Institut für Agribusiness

The Importance of Conservation Tillage as a Contribution to Sustainable Agriculture: A special Case of Soil Erosion

2nd Revised Edition

Agribusiness-Forschung

Nr. 33

Prof. Dr. Dr. h.c. P. Michael SCHMITZ

Dr. Puran MAL

Dr. Joachim W. HESSE

Gießen, Februar 2015

Preis: 30,- Euro **ISSN 1434-9787**

Institut für Agribusiness, Senckenbergstr. 3, 35390 Gießen
www.agribusiness.de

Content

1 Introduction

Increasing population as well as land and water scarcity has become the main challenges for food security which creates pressure on agricultural production. Therefore, sustainable agriculture is gaining increasing importance. The farmers are required to increase resource use efficiency, in order to meet the growing food demand as well as to reduce the pressure on natural resources. Thus, consumers can get quality food at affordable prices. Another requirement is the increase in production; this to the background of meeting the demand along with protection of soil, water, biodiversity etc. and to contribute in the mitigation of greenhouse gases (Basch *et al.,* 2012). To achieve sustainability or sustainable intensification, many problems have to be solved including - land degradation, water stress, climate change, deforestation, overexploitation of resources etc. (Corine, 1994; Lopez-Bermudes *et al.,* 1998). Land degradation is one of the most severe and important problems as it also involves soil, water, rocks, climate, relief and forestation (Stocking and Murnaghan, 2001).

1.1 Background and problem statement

Soil erosion is one of the major causes of land degradation. Generally, it happens by two ways i.e. soil detachment and soil transport. Raindrop is the main reason of soil detachment. In USA, soil erosion by raindrop is near about 0.18 cm or 25 tons ha^{-1} $year^{-1}$. It is also known as sheet erosion. It is very hard to identify the soil erosion at the starting phase. By the time the farmers identify soil erosion, the land most likely already has lost its productivity. Flowing water is another main reason for soil detachment which creates gullies. The nutrients from soil pass out through the gullies. Soil transport mainly happens through wind or air (McCarthy, 1993). Average soil formation rate in Europe, is about 0.3 to 1.4 tons ha^{-1} $year^{-1}$ whereas actual soil erosion rate is ca. 3 to 40 tons $ha^{-1}year^{-1}$. Sometimes soil erosion can increase to 100 tons ha^{-1} due to extreme events i.e. storms (Grimm *et al.,* 2002; Verheijen *et al.,* 2009).

Total land area affected by soil erosion through water and wind is 1643 million ha. Area affected by water erosion is 1094 million ha in which 751 million ha is severely affected (Lal, 2003). In Asia and Africa, soil erosion affected area is 407 and 267 million ha respectively. There is 132 million ha area under soil erosion in Europe, in which 93 million ha is affected from water erosion and 39 million is from wind erosion (Lal, 2003). At present in EU-27, there are 1.3 million km^2 surface areas which are affected by soil erosion through water which cost as 10 tons ha^{-1} $year^{-1}$ soil loss (Jones *et al.,* 2012). In the Mediterranean region, soil erosion has reached the last stages and the soils are close to losing their productivity. Furthermore, the issue that present soil erosion not compensated is reasoned in the slow rates of soil formation. The main cause of soil erosion are agricultural practices, deforestation, overgrazing and construction activities (Grimm *et al.,* 2002).

There are some other problems which are also directly or indirectly connected with soil, e.g. soil organic matter, carbon sequestration, greenhouse gases and climate change. Soil erosion increases the loss of soil organic matter as well as loss of capacity to sequester atmospheric carbon (EEA, 2000). It is due to the fact that increase in soil erosion decreases the carbon stocks in the soil (EEA, 2000). Agriculture plays a significant role in the production of greenhouse gases especially carbon dioxide (CO_2). Soil organic matter decreased significantly because of agricultural land use (Reicosky, 2001). Reduction of soil organic carbon (SOC) due to land use practices leads to release of CO_2 in the atmosphere because one percent reduction of SOC in the layer of 30 cm topsoil is resulted as the losses of around 45 tons of carbon or 166 tons of CO_2 per ha in the atmosphere (Basch *et al.,* 2012). Fuel burning by agricultural machinery during agricultural operations is the main source of CO_2 emissions. That's why intensive tillage increases the soil organic matter loss and influences the greenhouse gas emissions (Reicosky and Archer, 2007).

Soil resources have been lost as well as degraded because of economic sectors like agriculture, households, industry, transport and tourism. The pressure is coming out from the activities in restricted areas which create the problem of climate change. There is degradation in soil fauna and flora through forest fires whereas soil contamination and pollution occurs due to urbanization and industrialization (EEA, 2000; Blum, 2005).

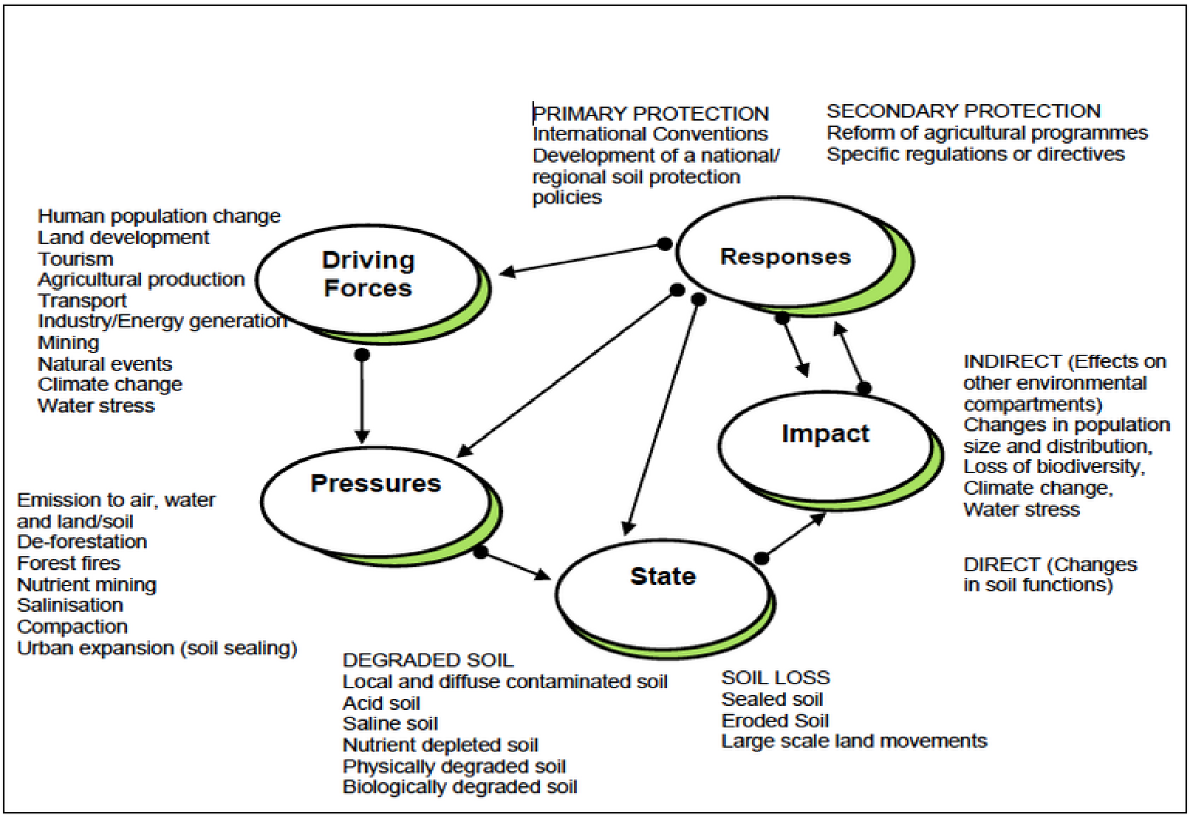


Figure 1.1: DPSIR Framework applied to soil erosion

Source: Blum, 2005

In order to achieve the objective of sustainable production in agriculture it is essential to solve the problem of soil erosion and related problems. There are some agronomic systems or practices which can help to mitigate these problems. Figure 1.1 also describes the relationship between driving forces, pressures, state, impact and responses to soil erosion. To mitigate or reduce the impact on soil, secondary protection activities as conservation agriculture (CA) or conservation tillage should be applied. CA is based on the principles of soil reconstruction, maximizing crop production inputs, including labor, and optimizing profits (Dumanski *et al.,* 2006). The main characteristics of CA production systems are optimization of the crop yield, farm income and minimization of the negative ecological impacts associated with conventional agriculture. Use of herbicides to control the weeds and soil management is an opportunity to minimize the production costs and to avoid negative effects through soil tillage (Basch *et al.,* 2012). It is also possible to have better water quality, soil erosion control; reduced GHG emissions etc. which are not possible with fully conventional tillage based agricultural land use (Kassam *et al.,* 2010). In CA, weeds are controlled by herbicides mainly glyphosate.

At present, CA occupies around 125 million ha in the world, increasing with the rate of 7 million ha annually (FAO, 2011). Generally, no till or zero tillage is considered as cornerstone for CA. The American continent has the highest adoption of conservation agriculture in the world because zero tillage is well adapted in this region. The adoption of conservation agriculture in Europe is much lower than in other continents, excluding Africa. In Europe, the area under reduced tillage (RT) is more than ten times higher than no-tillage or zero tillage (Basch *et al.,* 2008). A humid temperate climate and political support can be the main reason for lower adoption of no-tillage (Derpsch *et al.,* 2010; Mäder and Berner, 2012). There are many studies in Europe on the topic of conservation agriculture and conservation tillage. This study will give an overview of the different studies on conservation tillage in the world and specifically Germany. Conservation tillage has many different meanings. Some studies are using conservation tillage as reduced tillage especially in Europe and some are using conservation tillage as reduced tillage and no-tillage both. This study is an attempt to clarify the different tillage systems in agriculture. The main objective of this study is to explore the economic and environmental impacts (soil erosion and CO_2 gas emissions) of conservation tillage and herbicides use. Dependency on herbicides will increase in reduced tillage or no-tillage because monocotyledonous weeds increase in reduced tillage (Mäder and Berner, 2012). Without the use of herbicides, controlling the weeds in conservation tillage is not feasible. Therefore, it is important to look on effects of herbicides with conservation tillage.

1.2 Organization of the study

This study is divided into five more chapters. Second chapter will be about conservation agriculture and different tillage systems. Third chapter will be an overview on international experience of conservation tillage system. Fourth chapter will be mainly focused on conservation tillage experiences from Germany. Fifth chapter will be about economic analysis of conservation tillage and glyphosate use with different crop rotation in Germany. In the final chapter, the study will conclude with some suggestions.

2 Tillage systems and conservation agriculture

The aim of tillage is to prepare the soil environment favorable to plant growth (Klute, 1982). It consists of all operations for seed sowing which improves soil, and environmental conditions for seed germination to crop growth (Lal, 1983). Tillage is the traditional method to control weeds (Lahmar, 2010). Generally, there are two types of tillage systems i.e. conventional, and conservation tillage system.

A conventional tillage practice refers to use of a moldboard or animal drawn plow to incorporate residue into the soil by extensive tillage. It is two types i.e. Mechanized, and traditional systems. Traditional tillage system is mainly practiced in West Africa, and South America. It is carried out by manual labor using native tools. The cutlass and hoe are main tools in traditional tillage system. In mechanized system, mechanical soil manipulation of an entire field is done by ploughing through one or more harrowing (Opara-Nadi, 1993).

According to the Conservation Tillage Information Center (CTIC), conservation tillage eliminates conventional tillage operations that invert the soil, and burry crop residue. It is the collective umbrella term which is given for no-tillage, direct-drilling, minimum tillage, ridge tillage (Baker *et al.,* 2002). No-tillage, minimum tillage, reduced tillage, and mulch tillage are synonymous terms for conservation tillage (Willis and Amemiya 1973; Lal 1973, Phillips *et al.,* 1980; Greenland 1981; Unger *et al.,* 1988; Antapa, and Angen 1990; Opara-Nadi 1990; Unger 1990; Ahn, and Hintze 1990 cited in Opara-Nadi, 1993). Therefore, there are five types tillage in conservation tillage:

No-tillage: It is also known as zero tillage. In this system, soil, and surface residues are disturbed at minimal rate. The surface residues play an important role in soil, and water conservation. In this system, weeds are controlled by herbicides use or crop-rotation (Opara-Nadi, 1993). It reduces all pre-planting mechanical seed sowing preparation except to open a narrow (2-3 cm wide) strip or making small hole in the ground for seed sowing to ensure ample seed-soil contact. The soil surface is fully sheltered by crop residue mulch or killed sod (Lal, 1983). In 2011, South America had 44% of the total global area under no-tillage, followed by North America i.e.32%. Europe had 1.35 million ha under no-tillage which is about 1 percent of the total global area (Friedrich *et al.,* 2012).

Mulch tillage: It is based on the principle of reasonable least soil disturbance, and leaving maximum of crop residue on the soil surface. This can provide faster germination, and growth as well as good yield. A chisel plough can be used to open hard crust in pervious chopped crop residue. But, there should be no crop residue incorporated into the soil (Lal, 1975, 1986). It is also known as 'Stubble Mulch Tillage'. The tools such as chisels, field cultivators, discs, sweeps or blades can be used in this tillage system. Weed control is done mainly by herbicides application. Major existence of mulch tillage is in the USA, and Germany.

Strip or zonal tillage: It is mainly useful for soil which is naturally compact. A mole knife is used as a tool to till which is about 25 cm wide, and 10 to 13 cm high in the fall. The seedbed is mainly divided into two parts namely, seeding zone, and soil management zone. The seeding zone which is 5 to 10 cm wide would be mechanically tilled to improve the soil, and micro-climate environment for germination, and its growth. The area between the rows is undisturbed, and sheltered by mulch (Opara-Nadi, 1993).

Ridge till: In this practice, soil is left undisturbed prior to planting except one third of the soil surface. The sowing will be done on the ridge with sweeps, disk openers, coulters, and row cleaners. Crop residue is left on the surface between ridges. Ridges are re-established during row cultivation. Weeds are mainly controlled by herbicides (Opara-Nadi, 1993).

Reduced or minimum tillage: In this system, minimum 30% surface is covered with crop residue (Opara-Nadi, 1993). The number of tillage is reduced than conventional tillage system. Weeds are controlled by herbicides applications. This system is more popular in Europe than any other continent (Mäder and Berner, 2012).

Most of the studies related to 'tillage' use the term 'Conservation Tillage', but these studies don't have the same meaning of conservation tillage. American, Australian continent based studies used only no-tillage or zero tillage as conservation tillage. In these continents, the adoption of zero or no-tillage is much higher than other continents (Friedrich *et al.,* 2012). In Europe, conservation tillage means as reduced tillage or no-tillage or mulch tillage because there is higher adoption of reduced or mulch tillage than no-tillage. Reduced tillage is more favorable to Europe than no-tillage due to better suitability of reduced tillage under humid temperate climate. Reduced tillage may also better in crop establishment, and weed management than no-tillage under these conditions (Basch *et al.,* 2008, Mäder and Berner, 2012). In no-tillage especially when the surface soil is wet, seeds which are very close contact to straw, can suffer from fungal phytotoxicity problems (Morris *et al.,* 2010 in Soane *et al.,* 2012). These are main reasons which make reduced tillage more suitable to Europe.

2.1 History and present status of conservation agriculture

First time in 1930s, tillage was questioned to disturb the ecosystem due to the problem of dustbowls in wide areas of the mid-west United States. With the aim to protect the soil, concepts like minimizing tillage, and keeping soil covered came into existence. Use of these concept known as conservation tillage, was started. In 1940s, direct seeding without any tillage was also started. In the mean time, principles of conservation agriculture were elaborated by Edward Faulkner. Until the 1960s, no-tillage could not enter into farming practices in the USA. In the early 1970s, no-tillage farming was introduced in Brazil and farmers worked together with scientists to transform the technology into their system. Currently, it is known as conservation agriculture.

In 1990s, the adoption of CA reached at significance level in South America, and also in some other countries. At the end of millennium, the concept such as CA along with conservation and no-tillage also led to increased adoption in Europe. These crop production systems have gained popularity in most of the countries around the world (Friedrich *et al.,* 2012).

