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Possibilities and Limits for Natural Carbon Sequestration in Agricultural Used Soil

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Preface

This master thesis was written at the Institute of Hydraulics that belongs to the department of water-air and atmosphere which is part of the University for Applied life sciences in Vienna. As the first supervisor Ao.Univ.Prof.DI Dr. Andreas Klik, and as co-supervisor Dipl.-Hydrol. Gerlinde Trümper were giving helpful contributions and interesting hints for the advanced literature: thanks a lot to both of them for they patience and important guidance!

Also participating were lecturers from the Czech university of agriculture, where the winter term semester was the beginning of deeper interest in soil science and soil remediation. The library provided the ideal working environment with an access to all important literature just right to the personal working place which enabled a broad research in the field of the study around the clock. Last but not least I have to say that I am grateful to my friends and colleagues who gave me the time and the space to really focus completely on the subject of this thesis.

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Abstract

Natural sequestration of carbon is a process led by soil environment in exchange with many biotic and abiotic factors of great influence. Since the green revolution, the industrialisation of agricultural practices, the human being has changed the equilibrium between soil and air budgets of carbon totally. Research has been started for better estimation and simulation of the soil inherent processes which should lead towards increasing storage of carbon in the compartment of soils. Different methods are applied in numerous examples all over the world but the outcomes are not always satisfying for other regions with different surrounding environmental influences. This master thesis summarizes the efforts and strategies which have been made so far in research. The aim is to gain a better understanding and an overview about the possibilities and limits of mitigation measures for shifting high carbon concentration from the air towards enhanced carbon storage ability into agriculturally used soils. The beneficial side effects for soils, especially in dry climates are also a subject in this work, as well as future estimates in combination with improved management techniques like no tillage or crop rotation.

0. Abbreviations

Signs	Names
CEC	Cation Exchange Capacity
DOM	Dissolved Organic Matter
FYM	Farm Yard Manure
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
OC	Organic Carbon
TOM	Total Organic Matter
WRB	World Reference Base for Soil Resources

1Kg	Kilo Gramme (10^3 g)
1Mg	Mega Gramme (10^6 g) = 1 metric ton
1Gg	Giga Gramme (10^9 g) = 1 thousand metric tons
1Tg	Tera Gramme (10^{12} g) = 1 million metric tons
1Pg	Peta Gramme (10^{15} g) = 1 billion metric tons

Global warming potential (time horizon: 100 years)

1 kg N_2O = 310 kg CO_2-equivalents = 84.5 kg C-equivalents

1 kg CH_4 = 21 kg CO_2-equivalents = 5.73 kg C-equivalents

1 kg CO_2 = 1 kg CO_2-equivalents = 0.273 kg C-equivalents

1. Introduction

Natural Carbon Sequestration is the scientific term to express a process in which carbon (C) is fixed in the terrestrial ecosystem to reduce the concentration in the atmosphere. Through this process a mutual balance of C should be reinstalled between the main pools which are the terrestrial (1500 Pg) and the atmospheric pool (750Pg). There has been a historical balance between these pools which relate on the global scale on climatic conditions, photosynthesis and primary production of plants. But lately this balance became disrupted by the human consumption of the world natural resources, especially the exploitation of fossil fuels and biomass for combustion purposes. This causes rising CO_2 concentrations that were 280ppm in the pre-industrial years before the beginning of the 19th century and already 367ppm in the year 2001 (IPCC, 2001).

As one of the most pressing problems at the beginning of the 21st century, climate change debates are held all over the world, mitigation strategies are invented and effective measurements are needed to fight against global warming. Carbon and especially the gaseous form of it, CO_2, plays a major role in the agreement on strategies to reduce the harmful effect of global warming, namely by decreasing the emissions of greenhouse gases (CO_2, CH_4, SO_2). From land use and land use management reports it is known that agriculture can play an important role to achieve the reduction goals stated in the protocol of Kyoto (IPCC, 1996).
The reason for carbon losses from soil appeared since agro-industrialisation began to threaten the pedogenic environment by highways, long and heavy vehicles with their deep impacts through compaction and tillage practices that result in erosion and general soil degradation by the loosening of soil organic matter (SOM). This turned soil resources from a sink of C and CO_2 into a net source of CO_2 emissions, as it is shown in the simplified scheme of Figure 1 (FOLLET, 2001):

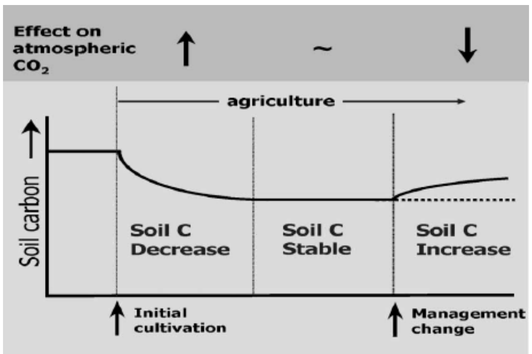


Figure 1: Changes in long-term storage and release of soil carbon in soil and its release as carbon dioxide as a function of agricultural practices (From: FOLLET, 2001 and JANZEN et al, 1998)

Since the end of the 1990´s different disciplines of the scientific community seem to have met each other on one and the same challenging topic: soil management for mitigating the effects of climate change.

Enhancing carbon sequestration in soils is one possibility to reduce the CO_2 concentration in the atmosphere by enhanced plant uptake for instance or through improved nutrient cycling in addition for example adding green- and farmyard manure. As soil resources are a basic need for the daily survival of human life and therefore should be also available for future generations; therefore land use and land use management will be indispensable for a sustainable cooperation between human societies and their natural heritage.

2. Goals and Problem Description

The main task of this work is to compile and compare results of studies investigating impacts of soil management systems on the carbon cycle. The literature which is currently available about the possibilities and limits of carbon sequestration in agriculturally used soils has to deal with a broad spectra ranging from cultivation methods like seed bed preparation and harvest techniques to residual management or crop rotation. There are several ways in which agricultural lands are used and managed nowadays which has a high influence on the carbon availability in these soils (KOMATSUZAKI and OHTA, 2006).

The main challenge will be to collect and summarize the results from different authors on different sites who might have also applied different methods in measuring the Carbon fluxes into and out of the soil. Beside of the unique set up of an example with all particularities from the biotic and a-biotic environment (e.g. localisation) it is crucial to distinguish and classify in and between soil orders and zones of climate and parent material of the derived data.
A screening of the actual data from field experiments and not the output from large scale models will be of interest in this work. Although for the international and governmental level the influences on carbon stocks and fluxes are of high interests. The fact that 5-8 Gt C are emitted annually by the burning of fossils, deforestation (especially the rainforest) as well as other environmental distortions but only 3-4 Gt can be measured to accumulate in the atmospheric concentration raises the question, where the other part of the emissions go to stay. In the scientific community this question is referred to as the “missing link” (SCHEFFER and SCHACHTSCHABEL, 2002).
A focus in this thesis lies on the processes of soil metabolism and the assessment of carbon stocks with the intention to trace current soil characteristics back to their stage of development thus to be able to determine positive and less positive influences on it.
Last but not least the aim will be a conclusion about the quantitative amount which the agricultural sector can make, if appropriately managed, to the overall goal of minimizing the total carbon emissions in the long run to approximately zero in each participating sector plus even to establish a sink option out of the current source function.
Chapter 4 (Material and Methods) describes several different methods that are used in measuring, calculating and estimating organic carbon stocks and fluxes in the soil environment. Chapter 5 (Results on SOC from field experiment) then consists out of results of research articles from the scientific community all over the world (in a geographic and climatic order)

3. Principles of Carbon Sequestration

Carbon is inherent in almost each and everything in the world. Lately it is becoming by its increasing concentration in the atmosphere to a threat for human society and peace in the world, as the high representative of the European Union, SOLANA, J., stated in a newspaper article (DER STANDARD, 13th March 2008). It is therefore more important than ever before to understand its global role and influence that it has nowadays. As it plays not only a functioning role in living and dead material of nature, where it can act as a solute, extracting, ad- and absorbent in physico-chemical processes, it is also in general the main component of biological and physiochemical energy transmittance.

Because of its existing diversity that Carbon has in terms of different forms and functions, as well as the spatial and temporal variability in occurrence and relation to other biotic and abiotic questions, it is a field that gains large interests in the scientific community (IPCC, 1996). Especially for the science of soil, which became lately an independent principal direction of science (cit.: verbally during lecture of GERZABEK, M., 2008), it is of growing interest for modern life and its societies, concerning the role which soil may play in terms of global warming and the effect of greenhouse gases.

In that sense it is unavoidable to study and to understand the different levels of carbon, nutrient levels (trophical niveaus), and especially soil organic carbon fluxes in and between the big pools of the planet Earth, where it comes from and where it goes through over the long range by metabolism and decay process.

3.1 Global Carbon Cycle

The organic matter in the soil is, as a part of the terrestrial land ecosystems, the second biggest pool of carbon in the world with 1580 Gt (more than twice as much than in the atmosphere) C stored in it. The biggest pool is the aquatic system and the oceans (39,000 Gt) before the aboveground biomass and vegetation (610 Gt) sink (NSW, 2008). The trapped reservoir of Carbonic resources in the geosphere, deep below the earth crust, does not play a role in human time scale; the earth Carbon Cycles is estimated to look on a simplified chart as followed:

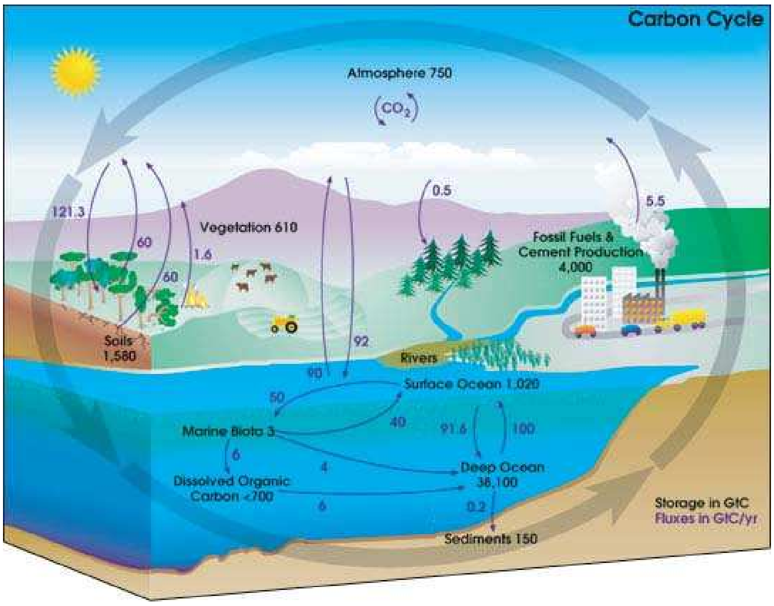


Figure2: The Global Carbon Cycle
(From: http://www.fao.org/docrep/007/y5738e/y5738e05.htm)

3.2 Regional Carbon Cycle

The occurrence of carbon stocks and fluxes depend strongly on biotic and abiotic environmental conditions and parameters of the ecological system in a specific region. Faunal, floral and fungal life is connected through the link of metabolisation of organic matter that it is incorporated in various trophical levels. That is well studied in ecological life sciences. The results are the typical eco-zones with established classes and niches which are primarily adapted to the site specific conditions in living and growing, like it is outlined in the climate zones by Koeppen, who linked geographic and meteorological properties together (KOTTEK et al, 2006).
Carbon is the basic module in all these biological systems around the world, ranging from a single cell organism onwards to the high-mass-levels of entire ecosystems.
Therefore the boarders of a carbon molecule can be seen rather arbitrarily, though there exist technological methods to follow them back in time and space to their date and place of origin, like for example the C^{14} (half time of more than 5000 years) method. In this case the content of carbon in the field has to be distinguished first, to be able to calculate the possible losses or gains after a certain period of time (STEVENSON and COLE, 1999). Furthermore the input of biomass during the investigation has to be overseen. Around 30% of organic matter arrives by plant root exudates and by the roots themselves into the soil substrate. Aboveground organic matter comes from plant residues which are either left after the cultivation season is over as plant or crop litter, e.g. from tree leaves, grasses, herbs and animal faeces or consciously left as

an organic fertiliser covering the land, if it is not incorporated by mulching methods into the soil body (KOMATSUZAKI and OHTA, 2006).

3.2.1 Soil Organic Matter (SOM)

Each soil type consists of several non-living (abiotic/inorganic) fractions such as stones, minerals and rocks, and on the other hand of living (biotic/organic) organisms like microbes, nematodes, invertebrates, and last but not least the soil organic matter. Organic matter itself occurs in different forms and states as exudates from plants or as litter from plants and decay residues from animals. Before it becomes partly dissolved in the soil solution, or bound into stable aggregates of clay and mineral complexes OM has to go through a long process which is called „turn over" or humification process, where 85% of SOM becomes humus (KLIK, 2008) while the rest is the end product of heterotrophic respiratory microbes. At the end of this process only a tiny little rest (in general 1% in aerated soils) stays in soil media for a long period of time as the soil inert organic pool (residence time from several hundreds to thousands of years). The biomass that is left consists already up to 58% of organic carbon (KUNTZE et al, 1994). This organic C can be further divided into humic substances (80% of the total material) and non humic substances (like lipids, carbohydrates, proteins, peptides and amino acids) although it is not always easy to distinguish between these two groups (STEVENSON and COLE, 1999): Humins can be separated again into Fulvic acids (light yellow ones) and into Humic acids (dark brown and black). The formation of these complex Humins is only possible after biochemical activity has produced enough metabolites (Monosaccharide, Amino acids, Peptides and phenol groups) out of the complex chains of Carbohydrates and Proteins from fresh biomass itself, which is then enabled to polymerise into humic macro molecules; this process of humification is still not fully revealed by scientific research (RAMPAZZO, 2008).
The total efflux of CO_2 from soil has mainly the following three sources (DOMANSKI, 2003):

- Root respiration
- Microbial decomposition of rhizodeposits or rhizosphere respiration
- Microbial respiration of SOM

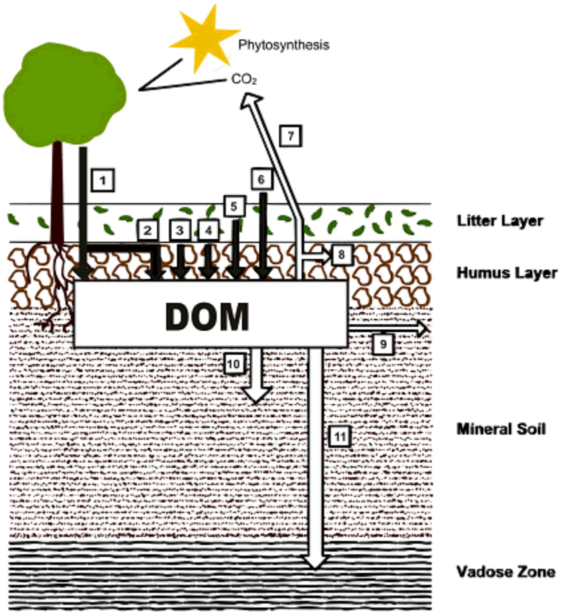


Figure 3: Sources and sinks of dissolved organic matter (DOM) in soils (Sources: 1. Through fall; 2. Root exudates; 3. Microbial lyses; 4. Humification; 5. Litter and root decomposition; 6. Organic amendments. Sinks: 7. Microbial degradation; 8. Microbial assimilation; 9. Lateral flow; 10. Sorption; 11. Leaching. (From: BOLAN et al, s.a.)

The pools of carbon in soils are manifold, and for practical reasons divided into different sub-assembly groups concerning their spatial and temporal resolution, which is referred more or less clear to the specific rate of decay. At first there is the pool of fresh residues that comes directly from the cover of vegetation or as an external organic amendment (e.g. farm yard manure). This organic plant or animal litter is divided into a fraction of faster decay (active fraction) and a slower, more stable decomposing fraction (e.g. lignin, chitins), whereby all fractions and pools are colonised by their own specific organisms and specimens which are most adapted to it:

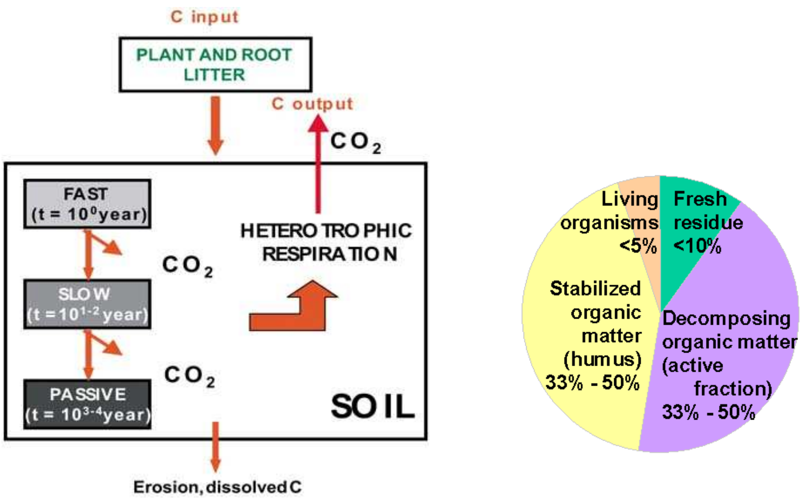


Figure 4: Simplified Soil Carbon Balance (left) and SOM fractions and pools (right)

Lit.: Carbon Sequestration in dry lands (FAO, 2004)   Lit.: Soil Biology and Landscape (INGHAM, s.a)

As it can be seen all the C emissions are lost to the environment by heterotrophic microbial respiration, which is at present the subject of many scientific research (KLIK, 2007) and not many detailed and consistent data are available, especially for Austria and the enlarged Europe.

