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Economic evaluation of specific measures of Regenerative Agriculture to increase the humus content considering present theories on humus formation

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List of Abbreviations

BLE	Federal Institute for Agriculture and Nutrition (Bundesanstalt für Landwirtschaft und Ernährung)
CA	Conversation Agriculture
EU ETS	European Union emissions trading system
GHG	Greenhouse gas
GMO	Genetic modified organisms
GPS	Global positioning system
GWP	Global warming potential
IPCC	International Panel on Climate Change
MACC	Marginal Abatement Cost Curve
MRT	Mean residence time
OA	Organic Agriculture
PDF	Portable Document Format
POS	Postmortal organic substance
RA	Regenerative Agriculture
RMP	Recommended management practice
ROC	Regenerative Organic Certification
SIC	Soil inorganic carbon
SOC	Soil organic carbon
SOM	Soil organic matter
UNFCCC	United Nations Framework Convention on Climate Change

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Abstract

The increase of greenhouse gases (GHGs) is attributed to be responsible for global warming. Sequestration of carbon through building up soil organic carbon (SOC) can, due to the large capacity for CO_2 in soils, therefore contribute to the mitigation of GHG in the atmosphere. Thus, soils came into focus to be an important compound of future strategies against climate change. Beside the mitigation effect, other benefits from increasing SOC are claimed (e.g. enhancing soil fertility, soil quality, productivity and water holding capacity). Despite the importance of organic matter in soils and huge efforts of investigation, the formation and dynamics of this complex soil compound still remains unclear. Furthermore, new insights have been provided by scientific progress and are currently challenging long-lasting paradigms, which is also part of the present study.

Due to the mitigation effect and the mentioned benefits, the management approach of Regenerative Agriculture (RA) has a strong focus on the enhancement of stable organic matter (humus) in soils. RA offers a framework, how the humus content can be raised, by following some specific practices. Farmers, who already established these practices, have been asked to fill out a prepared questionnaire to answer questions about measures of RA. These measures have been described and analysed in this study, due to their contribution to humus building (carbon sequestration) and financial impacts, supported by own calculations. The growing public interest in the matter of increasing SOC to buffer global warming can be seen in the establishment of different initiatives, which offer farmers a financial reward (humus-certificates) for increasing the humus contents in their soils. Scope and experience of these private initiatives, as well as procedure and contractual relationship have also been analysed. By comparing the costs of measures of RA and potential revenues by selling humus-certificates it could be shown, that the hitherto price is not cost-covering. Though, a high uncertainty remains, due to a lack of data and wide ranges of CO_2-mitigation potentials.

1. Introduction and objective

The *green revolution* between 1965 and 1980 enhanced crop yields two- to threefold and food production was carried ahead of population growth. This draw political attention mostly away from land, food and agriculture. Today, policymakers (and society) are again confronted with challenges concerning the food and agriculture sector (Dent 2014, p. 5):

- Following future prospects, food production must be raised 70 % compared to present supply by 2050 and this must be done with the same land and water resources (or even less, if present land degradation trends cannot be stopped).
- Peak soil has passed. The last quarter century has witnessed degradation of one-quarter of the land surface and todays agricultural practices are driving water shortage and contamination, loss of biodiversity and climate change.
- Climate change is driven by burning fossil fuels and by land use change, which offsets large amounts of greenhouse gases. Soils can therefore act as a source of greenhouse gases. But there is also the opportunity to buffer climate change by acting as a sink for greenhouse gases via building soil organic matter.

Regenerative Agriculture (RA) focusses on the opportunity of soils to be a sink for greenhouse gases, as a main goal of this new farming approach is the increment of organic matter in the soil. This is considered to reduce CO_2 in the atmosphere and to enrich the humus content in soils.

There is also a growing public interest to sequester carbon via humus building in soils. Several projects have been established, where farmers can apply with the prospect of revenues, if the soil organic matter has been raised. However, the increasement of humus contents can be a challenging goal. Traditional views suggest, that the humus content is a function of climatic conditions, type of soil and the agricultural use. The recommend site-typical amounts of SOM in cropland range between 1 – 4 % (Lütke Entrup and Oehmichen 2006, p. 76). However, protagonists of RA argue, that humus contents below 5 % lead to dysfunctional soils (Jones 2011; Kinsey et al. 2014, p. 61–64; Näser and Wenz 2016; Dunst 2019, p. 31–32) and endorse particular measures, how the humus content can be raised to this level. The costs of these measures, however, have not been kind of scientific investigations so far.

The **aim** of this study is therefore **to highlight this topic by calculating the greenhouse gas (GHG)-abatement costs for measures of RA and set them in relation to potential earnings by trading of CO_2-certificates. The results may therefore contribute to answer the question, if these certificates can be rational incentives for farmers**.

Despite huge efforts, which have been undertaken to understand the complex nature and properties of soil organic matter and humus, it has been pointed out, “how remarkably difficult it is to obtain conclusive evidence on most aspects of the issue” (Baveye 2015). Nevertheless, huge progress has been made in this field by using modern technologies of investigation. As the formation of humus is essential for carbon sequestration, another **aim** of this thesis is the **comparison between traditional views regarding the formation of soil organic matter and new insights, which might explain extraordinary results claimed by practitioners of RA.**

2. State of the art

This chapter provides an overview about the difficulties in defining the related and often used terms "soil organic matter" (SOM) and "humus". Subsequently the knowledge about enhancing soil organic carbon (SOC), as a possible component for mitigating CO_2 from the atmosphere through building up carbon in the soil, will be examined. This will be introduced by means of the 4p1000 initiative. Another important issue regarding SOM and humus is the term *site-typical amount* of humus, which will also be presented in this section. Afterwards an overview about traditional concepts and new findings concerning the synthesis of organic macromolecules will be given, as a deeper understanding of the mechanisms that control stabilization and release of carbon seems important for development of management strategies to enhance carbon sequestration of soils (Marschner et al. 2008).

The main focus of Regenerative Agriculture (RA) is an augment of SOC through agronomic techniques. RA is a relatively new management practice and conjuncts practices of different agricultural streams (Conventional, Conservation and Organic Agriculture, Holistic Management (Butterfield et al. 2019) and agroecology (Altieri 2019)). The basic knowledge, differentiation to related practices and specific measures of RA will be also part of this section.

Trading with CO_2-certificates in agriculture is not common in Europe and traces back to private initiatives. Chapter 2.3 provides therefore an overview about scope and experiences and also about procedures and the contractual relationship regarding this matter.

The last part of this section refers to the concept of Marginal Abatement Cost Curves, as these diagrams can be used to visualize the abatement potential of measures to combat global warming.

2.1 Soil Organic Matter

2.1.1 The concept of Soil Organic Matter

Organic matter is a general term to describe a mixture of fresh and dead organisms and this fraction of the soil body is respectively called *soil organic matter* (SOM). However, it should be considered, that using the term SOM and its components "reveals [often] a lack of precise and consistent definitions of what SOM is and what its various component fractions represent" (Baldock and Broos 2012). These problems derive from the heterogeneity of SOM, because of its source, chemical and physical composition, diversity of functions and its dynamic character (Baldock and Broos 2012).

The term SOM could be seen as a collective or umbrella term, which includes all the complex mixtures of broken down materials from living organisms, while ignoring the living fraction (Tan 2014, p. 2). SOM could therefore be divided into two groups. A group of organic matter at various degrees of decomposition, related to litter, and another group consisting of completely decomposed materials, which is identified as humus (Tan 2014, p. 37). Figure 1 gives a schematic overview about the labile and protected parts of SOM. As it can be seen, Weil and Brady (2017) include living organisms in their definition of SOM in contrast to the above mentioned definition of Tan:

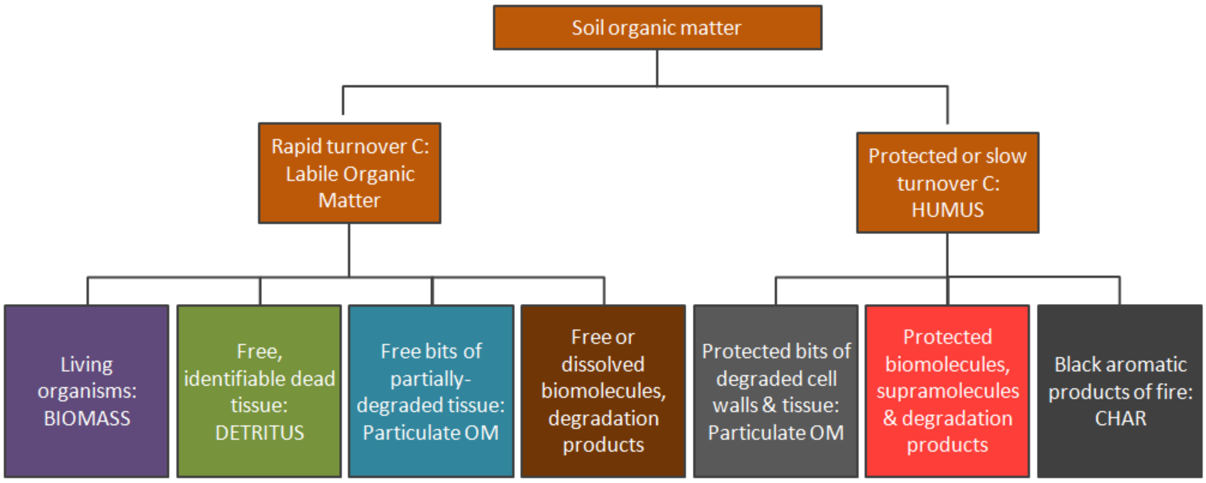

Figure 1: Contents of SOM, modified after Weil and Brady (2016, p. 562)

This underpins, that there is no universal accepted definition of SOM and the same is true for humus. Some authors refer to “all organic materials found in soils irrespective of origin or state of decomposition” (Baldock and Skjemstad 2005) and include plant litter in the term SOM. Other authors use the term *postmortal organic substance* (POS) or *humus* instead of SOM and include (i) fresh material, (ii) partial decomposed, (iii) newly synthesized organic matter, (iv) living microbial biomass (because of practical analytical reasons) and (v) black carbon (charcoal) in their definition (Ottow 2011, p. 278). Whereas other authors exclude charcoal (Oades 1988) or living biomass (Kögel-Knabner 2018, p. 64) or other fractions of organic derived matter in their definitions of SOM.

Usually the terms SOM and humus are used synonymous (Kumada 1988, p. 3; Ghabbour and Davies 2004), but it can also be found, that the term *humus* stands only for the stable part (right part in Figure 1) of SOM, which turnover rates are very slow (Weil and Brady 2017, p. 563). When the SOM content of a given material is analysed, some researchers discard any organic material, which is retained by various sizes of sieves (e.g. from 2 mm to 0.85 mm). This would mean, that only a fraction of SOM is part of the analysing result (Kirkby et al. 2011).

The whole issue gets even more confusing (Tan 2014, p. 38), when the term humic matter (humic substances like humic acid, fulvo acid and humin - compare also section 2.1.2) is also part of the discussion: Humic matter is addressed by some authors as an integral part of soil humus (via an alkaline-soluble extraction process) and by others as a synonym for SOM (Schnitzer 1999).

Thus, it is highly important, when results of enhancing SOM contents in soils are compared, to define what exactly is meant by the used terms. The methods measuring the SOM content of the probed soil must also be described in detail to be sure what exactly has been measured and compared.

In this thesis, the author follows the definition for SOM and humus by Weil and Brady (2016, p. 561) who stated, that **SOM refers to the entire organic portion of the soil**, while **humus is seen as the stable part of SOM**, which is stabilized and protected by various processes.

For quantitative discussions about SOM, it seems largely appropriate to use the term soil organic carbon (SOC), because most methods of determining SOM actually measure the Carbon (C) content in the material and use subsequent a conversion factor to estimate the organic matter (Weil and Brady 2016, p. 561). In most instances SOC and SOM can be used interchangeably (Baldock and Broos 2012), but it is worth noticing, that C can also be found in soils as a compound of inorganic (SIC) forms. Whereas SOC derived from plant or animal (microorganism) residues at different stages of decomposition and therefore part of the soil organic matter, SIC consists of lithogenic inorganic C, like primary or secondary carbonates ($CaCO_3$, $MgCO_3$) (Batjes 1996). The mean residence time (MRT) of SIC is much less dynamic (up to 85.000 years) than those of SOC (ca. 35 years), but it should be mentioned, that SIC and SOC can interact with each other. However, the underlying mechanisms are less well known (Lorenz and Lal 2018, p. 41) and regarding the extent of this thesis, it will only be dealt with aspects on SOC.

Considering the above mentioned difficulties of defining SOM, it should be clear, that the C content of SOM does vary substantially (from 40 to 70 % (Kögel-Knabner 2018, p. 85)) and an average C-concentration in SOM of about 50 % is today seen reasonable (Lal 2013, p. 66). However, older publications or other definitions of SOM refer to the average C-content (58.1 %) of humic substances, which would lead to a conversion factor of 1.727, as it is used in equation (1) above (Stevenson 1994, p. 7).

The humus content of the soil parallels the nitrogen (N) content, as the C/N ratio of humus generally falls within the range of 10 to 12. As it is easy to determine soil N, this parameter is often used as an index of humus content (Stevenson 1994, p. 7), because N is mainly bound organically (> 95) in soils (Kögel-Knabner 2010, p. 52). This leads therefore to the conversion factors:

$$soil\ organic\ matter\ (humus) = C\ \times 1.727\ \approx N \times 17.27 \qquad (1)$$

Beside carbon and nitrogen, humus consists also of constant proportions of phosphorus and sulphur and research lead to the ratios:

$$C{:}N{:}P{:}S = 10{,}000 : 833 : 200 : 143 \qquad (2)$$

Thus the availability of N, P and S may restrict both primary production and the formation of humus, by limiting humification efficiency (Kirkby et al. 2011). Another remarkably issue regarding humus could be found by analysing the amino acid pattern of humus samples, derived from different soils. The comparison of these patterns revealed the fact, that the amino acid profiles of humus is always nearly identical, irrelevant where (meadow, crop field, forest) the samples have been taken (Scheller 2013, p. 143–145).

2.1.1 Agriculture and climate

Since the Neolithic Revolution, agriculture has depleted the SOC stock by about 130 Pg (1 Pg = 1 Gt = 10^{12} g) C. The reason for the depletion of the SOC stock visualizes Figure 2: When natural ecosystems are converted to managed agroecosystems, a reasonable amount (30-50 % over 50 years in temperate climates and up to 75 % over 25 years in tropical climates) of C is lost due to mineralization of SOM to CO_2. A new equilibrium for the SOC pool is reached, when the soil is not exposed to wind or/and water erosion, otherwise the pool will be further depleted (Lal 2016).

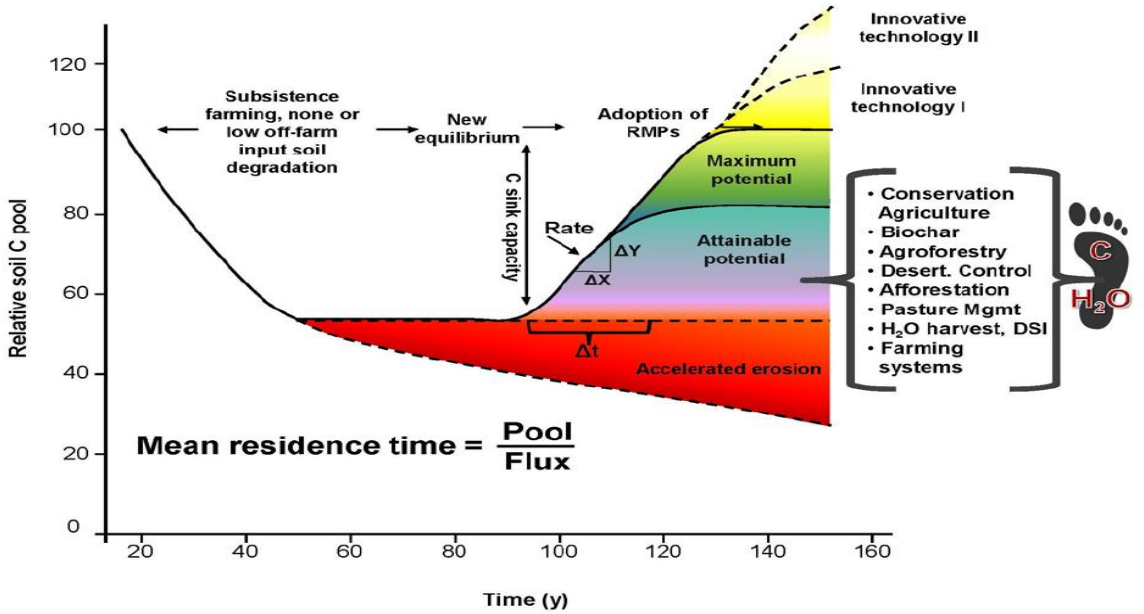

Figure 2: Effects of land use change and management on SOC pool, RMP = recommended management practice (modified from (Lal 2016))

Through the conversion to a restorative land use and adoption of recommended management practices (RMPs) in order to increase SOC, a positive C budget (input of biomass C exceeds the losses by erosion, mineralization and leeching) can be achieved. This is often referred as “the attainable potential”. By the adoption of some site-specific, innovative land use and management practices, additional SOC can be sequestered and it may be reached the antecedent pool, which is the “maximum potential” and correspondents to the “soil C sink capacity”. This capacity depends on site-specific factors including soil texture and mineralogy, depth of solum, climate, etc. A progressive adoption of certain RMPs (e.g. application of biochar, agroforestry) may even lead to an increase of the SOC pool above the antecedent level. The uncertainty regarding this matter is indicated by the dashed lines in Figure 2. Dividing change in SOC by the change in time results in the rate (Mg C ha^{-1} y^{-1}) of carbon sequestration or depletion (Lal 2016).

Despite the achievable goal of a positive C-budget, the agricultural sector is identified to be responsible for a significant share of global greenhouse gas emissions (Smith et al 2014, p. 811). The three important greenhouse gases in agriculture are CO_2, methane (CH_4) and nitrous oxide (N_2O). For calculating issues, CH_4 and N_2O are usually converted into the global warming potential (GWP) of one molecule CO_2 (Houghton 1998, p. 22) which results in the unit CO_2eq (CO_2-equivalent). Estimations on concrete numbers regarding the emissions of greenhouse gases through the agricultural sector are difficult and depend on what exactly is counted. Annual GHG emissions from agricultural production in 2000-2010 were estimated at 5.0-5.8 Pg CO_2eq yr^{-1}, comprising about 10-12 % of global GHG emissions. In addition, annual GHG flux from land-use and land-use change activities (which are often counted to the agricultural sector) increase the anthropogenic GHG emissions by 4.3-5.5 Pg CO_2eq yr^{-1} (Smith et al. 2014, p. 812). Global Agricultural emissions are projected to grow by approximately 1.0 % annually to about 8 Pg CO_2eq per year. The main driver for this trend is seen in expansions of population and meat consumption (McKinsey & Company, 2013, p.123).

The GHG emissions of the German agricultural sector are reported annually and include emissions from livestock husbandry, manure management and turnout of farm fertilizer and emissions from soils due to nitrogen fertilization. This amounts to a share of 7.2 % (67 Mt = 67 Mio. t) of the whole GHG-emission (909.4 Mt) in Germany in 2016 (Baumgarten et al. 2018, p. 34). However, this approach excludes supply chains for fertilizer production, heating of stables or the use of fuel for field work. When these emissions are also taken in account, the agricultural GHG-emissions increase to 12.9 % of global GHG emissions.

2.1.2 The "4 for 1000: Soils for Food Security and Climate"- Initiative

The 21st Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP21) took place in Paris in 2015. For the first time soil carbon and agriculture were on the agenda and the 4 per 1000 initiative (4p1000) was launched (Lal 2016). The aim of the initiative is to enhance – at least maintain (Aubert et al. 2017), the soil C stock on a large portion of the world managed soils by an average annual increase of 0,4 % (or 4 ‰) in 0-40 cm depth. This goal should be reached through the adoption of recommended management practices (RMPs), which has been emphasized as Carbon Farming. RMPs are for example mulch farming, cover cropping, agroforestry, application of biochar or improved grazing (Lal 2016).