In 2011, total area under CA was estimated about 125 million ha in the world (Friedrich *et al.,* 2012). Table 2.1 shows that South America has highest area under conservation agriculture which is about 30% higher than North America. Here, as conservation agriculture area, only no-tillage is accounted as conservation agriculture. Inclusion of reduced tillage/mulch tillage area will provide different picture of total area, and especially for Europe, as there it is more familiar than no-tillage.

Table 2.1: Worldwide area under conservation agriculture

Continent	Area (ha)	Percentage
South America	55,464,100	44
North America	39,981,000	32
Australia and New Zealand	17,162,000	14
Asia	4,723,000	4
Russia and Ukraine	5,100,000	4
Europe	1,351,900	1
Africa	1,012,840	1
World Total	124,794,840	100

Source: Friedrich *et al.*, 2012

2.2 Concept of conservation agriculture

Conservation agriculture (CA) is a combination of balancing agricultural practices. These agricultural practices are less disturbance to soil through reduced tillage or no-tillage and direct sowing; covering the soil through crop residue or mulching, cover crops, intercrops to mitigate soil erosion as well as improve the soil fertility, and soil functions; crop rotation to control weeds, insect-pests, and diseases (Derpsch, 2001). CA as an alternate to conventional agriculture is already recognized in many parts of the world (Dumanski *et al.,* 2006). Main aim of CA is to boost agricultural production by increasing the efficiency of farm resources, and facilitating to reduce land degradation through integrated management of available land, water, and natural resources combined with external inputs (SoCo, 2009). Conventional tillage is replaced by organic mixing of the soil in which soil micro-organisms, roots, and other soil fauna will take over the tillage function and improve the soil nutrients balancing. Soil fertility is handled and balanced by soil cover management, crop rotations, and weed management (SoCo, 2009). According to FAO, *conservation agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles, namely:*
1. Continuous minimum mechanical soil disturbance.
2. Permanent organic soil cover.
3. Diversification of crop species grown in sequences and/or associations.

CA principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. CA enhances biodiversity and natural biological processes above and below the ground surface. Soil interventions such as mechanical soil disturbance are reduced to an absolute minimum or avoided, and external inputs such as agrochemicals and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes.

CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, etc., CA is a base for sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of trees and pastures into agricultural landscapes (FAO, undated).

These three principles are described below:

*1. **Minimum Soil Disturbance**: Minimum soil disturbance refers to low disturbance no-tillage and direct seeding. The disturbed area must be less than 15 cm wide or less than 25% of the cropped area (whichever is lower). There should be no periodic tillage that disturbs a greater area than the aforementioned limits. Strip tillage is allowed if the disturbed area is less than the set limits.*

*2. **Organic soil cover**: Three categories are distinguished: 30-60%, >60-90% and >90% ground cover, measured immediately after the direct seeding operation. Area with less than 30% cover is not considered as CA.*

*3. **Crop rotation/association**: Rotation/association should involve at least three different crops. However, repetitive wheat, maize, or rice cropping is not an exclusion factor for the purpose of this data collection, but rotation/association is recorded where practiced* (FAO, 2011).

2.3 Implementation and major drawbacks of conservation agriculture

Conservation agriculture is mainly implemented through four phases, and each phase requires minimum two years. In first phase, ploughing will stop or reduce. Minimum 30 percent soil surface should be covered with crop residues from following harvested crops, and disc spike or rotary harrows can be used. However, yield reduction might be there. With the start of second phase, natural improvements in soil conditions, and its fertility gradually increase. Organic matters get composed naturally through the decomposition of plant, and crop residues. However, more insect-pests attack, and weeds germination might be there. In third phase, crop rotation is initiated. In the last and fourth phase, farming system gets stability, and yield might be higher than conventional farming. While, this system is incompatible for compacted soils because it may first require loosening (SoCo, 2009).

CA has lots of benefit like reduction in soil erosion, CO_2 emissions, improvement in water infiltration, higher farm income, labor reduction, and energy save etc. On the other hand, this system also has some drawbacks which have been mentioned as follows:

- In transition period, the yield might be lower and nitrous oxide emissions might be higher than conventional system.
- The risk of leaching might get increased in case of improper application of chemicals. Leaching takes place because of very quick movement of water through the bio pores.
- If crop rotation, soil cover and crop varieties are not appropriate to reach the optimized level, then there might be more requirements of chemicals to control weeds, and insect-pests.
- Farmers require more initial investments to buy specialized machinery.

- Farmers need training, and skilled advisory services to adapt conservation agriculture system (SoCo, 2009).

2.4 Concept of conservation agriculture for Europe

According to The European Conservation Agriculture Federation (ECAF), conservation agriculture (CA) is a combination of some practices which allow the soil management for agricultural use as possible with minimum changes in its structure and natural biodiversity as well as providing the protection from its degradation processes like soil erosion. There are some techniques which constitute conservation agriculture i.e. no-tillage or zero tillage, reduced tillage or minimum tillage, mulch tillage, mixing of crop residues and planting of cover crops in perennial woody crops or in between annual crops. Further, CA is simplified as composition of any of those practices which reduce soil tillage, avoid the crop residue burning and maintain enough surface residues to minimize soil erosion. On the other hand zero tillage or no-tillage with some other soil conservation practices, is the cornerstone of CA (Dumanski *et al.,* 2006). According to FAO, CA consists of three principles as minimal mechanical soil disturbance (no-tillage or zero tillage and direct sowing), permanent organic soil cover and diversification of crop (Friedrich *et al.,* 2012). Conservation tillage also follows these principles from conservation agriculture. But when it comes with severe regulation of these principles, then conservation tillage can not be fit for conservation agriculture. In Europe especially Germany, reduced tillage is more prominent than no-till or zero tillage due to its suitability with the climatic conditions. In the study, conservation tillage is mentioned instead of conservation agriculture due to strict principles of conservation agriculture. On the other hand, conservation tillage practices are considered as transition steps towards conservation agriculture (Hobbs *et al.,* 2008). Therefore, conservation agriculture should be considered with reduced tillage or conservation tillage for Europe especially Germany. This study is mainly focused on conservation tillage and its practices.

3 International experiences of conservation tillage

In this part, the worldwide impacts of conservation tillage (NT, RT, and MT) are discussed. The advantages of conservation tillage can be categorized into economic, environmental, climatic and soil. These are advantages as well as factors which are linked with adoption of conservation tillage worldwide (Soane *et al.,* 2012).

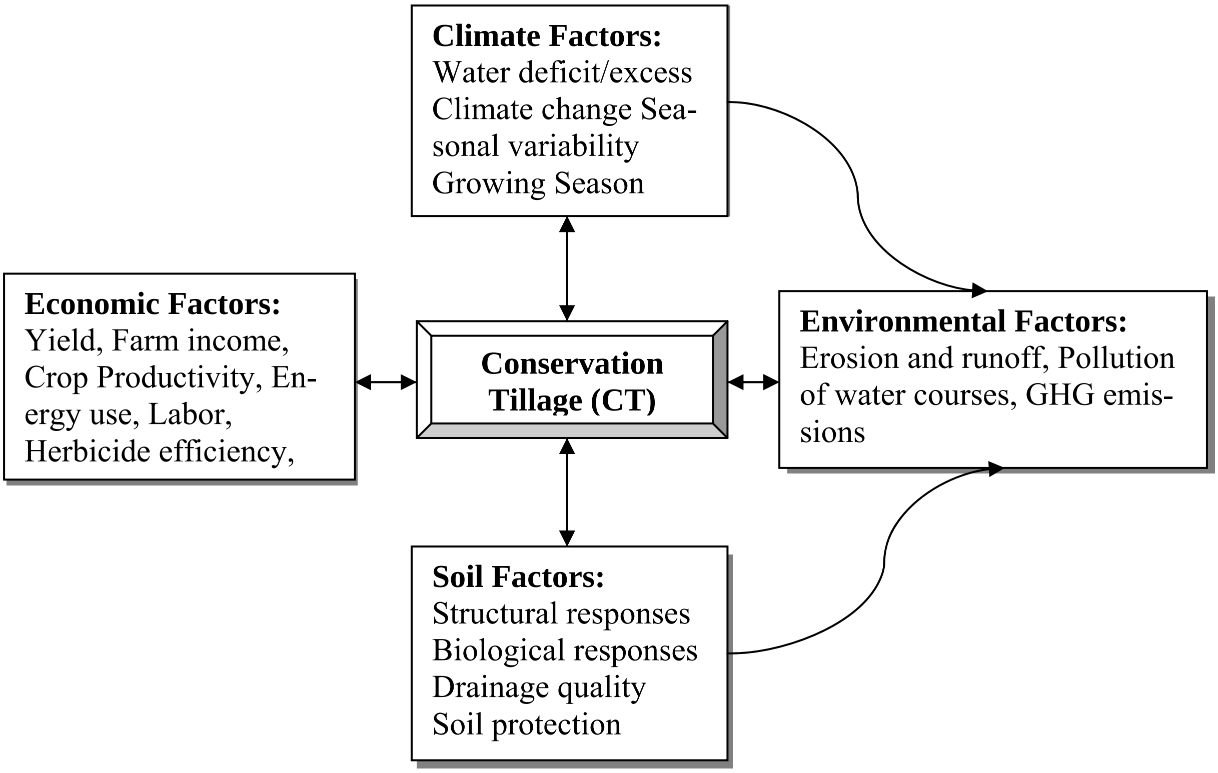


Figure 3.1: Impacts of conservation tillage

Source: Modified from Soane *et al.,* 2012

Through many studies, it has been found that the various existing tillage systems have a major influence on soil carbon and gas emissions in the world. Abdalla *et al.* (2013), in a review, concluded that climate and soil type are major factors affecting GHG emissions from conservation tillage practices. Farmers also need to modify conservation tillage practices according to soil and climate conditions in order to benefit from conservation tillage. The modification of conservation tillage practices can affect plant biomass production which influences vegetation cover or crop residue levels. This may be the reason that European farmers are more likely to adopt reduced tillage than zero tillage. Further, the impacts of conservation tillage will be discussed based on continents. In this study, there are four major continents considered, North and South America, (considered together) Asia & the Middle-East, Africa and Europe. North and South America have the greatest share of area under conservation tillage in the world at 95.45 million ha which is 77% of the total area under conservation tillage. Asia has only 4.7 million ha, which contributes as only 4 percent of the total area under conservation tillage. Africa and Europe have much less area under conservation tillage practices at 1.0 and 1.4 million ha respectively, approximately 1 percent for each (Friedrich *et al.,* 2012). This shows that the adoption of conservation tillage practices is most wide-spread in North and South America compared to other continents. Within the two it is more common in South America than North America. The reason may be that the start and longest development of conservation agriculture was in South America.

3.1 North and South America

In these regions, the drawbacks of tillage were noticed in the 1930s. Three countries, USA, Brazil and Canada represent North and South America in this study.

A 12-year study from 1999 to 2011 was conducted in the San Joaquin Valley with cotton production. The results from three years (2000 to 2003) show a lowering in tillage intensity while yield increased year-wise, concomitant with reduced operational costs. There was an approximate 50% reduction in fuel use. There was a difference in yield but none statistically significant. There was an approximately \$100 ha^{-1} reduction in operational costs because of the close to 50% reduction in tillage operations. In the case of long-term impacts in cotton-tomato rotations (2000-2011), the number of tractor trips across the field was diminished by about 40% for cotton and 50% for tomatoes. There was, however, an additional glyphosate application to kill weeds under conservation tillage conditions. The results confirmed that yield under conservation tillage can be maintained or improved compared to conventional tillage conditions. There was reduction in fuel and labor of around 30 gallons and 5 hours ha^{-1} respectively. The reduction in fuel, labor and maintenance were calculated to be \$175 ha^{-1} in 2011 (Mitchell *et al.,* 2012). Regarding soil improvement, under conservation tillage there was observed an improved Soil Conditioning Index (SCI) value. SCI value is an indicator of content of soil carbon which is considered a source element or component of soil quality because it is responsible for increasing water and nutrient-holding capacities whereas a decreasing value proposes a degrading trend in soil quality (Mitchell *et al.,* 2012). Soil tillage intensity rating (STIR) is very low in conservation tillage compared to traditional tillage. STIR evaluates the impact of tillage on soil quality and residue retention. It is very important in efforts to reduce soil erosion and water evaporation (USDA, NRCS 2003). A lower STIR value means more effective reduction of soil erosion and water evaporation (Mitchell *et al.,* 2012).

Another study was conducted by Young and Schillinger (2012) on winter wheat for three years (2008 to 2010). They found similar results in yield and diesel consumption in wheat production as Mitchell *et al.* (2012). There was annually 0.14 times less use of a rodweeder tool compared to conventional tillage. The farmers used nearly equivalent amounts of glyphosate in both tillage practices. There were more than 40% of farmers in the study who had higher profit with conservation than with conventional tillage. Conservation tillage helped to reduce wind erosion because most of the winter wheat residue from the previous crop was retained on the surface.

Franchini *et al.* (2012) highlighted the results of a 23-year experiment in Southern Brazil. They examined the yield of maize, soybeans and wheat with two crop rotations and crop succession. They had slightly different results than Mitchell *et al.* (2012) and Young and Schillinger (2012). They found that yields in soybeans were higher under conservation tillage while yields in maize and wheat were lower under conservation tillage. Further, they found that soil conservation systems are more efficient strategies to increase drought-tolerance compared to a traditional tillage system because soybean yields had a linear relationship with water requirement satisfaction index (WRSI). This is the ratio between the actual and maximum crop evapotranspiration. When crop water requirements are fully met, the index value is one. In the case of conventional tillage, when the WRSI index value is less than 0.80, yield decreased. On the other hand, in no-tillage, when the index was less than 0.70, then yield was low. Generally, yield of maize and wheat was lower in the stabilization phase, probably due to immobilization of N and low amounts of N fertilizer being applied.

Another 12-year study was conducted by Zotarelli *et al.* (2012) in Brazil. The experiment period was from 1997-2009 with three crop rotations. This study also supports the results from Mitchell *et al.* (2012) and Franchini *et al.* (2012). They found that average yields of soybeans were higher under no-tillage practices. It was only lower in the third crop rotation because this crop rotation was applied in the starting phase of the experiment. There was a yield difference between crop rotations among no-tillage practices. It shows that crop rotation was also responsible for yield. Maize yield was lower in no-tillage, influenced by the presence of lupins as the preceding crop and maize not being N fertilized. Further, they found that there was almost in all crop rotations lower C loss, and C and N stocks increased under no-tillage conditions. It can be concluded that introducing legume crops as green manure in crop rotations has advantages replacing the N lost, improving the residue quality as well as enhancing biological nitrogen fixation. The amount of crop residues returned to the field is very important, protecting the soil from wind and water erosion, preserving soil water and suppressing weeds.

A study by Khakbazan and Hamilton (2012) mainly focused on the profitability of conservation tillage. The study was conducted from 1998 to 2006 in South Tobacco Creek, Canada. Some results are different from those of Mitchell *et al.* (2012) and Franchini *et al.* (2012). It was found that canola and flax under conventional tillage has \$7 to 34 and \$9 to 19 ha^{-1} respectively higher net return than under conservation tillage. But it was an inverse situation in the case of cereals. They concluded that yields of canola were negatively related to conservation tillage, which was statistically significant. Yields of wheat and barley were positively related to conservation tillage. In the case of different crop rotations, conventional tillage has higher total costs than conservation tillage systems, up to \$21 ha^{-1}. This is due to about 50% higher tillage costs under conventional tillage. In all three crop rotations, net income is also more than 50% higher under conservation tillage. In one crop rotation, there is negative net income in all tillage systems. Further, they found that in some cases reduced tillage was more beneficial than no-tillage. In this region, canola was more profitable with conventional tillage than reduced or no-tillage and farmers would like remain with conventional tillage. Because of high crop prices for oilseeds, conventional tillage is being chosen as the growing system, as the returns to higher yield are greater than the cost savings generated by reduced and no-tillage systems.

There is one another study from Canada that was conducted in a water-stressed area. It was a 28-year long-term study and results were highlighted by McConkey *et al.,* (2012). There were differing results from previous studies. There was observed savings in labor, fuel, machine repair etc. with conservation tillage compared to conventional tillage. But, there was no significant difference in net returns among tillage systems due to higher expenditure on herbicide use and an about 4 percent lower grain yield under conservation tillage. Farmers in the brown and dark brown soils received higher economic benefits under conservation tillage because there was high risk of wind erosion with non-cereals crops. Therefore, conservation tillage practices can help to enable sustainable, diversified production systems. Higher non-renewable energy efficiency under conservation tillage was also noticed. Further, they found that there is a direct relationship between the increase in soil C in topsoil under conservation tillage management and on clay soils. That is the effect of finer-textured soils being more capable of protecting soil organic carbon from mineralization than coarse-textured soils under no-tillage. There was found to be higher soil organic carbon under no-tillage over time than other tillage systems.