3.3 Local Carbon Cycle

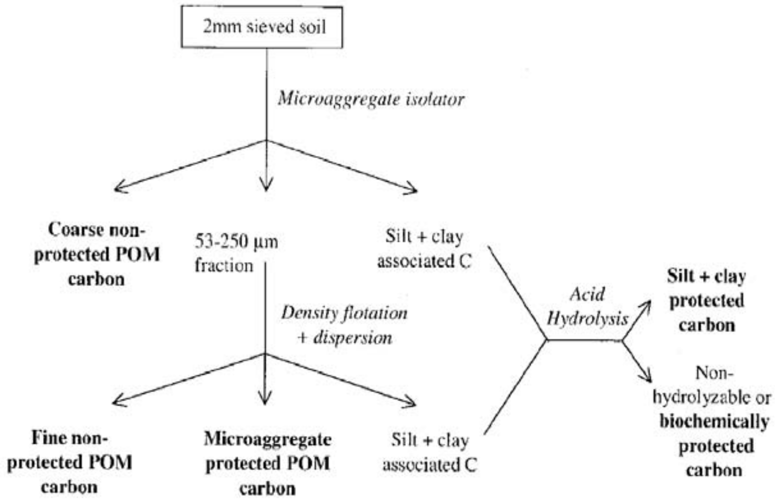


Figure 5: Fractionation scheme of SOM model (SIX et. al., 2002)

Because the light fraction bigger than 2 mm is not protected by micro aggregation it is very vulnerable to fast decrease. On the opposite biochemically protected organic matter turns over much more slowly, especially when it is not hydrolysable. Physically protected organic matter which is smaller than 2 mm has a high saving ability of SOM because it gets locked of from any disturbance. The best protection show the oldest carbon contents which are located in the finest silt and clay fractions with a mean residence time on average of several thousands of years (BATJES and SOMBROEK, 1997).

3.3.1 Soil Organic Carbon (SOC)

The main transmitter of SOC is located in the humus fraction since 58% is made of it. This humus fraction is very stable but has once again sub groups with longer and others with lower residence times in the soil environment. According to STEVENSON and COLE (1999) the mean residence time for fulvic acid is 495 years, for non hydrolysable humic acids 1400 years and for nonhydrolisable humins 1230 years (if they are hydrolysable between 10 and 100 times faster; +- 60years).

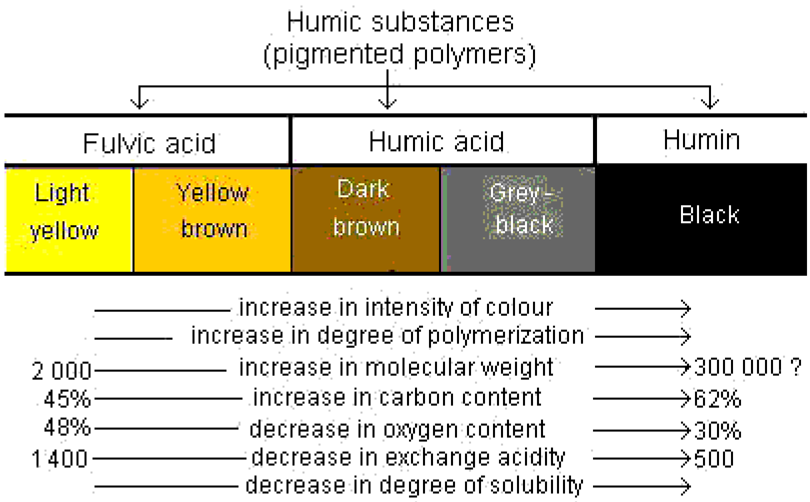


Figure 6: Properties of humic substances. Lit.: Soil Humic Substances (comp. WEBER, s.a. with STEVENSON, 1982)

The C content of a soil needs to be protected to escape mineralization and oxidation processes. This can be done by physical aggregation and air partitioning, close association with silt and clay particles or through biochemical protection for example in complexation to non hydrolysable C fractions (e.g. humins in figure 3.2.2). These specific aggregation of organic matter leads also to different pools which can be classified in order of their intrinsic decay rate and turnover time as well as according to a specific protection through silt and clay forces. The size of associated and single particle matter is another very important indication for stability and longevity (SIX et al., 2002): the pool with the biggest particle size is called the labile or light fraction (LF) and particulate organic matter (POM); both of them consist of unprotected organic matter with a high C/N ratio but only a minimal potential to mineralize N, and have hardly undergone any microbial decomposition. The quality and diversity of this fraction which is usually located at the top soil layer has a high impact on the further development of the decay process.

4. Methodologies of Measurement and Factors of Influence

The objective of this Master-Diploma-Thesis is to obtain a comprehensive view about the feasibility of how far natural carbon sequestration can contribute to mitigate global carbon emissions. Overall the following questions are to answer:

1. When do soils under agricultural use act as a sink for SOC or as a source of CO_2?
2. If agriculture may be enabled to act as a net sink, then how to achieve it most efficiently?

The research in literature for this thesis was led by these questions. As it is a topic which raised the interest of science and policy makers only during the last decade, it is not yet fully agreed and understood on and several different findings need to be further investigated, whether they may be interpreted positively or not. Examples will be given a lot, though it is still more a patchwork assessment rather than a full and holistic approach to find ways for natural mitigation measures against the imbalanced global greenhouse effect.

4.1 Measuring Approach: How to Measure SOM and CO_2 Emissions?

Before carbon can be lost by gaseous emissions from soil compartment it is more or less stable bound into the soil matrix. Therein exists a sequence of different pools of organic matter that can be further diversified, according to STEVENSON and COLE (1999), into: *litter* (hardly degraded parts of dead plants), *light fraction* (medium degraded plants already incorporated into the soil media), *microbial biomass* (bacteria and fungi), *faunal biomass* (macro soil biota, e.g.: nematodes and moles), *belowground plant constituents* (roots and root exudates), *water-soluble organics* (dissolved organic substances), and *stable humus* (the oldest and most decayed parts from all the other pools, which can be bound into long-lasting organic mineral complexes). For an absolute balance of organic carbon in the soil, all these compartments need of course to be added into the calculations - but is done rather seldom (GERZABEK, 2008; REICOSKI, s.a.). In recent years modern laboratory equipment has opened the way for investigation on another pool of soil organic matter which appears on the atomic scale and therefore is not so relevant anymore for quantification assumptions. The enzyme compounds which are fabricated by specific metabolisation steps of microorganisms can reversely be used to estimate the activity of the micro-organisms by themselves (KUZYAKOV and DEMIN, 1997).

If the carbon content of a soil should be analysed over a certain period of time (chronosequense), it needs to be known what the land was used for and how it was treated in the past, of course as well in the present, and then the hourly, daily, monthly and yearly dynamic fluxes can be estimated, due to emission measurement directly from the soil surface in the field. This so called total CO_2 efflux caused by soil respiration consists out of three different parts: Root respiration (gaseous root exudates), rhizosphere respiration (metabolites of microbial activity close to the roots), and microbial respiration (microbial mineralization of organic matter). All of these three processes have CO_2 as an end product (DOMÀNSKI, 2003), which is emitted under aerobic conditions in a direct exchange rate with oxygen to the atmosphere near the soil surface (SCHEFFER and SCHACHTSCHABEL, 2002, p. 249). In the same publication of the study book about „Soil Science" from SCHEFFER and SCHACHTSCHABEL (2002, p.75) there are three different methods stated about how to measure practically the C-content from a soil sample in the laboratory:

- Measuring the CO_2 emission by oxidisation through pyrolysis of the soil sample.
- Photometric determination of Cr(III) from the oxidised sample with Cr(VI) in sulphuric acid
- Calculating the loss of ignition at around 400°C (especially for sandy soils)

By measuring the CO_2 emissions by oxidisation through pyrolysis (combustion) over 900°C of a soil sample (method 1), it is necessary to subtract the inorganic CO_2 fraction, which may occur as a dissociation by-product at this temperature.

For the assessment of oxidisation processes in the field there exist also three main methods, which all relate somehow to a specific use of chamber measurements, therefore called chamber techniques (RETH, 2004):

- The non-steady-state non-through-flow techniques, also known as closed static chamber
- The non-steady-state through-flow techniques, also known as closed dynamic chamber
- And the steady-state through-flow chamber, also known as open dynamic chamber

The main difference lies between steady-state and non-steady-state through-flow techniques. In the first two chamber techniques, the concentration of the (rising) soil CO_2 efflux is measured typically after 2-3 minutes when the concentration has begun to stabilize in the chamber, while at the third (steady-state) technique the CO_2 can flow through the chamber, and therefore is measured by the in- and out-flowing flux. RETH (2004) conclude after calibration trials of all three chambers, that the closed static chamber underestimates CO_2 fluxes constantly at a rate between 4-14%, while the other two chamber techniques are very reliable in obtaining similar results which are highly comparable with each other. Nonetheless, it should be always taken care of wind or other disruptions to the chamber, which might cause turbulences in the field measuring. RUSTAD et al. (1999) reported for example, that chamber techniques always show higher results from soil measurements than the Eddy flux tower methods would reveal.

More complex measuring methods which can be used on a larger scale are provided with a Eddy Covariance meteorological setup (ultrasonic anemometer combined with a infrared gas analyser) that is useful for the combination of temperature, moisture and CO_2 efflux (RETH, 2004), and on the broadest scale there exists already even satellite systems like Land sat, which are of course at low resolution (km) to detect Carbon stocks from outer space by remote sensing technology (BRICKLEMYER et al, 2005).

4.2 Influencing factors towards carbon sequestration

The sequestration of carbon in agricultural soil is not a linear, but rather it is a dynamic development process which needs a long time and accurately adopted practices for the field site where it is applied on.

It can be distinguished between certain conveying ways how to attain higher carbon levels in the soil. Though as the soil environment is on the cutting site of several eco-zones (aquatic, terrestric, atmospheric) and with each of them similarly connected a multidisciplinary approach is necessary to solve the complexity step by step, always having in mind, that everything belongs and relates to each other, and nothing can be see unitarily. The basic factors that influence soil properties have biological, chemical and physical indicators (e.g.: diversity, disposition and constitution) and are of special importance for successful pedospheric operation (KLIK, 2008).

4.2.1 Biological indicators

The food web is responsible for the decay processes of organic matter. Especially near the soil surface an intact symbiosis of consumers, decomposers and detritus is very important to keep the nutrient cycles in a flowing movement. The soil flora and fauna („Edaphon“) is mainly represented by micro organisms from bacteria (several Billions per g dry soil mass), fungi and algae as well as by macro organisms like nematodes, spiders, beetles and snakes. All in all they are assumed to weigh between 2.6 and 26 t in the upper 30 cm soil layer per ha. It depends on the substrate how much they can contribute to the humified matter in arable lands (between 0.5 and 5%). The C which is bound in the microbial biomass themselves ranges between 0.027 and 4.8% (KUNTZE et al, 1994, p.132 ff).

As the majority of edaphic organisms are fungi and bacteria they are of particular interest for research. Their population growth is closely connected to respiratory activity from soil (CO_2

efflux), on the other hand restricted by the chemical-physical environment such as nutrient availability, moisture, aeration and temperature (KIRSCHBAUM, 1994).

Consequently research was carried out to investigate the co-evolution from fungi and bacteria under certain environmental conditions, with the result, that under a restored prairie (grassland) the ratio of fungi and bacteria respiration was the biggest (13.5) and also the carbon content was the highest (49.9g C/kg). In the adjacent cornfield the ratio of respiration from fungi and bacteria was much lower with 0.85 and the amount of carbon (therefore) only 36 g C/kg in that soil (BAILEY et al, 2001). Also the tillage application is significantly connected to the occurrence of microorganisms and in the end with the stored amount of carbon.

Table 1: Relation between total carbon and microbial respiration (modified from BAILEY et al, 2001)

Soil/Vegetation	Management Practices	pH	Soil Texture	Total g C/kg	Respiration (mg CO_2-Cg)	
					Fungal	Bacterial
Tallgrassland	Farmed	5.6	Clay loam	36.0	24.9	29.5
Tallgrassland	Restored	7.3	Silt loam	49.9	48.5	3.6
Agicultural land	No tillage	6.0	Silt loam	46.6	41.0	32.5
	Conventional	6.2	Silt loam	24.4	28.1	10.7

4.2.2 Chemical processes

Humic and fulvic substances (acidic) are valuable for several different reasons. They are characterised for instance through highly diversified compounds and structures which enables them to build even higher aggregates of organic chains, as well as complexes with inorganic substances (e.g.: organo-mineral complexes, so called „chelates“). Therefore the term „humus“ summarises a big variety of heterogeneous matter that varies in its reactivity with other substances, in their age by different rates of decay, and in the actual availability of nutrients. Beside the processes are interdependent to bio-physical functions and appear simultaneously to them, the main parameters which influence the vulnerable balance of soil chemistry are the pH-value, the cation exchange capacity (CEC) and the inherent ratio of carbon to nitrate, phosphorus and sulfur (140:10:1,3:1,3). It is argued by STEVENSON and COLE (1999, p.67) that residue input with low ratios like ashes from burning the straw shoots favours a net mineralization (opposite of immobilization) over longer time, while plant residues with medium C/N, C/P or C/S ratio are more likely to enable at first a net immobilization which is then followed by a net mineralization of nutrients (the opposite way to changing residue inputs). It is further stated, that at a C/N ratio below 20:1 only mineralisation of the nutrient will happen, and on the other hand beyond a C/N ratio of 30:1 only net immobilisation of the nutrient will occur. Approximately the same is true for P and S, though the ratios are 10-15 times smaller (STEVENSON and COLE, 1999, p.67).

The reactivity of chemical properties does not always show exactly the same result in the complex environment of soils, because if conditions change they can alter suddenly a chain of others as well. There exist patterns that influence the composition of the soil matter constantly. One of this pattern would be for example the variation of colloidal dispersed systems: that means, that the form of occurrence of different dispersed elements and aggregates which depend on the one hand on the concentration and temperature about how the condition of these substances are at the moment, and on the other hand has high impact on the specific (re-active) surface (m^2*m^3) itself that has developed (1 g pure clay = 200-1000m^2 surface area; from GERZABEK, 2008). Very common are transition states in colloidal systems which may vary from a so called tight „Sol“ state (flocculation) to a soft „Gel“ (coagulation) state and vice versa may change to dropping „peptisation“ state. All of this has impacts on the clay which is a hydrophobic colloid and therefore a flocculent, on the other hand humic substances, which are hydrophilic colloids with a strong effective water solvent capacity, which makes both together a very important and stable aggregate for soil morphology (KUNTZE et al, 1994, p.114).

Humates also have a large specific surface area (around 700 m^{-2}/g) which is like at clay minerals negatively charged and enables an higher cation exchange capacity (depend on pH). That (CEC) happens mostly through COOH- and phenolic OH-groups when pH is high and H+ cations dissociates which provides a dynamic balance between the nutrient solution and the adsorbed static phase in the soil (SCHROEDER,1983, p. 69).

4.2.3 Physical properties

From the physical point of view it is necessary for the well functioning of soils that they remain in a shape with high fertility that can only be achieved if they are used properly. Soil organic matter content is known to stabilise and maintain soil structure and aggregate stability. The structure of a soil is determined by the particle size, the density as well as the free porous space for water and air movement between them (up to 50 %) which gives each soil type a certain range of specific properties how it reacts towards environmental influences (RAMPAZZO, 2008): compressed soils for instance drain themselves less easier which results in bad aeration and deeper freezing depths in winter and later refreshing (lowered temperatures) in the upper solum layers during the spring time.

The physical properties basically have an impact on all other parameters that influence bio-chemical and physico-chemical processes, like temperature diffusion gradient, water retention capacity and nutrient ad- and desorption which provide either friendly or hostile living conditions for the soil flora development and enough grounded stability for faunal growth.

The buffering and filtering capacity is another characteristic physical soil property. Humic substances can also function beside clay minerals and sesqui-oxides as an agent for adsorption of organic and inorganic cations, anions as well as neutral molecules (KLIK, 2008). As humus is able to buffer acids over a wider range of pH, it is responsible for up to 70% of all possible exchange capacities in the solum (STEVENSON et al, 1999, p. 70).

Another chemo-physical characteristic feature is that different soils show certain different tones in their colour which varies according to the amount of organic C, the texture of the soil and the moisture content of the sampled profile. SCHEFFER and SCHACHTSCHABEL (2002) show that connection in a graph, where silty clays with the lowest carbon content (below 100 g/kg) have brighter colours than sands (around 100 g C/kg) and the darkest colour lines with the highest C content (up to 300 g/kg) which occur usually in peat soils (SCHEFFER and SCHACHTSCHABEL, 2002, p. 268).

Similar results have been found by ARROUAYS et al. (2004) when they observed thousands of arable soil samples with 99% particle size classes smaller than 20 micro meter (sand, silt and clay) from french topsoil down to 24.5 cm depths. They show from those results, that organic carbon content (OC) is highly effected by the fine clay and silt fraction in the top soil (20-2 micro meter and smaller). The more clay and silt were measured per kg the higher organic carbon level they attained. They conclude that the higher the aggregate stability and the lower the particle size, the more carbon is protected in the upper soil layer and therefore detained against erosion and leaching in lower depths of layers. In a further experiment ARROUAYS et al. (2008) explicitly describes, that the presence of complex organic compounds (COC) correlates with the total amount of organic carbon in french arable topsoil. The reason for this fact can be seen in the high specific area and the ability to adsorb and exchange cations between the negatively charged clay minerals and the organic substance (SCHROEDER, 1983, p. 68). This sorption between organic and mineral substances is often referred as organo-mineral aggregates, or „chelates“ (KOZÁK, 2007).

5. Results on SOC-dynamics from Field Research

The longest field experiments until today from where SOC content was continually investigated are reported from the United Kingdom (Rothamsted) and France (Versailles): At the experiment in Versailles („The 42 plots“; PERNES-DEBUYSER and TESSIER, 2004) the main question actually was to monitor how the soil will react and develop under chemical fertilization, biological amendments and without any treatment. As no crops were planted on the field (therefore no residues to for mulching available), it was found after 70 years of continuous cultivation that the physical structure collapsed everywhere in the field where organic matter content was low. On the opposite beside the field, where organic manure was added to the soil quality also was enhanced (more in detail about that research in chapter 5).

