Regenerative Agriculture and Climate Protection - High Expectations, Low Delivery

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Regenerative Agriculture and Climate Protection –

High Expectations, Low Delivery

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1 Introduction

Regenerative agriculture currently is a much- promoted concept because it is assumed to guide us towards more ecologically sustainable and climate-friendly agricultural production systems. For example, Nestlé, the world biggest food producer, recently issued guidelines for growers based on key features of regenerative agriculture (Nestlé, 2024).

Proponents of regenerative agriculture often claim extraordinary environmental and economic benefits from regenerative agriculture. For example, the Rodale Institute claimed that the global greenhouse gas (GHG) emissions from all sectors could be stored in the soils if growers globally would adopt regenerative agricultural practices, i.e. cover crops, crop rotation and conservation tillage (Rodale Institute, 2020). The Boston Consulting Company (BCG) published a report stating that German growers could improve their profits by more than 50 per cent when employing no-till practices, including direct seeding, minimal soil-disturbing subsoiling, cover crops, and interseeding (Kurth et al., 2023). For the World Economic Forum, regenerative agriculture is the pathway to a farming system resilient to climate shocks and a decarbonized food system (WEF, 2023).

As will be explained in more detail below, we have strong doubts about the empirical evidence of these claims as far as GHG mitigation, mainly due to soil carbon storage, and economics are concerned. This paper aims to substantiate our concerns by looking into two key features – cover crops and reduced tillage – their economics, and the leakage issue. Our critical perspective on the GHG mitigation effects of no-till and cover crops is very much in line with the results of the EASAC (2022) meta-analysis of main components of regenerative agriculture, i.e. soil restoration, carbon capture and storage, and reversal of biodiversity loss. The EASAC study found no effect of reduced, minimum or no tillage on total soil carbon. Cover crops showed positive but limited GHG mitigation effects. Based on previous critical literature and our own arguments, we suggest an alternative approach to guide global crop production to become more climate smart in a reliable and measurable manner.

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The authors belong to a global, not for profit network of crop production economists called agri benchmark Cash Crop. We combine unique farm-level data with a global network of on-the-ground experts to provide comprehensive information and advice on economic and environmentally sustainable crop production systems to agricultural stakeholders worldwide. The ideas outlined in this article have been intensively discussed in the network.

2 Key features of regenerative agriculture

While there is no unanimous definition of the term regenerative agriculture available, cover crops and no or reduced tillage are always key features. Furthermore, diverse crop rotations, legume cultivation, reduced application of pesticides and use of organic instead of mineral fertilisers are often promoted.

Since reduced tillage or no-till as well as cover crops are at the same time the key factors when it comes to greenhouse gas emission reduction or sequestration in crop production, our analysis will focus on these two practices.

Agriculture has one unique property in climate protection: It is a major source of GHG emissions and it can also become a sink by storing GHG in the soil. The key goal for regenerative agriculture in this respect is to sequester carbon in the soil. However, the reduction of ongoing emissions does not play a major role in this concept. Therefore, we will focus on the sequestration dimension.

3 Potential benefits from regenerative agriculture beyond GHG mitigation

We fully acknowledge the environmental benefits that reduced tillage systems and cover crops are able to deliver: Mainly less erosion, less nutrient losses, improved humus content (Dang et al., 2020). Furthermore, a reduced tillage usually does imply less fuel consumption and hence a reduction in GHG emissions.

A recently published multi- year study in Germany (Möller et al., 2023) concludes: (a) Even though microbial activity and aggregate stability improved when land was cultivated with regenerative agriculture principles, yields did not improve under drought conditions; (b) also, damages from pest and diseases were not different compared with conventional practices, and (c) differences in humus content in the soils were in the range of the error margin.

4 Tillage systems and GHG sequestration

No- till and reduced tillage practices have gained high relevance in many countries (e.g. USDA-NASS, 2024). Regarding the sequestration potential from no-till or conservation tillage, there are serious scientific concerns over the respective standards from the Intergovernmental Panel on Climate Change (IPCC). Based on IPPC, Tudela Staub (2023) calculated for a typical US corn/soybean farm moving from conventional tillage to no-till, an annual increase of soil carbon of about 500 kg CO 2eq/ha. To put these figures into perspective: For the same farm, the usual nitrogen fertilisation rate of 180 kg N/ha is emitting (direct and indirect) about 1,000 CO2eq kg/ha. So, for climate protection, no-tillage seems to be of high relevance at first sight.