3.2 Asia and the Middle East

In this region, adoption of conservation tillage is at a very low level, around 4 percent of total area under conservation agriculture. There is more than 20 million ha under conservation tillage. But most of the area under conservation tillage is temporary. In the Indo-Gangetic Plains, there are about 5 million ha under no-tillage systems in wheat-rice cropping systems. In India, no-tillage practice adoption has occurred mainly in the wheat crop portion of the wheat-rice double-cropping systems. There is much less adoption of permanent no-tillage and conservation tillage systems (Friedrich *et al.,* 2012).

Singh *et al.* (2008) found from a 3-year study in India that there was an about 50% lower net return for soybeans, wheat, peas and lentil cropping systems under conservation tillage systems than under conventional tillage despite having more than 10% lower total variable cost. There was about a 10 percent lower input of energy under conservation tillage than conventional tillage. On the other hand, there was higher output energy per ha with conventional tillage, but a greater output-input ratio under conservation tillage than conventional tillage. Whereas Saharawat *et al.* (2010) found different results than those from Singh *et al.* (2008). There was 6 percent higher profit with conservation tillage in wheat. Rice yield was lower under conservation tillage systems than conventional but there was an inverse situation in the case of wheat yield. There was significant reduction in machine (43-51%) and human labor (9-16%) in rice with conservation tillage. Therefore, there was about \$35 ha^{-1} higher income in rice with conservation tillage. There was higher water use efficiency in wheat under no-tillage practices. The same kind of results was achieved by Usman *et al.* (2012) for Pakistan. They found that wheat yield was higher with conservation tillage but required higher seeding rates. Conservation tillage with higher seeding rates not only improve yield and soil organic matter, but can also be the best alternate in case of high infestation of insect pests or weeds in poorly drained silt clay soil.

In India, Sharma *et al.* (2011) revealed from a 3-year study of a wheat-maize cropping system support of results from Saharawat *et al.* (2010). They found that farmers had 26 to 61% higher net returns with conservation tillage than conventional tillage. In both crops, yields were more than 2 percent lower in conservation tillage than conventional, but labor and energy savings in conservation tillage compensated that loss of yield. There was a 60 to 80% reduction of energy expense in tillage operations with conservation tillage. Therefore, farmers with conservation tillage had higher profit. Conservation tillage retained higher moisture at different soil depths. There was 1.2 to 1.6 times higher infiltration rate under conservation tillage than conventional tillage. Bhatia *et al.* (2010) found from a wheat-rice cropping system that the temporal emission of N_2O-N was higher in no-tillage plots on almost all days than conventional tillage. Generally, no-tillage soils were moist with organic matter more concentrated near the soil surface favoring N_2O production. No-tillage increased bulk density and water-filled pore space which resulted in decreased oxygen availability and higher N_2O emissions. But two new nitrification inhibitors i.e. S-benzylisothiouronium butanoate and S-benzylisothiouronium furoatewere effectively reduced N_2O emission as well as the global warming potential in wheat soils by 8.9 to 19.5%.

In China, there are more than 3.1 million ha under conservation agriculture. Huang *et al.* (2008) conducted a long-term rotation experiment from 2001 to 2005 in the western Loess Plateau of China. The result shows that water and nitrogen use efficiency was about 10% greater in no-tillage when stubble is retained in the field (NTS) than conventional tillage. Yield was also higher in the NTS treatment at 2.0 to 3.1 tons ha^{-1} and 1.5 to 2.6 tons ha^{-1} in conventional tillage. In the case of no-tillage, yield was lower but results were not significant. Conservation tillage increased rainfall storage during fallow time. Liu *et al.* (2011) summarized the results of many studies on tillage systems in China. Their findings also support the results from Huang *et al.* (2008). They found that conservation tillage had more economic benefits because yields of soybeans and maize were higher and input costs like labor and fuel were lower under conservation tillage than conventional tillage. Therefore farmers had higher net returns. Further they found that soil temperature was lowest under no-tillage. Annual water runoff and sediment loss was 92.4 and 98.3% less under no-tillage than conventional tillage respectively. No-tillage is more favorable than reduced tillage practices in China.

Liu *et al.* (2013) came out with the results of a 7-year study in China for a soybeans and maize cropping system. They have different results from Huang *et al.* (2008). They found that soybean yields were up to 7 percent higher in conservation tillage systems than conventional tillage system, while maize yields were up to 20% lower. Soil water contents were consistently highest under no-tillage whereas reduced tillage had lower soil water content than conventional tillage. While Zhang *et al.* (2013) found that soil bulk density was higher in topsoil with conservation soil than conventional tillage. Soil organic carbon (SOC) was higher at 0-5 cm soil depth with conservation tillage. Later conventional tillage had the highest SOC. Soil carbon sequestration rates under no-tillage was also significantly higher. There highest soil carbon storage rate was in no-tillage at 29.93% while it was only 25.94% in conventional tillage. There was a significantly lower hidden carbon cost with conservation tillage. No-tillage had lower carbon productivity than others. CO_2 is a major source for global warming potential and no-tillage reduced GHG emissions by 59.24% as compared to conventional tillage. No-tillage can be important for China because of savings in time, labor and energy and reductions in GHG emissions and benefits of SOC sequestration.

In the Middle East, a study was conducted in Iran by Tabatabaeefar *et al.* (2009). It mainly focused on the impact of different tillage systems on wheat yield and energy use. This study supports to some extent the previous study from Singh *et al.* (2008) and Sharma *et al.* (2011). The results show that conservation tillage had about 10% higher wheat grain and biomass yields than traditional tillage. Conservation tillage had lower input energy (16.33GJ) and higher output energy (79.55GJ) than traditional tillage (18.71GJ input and 68.27GJ output). Therefore, there was a significant higher net energy gain with conservation tillage. No-tillage had 11 to 21% higher energy productivity than other tillage systems. In no-tillage, 8.81 MJ energy was used to produce one kilogram of wheat which was lowest among the tillage systems.

There was another study in this region conducted by Kiani and Houshyar (2012). This study supports the results from Tabatabaeefar *et al.* (2009). They found that net returns with conservation tillage (\$650.7 & 501.5 ha^{-1}) was almost double that of conventional tillage (\$297.3 & 336.7 ha^{-1}) because there was less use of machine and human labor with a conservation tillage system. There were higher expenses on chemicals and fertilizers with conservation tillage but total cost with conservation tillage was significantly lower than traditional tillage. In the case of energy use status, conservation tillage systems had lower energy input (15829.07 MJ ha^{-1} in conservation and 16135.7 MJ ha^{-1} in conventional) and higher energy output (25849.95 MJ ha^{-1} in conservation and 11810.72 MJ ha^{-1} in conventional) while the inverse was true with conventional tillage. It shows that conservation tillage is more efficient in energy use.

3.3 Africa

In this region, the adoption of conservation agriculture is very low at about 1 percent of total area under conservation agriculture (Friedrich *et al.,* 2012). In this region, only South Africa has an increased area under conservation tillage (Kassam *et al.,* 2012).

The study was conducted by Rockstroem *et al.* (2009) in Ethiopia, Kenya, Tanzania and Zambia during the period 1999-2003. Results show that conservation tillage systems had higher grain yields than conventional tillage. There were about 40% higher maize yields in Ethiopia whereas it was more than double in Tanzania, 20% higher in Kenya, about 50% higher in Zambia. Maize yields with conservation tillage systems without use of fertilizer was also about 16% higher than conventional tillage without fertilizer application. In the case of *tef* grain yield which was grown only in Ethiopia, yield with conservation tillage systems was 11% higher than with conventional tillage. The yield difference became higher without fertilization, 31% higher with conservation tillage compared to conventional tillage. There was higher yield in drier periods with conservation tillage which shows that conservation tillage improves water-use efficiency and greater water holding capacity. There was a 50% labor reduction in tillage even though it increased 30% labor for weeding because in these countries, weeding is done by manual labor.

Another study was conducted by Kihara *et al.* (2011) in the eastern part of Kenya. This study produced opposite results from Rockstroem *et al.* (2009). They found that maize yields with conservation tillage were almost 50% lower than conventional tillage. There was improvement in yield with nitrogen application in conservation tillage but it was still lower than convention tillage. Yields improved with time and eventually became higher than conventional tillage.

There is one more study with a recent dataset, conducted by Ngwira *et al.* (2012) in Malawi from 2008 to 2011 which supports the results from Rockström *et al.* (2009). Biomass yield of maize per ha under conventional practices was 2.41 to 2.52 tons which was much lower than under conservation tillage practices with different crop rotations i.e. 3.36 to 4.90 tons. Almost the same situation was noticed in maize grain yields. The water infiltration rate was 19% higher in conservation tillage. Conservation tillage proved to be a labor-saving and more labor-efficient practice because there was a saving of 18 days ha^{-1} in producing maize with conservation tillage. Total variable costs were about 21% higher with conservation tillage but gross margins were about 61% higher than conventional tillage which favors conservation tillage in terms of labor productivity and lower production cost per kg of grain.

There was another study conducted in Malawi by Ngwira *et al.* (2012) over 6 years (2005-2011) in two locations, Lemu Bazale EPA and Zidyana EPA having results similar to those of Ngwira *et al.* (2012). The study shows the impacts of location on production with different tillage systems. Maize was used as the main crop and legumes were used as intercrops in some cases. They found that maize grain yield as well as biomass yield was higher under conservation tillage at Lemu Bazale EPA, 30 to 44 % higher with conservation tillage compared to conventional tillage. In 2009, there was lower yield than in other years and there was no significant difference in biomass yield among tillage systems. At the Zidyana EPA location there was no significant difference in maize grain yields during the first four cropping seasons. But in the fifth and sixth cropping seasons, maize grain yield was higher with conservation tillage than conventional tillage, by 29 to 51%. Almost the same situation was shown in biomass yields. There was a reduction in labor with conservation tillage, 12 days ha^{-1} lower than with conventional tillage to produce maize. There were no sprayer costs in conventional tillage because farmers used labor and ploughing to kill the weeds instead of herbicides.

Even though there were savings in labor costs with conservation tillage systems, variable costs were significantly higher with conservation tillage systems. At the Lemu Bazale EPA location, conservation tillage systems (maize, maize + a legume) resulted in more than three times higher net returns than conventional tillage systems. Whereas, at the Zidyana EPA location, 23 to 32% higher net returns were realized with conservation tillage systems compared to conventional tillage. Less labor and higher net returns make for higher profitability per labor with conservation tillage. Therefore, there was also a lower cost of production per kg of maize. Higher soil organic carbon and aggregate stability were reported with conservation tillage than conventional tillage but the difference was not significant. In the case of the presence of earthworms, it was about five times higher with conservation tillage than conventional tillage. There were 7 to 20% higher infiltration rates with conservation tillage systems as compared to conventional tillage.

3.4 Europe

Increased awareness by farmers, society and politicians regarding soil as a non- renewable resource is leading to gradual changes in the overall approach to soil conservation (Basch *et al.,* 2008). Many European countries have started to implement soil conservation practices like conservation tillage. But still the adoption of conservation agriculture in Europe is proceeding at a very slow rate. Area under conservation agriculture in Europe is at 1 percent of total area under conservation agriculture in the world (Friedrich *et al.,* 2012). Most of the studies in Europe are mainly focused on soil conservation or environmental issues instead of the economics of conservation tillage.

Chatskikh and Olesen (2007) conducted a study in Denmark during 2002 to 2004 on spring barley on a loamy soil. They found that tillage affected soil bulk density, which was reduced in a conventional tillage system within a period of 9 days between ploughing and rolling. This may be due to a decrease in volumetric soil water content. There were significant differences in N_2O and CO_2 emissions among tillage systems for the entire period of 113 days. The lowest emission of N_2O and CO_2 was with no-tillage. The highest emission was with conventional tillage, 65% more than no-tillage in the case of N_2O emissions. There was a positive correlation between N_2O and CO_2. N uptake in above-ground biomass was higher during the entire period for conventional tillage compared to conservation tillage. Further, they found that grain yields were lowered by 14 and 27% with reduced and no-tillage compared with conventional tillage respectively.

Similar results in almost the same conditions were found by Chatskikh *et al.* (2008). They conducted a study on winter oilseed rape followed by winter wheat during 2003 to 2005. They found that CO_2 emission was highest with conventional tillage in all periods or seasons. In autumn, it was about 8 percent higher with conventional tillage which increased to 29% higher in the spring seasons of two years. In the case of cumulative N_2O emissions, for two years there was no difference between conventional and reduced tillage, but it was about 23% higher in conventional tillage in the autumn season. It was the opposite in the spring season, N_2O emissions were highest with no-tillage whereas lowest with reduced tillage. The FASSEL model showed that soil CO_2 respiration level was lower than total C input in a simulated build-up of soil organic C for all tillage treatments. Net C sequestration was higher in conservation tillage systems than conventional tillage because some non-fertilized periods were not included in measurements.

Klik *et al.* (2010) conducted a study in Austria, with different findings from Chatskikh *et al.* (2008). There was a 16 to 39% reduction in CO_2 emission in winter wheat with reduced tillage. Average soil loss over 16 years through soil erosion was 3.1 to 5.3 tons ha^{-1} with reduced tillage. But with conventional tillage it was 6.1 to 25.6 tons ha^{-1}. In the case of surface runoff, it was 8.5 to 31.3 mm with reduced tillage, lower than conventional tillage at 13 to 36.9 mm. There was almost double the carbon loss with conventional tillage as compared to conservation tillage. There was 28.4 liters ha^{-1} fuel consumed with reduced tillage for tillage operations, but, this increased to 58.1 liters ha^{-1} with conventional tillage. There was a 55% time saving in the operation with reduced tillage at 77 minutes ha^{-1}. There was a 60% CO_2 emission reduction with reduced tillage for three years of tillage experiments. About 36% less energy was required with reduced tillage than with conventional tillage. Moitzi *et al.* (2013) also found that energy efficiency was higher with conservation tillage than conventional tillage. Energy efficiency ranged from 8.82 to 9.69 with conservation tillage whereas it was 7.70 to 8.74 with conventional tillage.

Lahmar (2010) also found that conservation tillage systems have positive impacts on soil structure and porosity. It helps to reduce soil erosion as well as increase soil organic matter and water infiltration. Basso *et al.* (2011) also found the same results in Northeastern Italy. They found that soil carbon sequestration was higher with no-tillage due to the lower soil disturbance and residues retained on the soil surface. Another study conducted by Mikanova *et al.* (2012) in Czech Republic was conducted on winter wheat, spring barley and peas during the period 2002 to 2009. Results also favored those from Chatskikh *et al.* (2008) and Klik *et al.* (2010). They found that the availability of organic carbon contents in the topsoil was higher in conservation tillage than conventional tillage. There was a positive relationship between winter wheat grain yield and soil organic carbon content. Biomass carbon and organic carbon were decreasing with conventional tillage, which have been due to more intensive mineralization of the soil organic matter and fewer inputs of substrate and energy from crop residues. Increasing biomass and organic carbon with no-tillage may be due to higher inputs of organic matter and less intensive mineralization processes. Mäder and Berner (2012) concluded that conservation tillage improves soil organic carbon content, soil structure and soil microbial activities. No-till practices also improve soil biodiversity. In Belgium, microbial biomass and enzyme activities were found to be higher in silt loam soil under no-till than under plow conditions (Bossche *et al.,* 2009).

Putte *et al.* (2010) found some results differing from Mikanova *et al.* (2012). They concluded that there is an average 4.5% reduction in yield with conservation tillage systems in Europe, but the reduction varies from crop to crop and type of conservation tillage applied. Overall yields were reduced when no-tillage was applied. In the case of reduced tillage, there was no significant yield reduction for fodder maize, potatoes; sugar beet and spring cereals. A significant reduction in yields with reduced tillage occurred for grain maize and winter cereals. In the case of soil type, there was yield reduction in reduced tillage except on loam soils and in no-tillage except on clay soils.