In the last decade some of them began to join together in a regional research cluster to specialize jointly on the soil organic matter assessment like the Soil Organic Matter Network (SOMNET). This Pan-European cluster collaborates in 11 European countries where it has over 40 different experiments with 18 different model applications going on, while it is connected on the global scale with every other continent and as a whole more than 70 ongoing experiments (POWLSON et al, 1998).

If soil types would appear only according to the longitudinal distance from the equator to the poles and every farmer would apply the same machinery and cultivation techniques, then it would be very easy to compare the parameters which are of interest, and conclude for other site locations and the management decisions that are needed over there. But unfortunately, this is not the case. Therefore this chapter has to be in the following order: The main chapters will be the land use (grassland, arable land) and the suborders will be climatic conditions and management practices (conventional versus organic farming). Large scale historical developments are shown in table 2 where around one third of the carbon stocks are depleted.

Table 2: Mass of C present in different soils and its loss due to cultivation (from: RASTOGI et al, 2002)

Soil type	Area (10^6 ha)	Organic C content (kg m^{-2})	Mass of C in virgin soil (Gt)	Mass of C in cultivated soil (Gt)	Loss of C due to cultivation (Gt)
Temperate forest soil	308	6.9–14.2	24.4	18.1	6.3
Temperate grassland soil	325	12.5–18.4	49.8	36.9	12.9
Tropical forest soil	439	7.1–14.5	47.3	35.1	12.2
Tropical grassland	161	9.4–17.8	21.4	15.9	5.5
Saline sodic arid soil	308	2.6–7.1	17.7	13.1	4.6
Wetlands/Paddy soil	89	11.9	10.6	7.8	2.8
Histosol	39	112	43.6	35.6	8.0
Andosol	31	23.7	7.3	5.4	1.9
Total	1727	–	222	168	54

Beside the climatic influences and the geographic particularities another thing has much impact on soil properties and processes: the way how agricultural land is systematically farmed has a big impact on the stability and fertility for the harvest and the possibilities to use it for in future again.

SOC under Tropical Climate

In a collected and edited literature from the Wageningen Press (AMÉZQUITA et al, 2008) there are reports about experiments carried out in the northern part of Latin America, namely in a small town of Costa Rica.

Esparza lies 400 meter above see-level and has 2000mm precipitation/year fro which 60% evaporates to the atmosphere. The soils are acidic with pH ranging between 5.2 and 6.2. The mean temperature between the growing season is 14-20℃.

The pastoral land use classes are described as:

a) degraded weedy pasture (longer than 50 years in use, 154.8 t/ha of C),

b) thatch grass (lat. Hyparrhenia rufa) which is longer than 100 years under the same mono cultivation and shows a soil carbon content of 220.9 t/ha^{-1},

c) sheep grass (Brachiaria decumbens) which is at least 8 years continually mono cultivated that has brought 109.6 t and for comparison reasons

d) a silvopastoral system with at least 9 years in use that has a soil C content of 120 t/ha.

The carbon contents are reported to be measured in 2002 and another time for replicates in 2004 without a significant difference. But in 2003 and 2006 other field measurements were undertaken with an improved land use management which was undertaken on three small scale farm sites. There was a) a grass monoculture: thatch grass (lat. Hyparrhenia rufa) and signal grass (lat. Brachiaria brizantha) b) a grass legume mixture: signal grass (lat. Brachiaria brizantha) and pinto peanut (lat. Arachis pintoi) which were both compared with a forage bank that exists mainly out of the leguminous pea family Veraniega (lat. Cratylia argentea).

Table 3: Total soil C stocks (t/ha/1m depth equivalent) improved land use systems in Esparza (CR) (mod. from: MARTINEZ-MENA, 2008)

Landuse	C stock in 2003	C stock in 2006	Sequestered C per year
B. brizantha pasture	145.8 +- 10.5	156.3 +- 9.3	3.5

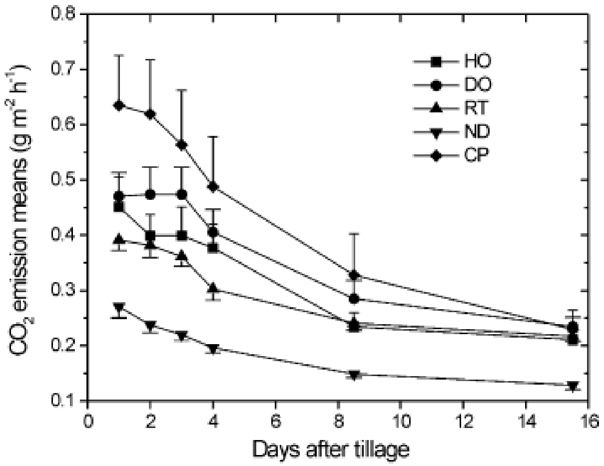
B. brizantha + Arachis pintoi	141.9 +- 11.1	154.2 +- 3.8	4.1
Hyparrhenia rufa	144.0 +- 12.5	155.2 +- 15.0	3.7
C. argentea forage bank	139.9 +- 16.7	145.9 +-8.8	2.0

It can be significantly seen, that the plots with pasture (brizantha, arachis pintoi, hyparrhenia rufa) were able to sequester more carbon, which they are well known for, because they are so called C-4 plants, which are able to use free air CO_2 more efficiently and therefore transmit more carbon directly into the soil. On the other hand, the forage bank cut offs are used for animal husbandry and are therefore not able to contribute more litter in the soil environment (MARTINEZ-MENA et al, 2008).

5.1.1 Subtropical Grassland

A field study was carried out by La Scala et al. (2000) in southern Brazil, in the state of Sao Paolo towards carbon sequestration by different tillage methods. The soil type is described as an acid (pH 4.8) Letosol with a red colour. It contains 12g C/kg^{-1} soil weight. The subtropical climate has mean temperatures around 21℃ and a mea n precipitation of 1380 mm per year. Before the experiment was installed, the field was used for growing conventional mais (lat. Zea mays) which was mechanically harvested three months before the experiment started: At the beginning of June in the year 2000 they began to set up five plots, each with an area size of 10 times 10 meter. Each plot was treated down to 20 cm in a unique way:

1) by rotary tiller (RT)
2) by chisel plough (CP)
3) reversible disk plough followed by offset disk (DO)
4) heavy offset disk harrow followed by offset disk harrow (HO)
5) was used for controlling measures and was not tilled or ploughed somehow (ND) but small crop residues were left after cultivation period.



Lit.: (LA SCALA et al, 2000)

Figure 1: Carbon dioxide emissions after application of tillage systems for a darkred Latosol, south Brazil

After tillage was applied in each of the 5 plots 8 PVC columns were buried in the centre, from which 24 hours after ploughing CO_2 emissions were measured twice a day by using a portable infrared gasanalyser from the type of a soil flux chamber technique of "Li-Cor" (serial number 6400-09). The data attained after two weeks were used under statistical analyses of the variance, and the following results were found (figure 1): emissions from DO and CP were the highest in the beginning of measurements 24 hours after the tillage events (0.47g $CO_2/m^{-2}/ha^{-1}$. The lowest emissions were measured at ND with 0.27g CO_2 per m^{-2}. The highest overall emission came from CP with 133g CO_2/m^2 then from DO (114g CO_2/m^{-2}); HO had 99.5 and RT 94 g CO_2/m^{-2}. At the end of the two weeks all tilled fields showed more ore less the same emission of 0.22g CO_2/m^{-2} /ha. The statistical means of the 5 plots were all significantly different throughout the two weeks (LA SCALA et al, 2000).

5.1.2 Subtropical Prairie

In the subtropics of southern Brazil (Paraná State) an experiment was carried out on Oxisol which is well known for the good structured porosity, a deep reaching profile and a high ability of drainage. The parent material is described as a reworked Shale and Sandstone material, the soil texture as clayey (CARLOS De M. SA et al, 2001).

The experiment was carried out to determine and compare tillage effects on frequently uncultivated soils and the effects of no tillage on the content of organic carbon. Six different plots which were divided as followed: 1) native field (NF), 2) 1-yr plough conversion of native field to cropland (PNF-1), (c) no-tillage for 10 years (NT-10), (d) no-tillage for 20 years (NT-20); (e) no-tillage for 22 yr (NT-22); and (f) conventional tillage for 22 years (CT-22). The planted crops were soybean, oats, corn and wheat at all plots (for the full input of plant residue see Annex 1).

The highest content of C sequestered by no-tillage practice was 80.6 g C m^{-2} yr^{-1} at the 0- to 20-cm depth and 99.4 g C m^{-2} yr^{-1} at the depth of 0- to 40-cm depth. The biggest amount to the total rate of sequestration appeared in the 0- to 5-cm layer (Figure 8). The amount of different depths were 31.9 g C m^{-2} yr^{-1} for the 0- to 2.5-cm layer, 21.2 g C m^{-2} yr^{-1} for the 2.5- to 5-cm layer, 12.5 g C m^{-2} yr^{-1} for the 5- to 10-cm layer, 15.1 g C m^{-2} yr^{-1} for the 10- to 20-cm layer, and 18.7 g C m^{-2} yr^{1} for the 20- to 40-cm layer. More than 60% of this increase at the no tillage plot occurred in the 0- to 10-cm soil layer.

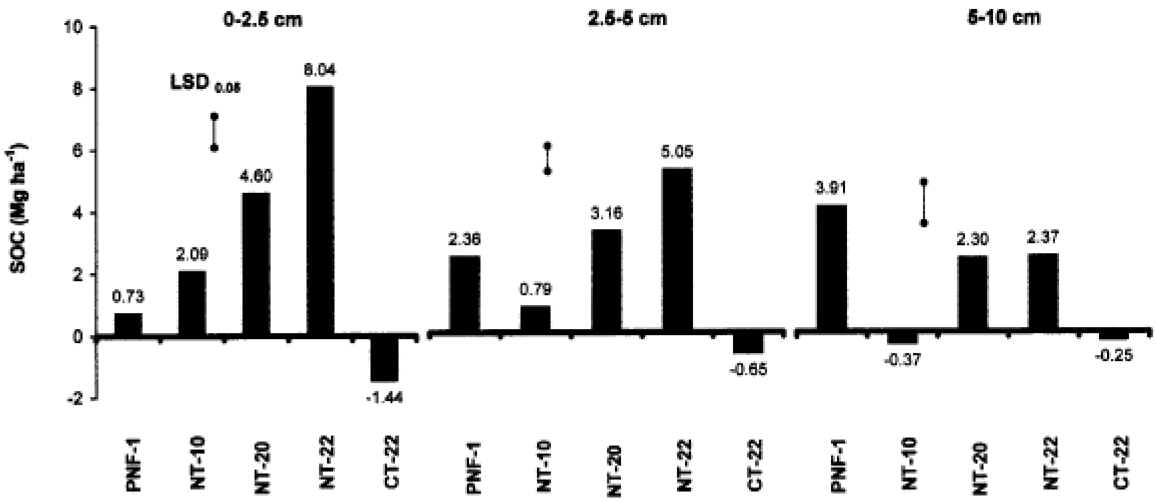


Figure 7: SOC for upper 3 soils layers of (no) tillage chronosequences treatments and LSD-Tukey test (Carlos de M. et al: Organic Matter Dynamics and Carbon Sequestration Rates for a Tillage Chronosequence in a Brazilian Oxisol)

The high increase in the top soil layers are explained as a result from high residue inputs and no soil disturbance through no-tillage effects. Silty aggregates showed disproportional higher contributions to increasing SOC at the soil surface. The long term effects of no tillage favours the conglomeration of stable macro aggregates that are mainly out of sand and silt fractions.

5.2 SOC in Drylands

Especially in dry areas where water shortage and sparse vegetation are already limiting factors, the soils are also mostly in very bad conditions. Nutrient depletion through leaching or runoff and erosion is the result from physical deterioration and chemical weathering. One of the leading soil scientists from the University of Ohio, R. LAL, describes the main soil forming factors in dry lands as calcification when the soils are well-drained (salinization if not well-drained). Therefore the most frequent soil types are characterised by low organic carbon content but high concentrations of carbonates (e.g. $CaCO_3$) and high texture which is not able to retain enough water. They are called Aridisols or Enisols and appear under hot and at least partially dry climate between the tropics and the temperate steppes and deserts (LAL, 2001).

5.2.1 Arid Conditions and Crop Rotation

Comprehensive data are reported from a long term study which took place at two sites (Bara and El Obeid) in rural areas of the province of northern Kordofan in the country of Sudan (ARDÖ and OLSSON, 2003). The experiments are located around the 13° of northern latitude and 30°eastern longitude in a semi desert environme nt with patches of forest savannah and grassland. In general only little vegetation can survive a whole year as the rainfall (280-450 mm yr^{-1}) is concentrated during a few months. According to ARDÖ and OLSSON (2003) the common grasses are Steud grass (lat. Aristida pallida), Dew grass (Eragrostis tremula) and Buffel grass (Chenchrus bifolius).

Most soils belong to three major types: they are either Xerosols (small grain size, high SOM content), Arenosols (mostly present with up to 70% coarse sand, the rest is finer sand and only 5% clay), and small parts in the south of („chromic“-) Vertisols which has more clay than sand (comp. ARDÖ and OLSSON 2003 with FAO-UNESCO 1977 and WARREN 1970).

The cultivated crops are millet (lat. Pennisetum typhoides), sesam (lat. Sesamum indicum), groundnuts (lat. Arachis hypogaea) and sorghum (lat. Sorghum vulgare). Because of several reasons, the farmers changed their cultvation habits from long fallow periods (15-20yrs) towards faster returns to the same field (4-5 yrs) with the effect of lowering yields (comp. ARDÖ and OLSSON, 2003 with OLSSON, 1993). Due to UN/FAO support already in 1963 two experiments were set up (named Kaba and Umm Higlig) from where almost full data records are nowadays available about SOC history with possible indications for the present potential of carbon sequestration (comp. ARDÖ and OLSSON, 2003 and DOXIADIS, 1964).

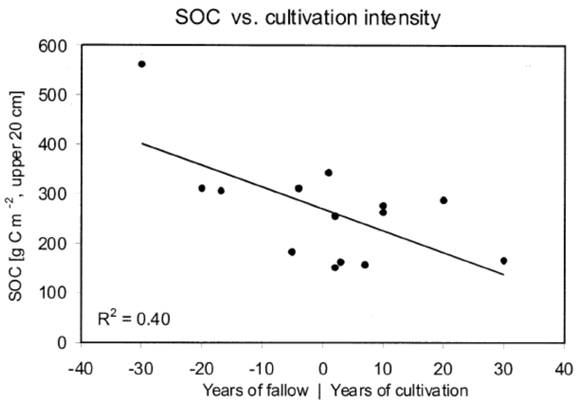


Figure 8: Soil Organic Carbon measurements versus Cultivation Intensity (ARDÖ and OLSSON, 2003)

The mean SOC content that was measured in 1963 at the site of Umm Higlig (851 g/m^2) which then lost 16.8 g C/m^2/yr^{-1} until the second measurement in the year 2000 (227 g C/m^2). The mean declines on the plots in Kaba were 15 g C/m^{-2}/yr^{-1} from 1008 g/m^{-2} down to 425 g/m^{-2} during 37 years. The statistic shows that the relationship is significantly negative between cultivation intensity and SOC content for the upper 20cm soil depth, because of decreasing SOC during cultivation periods and increasing SOC during fallow periods (Figure 9). Constant cultivation (Millet and Sorghum) statistically decreases the SOC by 4.3 g C/m^{-2}/yr^{-1} while constant fallow increases the SOC at a rate of 4.3 g C/m^{-2}/yr^{-1} which is 0.043 t C/ha^{-1}/yr^{-1} or 4.3 t C/km^{-2}/yr^{-1}. Therefore it is concluded that a cultivation-fallow cycle of 5:20 should be installed again so that carbon could be gained by 1-4 g each year per m^2 (ARDÖ and OLSSON, 2003) until a new equilibrium is established, because the schematic correlation line in figure 8 would not end abruptly, but it would adopt to either one or the other side.

5.2.2 Semi-arid Cultivation and Erosion

An experiment was conducted by MARTINEZ-MENA et al (2008) in Cehegin in the northwest of the Murcia region in the south east of Spain. At 600-800 m.a.s.l. three different land use types (abandoned land, olive plantage and forest land) were investigated on behalf of for SOC fractions:

- Total soil organic carbon (SOC)
- mineral-associated organic carbon (MOC),
- particulate organic carbon (POC)
- water extractable organic carbon concentration (WOEC)

The aim was to find out which of them would affect water erosion by rainfall events. The mean annual temperature is 16.9℃ and the precipitation balance negative with 800mm of evapotranspiration per year but only around 300 mm rainfall, so that the soil environment is mostly in an arid condition and under warm soil temperatures (comp. MARTINEZ -MENA et al. and ICONA 1988). The abandoned land was formerly used for over 100 years for cereal production with contour ploughing and has now a vegetation cover of 35% which consists in general out of native plants like rosemary (lat. Rosmarinus officinalis), rockrose (lat.Cistus clusi), and juniper (lat. Juniperus oxycedrus). The soils consist of limestone (forest and olive land) and marl (abandoned area) and are classified as Petric calcisol, Calcaric regosol and Hypercalcid calcisol for forest, abandoned and olive area, according to the international soil taxonomy (comp. MARTINEZ-MENA et al. and FAO, 2006).

Table 4: Summary of chemo-physical conditions at three different sites in Murciea region of S.E. Spain

	Horizons	Depth (cm)	Soil structure	SOC (g kg^{-1})	C/N	C.E. (d Sm^{-1})	pH H_2O	CO_3Ca (%)	Texture (%)		
									Clay	Silt	Sand
Forest	A	0–19	Moderate subangular blocky	13.5	9.37	0.59	8.02	38.2	28.1	41.4	30.6
	Ckm	+19	Structureless					81.9			
Abandoned	A	0–17	Moderate subangular blocky	6.1	5.73	0.80	8.30	32.3	26.1	42.8	31.2
	C1	17–42	Structureless	3.1	4.36	0.36	8.38	35.3	26.7	48.4	25.0
	C2	+42	Structureless	2.2	5.50	0.28	8.28	34. 9	23.3	48.6	28.1
Olive	Ap	0–20	Fine subangular blocky	6.7	6.74	1.16	8.13	61.9	22.3	41.5	36.2
	Ck	+20	Structureless	2.8	5.24	0.46	8.27	63.2	19.7	50.8	29.5

Effect of water erosion and cultivation on the soil carbon stock in Spain (MARTINEZ-MENA et al. 2007).