The reason for the detection of soils in order to mitigate global warming is the fact that soils can store two to three times more carbon than the atmosphere. A relatively small increase in the stocks (1 Pg of the soil C pool is equivalent to 0.47 ppm of CO_2 in the atmosphere (Lal, 2016)) may therefore lead to great effects in the atmospheric GHG content. The following example illustrates this argument and carries back to the 4p1000 initiative:

The estimations for annual emissions due to the combustion of fossil carbon were 9.4 ± 0.5 Pg C (without land use change) for the decade 2008 – 2017 (Le Quéré et al. 2018). And the estimation of the global total C stock to 1 m of soil depth is around 1,500 Pg or to the depth of 2m 2,400 Pg (Batjes, 1996). About 40% of the global SOC stocks to 1 m depth are currently stored in croplands, temperate grasslands/shrublands and tropical grasslands/savannahs (609 Pg) (Lorenz and Lal 2018, p. 56). When the ratio between global anthropogenic C emissions derived from fossil C and the total SOC stock (2m depth) is calculated (9.4/2,400) the result is roughly 4 ‰ (4 per mille). Taking the land area of the world as 149 million km², there is on average circa 161 tonnes of SOC per hectare (ha). An average sequestration rate to offset emissions from the combustion of fossil C is accordingly about 0.6 tonnes of C per ha and year (Minasny et al. 2017). Thus, an annual growth rate of the worldwide soil carbon stock by 0.4 % might stop the present increase of atmospheric CO_2 (French Ministry of agriculture, agrofood and forestry 2016).

However, it should be pointed out that the total land area includes deserts, mountains or wet lands, as well as settlement areas. Agricultural land, on which the 4p1000 Initiative focuses mainly (Rumpel et al. 2020), is therefore 49 million km², of which cropland is about 15 million km² (Minasny et al. 2017). This would lead to necessary sequestration rates of about 2 and 6.4 tonnes of C ha^{-1} y^{-1} respectively. Agricultural land It is also necessary to mention, that the distribution of soil carbon fluctuates with latitude and longitude. Greater stocks can be found on higher latitudes, the stocks decrease in mid-latitudes and increases in the humid tropics.

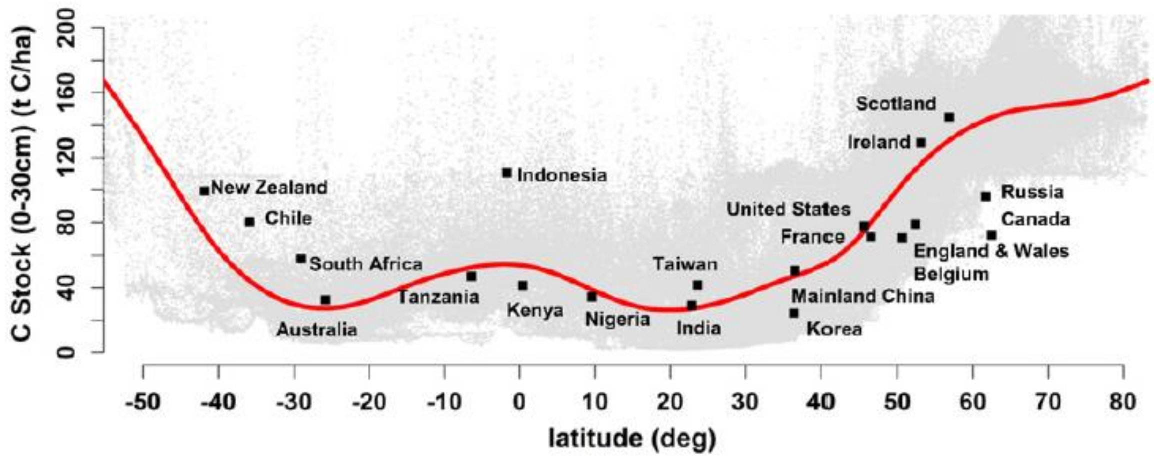

Figure 3: Soil C stocks (0-30cm) as a function of latitude. Black squares represent SOC-Stock from regional case studies (Minasny et al. 2017)

Regional case studies across the globe have suggested, that annual rates of 0.2 to 0.5 tonnes C per hectare are possible, when best management practices like reduced tillage in combination with legume cover crops are adopted (Minasny et al. 2017). There are also indications, derived from long-term field experiments, that annual increases in SOC of 0.4 % are possible for certain soil types. Although only under specific land-use and management practices and only for a limited period (Johnston et al. 2017; Lorenz and Lal 2018, p. 365–366). Estimations how much anthropogenic GHG emissions could realistically be offset via SOC sequestration in agricultural land range from 3 Pg C yr^{-1} (Minasny et al. 2017) to 1 Pg C yr^{-1} (Smith 2016), which counts for 35 to 12 % of the 4p1000 target respectively.

It has been intensively discussed, if the target of a global annual increase in SOC stocks of agricultural soils by 4‰ is achievable and the initiative had also faced criticism. Some criticisms were related to the suggestion, that SOC increase could offset *all* fossil fuel emission. This could, according to some authors, be used as an excuse not to drastically reduce GHG emissions, which seems necessary to reduce or even stop global warming (Rumpel et al. 2020). Other criticism focused on the assumptions and calculations, which quantities of SOC would be needed to partly offset anthropogenic CO_2 emission without considering other GHG emissions, mainly CH_4 or N_2O (Vries 2018). Apart from that, there were also more specific criticisms related to biophysical, agronomic and socio-economic issues. The detractors pointed out and the advocates of the initiative also admitted, that there are some challenges to deal with. As for examples the paucity of scientific data, the finite capacity of soil carbon sinks and the residence time of additional SOC due to change in practices (e.g. no-till and tillage) (Lal 2016; Minasny et al. 2017). Nevertheless, most authors and soil scientists agree with the aim to increase SOM, due to benefit effects regarding soil fertility and water holding capacity and the 4p1000 initiative should be seen more as a concept than just looking on the concrete number (4‰) itself (Lorenz and Lal 2018; Minasny et al. 2018).

2.1.3 The concept of optimal SOM contents

Despite the claim for higher stable SOM contents on which the above mentioned 4p1000 initiative aims, there are also researchers, who argue, that a "site-typical amount of humus" (e.g. 2,5 % for cropland soils) should not be exceeded (Körschens and Schulz 1999). However, the question, which actual height of humus (or stable SOM) in soils should be traced is difficult to answer, as there are only a few trails to define critical humus-contents. The conceptual attempt to define the optimum humus amount of soils is the idea, that too low humus amounts on one hand and too high amounts on the other might disable the fulfilment of soil functions or have environmental impacts (Wessolek et al. 2008, p. 61).

An *upper limit* value should not be exceeded, because crops would otherwise not be able to uptake mineralized nitrogen completely, followed by losses to atmosphere and groundwater. The building and maintaining of increased amounts of humus will also lead to unacceptable high efforts and costs for realizing this goal (Körschens and Schulz 1999). However, these theoretical observations have not been significant verified in field trails so far. High amounts of nitrate in groundwater are often more correlated with mineral fertilizing regime, than with the share of humus in soils. These findings lead to the insight, that a deduction of an upper boundary for SOM in soils is not yet possible (Wessolek et al. 2008, p. 72) and optimum humus contents seem still to be a research deficit, as it has already been emphasized by Kögel-Knabner and Beyer (1995).

For the consideration regarding the *lower limit* of humus in soils, it is necessary to introduce the concept of labile and stable fractions of SOM. Following this concept, SOM can be divided into a small labile (also called active, convertible or "Nährhumus") and a great stable (also called passive, inert or "Dauerhumus") pool. This divination derives from long-term experiments, where crops have been grown without any fertilization over a long time. The amount of SOM is therefore depleted and reaches a border, where no carbon is lost from the soil anymore, even when intensive tillage is performed (steady-state). This part of SOM is called stable, because it cannot be mineralized from soil microorganisms or other processes and has therefore a long turnover time (Körschens and Schulz 1999).

The labile part of SOM consists of easily decomposed materials and has a relatively high average C/N ratio (about 15-30). This part of SOM thus includes (depending on authors) the living biomass, tiny pieces of unprotected detritus and microbial transformed plant residues with a short turnover time (Weil and Brady 2016, p. 573). The classification of SOM in two fractions can be found in many publications, especially when referring to agriculture. Nevertheless, it should be stated, that there are other opinions regarding this matter. Some authors add an intermediate pool between the stable and labile pool (Kögel-Knabner 2010, p. 77) others divide SOM into five fractions (Jenkinson and Rayner 1977). Some authors advance even the opinion that discrete and homogeneous pools for labile or stabile carbon should be seen more as metaphors than as real, quantifiable pools, which can be found in soils (Janzen 2015; Kleber and Johnson 2010).

The lower limit of SOM in soils should add to the stable part the amount of active (labile) SOM, which is necessary to fulfil and maintain various functions of soils. A scientific deduction of concrete limits is again difficult, because which function should be valued to which amount (habitat function for soil biota due to higher aggregate stability or production function due to higher cation exchange capacity of SOM). More research regarding functional or numerical connections between critical soil functions and suitable fractions of SOM seems necessary for the determination of appropriate limits in between SOM should be hold (Wessolek et al. 2008, p. 74).

Nevertheless, comparing the amount of SOM that has been found on research projects to evaluate the SOM content in agricultural soils (Jacobs et al. 2018, p. 92–98) with the recommendation, derived from long-term field-trails (Körschens and Schulz 1999; Körschens et al. 2005; VDLUFA 2014) the results are similar. This seems to legitimate the classification of SOM content in different categories (Figure 4) and for some authors (Körschens and Schulz 1999) the deduction of upper and lower limits for the SOM-content as a function of clay and fine silt content (Figure 5).

	h1	h2	h3	h4	h5	h6
Humus (%)	< 1	1-2	2-4	4-8	8-15	> 15
organischer Kohlenstoff (g kg^{-1})	5,8	5,8-11,6	11,6-23,3	23,3-46,5	46,5-87,2	> 87,2

Figure 4: Classification of SOM after KA5, pedological mapping guidelines, 2005, (organischer Kohlenstoff = organic carbon)

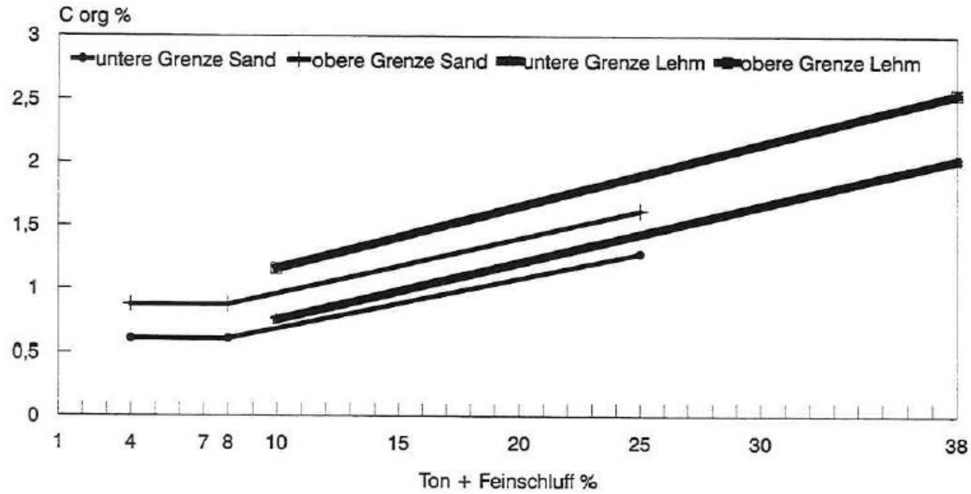

Figure 5: Guidelines for the upper and lower border of SOC level of sand and loam soils according to clay- and fine silt content. Source: Körschens and Schulz 1999

Whereas scientific evidence concerning upper and lower limits of SOM on a given site is lacking (Wessolek et al. 2008, p. 121), field-trails gathered plenty information how a particular humus content can be maintained on different soils, due to the growing of crops. This led to humus balances, where each crop and organic fertilizer is classified due to its humus reproduction value. In a whole crop rotation, the humus balance should be even or slightly positive (VDLUFA 2014; Körschens and Schulz 2005). Following these scientific based considerations, an accumulation of humus seems not necessary or might even have negative effects, due to nitrogen loss (to groundwater as NO_3 or to the atmosphere as N_2O). Beside this argumentation, it is doubted by many authors (Körschens and Schulz 1999; Körschens et al. 2005; Kolbe 2019; Poepelau 2019) that enhancing and maintaining the humus content noteworthy above the site typical content is achievable, due to financial and environmental restrictions.

2.1.3 Traditional concepts for the synthesis of humus

According to the traditional view, humus consists of humic-substances (e.g. Tan 2014, p. 79). These represent a complex mixture of molecules with various sizes and shapes (Stevenson 1994, p. 55). Thus, the nature of humic-substances is difficult to study, as transformation processes (biological, physical and chemical) convert plant material into organic products, which are able to form intimate associations with soil minerals. For studying nature and properties of humic-substances, it was therefore necessary to break these associations, as an observation in situ was not possible until modern analyse techniques have been invented.

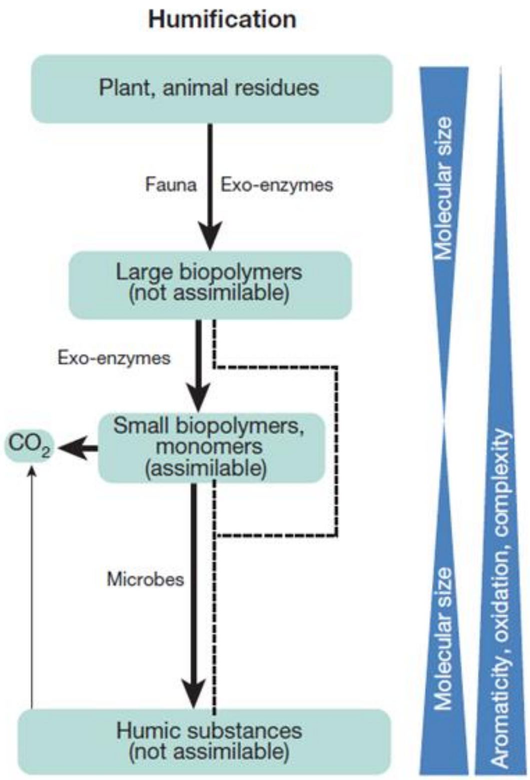

Figure 6: Schematic representation of the traditional humification model. Source: Lehmann and Kleber 2015

A common and since more than two centuries (first performed by Archard in 1786) used research-method based on the extraction of soil samples with alkali (usually 0.1 to 0.5*N* NaOH), followed by centrifugation and subsequent adding protons (usually as hydrochloric acid) (Stevenson 1994, p. 24). By refining this practice more and more, various humus fractions on the basis of solubility characteristics were suggested. This period was followed by a consolidation process and afterwards the three most frequently used terms "humic acid, humin, fulvic acids [...] survived and will undoubtedly continue to be used in future" (Stevenson 1994, p. 30–31). The classification into these three substances has been necessary, as they occur at different stages during the extraction process (Stevenson 1994, p. 41). Humin is therefore the insoluble fraction of humic substances, humin acid is soluble only under alkaline conditions, but not under acidic and fulvo (or fulvic) acids are soluble under all pH conditions (Sutton and Sposito 2005). The results of the treatment are yellow to black coloured chemical entities with a high molecular weight. These substances were meant to be formed during a humification process. The first step in this process is the decomposition of plant residues by the edaphon. Subsequent recalcitrant (resistant to decomposition) and large humic substances are formed by microorganisms. These substances could be found after soil sample treatment with alkali (Lehmann and Kleber 2015). This concept obtains to be the oldest scientific deliberations about humic matter and considers humic substances to be polymeric compounds (Tan 2014, p. 82).

A main part of SOM (or - depending on definitions – humus, see also section 2.1.1) was therefore classified as humic substances, newly formed by specific reactions of plant or microbial-derived organic compounds. Different reactions to form recalcitrant SOM have been considered (Stevenson 1994, p. 189) and these substances were meant to be resistant against microbial degradation and would therefore persist in soils for a long time period (up to thousands of years (Weil and Brady 2016, p. 564)). New SOM analysing methods have been developed in the 1960s and 70s and are composed of SOM degradation with harsh oxidation, subsequent reduction and pyrolysis procedures. These have been followed by extraction with organic solvents, separation with gas chromatography and identification with mass spectrometry. The results indicated, that SOM consists of aromatic structures. These structures were believed to derive from the aromatic plant residue lignin. According to studies, it seemed clear, that lignin must be the major precursor of SOM. It was thought, that condensation of lignin parts with nitrogen is a major humification process (Kögel-Knabner and Rumpel 2018). This results in the understanding, that soil humus is composed of the end products of synthetic reactions, which alter the structure of plant degradation products. These newly synthesized materials have unique properties by which they could be distinguished from non-humified organic matter. The main mechanisms of SOM stabilization have traditionally been regarded as the selective preservation of certain organic compounds and the formation of recalcitrant humic substances. This process must therefore operate independent from the standard process of decay, merely as a process in addition to it. Further, the process of secondary synthesis reassembles plant degradation products into new, molecularly and functionally distinct compounds. The resulting materials have been called humic substances (Kleber and Lehmann 2019a) and the reputation of this mechanisms by soil and environmental scientist was designated by Wershaw (2004) as the "humic-substance paradigm".

2.1.4 New findings in humic substance synthesis

The nature and dynamics of SOM has been researched by scientists for more than 200 years, but until today different views about properties and structure exist (Kleber and Lehmann 2019b). Since the beginning of the 21st century more and more doubts regarding the traditional concept for the synthesis of organic macromolecules emerged and even a "paradigm shift" in soil science was pronounced (Kästner and Miltner 2018, p. 142). Although the concept of humic substances has faced criticism ever since it was launched by Berzelius in 1839, more and more evidence arose, especially since the beginning of the 21.Century, that humic substances might be artificially produced compounds during isolation analyses (Tan 2014, p. 80). The main critic on the alkaline extraction method has been and still is, that the strong alkaline substances (treatment with 0.1*N* NaOH is equivalent to pH 13) ionize many functional groups associated with common biomolecules (alcoholic, phenolic, carbonyl, carboxyl, etc.). Already Liebig (1840) stated that "there is not the slightest reason to believe that one or another of these [alkali soluble] products should have the shape or the properties we assign to the humus existing in nature". The above-mentioned ionization of functional groups due to the use of alkali would never occur under pH conditions existing in natural soil systems. The real share of active functional groups in the sample would be distorted (Kleber and Lehmann 2019a) and "the isolation of a few substances by arbitrary chemical procedures fails to give a picture of the true nature of humus, it's origin, and its dynamic condition in soil" (Waksman 1936, p. 62).

A further question is the so-called recalcitrance of the humic substances. Recalcitrance means, that the stable part of SOM would be persistent against chemical or microbial decomposition, due to its molecular structure, which emerged from elemental composition, presence of functional groups and molecular conformation (Kleber et al. 2005; Marschner et al. 2008). It has long been thought, that this structure of organic material would determine long-term decomposition rates in soils, because the initial decomposition rate of plant residues correlates broadly with their chemical composition (e.g. nitrogen or lignin content). However, the use of compound-specific isotopic analysis-methods showed, that molecules, which have been meant to persist in soils (such as lignin or plant lipids), turn over quickly in the bulk soil matrix. Whereas potentially labile compounds (e.g. sugars) can persist for decades. It is therefore not possible to extrapolate the initial stages of litter decomposition to explain the persistence of organic compounds in soils for centuries to millennia (Schmidt et al. 2011). Figure 7 shows the mean residence time of some chemical compounds, which can be found in bulk SOM. The new view indicates that formerly believed long lasting compounds (e.g. lignin) in soils are much quicker degraded than saccharides or some microbial derived compounds.