Basso *et al.* (2011) concluded from a one-year field trial experiment with maize in Italy that there was no significant yield difference among tillage systems except for reduced tillage. Reduced tillage plots had about 15% higher yields than conventional and no-tillage plots. But there was a significant difference in production costs especially machinery costs between conventional and conservation tillage. No-tillage had the lowest and conventional had the highest machinery costs. Conventional tillage had about 5 times higher total costs compared with no-tillage. Reduced tillage had 3 times higher total costs than no-tillage. Farm gross margin (FGM) was highest with no-tillage practices at 673 Euro ha^{-1} and lowest with conventional tillage at 558 Euro ha^{-1}. FGM is the difference between economic value of the yield and cost for tillage at variable intensity.

Miknova *et al.* (2012) also found a reduction in yield with conservation tillage during the initial period. At the start of the 5-year study, yields did not show any significant difference between tillage systems. After that there was more than 35% higher yield with conservation tillage than conventional tillage. Lahmar (2010) summarized the results of the KASSA project, which showed that conservation agriculture practices do not necessarily increase yield. As an average in northern Europe, yields on poor and medium-fertile soils did not change drastically. It should be kept in mind that the favorable effects of soil conservation technologies may be exhibited later, especially after the stabilization of soil properties. The adoption of conservation agriculture practices in Europe take place, keeping in mind climate change, soil limitations, water availability and soil erosion problems instead of only increasing yield. He found that there was 10-15% yield increase with no-tillage in Spain. There was a significant reduction in labor and fuel charges with conservation tillage.

A pertinent study was conducted by Kairis *et al.* (2013) in Greece during the period 2008 to 2011 on an olive grove. They found that water runoff was affected significantly by land management practices. The highest water runoff was found with conventional tillage, followed by no-tillage with herbicide use. Cumulative surface water runoff for three periods was about 45% higher with no-tillage and herbicide use than no-tillage without herbicide use. Water runoff was more than 4 times higher in conventional tillage compared with no-tillage without herbicide use. Similar trends were found for sediment loss with different land management practices. It may be due to higher plant cover with no-tillage practices compared with conventional tillage. There were average sediment losses of 29.3, 113.1 and 261.7 kg $ha^{-1}year^{-1}$ with no-tillage, no-tillage with herbicide use and conventional tillage respectively. There was an average of 3.7 mm sediment loss per year with conventional tillage. This is a massive loss as a result of soil erosion due to surface runoff. Soil moisture content and bulk density was higher with no-tillage than conventional tillage. Bulk density is an important indication of soil compaction. It shows that conservation tillage has a significant impact reducing soil erosion and water runoff.

There is a recent study in France by Davin *et al.* (2014) which found that conservation tillage provide an option to mitigate climate change. This study shows that during hot summer, heat wave impacts would be reduced locally by increasing surface albedo through conservation tillage. In South Europe with increasing surface albedo, there is up to 2°C lower air temperature in hot summer days under conservation tillage especially no-tillage as compared to conventional tillage. The main reason for lower temperature of soil is due to low evaporation rates caused by soil covered with crop residues.

3.5 Interim Conclusion

In spite of positive socio-economic and environmental impacts of conservation tillage, adoption of conservation tillage is still limited. Large farms are the most common adopters because of their ability to absorb the risk as well as their lack of labor (Lahmar, 2010). Investment in new machinery can be the major challenge for adoption of conservation tillage by small farms. Initial higher investment and lack of knowledge about crop rotation may be the reasons for lower adoption of conservation tillage in Asia and Africa. Conservation tillage with crop rotation helps to achieve higher yields even in water-stress conditions. In some cases, yield is increased with conservation tillage but mainly in Europe, there are fewer incidences for yield increasing. But, still there is potential for economic benefit because of the significant reduction in labor and fuel charges. For yield, type of soil plays an important role. In Asia and Africa, farmers are adopting conservation tillage practice to increase yields and current economic benefits. In Europe, farmers are more concerned with the environmental impacts of conservation tillage. Therefore, the results from European studies show that conservation tillage helps to reduce soil erosion, GHG emissions, SOC sequestration, lowers the temperature and helps to mitigate climate change, and increase water infiltration rate. Conservation tillage not only reduces costs but also increases resource-use efficiency. It also maintains soil biodiversity through increasing the presence of earthworms. Many studies show that there is no need to use extra herbicides to control weeds. In other words, conservation tillage can help to attain sustainable agriculture.

4 Conservation tillage – A case study of Germany

4.1 Introduction and major problem

On the one hand, world population is increasing very rapidly and on the other hand agricultural land is decreasing due to population pressure. Therefore, to increase production while improving soil health is the main challenge facing world agriculture. Germany is not untouched by these problems. Soil is considered a vital natural resource responsible for the growth of land plants. Generally soil is comprised of 45% minerals, 25% water, 25% air and 5% organic matter (Jones *et al.,* 2012). Good soil health is very important for productivity. But soil degradation is one of the main problems in Europe. Major causes of soil degradation are soil erosion and pollution (Jones *et al.,* 2012; Grimm *et al.,* 2002).

In Europe, about 115 million ha area are affected by soil erosion i.e. 12% of Europe's total land area. This leads to a 53 Euro ha^{-1} $year^{-1}$ loss in agricultural areas (CEC, 2006). Water and wind can be harmful to a soil that is without vegetation or lacks crop residues. This can result in soil erosion on agricultural land with heavy rainfall or strong winds. In Germany, with present soil management practices, the potential soil erosion risk is more than 7 tons ha^{-1} $year^{-1}$, while annual soil formation is much less than soil loss (Erhard *et al.,* 2003). 2.1 million ha in Germany are highly affected by soil erosion. This is about 17% of the total arable land area in Germany at 11.8 million ha of arable land. Out of 2.1 million ha, 1.8 million ha are affected by water and the remaining 0.3 million ha by wind erosion (Schmitz *et al.,* 2013).

Soil erosion poses a severe problem because soil erosion can quickly alter fertile soil into unfertile soil for agriculture. In extreme cases, soil erosion can lead to desertification in which the land is no longer capable of supporting plant growth (Jones *et al.,* 2012; Grimm *et al.,* 2002). The states of Germany are affected by erosion at different levels because of their different agro-climatic conditions. Therefore, northern German states have larger proportions of vulnerable area with wind erosion whereas major erosion in southern Germany and the Central Mountain areas are due to water (Schmitz *et al.,* 2013). Rainfall is the main factor for soil erosion through water. Total rainfall with precipitation of $\geq$10 mm and rainfall with an intensity of $\geq$ 10 mm per ha can be considered an erosive factor (Rogler and Schwertmann, 1981).

4.1.1 Present situation of soil erosion

In 1998, a legal framework for soil protection in Germany at the federal level was performed through the Federal Soil Protection Law. A State Soil Protection Law for the Federal State of Lower Saxony came to effect in 1999. The main focus of these laws is to protect the soil from existing dangers especially in the areas of old sites and detrimental change of the soil (Gunreben, 2004). There are different levels of erosion by water and wind which are determined by the combined effects of soil erosion (K), slope (S) and rainfall factors (R). Table 4.1 shows the different categories of soil erosion by water. The last two rows determine the real endangerment class for water erosion (Schmitz *et al.,* 2013).

Table 4.2 shows the determination methods of high wind erosion endangerment locations by wind speed. It clarifies that medium wind erosion danger locations can be converted into very high wind erosion danger location with high wind speeds. At low speeds, very high erosion endangered soils have less danger of erosion (Gunreben, 2004). With wind erosion, only land under very high erosion endangerment classes is determined to be area under wind erosion.

Table 4.1: Classification of potential of water erosion danger and water erosion endangered classes (DIN 19708)

Erosion classes based on DIN 19708	Description	K*S*R*2 (with R=50)	Water erosion endangerment classes based on cross compliance (CC)
$E_{nat}0$	None to very low erosion danger	< 1	CC 0
$E_{nat}1$	Very low erosion danger	1- < 5	
$E_{nat}2$	Low erosion danger	5 - < 10	
$E_{nat}3$	Medium erosion danger	10 - < 15	CC 0
$E_{nat}4$	High erosion danger	15 - < 30	
$E_{nat}5.1$	Very high erosion danger	30 - < 55	CC_{water1}
$E_{nat}5.2$	Very high erosion danger	≥ 55	CC_{water2}

Source: Schäfer *et al.,* 2010

Table 4.2: Classification of location-based erosion susceptibility relationship between wind speed and soil erosion (DIN 19706)

Soil erodibility class	Mean annual wind speed in exposed areas at a height of 10m above ground in m/s					
	<2.0	2.0 to 2.9	3.0 to 3.9	4.0 to 4.9	5.0 to 5.9	>5.9
0	0	0	0	0	1	1
1	0	0	1	1	2	2
2	0	1	2	2	3	3
3	1	2	3	3	4	5
4	2	3	4	4	5	5
5	3	4	5	5	5	5

Source: Gunreben, 2004

Table 4.3 represents the areas highly endangered by erosion in Germany. There is a total area under erosion of 2,048,477 ha which contributes 17.3% to the total arable area in Germany. In the case of total area, Bavaria has most arable and erosion-endangered area. It has 23.6 percent of its area under erosion danger, in which almost area is endangered by soil erosion through water. Saxony has the second highest erosion danger area at 283,800 ha, which contributes 39.5 percent to total arable land area of Saxony. Thuringia has the third most erosion danger area at 244,593 ha which makes up 40% of total arable land area of Thuringia and the soil erosion area is affected mainly by water. Saarland has the least arable land area in Germany at 36,800 ha but out of it, 44% of area is affected by water erosion. Hesse has 35% water eroded area whereas Rhineland-Palatinate contains 28% area under water erosion. In these two states, there is no area under wind erosion. In the case of wind erosion, Lower Saxony has the greatest area affected by wind erosion at 103,619 ha, which is 47% of the total eroded area of the state.

Table 4.3: Area under erosion endangerment based on Cross Compliance (in 2012)

State	arable land	CC_{water1}	CC_{water2}	CC_{wind}	CC_{water1} +CC_{water2} +CC_{wind}	
	ha	ha	ha	ha	ha	% area
Baden-Württemberg	830,000	102,164	31,289	45	133,498	16.1
Bavaria	2,062,300	394,352	91,321	281	485,954	23.6
Brandenburg and Berlin	1,029,500	725	98	78,192	79,015	7.7
Hesse	476,900	132,700	35,800	0	168,500	35.3
Mecklenburg-Western-Pomerania	1,077,900	80	4	41,681	41,765	3.9
Lower Saxony and Bremen	1,886,000	76,964	38,099	103,619	218,682	11.6
North Rhine-Westphalia	1,046,700	85,058	37,439	2,903	125,400	12.0
Rhineland-Palatinate	401,600	80,601	33,001	0	113,602	28.3
Saarland	36,800	5,893	10,367	0	16,260	44.2
Saxony	719,100	210,000	72,000	1,800	283,800	39.5
Saxony-Anhalt	995,500	74,206	15,792	24,310	114,308	11.4
Schleswig-Holstein and Hamburg	672,700	3,000	100	20,000	23,100	3.4
Thuringia	610,800	189,162	55,431	0	244,593	40.0
Germany	**11,850,100**	**1354,905**	**420,741**	**272,831**	**2,048,477**	**17.3**

Source: Schmitz *et al.*, 2013

Mosimann *et al.* (2009) found that 15-55% of the area of Lower Saxony is affected by soil erosion. Brandenburg and Mecklenburg-Western Pomerania have almost all erosion danger area under wind erosion. Schleswig-Holstein also has a higher proportion of erosion area under wind erosion. Mostly wind erosion-affected states have lower total erosion danger area than other states. Mainly the northern sates of Germany are affected by wind erosion.

4.1.2 Effects of soil erosion

Soil erosion is a natural process, but because of human activities it can increase by 10 to 40 times. It creates problems including desertification, lower agriculture productivity due to land degradation, ecological collapse due to loss of nutrient-rich topsoil and sedimentation of waterways (Blanco and Lal, 2010). Erosion is mainly removal of the upper rich layer of the soil which results in reduction of soil quality. It leads to decreased suitability of soil for agriculture or vegetation purpose. Mosimann *et al.* (2009) conducted a study during 2000-2009 in Lower Saxony. They found that mean soil loss ranges between 1.0 to 2.3 tons ha^{-1} $year^{-1}$ whereas this figure increases 1.4 to 3.2 tons ha^{-1} $year^{-1}$ when including sheet erosion. In the case of high erosion-endangered conditions, erosion rates increase and soil loss exceeds 5 tons ha^{-1}. This results in a loss of more than 1 mm of soil per year. Due to rill erosion, there is a total soil loss of 15 to 40%. Transport of soil due to water erosion becomes a major environmental problem because it creates more problems than just soil loss. Further they found that traces of deposition through transport of soil with water erosion were only 40% visible. This shows that transport of soil matter with water erosion can covers great distance.

Erosion is not only responsible for soil loss and decreasing soil quality, but also creates problems for sustainable productivity in agriculture. Wind erosion can be more dangerous than water erosion. In Germany, only 2.3% of total arable land is affected by wind erosion. It contributes 13% to total erosion endangered area. There seems to be much less area under wind erosion than water erosion. In April, 2011, there was a strong sandstorm along a roadway in Mecklenburg-Western Pomerania. This sandstorm in northern Germany caused a huge pile-up which killed eight people and injured many more. A total 100 people, 80 cars and three trucks were involved in this crash (The Guardian, 2011).

Following are some figures which represent different types of soil erosion and their impacts. Figure 4.1 shows a potential loss of up to 32 cm or 40 tons ha^{-1} soil in a period of 80 years with highly erosion-endangered soil. Whereas, non-endangered soil has a very low risk of soil loss with soil management practices. Figure 4.2 shows soil erosion by water on the field. Water erosion creates gullies on a field which are responsible for higher soil loss and transfer of soil nutrients to other places. Figure 4.3 shows wind erosion on a farm. In wind erosion, the soil transfer from one place to another is through the air.

Mosimann *et al.* (2009) suggested that soil tillage in the direction of water flow; along slope length, together with soil type and its compaction are major reasons for high soil erosion rates. Tractor tracks were responsible for rill erosion. It can be concluded that soil erosion can be reduced by reducing tillage, lowering the traffic on the field, reducing the slope as well as increasing more vegetation to reduce runoff water and wind erosion. Conservation tillage can be a solution to reduce soil erosion and to sustain the productivity of agriculture.

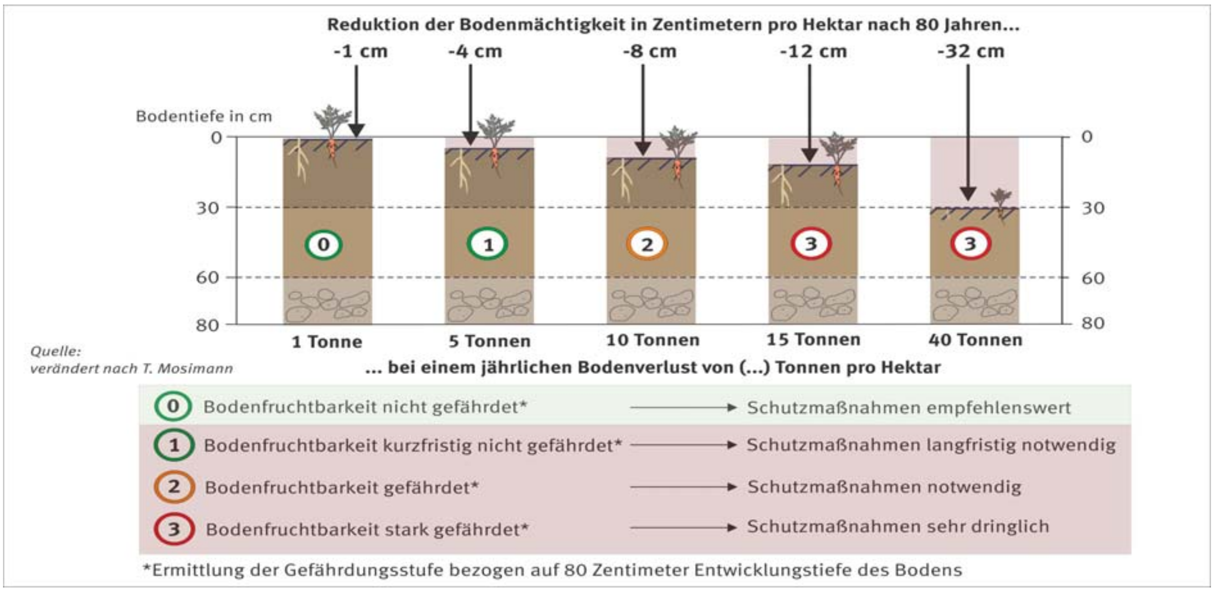


Figure 4.1: Long-term effects of soil erosion

Source: FG II 2.7 / Umweltbundesamt, 2013

Figure 4.2: Soil erosion by water on the field

Source: Mosimann *et al.*, 2003; Ingenieurbüros Feldwisch, (undated)

Figure 4.3: Wind erosion on the field and famous road accident due to a wind storm in Germany

Source: Schäfer (LBEG) in BGR, 2013; The Guardian, 2011

4.2 Overview of conservation tillage

In Germany, conservation tillage is also known as reduced tillage, no- or zero tillage, mulch tillage and strip till. In other words, it is the tillage system in which minimum soil disturbance occurs. Table 4.4 represents the area under different tillage systems in Germany. About 39% of crop area is cultivated under conservation tillage in Germany. And about 38% area is under reduced or mulch tillage practices whereas there is only 1% area under no-tillage practices.