The rate of erosion was measured by sediment traps of the type „Gerlach“ which lead the runoff from rainfall events into plastic bottles. They were filtrated and analysed according to the overall content and to the particle size related that to the organic carbon content:

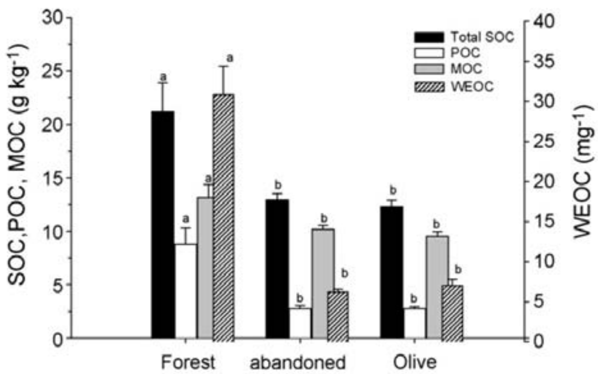


Figure 9: Total soil organic carbon (SOC, particulate organic carbon (POC), mineral-associated organic carbon (MOC) in g C/kg and water extractable organic carbon concentration (WOEC) in ml C/l for each land use type. From: (Martinez Mena et al. (2007)

A significantly higher runoff rate between intense olive crop land (24.3 mm) and forest plot (57.3 mm) was measured while the sediment concentration was around 3.4 g from the olive runoff and only 1.3 g from the forest area (each +- 1.0 g/l^{-1}). Therefore the loss of SOC was also up to seven times higher from the olive plot (273.9 g/m^{-2}) compared to the forest plot (38.3 g/m^{-2}) and the abandoned land with about twice as much as the forest plot (around 76 g/m^{-2}).

Total OC losses were 105.6 g m^{-2} in the olive area during one year, 24.8g m^{-2} on the abandoned plot during half a year, and 11.6 g m^{-2} in the forest area again during one year. Especially the three heaviest rainfall events contributed more than ¾ to the overall 16 rainfall events during the one year assessment period to the losses from the olive plot. The heavier the rainfall the more soil gets lost through erosion which can also be statistically shown. It was described by MARTINEZ-MENA et al. previously that heavy rainfall events in combination with high rates of erosion are typical for the semiarid regions in Mediterranean field experiments.

Table 5: SOC stock and SOC losses at the top 5 cm after land use change

	Soil OC stock ($g\ m^{-2}$)			Soil OC losses (%)		
	Total SOC	POC	MOC	Total SOC	POC	MOC
Forest	1397.4 (151.48)^b	599.9 (82.71)^b	837.5 (83.29)^b			
Abandoned	821.1 (29.26)^a	172.8 (16.84)^a	647.2 (21.49)^{ab}	46.4	71.2	22.7
Olive	722.8 (34.23)^a	127.2 (12.95)^a	588.7 (47.11)^a	48.3	78.9	29.7

Different letter (a, b or c) in the same column means significant statistical difference at P=0.01(Tukey T.)
From: (MARTINEZ-MENA et al. (2007)

The more rainfall occurred during a certain period of time, the higher the erosion, and the higher the loss of total soil organic carbon (P=0.01); once also the C sediment concentration (0.53 g/kg) was significantly correlated to the erosion event, and another time the dissolved organic matter (0.58 mg/l) was closely related in the statistic to a rainfall event. This and more detailed information about the data sets measurements on the erosion for each land use type can be found in the Annex 2 of Chapter 9.2.

5.3 SOC in Temperate Climate

From a survey in Switzerland (BASSIN et al, 2003) some data are available for land use types per area, altitude and the content of carbon in different soil types. That aim is to assess a national database and to reveal past and present carbon stocks and to find out more about the future possibilities to close the gap of knowledge. Because of the big amount of processed data by different statistical analyses only the most significant and important ones will be showed here in this work. A more uncommon speciality of this published data is the general differentiation between mineral (<5-10%SOC) soils and organic soils (peat lands with approximately more than 5% C content).

Usually more than 50% of the SOC stock is located in the upper 20 cm below the soil surface. Although permanent grassland is supposed to have a more shallow profile than temporary grassland it has 15-30% more carbon stored per ha on average. But it is mentioned, that there is a difference of carbon stocks between different volumes of soil bulk densities which can vary from land use methods (especially between permanent grassland and arable land) by over a 100% of difference in the bulk density with a high influence on the carbon storage capacity (BASSIN et al, 2003).

Cultivated peat lands have shown values that are 10 times higher than those from mineral soils (BASSIN et al, 2003). Of course the loss through erosion and oxidation by contra productive applied management measures is also much higher.

Table 6: Mean SOC stocks (t OC ha^{-1}) of various land-use types in mineral soils (BASSIN et al, 2003)

	Temporary grassland	Favourable permanent grassland	Unfavourable permanent grassland	Arable land
Mean SOC stocks 0-20 cm (t OC ha^{-1})	43,43	50,71	47,65	40,6
Mean SOC stocks 20-100 cm (t OC ha^{-1})	117,39	92,28	62,88	90,38

From: BASSIN et al. (2003): Carbon stocks and carbon sequestration potentials in agricultural soils in Switzerland

In the 1198661 ha grassland plus in the 289339 ha arable land (both on mineral soil) and approximately 17000 ha (organic soil) of cultivated land there is around around 170 Mt of organic stored; 72% in mineral soils, and 28% in organic soils. 24- 37 Mt (14-22%) of SOC has been lost in the past because of destructive measures such as peat land cultivation, but still maintain values which are more than 10 times higher than those from mineral soils.

5.3.1 SOC Content in a Wet and Cold Area (Grassland versus Tillage Treatments)

Another survey from Switzerland that was carried out by HERMLE et al. (2007) is focusing on a special site in the region of Tänikon. The characterisation of the area with the coordinates 8°54′22″; 47°28′53″ is a well-drained stony Orthic luvisol that has a pH of 6 and approximately 18g of SOC per each kg of dry soil matter. The mean temperature throughout the last years of the study period was 8.4°C while the precipitation amounted on average 1183 mm in each year. The aim of the study was to find out if the specific conditions of this site have an impact on tillage induced soil SOC dynamics and if yes, how the different fractions will react to it. The three different tillage methods applied were mouldboard ploughing (PL), shallow tillage (ST), and no-tillage (NT). Until the fields were cultivated rotationally every four years with winter wheat (lat. Triticum aestivum), maize (lat. Zea mays) and winter wheat-winter (lat. Brassica napius) the sites consisted of a mixed grassland. Between 1987 and 2006 the soil samples were taken at five times.

The following results have been found out by physico-chemical investigations and statistical estimations (in use of particularly small levels of significance like P<0.0001 for SOC). The bulk densities of the soil samples did not reveal to have big differences in their size (between 1.4 and 1.5 g cm^{-3}), but were larger in NT and increased everywhere in the lower soil layers. The SOC content decreased mostly at the beginning of the field study in 1987 under all 3 tillage methods and then remained stable in the 20-40 cm depth. Despite NT showed a significantly higher SOC content in the 0-10 cm layer the overall amount of SOC of the 3 methods to a depth of 40 cm was the same. In contrast to most other results reported from such experiments, the 20-30 cm surprisingly had higher SOC amount in the PL than under NT treatment (!). So the SOC per area (SOC_{ha} [Mg C ha^{-1}]) did not show a significance difference between the 3 different tillage methods, only at grassland the measurement resulted in a significant higher SOC content (P=0.003). The different pools of carbon (see also chapter 3.3.1) where divided into the labile, the intermediate and the resistant SOC fractions with the only difference experienced between grassland and NT, PL and ST at 0-10 cm level and in-between the three cultivation methods the NT differed by a higher labile organic pool from the other two methods. It can be seen in the figure 10 that under ST treatment all the fractions are higher than under PL method (HERMLE et al, 2007):

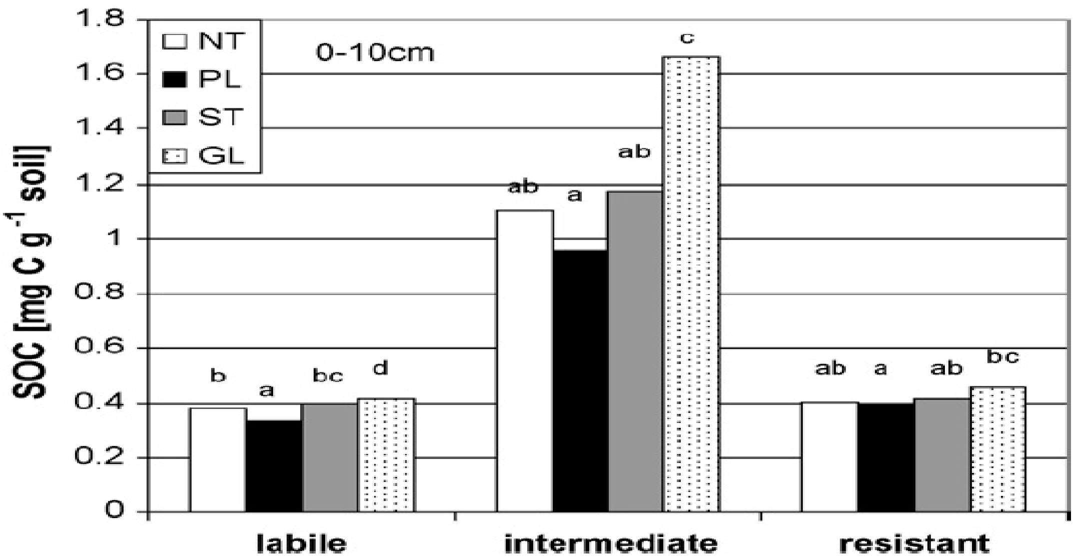


Figure 10: SOC concentration from the three different C-fractions in the 0-10cm layer
Lit.: The effect of the tillage system on soil organic carbon content under moist, cold-temperate conditions
Expl.: The statistical (p<0.0001)difference is shown in unitarily different case letters.(HERMLE et al, 2007)

The insignificance of SOC content between the different tillage methods are assumed to result from the environmental conditions (cold and wet) which are described in the literature (comp. HERMLE et al., 2007 with DEEN and KATAKI 2003, GREGORICH et al., 2005 and FRANZLUEBBERS and ARSHAD (1996) as typical side effects for a lowered turnover rates and disturbed mineralization procedures due to less activity from micro-organisms and suboptimal moisture conditions. Another deficit may be that only few measurements have been carried out during the long period of 19 years and therefore the vague conclusion needs to be taken, that in the arable soil after the initial loss of C at the beginning of the experiment the change from 3 mg C g^{-1} soil in the former pasture to finally about 1.75 mg C g^{-1} soil took place inbetween 7-14 years (HERMLE et al, 2007).

5.3.2 Humid Oceanic Climate: Land Surface Influence of Hedgerows on SOC

Hedgerows are linear plantations between agricultural fields which have been used for a long time for various positive effects like natural fences and boarders of human property, which also seemed to play an ecologically important role in the provision of the more and more decreasing niches for animals as well as functioning as a stabilisation structure for soil and water properties.

In the past the agro-ecologic value of these hedgerows were gaining more interest from pedologic sciences as they can also help to protect fields against soil erosion. Therefore a field experiment was conducted by FOLLAIN et al. in 2007 in the north west of Brittany (48°26´N, 1°19´ W). On the area of 8.5 ha hedges of chestnut (lat. Castanea sativa) and oaks (lat. Quercus robur) were grown. The soil is described as heavy, deep and loamy („Weichselian Aeolian loam“) on a 580 mio. year old pre-Cambrian granodiorite, and that is now used for the last 30 years at least as a grassland that gets slightly ploughed very seldom; last time in 1990 (FOLLAIN et al, 2007). By the use of 3D models and remote sensing techniques as well as data taken directly from soil samples in the field, they aimed to find out results on SOC evolution, dynamics and deposition which they want to derive from topographical influenced changes.

The stocks of SOC are widely dispersed (ranging from 0.1-10.3 %). The smallest level of SOC was exactly measured at the highest elevation of the plot. On the opposite the highest amounts (more than 4.8%) of SOC follows four patterns: they are located on the strip of a hedge and around 20m beside the hedge (in total 43% of the area that contribute 50% to the total C stock), as well as on thin soil layers (smaller than 40 cm), and at the lower side of small slopes (10% of the total area that contributes 20% to the total C stock) as well as in boundary areas like in the north-west of the study site (see graphic map with SOC content in Annex 10.3a). As already communicated in literature (BURKE et al, 1989, WALTER et al, 2003) the structure of a landscape (slope gradient, soil properties, drainage) has major influences on the SOC content especially on the thickness of the A-horizon near the top soil.

The investigation was focused on three different soil layers. The statistical calculations show, that the highest aerial mean (5.7 kg C m^{-2}) and median (5.2 kg m^{-2}) values are located in the 10-30cm layer. The volumetric calculations show a mean SOC stock (41.2 kg C m^{-3}) in the surface layer, followed by the maximum value (97.7 kg C m^{-3}) in the middle layer and the medium amount (77.0 kg C m^{-3}) in the deepest soil layer (30-50cm); (FOLLAIN et al, 2007).

The rise of the C/N ratio correlates positively with the SOC level in vicinity with the hedge rows (12-16), because at the plateau in the north east where no hedges can be found the C/N ratio is low (7-11) as well as the SOC content (see Annex 4a of chapter 9.7).

In conclusion the ability to sequester carbon at that specific site is in total around 15 kg C m^{-2}, respectively 9.2 kg C m^{-2} in the upper 30cm referring to 65% of the total C stored in the A-horizon, which is more than most of the other investigators derived from their experiments (see Annex 4b of chapter 9.8).

5.3.3 Sub-humid Farmland

At a long term experimental site from the University of Padua in northern Italy several examinations were made to determine soil organic dynamics under long-term trials and improved farming methods (MORARI et al, 2006):

At the site where annual rainfall is about 850 mm and temperatures range from −1.5℃ in January to a maximum average of 27.2℃ in July the evapotranspiration of 945 mm has the peak in July (5 mm d^{-1}). The water table lies through out the year close to the surface and does not fall below 2m during summer time.

Table 7: Physico-chemical characteristics of the 0-30 cm at the Old Crop Rotation (MORARIet al, 2006)

Parameters	Old Crop Rotation Trial	Soil type & fertilization exp.		
		Clay	Sand	Peat
Sand (2 mm –50 μm) (%)	47.0	25.0	93.4	38.0
Silt (50–2 μm) (%)	38.0	23.0	6.0	13.6
Clay (< 2 μm) (%)	15.0	52.0	0.6	48.4
pH	7.8	7.9	8.1	4.9
Total carbonate (g kg^{-1})	234.0	26.0	39.0	0.0
Organic carbon (g kg^{-1})	12.0	14.5	1.7	105.0
Total nitrogen (g kg^{-1})	0.99	1.5	0.15	6.7
C:N	12.0	10.0	12.0	16.0
Total phosphorus (g kg^{-1})	0.7	0.5	2.8	1.1
Available phosphorus[a] (mg kg^{-1})	47.2	161.5	26.2	100.4

The long-term experiment, which is referred to „the old crop rotation“ consists of the following five sub sample plots: (a) crop rotations (CR), (b) grass (G), (c) wheat monoculture (WHM), (d) silage maize monoculture (SMM), and (e) a high-input maize monoculture (HMM). Because of the intensive farming systems applied, most of the experiments showed a depletion of soil organic carbon contents in the long run (MORARI et al, 2006). Details for the high input amendments used at the maize monoculture plot can be found in Annex 4 (chapter 9.7).

The crop rotation (CR) took place every one (maize monoculture), two (maize-wheat), four (sugar beet-maze-wheat-maze), and every six years maize (lat. Zea mays), sugarbeet (lat. Beta vulgaris), maize-wheat (lat. Triticum aestivum), and purple medic (Medicago sativa).

Table 8: C balance from crop rotation trial (0-30 cm depth)

	Period	ΔC^a ($t\ ha^{-1}\ year^{-1}$)	C input ($t\ ha^{-1}\ year^{-1}$) Crop	FYM	Slurry	Total
High input	1962–1974	−1.23	1.99	1.86	0.00	3.85
	1974–1994	0.07	2.88	1.30	0.33	4.50
	1994–2000	−0.46	5.02	0.00	1.09	6.11
	1962–2000	−0.42	2.94	1.27	0.34	4.55
Low input	1962–1974	−0.96	1.97	1.86	0.00	3.83
	1974–1994	−0.23	3.52	0.53	0.00	4.05
	1994–2000	−0.15	3.69	0.47[b]	0.00	4.16
	1962–2000	−0.45	3.06	0.94	0.00	4.00

Lit.: Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy (MORARI et al, 2006) Explanation: a = annual change in SOC, b = applied only in the 6 year rotation

It can be seen clearly that the balance of the crop rotation is negative as only one period (1974-1994) of high fertilization input was bigger in total (crop residues, farm yard manure and slurry) than the total results of sequestered carbon showed afterwards. The details of the farming method applied can be studied in Annex 4 (chapter 9.8).

In another experiment it was tested, whether the soil particle size makes a significant difference for carbon sequestration or not. And as already seen and shown from other investigations (KUNTZE et al., 1994, chapter 4.2.2), the clay fraction has proved once again to be able to attach twice as much organic carbon to the surface than for example sand (MORARI et al, 2006).