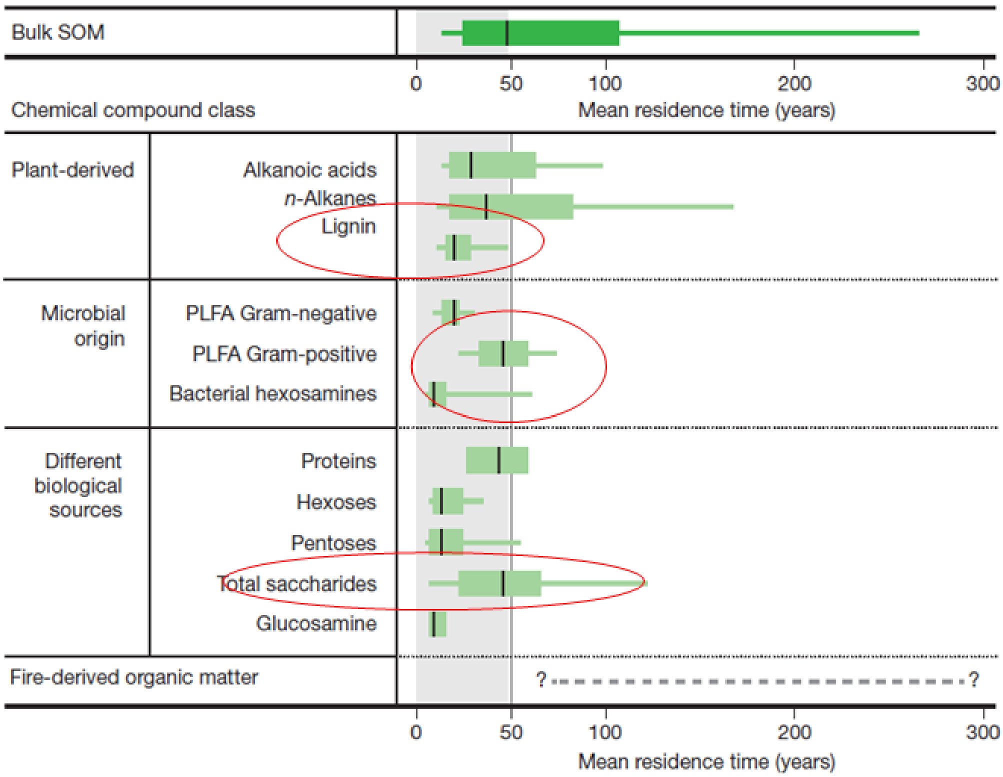

Figure 7: Molecular structure does not control long-term composition of SOM. Thin horizontal lines represent 10th and 90th percentiles; boxes represent 25th and 75th percentiles, (modified after Schmidt et al. 2011)

New isotopic, spectroscopic and molecular-marker analytical techniques made it possible to study the nature of SOM *in situ*. Large, complex macromolecules (the humic substances from extraction process) have been found only to a small fraction of total SOM (Weil and Brady 2016, p. 567) and the new methods revealed, that aromatic carbon is not dominating the composition of SOM in many soils (Kögel-Knabner and Rumpel 2018). These substances are now thought to be derived from fire (black carbon), as there is not enough evidence to support the hypothesis of *de novo* synthesis of humic polymers to be quantitatively relevant for humus formation in soil (Schmidt et al. 2011).

The long lasting paradigm of chemical recalcitrance as a stabilization mechanism is, following these findings and assumptions, discarded (Marschner et al., 2008) and replaced by the study of SOM composition within the bulk soil matrix (*in-situ*). Instead of chemical defined fractions (e.g. humin, humic acid, fulvic acid), physical fractions, which were more related to biological processes, are nowadays objectives of SOM research. This lead to the perception, that interactions of labile compounds with the mineral phase and microbial inaccessibility are the main stabilization mechanism (Kögel-Knabner et al. 2008; Kleber and Lehmann 2019a).

Thus, the description of SOM should move from decay rate, stable and labile pools, or level of recalcitrance to quantifiable environmental characteristics governing stabilization, such as solubility, molecular size and functionality (Schmidt et al. 2011). This leads to the conclusion, that persistence of SOM could no longer be seen as an intrinsic property of the molecular structure (chemical recalcitrance) but as an ecosystem property, due to the physiochemical and biological influences from the surrounding environment.

Derived from this deeper understanding and changed views concerning SOM, theoretical considerations and practical experiments offered new hypothesis to explain structure, chemical composition and formation of humus. Namely the hypothesis of the self-association of organic micelles (Wershaw 2004; Ottow 2011, p. 279), the hypothesis of the supramolecular structure (Piccolo 2001; Piccolo et al. 2018, p. 88) or the nanotube membrane concept (Tan 2014, p. 100) are established approaches regarding this matter.

The model, however, which attracted most interest (and controversy) in recent time, was launched by Lehmann and Kleber and is called the soil continuum model (SCM). The authors argue, that the whole concept of humic substances and even the term humus itself should be abandoned in favour for focussing on SOM as a "continuum, spanning the full range from intact plant material to highly oxidized carbon" (Lehmann and Kleber 2015). The decomposer community continuously processes the material towards smaller molecular size. This increases the amount of polar and ionisable groups of the fragments and leads to enhanced solubility in water. The higher number of ionisable groups and the greater surface area, due to advanced degradation, increases also the opportunity for protection against further decomposition. The reason is a greater reactivity towards mineral surfaces and incorporation into aggregates (Lehmann and Kleber 2015).

Major carbon inputs into soils are plant litter and rhizodeposition (root debris and root exudates), which will be reworked by microorganisms. When the supply ceases or the environmental conditions become unfavourable, the microorganisms die and leave dissolved organic matter (DOM) and also cell envelope fragments behind. Beside the production of CO_2 during this process, the particular cell envelope fragments will be preserved and contribute to SOM, or serve as a substrate for other microorganisms and thus might be recycled several times. Each recycling-rotation will results in carbon loss as CO_2 and DOM, but there will always be parts of SOM, which will be preserved (Miltner et al. 2012; Kästner and Miltner 2018, p. 152).

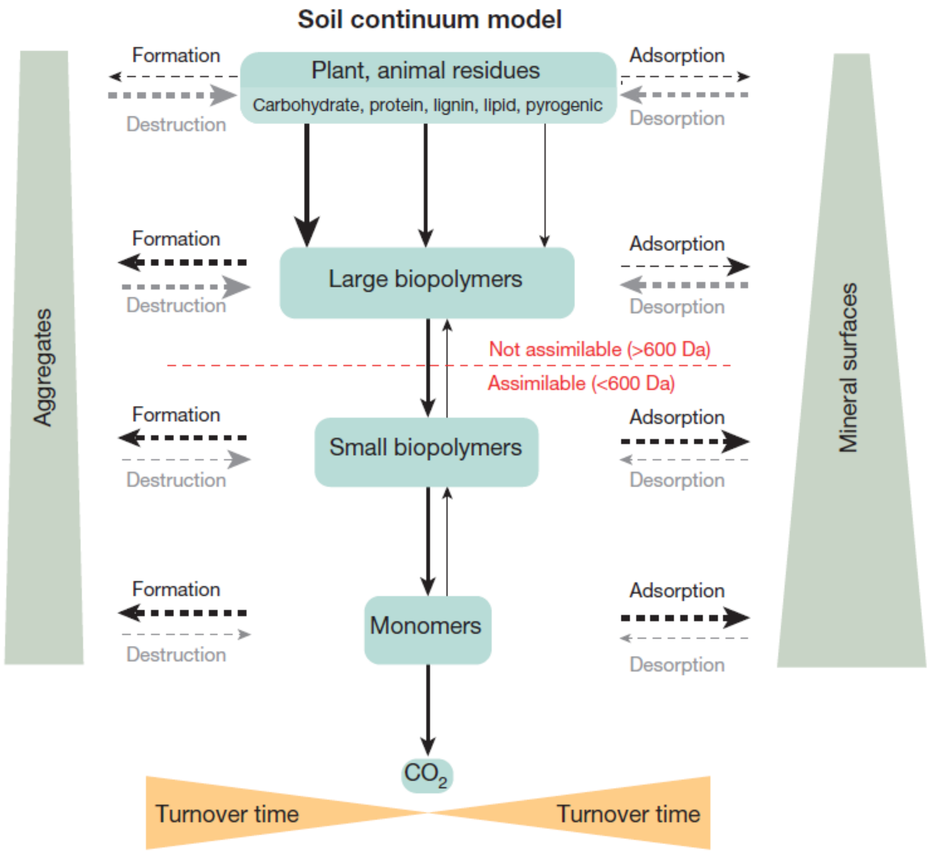

Figure 8: Soil Continuum Model (SCM): Organic fragments are continuously processed by the decomposer community. Simultaneously, greater oxidation of the organic materials increases solubility in water and the opportunity for protection against further degradation. Dashed arrows indicate mainly abiotic transfer, solid lines mainly biotic transfer; thicker lines denote quick transfer rates and larger boxes and ends of wedges indicate greater pool sizes; all differences are illustrative. Source: Lehmann and Kleber 2015.

The SCM offers new answers to many questions regarding properties of alkaline extracts, which have been answered rather by historical interpretations (humification concept) than by evidenced-based considerations. The dark colour of the extract, for example, derives not from (unverified) secondary synthesis to large molecules that appear black, but from the degradation of pigments. The greater aromaticity in the extracts compared to whole soil is explained by the traditional view as humification, which would create polyaromatic molecules. Protagonists of the SCM instead emphasize, that pyrogenic carbon (derived from fires) and microbial metabolites create these aromatic-rich alkaline extracts (Lehmann and Kleber 2015).

The new views regarding humic substances has also implications on forecasting effects of global warming concerning the SOM pool. Despite the efforts, which have been invested in researching possible effects of global warming on the carbon stock in soils over the last 30 years, the results of thousands of publications remain inconsistent and confusing (Wu et al. 2011). The range of the effect of increased temperatures can have strong positive effects, no noticeable effect or even a negative effect on decomposition in the long-term (Baveye 2015). The hypothesis of SOM as a stable (recalcitrant, refractory) product of secondary synthesis has been adopted widely and has been integrated in soil carbon models (e.g. RothC, CENTURY). These assumptions influences the ways how the effects of management and global warming are projected (Kleber and Johnson 2010, p. 119). The 'carbon-quality-temperature theory' suggests, for example, that SOM pools with slow turnover respond more sensitively to global warming than those with a fast turnover. This theory combines classical humification theory (decomposition creates complex, recalcitrant compounds) with the Arrhenius theory that chemical reactions are faster at higher temperatures (Lehmann and Kleber 2015). As the classic humification theory has been challenged by new insights, it seems problematic to derive results from models, which run with these theories.

Summing up, many results and interpretations of the traditional extraction method have been defied and replaced by new insights through the use of modern analytical methods. Nevertheless, these new conceptualizations are accomplished by heavy disputes and defends of the traditional explanation model (Nobili 2019; Olk et al. 2019). The most radical new concept regarding SOM is called soil continuum model and has been explained more in detail. However, Baveye and Wander (2019) argue, that this model corresponds closely with several similar considerations, even with the description of humic substances given in Waksman's (1936) published book on the topic. Already Waksman emphasized the important role of soil microorganisms, through their intimate connections between living (plants) and dead (humus) organic matter. A reason for this "agonizingly slow progress" (Baveye and Wander 2019) might be the extreme compartmentalization of research and education in soil science, which makes interdisciplinary efforts for understanding the dynamics of SOM very hard to launch (Baveye and Wander 2019).

2.2 Regenerative Agriculture

2.2.1 Definition

The term Regenerative Agriculture (RA) was firstly mentioned in a publication by Robert Rodale in 1983. Afterwards the Rodale Institute in Kutztown, Pennsylvania began using the term in the 1980s, but stopped utilization (at least in publications) shortly after adopting the term, until a paper was launched with the title: "Regenerative Organic Agriculture and Climate Change" in 2014 (Rodale 1983; Rodale Institute 2014). Today, the term RA is widespread, especially in Australia and USA, where already a certification scheme has been established (Regenerative Organic Certified 2018). However, an uniformly accepted definition is not available yet (Elevitch et al. 2018). The authors Soloviev and Landua (2016) even argue, that it is not possible or constructive to define Regenerative Agriculture, as the verb define derives from the Latin verb *definire*, which can be translated with bound, limit, end. The authors claim, this would be the opposite of the processes which are associated with RA, as they were referring to terms like building and providing or to “the capacity to bring into existence again”, as it was stated by Rhodes (2015). They further argue, that their living framework for understanding, practicing and expanding Regenerative Agriculture provides an even-more effective and holistic system of farming and culture than a simple definition (Soloviev and Landua 2016, p. 5). Nevertheless, there are still some definitions to find in other publications and both originally (Rodale 1983) and new publications (Anonymus 2017) could be condensed to following goals:

1. Soil: Increasing soil fertility and soil health. Increasing stable soil organic matter (humus) to sequester carbon
2. Water: Increase water percolation and retention
3. Biodiversity: Conserve and enhance biodiversity
4. Ecosystem health: Capacity for self-renewal and resiliency

(changed after Elevitch et al. 2018).

The main feature, which is often singled out in the definitions is the strong focus on the storage of carbon (increasing stable SOM) through the revoke of CO_2 from the atmosphere (carbon sequestration). RA has at its core the intention to improve soil health and/or to restore highly degraded soils, which symbiotically enhances water quality, vegetation and land productivity (Rhodes 2017).

To use “regenerative” as a term, the accurate description of a product must not only be 100% recycled and recyclable, but also improve the environmental conditions at all stages of its manufacture and usage. The improvement of conditions might include the creation of habitats (including building soil), water purification and the enhancement of nitrogen- and carbon-fixing processes in soil (Rhodes 2015).

2.2.2 Comparison of Regenerative Agriculture with other practices

In order to categorize and differentiate a new term, it can be helpful to compare it with other, already established ones. As it will be shown, exact boundaries are difficult, as RA has many goals, principles and features, which can also be found in other practices. Nevertheless, working out main differences could make things better understandable. For that reason, RA will be compared with practices used in Conservation Agriculture and Organic Agriculture. Some authors quote, that the term “regenerative” even goes beyond the principle of “sustainability” (e.g. (Rhodes 2017; Rodale Institute 2015; Soloviev and Landua 2016)). Sustainability is often said to the main goal for society (compare United Nations 2015) and therefore the terms regenerative and sustainable have also been compared.

2.2.2.1 Comparison with Conservation Agriculture

Regenerative Agriculture encompasses soil cultivation according to Conservation Agriculture (CA) principles. CA describes a system-based farming approach, which rose in the late 1990s (Rhodes 2017) and was practiced worldwide on 157 million ha in the year 2013. This area represents about 11% of the worldwide cropland (Kassam et al. 2015). The principles of CA include:

1. Continuous no tillage or minimal mechanical soil disturbance (e.g. no tillage, reduced tillage, strip tillage)
2. Permanent organic soil mulch cover (crop residues, cover crops)
3. Diversification of crop species, including a balanced mix of legume and non-legume crops

(changed after Kassam et al. 2015).

These principles would also fit for RA and thus can be find in data about practices (Anonymus 2017). Though with the exception, that one principle of RA is maximizing of photosynthesis on each field, which means to have always green plants growing, despite just mulch cover, as it was stated in point 2 in the above enumeration. Another difference is the fact, that methods of CA are usually associated with the use of herbicides and genetic modified organisms (at least in North and South America: e.g. Roundup Ready© Soybeans with a resistance against glyphosate) in order to counteract against weeds (Wilhelm 2010, p. 18), as a main function of tillage (elimination of competitor plants) is omitted (Estler and Knittel 1996). The use of synthetic fertilization (e.g. nitrogen and phosphor) and fungicides destroys the partnership between plants and mycorrhiza fungi, which is seen as an key component for soil health and carbon sequestration (Jones 2011; Rodale Institute 2014; Serle 2017).

2.2.2.2 Comparison with Organic Farming

RA typically uses techniques that are (or should be) used more generally in Organic Agriculture (OA), with the aim to preserve or built humus (e.g. minimum tillage, high variety of grown crops, cover crops and the integration of livestock within the system). At the same time, the application of synthetic fertilizer and pesticides is refrained.

Following these considerations, the Rodale Institute uses the term "regenerative *organic* agriculture" for practices of organic farming, which maximize carbon fixation, while minimizing the loss of carbon once it is stored in the soil. These farming practices restore and improve the soils natural ability to hold carbon. In a more broader view, regenerative organic farming can be seen as a holistic approach to agriculture, which "encourages continual on-farm innovation for environmental, social, economic and spiritual wellbeing" (Rodale Institute 2014).

The close relationship between RA and OA can also be observed by studying the Regenerative Organic Certification (ROC) Initiative, which was launched as a program in the USA to set standards beyond the organic certification scheme. ROC is based on the United States Department of Agriculture's National Organic Program (USDA Organic) and the goal is to promote holistic agriculture practices in the frame of one certification (Regenerative Organic Certified 2018). Advocates of the initiative stated, that standards of organic certification are not addressing a number of problems, like soil degradation, labour injustice and global warming. Whereas ROC includes guidelines for farming operations and adds criteria to build upon these standards in the areas of soil health and land management, animal welfare and farmer and worker fairness. These issues are consolidated in three specific modules, which include several important practices respectively (e.g. agroforestry, cover crops, rotational grazing, fair wages). Depending on how many practices have been established on the farm, the ROC offers a three-level certification scheme (Regenerative Organic Certified 2018).

Nevertheless, adopting conservation tillage practice as an integral part of RA to minimize soil disturbance and enhance soil health might be challenging for organic farms, as the use of herbicides for weed control and cover crops termination is prohibited (Rodale Institute 2014; Weil and Brady 2017, p. 1041) . Some authors remark the lack of scientific evidence, that no-till can be used effectively in organically managed agricultural systems. The scientific knowledge about no-till organic farming methods is only based on single cases and therefore fragmented. Especially the weed management problem is so far not sufficient solved (Gattinger et al. 2011).

In conclusion, it can be stated, that there might be a trade-off between widespread practice of tillage in organic agriculture and the claims of RA to minimize soil disturbance and enhance soil health (Serle 2017). The integration of principles of RA on organic farms might therefore be a balance act, which needs pioneers to localize critical points in agricultural practice (Montgomery 2018, p. 142). The aforesaid can be also be condensed to the statement, that regenerative food is all organic, but not all organic food is regenerative (Rhodes 2015; Brown 2018, p. 135).

2.2.2.3 Regenerative Agriculture and Sustainability

The most widely used definition of the term ‘sustainability’ goes back to the report “Our common future” by G. H. Brundtland and defines Sustainable Development as a development, “which meets the needs of the present without comprising the ability of future generations to meet their own needs” (Brundtland 1991). It has been emphasised, that such terms as ‘sustainable agriculture’ can be seen as a paradox, since nowadays agriculture is by its very nature unsustainable - as any human intervention means a manipulation apart from early hunter and fishermen - and our present form of industrial food production cannot be maintained in perpetuity (Rhodes 2015). Modern food production relies on inputs of finite fossil fuel energy and common agricultural practices expose the soil to erosion (bare soils and tillage). Even types of farming, which are referred to as “sustainable agriculture”, are dependent on fossil fuel utilization (at least fuel for farm machinery and transportation), while the reduction rate of soil degradation and erosion may be lower. As a multifarious subject, different intentions and practices are summarized with the underlying tenets of ‘sustainable agriculture’. The practices may be considered ‘organic’, ‘low input’, ‘biodynamic’, ‘integrated’ or ‘holisic’. The core of these approaches is a simulation of natural ecology processes, while reducing or abandon the use of artificial fertilizers or pesticides (Rhodes 2017).

All sustainable solutions would be unsustainable over the long run, if they are not also intrinsically regenerative. Strictly seen, the word sustainable means self-sustainable, but is often understood to merely mean ‘able to last’ or ‘the capacity to endure’. Sustainable systems maintain what already exists, but does not restore ecosystems, that have been lost (Rhodes 2017).

Regenerative Agriculture goes beyond simply ‘sustainable’, as it is taking advantage of natural tendencies of ecosystems to regenerate when they are disturbed (Rodale Institute 2015). This can be seen as the property of a system, which actually benefits from disorder and disturbances (Soloviev and Landua 2016, p. 10) and has been named *antifragility* (Taleb 2013, p. 27) . These tendencies, transferred into agroecosystems are seen as closed nutrient loops, greater diversity in the biological community, fewer annual and more perennial plants and greater reliance on internal, rather than external resources (Rodale Institute 2015). Robert Rodale, the founder of the Rodale Institute in USA formulated already three decades ago the hope, that the period of sustainability will be detached by the idea of regeneration, where not only food will be produced, but “regenerating, improving, reforming [the American land] to a higher level” should be realized (Rodale Institute 2015).

2.2.4 Overview about the agricultural measures

This chapter explains the agricultural measures, which are performed by practitioners in order to meet the implications of a Regenerative Agriculture, as it has been described above. As the author of this thesis has participated on a course of RA (Näser and Wenz 2016), the described measures refer to the conveyed course contents. These measures refer also to the questionnaires, which have been sent to practitioners of RA (see also Appendix 1).