However, the figures for GHG sequestration through less tillage are heavily challenged by research results. Meta-analyses conducted by Vanden Bygaart et al. (2003), Baker et al. (2007) and EASAC (2022) found no difference in carbon (C) content between conventional and no-till systems when the entire growth horizon of the soil was analyzed. When a difference was measured, it was often caused by the different depth in soil analyses: Under no-till, an accumulation of C in the upper soil layers is often observed, while lower soil parts show lower C contents. Baker et al. (2007, p. 4), stated: ‘The widespread belief that conservation tillage favors carbon sequestration may simply be an artifact of sampling methodology’.

Furthermore, in the case of Asian rice production in irrigated lowland rice systems, which produce some 70 per cent of the world’s rice, reduced tillage shows negative effects on yields. Under the prevailing climatic and soil conditions, intensive tillage is often essential because soils are very heavy and wet and a major goal of the operation is to create a soft soilfor easy planting of seedlings above a compacted soil layer plough pan that results in low water percolation and better water use efficiency. For about 30 years people have been trying to diversify these systems or move to reduced/no- till and dry direct seeding. It has proven to be very difficult, particularly in terms of maintaining crop yields and soil health (Bouman et al., 2007).

We also need to be aware of an important trade-off: reduced tillage usually leads to an increase in crop protection usage. Not only is weed control more challenging with no-till or even reduced tillage (Sims et al., 2018), the pest and disease pressure usually goes up as well because crop residues and weeds create so-called ‘green bridges’ between the previous and the subsequent crop (Singh et al., 2018).

5 Cover crops and GHG sequestration

Cover crops are currently of limited but growing relevance, for instance in the United States and the European Union. In the USA the share of crop land on which cover crops have been grown was about 4.7 per cent in 2022 (up 17 per cent against 2017) (USDA-NASS, 2024). For the EU in 2016 the respective share was 8 per cent (Eurostat, 2024). However, in both cases, financial government support is involved to promote cover crops (Kathage et al., 2022; Wallander et al., 2021).

Cover crops promise many advantages with regard to nutrient losses, biodiversity and soil erosion (Blanco- Canqui, 2018; Chen et al., 2022; EASAC, 2022). Nonetheless, we have concerns regarding the often claimed extent of the ability of cover crops to act as a global tool to store carbon in the soils. The meta-analysis of EASAC (2022) shows a positive but, all in all, limited effect which is largely dependent on whether or not legumes are present in the cover crop mixture.

Globally, the GHG mitigation potential of cover crops is further limited because many agricultural production systems in which cover crops are not feasible for agronomic reasons, such as: (a) unfavourable climatic conditions (e.g. too cold in the Canadian prairies); (b) too dry to establish a cover crop (e.g. in Spain); (c) too short a time span before the next winter crop (e.g. in France) or (d) double- or triple-cropping systems and hence no time in which the land is otherwise idle (e.g. in Asia or Latin America).

Despite these limitations, agri benchmark data show that in principle many more farms could grow cover crops. Depending on the cropping system and the climatic conditions, the agronomic potential ranges from 10 per cent up to 70 per cent of the individual farm acreage. Tudela Staub (2023) showed that in a short- term perspective cover crops offer GHG mitigation potentials which vary substantially depending on farm- and site-specific effects.

But a major issue associated with cover crops to sequester GHG is the lack of permanence of the carbon capture: It is a reversal concept. Each grower can decide to stop growing cover crops and whenever he or she does so, the carbon accumulated in the soil will then be released gradually to the atmosphere again (Tudela Staub, 2023). Hence, regarding GHG mitigation goals it is a risky strategy for society.

6 Economics of regenerative agriculture

The Boston Consulting Company's report on regenerative agriculture in Germany is claiming an increase of profits by 52 €/ha (Kurth et al., 2023). We think that this claim is based on a number of mistakes or unrealistic assumptions: For example, their German case study suggests that growers can earn 38 €/ha as GHG credits for growing cover crops. However, since cover crops are already subsidised by the EU, no additional revenue can be generated. Furthermore, the assumed price per ton of CO_2 sequestered is much higher than the amount growers can usually achieve.