5.3.4 Moderate-Humid Conditions

The Hilton experimental site of east Shropshire in the United Kingdom (52°33′5.7″N, 2°19′18.3″W) points out the necessity for lay farming especially for sandy soils to regenerate and reverse depletion of SOM by erosive processes (FULLEN et al. 2006). In 1991 several plots of bare soil (on sandy loam) were converted into grassland (slightly loamy sand) by sawing different kinds of perennial ryegrass (lat. Lolium perenne), timothy (lat. Phleum pratense) and white clover (lat. Trifolium repens). According to the advice from the government extensive farming practice was conducted by two grass cuts without removing the grass from the field (comp. FULLEN et al. 2006 and MARGACH, 1993) while the runoff from precipitation was carried to laboratory where it was dried at 105 °C for 24 h and weighed afterwards. Every 2-4 years soil samples were taken before and after grassland conversion was made. Altogether 400 samples were analysed to determine aggregate stability by a drip-screen rainfall simulator. The fine SOM fraction below 2 mm was measured by loss on ignition at 375 °C for 16 h (comp. FULLEN et al., 2003 with BALL, 1964 and FOSTER et al, 2000). Particle size was analysed in sieving and laser diffraction method (comp. FULLEN et al 2005 and FULLEN, 1998).

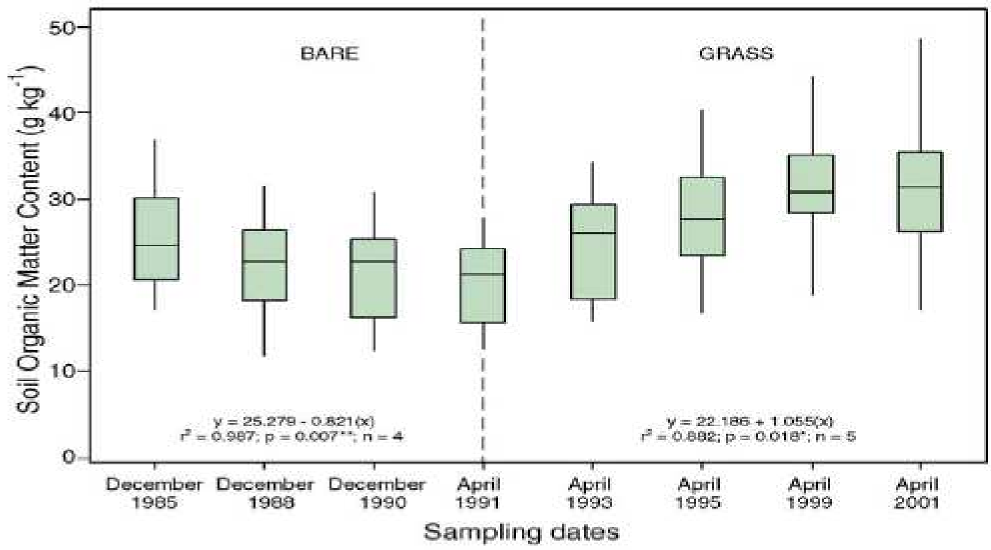


Figure 11: Box plot of Soil Organic Matter Content (g kg) at Hilton experimental site (FULLEN et al., 2005)

The Box plot shows that the highest gain of SOC occurred at the beginning of the measuring period in the grassland (between 1991-1993 and 1995). The reasons are probably the improved moisture retention capacity, a higher nutrient availability and the reduced erosion vulnerability (comp. FULLEN at al, 2005 with GUERRA 1994, and FOSTER et al, 2000) as well as the faster rate of carbon sequestration (comp. FULLEN et al, 2005 with WEDIN and TILMAN 1996, ARNALDS 1999 and LAL, 2003).

As SOM consists of about 60% SOC wherever SOM levels rise, the content of SOC will rise too. But the rate of significance that was shown in that experiment (Table 9) are surprisingly very high, maybe „that samples were not properly dispersed to their primary particle size, and consequently, the clay content was underestimated. However, this is considered unlikely, as both a chemical dispersant (sodium hexametaphosphate solution) and an ultrasonic bath were used to disaggregate samples before analysis“ (zitation from: FULLEN et al, 2005).

Table 9: Correlation coefficient (*r*) values between soil organic matter (SOM) content and particle size[a] (*n* = 50 samples)

Texture fractions	**SOM**	**Discrete silt fractions**	**SOM**	**Cumulative fine fractions**	**SOM**
Sand (60–2000 µm)	−0.51***	Coarse silt (20–60 µm)	0.43**	Clay + fine silt + medium silt + coarse silt	0.51***
Silt (2–60 µm)	0.52***	Medium silt (6–20 µm)	0.54***	Clay + fine silt + medium silt	0.51***
Clay (<2 µm)	0.37**	Fine silt (2–6 µm)	0.53***	Clay + fine silt	0.47***

Significance level: ** $P < 0.01$; *** $P < 0.001$

[a] Particle size boundaries reported are those employed by the Soil Survey of England and Wales, now renamed the National Soil Resources Institute. From: Long-term effects of grass ley set-aside on erosion rates and soil organic matter on sandy soils in east Shropshire, UK (FULLEN at al, 2005).

In an earlier experiment at the same field the connection between SOM and particle size was shown where also the pH in the sediments (less organic matter and lower pH) and the soil was compared (FULLEN et al, 1995). In this case it can be concluded that the set-aside strategy has brought very good results against soil erosion and nutrient replenishment. Even though through the sandy environment the amount of clay was small, the silt fraction outweighed the available deficit to reach a higher level of SOM and therefore sequestrating carbon significantly (FULLEN et al, 2005).

5.4 SOC under cool Environmental conditions

To close the cycle of all major climate zones around the globe, data from a long-term tillage and crop residue experiment will be presented in this chapter. The location of this survey is at one of the University of Alaska Fairbanks Delta Field Research Site (63°55′N, 145°20′W) on a silty loam, so called „Volkmar" of central Alaska (SPARROW et al, 2006). The climatic conditions are referred to as very cold, semi-arid and under a strong continental influence. The investigated tillage treatments consist out of three different forms: no tillage (NT), one time disk tillage during springtime (DO) and double application of disk tillage during spring and also in autumn (DT). The crop residues are straw and stubble, which were only removed from replicate sites to have a diversified result. Additional fertilizer were also applied, namely 112 kg of mono-ammonium phosphate and 112 kg of potassium chloride as well as 190 kg urea ha to reach 100kg of N ha, 50kg of K ha and 30 of P ha. The cropped grain is barley (lat. Hordeum vulgare). Soil samples were taken from 10 cm (depth of ploughing) and 20 cm depth. Various physical and chemical analysis were made (e.g.: wet aggregate stability, C and N content of the surface litter) as well as statistical procedures were applied (e.g. Waller-Duncan Bayes least significant difference test) to gain the following results (SPARROW et al, 2006):

Table 10: Soil profile including C content under various tillage treatment plus mineralization potential

Tillage Treatment (0-10cm depth)	Soil C (g kg^{-1})	Soil C (g m^{-2})	C mineralization potential (mg kg^{-1}soil)
Disked twice	47,0	3626	1167
Disked once	60,5	5121	1620
No-till	53,0	4879	1753
LSD	8,4	649	424

From: Soil quality response to tillage and crop residue removal under subarctic conditions
(SPARROW et al, 2006)

It is estimated that the two times disk ploughing lowers the C content in that specific soil type by 18% already after 4 years. On the other hand, crop residue management is having a high impact on the C content too (7433 g C m^{-2} with residue input, 6802g C m^{-2} without residue input). The C/N ratio was lowest with 11.3 in the DT treatment and highest with 14.4 in the NT treatment, which might be a reason for increasing appearance of fungi because of less tillage. The highest grain yields of barley were accounted during the 17 year period when investigation took place under DO (one time during spring) treatment, without difference between the other NT and DT treatment. The spring disking resulted especially in high SOM losses and soil quality deterioration (SPARROW et al, 2006).

In the 0-10cm layer the wet aggregate stability was for example found to be twice as much in the NT treatment compared to the DT treatment. It was also higher when crop residues were applied (16.2%) than without (13.8%). This correlates with similar results of different studies, which are mentioned by Sparrow (comp. SPARROW et al, 2006 and SHARRAT, 1996).

The C content, as well as the N content, were also significantly influenced by the different forms of tillage that were used (especially in the top 10 cm). The 10-20 cm soil layer was not significantly changed anymore by tillage.

6. Interpretation and Discussion of the Results

Soils with naturally high contents of C are likely to have deeper profiles, less stones and occur as nutrient rich because of higher clay contents (e.g.: deep Eutric cambisols and Orthic luvisols versus shallow Regosols and Rendzinas) and are therefore used in arable cultivation and crop rotation (BASSIN et al, 2003).

6.1 Approved Management Practices

In the previous chapters it was shown that there are ways to limit CO_2 emissions from cultivated soils and to enable the restoration of carbon in depleted soil. The possibilities are numerous, some of them are more effective and some still need to be improved. As far as it has been approved until now, the main categories of land use management for all agricultural land use types have the same principles: a) minimum tillage, b) crop rotation and therefore as much as possible input of diverse residuals, c) closed nutrient cycle through balance of fertilization and d) protection against physical erosion and chemical leaching of important soil particles through integrated water management (BATJES, 2002). More detailed assumptions about the possibilities for the future to store C in soil will be given in the outlook of chapter eight. Figure 12 shows a simulation about improved tillage practice and assumed complementing side effects (e.g.: organic farming) between SOC and increase of yields (POST et al., 2001):

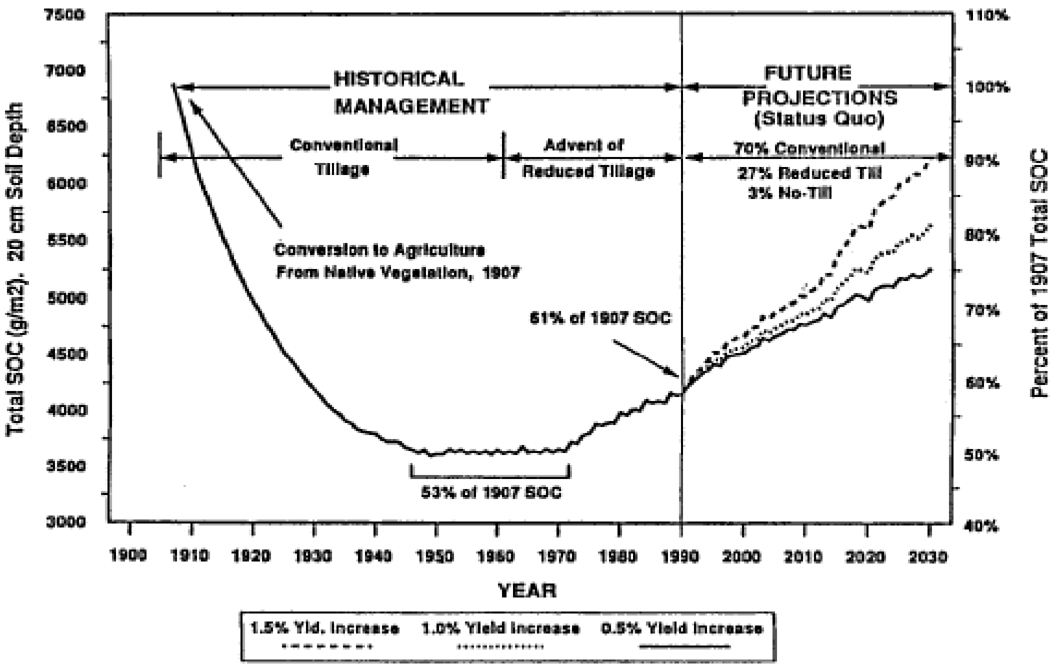


Figure 12: SOC model simulation under the assumption of higher yields in the future (POST et al., 2001)

6.1.1 Reduced Tillage and No-tillage Management

The principle idea of tillage application in farming system is to mix the upper soil layers for the main purpose that nutrients come faster into contact with metabolisation so that no natural horizons develop which then would prolong the decay times until organic matter is mineralised (FOLLET, 2001). Tillage increases the speed at which certain processes occur. For example the water-air movement together with the change of the temperature gradient, mineralisation in combination with emissions, and all kinds of weathering processes that may help to restore equilibrium state or further destabilize the development of soils which might also result in erosion. Therefore different kinds of tillage operations are now in practice (LAL and KIMBLE, 1997): „No tillage“ is considered to be the soil friendliest way of cultivation, because not more than 25% of the field width is disturbed by machinery which is only used for the sawing of seeds or plants by disk openers, in-row chisels or so called roto-tillers. „Ridge-tillage“ is also a form in which not the whole field is mechanically changed, as only the seedbed is opened in ridges with disk openers or so called row cleaners. „Mulch-tillage“is using also special techniques to incorporate weeds before cultivation starts into the soil; therefore herbicides does not need to be used and green manure is amended also at the same moment (similar to moldboard ploughing). „Reduced-tillage“is called a change of the field surface by mechanical means at which at least 15-30% of the original cover remains undisturbed. „Conventional-tillage“is when 15% and less of the initial plants and weeds can be still found in the field. Usually the term conventional tillage is combined with decreasing SOM and destabilisation of particulate SOC and disappearance of the light fraction (LAL and KIMBLE, 1997). On the other hand the term conservation tillage (CT) is referred to as increasing soil quality, with a few exceptions, because LAL (1997) explained that ploughing enabled the formation of organic clay-minerals in an experiment on a soil from West-Africa (compare CHARREAU and NICOU 1971 with LAL, 1997). Also the decline in tillage intensity especially on coarse textured soil may have very small influence on the stabilisation of SOM (LAL, 1997). So it is considered that the environmental conditions are responsible for the effects which result from tillage induced changes. The tendency of improved preservation in soils with high SOM and SOC (e.g. +8% C in a Mollisol of Argentines Rolling Pampa through NT) seems to have good reasons, as the potential gains or losses are much bigger than in areas where natural conditions are restricted for instance through aridity and therefore the effect from short term CO_2 emissions as well (ALVAREZ et al, 2001 or ELLERT and JANZEN, 1998).

In a review of PEIGNÈ et al. (2007) the results from different authors are mentioned towards a comparison between conservation tillage and conventional tillage under organic farming: ANDRADE et al. (2003) found that organic matter is more likely to come up in the tilled layer, whereby KAY and VANDENBYGAART (2002) believe that the OM content is similar between the tilled and the untilled layer (comp. PEIGNÈ et al, 2007 with ANDRADE et al, 2003 and KAY and VANDENBYGAART 2002). Similar the understandings about the content of organic carbon: some assume that it occurs more in the tilled layer like TEBRÜGGE and DÜRING (1999) or ANDRADE et al (2003), while others like BALESDENT et al. (2000) and DEEN and KATAKI (2003) think that the OC content is similar between the tilled and the untilled soil layers and only ANKEN et al. (2004) founds that the OC content is the same throughout the top soil layers (comp. PEIGNÈ et al, 2007 with TEEBRÜGGE and DÜRING, (1999), ANDRADE et al (2003), BALESDENT et al. (2000), DEEN and KATAKI, (2003) and ANKEN et al (2004). Last but not least, SIX et al (1999) have claimed to found out, that the total organic carbon content is higher under no-tillage in the 0-5 cm layer but similar in the 5-20cm horizon (comp. PEIGNÈ et al, 2007 and SIX et al (1999).

A summary of comparisons between tillage and no-tillage results about the specific C content from dozens of countries and plots can be found in MANLEY et al. (2005) under Annex 5. Several special examples among those under Annex 5 can be studied in more details, if they were available also in table 11, which combines the results from the summary of MANLEY et al. (2005) plus the extended information from the journal articles of the single authors as well.

Table 11: Extended summary from studies that compare soil organic carbon content

Source	Location	Year	Mean stored (Mg C/ha^{-1})		Max. depth (cm)	Land use	Soil type	Result/Findings
			Conv.till	No till				
Angers et al.	Eastern Canada	(1994) 11years	31.74	31.23	60	Continous tillage mgmt.	Spodsol and Inceptisols	Residue input versus tillage
Clapp et al.	Minnesota (USA)	(1993)	29.36	30.05	30	Residue (N) management	Haplic Chernozem	SOC^{13} pools
Doran et al.	Nebraska (USA)	(1981 - 86)	17.91	19.18	122	Intensive cropping, tillage mgmt.	Luvic Castanozem (silty loam)	More crops=less erosion
Hendrix et al.	Georgia (USA)	(1989)	12.14	15.38	20	Diverse tillage mgmt.	Kanhaplodult (Sandy clay loam)	29 Mg C ha^{-1} 20yr = around steady state

Larney et al.	Alberta (Canada)	(1992)	13.39	13.80	15	Continuous cropping and conservation tillage	Haploboroils (sandy clay, sandy loam)	3 diff. fractions (or pools) of C
Potter et al.	Texas (USA)	(1996)	13.92	14.29	20	Crop rotation, and residue management	Torrertic Paleustoll: sandy silt, cleyey sand	Tillage practice varitations influence SOC content
Sainju et al.	Georgia (USA)	(1995-99)	8.05	9.43	20	Legumes vs. cover crops	Kandiodults (fine loamy)	Ryegrass, no tillage and anti-erosion= +3-4%C in 5yr
Yang and Wander	Illinois (USA)	(1997)	21.89	22.58	90	Div. tillage management practices	Orthic Greycems (fine silt)	Layers of diff. SOC concentrations

From: MANLEY, J. et al, (2005) in combination with: ANGERS et al. (1997), CLAPP et al. (2000), DORAN et al. (1998), HENDRIX et al. (1998), LARNEY et al. (1997), POTTER et al. (1998), YANG and WANDERER (1999).

All extra information which was available belongs to northern America. One reason for this is, that MANLEY et al. (2005) did not write the complete literature data which they have used in their article into the literature directory of their article, therefore it is unclear where they have taken it from; of course, some of the used information comes from Journals which are locked and therefore not easily to be used. Nevertheless, in this section the available results from table 11 will be explained furthermore and compared with another summary or meta-analysis from a similar research work from OGLE et al (2005). The results come from a wide geographic range (northern America) and a broad spectrum of management practices (conventional to conservational tillage, crop rotation and residue management) it should be possible to derive similarities or conflicting measurements from most of the surveys.