Adopting RA requires a paradigm shift by farmers towards maximizing the utilization of the photosynthetic capacity of plants, maintaining actively growing roots to support soil microbes and address soil mineral and microbial balance (Serle 2017). According to Näser and Wenz (2016), there are five steps, which should be implemented in the agricultural system to fulfill the demands of a regenerative agriculture. These steps are:

1. Balance of nutrients
2. Keeping the soil always covered by green plants
3. Transfer the plant cover in a rotting process
4. Control of the rotting process
5. Plant vitalizing

(adopted from Näser and Wenz 2016)

It should be mentioned however, that RA is rather a continuous process than a fixed system and it is still evolving (Soloviev and Landua 2016, p. 13). Nevertheless, core insights of RA can be established on every farm, modified by particular demands of the respective farms.

1. Balancing of nutrients:

One of the international protagonists of RA pointed out, that over-emphasis of the small number of elements (notably nitrogen, phosphorus and potassium) which refer to the standard soil test methods would mask the myriad microbial interactions that take place in soils and which built soil health and enable carbon sequestration (Jones 2011). The aim of RA is therefore, to feed the soil and build soil health instead of having a narrow focus on the plants, which would just represent one part of the system. Thus, plant nutrition management in regenerative farming system lays the focus on the balance of macro- and micronutrients in the soil. Optimum mineral levels are based on the research of soil scientist William A. Albrecht (Serle 2017) and the continuation of his work by Neal Kinsey (Kinsey et al. 2014). Declining soil fertility, identified by a lack of organic matter, has therefore been described as an imbalance of major and trace elements. According to Albrecht and Kinsey, cations within the soil should be in a particular ratio for the maintenance of soil structure and adequate plant nutrition. The ideal ratio on the base saturation lays around 60-70 % Ca, 10-20 % Mg, 3-5 % K, 1 % Na, 10-15 % H^+ and 2-4 % other cations. Further ratios should also be observed, for example the ratio phosphorus to zinc (10:1) or the iron to manganese ratio (2:1) and the application of minerals to the soil aims to achieve the ideal ratios (Kinsey et al. 2014, p. 59). While achieving these ideal ratios in high cation exchange capacity is often not economic, practitioners of RA have developed foliar applications of minerals, which have been deficient in the plant (detected through leaf analysis), to be an alternative method to optimize plant health (Serle 2017).

2. Keeping the soil always covered by green plants

An important keystone for implementing RA (and often the entry in the system) is the avoidance of bare soils, because fallow land fails to accumulate biomass carbon, as it would do otherwise, when always kept green. In contrast to the aforesaid lead deep tillage with ploughs to the breakdown of soil aggregates and destruction of the natural living zones of soil biota (e.g. earthworm tunnels or habitats for aerobic and anaerobic microorganisms). The growth of mycorrhizal fungi, which are essential for long-term carbon sequestration due to their role in soil-aggregate formation, is debilitated (Rodale Institute 2015).

In a no-till system, seeds are deposited directly into untilled soil by opening a narrow slot trench or band to assure proper seed coverage without moving much soil (Derpsch et al. 2010). Despite the fact, that no-till would be the achievable goal, it is often necessary to move more soil on the way to this aim, as the soil has to be "ready" for this kind of practice (Dunst 2019, p. 168). Reduced or no-till however, should only be adapted in organic agriculture systems, as soil carbon gains under conventional no-till agriculture are countervailed by greater area-scaled N_2O emissions from nitrogen fertilization. Synthetic nitrogen fertilization increases also microbial respiration of CO_2 while phosphorus fertilization suppresses the growth of mycorrhiza fungi, which are important for soil carbon storage (Rodale Institute 2015).

For keeping the fields always green, cover crops, which provide temporary vegetation cover between two main crops and add carbon (and nitrogen via symbiosis) to the soil during growth, are widespread. Cover crops can extract plant available nutrients from the soil and conserve these nutrients for the next plants (Smith et al. 2008). Furthermore, while keeping the soil with a vegetation cover, an effective protection against wind and water erosion will be provided. Additional benefits of integrating cover crops are the reduction of weed pressure, improved soil structure and capture of atmospheric nitrogen in legume leys (Rodale Institute 2015). For the focus of humus building, cover crops provide with their plant and roots residues forerunners to soil organic matter (Smith et al. 2008).

Cover crops should always be a mixture of many plant species, as every species has its own "diversity footprint" because of root exudates in the rhizosphere. There are, for example, 25 plant species in a cover crop mixture, which is recommended for RA (Näser and Wenz 2016).

Beside cover crops, enhancing crop rotation can also lead to an evergreen cropping system without fallows. Especially the integration of seeded grass species as undersown (or catch) crops in crop rotations is seen as a prevailing method of increasing soil carbon. The main reasons therefore can be seen in the deep, bushy root systems of many perennials, which increases soil microbial biomass by ensuring available energy and root hosts for bacteria and fungi (West and Post 2002; Rodale Institute 2014).

3. Transfer the plant cover in a rotting process

A crucial point for the transfer of the green plant mass on the field into a rotting process in order to sow the main crop is the choice of the right machinery tool. As soil disturbance should be avoided (Brown 2018, p. 108) and tillage is abandoned (Montgomery 2018, p. 67), other instruments have been tried out and developed. In the above mentioned course of RA (Näser and Wenz 2016), a rotary tiller is recommended, as a very useful tool (among others) to kill green plants and cover the residues with soil (Dunst 2019, p. 109). The adjustment of the rotary tiller is important to get the favoured results and to avoid trouble with smeared horizons and fouling processes. After the treatment, the field should not be touched, until the rotting process is expired, which can take 5 to 14 days and depends on weather and temperature conditions (Näser and Wenz 2016; Weisshäuptl 2019).

To assert if the process has worked properly, there are some indicators. The structural form of the soil should be transformed into a crumbly structure, with rounded and irregular shaped aggregates. This indicates high levels of biological activity with simultaneous high organic matter contents. Other indicators are the smell of the soil and the appearance of the residues. The soil should smell like carrots or forest earth, for which soil microbes (especially actinomycetes) are responsible and the residues should mainly be gone and transformed into small pieces of fragile plant litter (Näser and Wenz 2016).

4. Control of the rotting process

When the green plant mass is killed via rotary tiller and transferred in a rotting process, there is a huge amount of sugary plant sap and therefore a great food supply for soil microorganisms, which can use it due to their high reproduction rate. The biomass doubling rates of bacteria can be in favorable conditions approximately every 20 minutes (Gisi 1997, p. 167).

It is recommended by the protagonists of RA to "steer" the rotting process of the plant residues especially when the conditions are unfavorable (cold and wet) (Näser and Wenz 2016; Weisshäuptl 2019). This steering process could be done by application of microbes, via spraying on the surface of the plants, which are supposed to be incorporated. Practitioners of RA have realized these claims often by using tractors with front tanks, equipped with a spraying appliance, while a rear mounted implement is used for killing the plant cover.

There are different spraying formulations (called generally ferments), which have been developed and are used in the practice of RA. A widespread group of beneficial microbes are commercially known as Effective Microbes (EM©). This formulation consists of five families of microbes (lactic acid bacteria, yeasts, actinomycetes, photosynthetic bacteria, fungi) and these microbes are meant to suppress soil-borne pathogens, accelerate decomposition of organic wastes and increase the availability of mineral nutrients to plants (Serle 2017). The organisms from the commercial available EM©-products can be replicated on-farm and the individual farm aspect can be integrated by adding plants, which grow on the farm (without soil and roots) during the replication process (Näser and Wenz 2016). Other farmers use sauerkraut juice or other lactic acid ferments for spraying.

5. Plant vitalizing

Only vital and healthy plants have the ability to maintain high amounts of root exudates rates and are therefore keystones for a productive plant-soil-microbes system (Brinton et al. 1996). Plant vitalization is therefore an important measure, which is performed by many practitioners of RA (Radelhof 2018a, 2018b) with the application of compost-tea. Compost-tea is a compost extract, which is applied as a foliar spray. There are different formulations to produce it, essential is the use of mature compost with high quality. Further common ingredients are brown sugar or molasses, humate, mycorrhiza, stone dust and salt. The ingredients are put together and brewed with water for 24-48 hours in a special machine (e.g. Vortex© - cyclone). The resulting compost-tea consists of microorganisms, which have been extracted from the compost and augmented. It can be seen as a catalyser for life-sustaining processes in the soil with benefits for the growing crops (Taurayi 2011, p. 102).

Compost tea should be applied (diluted 1:10 till 1:30, quantity needed: 10-30 (100) l / ha) in cases, when the plants are confronted with stressful situations (e.g. droughts, high disease or pest pressure) or when crucial points for yield production (e.g. tillering, stem elongation, coming into ear) are reached. Stress levels in plants can be identified by a refractometer, which measures the brix value of the plant sap. The results can be compared with reference values from tables for several plant species to different times of development.

Beside compost tea, also other suitable appliances are recommended to use in terms of enhancing plant resistance against stress. The most common for example is hay tea, for which hay of highest quality should be put for 1-2 hours in warm water and subsequently removed. During this time, especially the microbe Bacillus subtilis should be grown to a reasonable amount and will, according to Näser and Wenz (2016), increase plant resistance. Other suitable and recommended appliances for plant vitalizing in special cases are the biodynamic preparation "hornkiesel" (P501) or the above-mentioned ferments, which are suitable especially for cruciferous plants

2.3 Trading with CO_2-Certificates in agriculture

The European Union emissions trading system (EU ETS) was launched in 2005 as the first large greenhouse gas emissions trading scheme worldwide. It covers currently (October 2019) 45 % of the European GHG-emissions (Kempfert et al. 2019) and the price for a CO_2-certificate (permits a emission of one ton CO_2) lays currently around 20 € (status May 2020).

Figure 9: Development of the price [€] for CO_2-certificates. Source: https://ember-climate.org/carbon-price-viewer/

Some Sectors are excluded, e.g. heating and fuel use of private households, trade sector and agriculture (Böhringer and Lange 2012). The trading with "official" CO_2-Certificates is thus currently not implemented in the agricultural sector as a mitigation strategy. Looking outside Germany and EU, integrating agriculture into the trading of CO_2-emission trading is usually not the main focus of political efforts. An exception is New Zealand, where agriculture is responsible for almost half of the GHG-emissions of the country and where agriculture is part of the GHG-trading scheme (Wreford et al. 2010, p. 90–91)

In their analyses of possibilities regarding an introduction of GHG emission-trading within the agricultural sector, Lünenberger (2013) concluded, that an implementation would be highly demanding for monitoring and enforcement, due to the diffuse GHG-emission structure and the high number of (small) farms. This may lead to high transaction costs and the necessity of setting thresholds, which can be undergone by dividing the farm in smaller units. Other problems may be avoiding-reactions (e.g. business relocation) and thus stressing the transport sector. The authors advocate, that agriculture can be integrated in the trading-scheme, when the above-mentioned problems are solved and the actors prepared. The time after 2027 might therefore be a realistic time horizon (Lünenberger 2013, p. 30).

The idea of engaging agriculture on the EU ETS aims on reducing GHG emission from the agricultural sector. On the other hand, it seems also conceivable to engage agriculture on emission trading schemes in order to sequester carbon. This idea can be found in some articles, especially referring to the above (2.1.1.) mentioned 4p1000 initiative. Lal (2016) for example emphasizes, that paying a reward to farmers in order to sequester carbon would be a “challenging, but crucial step for implementing the 4p1000-initiative”. Mechanisms like government payments, tax credits or emissions trading within the private sector have been discussed (Marland et al. 2001). As there are already some initiatives, which focus on emission trading within the private sector by selling humus certificates, this particular case will be part of the following investigations.

2.3.1 Scope and experiences in Europe

Focussing on soil as a carbon sink, private initiatives have been established with the emphasis to pay farmers a reward for building up humus on their fields and enable companies or private persons to pay voluntary for their offset of GHG.

One of the first initiatives in Europe was the Ökoregion Kaindorf, which started in 2007 with a project to increase the amount of humus in soils. The pilot phase of the project took place on model plots, linked with cost accounting to determine the amount of money, which is needed to restore one ton of CO_2 in the soil. The calculated investment lay by 22 – 30 € and at the same time, when the project was launched, the initiators were looking for companies, which wanted to pay a price voluntary for their unavoidable CO_2-emissions (Dunst 2019, p. 126). The initiative started with 3 farmers on 3 ha and increased the number of participated farmers to ca. 250 with ca. 3,220 ha in whole Austria by November 2019. It is claimed, that ca. 7,400 t CO_2 have been sequestered due to humus building and thus ca. 220,000 € have been paid to the farmers (Forstner 2019).

Beside the pioneer work of Ökoregion Kaindorf in Austria, other providers of humus certificates have meanwhile established own initiatives. In Germany and Switzerland the company CarboCert started their business in 2016 and, according to their own information, more than 230 farmers with a processed area of more than 10,000 ha have attend so far (CarboCert 2019). Other initiatives (association “Boden Op” in the region Angeln (North-Germany), foundation “Lebensraum” in Rheinland-Pfalz) have launched their engagement in this matter in 2019 after the successful example of and with support from the Ökoregion Kaindorf, who also supports regional initiatives in Friesland and Slovenia. Beside local initiatives in certain regions (as described above), an interregional institution is actual (2019) in the course of formation to implement standards for the trading with humus-certificates in Germany (Forstner 2019).

2.3.2 Procedure and contractual relationship

The following description of the procedure to implement a trading system for humus-certificates refers exemplary to a system, which was established by Ökoregion Kaindorf. Other initiatives work with quite similar pattern, especially the prices for sequestering carbon (for farmers) and for compensate CO_2-emissions are the same.

The farmer, who wants to enhance the humus content of a field in order to trade humus-certificates closes a contract with the Ökoregion Kaindorf and has to pay for soil analysis (currently 390 € for each participating plot) for the determination of the actual humus content. A certified lab (in the case of Ökoregion Kaindorf: certified from the Austrian Agency for Health and Food Security – AGES) is assigned to take a number of GPS-located individual samples (25 samples on plots with maximal 5 ha, 0 - 25 cm depth), which are mixed together and tested for different parameters (C_{total}, N_{total}, $CaCO_3$, pH, P_{CAL}). The referring European Norms for sampling and analysing are EN ISO 9001:2000 and EN ISO/IEC 17025 respectively (Ökoregion Kaindorf 2019).

After 3-5 years, the farmer can apply for a following examination with the same process (and similar costs) as it has been described above. The sequestered tons of CO_2 are calculated on the basis of soil analysis (detection threshold: > 0.2 % humus building) and the farmer can sell humus-certificates to Ökoregion Kaindorf and is partly paid-off with a share of 30 € per ton sequestered CO_2. By receiving this redemption, the farmer commits to hold the humus content stable for at least five years. After this period, a control soil analysis is performed, which has also to be paid by the farmer. In the case of holding the humus content stable, the farmer earns the share of 30 € per ton CO_2, which has not been paid off in the first place. Otherwise, if the humus-content was depleted, the farmer has a repayment requirement for the lost proportion. In the case, that the humus content has been further enriched in relation to the second analysis, the farmer can apply for a repeated compensation and the humus content has to be stable (or increased) for another five years (Ökoregion Kaindorf 2019). In addition, the farmer has to document the performed measurements on the plot(s), which participate on the humus building project (e.g. information regarding fertilizer appliance, soil cultivation, use of pesticides, yields, grown crops).

The Ökoregion Kaindorf offers the humus-certificates to companies, which want to receive (and promote) the status "CO_2-neutral", for 45 € per ton CO_2 and uses the margin of 15 € per ton CO_2 for administration and improvements on the system (Dunst 2019, p. 138).

2.4 Marginal Abatement Cost Curves

Marginal Abatement Cost Curves (MACC) were first developed in the 1970s as a result of the oil price shocks and aimed at reducing crude oil consumption. Afterwards they were used on other items in environmental economics (e.g. abatement potential and costs of air pollution or for calculating water availability) and become very popular with policy makers in recent years (Bockel et al. 2012). Especially McKinsey & Company released a comprehensive report and analysed the global GHG abatement cost curves for different sectors, including agriculture (McKinsey & Company 2013).

MACC for GHG emissions represent the relationship between the cost-effectiveness of different abatement options and the total amount of GHG abated. This enables the comparison of the cost-effectiveness between different strategies of mitigation. While there is a wide range of technical solutions, it is not immediately apparent which options deliver the most economically efficient reductions in GHG within agriculture. Marginal Abatement Cost Curves (MACC) enables the comparison to the cost-effectiveness of mitigation options between different sectors and have thus become a useful tool for policy makers to prioritize mitigation options and derive information for costs and abatement potential for different measures (Bockel et al. 2012).

MACCs can be illustrated in different ways, most commonly as a histogram (Figure 10), but also curves can be found (Bockel et al. 2012). The histogram assesses the cost and reduction potential of each measure, which is represented by bars. The width of the bar represents the amount of abatement potential available from the action (in Mt CO_2eq) and the height of the bar represents the average unit cost of the action (cost per ton of CO_2eq) saved. The area (height x width) of the bar represents the total cost of the action, i.e. how much it would cost altogether for delivering all the CO_2 savings from the action.

Moving along the curve from left to right worsens the cost-effectiveness of low carbon options, because each ton of CO_2eq mitigated becomes more expensive. Some options will therefore reduce emissions and save money (under the horizontal line in Figure 10), whereas other options may reduce more emissions, but induce costs (above the horizontal line). The more measures are executed, the higher is the cumulative abatement potential (indicated by the horizontal line in Figure 10).

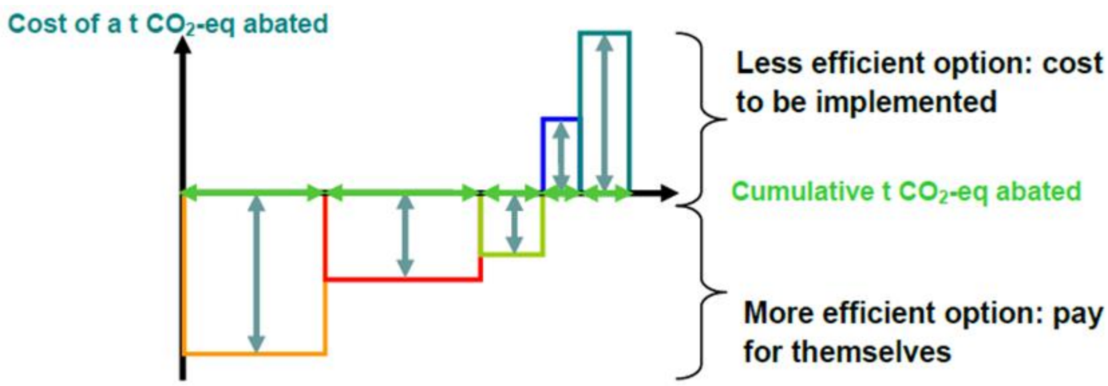

Figure 10: Marginal Abatement Cost Curve and the underlining information, changed after Bockel et al. (2012).

The abatement potential in the agricultural sector is, according to McKinsey & Company (2013), seen quite large and estimated by 4.6 Pg CO_2eq yr^{-1} (from which the main part - ca. 90 % is CO_2) worldwide by 2030. The potential can be partitioned in different categories with altogether eleven measures related to them (Figure 11). The categories are pastureland with a share of 29 % of the abatement potential, land restoration (34 %), cropland management (27 %) and livestock management (10 %). Improved grassland management is the single largest abatement lever, which consists of increased grazing intensity, increased productivity, irrigations of grassland and species production. Nearly three quarter of the abatement potential is related to CO_2 due to the avoidance of the release from soils or through carbon sequestration (McKinsey & Company 2013, p. 123).