Furthermore, BCG assumes fertiliser cost savings of 89 €/ha due to cover crops (Kurth et al., 2023). We are not aware of any trials that show savings that come even close to such a value. The two issues alone eat up the suggested net benefit from cover crops of 52 €/ha. The Sustainable Markets Initiative, thus, concludes that the short-term economic case of regenerative agriculture is not compelling enough for the average farmer (SMI, 2023).

This is why cover crops are in most parts of the world only a niche technique: They come at a net cost to most producers, even with optimistic assumptions regarding the measurable economic benefits from (a) yield improvements in subsequent crops and (b) savings in fertiliser cost due to lower nutrient losses.

Consequently, Kathage et al. (2022; p. 1) concluded 'We find that policies by far the strongest determinant of adoption rates and adoption intensities. CCC adoption patterns have been shaped mainly by the Nitrates Directive and the Common Agricultural Policy's greening requirements'. The only exception from that rule is when cover crops have a significant benefit for a particular subsequent crop, e.g. sugar beets.

Figure 1: A critical review of farming practices is needed.

Source: agri benchmark Cash Crop, 2025

Accordingly, agri benchmark data show that only 20 per cent of our typical farms all over the world – primarily those in the EU – grow cover crops; the average share of cover crop acreage in the acreage of these farms is 19 per cent. Outside of the EU cover crops play a certain role in Argentina, Uruguay and South Africa.

From other innovations in agriculture we know that when they are profitable, their uptake is rather quick, e.g. genetically modified crops (Dillen et al., 2013). Hence, if cover crops were as profitable as claimed many more producers would grow them.

This implies that growing cover crops is usually dependent on external funds – either from government or from value-chain actors that put value on the related GHG emission mitigation or other environmental benefits (SMI, 2023). Whereas it might be conceivable to realise either of the two framework conditions in the developed world, it is difficult to imagine that this will be possible in a foreseeable future in the developing world.

7 Regenerative agriculture and leakage

In crop production – except for legumes – about 80 per cent of CO2eq emissions from arable crop production stem from the manufacture and use of mineral nitrogen fertilisers (Brandes, 2024). Therefore, some supporters of regenerative agriculture suggest reducing or even forgoing the use of mineral nitrogen fertiliser – and they accept a significant decline in crop yield per unit of land. The consequence of such a decline in crop yield would be the need to intensify production on existing arable land – usually accompanied by an increased use of fertilisers, plant protection and other input factors – or a substantial leakage effect.

Furthermore, under certain climatic and soil conditions we have to consider negative yield effects when moving from conservation tillage to no- till. These effects will also go along with intensification of production on existing arable land or cultivation of new arable land. In most cases these issues are not taken into account by the proponents of regenerative agriculture.

What is the leakage effect and why do we care about it? From a global perspective, the most important source for GHG emissions related to agriculture is land use and land use change (Crippa et al., 2021). This in turn implies that a GHG mitigation measure that leads to a yield decline on site ‘a’ will usually cause disproportionally more GHG emissions on site ‘b’ due to the need to convert grassland or forest land into arable land to compensate for the decline in output on site ‘a’. Therefore it is essential to critically review all changes in the production system that imply yield penalties as part of a full-fledged environmental performance evaluation (Jasch, 2000). In case leakage effects occur, one has to assume that net GHG emissions will go up.

Figure 2: Subsurface fertiliser application – one option to improve nitrogen use efficiency.

Source: Reichert, 2025.

8 What alternatives do we suggest?

Not only is mineral nitrogen by far the most important factor when it comes to GHG emissions from crop production, there is also strong empirical evidence that there is relevant potential to improve the efficacy of nitrogen use in crop production and thereby significantly reduce related GHG emissions. In-depth case study research on existing farms in North and South America and the EU shows that the GHG mitigation potential of improved nutrient use efficiency depends on prior farming practices and the regulatory framework. As a consequence, nutrient use efficiency is higher in Europe than, for instance, in South America due to a tighter legislative framework. Nonetheless, prior research shows that the recovery rate of nitrogen applied to major crops, for instance cereals, is low and a considerable share of nitrogen fertiliser is lost to the environment as gas and via leaching to underground water bodies (Bowles et al., 2018; Omara et al., 2019; Tudela Staub, 2023).