ANGERS et al. (1994) observed carbon stock changes on eight different sites under continuous corn and small grain cereal cultivation by measuring three different increments from 0-40 cm and one extra measurement between 40-60 cm. According to ANGERS et al. (1994) the bulk density was not influencing the soil mass due to different tillage practices. The level of carbon only varied between upper and lower layers but not between different tillage practices as a whole. Therefore it is concluded that the site specific conditions which are commonly known for that region in eastern Canada (temperate moist) have not such an impact on tillage systems, on the crop production and again on the residue inputs, at least under a 5-10 year period of time. YANG and WANDERER (1999) also come to the conclusion, at least on their field plot with a fine silty soil (Orthic greyzems), that each applied tillage practice has no significant influence on the overall amount of SOC which is stored in the 0-35 cm soil layers. Only if the measurements are applied on a volumetrical level with a specific concentration, then the no tillage practice shows higher levels of carbon than the plots which where conventionally ploughed.

DORAN et al. (1998) reports also about conventional and reduced tillage management practices on a field plot which was used for in cultivating wheatgrass (lat. Agropyron cristatum) for ten years before it was changed to wheat again, and others, that where in use of a winter wheat-fallow system together with three different tillage practices on a former native mixed prairie sod (pasture). After 22-27 years the losses of SOC in the winter wheat rotation where raised in the 0-30 cm soil depth from 320 kg C ha^{-1} $year^{-1}$ where no tillage was applied, and 530 kg C ha^{-1} $year^{-1}$ losses at the ploughing field plots (12 to 32 %). Therefore it is concluded, that soil degradation is slowed down with reduced tillage practices in that case, but when at the same time more intensive cropping systems with longer cropping periods are cultivated, then it reduces the destructive time of fallow periods.

HENDRIX et al. (1998) have observed after 16 years of intensive cultivation a decline of 18% in SOC under not tillage and even minus 40% under conventional tillage practices applied at the Horseshoe Bend site. Surprisingly no significant differences are reported from a neighbouring site called Griffin, because of the higher clay content in that area, as it is assumed. But surrounding conditions may also influence the accumulation of carbon, as it is stated by around 0.6 Mg C ha^{-1} yr^{-1} reaching 29 Mg C ha^{-1} after 20 years, with an assumed potential on the top of accumulation level as a whole of 40 Mg C ha^{-1} in the 0-20 cm depth (HENDRIX et al.,1998).

SAINJU et al. (2002) focused in their research on soil amelioration through green manure, zero tillage and soil quality and productivity at the same time: their result showed the highest increase of SOC (+ 3-4%) when non legumes like rye grass was incorporated in the process of cultivation (instead of hairy vetch and crimson clover) and that the use of nitrogen fertilizers has to be higher, the higher SOC and SON already are (because of the filtering and buffering capacity of SOM; see chapter 3 and 4.2: influencing factors towards carbon sequestration).

CLAPP et al. (1997) investigated the amount of C^{13} in relationship to the ordinary SOC in a over 13 years continuing corn (lat. Zea mays) plot, applying different tillage practices, as well as residue input from different kinds of green manure like alfalfa (lat. Medicago sativum) and oat (lat. Avena sativa). As the time of duration from fresh ("current") and that from the older ("relic") pools were distinguished, it occurred especially when the green manure was applied, that it brought significantly different results: both (young and old) pools of SOC showed longer half-life residence times when the stover was returned to the soil and shortened when it was harvested. The longest SOC residence times where measured when the stover was not harvested at all but extra nitrogen added (CLAPP et al.,1997). LARNEY et al. (1997) investigated the influences of increased cropping intensity and decreased tillage intensity in dry areas of the Canadian prairies by refering also to three different fractions (light, mineralizable and total) of carbon in the soil. They found out, that cropping intensity by reducing fallow periods (e.g. by rotation) enables carbon sequestration, and is even more apparent if it is combined with reduced or no tillage practices. The way fallow periods are established (with or without vegetation cover) can have therefore different kind of effects on the dimension of carbon restored in the soil.

POTTER et al. (1998) claim, that although residue management is well known for enhancing the amount of SOC in soil, it is not sure, how far it influences the total amount of carbon in the soil. Therefore investigation over a thousand km throughout Texas (USA) were made with the conclusion derived from it, that on the one hand fertilization had little effect on carbon sequestration in that area of Texas, and on the other hand, that the ability for carbon sequestration is smaller the higher the mean annual temperature rises. Also the findings from OGLE et al. (2005) say, that carbon sequestration is closely connected to soil moisture, because it was found, that tropical moisture enables higher rates of sequestration then tropical dry climates, and temperate moisture conditions enables higher levels of sequestrated carbon than under a temperate dry climate.

6.1.2 Crop Rotation and Residue Management

As it is known from conservation tillage incorporation of residual parts of harvested plants are multi-purpose amendments for the soil nutrient cycle that help to improve the stability and quality at the same time. Therefore specific crops are planted to attain the best mix of underground plant residuals (e.g. N from leguminous) and aboveground litter (e.g. rye grass and Persian clover) for a natural soil amelioration. FOLLET (2001) assumes that from 100 kg crop residues 50% can be managed to be used effectively for carbon sequestration with a final result of 5-10kg that is found in SOC. If all crop residues would be used for carbon sequestration continually for 20 years then LAL foresees a potential of 5 Pg to be stored in the soil (LAL and KIMBLE,1997) and that would increase the global carbon stock in agrosoils by 0.001%.

The philosophy of organic farming tends to close nutrient cycles on the farm side by redistribution of the same amount as one commodity was withdrawn during cultivation period.

Organic farming increases the microbial biomass of the soil as well as the stability in the structure, and assures the efficient use of C and N by soil micro-organisms. This indicates also the faster rate of decay and mineralisation, especially under conventional tillage possibly to be twice as fast as under no-tillage (BALESDENT et al., 2000). Where it is not possible with a single amendment, a combination of selected additives needs to be found like a mixture of farm yard manure and clover to maintain the original humus content in a loamy sand soil (comp. FRIEDEL, 2007).

A clear indication for different plant residues from two different mono-cultivations is known from wheat (lat. Triticum aestivum) and ordinary grass land. After 100 years of permanent cultivation the old C content in the top 20 cm were 6.5 mg per each g soil in the wheat field and 10.5 mg C in each g of the soil at the grass site (BALESDENT et al. 2000). Certain plants can be grown only for amelioration purposes of the land itself. Table 12 shows some of these plants which have a high sequestration effect due to their deep reaching roots:

Table 12: Increase in SOC content (Mg/ha) of Colombian Savannah by deep rooted pastures (LAL and KIMBLE, 1997, adopted from FISHER et al., 1994)

Depth	Gamba Grass (A, gayans + S. capitata)	Koronivia grass (B. humidicola)	Koronivia+Signalgrass (B. humidicola + A. pintoi)
0-20 cm	7,1 +- 2,0	5,7 +- 4,3	17,8+- 4,2
20-40	9,3 +- 2,8	5,3 +- 3,2	18,6 +- 6,0
40-100	34,3 +- 9,3	14,9 +- 6,2	34,0 +- 10,0
Total increase	50,7 +- 11,4	25,9 +- 7,7	70,4 +- 15,5

As a general rule in land use and land management systems it is claimed in a pan European study of carbon budgets in different land ecosystems (JANSSENS et al., 2004) that grasslands act always as a sink that enables carbon sequestration while arable land under ordinary management is in almost every case a net source for CO_2 emissions.

6.1.3 Fertilization and Nutrient Management

The aim of a sustainable land management is to preserve and improve the production factor of soil. This can be done for example through effective mechanisms of carbon sequestration (LAL and KIMBLE, 1997): the two strategies to enhance the fixation of the (non-)labile C pool is either to increase micro-aggregation or the incorporation of SOC (e.g. manure) into the subsoil layers.

Especially for N fixation the cropping system may be adopted productively by intercropping (combining cereals and legumes for instance), crop rotation management (iteration every couple of years) or other symbiotic measures to improve plant growth and soil quality like the application of legumes and crops which have different root depths (PEIGNÈ et al, 2007).

Farmers explore nowadays more and more again low input cultivation, as it was already before the green revolution began to intensify the agriculture, by installing fallow lands. In this system, arable fields are used for a couple of years before they are set aside for natural recreational purposes, even sandy soils, as observed by MARTINS et al. 1991 (comp. LAL and KIMBLE, 1997 and MARTINS et al, 1991). As the depletion of C sources goes fast, the restoration takes much longer scales of time; although the speed can be a little bit increased by the use of farm yard manure (FYM) plus chemical fertilisers, which in the combination shows the highest effects towards carbon sequestration. Just for maintaining the stock of carbon although ordinary cultivation takes place, FYM and clover grass can add enough fresh humus into the soil system, but the pH content should be kept between 5-7 for better stability of the soil structure (FRIEDEL, 2007).

Cover crops are also an effective strategy to protect the soil surface against all kinds of destructive forces. Furthermore the soil moisture is stabilised and the nutrients are retained against mineralisation processes. LAL et al (1978) also reported that already after two years the SOC increased when grasses and leguminous cover crops were planted in a disturbed Alfisol of Western Nigeria (comp. LAL et al, 1997 with LAL et al, 1978).

6.1.4 Erosion Control and Water Management

The prevention of erosive processes needs to be evaluated carefully. From the slope angle onwards at the macro scale, to the cropping system (plantage, agro-forestry, crop rotation etc.) at the mesoscale down to the micro scale where the main soil parameters like aggregate stability, bulk density, and porosity and pore size distribution can provide an extensive view about the soil vulnerability towards erosion. These soil parameters are again closely connected to the land management under which cultivation takes place. Therefore the summary of PEIGNÈ et al. (2007) about different tillage systems provides a comprehensive overview about the influence on the effected parameters:.

Table 13: Effects of tillage systems on soil porosity and aggregate stability, bulk density and pore size

Soil components	Comparison of conservation tillage vs. conventional tillage	References
Aggregate stability	More stable in surface layer	Ball *et al.* (1996), Arshad *et al.* (1999) and Stenberg *et al.* (2000)
	More clay decreases differences between tillage system	Tebrügge & Düring (1999)
Total porosity	Greater or no difference in surface layer (0–5 cm) with no tillage	Guerif (1994) and Rasmussen (1999)
	No difference in tilled layer with shallow tillage	
	Less in the untilled layer and the whole topsoil	Ball & O'Sullivan (1987) and Kay & VandenBygaart (2002)
Soil bulk density	Smaller or no difference in surface layer (0–5 cm) with no tillage	Tebrügge & Düring (1999)
	Greater in the untilled layer and the whole topsoil	Arshad *et al.* (1999), Rasmussen (1999) and Deen & Kataki (2003)
	No difference or higher in the subsoil	Tebrügge & Düring (1999)
Pore size distribution	More micro and mesopores in conservation tillage	Guerif (1994) and Kay & VandenBygaart (2002)
	Fewer pores with diameter from 30 to 100 μm	Chan (2001)
	More biopores (diameter 100–500 μm)	Ball & O'Sullivan (1987) and Kay & VandenBygaart (2002)
	Fewer irregular and elongated shaped pores > 1000 μm	
	Greater connectivity of vertical biological porosity in long term	Chan (2001) and Anken *et al.* (2004)

From: Is conservation tillage suitable for organic farming? A review (PEIGNÈ et al, 2007)

Rain events as well as the experimental water drop method show that macro aggregates are more vulnerable to be physically destroyed by the mechanical influence of water and temperature (through swelling and shrinking – especially of the clay fraction) than micro aggregates, which are then more affected by microorganism through oxidation and mineralisation. These effects can be not only reduced by no tillage but also by applying mulching methods (GREGORICH et al., 1998).

The threat of long term destruction due to topsoil compaction from physical distortion needs to be managed (comp. PEIGNÉ et al, 2007 with ARVIDSSON and HAKANSSON 1996). Especially when the soil moisture content is regarded as a key parameter for success of harvest and soil fertility, infiltration rates should be high for enough water uptakes by the soil.

Water management has to play an important role in C sequestration, as the soil water has a great impact on soil inherent processes of all different kinds. Possibilities to alter water management practices are in the fields of water conservation, water harvesting and drainage (LAL et al., 1997).

The main reasons for soil erosion vulnerability through wind and water erosion are the increase in bare soil surface due to late and low soil cover. Such a shift in cultivation and crop rotation in combination with the wrong tillage practices leads to the destruction of the soil structure (KLIK, 2008). That some areas in the field might be especially effected due to its exposition have been already shown in connection with SOC accumulation at certain hidden places (French example from FOLLAIN et al., 2007). The opposite way of dissaccumulation is shown in Table 13 from a paired toposequence of cultivated and native soils in Saskatchewan, Canada (GREGORICH et al., 1996). The lower ends of slopes were depicted to have higher SOC content as their A horizon is thicker because they were less exposed to water and wind erosion, while top slopes with thin upper soil layers showed erosion rates between 40-70%. It is further reported that the loss of SOM and SOC content at the beginning of cultivation on a native field is caused by mineralisation (during the first two decades approximately 20% loss of SOC) but the main loss of C is induced at a later stage due to wind and water erosion of soil which amounts around 50% losses after 5 decades of cultivation (GREGORICH et al., 1996).

Table 14: Average depth and carbon concentration in the A horizon and the solum carbon content in native and cultivated Chernosemic toposequences (GREGORICH et al., 1998):

Toposequence slope position	A horizon		Solum Organic C (Mg ha^{-1})
	Depth (cm)	Organic C (g kg^{-1})	
Brown Chernozem			
Native [a]			
Upper	9	27	47
Mid	12	29	82
Lower	14	42	158
Cultivated			
Upper	10	14	23
Mid	15	17	89
Lower	32	25	188
Dark Brown Chernozem			
Native			
Upper	7	63	85
Mid	10	49	87
Lower	13	50	129
Cultivated			
Upper	9	17	25
Mid	11	18	50
Lower	20	22	98
Black Chernozem			
Native			
Upper	15	46	78
Mid	21	44	129
Lower	19	49	149
Cultivated			
Upper	11	22	46
Mid	17	29	99
Lower	29	31	164

[a] n=4 toposequences under each management.

From: Carbon distribution and losses, erosion and deposition effects (GREGORICH et al., 1996)

6.2 Conclusion

High losses of carbon appear when native (uncultivated) soils are changed into arable lands. Most of the losses occur at the beginning of the cultivation period. The losses can amount to more than over 50% of the initial C stock that was formerly stored during a much longer period of time. The main factors beside the weather are qualitative soil properties such as texture and particle size fractions for instance as well as the quantitative soil composition. The highest losses take place on coarse-textured soils and in a wet climate (comp. BALESDENT et al, 2000 with BURKE et al., (1989), and BROWN and LUGO 1990).

Table 15: Evaluation of soil management practices to increase carbon stocks

Treatment	Effect on OM input (changes to primary production and/or supplied to the soil)	Effect on OM output (rate of mineralization)	Other positive effects	Negative secondary environmental effects	Additional carbon stock (Mg C ha^{-1} $year^{-1}$)
No-till	Slightly low production, slightly low level of OM conversion into humus	Low rate (increased protection of OM due to improve soil aggregate)	Erosion control, reduced fuel consumption	Slightly low production use of pesticide, emission of N_2O to be confirmed	0.07–0.33
Crop rotation	Increase OM input	Increases soil respiration	Breaks the insect and pest cycle	None	0.05–0.25
Cover cropping	Annual production and increase OM returned (crop not harvested)	Increases soil respiration	Scavenging residual nutrients, erosion control, reduces fertilizer consumption	Possible emission of N_2O	0.15–0.25
Manure application	Exogenous OM input increases production by the addition of nutrients	Increases soil respiration	Improves soil productivity	N leaching and N_2O emission if excessive inputs occur	0.05–0.15

From: Technical Report Soil management practices for sustainable agro-ecosystems (KOMATSUZAKI and OHTA, 2006 with ARROUAYS et al., 2002, LAL 2004 and ROBERTSON et al., 2000).

Table 16: Sumary of data used in the previous chapter 5 from various sources

Place	Plot	Time	Climate	Soil	Result	Scale	Literature
Esparza, Costa-Rica	Improved grass (1m depth)	2003-2006	Tropical (Grassland)	Alfisol, Inceptis.	3,5 - 4,1	C t ha yr	Mannetje et al., 2008
Sao Paolo Brasil	Tillage Mgmt.	2-3 week	Subtropical (Grassland)	Latosol	99,5 - 133	g CO_2/ m^2	La Scala et al., 2000
Paranà Brasil	Tillage and Residue Mgmt.	22 years	Subtropical (Prairie)	Clayey Oxisol	-1,44 - +8,04	g CO_2/ m^2 per year	Carlos et al., 2001
Kordofan (Sudan)	Crop Rotation	1963-2000	Semidesert (Savannah)	Xerosol, Vertisol	-4,3 - + 4,3	g C/ m^2/yr	Ardö et al., 2003
Murcia (Spain)	Cultivation and Erosion (Olive)	2007	Semiarid (Plantage)	Calcisol, Regosol	24,8- -105,6	g C / m^2	Martinez et al 2007
Tänikon (Suisse)	Grassland and Tillage Mgmt.	1987-2006	Wet+Cool (grassland)	Orthic Luvisol	-1,25	mg C / ha	Hermle et al., 2007
Padua (Italy)	High v.s. low-input Cropland	1962-2000	Sub humid (Farmland)	Not identified	-1,23 - + 0,07	t ha year	Morari et al., 2006
Shropshir (UK)	Baresoil con-version tograss	1991-2001	Moderate Humid	Sandy, Loamy	22-31 + 25 - 30	SOM g/kg (means)	Fullen et al., 2005
Faribanks (Alaska)	Tillage and Residue Mgmt.	17 years	Cold, arid, Continental	Silty loam	53 - 47	SOC g/kg	Sparrow et al., 2006

Symbiotic side effects beside a decreasing C concentration in the air are an increased soil fertility, improved water holding capacity and many other enhanced functions from the soil like the filtering and buffering capacity, the cation exchange capacity plus a gain of structural diversity and stability which enable again important a-biotic functions.

Although exact findings from the past are scarce and only available in a limited length more and more estimations are currently made for future simulations with a broad range of uncertainty. So the current methods could be unified with their application focused by the same weighted effort on applied natural science as well as on the socio-economic background to achieve a technical and environmental feasible way to solve the gaps of knowledge plus increasing the confidence in approved land use management practices. For Canada it is for example estimated, that a conversion during the next 50 years from summer fallow to cerreals would result in 0.4 Tg C per year and with hay up to 1.8 Tg C per year increase of SOC, which is 11.8% respectively 54.1% of their total agricultural emissions (DUMANSKI et al., 1998).