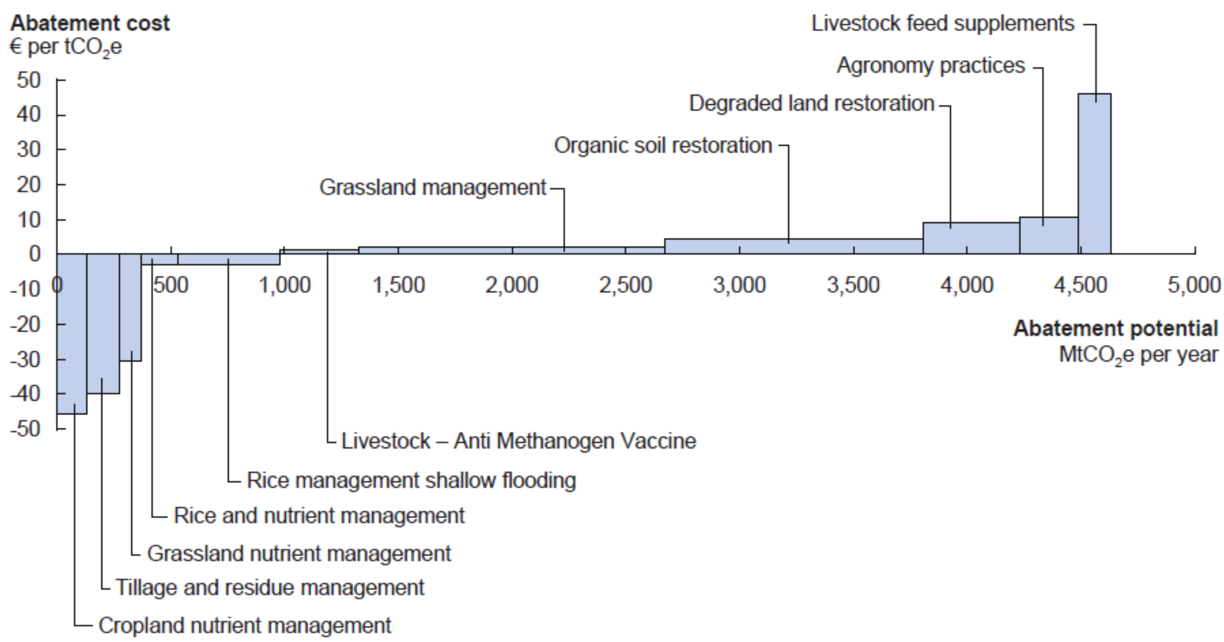

Figure 11: Global GHG abatement cost curve for the Agriculture sector (societal perspective), Source: McKinsey & Company (2013, p. 125)

Most measures of abatement would be very inexpensive as they are assumed to imply small changes in agricultural practices with no significant capital investments for adaption of measures. For example, cropland nutrient management is on average highly net-profit-positive, because less fertilizer is used and this would lead to lower input costs for crop production (and less fertilizer has to be produced). Soil restoration, on the other hand, requires significant implementation and opportunity costs, but these are balanced by a large CO_2eq abatement potential per hectare. However, exact costs for abatement are very hard to estimate, due to uncertainties regarding sequestration rates and transaction costs. The authors of the above mentioned large, comprehensive report of MACCs (McKinsey & Company 2013) investigated three categories of implementation costs:

- Measurement and monitoring (estimated at 0.2 € per tCO_2eq)
- Capacity and infrastructure building (0.7 € per tCO_2eq)
- Carbon-credit-monetization costs (0.2 € per tCO_2eq).

Adding up these categories leads to an estimation of 1.1 € implementation costs per ton CO_2 abated and a total implementation cost of about 3.8 billion € for the Agriculture sector in 2030. Other studies came to similar results, most measures would be highly cost effective (Lanigan et al. 2018).
The comparatively low costs are due to the fact, that the implementation of abatement levers might have beneficial effects. A higher amount of stable SOM (carbon sequestration) leads to a better water-holding capacity and less fertilizer might be needed for the same yields. However, uncertainty is high (by a factor of two or three times) in all cost estimates and further investigations necessary, given the magnitude of implementation costs and the high uncertainty level of current best estimates (McKinsey & Company2013, p. 128).

3. Material and methods

The purpose of this chapter is to outline research design and methodology, which has been undertaken to answer the research questions of this thesis. The results derived from:

- Literature research (section 3.1), which can be found mainly in part 2. State of the art
- Inquiry among practitioners of RA by the use of a prepared questionnaire (section 3.2)
- Own calculations to support the small database, as only four questionnaires could be evaluated and only two made particulars about measures and costs of RA (section 3.3)
- The calculation of GHG abatement costs used estimations for the carbon sequestration potential of different measures, which have been mainly published in peer-reviewed journals, and the above-mentioned sources for the cost of measures of RA.

3.1 Overview about the used literature

The present thesis can be divided in four main topics, as it deals with Regenerative Agriculture and its contribution to carbon sequestration, by referring to older and current knowledge of humus building. Another focus is the calculation of costs and potential for GHG abatement on farms, by using measures of RA. Thus, the four main topics are:

- SOM concepts
- Carbon Sequestration
- Regenerative Agriculture
- GHG abatement

Gathering knowledge for each topic was different, and this chapter gives an overview, which kind of literature was used on the respective topic to provide a reasonable database and reach the scientific goals of objectivity and reproducibility.

Regenerative Agriculture	There are just a few in peer-reviewed journals published studies, which deal with definitions, descriptions and measures of RA (Rhodes 2015, 2017; Elevitch et al. 2018; LaCanne and Lundgren 2018). Most knowledge is gathered by practitioners (Brown 2018; Brunner 2018; Massy 2018; Montgomery 2018) or consultants, who offer courses (Näser and Wenz 2016) or presentations (Jones 2017) regarding this matter. Thus, these sources have also been used, especially when referring to practical measures (2.2.4) of RA and conceptions on humus building (section 4.1). Information has also been found at various pages on the internet namely the page: www.regenerationinternational.org offers plenty information and the access to a worldwide network of research institutes, initiatives and practitioners.
Carbon sequestration	Carbon sequestration is an important topic in terms of mitigation effects on GHG and many papers deal with research on this item. Secondary literature provides

a more comprehensive background and especially the book *Carbon Sequestration in Agricultural Ecosystems* (Lorenz and Lal 2018) was useful to find primary literature in this matter.

The 4p1000 initiative (section 2.1.2) lead to an intensification in research (Rumpel et al. 2020) and in surveying and launching of regional studies regarding this matter (Minasny et al. 2017; Don et al. 2018; Wiesmeier et al. 2019). Whereas the research, evaluation and critics have often been published in peer-reviewed journals, regional studies have not always faced the scientific method of perception but provide practical insights and limitations, which have occurred in field studies.

SOM concepts

Regarding the overview and traditional view (sections 2.1, 2.1.4), textbooks (e.g. Waksman 1936; Stevenson 1994; Tan 2014; Weil and Brady 2017; Amelung et al. 2018) offer good surveys on the matter, which have been used to summarize the knowledge.

For the editing of the new insights (sections 2.1.5, 4.2) mainly primary literature have been used, which has been published in peer reviewed journals (e.g. Geoderma, Nature, Journal of Plant Nutrition and Soil Science, Journal of Environmental Quality).

GHG abatement cost curves

There are only a few studies, which deal with agriculture in this matter. The cited study of Bockel et al. (2012) was provided by the FAO and also a comprehensive report from McKinsey and Company (2013) was used to edit this topic. Another helpful study was provided by Teagasc and analysed the abatement potential of Irish Agriculture (Lanigan et al. 2018).

3.2 Structure of the questionnaire

The questionnaire was designed by the author, encompassed four pages and can be found in the appendix, translated into English (Appendix 1). It was drafted with Apache OpenOffice 3.4.1 Writer© 2012 and transferred into a portable document format (pdf). The participated farmers could open the document with Adobe Acrobat Reader© DC, fill in directly into the questionnaire and sent it back via email. It was also possible to print out the document and fill out by hand (which was done by one participant). The questionnaire contained questions about farm-structure, organic residue management and environmental conditions of the farm. The last part of the questionnaire was dealing with the issue of Regenerative Agriculture and raised also questions about costs of specific measures of RA.

3.3 Calculating basis of the Greenhouse Gas (GHG) Abatement Costs

The calculation of GHG abatement costs in the result part (4.3.1) was done by the following steps:

1. **Evaluations of GHG abatement potentials of different agricultural measures by consulting literature regarding this matter:**

   For the evaluation of the GHG abatement from the relevant RA measures, only one questionnaire provided information about the humus building potential. Thus, other sources had to be consulted to have a solid basis for the calculation. Many measures, which are used by practitioners of RA, have already been evaluated due to estimate the carbon sequestration potential within the agricultural sector. The use of the methods by practitioners of RA might differ in details (e.g. use of special machinery like the rotary tiller and application of microbial inoculates to "steer" the rotting process) but tendencies can probably be derived. The assumptions of sequestration potential have been adopted from studies and reviews, as indicated in the result part.

   Beside the peer-reviewed sources, provided by scientific evidence, it may also be possible (and interesting in terms of scientific progress), that data from alternative projects as the Ökoregion Kaindorf with eleven years of experience on humus building or results from practitioners in Australia and USA offers valuable information. Thus, carbon sequestration rates of these projects have also been integrated into the result part of this thesis for comparing issues. However, it has to be kept in mind, that there is no scientific evaluation of these projects available so far.

2. **Allocation of the abatement potential to costs of conducted measures of RA and calculation of the GHG abatement costs by dividing the costs of the referring measure by the abatement potential:**

   For classifying the results of the questionnaire concerning costs of measures of RA, these were compared with an own calculation. This was necessary as only two practitioners furnished particulars of implementation measures of RA and these predications varied considerably. For the calculation of the costs, different sources have been consulted:

   - The calculation of the costs for the soil test methods referring to Kinsey based on a price list from a commercial agency, which can be found in the Appendix 2.
   - The calculation of the costs for transferring the plant cover into a rotting process based on evaluations of the Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL), which has published comprehensive knowledge concerning machine costs and working times for various methods of field work (Bachinger 2015). The internet application "fieldwork calculator": https://daten.ktbl.de/feldarbeit/entry.html; Feldarbeitsrechner in German) was used to evaluate the working time for different measures of RA. However,

as the recommended tool (rotary tiller) for the rotting process is used in a specific configuration (high rotation with moderate force due to the shallow working depth), the results have been adjusted.

- The calculations of the costs for the application of microbes in order to “steer” the rotting process and for plant vitalizing are based on own calculations, as no profound estimation could be found. This calculation can be found in the Appendix 3.
- The calculation of the costs for an implementation of cover crops and undersown crops based on different offerings (can be found in the Appendix 4 & 5 in German) for diverse plant mixtures, which are recommended by consultants of RA. The costs for machinery and working time based on the above-mentioned knowledge of the KTBL.
- A calculation of the costs for fertilization due to the recommendations of the Kinsey soil testing methods, costs for the use of organic amendments (charcoal, rock flour) and the application of compost did not seem purposeful, as these operations are quite farm specific. However, it should be noted, that many practitioners of RA make use of a variety of fertilization and soil improving measures and claim, these are very important (Radelhof 2018a, 2018b). Therefore, an estimate based on the average mean from the questionnaires was presumed.

3. Visualization of GHG abatement costs by creating Marginal Abatement Cost Curves

4. Results

The result part is divided into three sections. Section 4.1 deals with the comparison of insights gained by practitioners and consultants of RA regarding humus building with present theories concerning humus formation. Section 4.2 shows the evaluations of the questionnaires and own calculations regarding the costs of specific measures of RA. The third section of the result part refers to the calculation of the GHG abatement costs and compares the potential returns by selling humus certificates with the costs of humus building by using methods of RA.

4.1 Humus building potential of Regenerative Agriculture

The aim of this chapter is to provide information about the conception of building SOM by protagonists of RA and the integration of scientific theories into this framework. Nevertheless, as it has been shown in chapter 2.2, RA is mere a conglomerate of many different farming methods (e.g. Conservation and Organic Agriculture, together with application of microbes and a strong focus on humus building) as an autonomous approach on farming. Thus, many recommended measures of RA are not new and have also be formulated recently (Gattinger et al. 2012; Gattinger et al. 2019) and in earlier times, especially by pioneers of agricultural bacteriology (Hartmann et al. 2008) and organic agriculture (Howard 1979; Fukuoka 1994; Rusch 2014). However, the success of some practitioners (Brown 2018; Massy 2018, p. 166–197; Montgomery 2018, p. 229–239) and the change in the scientific background (Baveye and Wander 2019) made it possible, that RA is broadly noticed within the farming community (Steinert 2016; Radelhof 2018a, 2018b; Steinert 2018), especially in USA (Regenerative Organic Certified 2018) and Australia (Serle 2017).

Covering the soil always with green plants is a major demand of RA, as this practice ensures, that carbon inputs by plants via rhizodeposition is constantly supporting the microbial community in the soil, which has been formulated as the "Liquid Carbon Pathway" (Jones 2013). Already establishing undersown crops (e.g. 90% English ryegrass (*Lolium perenne)* with 10% white clover (*Trifolium repens*)) and no further methods after harvesting the cash crop (in this case blue lupin (*Lupinus angustifolius*) with oat (*Avena sativa*)) lead to visible changes in the soil, as Figure 12 indicates.

Figure 12: Comparison between the soil after conventional treatment (grubbing after harvesting blue lupin and oat) on the left-hand side and another plot on the same field (right side), where an undersown crop was established and had almost nine weeks for growing. Harvesting cash crop: 2016-08-17, picture taken: 2016-10-16 by the author.

Carbon derived by roots (provided in this example from an undersown crop during late summer) is absorbed much more efficiently than above-ground inputs of litter (e.g. leaves and needles or straw - or HMW (high molecular weight) in Figure 13). The reason is the provision of a more suitable C/N ratio for incorporation in microorganisms (Kästner and Miltner 2018, p. 144). This phenomenon is indicated by LMW (low molecular weight) in Figure 13. The carbon atoms, derived from root exudates, cycle therefore through soil microorganisms ("microbial pump"), before being stabilised as necromass with higher persistency (cell envelope fragments) in SOM (Miltner et al. 2012; Schurig et al. 2013) or being lost as dissolved organic carbon (DOC) to deeper soil horizons or groundwater.

Also, the insights derived from the soil continuum model (section 2.1.4.) suggests, that microbial recycling could be an important process and responsible for C-stabilization in soils (Lehmann and Kleber 2015). Recent studies indicate, that soil microbiological indicators can explain 82 % of the variation in soil carbon cycling (Creamer et al. 2014) or bacterial and fungal diversity explains a significant share of carbon mineralization (Tardy et al. 2015; Bender et al. 2016). Thus, these new insights suggest, that the dominant pathway for soil carbon storage proceeds via cycling through microbial biomass and is therefore highly dependent on the soil microbiome.

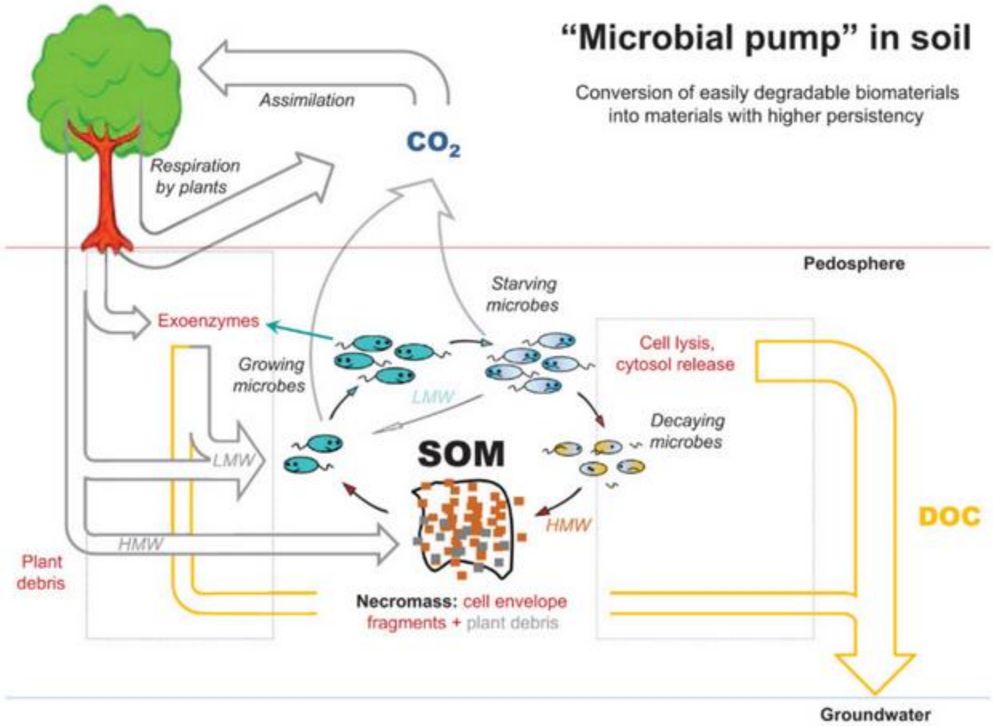

Figure 13: Contribution of microbes to carbon sequestration. HMW, high molecular weight compounds; LMW, low molecular weight compounds; DOC, dissolved organic carbon; explanation in the text. Source: Kästner and Miltner (2018), p. 135

As the soil microbiome comprise such high diversity and such high level of functionally redundant organisms (Ottow 2011, p. 82–84), it has long been thought, that changes in microbial community composition would not translate into changes in functioning (Strickland et al. 2009). However, these assumption have been challenged by recent studies, which have shown that community compositions have effects on carbon mineralization (Strickland et al. 2009) or denitrification (Philippot et al. 2013). The application of microbes in order to steer the rotting process (section 2.2.4) as an important measure of RA might therefore be an important tool for enabling SOM formation.

An enhanced biodiversity on the field (and thus in the soil as roots) enables a multifarious microbe collective (Eisenhauer et al. 2017; Brown 2018, p. 115), which is therefore more likely to fulfil the diverse ecosystem functions in the soil. This would lead in the end to a highly effective triangle "soil structure - microbiome - plant roots" with plant-growth-promoting (increasing stress tolerance, nutrient availability, mycorrhiza effects) results in line with stable SOM formation and thus carbon storage (Kästner and Miltner 2018, p. 131). Field experiments (Lange et al. 2015; Liang et al. 2016) and observations of practitioners of RA (Brown 2018, p. 139; Montgomery 2017, p. 101; Jones 2011) have shown that an increasing diversity of plant communities results in higher levels of carbon inputs in the soil and more favorable microclimatic conditions. The denser vegetation in more diverse plant populations reduces evaporation from topsoil and results also in higher microbial activity and growth (Kästner and Miltner 2018, p. 129).

The aforesaid can thus be concluded, that especially the maintaining of green plant cover (undersown and cover crops) and the enhancing of plant diversity (diverse cover crops mixtures) seems to be important keys in terms of RA for increasing carbon sequestration.

Another important component for humus building seems to be the avoidance of soil disturbance, as it has been shown, that intensive soil tillage and practices of conventional agricultural (like application of pesticides), have adverse effects on several groups of soil organism (Verbruggen and Toby Kiers 2010) and the overall biomass (Mäder et al. 2002). The database of Ökoregion Kaindorf also indicates, that humus building is negatively correlated with the number of measures for soil cultivation (Dunst 2019, p. 161). As it has been described above (section 2.2.4), the transfer of plant biomass into a rotting process should be done by one or two shallow work steps with a rotary tiller or other machinery, which ensures an intensive, but also shallow mixing of plant biomass with soil material. This can be seen as a very important step to speed up the rotting process, while keeping the structure and architecture of the killed plant roots untouched and convert the fresh plant assimilates into the SOM fraction.

However, it should be taken into account, that stabilized SOM has a near constant C:N:P:S ratio (10,000:833:200:143, compare with section 2.1) and is more nutrient rich per unit of C than fresh plant material inputs or the light (labile) fraction of SOM (Kirkby et al. 2011; Kirkby et al. 2014). Thus, for enhancing the humus content from 2 % to 5 % the availability of reasonable amounts of nitrogen, phosphorus and sulphur is necessary. To illustrate this, the following table shows the necessary inputs of minerals for 1 ha (assumptions in line with the results of the first soil status report in Germany (Jacobs et al. 2018) and Kirkby et al. 2014, 2011)):

Table 1: Necessary inputs of minerals in order to enhance humus content of soils

Assumptions: Dry bulk density: 1.4 g cm^3, depth of A-horizon: 0.3 m = **4,200 t ha^{-1}** soil in A-horizon layer, C: N:P:S ratio 10,000:833:200:143; calculation base: 1 ha					
Humus (stabilized SOM) content per ha		Carbon (50 % of SOM, see also section 2.1)	Nitrogen (8.33 % of C; C/N ratio 12)	Phosphorus (2 % of C)	Sulfur (1.43 % of C)
2 %	84 t	42 t	3,500 kg	840 kg	600 kg
3 %	126 t	63 t	5,250 kg	1,260 kg	900 kg
4 %	168 t	84 t	7,000 kg	1,680 kg	1,200 kg
5 %	210 t	105 t	8,750 kg	2,100 kg	1,500 kg

Thus, for enhancing the humus content from 2 % to 5 % the amounts of 5,250 kg N, 1,260 kg P and 900 kg S per ha would be needed for humus formation. Taking further into account, that applied nutrients would only be incorporated into the humus pool to a certain percentage (Hüttl et al. 2008, p. 148; Scheller 2013, p. 146) the real demand may be much higher.