There are many reasons for greater acceptance based on the suitability of reduced tillage in a humid temperate climate, such as manure absorption, more rapid warming of the soil during spring, resulting in faster nitrogen mineralization, better perennial weed control and removal of grass cover by shallow undercutting of the whole field. In the case of a maize and wheat crop rotation, a shallow incorporation of straw residues into the soil may result in faster decay, and thus in a better regulation of pathogens such as *Fusarium species.* In this way, reduced tillage may also lead to better and faster crop establishment to compete with weeds as compared to no-tillage systems (Peigne *et al.,* 2007; Hobbs *et al.,* 2008).

Among the states, the range of actual area under conservation tillage is 100 to 603,700 ha whereas the percentage area range is 6.7 to 66%. Berlin has the lowest area under conservation tillage. Mecklenburg-Western Pomerania has the greatest area under conservation tillage at 603,700 ha, which is about 56% of total arable area in the state. In this state, erosion mainly occurs with wind. Saxony-Anhalt and Lower Saxony also have comparatively greater area under conservation tillage than some other states. In these two states, soil erosion happens due to high-speed wind. Thuringia has the highest area share under conservation tillage at 66% of the state's arable area. Thuringia also has comparatively more erosion endangered area. That may be why farmers would like to adopt soil conservation techniques to reduce soil erosion. Bavaria has comparatively less area under conservation tillage. The reason may be that there is a more area under organic farming than other states (Munoz *et al.,* 2012). Therefore, they have more problems with weeds with conservation tillage (Mäder and Berner, 2012). In the central part of Germany, Hesse has 179,500 ha under conservation tillage which contributes a 37.5% share to the state's arable area. Area under conservation tillage in Hesse is comparatively lower than other neighboring states (Table 4.4).

Table 4.4: State wise area under different tillage systems in Germany (1,000 ha)

State	Total area	Conventional tillage	Reduced/ Mulch tillage	No-tillage	Conservation tillage	Conservation tillage (%)
Germany	11,896.8	6,608.2	4,469.3	146.3	4,615.6	38.8
Baden-Württemberg	839.2	456.2	333.0	11.0	344.0	41.0
Bavaria	2,066.3	1,524.2	459.8	12.3	472.1	22.8
Berlin	1.5	0.9	0.1	0.0	0.1	6.7
Brandenburg	1,032.2	504.7	397.7	12.0	409.7	39.7
Bremen	1.6	1.2	0.6	0.1	0.7	43.8
Hamburg	5.7	3.8	1.1	0.0	1.1	19.3
Hesse	478.9	273.5	175.2	4.3	179.5	37.5
Mecklenburg Western Pomerania	1,083.6	414.5	596.9	6.8	603.7	55.7
Lower Saxony	1,869.2	1,185.6	530.5	26.8	557.3	29.8
North Rhine-Westphalia	1,069.0	701.9	312.0	10.9	322.9	30.2
Rhineland-Palatinate	404.8	227.9	144.8	4.7	149.5	36.9
Saarland	37.3	18.3	14.2	0.5	14.7	39.4
Saxony	720.7	290.0	386.0	11.0	397.0	55.1
Saxony-Anhalt	1,001.9	365.7	549.9	36.8	586.7	58.6
Schleswig-Holstein	671.8	445.5	168.5	3.2	171.7	25.6
Thuringia	613.1	194.4	398.9	5.9	404.8	66.0

Source: Statistisches Bundesamt, 2010 and own calculation

The Government pays 340 Euro $ha^{-1}year^{-1}$ to farmers. Farmers have to apply some extent of soil conservation activities to meet the requirements of GLÖZ (Schmitz *et al.,* 2013). The second pillar of Common Agriculture Policy (CAP) establishes a strong financial tool with its European Agricultural Fund for Rural Development (EAFRD) to promote agriculture and rural development. Competitiveness, Environment & Agriculture, and Diversification & Quality of Life (CAP towards 2013) are the three main priorities to create regional or state-support programs which are co-funded by Germany and its states. Some states already have started a Rural Development Program (RDP 2007 to 2013) and introduced conservation tillage in the framework. For example, Saxony provides 68 Euro ha^{-1} for permanent conservation tillage through its agri-environmental measures policy (AuW, 2007). Bavaria, for its cultural landscape program, (KULAP) pays 100 Euro ha^{-1} to adopt mulch sowing. Whereas Rhineland–Palatinate provides 50 Euro to 120 ha^{-1} for mulching methods to promote low-input production practices in the agricultural sector (PAULa). Compensation depends on the measures of conservation methods. It shows that the government also motivates farmers to adopt soil conservation practices. In the next sections, the study concentrates on the impacts of conservation tillage in Germany.

4.3 Environmental impact of conservation tillage

Many studies show that conservation tillage has a significant impact as reduction in tillage intensity directly or indirectly influences the environment. This part will describe about the ecological impacts of conservation tillage.

4.3.1 Soil organic matter and emission of CO_2 and N_2O gases

A study conducted by Vogeler *et al.* (2009) in Braunschweig during the period of 1998 to 2006. They found that the topsoil pH under conservation tillage (5.90) was slightly higher than conventional tillage (5.20). But below the topsoil, it decreases under conservation tillage. Short term bulk density was also higher under conservation tillage than conventional tillage in the topsoil. In the case of soil organic matter, it increases in all tillage management systems during the period. Generally, soil organic matter was higher under conservation tillage than conventional tillage.

Ernst and Emmerling (2009) found results similar to Vogeler *et al.* (2009) that soil organic carbon was increased by about 10 to 24% in the topsoil under conservation tillage compared to conventional tillage. But, conventional tillage had higher soil organic carbon at deeper levels. They also assumed that soil tillage and vertical soil organic carbon affects the density, biomass and community composition of an earthworm population. Chen *et al.* (2009) support the results from Vogeler *et al.* (2009) and Ernst and Emmerling (2009). They noticed that conservation tillage resulted in more than 43% higher soil organic carbon and total nitrogen than conventional tillage at 0-20 cm soil depth. Further, they estimated that the rates of soil organic carbon and total nitrogen accumulation at 0-20 cm soil depth for conservation tillage were 0.32 to 1.27 tons C ha^{-1} $year^{-1}$ and 0.03 to 0.13 tons N ha^{-1} $year^{-1}$ over an average of 11 years.

Ulrich *et al.* (2010) brought forth findings from a very long study (1965 to 2001) which also supports the results from the above-mentioned studies. They highlighted that C and N content changed in the topsoil with different tillage systems. The vertical distribution of soil organic carbon and total N content in topsoil were 23 to 36% and 14 to 29% respectively higher under conservation tillage management as compared to conventional tillage management. Conservation tillage almost doubles microbial biomass in top soil compared to conventional tillage. There is an increase in soil organic carbon and total soil N in the topsoil (10cm) due to a reduction in soil tillage intensity and/or depth. The main cause is the decreased input of organic manure and crop residues in deeper layers (Teebrüge and Düring, 1999). Jacobs *et al.* (2010) also found that bulk densities with conservation tillage are significantly higher than conventional tillage even over a different time span. Organic carbon contents under conservation tillage are 70% higher than conventional tillage. Furthermore, they found that after 28 days of incubation at 22°C and 50% of maximum water holding capacity, the cumulative CO_2-C emission was significantly higher in minimum tillage than conventional tillage. It shows the higher potential organic matter mineralization in reduced tillage compared to conventional tillage. Bischoff (2010) also found that organic carbon content was higher or equal under conservation tillage as compared to conventional tillage in topsoil (0-10 cm soil depth). Potassium in topsoil was significantly higher under conservation tillage than conventional tillage. Cation exchange capacity was also higher in topsoil under conservation tillage than conventional tillage but the difference was not significant.

There was a 12-year long-term study conducted in Northeast Brandenburg by Joschko *et al.* (2012). They also confirmed the results from Vogeler *et al.* (2009), Ernst and Emmerling (2009) and Ulrich *et al.* (2010) that under reduced tillage systems, soil organic carbon content in the topsoil increased up to 30% compared to a conventional tillage system. Generally, organic carbon stocks increased during the study period in all tillage systems. But in reduced tillage, increases in carbon stocks were slightly more pronounced. The same results were previously confirmed by Vogeler *et al.* (2009). There was higher humus balance with reduced tillage, +348 kg humus-C ha^{-1} $year^{-1}$ which was more than double that of conventional tillage at +163 kg humus-C ha^{-1} $year^{-1}$. Humus balances between -75 to 100 kg humus-C ha^{-1} $year^{-1}$ are optimal; values higher than 300 kg humus-C ha^{-1} $year^{-1}$ greatly exceed the desired range and potentially pose risk for N losses (Körschens *et al.,* 2004).

Andruschkewitsch *et al.* (2013) conducted a long term study (18-25 years) with slightly different results than previous studies. They found that organic carbon under mulch tillage is higher than conventional tillage in up to 25 cm soil depth. There were more than 50 and 40% higher organic carbon and total N respectively at 5 cm soil depth. There was about a 7% higher ratio of organic carbon and total N with mulch tillage than conventional tillage. But no-tillage does not have any effect on organic carbon storage. There is about a 44% higher ratio of microbial biomass carbon to soil organic carbon with conservation tillage (Ulrich *et al.* 2010). Further, they found that water-extractable organic carbon and macro-aggregate contents are significantly higher with conservation tillage than conventional tillage at 5 cm soil depth. The calculated C sequestration rate for mulch tillage in comparison to conventional tillage is 31g C m^{-2} $year^{-1}$. Whereas, there is no C sequestration under a no-tillage system, this may be due to decreased above-ground and root biomass input because of lower yields.

Küstermann *et al.* (2013) accomplished a long-term study in southern Germany that also favored the results from the above-mentioned studies, but with slightly different results from Andruschkewitsch *et al.* (2013). There was a change in soil organic carbon of 258 to 290 kg ha^{-1} at 8 cm soil depth with conservation tillage which was more than 10 times higher at 18 cm soil depth. The same trend was noted with soil organic nitrogen. Lowering the depth of soil loosening and mixing, soil organic carbon content was higher in the soil close to the surface. Soil organic carbon content decreased with increasing soil depth. During the reference period there was a 300 kg ha^{-1} $year^{-1}$ increase in soil organic carbon reserves in conventional tillage whereas, this increased to 150-500 kg ha^{-1} $year^{-1}$ in conservation tillage. Loibl (2013) also found at experiment fields that soil organic carbon was 33% (12g/kg in conventional tillage and 18g/kg in mulch tillage) higher under conservation tillage at soil depth of 0-10 cm. After 10 cm soil depth, it decreased with mulch tillage but increased with conventional tillage.

Ulrich *et al.* (2010) found that microbial biomass carbon and soil organic carbon ratio was 2.18% and 3.14% in conventional and conservation tillage respectively. Generally, the amount of microbial biomass in a soil reflects the total organic matter content, with the living microbial component forming a low proportion of the total. Microbial biomass and organic matter are highly correlated. Under conventional tillage another bacterial population with a specific degradation rate of organic matter is present than under conservation tillage. Therefore, the greater bacterial diversity under conventional tillage has more potential for degradation of organic matter and stress resistance. Humus accumulation also cannot take place under these conditions. Therefore, more CO_2 from the atmosphere is sequestered under conservation tillage soils. A study conducted by Schmitz *et al.* (2011) also calculated that there is up to 55% lower CO_2 emission through fuel consumption under conservation tillage as compared to conventional tillage.

Küstermann *et al.* (2013) also found that greenhouse gas emission is much lower with conservation tillage than conventional tillage. Negative net greenhouse gas emissions (-220 kg CO_{2eq} ha^{-1}year^{-1}, -28 kg CO_2 per gas emission) were measured for conservation tillage whereas for conventional tillage, it was 2,276 kg CO_{2eq} ha^{-1} year^{-1} and 346 kg CO_2 per gas emission. The greenhouse gas emission was calculated as CO_2 emitted from the consumed fossil fuels, the soil organic carbon changes and N_2O emissions. N_2O emission was also lower under conservation tillage than conventional tillage but there was no significant difference.

4.3.2 Impact on soil erosion/ compaction and water

Generally, the improvement of C sequestration with adoption of conservation tillage is due to less tillage-induced soil disturbance, reduced soil erosion, more root biomass, rhizodeposition, and litter biomass relative to row cropping systems (Lal, 2004). A study conducted by Mueller *et al.* (2009) in Germany, Canada and China through long-term experiments (more than 10 years) found that penetration resistance is higher under no-tillage than conventional tillage. With no-tillage, in some cases there was a greater resistance of the soil to compaction. The subsoil had been compacted by conventional tillage over some decades. Therefore, no-tillage has an advantage to avoid subsoil compaction. Traffic is a reason for over-consolidation of soil and unfavorable visual soil structure and no-tillage practices may have a permanent advantage over conventional tillage. Vakali *et al.* (2011) conducted a study with organic farming that supports the results from Mueller *et al.* (2009). They found that soil aggregate stability values were about 56% higher with conservation tillage compared to conventional tillage in barley. In the case of rye, it was more than 100% higher with conservation tillage than conventional tillage. In the case of penetration resistance, which is measure of soil compaction, it was 30 to 50% higher with conservation tillage as compared to moldboard plow practice. Soil respiration was about 24% higher with conservation tillage than traditional tillage. It can be concluded that the conservation tillage system improved soil physical and biological properties. Whereas, Vogeler *et al.* (2009) suggested that conservation tillage can reduce surface runoff by increasing porosity. They also found that the steady infiltration rate increased to three times higher under conservation tillage than conventional tillage within the time period.

Volk *et al.* (2010) used the empirical Universal Soil Loss Equation (USLE) ABAG-flux and estimated that soil loss with conventional tillage is 5.4 tons $ha^{-1}year^{-1}$ which is more than double the soil loss under conservation tillage at 2.2 tons $ha^{-1}year^{-1}$. They revealed that vegetation strips can lead to a mitigation of sediment matter transport locally and thus also decrease its entry into waterways. They suggested that the risk of soil erosion can be further reduced through using vegetation stripes and riparian buffer strips with conservation tillage practices. Mosimann *et al.* (2009) also found that conservation tillage reduced soil erosion by 75% in sugar beet cultivation compared to conventional tillage in Lower Saxony. Scheid (2010) also found that conservation tillage has significant impact on soil erosion. There was lowered soil loss by 5.2 tons ha^{-1} as compared to conventional tillage. Schmitz *et al.* (2011) also have similar results like that of Scheid (2010). They found that soil under conventional tillage was high (i.e. 6.1 tons ha^{-1}) whereas soil erosion under reduced and no-tillage was low (i.e. 1.8 tons ha^{-1} und 1 tons ha^{-1} respectively). In case of water run off, there was 23.5 mm with conventional tillage while it was only 21.4 and 18.3 mm with reduced and no-tillage. Lower herbicide loss through erosion and leaching was also noticed with conservation tillage as compared to conventional tillage.

Schmidt *et al.* (2012) found in their 8-year experiment that conservation tillage reduced soil erosion and improved soil quality. Table 4.5 shows that conservation tillage has higher mulch cover which reduces soil erosion. Conservation tillage has higher earthworm quantity and macro-pores than conventional tillage. It means soil under conservation tillage has better quality and higher infiltration rate than soil under conventional tillage.