Table 17: SOC sequestration possibilities under different management practice for the EU and the USA

Region	Practice	MMTC yr	Carbon Sequestration potential (t C ha yr)	Yearly increase in SOC (Tg yr)	MMT C	Reference
EU15	No-till		0,34% - 1,12%	10,9 – 35,8		SMITH et al. 1998
Wider Europe	No-till		0,34% - 1,12%	20,3 – 66,5		SMITH et al. 1998
	No-till	24,4	0,38	2,4		SMITH et al. 2004
	Permanent Crops	?	0,62	?		SMITH et al. 2004
	Animal manure	23,7	0,38	?		SMITH et al. 2004
	Cereal straw	5,5	0,69	?		SMITH et al. 2004
	Composting	3	0,38	3		SMITH et al. 2004
	Bio-energy crops	4,5	0,62	0,9		SMITH et al. 2004
	Organic farming	3,9-11	0,54	3,9		SMITH et al. 2004
	Convert cropland into grassland	8,7 – 12,13	1,2 - 1,69	?		SMITH et al. 2004
	Convert arable into grassland	0?	1,4	0?		FREIBAUER et al. 2004
	Avoid deep ploughing	0?	1,4	0?		FREIBAUER et al. 2004
	More shallow watertable	4	1,4 – 4,1	4		FREIBAUER et al. 2004

	New crops on restored wetland from arable land	0?	2,2 – 4,6	0?	FREIBAUER et al. 2004
	New crops on restored wetland from grassland	0?	0,8 – 3,3	0?	FREIBAUER et al. 2004
USA	Conservation Tillage	17,8 – 35,7			FOLLET 2001
	Crop residue/ biomass management	11 – 67			FOLLET 2001
	Fallow reduction	1,4 – 2,7			FOLLET 2001
	Rotation and winter cropping	5,1 – 15,3			FOLLET 2001
	Fertilizer management	6 - 18			FOLLET 2001
	Farm manure	3,6 – 9,0			FOLLET 2001
	Supplemental irrigation	1,0 – 3,2			FOLLET 2001

From: (SMITH et al, 2004; FOLLET, 2001; FREIBAUER et al., 2004).

There exist global estimates which say that the total fossil fuel consumption from the whole world during ten years could be stored in soil during the next 50-100 years. This means it takes a long time and the saving potential is not without an end. Nevertheless if all the positive side effects especially those for disadvantegeous countries (naturally poor, dry aridic conditions) are kept in mind, the fostering of carbon sequestration gains a high value for a clean and profitable way of development with poor states.

An IPCC publication in 1996 about a user manual for land managers pointed out the clean development mechanism which should lead towards effective changes of land use practice. A clean development mechanism (CDM) is mentioned there in connection with development aid and international carbon trading. The aim is and will be more than ever to stimulate the international trade of GHG between the rich and the poor countries by using this „clean development mechanism.

7. Summary

The main objective of this master thesis was a comprehensive research in literature about the topic of how much carbon is possible to store in an agricultural used soil under certain management practices. Therefore the specific site conditions of a field had to be focused on and in particular the history of the land use which has exceptional implications to derive further management options.

To resolve a considerably large spectrum of this broad topic an extensive research in literature was necessary. The coverage followed books from the library concerning the same field of interest as well as papers from Internet data banks of “CAB-Abstracts”, “Science Direct” and “Springer Link” (http://www.boku.ac.at/datenbanken.html). As a whole about 100 different texts were used to complete this master thesis within the winter semester of the year 2008.

As a final conclusion of this work it can be derived, that land use management is a important working area for mitigating measures towards a more friendly and environmentally sound way to reduce harmful greenhouse gases for an enhanced world climate. Sometimes a properly managed land use can even contribute to return some of those polluting gases like CO_2 if they are brought back into the natural cycle of pedogenic elements. Restraints may occur after some decades of the same management practice when new equilibrias have filled up the potential of carbon stocks in formerly depleted soils.

In general the conclusion for agricultural fields beside forests and plantations, that wherever the natural ecological conditions enables the accumulation of soil organic matter, it is more easy to deplete them but also more likely to restore them in an efficient manner after a durable period of time.

The following table 18 shows a summary of all data which were used in the previous chapters about carbon storage under different management practice.

Table 18: Summary of all used datasets for different Management Practices and surveyed SOC dynamics (combination of table1,10,11 and16).

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Esparza, CostaRica	Improved grass (1m depth)	2003-2006	Tropical (Grassland)	Alfisol, Inceptis.		3,5 - 4,1		C t ha yr	Mannetje et al.
Sao Paolo Brasil	Tillage Mgmt.	2-3 week	Subtropical (Grassland)	Latosol		99,5 - 133		g CO_2/ m^2	La Scala et al.
Paranà Brasil	Tillage and Residue Mgmt.	22 years	Subtropical (Prairie)	Clayey Oxisol		-1,44 - +8,04		g CO_2/ m^2 per year	Carlos et al.
Kordofan (Sudan)	Crop Rotation	1963- 2000	Semidesert (Savannah)	Xerosol, Vertisol		-4,3 - + 4,3		g C / m^2/yr	Ardö et al.,
Murcia (Spain)	Cultivation and Erosion (Olive)	2007	Semiarid (Plantage)	Calcisol, Regosol		-105,6- +24,8		g C / m^2	Martinez et al.
Tänikon (Suisse)	Grassland and Tillage Mgmt.	1987- 2006	Wet+Cool (grassland)	Orthic Luvisol		-1,25		mg C / ha	Hermle et al.

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Shropshir (UK)	Baresoil con-version tograss	1991- 2001	Moderate Humid	Sandy, Loamy		22-31- +25-30		SOM g/kg (means)	Fullen et al.
Fairbanks (Alaska)	Tillage and Residue Mgmt.	17 years	Cold, arid, Continental	Silty loam		53 - 47		SOC g/kg	Sparrow et al.
Padua (Italy)	High v.s. low- input Cropland	1962-2000	Sub humid (Farmland)	Not identified		-1,23 - +0,07		t ha year	Morari et al.
Eastern Canada	Continous tillage mgmt.	(1994) 11years	Atlantic Influence	Spodsol and Inceptisols (60cm)	31.74		31.23	Mean stored (Mg C/ha^{-1})	Angers et al.
Minnesota (USA)	Residue (N) management	1993	Continental Climate	Haplic Chernozem (30cm)	29.36		30.05	Mean stored (Mg C/ha^{-1})	Clapp et al.
Nebraska (USA)	Intensive cropping, tillage mgmt.	(1981 -86)	Cool winters semi-arid summers	Luvic Castanozem (silty loam) (122cm)	17.91		19.18	Mean stored (Mg C/ha^{-1})	Doran et al.
Georgia (USA)	Diverse tillage mgmt.	1989	Humid sub-tropical mildwinters	Kanhaplodult (Sandy clay loam; 20cm)	12.14		15.38	Mean stored (Mg C/ha^{-1})	Hendrix et al.

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Texas (USA)	Crop rotation, and residue management	1996	Hot and dry semi desert or deserted climate	Torrertic Paleustoll: sandy silt, cleyey sand (20cm)	13.92		14.29	Mean stored (Mg C/ha^{-1})	Potter et al.
Georgia (USA)	Legumes vs. cover crops	(1995-99)	Humid sub-tropical mildwinters	Kandiodults (fine loamy; 20cm)	8.05		9.43	Mean stored (Mg C/ha^{-1})	Sainju et al.
Alberta (Canada)	Continuous cropping and conservation tillage	1992	Cold winters, warm summers; very dry	Haploboroils (sandy clay, sandy loam; 15cm)	13.39		13.80	Mean stored (Mg C/ha^{-1})	Larney et al.
Illinois (USA)	Div. tillage management practices	1997	Humid continental climate	Orthic Greycems (fine silt; 90cm)	21.89		22.58	Mean stored (Mg C/ha^{-1})	Yang and Wander
(Richland, WA, USA).	Farmed	2000	Hot and dry climate	Clay loam		36.0		Total g C/kg	Bailey et al.,
(Batavia, IL, USA).	Restored	2000	Humid continental	Silt loam		49.9		Total g C/kg	Bailey et al.,
(Atmore, AL, USA).	No tillage	2000	Warm, humid	Silt loam		46.6		Total g C/kg	Bailey et al.,

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Fairbanks (Alaska)	Disked twice	1980-2000	Arctic Cold semi arid	Coarse silt over sand	47			Soil C (g kg^{-1})	Sparrow et al.
Fairbanks (Alaska)	Disked once	1980-2000	Arctic Cold semi arid	Coarse silt over sand		60,5			Sparrow et al.
Fairbanks	No-till	1980-2000	Arctic Cold semi arid	Coarse silt over sand			53	Soil C (g kg^{-1})	Sparrow et al.
(Alaska)	LSD	1980-2000	Arctic Cold semi arid	Coarse silt over sand		8,4			Sparrow et al.
Fairbanks	Disked twice	1980-2000	Arctic Cold semi arid	Coarse silt over sand	3626			Soil C (g m^{-2})	Sparrow et al.
(Alaska)	Disked once	1980-200	Arctic Cold semi arid	Coarse silt over sand		5121			Sparrow et al.
Fairbanks	No-till	1980-2000	Arctic Cold semi arid	Coarse silt over sand			4879	Soil C (g m^{-2})	Sparrow et al.
(Palouse, WA, USA).	Conventional	2000	oceanic	Silt loam		24.4		Total g C/kg	Bailey et al.,
Argentina		1994		20	49		51	(Mg C/ha^{-1})	Alvarez et al.
East. Can.		1994		60	31,74		31,23	(Mg C/ha^{-1})	Angers et al.
France		1990		30	25,55		26,11	(Mg C/ha^{-1})	Balesdent et al.

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Bolivia		1993		15	12,04		14,7	(Mg C/ha^{-1})	Barber et al.
Brazil		1994		30	47,4		52,9	(Mg C/ha^{-1})	Bayer et al.
Georgia		1991		15	17,7		22,74	(Mg C/ha^{-1})	Beare et al.
Manitoba		1998		48	21,9		20,52	(Mg C/ha^{-1})	Bergstrom et al.
North Dakota		1989		91,2	68,69		67,92	(Mg C/ha^{-1})	Black and Tanaka
Kentucky		1975		30	27,43		31,53	(Mg C/ha^{-1})	Blevins et al.
Kentucky		1980		15	17,48		25,04	(Mg C/ha^{-1})	Blevins et al.
Saskatchewan		1986-94		15	7,14		7,63	(Mg C/ha^{-1})	Campbell et al.
Australia		1989		20	11,49		13,82	(Mg C/ha^{-1})	Chan et al.
Minnesota		1993		30	29,36		30,05	(Mg C/ha^{-1})	Clapp et al.
Australia		1981		120	34,47		35,55	(Mg C/ha^{-1})	Dalal
South Carolina		1999		15	9,34		12,53	(Mg C/ha^{-1})	Ding et al.
Nebraska		1980		30	12,67		14,48	(Mg C/ha^{-1})	Doran

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Nebraska		1981-96		122	17,91		19,18	(Mg C/ha^{-1})	Doran et al.
Alabama		1990		20	10,49		15	(Mg C/ha^{-1})	Edwards et al.
Nebraska		1989		30	52,11		57,27	(Mg C/ha^{-1})	Eghball et al.
Texas		1991		20	21,16		27,18	(Mg C/ha^{-1})	Franzluebbers et al.
Brazil		1998		30	36,09		38,4	(Mg C/ha^{-1})	Freixo et al.
Georgia		1983		21	19,12		22,88	(Mg C/ha^{-1})	Groffmann
Minnesota		1991-95		7,5	8,71		9,56	(Mg C/ha^{-1})	Hansmeyer et al.
Georgia		1989		20	12,14		15,38	(Mg C/ha^{-1})	Hendrix et al.
Illinois		1997		15	35,63		43,47	(Mg C/ha^{-1})	Hussain et al.
Kentucky		1989		30	12,97		15,56	(Mg C/ha^{-1})	Ismail et al.
Iowa		1992		20	37,47		52,42	(Mg C/ha^{-1})	Karlen et al.
Nebraska		1995		15	10		11,66	(Mg C/ha^{-1})	Kessavalou et al.
India		1998		10	11,03		11,77	(Mg C/ha^{-1})	Kushwaha

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Nebraska		1981-82		30	10,29		11,32	(Mg C/ha^{-1})	Lamb et al.
Alberta		1992		15	13,39		13,8	(Mg C/ha^{-1})	Larney et al.
Brazil		1998		200	101,35		105,22	(Mg C/ha^{-1})	Lilienfein et al.
Brazil		1995		40	41,66		44	(Mg C/ha^{-1})	Machado and Silva
Ohio		1991		15	19,65		51,07	(Mg C/ha^{-1})	Mahboubi et al
Morocco		1998		20	16,98		20,03	(Mg C/ha^{-1})	Mrabet et al.
Alberta		1990		15	15,98		16,81	(Mg C/ha^{-1})	Nyborg et al.
North Dakota		1982-91		30	15,59		15,59	(Mg C/ha^{-1})	Peterson et al.
Michigan		1997		20	28,78		33,89	(Mg C/ha^{-1})	Pierce
Texas		1996		20	13,92		14,29	(Mg C/ha^{-1})	Potter et al.
US South		1991		15,2	16,26		20,01	(Mg C/ha^{-1})	Rhoton et al
Georgia		1995-99		20	8,05		9,43	(Mg C/ha^{-1})	Sainju et al.
Midwest		1995		20	11,75		13,55	(Mg C/ha^{-1})	Six et al.

Place	Plot	Time	Climate	Soil	Conventional Tillage	Improved Management Plot Practice	No Tillage	Scale	Literature
Ontario		1994		50	9,46		8,94	(Mg C/ha^{-1})	Wanniarachchi et al.
Ontario		1999		60	32,88		39,07	(Mg C/ha^{-1})	Yang and Kay
Illinois		1997		90	21,89		22,58	(Mg C/ha^{-1})	Yang and Wanderer

8. Literature

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9. Content of the Annex

9.1 Annex :1

Treatments	Crops	Total Fertilizer† N	Total Fertilizer† P_2O_5	Total Fertilizer† K_2O	Dry Mass Total	Dry Mass Relative
		kg ha^{-1}				%
NT-10‡	Soybean	–	285	326	21 900	23.9
	Oat§	–	–	–	25 500	27.8
	Corn	269	216	228	31 700	34.7
	Wheat	138	184	160	12 400	13.6
	Lupine§	–	–	–	–	–
	Lolium¶	–	–	–	–	–
	B. Bean	–	–	–	–	–
	Total	407	685	714	91 500#	100
	Annual input	40.7	68.5	71.4	9 150	–
NT-20††	Soybean	38	611	625	48 400	27.3
	Oat§	–	–	–	48 100	27.1
	Corn	383	350	363	55 700	31.5
	Wheat	222	511	333	20 200	11.4
	Lupine§	–	–	–	4 780	2.7
	Lolium¶	–	–	–	–	–
	B. Bean	–	–	–	–	–
	Total	643	1 470	1 320	177 000#	100
	Annual input	32.2	73.6	66.1	8 860	–
NT-22‡‡	Soybean	100	730	730	51 200	30.6
	Oat§	–	–	–	14 300	8.5
	Corn	541	531	513	55 900	33.4
	Wheat	190	735	735	32 200	19.2
	Lupine§	–	–	–	4 380	2.6
	Lolium¶	225	450	450	7 180	4.3
	B. Bean	55	75	75	2 380	1.4
	Total	1 110	2 521	2 503	167 000#	100
	Annual input	50.5	115	114	7 610	–

† Total fertilizer used for each crop.
§ Cultivated only for cover crop.
¶ Cultivated for silage.
# Sum of aboveground biomass plus roots of each crop.
‡ NT-10, 10 yr of continuous no-tillage application.
†† NT-20, 20 yr of continuous no-tillage application.
‡‡ NT-22, 22 yr of continuous no-tillage application.

Lit.: CARLOS DE M. SÀ et al., (2001).

9.2 Annex: 2a

Eroded soil organic carbon for each land use

	Date	Total OC sediments ($g\ kg^{-1}$)			OC enrichment ratio			Total OC sediments ($g\ m^{-2}$)			DOC runoff ($mg\ l^{-1}$)			DOC runoff ($mg\ m^{-2}$)	
		F	A	O	F	A	O	F	A	O	F	A	O	F	O
1	09/09/2005	26.99	*	22.17	1.02	*	2.06	0.014	*	0.075	*	*		*	*
2	15/09/2005	56.67	*	17.71	2.14	*	1.65	0.942	*	2.415	*	*		*	*
3	20/09/2005	51.76	*	16.87	1.96	*	1.57	0.215	*	0.331	*	*		*	*
4	14/11/2005	54.27	*	25.48	2.05	*	2.37	0.267	*	0.223	21.40	*	5.41	70.58	22.64
5	25/11/2005	41.73	*	27.95	1.58	*	2.60	0.003	*	0.000	11.82	*	5.76	4.150	0.328
6	10/01/2006	33.41	*	23.47	1.26	*	2.18	0.002	*	0.000	14.14	*	7.64	5.784	0.515
7	12/01/2006	37.94	*	15.14	1.43	*	1.41	0.010	*	0.001	9.08	*	5.44	15.24	2.128
8	20/01/2006	40.58	*	23.97	1.53	*	2.23	0.001	*	0.000	11.39	*	4.72	3.975	0.736
9	03/05/2006	51.03	52.12	33.81	1.93	1.66	3.15	0.005	0.007	0.001	14.56	6.25	7.97	5.403	0.573
10	17/05/2006	53.52	31.15	37.69	2.03	2.43	3.51	0.061	0.024	0.026	21.57	11.21	13.1	11.54	1.258
11	23/05/2006	55.55	25.83	12.27	2.10	2.02	1.14	0.119	0.065	0.161	14.62	3.42	2.92	15.50	3.103
12	31/05/2006	49.96	19.33	18.88	1.89	1.51	1.76	0.079	0.028	0.185	9.19	2.24	3.63	12.01	6.693
13	15/09/2006	54.35	26.27	19.57	2.06	2.05	1.82	0.300	0.269	1.369	18.06	32.77	4.28	54.24	30.27
14	23/09/2006	54.94	36.89	50.39	2.08	2.88	4.69	0.001	0.086	0.004	25.24	15.99	15.5	0.757	3.00
15	07/11/2006	65.64	37.27	38.01	3.00	2.91	3.54	0.000	0.155	0.077	16.12	5.13	6.05	33.23	17.75
16	09/11/2006	61.62	18.88	25.27	2.33	1.47	2.35	0.050	0.055	0.247	12.67	6.12	8.25	54.21	124.73

F: forest; A: abandoned, O: olive. The values given are the mean value of two plots (forest and olive) and the three sediment traps (abandoned).
*: no data.