Excess of carbon supply with simultaneous nitrogen (and other nutrients) limitation leads therefore finally to carbon losses due to changes in microbial metabolism. When sufficient nitrogen is supplied, lower mineralization and higher activity with carbon and nitrogen storage can be observed. Major driver for SOM formation is therefore the carbon use efficiency (CUE). This indicator refers to the ratio between biomass formed to substrate consumed. Highest CUE in terrestrial ecosystems was found with C:N ratios around 10:1, which is in the range of microbial biomass itself and thus favours microbial anabolism (Kästner and Miltner 2018, p. 143).

The necessary supply of nitrogen and other nutrients to enable humus building led to the application of high amounts of composts (e.g. 240 m^3 ha^{-1} in two years with ca. 1,900 kg total-N; see also Dunst 2019, p. 136) at the humus building project in Kaindorf. The aim of this practice was the attainment of at least five percent humus, as this threshold was seen necessary to stabilize the SOM content, indicated by a C:N ratio of 9-10 (Dunst 2019, p. 163). Nevertheless, after 11 years of experience and the evaluation of many datasets, derived from measurements and farmers, the enrichment of some soils especially with N, due to proven humus building could not be explained satisfactory (Dunst 2019, p. 210). The same experience was reported by Jones (2011), where a humus enrichment project ('Winona') was evaluated. In this project 44.7 t C per ha have been sequestered in ten years, what increased the total N-Pool by 48 % (>2,000 kg ha^{-1}). Thus, the potential of N-fixation by soil microbiology might be underestimated (Dunst 2019, p. 59; Jones 2011). Given the fact, that the main share of soil microbes (≈ 98.5 %) are not identified yet (Stein and Nicol 2011) and thus many microbial driven soil processes might not be identified, this possibility should be taken into account.

4.2 Evaluation of the questionnaires and own calculations about costs of measures of RA

The questionnaire has been sent via email in June 2019 with a short text about the research project and a document with the expected structure of the master thesis to twelve farmers, who use measures of Regenerative Agriculture. In addition, emails have been sent to one of the adviser-team of RA in Germany (www.gruene-bruecke.de) and to companies, which market humus-certificates (CarboCert and Ökoregion Kaindorf) with the request for transfer the questionnaire to farmers, who have implement methods of RA and participate on the trade of humus-certificates. Furthermore, while attending on an agricultural symposium during a conference (EM-Days) in August 2019, farmers have been asked directly, if they already use measures of RA and if they would like to fill out a questionnaire respective their experience. In the end, four questionnaires have been sent back, two of them with particulars about costs of the used measures.

The size of the farms varies between 215 ha and 35 ha, with a share of grassland between 7 and 17 %. Two of the farms are certified organic and encompassing five to eight course crop rotations. The farmers used cover crops (between 30 – 78 %) and undersown crops (10 – 90 %) on cropland. Two of the farms were keeping cattle (0.35 and 0.16 GV/ha, both with solid dung as farmyard manure and no manure bought in addition). One farmer kept chicken for egg-production (0.1 GV/ha) and uses 100 t grass, which grew on landscape conservation areas, for a fermentation process called “bokashi”. One farmer runs a biogas plant with 750 kW installed power and buys 7,000 t cattle liquid manure and 3,000 maize in addition, but uses only 50 % of the digested residues as fertilizer.

Measures of RA have been used between four and eight years and three farms are participating on trading with CO_2-certificates (CarboCert and Ökoregion Kaindorf). One farm manager could give information, how the humus content changed over five years (from 2.8 % to 5.4 % => + 2.6 %). Three farm managers specified the measures of RA, which were used on the farm and two of them made predications about costs of these measures. As these predications varied considerably, own calculations have been made in order to classify the results and to have subsequently a better basis for the calculation of the GHG abatement cost. Table 2 shows the estimated costs of RA measures, provided by two questionnaires (Q1 and Q2), the calculation of the costs by the author and the arithmetic mean between the costs of Q1, Q2 and the own calculation.

Table 2: Overview about measures and their costs of RA given in questionnaires and own calculations

Measure	Q1 - Cost per ha [€]	Q2 - Cost per ha [€]	Own Calculation Cost per ha [€]	Mean [€]
(1) Kinsey Soil Analysis	2	10	20	10
(2) Fertilization, derived from Kinsey recommendations	80	-	Very farm-individual	80
(3) Transfer into a rotting process	15 (disc harrow)	150 (rotary tiller, usually 2-3 operations)	30 (pro working operation with a rotary tiller)	65
(4) Use of ferments	15	120	90	75
(5) Use of compost tea	10	80	20	40
(6) Use of organic amendments	30	150	Depends on the used amendments	90
(7) Undersown Crops	20	150	110	90
(8) Cover Crops	75	80	125 (350, when two cover crops in one year are grown – special mixtures are used in this case)	90
(9) Use of ‘Bokashi’ (silage like fermentation process) 10-20 m^3 ha^{-1}	-	150	Farm specific treatment	
SUM	247	890	395	540

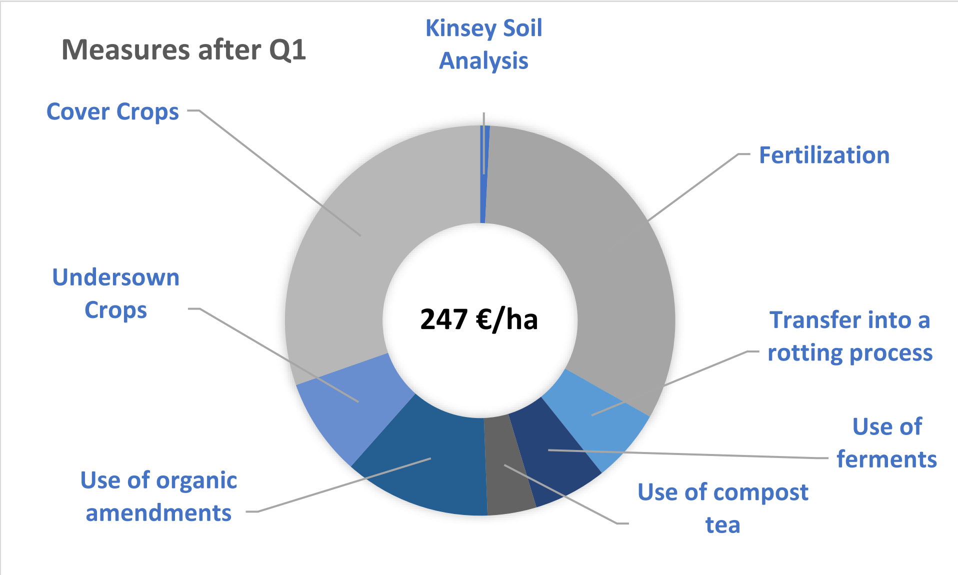

Figure 14: Visualization of RA measures provided by Q1

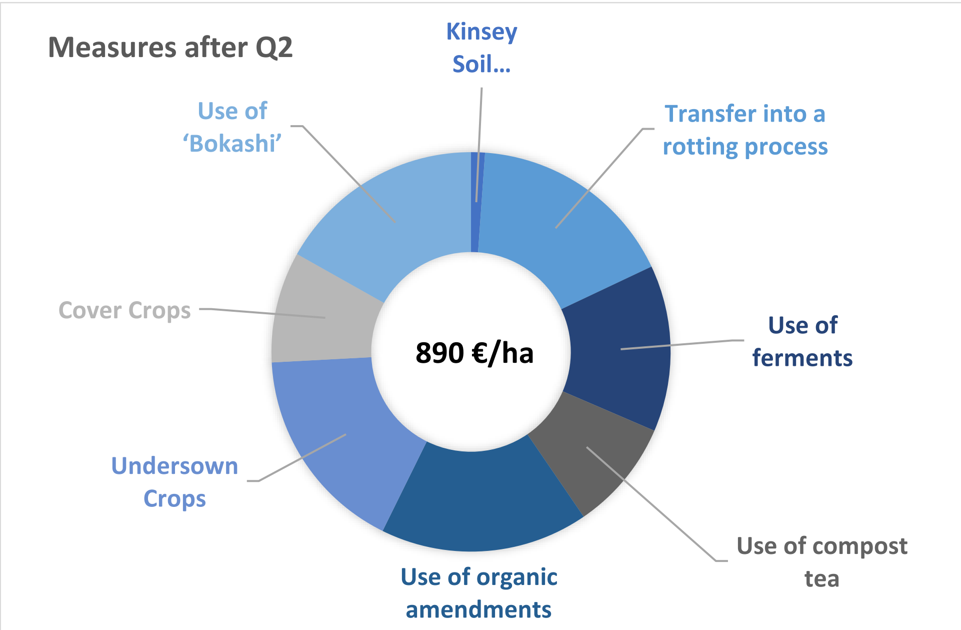

Figure 15: Visualization of RA measures provided by Q2

However, it has to be considered, that the conducted measures create not always additional cost. For example, instead of ploughing, other methods (rotary tiller, disc harrow) are used, which may be less cost extensive. Another example is the use of cover crops, which might be grown anyway for other reasons (*Greening* measure for subsidies, N-fixation). Also, the use of measures of RA could lead to cost savings, as one participant provides the information, that the expense for pesticides could be reduced by 100 € ha^{-1}. Other benefits are due to humus building, which leads to higher water holding capacity, as it was reported by two questionnaires. The aforesaid made it thus necessary to reduce the above calculated sum by the information given in the questionnaires. For the own calculation, it was assumed, that all measures of RA are additional to conventional production. Only the transfer into a rotting process was compared with the mean (52.5 € ha^{-1}) between primary soil preparation by ploughing (65 € ha^{-1}) and the double use of cultivators (40 € ha^{-1}), as direct seeding methods are usually not common agricultural practices in Central Europe.

Table 3: Reduction of the costs calculated in Table 2 due to cost savings compared to conventional treatment

	Q1 - Cost per ha [€]	Q2 - Cost per ha [€]	Own Calculation Cost per ha [€]	Mean [€]
SUM	247	890	355	530
Reduction	175	160	52.5	
SUM	72	730	302.5	368

Table 3 shows, that the cost calculations of the two questionnaires offer a wide range. The own calculation lays in between.

4.3 GHG Abatement Costs and efficiency of humus certificates

4.3.1 Calculation of the GHG Abatement Costs

For the calculation of the GHG Abatement Costs, it was necessary to made some assumptions, as the measures of RA have not yet been researched explicitly for their carbon sequestration potential. However, as it has been pointed out before (section 2.2), many measures of RA can be found in other production methods (e.g. OA, CA) and thus can be found in different sources regarding this matter. Thus, it was possible to allocate some measures to abatement potentials, which have been described in the literature (Table 4).

As the ranges of some estimations in the following table indicate, there are often high levels of uncertainty, which made it difficult to compare studies, or even the results within one study. Nevertheless, many investigations showed, that it is possible to sequester carbon in the soil.

Protagonists of RA state, that "RA is a holistic system approach to appropriate farming in context", thus the "conducted measures are not intended to be judged or implemented in isolation" (Rhodes 2017). Therefore, the whole cost performance of RA, as it has been calculated in the previous section, is compared to studies, where field-trails showed the supposed potential of RA. One questionnaire provided information about the change of the humus content within five years due to the measures of RA. This made it possible to assign the reported costs to the measured GHG abatement. It should be considered, however, that only one database is insufficient for generalization.

The following Table 4 illustrates the abatement potential of specific agricultural measures. Different units (GHG, SOC, CO_2) were used in the consultant publications. As an important regulation of UNFCCC and IPCC all GHG-sources are expressed as CO_2eq (see also section 2.1.1) by using specific conversion factors for the global warming potential of these gases for 100 years (Houghton 1998, p. 21–22) The main GHGs, which occur in the agricultural sector beneath CO_2, possess therefore the conversion factors 21 for CH_4 and 210 for N_2O. The units SOC and CO_2 on the other hand can be converted into each other by the calculation factor 3.67 (0.27), which is simple a conversion by using the molecular weight of the particular atoms: $\frac{\text{molecular weight CO2}}{molecular\ weight\ C}$ $\frac{12+16*2}{12}$ = ***3,67***

This means, that one ton of SOC correspondents to 3,67 tons CO_2.

Table 4: GHG abatement potential of different agricultural measures

Measure	Abatement Potential ($tCO_2eq\ ha^{-1}\ yr^{-1}$)	Reference
Nutrient Management (e.g. Kinsey-Fertilization)	**0.62** (0.02 – 1.42)	Smith et al. 2008
Agronomy (e.g. no fallow land, crop rotation)	**0.98** (0.51 – 1.45) SOC 0.16 (0.11 – 0.21) equal to CO_2 **0.59** (0.40 – 0.77)	Smith et al. 2008 Wiesmeier et al. 2017
Adoption of No-till methods	**0.53** (-0.04 – 1.12) SOC 0.35 (0.3 – 0.4) is equal to: CO_2 **1.29** (1.10 – 1.47) No significant effect	Smith et al. 2008 Powlson et al. 2014 Dimassi et al. 2014
Application manure/biosolids	**2.79** (-0.79 – 7.50)	Smith et al. 2008
Cover Crops	SOC 0.32 (0.26 – 0.40) is equal to: CO_2 **1.17** (0.88 – 1.47)	Poeplau and Don 2015
Fertilization with farmyard manure (5-10 t $ha^{-1}yr^{-1}$)	SOC 0.16 is equal to CO_2 **0.59**	Don et al. 2018
Regenerative Organic Agriculture (field trail in USA)	SOC 2.36 is equal to CO_2 **8.66**	Rodale Institute 2014
Conversion to Organic Farming	SOC 0.27 (-0.10 – 0.64) is equal to CO_2 **0.99** (-0.37 – 2.35)	Gattinger et al. 2012
Fully integrated approach of Conservation Agriculture	SOC 0.55 (-0.24 – 0.79) is equal to CO_2 **2.02** (-1.14 – 2.90)	Srinivasarao et al. 2015
'Winona' data summary	CO_2 **4.47**	Jones 2011, (appendix 8)
Regenerative Agriculture after questionnaire 2 (humus content raised from 2.8 % to 5.4 % in five years)	CO_2 71.7 in five years = **14.3** in one year	Questionnaire 2, measurement in the course of humus building project at Ökoregion Kaindorf

Toensmeier (2016) has found similar results in his comprehensive description of various farming methods to sequester Carbon as the following figure indicate. The estimations in the line 'regenerative organic' refers to research of the Rodale Institute, which is also shown in table 4.

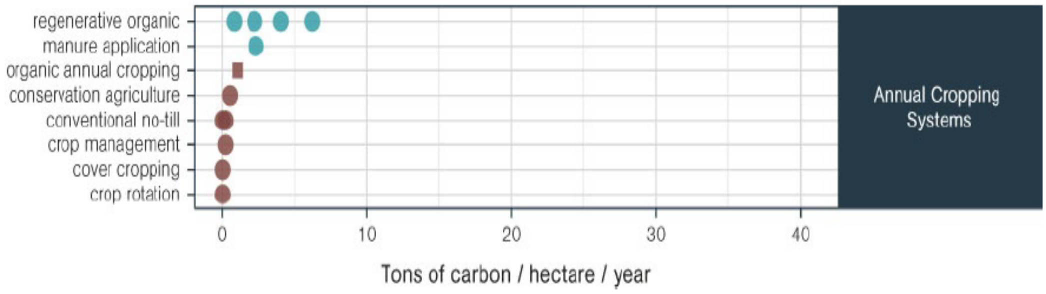

Figure 16: Sequestration potential of different cropping systems. Blue indicates results from a single study, red indicates scientific reviews. Circles represent single points of data; rectangles represent ranges. Source: Toensmeier (2016)

The next step for the calculation of the abatement potential of different measures was the allocation of the potential to the respective costs. An overview provides table 5 and for comparing the measures, GHG abatement costs for the particular measures have been calculated by dividing the cost of the measure by the abatement potential. When two or more data was given (referring to different studies), the arithmetic mean was calculated. It seemed also appropriate to show the range of the results, when always taking the lowest and highest number of the potential, which was also provided by the studies, mentioned in Table 4.

Table 5: Allocation of the abatement potential to costs of conducted measures of RA

Measure	Abatement Potential ($tCO_2eq\ ha^{-1}\ yr^{-1}$)	Referring measure (Table 2)	Costs of measures (€)	GHG abatement costs (€ t^{-1} CO_2)
Nutrient Management (e.g. Kinsey-Fertilization)	**0.62** (0.02 – 1.42)	1, 2	90	**145** (4,500 – 63.4)
Agronomy (e.g. no fallow land, crop rotation)	**0.98** (0.51 – 1.45) **0.59** (0.40 – 0.77)	7, 8	180	**229** (450 – 124)
Adoption of No-till methods	**0.53** (-0.04 – 1.12) **1.29** (1.10 – 1.47)	3, 4	140	**153** (no value – 95.2)
Cover Crops	**1.17** (0.88 – 1.47)	8	90	**76.9** (102 – 61.2)
Regenerative Organic Agriculture (Field trail in USA)	**8.66**	1, 2, 3, 4, 7, 8	403	**46.5**
Conversion to Organic Farming	**0.99** (-0.37 – 2.35)	6, 8	180	**181.8** (no value – 76.6)
Fully integrated approach of CA	**2.02** (-1.14 – 2.90)	3, 8	155	**76.7** (no value – 53.4)
RA after questionnaire 2	**14.3**	1, 3, 4, 5, 6, 7, 8, 9	730	**51**

The allocation of the abatement potential to the cost of each measure (and to full approaches of some management practices as described in the literature) in table 5 shows, that most CO_2eq per ha and year has been captured by RA after questionnaire two. However, also the costs for conducting these measures have been the highest. The GHG abatement costs shows also, which should be the minimum price (cover the costs) for CO_2-certificates referring to the respective measure.

For a single measure the cultivation of cover crops shows the highest benefits in terms of CO_2-abatement (1.17 t CO_2eq per ha and year) with lowest costs (76.9 € t^{-1} CO_2). As it has been emphasized in section 2.4 marginal abatement cost curves (MACC) can be used to illustrate the results given in the above table. The following two figures show the abatement potential of single measures (Figure 17) and the potential of full integrated approaches of certain management practices (Figure 18).

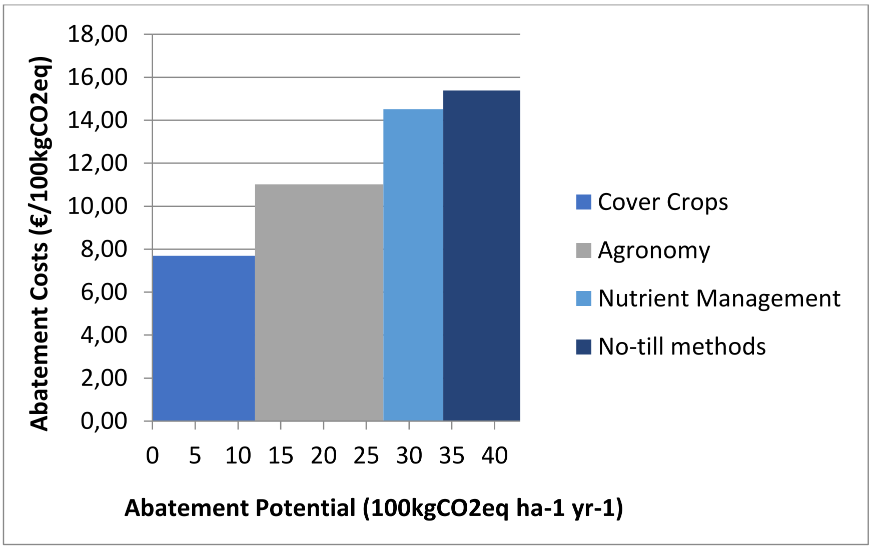

Figure 17: MAAC for single measures, referring to Table 5. It should be noticed, that for presentation reasons CO_2eq mass units are 100 kg.