Table 4.5: Comparison of conventional and conservation tillage systems (after 8 years)

Parameter	unit	Conventional tillage	Conservation tillage
Mulch cover	%	1	13 - 77
Humus	%	2.0	2.2 - 2.5
Microbial biomass (0-5cm soil depth)	µg C_{mic} / g dry soil	415	575 - 626
Aggregate stability (Liming soil)	%	20	22 - 25
Earthworms Deep digger (*L. terrestris*)	No./m^{-2}	125 4	312 - 358 29 - 37
Macro-pores	No./m^{-2}	264	493 - 775

Source: Schmidt *et al.*, 2012

Further they found through rain simulation experiment that conventional tillage has a lower infiltration rate than conservation tillage, 55% for conventional and 93% for conservation tillage. Through 20-minute experiments, they found that with conventional tillage, water infiltration came down after the 4th minute and was less than half of the initial stage at the 8th minute. At the end of the experiment, infiltration was only about 0.5 mm per minute. With conservation tillage, infiltration rate was stable until the 15^{th} out of 20 minutes. At the end, infiltration was more than 1mm per minute, about double that of conventional tillage. Soil loss with conventional tillage was 246 g/m^2 whereas, it was much lower with conservation tillage at 36 g/m^2. Further they found in their 10-month experiment that conservation tillage produces higher relative soil water content than conventional tillage.

Piegholdt *et al.* (2013) produced results from a long-term field trial at four sites in Eastern and Southern Germany during 1990 to 1997 and favored the findings from Schmidt *et al.* (2012). They found that tillage system had little effect on total P content. Soil P contents slightly increased under no-tillage as compared to conventional tillage. Total P was higher in the topsoil under no-tillage than conventional tillage which may have resulted from higher organic carbon content in the upper soil up to 5 cm. They also estimated potential soil losses by water erosion and found a 0.1 to 1.4 tons $ha^{-1}year^{-1}$ soil loss in no-tillage practice with the least slope (0.25%) and annual precipitation 512 mm from three sites Germany. It was much lower compared to conventional tillage at 0.4 to 3.5 tons $ha^{-1}year^{-1}$ soil loss. The potential soil loss slightly increased at a fourth site, estimated at 4.7 and 8.4 tons $ha^{-1}year^{-1}$ for no-tillage and conventional tillage respectively. It may have been due to greater slope (5.5% and annual precipitation of 776 mm. Lorenz *et al.* (2013) also estimated 80% less soil erosion with conservation tillage than conventional tillage. Soil erosion with no-tillage practices can be reduced by 88% compared to conventional tillage. Further, they reported that the most soil erosion arises in crop rotations with a high share of summer crops. Reducing tillage intensity, the differences in soil erosion becomes smaller. The maximum difference in soil erosion between the crop rotations when applying conservation tillage practices was about 29%, whereas with no-tillage practice it was about 8%. Loibl (2013) also found that there was a more than 50% reduction in soil erosion under conservation tillage. Through rain simulation experiment, it was calculated that soil loss was 542 g/m^2 with conventional tillage. With conservation tillage it ranged from 12 g/m^2 to about 270 g/m^2.

4.3.3 Impact on soil biodiversity

Soil conservation practices helps to improve soil quality, enhance the productivity as well as soil biodiversity. Joschko *et al.* (2009) conducted a study during 1996 to 2006 related to soil biodiversity in Brandenburg. They finalized that deep burrowing earthworms (*L. terrestris*) increased in number under reduced tillage. The activity of earthworms with finer textured soils was increased under reduced tillage. Earthworm activity and soil properties showed that, in addition to soil texture, earthworm activity was closely related to the organic matter content in the upper soil layer (0-15 cm soil depth). Generally, earthworm activity was less in all earthworm parameters studied. Spatial variability was more prominent under reduced tillage as compared to conventional tillage. There were about 53% more earthworms under conservation tillage compared to conventional tillage. Abundances varied from approximately 0 to 150 worms pro m^2 under reduced tillage in different years. Abundance of earthworms in conventional tillage were very low, from zero to 30 worms pro m^2 observations.

There is another study related to earthworm density conducted by Ernst and Emmerling (2009). They found that average earthworm abundance was higher under conservation tillage than conventional tillage. There were 38 more earthworms prom^2 under conservation tillage because earthworms' abundance under plowing was 119 individuals pro m^2 which is much lower than under conservation tillage practices at 157 individuals pro m^2. Further, they reported that soil tillage and vertical soil organic carbon distribution considerably affected the density, biomass and community composition of the earthworm population.

A 37-year long-term study, conducted by Ulrich *et al.* (2010) concluded that earthworm population was affected by different soil tillage practices. The highest abundance and biomass of earthworms was noticed in reduced tillage with 221 individuals pro m^2 and 64.7 g/m^2, respectively. There were about 80 more individuals m^{-2} under reduced tillage compared to no and conventional tillage. There was no significant difference between conventional and no-tillage practices for abundance and biomass of earthworms. It showed that reduced tillage had a positive effect on the earthworm population. The highest species diversity was measured in the conventional tillage variant (1.26) followed by reduced tillage (0.91). Klarhölter (2010) also confirmed that the quantity of earthworms increased with conservation tillage. Therefore, the quality of the soil improved because of earthworms. Enzyme activity of tested soils turns down with soil depth. The highest enzyme activities were noticed in the upper layer (10 cm) of the soil in the conservation tillage (Ulrich *et al.,* 2010).

Joschko *et al.* (2012) also confirmed the results from Joschko *et al.* (2009), Ernst and Emmerling (2009) and Ulrich *et al.* (2010). They reported that the overall population of earthworms tended to be low due to sandy soil texture and low soil carbon content, but still significant differences were measured between the tillage systems. Since the start of the experiment in 1996, earthworm abundances were higher in almost all cases under conservation tillage than conventional tillage. The increase in earthworm abundance was mainly due to deep-burrowing *Lumbricus terrestris* individuals with conservation tillage. Schmidt *et al.* (2012) found that there was a more than double the population of earthworms pro m^2 in which especially deep digger earthworms were 7 times higher under conservation tillage than conventional tillage. There were similar results from Loibl (2013).

Some other effects on soil biodiversity were also noticed by Vakali *et al.* (2011). They found that conservation tillage has an effect on biodiversity in organic farming. Shoot mass of barley was significantly affected by tillage systems with lower crop mass with reduced tillage intensity. Barley shoot mass decreased and weed shoot mass increased significantly with decreased tillage intensity, whilst in rye shoot masses of crop and weeds were unaffected.

4.4 Social impacts of conservation tillage

Generally, it is very hard to distinguish the social and economic impacts of conservation tillage. In this section, the social impacts of conservation tillage are discussed. Here, social impacts will be considered through savings of labor use. Hermann (2008) reported that conventional tillage required 4.01 labor hours ha^{-1} for production operations which was 25 and 50% higher than mulch and strip till practices. Aurich *et al.* (2009) also found that conventional tillage requires more labor for its production operations than conservation tillage. They stated that potatoes and maize under reduced tillage had lower labor cost but not significantly. Reduced tillage requires a higher labor cost in wheat after maize because there is an additional costs for operations to improve crop residue incorporation after the maize harvest. It increases production costs for wheat after maize. There can be savings of about 2 hours $ha^{-1}year^{-1}$ with conservation tillage. Lütke Entrup and Kivelitz (2010) also showed that there is a 13% savings of labor with conservation tillage, which increases with different crop rotations.

Reducing labor use can directly affect the social life of farmers. In the peak time of harvesting and sowing, labor requirements are more crucial in a conventional tillage system than a conservation tillage system. Farmers can reduce labor pressure through conservation tillage practices. Farmers can use this labor or time savings for other choices like social events or other business activities. Conservation tillage also can be more helpful in the situation of increasing labor scarcity. The main disadvantage of reduced tillage is higher pesticide use (Küstermann *et al.,* 2013) which requires more labor but can easily be compensated by reduced labor in tillage and other weed control operations.

4.5 Economic impact of conservation tillage

Conservation tillage is a soil conservation practice which helps to maintain and improve the soil quality. Economic aspects can be the main reason for farmers to adopt conservation tillage or soil conservation practices.

Hermann (2008) reported that conventional tillage required a higher quantity of fuel, 64 liters ha^{-1} whereas it was about 40 to 60% higher than mulch and strip-till systems. Aurich *et al.* (2009) found a significant reduction in fuel costs with conservation tillage. Conservation tillage reduced the fuel quantity requirement by 20% for potatoes under conventional tillage because fuel requirement lowered from120 liters ha^{-1} in conventional tillage to 107 liters ha^{-1} in conservation tillage. In the case of maize, the fuel requirement was 71 liters ha^{-1} and 58 liters ha^{-1} for conventional and conservation tillage respectively. In the case of potatoes, there is a large difference in fuel requirements among tillage systems. Schaper (2010) also found that with conservation tillage, there was a saving of about 100 Euro ha^{-1} and 60 liters of diesel ha^{-1} $year^{-1}$. There was no requirement for new machines in mulch tillage practices. Küstermann *et al.* (2013) also found that there was a reduction in fuel requirement under conservation tillage. They reported that there was a savings of 30 liters ha^{-1} $year^{-1}$ and 1.20 GJ ha^{-1} $year^{-1}$ with conservation tillage. The benefit of reduced soil tillage over conventional tillage is a lower consumption of diesel fuel (reduced by 35%) and fossil energy (by 10%).

The reduction in fuel requirements with conservation tillage can be included in economic as well as environmental impact. Lower fuel requirement is directly connected with less use of machinery and less traffic on the field. Lower use of energy inputs and having more energy output shows higher energy-use efficiency. Lower use of machinery directly affects the environment with greenhouse gas emissions.

Hermann (2008) found that conservation tillage was more economical than conventional tillage on the base of operational costs like plowing, stubble cultivation, rolling, herbicide use, strip loosening, seedbed preparation, and seed sowing. There were 20% lower operating costs with conservation tillage because total operational costs for conventional tillage were 285 Euro ha^{-1} whereas it was lower in the case of mulch and strip till at 227 Euro ha^{-1} and 210 Euro ha^{-1} respectively.

Aurich *et al.* (2009) conducted a long-term experiment in Munich having some different results than Hermann (2008).They found that average net returns are higher with conventional tillage systems than conservation tillage systems, but the net returns become higher with conservation tillage than conventional tillage if the farmers used increased fertilizer quantity. Net returns are calculated by subtracting total production costs from gross returns without accounting for any direct payments or other subsidies. In the case of maize grain yields, with conventional tillage yield was 9.59 tons ha^{-1}, higher than conservation tillage at 9.01 tons ha^{-1}. Maize grain yields with conservation tillage and chisel plow is relatively higher than conventional tillage but with a shallow chisel plow yields are significantly lower than conventional tillage. Therefore, the net return with chisel plow (reduced tillage) is also higher than other tillage systems in a maize grain crop. In the case of potato yields and net returns, conventional tillage has higher yields and net returns than conservation tillage systems. But there is no significant difference in net returns. Increasing fertilizer quantity has a positive impact on yield in all tillage systems but a significant impact was noticed under conservation tillage. Conventional tillage has significantly higher yields and net returns for wheat after maize. A net return in conventional tillage was 163.40 Euro ha^{-1} higher than in reduced tillage with a shallow chisel plow. The main reasons for low net returns with conservation tillage systems were yield penalties and additional costs after maize production for incorporation of crop residues into the soil before growing wheat. There was no significant difference in yield and net return from wheat after potatoes. Relative net return was higher with conservation tillage than conventional tillage.

Verch *et al.* (2009) tested different tillage systems in Northeast Germany during the period 2002 to 2005 and had some different results than Aurich *et al.* (2009). They found that operational costs of conservation tillage were much lower than conventional tillage (Table 4.6). They found that yields may be lower with conservation tillage than conventional tillage in the initial period. In the case of winter wheat after rapeseed, conventional tillage had lower net returns, except in 2002, than conservation tillage systems. The main reason was higher wheat yield with conventional tillage than soil conservation practices in 2002. After 2002, yield was higher with conservation tillage systems as well as net returns. Here, net returns is the difference between gross returns and costs including direct costs (seed, fertilizer, crop rotation), operating costs (inclusive of wage 15 Euro ha^{-1} and diesel fuel at 0.80 Euro $litre^{-1}$), depreciation and land rent (150 Euro ha^{-1}). EU premium payments are not taken into account. The average wheat yield after rapeseed with conventional tillage was 8.40 tons ha^{-1} which was much lower than reduced and no-tillage practices at 8.92 and 8.74 tons ha^{-1} respectively. There was almost 6% higher wheat yield after rapeseed with conservation tillage. Yield and return was lowest in 2003 with all tillage systems due to drought, whereas yield and returns were highest in 2004 due to cool, wet weather. In both situations, conservation tillage had higher net returns than conventional tillage. In the case of winter wheat after maize, the situation was totally different. On average net returns with conventional tillage was -135 Euro ha^{-1}. Conservation tillage systems led to improvement in net returns in 3 out of 4 years, due to cost reductions. However, conservation tillage practices also could not show the positive gains at the midpoint of the experimental period, -14 Euro and 12 Euro ha^{-1} for reduced and no-tillage practices respectively. The retention of maize stubble on the soil surface is the main cause of the infection of wheat with *Fusarium spp* which may also lead to a reduction in yield (Maiorano *et al.,* 2008).

The returns from winter rapeseed were found to vary quite strongly in the individual years. There was no clear cut trend for the tillage systems. But it can be concluded that conventional tillage was the most unprofitable practice for winter rape. Conventional tillage was found to yield unsatisfactory returns for grain maize. Conservation tillage had higher net returns than conventional tillage due to a reduction in costs (Verch *et al.,* 2009). On average net return from winter barley were the highest at 111 Euro ha^{-1} under reduced tillage. No-tillage had approximately 50% lower than reduced tillage at 55 Euro ha^{-1}.

Table 4.6: Operating costs (including wage, fuel and depreciation) (Euro ha^{-1})

Tillage system	Wheat	Barley	Rapeseed	Maize
Conventional	365	374	381	509
Reduced	282	276	307	406
No-till	233	249	241	354

Source: Verch *et al.,* 2009

Whereas, the most common tillage practice in Germany is conventional tillage, was found unprofitable at all (-7 Euro ha^{-1}) (Verch *et al.,* 2009). There is a study conducted by Mueller et al. (2009) which shows that grain yield under conventional tillage was 10% higher than conservation tillage (8.93 and 8.06 tons ha^{-1} for conventional and conservation tillage respectively). A study conducted in Braunschweig by Vogeler *et al.* (2009) produced results similar to Mueller *et al.* (2009). They also found that winter wheat yield was relatively lower under conservation tillage as compared to conventional tillage. Overall, there are no statistically significant differences in yield between tillage systems. Yield was increased due to fertilizer treatments in all tillage systems. But there is no significant difference in yield among the tillage systems. Joschko *et al.* (2012) and Schneider (2010) also confirmed that there was relatively lower yield under conservation tillage than conventional tillage.

Further, Schneider (2010) found that even though average yield was lowered by 1.4 tons ha^{-1}, net returns under conservation tillage were 59 Euro to 163 Euro ha^{-1} higher because there was also up to 65 Euro ha^{-1} savings in tillage work as compared to conventional tillage. He calculated the net return as the difference between gross returns and direct and operating costs (DAL basis). Lütke Entrup and Kivelitz (2010) had different results than Vogeler *et al.* (2009); Mueller *et al.* (2009); Joschko *et al.* (2012) and Schneider (2010). They found that there was no significant difference in total yield of different crops but mulch tillage had 5% higher yields than other tillage systems. Further they reported that there is about a 24 to 66% reduction in tillage costs with conservation tillage systems and crop rotations also have an impact on production costs. They found that the crop rotation of peas/beans-winter barley under conservation tillage had 256 Euro to 306 Euro ha^{-1} lower production costs than a crop rotation of wheat-winter barley under conventional tillage. Whereas crop rotation of rapeseed/legume-wheat under conservation tillage had 55 Euro to 205 Euro ha^{-1} lower production costs than a crop rotation of wheat-wheat under conventional tillage. The gross margins with a crop rotation of sugar beet / winter wheat / winter wheat / winter wheat were 415 Euro, 477 Euro and 324 Euro ha^{-1} under conventional, mulch and no-tillage respectively. Whereas the gross margin with a crop rotation of sugar beet-winter wheat-beans/legumes-winter wheat increased to 465 Euro, 538 Euro and 537 Euro ha^{-1} under conventional, much and no-tillage respectively. In the case of a winter wheat-winter wheat crop rotation, direct costs were higher in both tillage systems. In the case of a rapeseed / winter wheat /winter wheat / winter wheat crop rotation, labor use ha^{-1}, machine use in Euro ha^{-1} and fuel quantity in liters ha^{-1} was lowered by 13%, 25% and 33% respectively under conservation tillage compared to conventional tillage. This difference increased to 26%, 36% and 44% with a crop rotation of rapeseed-winter wheat-legumes-winter wheat.