Lit.: MENEZ-MENA, et al., (2008).

9.3 Annex: 2b

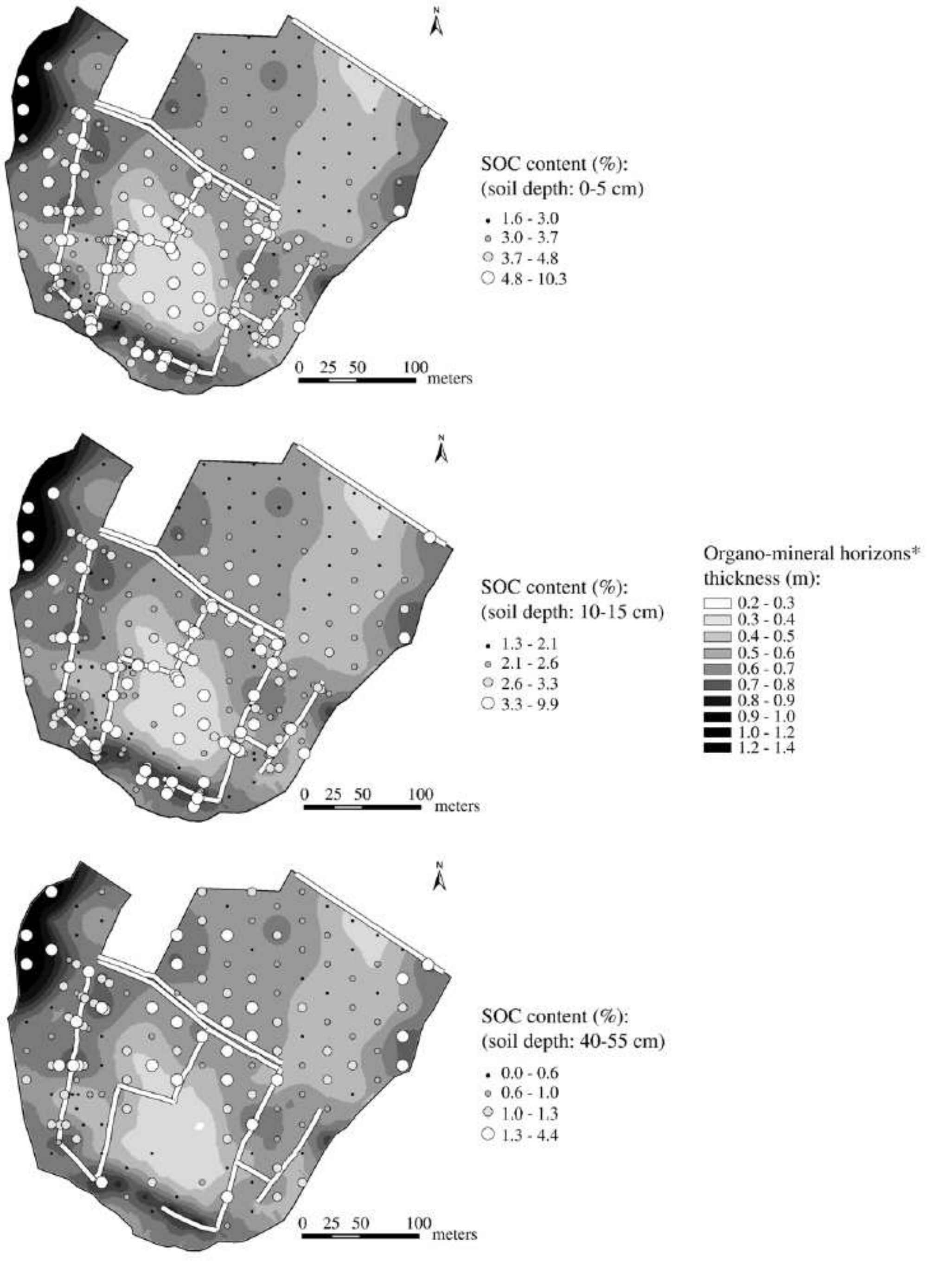
Correlation between rainfall characteristics, erosion, sediment OC concentration and total OC loss by erosion

	I_{30} ($mm\ h^{-1}$)	Erosion ($g\ m^{-2}$)	C sediment concentration ($g\ kg^{-1}$)	DOC ($mg\ l^{-1}$)	Total C loss ($g\ m^{-2}$)
Forest					
Rainfall (mm)	0.349	0.37	0.39	−0.21	0.39
I_{30} ($mm\ h^{-1}$)		**0.95****	0.47	0.35	**0.94****
Erosion ($g\ m^{-2}$)			0.38	0.16	**0.97****
Sediment concentration ($g\ C\ kg^{-1}$)				**0.58***	0.45
Abandoned					
Rainfall (mm)	0.12	**0.68***	-0.16	0.20	**0.72***
I_{30} ($mm\ h^{-1}$)		0.58	-0.59	0.09	0.38
Erosion ($g\ m^{-2}$)			-0.37	0.20	**0.95****
Sediment concentration ($g\ C\ kg^{-1}$)				−0.11	−0.21
Olive					
Rainfall (mm)	0.3349	0.47	-0.22	0.22	0.48
I_{30} ($mm\ h^{-1}$)		**0.88****	-0.43	0.24	**0.80****
Erosion ($g\ m^{-2}$)			**−0.53***	−0.04	**0.94****
Sediment concentration ($g\ C\ kg^{-1}$)				0.31	−0.17

* Significant at $P < 0.05$.
** Significant at $P < 0.01$ according to Spearman test.

Lit.: MENEZ-MENA, et al., (2008).

9.4 Annex: 3



* A, Aw, T and Tw-horizons

Fig. 4. Joint representation of soil organic carbon (SOC) content for various soil depths, organo-mineral horizon thicknesses and distance to hedges. SOC contents are symbolised in accordance with the non-parametric statistics: min, max, quartile and median values.

FOLLAIN, S., et al., (2007).

9.5 Annex 3b

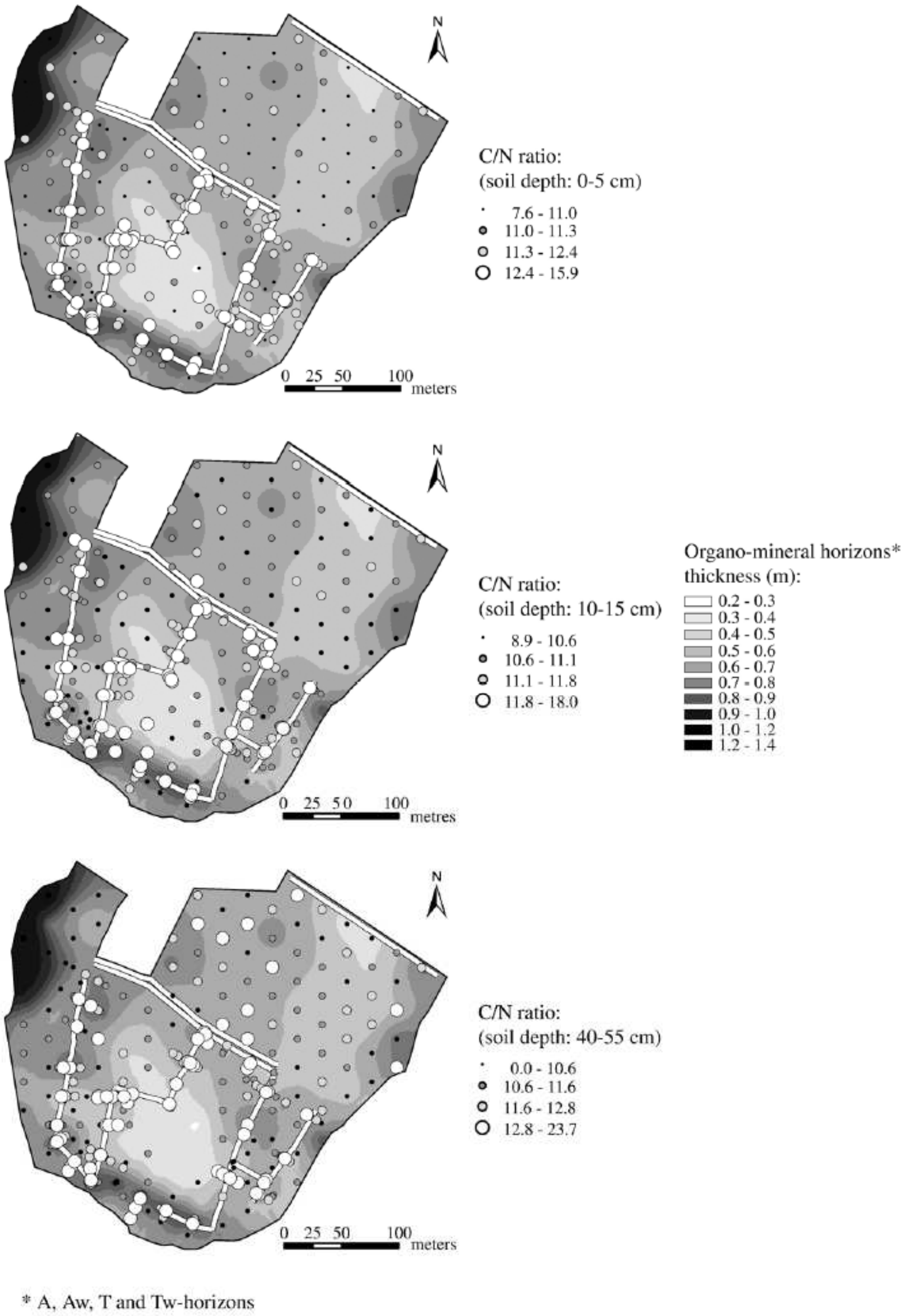


Fig. 5. Joint representation of the C/N ratio values for various soil depths, organo-mineral horizon thicknesses and hedges. C/N values are symbolised in accordance with the non-parametric statistics: min, max, quartile and median values.

Lit.: FOLLAIN, S., et al., (2007).

9.6 Annex 3c

Soil organic carbon stocks (CS) established for various soil uses and spatial resolutions
P =punctual stock. * * : median stock. * * * : extrapolated stock.

Country	**Land use**	**Soil depth (m)**	**SOC stocks (kg m^{-2})**
France	Cultivated soils	0.3	6.0^{P}
France	Grassland/luvisols	0.3	8.4
Eastern Europe	Luvisols	0.3	5.0
Eastern Europe	Luvisols	1.0	9.1
Denmark	Cultivated soils	1.0	14.0
Denmark	Cultivated soils	0.3	9.5
Denmark	Cultivated soils	0.5	10.9
Swiss	Temporary meadow	0.2	2.5
Swiss	Temporary meadow	1.0	11.7
Belgium	Grassland	1.0	13.0
Spain	Grassland	> 1.0	12.5
Spain	Pasture	> 1.0	7.5
Europe	Cultivated soils	0.3	5.3
United Kingdom	Cultivated soils	0.3	8.0
U.S.A	Grassland	0.3	5.8
France (Britany)	**Cultivated sols/grassland**	**A-horizons**	**9.5 (Example given in Chapter 5.2.2)**

Lit.: FOLLAIN, S., et al., (2007).

9.7 Annex: 4a

Rotation cycle	High input (HI) 6-year	4-year	2-year	Monoculture	Low input (LI) 6-year	4-year	2-year	Monoculture
	Intensification of husbandry							
I (1964–1975)								
Crop	M-IS	M-IS	M-IS	M-IS	M-IS	M-IS	M-IS	M-IS
Residue incorporation	No	No	No	No	No	No	No	No
Irrigation	Yes	Yes	Yes	Yes	No	No	No	No
Organic inputs								
Slurry (t ha^{-1})	0	0	0	0	0	0	0	0
FYM (t ha^{-1})	20	20	20	20	20	20	20	20
II (1977–1988)								
Crop	M-IS	M-IS	M-IS	M-IS	M	M	M	M
Residue incorporation	No	No	No	No	No	Yes	Yes	Yes
Irrigation	No	No	No	No	No	No	No	No
Organic inputs								
Slurry (t ha^{-1})	0	0	0	0	0	0	0	0
FYM (t ha^{-1})	20	20	20	20	20	0	0	0
III (1990–2001)								
Crop	M	M	M	M	M	M	M	M
Residue incorporation	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Irrigation	No	No	No	No	No	No	No	No
Organic inputs								
Slurry (t ha^{-1})	40	40	40	40	0	0	0	0
FYM (t ha^{-1})	0	0	0	0	20	0	0	0

M, main crop; IS, interannual succession: autumn-spring forage crop (oat, *Avena* spp.; vetch, *Vicia sativa* L.; peas, *Pisum sativum* L.) before summer crops; densely sown maize cut at flowering after wheat. Both forage crops were harvested as animal forage. FYM, farmyard

Lit.: MORARI et al., (2006).

9.8 Annex: 4b

Parameters	Old Crop Rotation Trial	Soil type & fertilization exp. Clay	Sand	Peat
Sand (2 mm –50 μm) (%)	47.0	25.0	93.4	38.0
Silt (50–2 μm) (%)	38.0	23.0	6.0	13.6
Clay (< 2 μm) (%)	15.0	52.0	0.6	48.4
pH	7.8	7.9	8.1	4.9
Total carbonate (g kg^{-1})	234.0	26.0	39.0	0.0
Organic carbon (g kg^{-1})	12.0	14.5	1.7	105.0
Total nitrogen (g kg^{-1})	0.99	1.5	0.15	6.7
C:N	12.0	10.0	12.0	16.0
Total phosphorus (g kg^{-1})	0.7	0.5	2.8	1.1
Available phosphorus[a] (mg kg^{-1})	47.2	161.5	26.2	100.4

Lit.: MORARI et al., (2006).

9.9 Annex 5

Summary of studies of soil carbon comparisons

Source	Main Location	Year data collected	Number of observations	Mean stored (Mg C per ha) Conv til	No till	Max sample depth
Alvarez et al.	Argentina	1994	1	49	51	20
Angers et al.	East Can.	1994	7	31.74	31.23	60
Balesdent et al.	France	1990	6	25.55	26.11	30
Barber et al.	Bolivia	1993	2	12.04	14.70	15
Bayer et al.	Brazil	1994	2	47.4	52.9	30
Beare et al.	Georgia	1991	2	17.70	22.74	15
Bergstrom et al.	Manitoba	1998	17	21.90	20.52	48
Black and Tanaka	North Dakota	1989	30	68.69	67.92	91.2
Blevins et al.[a]	Kentucky	1975	12	27.43	31.53	30
Blevins et al.	Kentucky	1980	16	17.48	25.04	15
Campbell et al.[b]	Saskatchewan	1986–94	10	7.14	7.63	15
Chan et al.	Australia	1989	4	11.49	13.82	20
Clapp et al.	Minnesota	1993	8	29.36	30.05	30
Dalal	Australia	1981	6	34.47	35.55	120
Ding et al.	South Carolina	1999	3	9.34	12.53	15
Doran	Nebraska	1980	18	12.67	14.48	30
Doran et al.	Nebraska	1981–96	14	17.91	19.18	122
Edwards et al.	Alabama	1990	9	10.49	15.00	20
Eghball et al.	Nebraska	1989	1	52.11	57.27	30
Franzluebbers et al.	Texas	1991	3	21.16	27.18	20
Freixo et al.	Brazil	1998	8	36.09	38.4	30
Groffman	Georgia	1983	3	19.12	22.88	21
Hansmeyer et al.	Minnesota	1991–95	2	8.71	9.56	7.5
Hendrix et al.	Georgia	1989	2	12.14	15.38	20
Hussain et al.	Illinois	1997	2	35.63	43.47	15
Ismail et al.	Kentucky	1989	12	12.97	15.56	30
Karlen et al.	Iowa	1992	3	37.47	52.42	20
Kessavalou et al.	Nebraska	1995	1	10.00	11.66	15
Kushwaha et al.	India	1998	2	11.03	11.77	10
Lamb et al.	Nebraska	1981–82	6	10.29	11.32	30
Larney et al.	Alberta	1992	4	13.39	13.80	15
Lilienfein et al.	Brazil	1998	5	101.35	105.22	200
Machado and Silva	Brazil	1995	10	41.66	44	40
Mahboubi et al.	Ohio	1991	2	19.65	51.07	15
Mrabet et al.	Morocco	1998	3	16.98	20.03	20
Nyborg et al.	Alberta	1990	18	15.98	16.81	15
Peterson et al.	North Dakota	1982–91	8	15.59	15.97	30
Pierce	Michigan	1997	8	28.78	33.89	20
Potter et al.	Texas	1996	7	13.92	14.29	20
Rhoton et al.	US South	1991	6	16.26	20.01	15.2
Sainju et al.	Georgia	1995–99	30	8.05	9.43	20
Six et al.	Midwest	1995	4	11.75	13.55	20
Wanniarachchi et al.	Ontario	1994	1	9.46	8.94	50
Yang and Kay	Ontario	1999	21	32.88	39.09	60
Yang and Wander	Illinois	1997	8	21.89	22.58	90
Total articles: 51	Means	1991–96	7.71	24.14	27.50	35.66
Total observations:	Median	1992	6	17.7	20.52	20
374	Minima	1975	1	7.14	7.63	7.5
	Maxima	1999	30	101.35	105.22	200

[a] As quoted in Frye and Blevins (1997).
[b] Numbers in Campbell et al. (1995, 1996, 1999).

Lit.: MANLEY, J., et al., (2005).