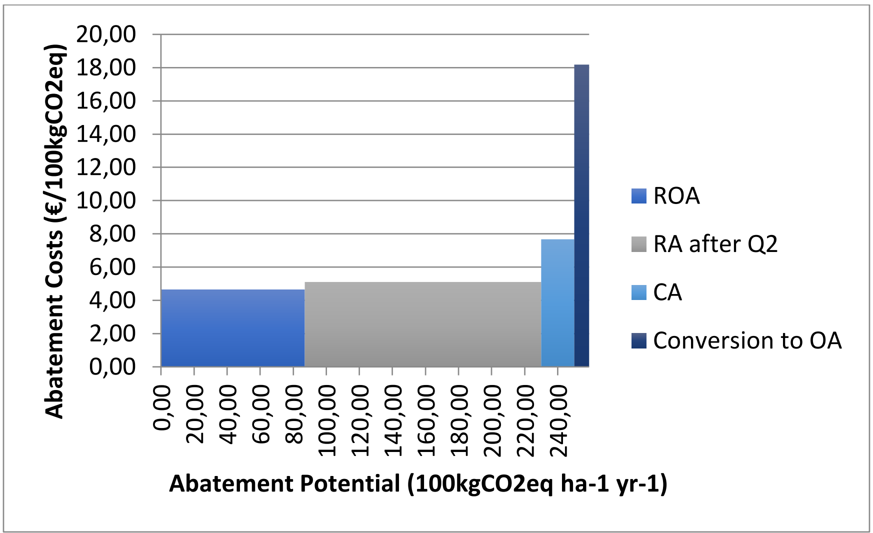

Figure 18: MAAC for full approaches of certain management practices, referring to Table 5. It should be noticed, that for presentation reasons CO_2eq mass units are 100 kg.

Full integrated approaches of management practices will lead therefore to a higher abatement potential at lower costs. However, it should be considered, that by illustrating the results of Table 5 with MACCs the high range of abatement-potential results provided by the cited literature is neglected, as the diagram is calculated with mean values. The abatement potential of Conservation Agriculture for example ranges from -1.14 to 2.9 $tCO_2eq\ ha^{-1}\ yr^{-1}$, which means, that the change of management practice to Conservation Agriculture may lead to an offset as well as storage of CO_2, depending on the respective situation. This high degree of uncertainty should be integrated into the diagram by error bars. However, this has not been done by the authors of the MACCs (Bockel et al. 2012; McKinsey & Company 2013), which have been the templates for the own illustrations, and might also leads to confusion.

4.3.2 Comparison between potential returns from CO_2-trading and cost of humus building

The private initiatives, which have been described in section 2.3.1, offer a price of 30 € for each sequestrated ton CO_2. This price can vary due to demand of the certificates by private institutions or persons. However, the experience of the Ökoregion Kaindorf showed that the price was stable over the years since the humus-project was launched (Dunst 2019, p.138; Forstner 2019) in contrast to the CO_2-certificate price of the European Union emissions trading scheme (Figure 9).

The expected earnings for the farmers, when participate on a humus-certificate trading-scheme, have therefore been supposed to be 30 €. However, these earnings must be reduced by the costs of soil analysis due to the determination of humus building. Overall, three soil analysis (first analysis for humus content determination of a homogeny plot, following analysis and control analysis) are necessary for rewarding the humus building (see also section 2.3.2). Each analysis has to be paid by the farmer and costs currently (November 2019) 390 € for a maximal plot size of 5 ha.

It seems rational for farmers and is done commonly (Weisshäuptl 2019) to exhaust the plot size in order to reach the maximum plot size, where humus can be enriched. The costs for soil analysis decrease therefore per ha and the potential revenues might increase, when humus building was successful. This practice is indicated by the following Table 6. As the duration of the contractual relationship is about (on average) 10 years, the costs of the following and the control analysis accrue on a later time. Thus, the present value of these costs should be used for calculations. At the current (2020) low interest level and given the short time period, the difference would just be about 10 € and due to the high uncertainty in the assumption made above (section 4.2.2) this seems negligible.

Table 6: Occurring Costs for soil analysis, when taking part on the humus building project of the Ökoregion Kaindorf

	Costs for plot size:1 ha	Costs for plot size: 5 ha
First analysis (t_0)	390 €	78 €
Following analysis (t_0+5 years)	390 €	78 €
Control analysis (t_0+10 years)	390 €	78 €
Sum	1,170 €	234 €
Costs for each year and ha	170 €	23.40 € ≈ **25 €**

This calculation (Table 6) indicates, that 0,83 t (25 €/30 €) of CO_2 has to be sequestered each year to cover the costs for soil analysis, when a revenue of 30 € for one ton of sequestered CO_2 is supposed and the plot reaches the maximal size of five ha.

The potential earnings of every measure (abatement potential multiplied with 30 € ha^{-1}) can thus be compared with respect to the various costs. This was done by the following Table 7. The costs for soil analysis are assumed to be around 25 € ha^{-1} yr^{-1} (Table 6). While the soil samples for the determination of humus contents are analysed with the Kinsey soil analysing procedure to show potential nutrient imbalances, these costs will not occur on the measures "Nutrient management" and "Regenerative Agriculture after questionnaire 2", as these already include these costs.

Table 7: Comparison between cost of the measures inclusive costs for soil analysis and the potential revenues due to humus building

Measure	Abatement Potential (tCO_2eq ha^{-1} yr^{-1})	Potential returns (€)	Costs of measures (€) plus costs for soil analysis	Differ-ence (€)
Nutrient Management (e.g. Kinsey-Fertilization)	0.62 (0.02 – 1.42)	19	90	**-71**
Agronomy (e.g. no fallow land, crop rotation)	0.98 (0.51 – 1.45) 0.59 (0.40 – 0.77)	24	198	**-174**
Adoption of No-till methods	0.53 (-0.04 – 1.12) 1.29 (1.10 – 1.47)	27	165	**-138**
Cover Crops	1.17 (0.88 – 1.47)	22	115	**-93**
Regenerative Organic Agriculture (Field trail in USA)	8.66	260	428	**-168**
Conversion to Organic Farming	0.99 (-0.37 – 2.35)	30	205	**-175**
Fully integrated approach of CA	2.02 (-1.14 – 2.90)	60	190	**-130**
RA after questionnaire 2 (humus content raised from 2.8 % to 5.4 % in five years)	14.3	429	730	**-301**

The calculation shows, that no measure is cost-covering when just addressed in respect to potential earnings of a humus building project. The potential returns by conducting the measures (Table 7) range from 19 € ha^{-1} for the measure Nutrient Management with a calculated deficit of 71 € ha^{-1} between costs per measure and potential returns from a humus building project to a maximum return of 429 € ha^{-1} but with a deficit 301 € ha^{-1} respective.

5. Discussion

The discussion section is divided into three parts. Part one refers to the discrepancy between the traditional conceptions of humus building and the observations of practitioners of RA, who claim, that the increase of humus can be done much faster than scientific field-trials may indicate.

The second part deals with the results of the questionnaires, in particular referring on cost of the measures of RA in relation to GHG-abatement potential.

The last part discusses the questions, if an upscaled (compared with local initiatives) trading with CO_2-certificates may offer rational incentives for farmers and society to fight global warming and which steps might be necessary to develop a functional evaluation and trading for these certificates.

5.1 Humus building

By comparing the different views of humus building, controversial opinions are apparent. The exceptional results claimed by some practitioners of RA are skeptical considered by orthodox soil science, what has been entitled recently as a 'clash of cultures' (White and Andrew, 2019). Alternative practitioners argue, that a noteworthy increase of humus contents in soils is achievable (Brown 2018, p. 76; Dunst 2019, p. 20) or even highly necessary (Toensmeier 2016) due to many beneficial effects on soil health and fertility (Brown 2018, p. 23; Montgomery 2018, p. 119). However, orthodox soil science and scientific humus researchers are very sceptical fulfilling this demand (Körschens et al. 2014). The change of a fields soil carbon content should be, according to traditional views, observed for a long time to meet the researchers demand for statistical significance (Hüttl et al. 2008, p. 150). Only long-term field trails would fulfil the demands of statistical significance and objectivity (Kolbe 2019). Whereas practitioners argue, that changes in the SOM content of soils could be realised much faster and that the 'classic' models for soil carbon dynamics are based on data, which were collected from conventionally treated pastures or arable lands, where the plant-microbe bridge is dysfunctional. These models would not be able to explain rapid topsoil formation, which could be observed on farms where regenerative agricultural methods have been used. These measurements, however, were made outside of institutionalised science and are therefore largely ignored by scientists (Jones 2011).

A main reason for this dispute might be the fact, that researchers and practitioners are not speaking the same language. The scientist fraction relies on objective experiments for gathering knowledge and alternative practitioners use a more holistic and subjective approach of observing, by using other methods of epistemology (e.g. senses like eyes (darker colour – compare figure Figure 12) or nose (smell of the soil)) rather than laboratory instruments. For the design of a scientific experiment, a theory is needed, because it has to be stated before, what can be found afterwards. This narrowed focus has to suppress all other possible insights to gain knowledge except the one (or the few) questions, in which the experimenter is interested. Practitioners might be therefore more open minded, especially when they did not have recognised the axioms and paradigms in the discipline of agricultural or soil science.

Bringing together these different epistemologies might be a challenge of integrative research, but could offer a great opportunity for a common approach towards the entangled matter of humus building and carbon sequestration. Researchers and practitioners should therefore become immersed in one another's knowledge cultures to understand the fundamental differences in their basic theories and axioms (Tress et al. 2005). Many tools of soil science are essential to conduct evidence-based research towards elucidating how and why the exceptional results by practitioners of RA might have been achieved (White and Andrew 2019).

The formation of the soil and health institute in USA is cited as a good example, how a collaborative-oriented organization might bring together these groups. The focus of the non-profit organization is fundamental and applied research with the aim to bring knowledge from the research laboratory to the farm field. A detailed and comprehensive strategic plan has been set out by scientists and farmers for fulfilling the demand "Restore the soil: prosper the nation". The combination of fundamental and applied research is also well known in Germany (Landwirtschaftskammern, Thünen-Institut, VDLUFA) and mutual learning between agents and translating the language from the scientific and non-scientific world (and vice versa) might be a promising approach to overcome the above mentioned `clash of cultures` (White and Andrew 2019). The 4p1000 initiative for example lead to investigations of applied research institutes, how the claims of the initiative could be fulfilled by the agricultural community (Wiesmeier et al. 2017; Don et al. 2018).

The intrinsic complexity of the soil system is enormous, as there are myriad of possible interactions between the thousands of microbial species and also between those species and plant roots (Baveye 2015). Many aspects, which might play a crucial role in terms of humus building and carbon sequestration, have not been worked out in this thesis. For example, the interest in fungi (especially mycorrhiza) in soil has raised enormous due also to modern analytical methods. The ratio between fungi and bacteria and the interactions between these highly important groups for humus building and nutrient mobilization has been emphasized by researchers (Solaiman 2014; Wallander and Ekblad 2015) and consultants of RA (Dunst 2019, p. 115–116). Another example is the issue of biochar, which drew special attention over the last years in the scientific (Lehmann and Joseph 2015) and public (Scheub et al. 2017) community. The research question of carbon sequestration via humus building might therefore be one of the pressing research questions in relation to environmental concerns, which confronted researchers and practitioners with issues of high complexity and technical difficulty (Baveye et al. 2014).

5.2 Classification of the results from the questionnaires

The results of the questionnaires and own calculations indicate, that the adoption of management practices of RA can be cost-intensive. However, the range between the two participants of the survey, who provided information about cost of measures of RA, indicates, that more data is needed to derive valid cost-performances. The main cost differences between the questionnaires regarding the measures of RA (Table 2) can be found in the transfer of plants into the rotting process, the use of ferments, compost tea and organic amendments. As only questionnaire two (Q2) provided data concerning the augment of humus, it remains unclear, if an enhancement of humus contents can be reached at lower costs.

The assignment RA measures to single measures with their abatement potential, which has been reported in the literature (Table 4) can also be critically questioned. Some measures seem easy to assign, as cover crops in one production method may be similar to cover crops in RA. But it has to be considered, that cover crops used in the context of RA should consist of many species (section 2.2.4), whereas the investigated cover crop cultivation may just contain two or three species. Other measures are difficult to assign to investigated methods, as, for example, fertilization after Kinsey. This measure refers actually to nutrient management, but was never object of scientific research and to assume the abatement potential of nutrient management seems highly speculative. The high uncertainty of the abatement potential of some measures is indicated by the ranges, which can be found in Table 4. In their report about GHG-abatement McKinsey & Company (2013) state also, that the uncertainty around the abatement potential is significant. This seems consequential, given the fact, that many processes of humus building are not fully understood (see also section 2.1.4). Baveye (2015) even argue in the context of the complex formation process of humus and the possible trading of CO_2-certificates due to humus building, that it seems “not straightforward to assign a price to features or processes one does not understand”.

Beside the direct costs of measures of RA, it must also be considered, that additional nutrients like nitrogen, phosphate and sulphur might be necessary to increase SOC in stable microaggregates (section 4.1.2). Protagonists of the humus building project in Kaindorf recommends, that these nutrients should be supplied by the use of stable composts. The production of composts, however, is also a complex process. It involves typically aeration of the material and is usually connected with the disposal of large amounts of CO_2 (and tentative other greenhouse gases) due to the microbial driven mineralization of organic matter. Whereas Dunst (2019) state, that stable compost can also be produced with a high carbon efficiency (i.e. most carbon from the raw material is preserved), even when it is aerated (Dunst 2019, p. 77–79). Other researchers in this field, however, propagate that only an anaerobe treatment of the raw material is able to provide composts with a high carbon efficiency (Witte 2013, p. 49–50; Wonschik 2016, p. 58–59). The matter of preservation of the carbon

compounds from the raw material or disposal of CO_2 (and other greenhouse gases) should therefore be part of a full life cycle analyzation, as it seems questionable to enable a storage of carbon in the soil, while releasing GHGs during the production process of necessary agents for this storage ("leakage").
A full-life-cycle analysis could also provide information about the trade-off between the built-up of stable SOM for carbon sequestration on one hand and the enhanced risk of nitrous oxide release as a result of carbon-induced denitrification processes in soils. These mechanisms are not thoroughly understood and are therefore a major challenge for the quantification of carbon gains for any soil management system, including for example no-till (Gattinger et al. 2011). An assumed net benefit from sequestering CO_2 can thus only be calculated by considering all GHGs, as early benefits from carbon gains could be increasingly offset by other emissions (CH_4 and N_2O), with much higher GHG-potential than CO_2 (Janzen 2015; Toensmeier 2016).
It has also been shown in the result part (section 4.2.3) of this thesis, that a compensation of 30 € for every ton CO_2 by the trading with humus-certificates cannot account for the whole arising expenses. The deficit depends on the conducted measures and ranges from 71 € ha $^{-1}$ to 301 € ha $^{-1}$ and prices from selling CO_2-certificates should amount 50-150 € for every sequestered ton of CO_2. Smith et al. (2008) came in their comprehensive analysis regarding this matter to similar results (50-100 \$ t CO_2^{-1}). However, it should be noticed, that other benefits from elevation the humus content of a field has not been considered so far. Participants of the survey have indeed been asked to estimate the cost-savings of methods of RA compared to conventional treatment (Table 3) and these data were integrated into the calculation of the abatement costs (Table 5). But benefits like the increase of the water-holding capacity or higher yields (because of sufficient supply of nutrients due to higher humus contents) have not been evaluated.
When MACC (Figure 11) of McKinsey & Company (2013) are compared with the results of this thesis (Figure 17 & Figure 18) a discrepancy is occurring. Figure 11 indicates, that most abatement levers are cost neutral, or even net-profit-positive, whereas the results of this thesis indicate, that no measure is cost effective and even the revenues from selling humus-certificates would not be cost covering. The reason for this discrepancy is a question of the particular perspective. Figure 11 shows the societal perspective of measures to abate greenhouse gases. Compared with other sectors, where GHG-abatement is discussed (e.g. energy production, industrial sector), the investment in order to sequester carbon or avoid emissions seems quite small and society might benefit from enhanced carbon sequestration. The perspective of a farmer, as it has been occupied in this thesis, leads mainly to additional costs, when the described measures are conducted.
In conclusion, it should be kept in mind, that it is not possible to derive robust estimations from one or two questionnaires or field trails about costs and abatement potential. Gattinger et al. (2012) for example analysed in their study to top soil carbon stocks 74 studies from pairwise comparisons

between organic and non-organic systems. Every farm has its own climatic and pedologic conditions, not to mention production focus and management and therefore more participants must be won for making particulars on costs of measures and documented humus building. The reported results can only provide first indications, how research regarding the entangled topic of humus building and trading of humus certificates could be done, while observing the above mentioned (section 5.1) demands of integrate experience and extraordinary results of farmers into the scientific forms of gathering knowledge.

5.3 Are CO_2-certifications rational incentives for farmers and society to fight global warming?

The issue of carbon sequestration via building humus is seen as a promising field for many farmers and attracts much attention within the farming community (Netzwerk Nachwachsende Rohstoffe und Bioökonomie 2019; Wiesmeier et al. 2020). The above-mentioned initiatives (section 2.3.1) promote the capture of CO_2 to build up soil health and to make agricultural-used soils resilient against droughts and floods. A raising number of participants in diverse humus-certificate initiatives shows, that the incentive of selling CO_2-certificates (or humus-certificates) is able to engage farmers in this matter. As the farmer has only to pay for soil analyses and, if the SOM content has been raised, to hold the SOM content stable (section 2.3.2) it seems rational to invest the cost for soil analysing and try to enhance soil carbon. However, for increasing the humus content only 0.1 %, a change in the management of soil cultivation is often necessary (e.g. adoption of RA measures). Perhaps even a change in the crop species, which are cultivated, as some crops may lead to a depletion of SOM (e.g. corn, potatoes, beet root). This may add opportunity costs, as the change in grown crops might lead to lower marginal returns. As pointed out above (section 5.2), adding nutrients for enabling humus formation might also be necessary. Farmers should therefore be aware of the difficulties in order to increase and stabilize the humus content on a higher level and consider the costs, which might occur for the change of a production system to reach a rational decision.

The counterpart of the farmers in a humus-certificate trading agreement are companies, which want to neutralize their carbon emissions or private persons with the same aim. The participation on this kind of agreement is voluntary and within the context of the climate debate, the involvement of agriculture in the trading of CO_2-certificates due to carbon sequestration in soils is discussed (Wreford et al. 2010; Lal 2016; Gattinger et al. 2019). For this reason Leitfeld et al. (2019) and Wiesmeier et al. (2020) analysed conditions for using soils as a sink of CO_2 (carbon sequestration) and provided important insights, if CO_2-certificates in the context of agriculture could be a promising measure in order to fight global warming.

Following these authors carbon sequestration needs to be quantifiable. This demand leads to an extensive analytical effort (as it has been descripted in section 2.3.2) to show an accumulation of soil organic carbon due to a change of management practice. However, carbon changes in topsoil (<30 cm), as detected by soil sampling for trading with humus certificates, ignores the possible management-induced redistribution of soil carbon at different soil depths. This problem was addressed by research concerning carbon sequestration rates (367-3,667 kg CO_2 ha^{-1} $year^{-1}$) during conversion from conventional tillage to no-till. These rates may thus be an artifact of shallow soil sampling (Luo et al. 2010; FAO 2011), which lead to a distortion of the real accumulation of SOC (Powlson et al. 2014). The interpretation of SOC increases should therefore be done carefully. The two options are: Is there a net transfer of carbon from atmospheric CO_2 to soil or vegetation (i.e. carbon sequestration) or is the increase of SOC avoided emission of CO_2 from soil by using methods (e.g. no-till) to converse the humus content.

