al., 2019; Quinn, 2021). Summarising these effects, Carbon Farming as a business model is merely a motivational boost to target the long-term positive side effects of humus-rich soils. Nevertheless, it is to be expected that the EU will take up the considerable potential, considering the numerous positive side effects, and initiate funding. In order to achieve acceptance by society, the positive side effects should always be conveyed by both policymakers and providers. In this way, uncertainties in the quantification of actual carbon storage can be accepted without completely calling into question the Carbon Farming approach. However, as the political implementation path can be quite lengthy, the issuance of climate certificates is in principle a reasonable interim solution - which does not have to conflict with political measures. By applying optimizations to some problem areas (some of which are described in 2.5.), a uniform standard with a relatively secure methodology could be developed and validated. Including e.g., risk buffers to address the permanence problem, a certification issue in Germany is feasible. So that farmers do not have to pay too much in advance, a combination of annual payment according to conservative expected value (measure-based) and control measurement (result-based) could be used after around 4 years. Depending on the results of the measurements and new scientific findings, the expected values would have to be adapted and adjusted. New technologies like algorithms for remote sensing. New technologies such as remote sensing algorithms for determining organic carbon content could provide additional potential.

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