Against this background, the so-called nitrogen use efficiency indicator is an adequate and goal-compatible indicator to measure and manage GHG emissions from crop production. This indicator coincides with growers' interests: Lower nitrogen losses mean less cost and higher margins. Therefore, societies do not have to fight an uphill battle but rather use gravity to reduce GHG emissions from crop production, despite some investments, for instance in precision farming equipment, which may be necessary to further improve the nutrient use efficiency. Improving the efficiency of nitrogen use and reducing nitrogen losses generates significant co-benefits such as improved water quality. And this GHG mitigation is stable, with no need to police it and no need to compensate growers in perpetuity as is the case with regard to cover crops and conservation tillage which are proposed as corner stones of regenerative agriculture.

Figure 3: In some cases, drones might help to make better use of nitrogen.

Source: Indiamart, 2025.

9 Outlook

There is strong scientific support for the objectives of policymakers, growers and industry to substantially reduce the environmental footprint of agriculture in general and GHG emissions in particular (FAO, 2023). Regenerative agriculture is increasingly promoted as a viable pathway to reduce the ecological footprint of agriculture.

However, a careful review of existing data indicates that most proponents of regenerative agriculture are massively overselling the potential upside for climate protection: Even with very optimistic assumptions regarding the GHG mitigation potential of cover crops and no-till, the theoretical GHG mitigation potential, at best, is less than 10 per cent of the amount claimed by the Rodale Institute.

Furthermore, studies proposing regenerative agriculture often do not take into account land use change and other leakage effects and, thus, have to be complemented by thorough environmental performance evaluations.

We have demonstrated that often reduced tillage and cover crops are (a) agronomically not feasible, (b) create a negative effect on yields, or (c) are associated with environmental trade-offs.

Whether intended or not, we see the risk that policymakers, industry and growers are intrigued by a fancy term, while not tackling the really important issues in GHG mitigation such as nitrogen use efficiency of agricultural production systems.

We sense that the concept of regenerative agriculture is so attractive to agricultural stakeholders because it is focusing on GHG sequestration and therefore – at least in theory – can become a source of farmers income by selling certificates. In this world, agriculture is no longer a problem but a part of the solution. However, the key challenge is to reduce ongoing emissions.

Given the high relevance of mineral nitrogen for agricultural GHG emissions, we suggest focusing on nitrogen use efficiency to access and reduce the carbon footprint of agricultural products.

Some of our concerns regarding the concept of regenerative agriculture have also been put forward by the 'Sustainable Markets Initiative' (SMI). The SMI calls for less effort in defining an 'ideal' system, but rather to focus on outcome-based solutions by developing a metric to assess the environmental footprint of agriculture, to measure improvements over time and to compensate growers for their efforts. SMI also proposes to share the costs of farmers' transition along the food value chain and set incentives appropriately so that farmers can build income from environmental measures (SMI, 2023).

More in-depth analyses of the potential of regenerative agriculture and other transition concepts for the agricultural sector require a global network of agronomists and crop production economists with access to a vast pool of data on diverse arable farming systems and a strong expertise in crop production systems and GHG mitigation strategies. We share the view of the SMI regarding the suggested focus on globally relevant and practical metrics.

We are looking forward to a critical and constructive debate about this thesis. We hope, in the end, agricultural stakeholders will be aware of the limitations and shortcomings of the key elements of regenerative agriculture when it comes to GHG mitigation and sequestration. Based on that they will be better equipped to contribute to the much-needed improvement of GHG balances in global crop production.

10 Summary

Regenerative agriculture has gained attention for its potential to mitigate greenhouse gas (GHG) emissions from crop production and improve farm profitability through practices like cover cropping and reduced tillage. However, empirical data suggest that the carbon storage potential and economic benefits of these methods are often overstated. Research shows that the capacity of these practices to sequester carbon is limited. Furthermore, under challenging climatic conditions, these techniques can even reduce crop yields.

The paper demonstrates that economic benefits are often based on assumptions that do not account for challenges, such as the limited feasibility of cover crops in certain cropping systems and exaggerated savings from reduced inputs. Moreover, the potential for 'leakage' – where lower yields lead to land conversion and emissions elsewhere – raises further concerns about the effectiveness of the concept.

A more promising approach lies in improving nitrogen-use efficiency, which addresses the major source of GHG emissions from crop production while reducing input costs and improving productivity. Unlike regenerative practices that often depend on subsidies, improving nitrogen use efficiency offers stable, measurable results without yield penalties or the need for continuous financial compensation of growers. This ensures long-term sustainability and climate benefits, making it a more promising strategy

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