A further argument is the fact, that carbon, stored in soils as humus, could be released again. Temporary storage of carbon by just increasing the SOM pool (application of high amounts of organic matter) will thus be not suitable for slowing down global warming in the long run. Suitable management practice must rather stabilize the SOM content by its conversion to humus-compounds in deeper soil layers. Beneath the management, land use history and climate (see also Figure 2 and Figure 3) are also significant players for SOM enrichment or depletion (Kolbe 2019). Soil carbon gains depend therefore not solely on current practice, but on how that practice compares with the treatment of the land in the past. The same soil (annual crops, no-till) might be gaining carbon, when it has until recently been intensively-tilled with frequent fallowing, but it will probably lose carbon, if the land had freshly been broken from grassland (Hüttl et al. 2008, p. 149–150; Janzen 2015). More general, if the carbon depletion due to previous degrading practice was quite large, the likelihood of future carbon gains is rather high. But carbon gains are limited, as the humus content cannot be raised unbounded. Thus, a high efficiency of SOM formation does not necessarily correspond with high persistence of the formed organic C in soil. As described in section 2.1.4, microbial access to SOM, rather than chemical composition, controls its turnover. Microbial access to SOM is restricted by carbon association with mineral surfaces and by spatial isolation within soil aggregates (Masciandaro et al. 2018, p. 10–11). However, as mineral surfaces in the soil became saturated with carbon-atoms, carbon decomposition rates increase and the rate of SOC storage per unit declines (Heitkamp et al. 2012). This phenomena is called sink saturation (Smith 2016) and depends on soil type and prevailing environmental conditions. By reaching this point, the soil will no longer act like a sink and may achieve a steady state, where it emits as much carbon as it absorbs. However, due to poor management and degradation, many soils are far away from saturation (Rhodes, 2017) and most of the sequestration

measures are estimated to be active for 20-40, in specific cases for 120 years (Poeplau and Don 2015; Rumpel et al. 2020), before a saturation point is reached (McKinsey & Company 2013, p. 127).
A further problem, which must also be addressed is the demand, that a certificated sink project must fulfil the condition of "additionality" (Leitfeld et al. 2019). This means that a respective measure is only cost-efficient, if CO_2-certifcates can be sold. As the results of this thesis indicate, measures of RA can fulfil this demand, because they might lead to an increase of the humus content and are cost-intensive. An adoption seems rational, when the additional costs, compared to conventional (or *business-as-usual*) treatment, are compensated by CO_2-certifcates. However, a change of management practices is usually not (or not only) implemented solitary for the reason of climate protection. Other reasons might be the main focus, like increasing of soil fertility and soil health, enhancing water holding capacity or reduction of soil erosion.
The last insight, which has to be considered, is the outsourcing of emissions or "leakage" (Leitfeld et al. 2019). This point was touched in section 5.2, when the practice of composting in order to enhance SOM was questioned. Leakage occurs, when a sink is established at the expense of another sink or even at the evocation of a source. Composting for example leads to a concentration of organic matter on one point, but also to a depletion on the place of origin. Beside leakage (McKinsey & Company 2013, p. 34), rebound and backfire effects from increased efficiency (Lanigan et al. 2018, p. 32) are serious problems concerning measures to address climate change. Thus, high requirements in order to define the system boundaries must be satisfied and Leitfeld et al. (2019) advocate a scientific monitoring of CO_2-certification projects to avoid trade-offs , when the "worthy, laudable endeavour" (Janzen 2015) of increasing SOC leads in the end to unintended side-effects.

6. Conclusion

By considering the human activities which are meant to be responsible for global warming, it is conspicuous, that the agricultural sector is unique. This is due to the property, that the mitigation potential can be derived from both a reduction of emissions through management, as well, as an increase of removals of greenhouse gases to store it in soils. The present thesis provides information regarding the latter possibility as it discussed topics about soil humus formation, a new farming approach called Regenerative Agriculture (RA) and tried to highlight an economic perspective regarding measures of RA. Annual emissions due to the combustion of fossil carbon have been estimated with 9.4 ± 0.5 Pg C (Le Quéré et al. 2018) and researchers are discordant regarding the mitigation potential of agriculture. It has been shown, however, that actual levels of GHG mitigation are far below the technical potential (Smith et al. 2008). An important barrier for increasing current mitigation rates are economic constraints, as it was shown in this study, that implementing measures of RA can lead to additional costs. The trading with CO_2-certificates ("humus-certificates") as a possible solution for overcoming this barrier has been discussed in this study by calculating the probable returns from selling certificates in relation to costs for humus augmentation. This calculation shows, that the offered price for certificates is not cost covering, but it has to be considered, that uncertainty is high, due to a lack of data and the complex matter of humus, just at the border between the unanimated and the animated world of soils.

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Appendix 1

<u>Questionnaire:</u>

<u>Operating data</u>

Conventional or Organic

Operating Area ha

Of which ha cropland und ha pasture

Crop rotation

% Wheat	% Buckwheat
% Barley	% Field beans
% Rye	% Peas
% Triticale	% Lupins
% Oat	% Clover- / alfalfagrass
% Maize	% Arable fodder
% Rape	%
% Potatoes	%

On which area cover crops and undersown crops are grown?

% Cover crops

% Undersown crops

Please furnish particulars to average yields over the last years .

dt/ha Wheat	dt/ha Buckwheat
dt/ha Spelt	dt/ha Field beans
dt/ha Barley	dt/ha Peas
dt/ha Rye	dt/ha Lupins
dt/ha Triticale	dt/ha Clover- / alfalfagrass
dt/ha Oat	dt/ha Arable fodder
dt/ha Maize/Corn	dt/ha
dt/ha Rape	dt/ha
dt/ha Potatoes	dt/ha

Straw Management

On the fields remain % of straw.

Recovered and sold % of straw

Recovered and spread into stables % of straw.

% of straw is treated otherwise. Treatment:

Husbandry

How many animals are kept on your farm. Data calculated in livestock unit (GV)

Livestock unit Cattel

Livestock unit Pigs

Livestock unit Poultry

Livestock unit Sheep/Goats

Livestock unit

Farm manure

Which kind of farm manure are used?

Solid manure, slurry, poultry manure

% of the manure are used on own fields.

% of the manure are sold.

Is farm manure bought in addition?

How many tons of farm manure are bought?

Which kind of farm manure is bought?

Biogas

Biogas plants with altogether kW installed power are run on the farm

Used substrates:

How much substrate is bought in addition (t)?

% of fermentation residues are applicated on own

Soils

Average ground points:

Range of ground points

Which soil types are typical for your farm?

Climate

Altitude: m

ø precipitation per year in mm

Mean annual temperature °C

Regenerative Agriculture

How many years are measures of RA used?

Are there records how the humus content has changed over this period?

Yes / No

If so, how?

Increased from   % to   %)

Reduced from   % to   %)

Are there other changes, which have been noticed?

Participant on CO_2 – certificate trading? Yes / No

If so, which provider?

Which measures of RA are conducted on the operating area?

Measure	Expected Costs in €/ha	Additional cost compared with conventional treatment in €/ha
Soil analysis after Albrecht/Kinsey		
Fertilization after Albrecht/Kinsey (inclusive micronutrients)		
Transfer into rotting process with rotary tiller		
Transfer into rotting process with skimmer		
Transfer into rotting process with other machinery		
Use of ferments		
Use of compost tea		
Composting		
CMC-/ MC- Composting		
Use of biochar, rock flour or other auxiliary materials		
Undersown crops		
Cover crops		
Additional measures:		

Appendix 2

Bayer Handelsvertretung
Pichelsdorfer Str. 71
13595 BERLIN, DEUTSCHLAND
TEL. 030-7570462-0 – FAX: 030-7570462-1
E-MAIL: bp@beratung-mal-anders.de
www.beratung-mal-anders.de

Pricelist

State: 01.01.2016

Standard soil analysis, incl. specification fertilization priority sequence: 85,- €…………..

Participants on training courses and educated consultants: 75,- €.

(implies results overview and fertilization recommendation

Fast Response

(only upon consultation) 15 € extra per samplealu.

Aluminium, Cobalt or molybdenum analysis: each sample 18,- € ....………..

Chloride & salt conzentration: 11,- €……......................…………………………............

CaCO3: 20,-…………………............

K-Displacement analysis: je 26,- €…………………………………………….............

For soils with high CEC. This additional analysis leads to a better determination of the characteristics for these soils and the expense for correction and fertilization will therefore be reduced

Recommendations for additional crops: 5,- €/sample......

New recommendations:

- for analysed soil sample, when another crop is grown*:* 15,- € Probe………...
- for analysed soil sample, for following crop: 50,- € Probe........

Leaf or plant-analysis: on request…………………………………………......

Lime analysis: each sample 45,- €… /

Gypsum analysis: each sample50,€…………………….........

Standard compost analysis, inclusive micronutrients: 135 €…………………….....

Telephone consultation: 35,- € (for the first 10min.) + 3,- €/for each further minute.

(Discussion of soil analysis results: Discussion of implementation and strategy development).

On-site consultation: on request

Training courses (Modules: Basic & Advanced I & II *(incl. Introduction in the maths behind the analysis. From the laboratory result to a fertilization recommendation):* on request

CAUTION: minimum quantity surcharge: 25,- €

Submission less than four samples

After: © 2016 York-Th. Bayer , changed by the author. The original price list is in German and can be accessed on request.

Appendix 3

Plant vitalising with compost tea

KTBL-fieldwork calculator

Working method: Plant protection measure, Crop protection sprayer, volume 1.500 l; 67 kW power requirement, 15 €/h working costs

Field size: *1 ha*, farm-field-distance 1 km, working width 21 m, output-quantity 300 l/ha, , price of diesel 1,10 €/l

Working time requirement (h/ha)	0.33
Area performance (ha/h)	3.13
Depreciation (€/ha)	4.94
Interest cost (€/ha)	1.19
Other costs (€/ha)	0.40
Repair costs (€/ha)	1.78
Operating materials (€/ha)	1.15
Sum machine costs(€/ha)	9.46
Sum working costs (€/ha)	4.95
Total Costs (in €/ha)	**14.41**

Costs for compost tea production: 300 l Vortex brewer, acquisition cost 2,900 €, 10 years operating life, 15 €/h working costs, quantity needed 10-30 l/ha

Working time for production (h/ha)	0.1
Depreciation (€/ha)	3.00
Material costs (€/ha)	2.05
Operating costs (water, electricity €/ha)	0.40
Sum machine costs (€/ha)	5.45
Sum working costs (€/ha)	1.50
Costs for spraying (calculation above)	14.41
Total costs compost tea (prodcution and application (€/ha)	**21.36** (20 € in calculation – Table 3)

Costs for controlling the rotting process (EM): 1000 l IBC-container (EM Chiemgau, product *Bodenverjünger*) 0,77 €/l (without transportation), quantity needed 100-150 l/ha

Total costs: Purchase *Bodenverjünger* by using 100 l/ha (**77 €**) + costs for application (as above calculated: **14,41 €**) = **91,41 €** (90 € in calculation – Table 3)

Appendix 4

Bio-Dominanzgemenge

Regenerative Landwirtschaft: Nutzung des mikrobiellen Bodenlebens zur Steigerung der Bodenfruchtbarkeit.

Saaten aus biologischer Vermehrung — Euro / 100 kg

Regenerative Landwirtschaft

DOMINANZGEMENGE **mit 70 % biol. Anteil** — 25 kg/Sack — 322,-
(Sommerzwischenfrucht)

Leguminosenanteil 26 %

Die Zwischenfrucht Dominanzgemenge ist eine stark deckende Mischung für kurze Wachstumszeit. Sie kann vor Wintergetreide stehen, aber auch als Erstsaat der „doppelten Zwischenfrucht" angebaut werden. Diese Zusammensetzung keimt auch bei trockenem Boden und ist bevorzugt für frühe Saattermine geeignet. Die Wachstumsdauer sollte max. 7 Wochen betragen. Marktfruchtbetriebe, die eine erhöhte Stickstoffspeicherung im Boden wünschen, können zu der Mischung noch den Lauenauer Aktivhumus 1 im Verhältnis 60:40 sich selbst dazumischen. Für abfrostende Zwischenfruchtsaaten sollten andere Mischungen gewählt werden, z.B. das Biodiversitätsgemenge. Saatzeit bis Ende Juli.

Aussaatmenge: 25 kg/ha = 80,50 Euro/ha

17 % Buchweizen zur Gründüngung, *aus biol. Vermehrung*
12 % Öllein Lola, konventionell
11 % Öllein Lirina, *aus biol. Vermehrung*
7 % Serradella Emena, konventionell
5 % Badischer Landmais, konventionell
6 % Sonnenblumen Peredovick, *aus biol. Vermehrung*
5 % Sandhafer Pratex Z2, *aus biol. Vermehrung*
4 % Leindotter, *Umstellungsware*
4 % Sommerfutterraps Jumbo, konventionell
3 % Gelbsenf Litember, *aus biol. Vermehrung*
3 % Ölrettich Romesa, *aus biol. Vermehrung*
2 % Sudangras Piper, konventionell
2 % Phacelia Natra MS, *aus biol. Vermehrung*
6 % Sommerwicken Mery, *aus biol. Vermehrung*
7 % Alexandrinerklee Axi, *aus biol. Vermehrung*
6 % Perserklee Marco Polo, *aus biol. Vermehrung*

Mischung ist bereits genehmigt!
Alle konv. Komponenten sind ungebeizt!

Appendix 5

camena SAMEN

Telefon: 0 50 43 / 10 75
Telefax: 0 50 43 / 10 78
e-mail: info@camena-samen.de

Bio-Green Carbon Fix

Saaten aus biologischer Vermehrung — Euro / 100 kg

Regenerative Landwirtschaft

GREEN CARBON FIX mit 70 % biol. Anteil — 20 kg/Sack — 516,-
(Untersaat) **Nur zur Gründüngung**
Leguminosenanteil 38,8 % — verbesserte Rezeptur!

Diese Untersaat fördert die Blattgesundheit und unterdrückt den Unkrautwuchs. Sie schließt die Ernährungslücke für die Boden-Mikroorganismen zwischen Abreife der Erntekultur und Bestandesschluß einer Zwischenfrucht. Das ist eine wesentliche Vorausssetzung für die Humusbildung! In dieser Mischung sind tief- und flachwurzelnde Arten und Sorten kombiniert. Sie ist für trockene und wechselfeuchte Standorte geeignet. In der Mischung sind Blühkomponenten enthalten, die vor allem im Frühjahr Insektennahrung in Kulturen bieten, die bisher für Insekten wenig attraktiv waren.

Nutzung nach Ernte:

Die Untersaat begrünt die Stoppeln. Stoppelhöhen von mehr als 10 cm sollten nachgemäht werden, damit ein dicht wachsender Bestand entsteht. Ab ca. zwei Wochen nach Ernte kann in diesem Bestand die Unterkrumenlockerung durchgeführt werden. Der Bestand kann vor Raps, Futtersaaten und frühen Saatterminen von Wintergetreide geschält werden. Zwischenfrüchte sind auch mit teilweiser Beseitigung der Untersaat etablierbar. Wenn die Zeit zwischen Ernte und Wiederbestellung weniger als sechs Wochen beträgt, kann diese Untersaat die Gründüngungsfunktion vor der nächsten Kultur übernehmen. Wenn im Herbst schwierige Bedingungen herrschen, kann diese Untersaat als Kompromiss überwintern. Eine herbstgrüne oder wintergrüne Zwischenfruchtsaat ist für die Nährstoffspeicherung und Humusbildung eine bessere Alternative.

Bevorzugte Einsaat in:
- Winter- und Sommergetreide
- Körnerleguminosen, Sonnenblumen
- gepflanztes Feldgemüse
- Fahrgassen in Obst und Reben

Im Mais empfehlen wir zur Untersaat, bewährte Mischungen zu verwenden, ab Seite 46.

Saattermin:
- extensive Kulturführung im Wintergetreide: mit der Saat
- intensive Kulturführung im Wintergetreide: ab 15. Oktober

Aussaatmenge: Im Getreide 20 kg/ha bei Erstanwendung (15 kg/ha bei Folgeanwendungen), in Reihenkulturen 10 kg/ha = 51,60 Euro/ha bis 103,20 Euro/ha

19,00 % Dt. Weidelgras Transate, *Umstellungsware*
19,00 % Dt. Weidelgras Double, *aus biol. Vermehrung*
5,20 % Dt. Weidelgras Kaiman, *aus biol. Vermehrung*
2,00 % Lieschgras Switch, *aus biol. Vermehrung*
6,00 % Lieschgras Alma, konventionell
4,00 % Weissklee Vysocan, konventionell
4,00 % Weissklee Huia, konventionell
10,80 % Inkarnatklee Heusers Ostsaat, *aus biol. Vermehrung*
8,00 % Serradella Emena, konventionell
4,00 % Perserklee Ciro, *aus biol. Vermehrung*
4,00 % Gelbklee Virgo, konventionell
4,00 % Hornklee Leo, konventionell
6,00 % Leindotter, *Umstellungsware*
2,00 % Phacelia Natra MS, *aus biol. Vermehrung*
2,00 % Koriander, *aus biol. Vermehrung*

Mischung ist bereits genehmigt!
Alle konv. Komponenten sind ungebeizt!

Appendix 6

Growing cover crops with recommended plant species mixture for RA

KTBL-fieldwork calculator

Working method: Sowing cover crops „Dominanzgemenge“ (see also Appendix 4), standard seed drill, 67 kW power requirement, working costs: 15 €/h

Field size: *1 ha*, soil resistance against mechanical disturbance: *low*, farm-field distance *1,0 km*, sowing quantity: *25 kg/ha*, working width *3 m*, price of diesel 1,10 €/l

Seed costs: $\frac{Price\ for\ 100kg}{Sowing\ quantity\ per\ ha}\frac{322\ €}{25\ kg} = 80{,}50\ €\ ha^{-1}$

Working time requirement (Akh/ha)	1,06
Area performance (ha/h)	1,23
Depreciation(€/ha)	9,48
Interest cost (€/ha)	2,74
Other costs (€/ha)	1,18
Repair costs (€/ha)	9,61
Operating materials (€/ha)	4,82
Sum machine costs(€/ha)	27,83
Sum working costs (€/ha)	15,90
Seed costs	80,50
Total Costs (in €/ha)	**124,23** (125 € in calculation – Table 2)

Appendix 7

Growing undersown crops with recommended plant species mixture for RA

<u>KTBL-fieldwork calculator</u>

Working method: Sowing undersown crops „Carbon Fix“ (see also Appendix 5), centrifugal spreader, 37 kW power requirement, working costs: 15 €/h

Field size: *1 ha*, soil resistance against mechanical disturbance: *low*, farm-field distance *1,0 km*, sowing quantity: *25 kg/ha*, working width 12 *m*, price of diesel 1,10 €/l

Seed costs: $\frac{Price\ for\ 100kg}{Sowing\ quantity\ per\ ha}\frac{514\ €}{20\ kg} = 102{,}80$ € ha^{-1}

Working time requirement (Akh/ha)	0,35
Area performance (ha/h)	4,76
Depreciation(€/ha)	0,73
Interest cost (€/ha)	0,2
Other costs (€/ha)	0,14
Repair costs (€/ha)	1,74
Operating materials (€/ha)	0,68
Sum machine costs(€/ha)	3,49
Sum working costs (€/ha)	5,25
Seed costs	102,80
Total Costs (in €/ha)	**111,54** (110 € in Calculation – Table 2)

Appendix 8

'Winona' data summary

2000-2010: 164 tonnes CO_2 sequestered per hectare (44.7 tC/ha).
2008-2010: Sequestration rate 33 tonnes CO_2 per hectare per year (9 tC/ha/yr).
Permanence: 78% of the newly sequestered carbon is in the non-labile (humic) fraction of the soil - rendering it highly stable.
Location: The greatest increases in soil carbon have occurred at depth, overcoming subsoil constraints. Non-labile soil carbon has doubled in the 10-20cm increment, tripled in the 20-30cm increment and quadrupled in the 30-40cm increment.
Nitrogen: An extra 2t/ha (48% increase) in Total N, which would not be possible unless associative N-fixing bacteria were being supported via the liquid carbon pathway.
Minerals: The following increases in soil minerals have occurred - calcium 177%, magnesium 38%, potassium 46%, sulphur 57%, phosphorus 53%, zinc 86%, iron 22%, copper 102%, boron 56%, molybdenum 51%, cobalt 79% and selenium 17%.
Cash benefit: At a carbon price of $20 per tonne, and assuming payment for non-labile (stable) carbon only, the value of the sequestration of 33 tCO_2/ha/yr would be $660 x 78% = $515/ha/yr.
A price on non-labile soil carbon would provide worthwhile incentive for progressive farmers to rebuild our precious agricultural soils.

Source: Jones 2011