A long-term study was conducted by Gruber *et al.* (2012) during 1999 to 2010 to analyze the effects of different tillage systems on yields and weeds. They found a significant effect of tillage on yields. None of the tillage practices came out to consistently promote yield. No-tillage had a 7.3% lower yield than conventional tillage. Spring barley showed the poorest performance under no-tillage as compared to other crops. In some cases, the yield, emergence of plants and crop density under reduced tillage was higher than conventional tillage. There was a lower yield with conservation tillage than conventional tillage except in fava beans. The range of yield loss with conservation tillage was -2.5 to -22.5% compared to conventional tillage. Further they found that replacement of a moldboard plow (conventional tillage) with a chisel plough (reduced tillage) seems feasible under temperate conditions without resulting in major drawbacks in yield. Weed density was higher under no-tillage than conventional tillage. Though herbicides were applied in all tillage systems, weeds were found to survive and to multiply more with no-tillage than conventional tillage.

A long-term study conducted by Andruschkewitsch *et al.* (2013) has similar findings on yield to Lütke Entrup and Kivelitz (2010). They found no significant difference in yield among the tillage systems. Conventional tillage had highest sugar beet yields at 72.7 tons ha^{-1}, much higher than in mulch and no-tillage (69.7 and 62.8 tons ha^{-1}). There was no effect of more nitrogen fertilization on yield which is an opposite result from Aurich *et al.* (2009).

Table 4.7: Grain yields for sugar beet and winter wheat for different tillage systems (tons ha^{-1})

Crop and year	Conventional tillage	Mulch tillage	No-tillage
Sugarbeets (2009)	72.7	69.7	62.8
Winter Wheat (2009)	8.0	8.2	7.8
Winter Wheat (2010)	8.0	7.9	7.4
Winter Wheat (Mean)	8.0	8.05	7.6

Source: Andruschkewitsch *et al.*, 2013

No-tillage had the lowest yields among the tillage systems. In the case of winter wheat yield, mulch tillage had the highest yield. Conventional tillage had the same yields in both cropping years. In the case of conservation tillage, yield decreased in the second year. No-tillage had the lowest yield in all crops and in both years (Table 4.7). There was no significant difference in yield between conventional and mulch tillage.

The study conducted by Piegholdt *et al.* (2013) had the same kind of the results as Andruschkewitsch *et al.* (2013). They found that winter wheat yields at Friemar, Lüttewitz, and Zschortau (averaged from 2004 to 2010) were up to 16% higher compared to the mean yields in Germany of 7.6 tons ha^{-1} in 2010. Winter wheat yields in Grombach were lower than the mean yield in Germany. Yields of sugar beets under conventional tillage at all sites were higher compared to the German mean of 61.9 tons ha^{-1}. Tillage had significant impacts on yields of sugar beets. There was an 11% higher yield with conventional tillage compared to no-tillage. Sugar beet yields under no-tillage were lower than the mean yield of Germany, except at Friemar. Different yields at different locations show that yield was affected not only by tillage systems but also by location (Table 4.8).

Table 4.8: Grain and taproot yields[a] (averaged 2004-2010) of winter wheat and sugar beets (tons ha^{-1})

Field site	Tillage	Winter Wheat	Sugar Beets
Friemar (Thuringia)	Conventional tillage	8.2	74.3
	No-tillage	7.6	69.8
Grombach (Baden-Württemberg)	Conventional tillage	7.3	69.9
	No-tillage	7.3	58.5
Lüttewitz (Saxony)	Conventional tillage	8.8	67.8
	No-tillage	8.3	61.1
Zschortau (Saxony)	Conventional tillage	8.1	62.3
	No-tillage	7.8	56.6

Source: Piegholdt *et al.*, 2013, [a] Yields are given in dry matter for winter wheat and taproot fresh matter for sugar beets

Küstermann *et al.* (2013) conducted a study which had different results than those of Andruschkewitsch *et al.* (2013) but similar results to Aurich *et al.* (2009). They found that nitrogen fertilization had a significant impact on yields in all tillage systems. Yields with reduced tillage at 8 cm soil depth plowing had the lowest yield. This means that reduced tillage tending to no-tillage had lower yields than other tillage systems. There was no significant difference in yields with reduced and conventional tillage. In some treatments of N fertilization, yields were relatively higher under reduced tillage than conventional tillage. Yields of wheat after maize were the lowest in all tillage systems and in all crop rotations. There was an 11%

increase in yield with N fertilization in wheat after potatoes whereas it increased up to 19% for winter wheat after maize. It can be concluded that reduced tillage tending to no-tillage leads to significant yield losses and therefore cannot be recommended.

Loibl (2013) also highlighted the findings similar to Küstermann *et al.* (2013). There was no significant yield difference among tillage systems, but conservation tillage with the exception of no-tillage had relatively higher yields in sugar beets and winter wheat. Savings in production costs were 5 to 15% with conservation tillage. Therefore, gross margins were 5 to 10% higher with sugar beets and winter wheat under conservation tillage.

4.6 Results from expert discussion

Experts from Hesse and Rhineland-Palatinate were engaged concerning conservation tillage and different crop rotations. They agreed with the above-mentioned results from different studies. According to them, conservation tillage reduces one-time tillage plus plowing. Using modern techniques with conservation tillage saves about 40 minutes ha^{-1} $crop^{-1}$. No-till is not suitable for Germany because of agro-climatic conditions. Reduced tillage is applied on loess sediment in Rheinland-Palatinate and Hesse. The main crop-rotation in this region is winter raps - winter wheat - winter wheat - winter cereals, but in dry periods there are also summer cereals. In conservation tillage, this crop-rotation is not changed. In Eifel, the soil is rich clay which is mainly hard, wet and cool. Green parts of this area are used for dairy cattle and as arable land where silage corn is grown. The arable land is plowed one time to plant maize. The following tables 4.9 and 4.10 explain different crop rotations and field preparation activities.

Table 4.9: Crop rotation and reduced tillage on loess soil (cereals)

Winter Rape (WR)	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 2) Deep-cultivator (15 cm) 3) Sowing (equal seed rate to conventional tillage)
Winter Wheat (WW)	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 2) Sowing (integrated seedbed preparation)
Winter Wheat (WW) (Wheat Stubble)	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 2) Cultivator (5 cm soil depth) 3) Sowing (integrated seedbed preparation with Roller)
Winter Cereals (WC)	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 2) Cultivator (5 cm soil depth) 3) Sowing (integrated seedbed preparation with Roller)

Notes: High crop residue problem (Straw management, root disease); Increase the possibility of different selective herbicides used in cereals; Problem with mouse control bait method; Narrow time Schedule (three weeks for WW to WW). Therefore farmers would like to use mulch tillage to save time.

Table 4.10: Crop rotation and reduced tillage on loess soil (sugar beet)

Cover crop I	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 2) Sowing in Autumn after summer cereals (Phacelia, Mustard or mixture)
Sugar beets (SB)	1) Before sowing: glyphosate (680 g ai ha^{-1} for intercrop and weeds) 2) Cultivator (10 to 15 cm) 3) Drill the beet seed 4) Less use of herbicide than conventional tillage
Winter Wheat (WW)	1) Ideally sowing with integrated seedbed preparation 2) On machinery pathway, before sowing, tillage should be done with deep-cultivator or even plow.
Cover crop II	1) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth)
Summer Cereals (SC)	1) Before sowing: glyphosate (680 g ai ha^{-1} for intercrop and weeds) 2) Before sowing, stubble plowing with Disc Harrow (5 cm soil depth) 3) Sowing (integrated seedbed preparation)

Notes: As an alternate to SC, stubble wheat in the fall and the second cover crop can be omitted.

Maize is a good preceding crop for wheat, but especially in reduced tillage, *Fusarium spp* attacks wheat. *Fusarium spp* resistant varieties have about 5 tons ha^{-1} lower yield than normal varieties. For maize heavy soils must be loosened by deep cultivator (30 cm). This makes maize more profitable with plowing than with reduced tillage. In the future, strip tillage may be more interesting for maize. To reduce soil erosion, maize can be grown with under-sown crops (for several years).

4.7 Potential of herbicide use

Plowing is the traditional method for weed control. In conservation tillage, weed control is the main problem. In reduced tillage systems, monocotyledonous weeds will increase (Mäder and Berner, 2012). Reduced tillage improves physical and biological soil properties but on the other hand crop growth decreases with reduced tillage in organic farming due to more weeds (Vakali *et al.,* 2011). Generally in conservation tillage, weeds are controlled by herbicides use or crop-rotation (Opara-Nadi, 1993). Conservation tillage improves soil quality but also results in an increased need for herbicide use due to increased weed appearance (Deike *et al.,* 2008). In the case of Maize, there are more weeds between crop rotations without tillage which is not easy to handle without herbicides (Gehring, 2010). The use of herbicides is an opportunity to minimize production costs and to avoid negative effects through soil tillage. There is also no increase in the used quantity of herbicides due to conservation tillage as compared to conventional tillage (Basch *et al.,* 2012). It seems that modern agriculture (Conservation agriculture) does not have an alternate to control weeds except herbicide use. In other words, adoption of conservation tillage seems implausible without herbicide use. Particularly in Germany, around 1960, industry required an increasing number of employees and rural people left their fields. Without herbicides to replace the departed workers farming seems to be impossible. Therefore, farmers are more dependent on herbicide use (Koch, 1992 cited in Gianessi, 2013).

Herbicides especially glyphosate plays an important role with conservation tillage in Germany. Black grass is one of the main weeds in some regions and is resistant against some herbicides. Black grass and other stubborn weeds can be controlled by glyphosate. Therefore, unavailability of glyphosate affects not only costs and profits but also crop yields. In the absence of glyphosate in Germany, there will be about 10% yield depressions reducing the profit margins up to 36% (Schmitz and Garvert, 2012; Garvert *et al.,* 2013). Figure 4.4 also shows the importance of herbicide use with conservation tillage. Without using herbicides, it seems very hard to accept conservation tillage. Therefore, herbicide use is a very important part of accepting conservation tillage.

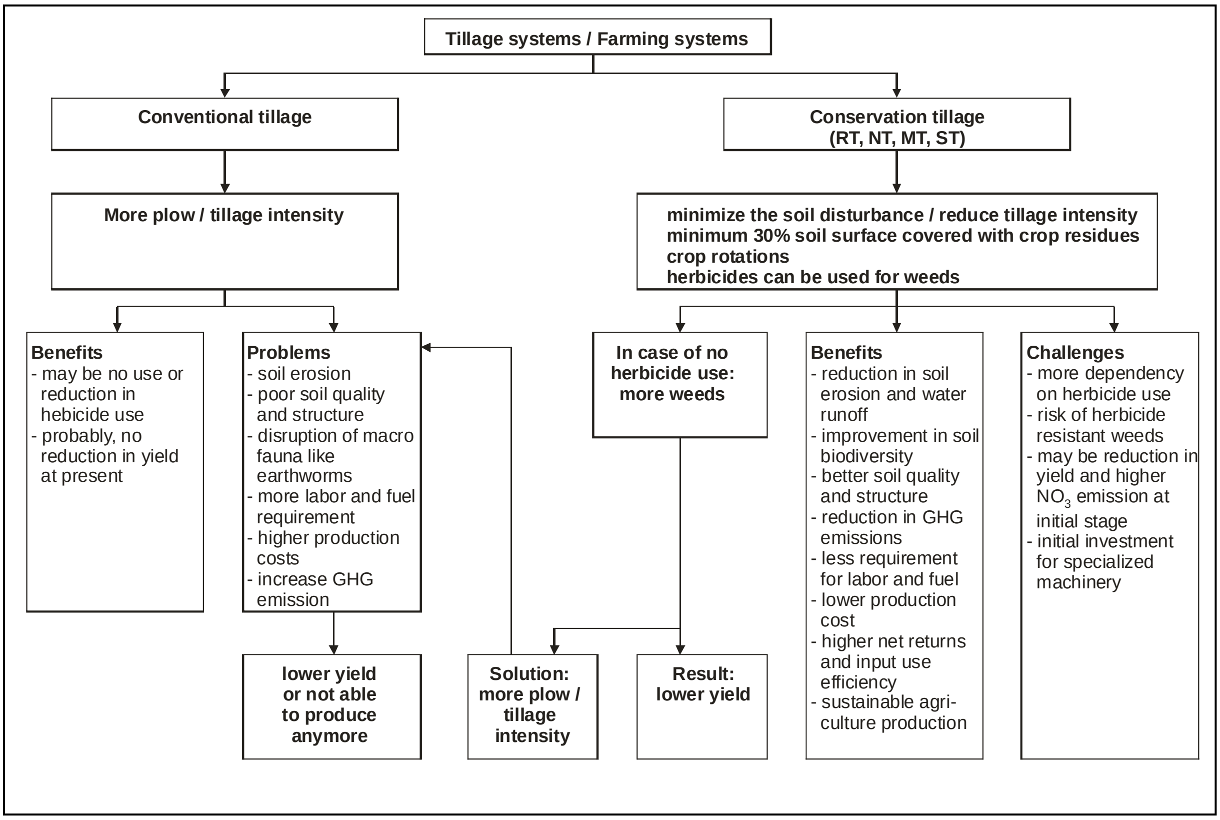


Figure 4.4: Importance of herbicide use with different tillage systems

Source: Own presentation

4.8 Interim Conclusions

In Germany, soil erosion is a severe problem and more than 2 million ha area are suffering from soil erosion. In this area nearly 87% of the area suffers from erosion by water and only 13% area suffers from wind erosion. The soil erosion problem is more a dangerous problem for production sustainability because it is very hard to identify at the initial stage and sometimes when the farmers do identify the problem, it's already too late. Government also motivates farmers to apply soil conservation practices. Rainfall is the main factor for water erosion. Bavaria, Saxony and Thuringia states have relatively more area suffering soil erosion than other states. Soil erosion affects the soil quality because it removes the upper rich layer of soil. There is soil loss risk due to erosion of about 7 tons $ha^{-1}year^{-1}$ or a loss of more than 1 mm soil per year. Wind erosion sometimes creates problems for human daily life, for example the sandstorm in 2011 in northern Germany. Conservation tillage can be a tool to reduce soil erosion. Following are some impacts of conservation tillage in Germany:

- Yield under conservation tillage was almost equal or lower than conventional tillage but in some cases yield was higher. On the other hand, returns under conservation tillage were almost higher than conventional tillage. Among conservation tillage, reduced tillage had higher yields than no-tillage. Yields were also dependent on crop rotation. For example, under conservation tillage, wheat yield after maize was lower, but wheat yield after potatoes was higher.

- Under conservation tillage, there was a 25% to 50% reduction in labor and fuel requirements. Therefore, farmers can save time especially in peak work periods. They have less pressure of labor and fuel expenses with conservation tillage. It also increases the energy use efficiency.
- Due to reduction in fuel requirements or lower use of machinery in conservation tillage, it reduces CO_2 gas emissions into the environment.
- Soil organic carbon increases in the topsoil under conservation tillage. GHG (CO_2 and N_2O) emissions into atmosphere are lower under conservation tillage.
- Soil biodiversity also improves under conservation tillage through a higher abundance of earthworms in the soil. Earthworms are the most important soil animals in terms of plant productivity because they influence the soil physical, chemical, and biological properties related to plant yields. However, agricultural management practices such as tillage, crop rotation, and use of agrochemicals significantly affects earthworm populations.
- Conservation tillage reduces surface water runoff due to higher porosity. It can reduce soil erosion by more than 50%. It also reduces the nutrient loss through erosion and leaching. No-tillage also offers the advantage of avoiding subsoil compaction.

In Dedelow, Northeast Germany, winter wheat after rapeseed has very low net returns in conventional tillage and in the case of wheat after maize; negative net returns are common in all tillage systems. Whereas, in Munich, Southeast Germany, wheat after maize has good net returns in all tillage systems. This shows that yields also depend on agro-climatic conditions along with practices. The extension of soil conservation practices could realize uncontested ecological as well as economic benefits in Germany as compared to conventional tillage. Klarhölter (2010) also suggested that the farmers know well about plant protection and production but they do not know as much about the soil. Therefore, they should consider conservation (mulch) tillage to improve and maintain soil quality. Sattler and Nagel (2010) also found that soil protection was the most crucial farm objective to adopt conservation tillage practices. The reason may that soil is considered a primary resource in agricultural production and protection of its fertility is of the highest importance to ensure high yields. Further, they found that costs were an important but not the most important factor to adopt conservation tillage. Decreasing time or labor was the most important factor for farmers adopting conservation tillage. In conservation tillage, weed control is the main challenge because the traditional method for weed control is plowing. Therefore, herbicide use is very important in conservation tillage. Without herbicide use, especially glyphosate, conservation tillage systems seem implausible.

5 Benefits of conservation tillage with the combination of glyphosate use

This chapter is dedicated to examine the impacts of conservation tillage with glyphosate use and is mainly divided in three parts. First part describes about data collection and analytical approach. The second describes the results of farm economic analysis and third presents the results from long term economic and environmental benefits with conservation tillage through reduction in soil erosion and CO_2 emission. From different studies, it was found that conservation tillage can be an important tool to achieve the goal of sustainable agriculture. It reduces soil erosion, water-runoff, GHG emission, diesel consumption; surface albedo as well improves soil biodiversity and profitability. It reduces number of tillage, therefore herbicide especially glyphosate is the main tool to control the weeds. To calculate the impacts of conservation tillage with glyphosate use over conventional tillage, different farming systems i.e. with plow/ conventional and conservation tillage/ reduced tillage, are considered. The production costs of these systems are derived from two crop rotations and two regions (North-East and Low Mountain range) in Germany. Both regions are affected from soil erosion problems. North-East Germany faces the problem of wind erosion, while the Low Mountain areas are mainly affected by water erosion. To take account of these conditions in both regions, two crop rotations i.e. rape-cereals and a row crop (corn and sugar beets) crop rotations, are examined.

5.1 Methodological Approach

In order to capture all relevant costs for the comparison of the production processes, the method of cost-benefit analysis is used. As a limitation, only direct costs and labor and machinery costs are used.

The profit margin is determined as the difference between total revenue and direct costs and working costs (Direktkosten und Arbeisterledigungskosten freie Leistung, DAKfL). This can be formulated as:

Profit Margin = Total Revenue - (Direct Costs + Working Costs [labor and machinery])
Total Revenue = Yield * Price

To create an initial data set for direct costs, two expert interviews based on regionally differentiated information from Mecklenburg Western Pomerania (North-East) and Hesse / Rhineland-Palatinate (Low Mountain range) were done, concerning:

- Crop rotations,
- Plowing and reduced tillage systems,
- Different strategies in plant protection use and in tillage,
- Strategies of application and extent use of glyphosate.

The data related to yield and prices were collected from the Federal Statistical Office (Statistisches Bundesamt, 2013), Federal Ministry of Agriculture (BMELV), Agrar-Market-Information (AMI) and the agri trade AGRAVIS. The machinery costs on the basis of KTBL-Data are included in the operating costs.

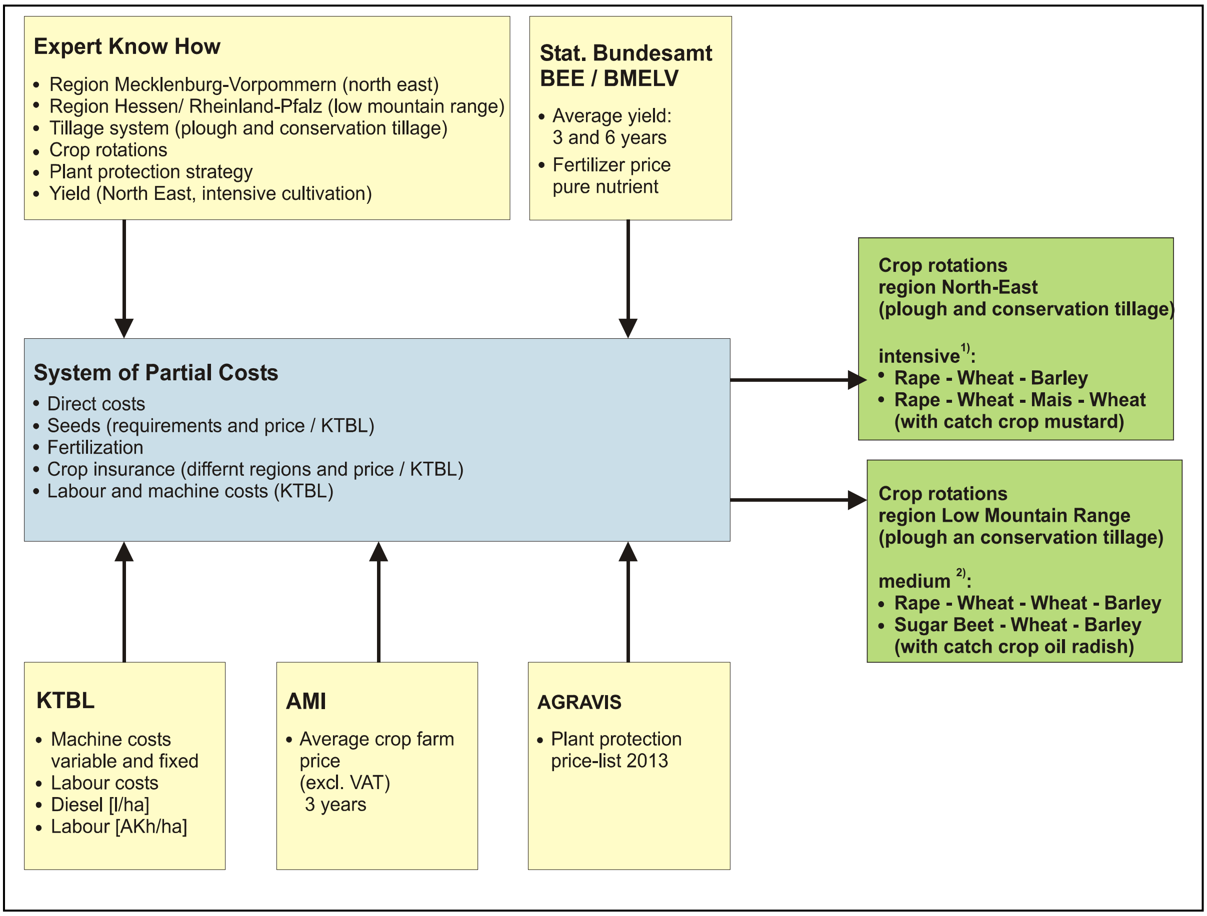


Figure 5.1: **Methodology and Data Sources**

Source: Own presentation

5.1.1 Yields and prices

The yields [dt/ha (quintal/ha)] for wheat, barley, rape, sugar beet and maize correspond to the average of the years 2010 to 2012 and the expert information were used. The prices [Euro/dt] correspond to the average of the years 2010 to 2012 (Table 5.1). They were obtained from the AMI Market Report 2011 (AMI, 2010).

Table 5.1: **Prices (Euro/dt) for cereals, rapeseed, fodder maize and sugar beets in Germany (average value 2010 to 2012)**

	Wheat	Barley	Rapeseed	Fodder Maize	Sugar beets
Price	21.61	19.15	43.68	4.40	4.60

Source: AMI, 2014

5.1.2 Cost factors and profit margin calculation

The direct costs in the profit margin calculation consist of fertilizer and plant protection costs. The fertilizer costs are obtained from the Statistical Yearbook 2013 and used as three-year-average from 2010/11 to 2012/13 (BMELV, 2013). The fertilizer use per hectare is based on plant consumption.

Based on the expert interviews and the recommendations in 2013 by the chambers of agriculture and the state institutes for agriculture in Lower Saxony, Mecklenburg Western Pomerania, Hesse and Rhineland-Palatinate, different plant protection strategies have been developed. The costs for the plant protection components are calculated as purchasing prices of the agricultural enterprises in spring 2013.

Furthermore, the working hours (25 Euro/h) consisting of machinery and labor costs are considered. They are based on the information provided by the "Kuratorium für Technik und Bauwesen in der Landwirtschaft" (KTBL, 2014). For a better comparability, the total fixed and variable machinery costs are considered, so that a comparison between a self-mechanized enterprise and an enterprise hiring contractors can be facilitated.

5.2 Results of the farm economic analysis

In this section, economic analyses of different crop rotations with different farming systems are discussed. Below, the results of the cost calculations for the selected crop rotations of the regions North-East and Low Mountain areas are tabulated. Tables 5.2 to 5.5 show two typical crop rotations (with and without catch crop) for the North-East region with conventional/plow and conservation tillage. In the example of this region, the farmers used a full quantity of plant protection chemicals. Therefore, it is termed as intensive cultivation. Tables 5.6 to 5.9 show two typical crop rotations (with and without catch crop) of the Low Mountain areas with conventional/ plow and conservation tillage.

Tables 5.2 and 5.3 compares the costs and returns of the crop rotation of rape-wheat-barley in North-East region with conventional/plow and conservation tillage. In case of conservation tillage, 850 g ai ha^{-1} to 1360 g ai ha^{-1} glyphosate was used per crop to control the weeds. In conventional/ plow tillage, glyphosate was not used. Instead of glyphosate, plowing was used to control the weeds. There is not a huge difference in yields between both farming systems. Therefore, there is not a huge difference in total revenue; even conservation tillage sometimes has relatively higher total revenue. With conservation tillage, there are about 4% and 11% higher direct costs and plant protection cost respectively. However, conservation tillage has about 4% higher profit margin per crop rotation as well as average per crop because it has more than 10% lower working costs. Among the crops under conservation tillage, rape has the highest profit margin. Barley under conservation tillage has relatively lower yields than barley under conventional/ plow tillage. But barley under conservation tillage has relatively higher profit margins ha^{-1} because it has more than 13% lower working costs than barley under conventional/ plow conditions. The crop rotation with conservation tillage reduces about 8% labor requirement and 11% diesel consumption.

Table 5.2: Profit Margin Region North-East (intensive cultivation, plow)

Rape – Wheat – Barley (field size 20 ha, farm-field 4 km)

		Rape	Wheat	Barley	crop rotation
Tillage and seeding		chisel plain	chisel plain	chisel plain	
		plow	chisel deep	plow	
		Seed-bed com.	Seed-bed com.	Seed-bed com.	
		seeder	seeder	seeder	
Yield	dt/ha	47	85	80	
Total revenue	Euro/ha	2053	1836	1.532	5421
Direct costs	Euro/ha	659	712	544	1915
Plant protection	Euro/ha	238	253	156	647
Working costs	Euro/ha	561	504	547	1612
Profit Margin	Euro/ha	833	621	441	1895
Profit Margin per crop	Euro/ha				632
Labor requirement	h/ha	4.95	4.54	4.72	14.21
Diesel consumption	l/ha	69.67	56.93	61.73	188.33

Source: Own calculation

Table 5.3: Profit Margin Region North-East (intensive cultivation, conservation)

Rape – Wheat – Barley (field size 20 ha, farm-field 4 km)

		Rape	Wheat	Barley	Crop rotation
Glyphosate	g ai ha^{-1}	1360	850	1360	
Tillage and seeding		chisel plain	chisel plain	chisel plain	
		chisel deep	chisel deep	chisel deep	
		mulch seeder	mulch seeder	mulch seeder	
Yield	dt/ha	48	85	78	
Total revenue	Euro/ha	2097	1836	1494	5427
Direct costs	Euro/ha	710	723	556	1989
Plant protection	Euro/ha	281	264	173	718
Working costs	Euro/ha	499	478	482	1459
Profit Margin	Euro/ha	888	635	455	1978
Profit Margin per crop	Euro/ha				659
Labor requirement	h/ha	4.50	4.28	4.25	13.03
Diesel consumption	l/ha	60.15	53.96	52.7	166.81

Source: Own calculation

Table 5.4: Profit Margin Region North-East (intensive cultivation, plow)
Rape – Wheat – Maize – Wheat (field size 20 ha, farm-field 4 km)

		Rape	Wheat	Mustard	Fodder Maize	Wheat	Crop rotation
Tillage and seeding		chisel plain	chisel plain	chisel deep	chisel plain	chisel deep	
		plow	chisel deep	plow	chisel deep	plow	
		Seed-bed com.	Seed-bed com.	Seed-bed com.	Seed-bed com.	Seed-bed com.	
		seeder	seeder	seeder	drill	seeder	
Yield	dt/ha	47	85	0	430	82	
Total revenue	Euro/ha	2053	1836	0	1892	1772	7554
Direct costs	Euro/ha	659	712	26	793	628	2792
Plant protection	Euro/ha	238	253	0	102	180	773
Working costs	Euro/ha	561	504	145	681	823	2414
Profit Margin	Euro/ha	833	621	-171	418	621	2322
Profit Margin per crop	Euro/ha						581
Labor requirement	h/ha	4.95	4.54	1.30	7.08	4.63	22.50
Diesel consumption	l/ha	69.67	56.93	25.87	71.71	60.45	284.63

Table 5.5: Profit Margin Region North-East (intensive cultivation, conservation)
Rape – Wheat – Maize – Wheat (field size 20 ha, farm-field 4 km)

		Rape	Wheat	Mustard	Fodder Maize	Wheat	Crop rotation
Glyphosate	g ai ha^{-1}	1360	850	-	2380	-	
Tillage and seeding		chisel plain	chisel plain	chisel plain	chisel plain	chisel plain	
		chisel deep	chisel deep	chisel deep	chisel plain	chisel deep	
		mulch seeder	mulch seeder	mulch seeder	drill	mulch seeder	
Yield	dt/ha	48	85	0	400	82	
Total revenue	Euro/ha	2097	1836	0	1760	1772	7466
Direct costs	Euro/ha	710	723	26	763	629	2825
Plant protection	Euro/ha	282	264	0	102	181	829
Working costs	Euro/ha	499	478	103	681	472	2233
Profit Margin	Euro/ha	888	635	-129	315	671	2380
Profit Margin per crop	Euro/ha						595
Labor requirement	h/ha	4.50	4.28	0.99	7.08	4.16	21.01
Diesel consumption	l/ha	60.15	53.96	18.93	71.71	53.79	258.54

Source: Own calculation

Tables 5.4 and 5.5 compare the costs and returns of the second crop rotation in North-East region with conventional/ plow and conservation tillage i.e. rape-wheat-maize-wheat. In case of conservation tillage, 850 g ai ha^{-1} to 2380 g ai ha^{-1} glyphosate was used. This is a higher quantity than previous crop rotation. Yield is almost the same in both farming systems except maize.

There is about 7% lower yield in maize with conservation tillage than traditional tillage. Therefore, total revenue is also higher with conventional tillage. It may be due to the use of glyphosate, the crop rotation with conservation tillage has higher direct costs. The results from this crop rotation have same trends like previous crop rotation. Conservation tillage has more than 2 percent higher profit margins for whole of the crop rotation as well as average per crop than conventional tillage because it reduced the working costs more than 7%. It also reduces the labor and diesel requirement about 7% and 9% respectively. Among the crops, maize has lower yields and profit margins with conservation tillage than conventional tillage.

Tables 5.6 and 5.7 contrast the costs and returns of the crop rotation for example of rape-wheat-wheat-barley in the Low Mountain range region from the conventional/plow and conservation tillage. In case of conservation tillage, 1800 g ai ha^{-1} glyphosate was used to control the weeds. glyphosate was used only once for two crops. There is no difference in yield between both farming systems. Therefore, there is no difference in total revenue. As like previous, direct costs under conservation tillage are higher than conventional tillage. But, profit margins with conservation tillage are more than 60% higher than conventional tillage because conservation tillage has 24% lower working costs than conventional tillage. There is about 30% saving of labor with conservation tillage. There is a saving of about 118 liters diesel ha^{-1} crop $rotation^{-1}$ with conservation tillage which is more than one third of the diesel requirement under conventional tillage.

Tables 5.8 and 5.9 describe the costs and returns of second crop rotation in Low Mountain range region with conventional/plow and conservation tillage i.e. sugar beet-wheat-barley. In case of conservation tillage, 1800 g ai liter ha^{-1} glyphosate was used to control the weeds only in sugar beet. There is no difference in yield among both farming systems. Therefore, there is no difference in total revenue also. There are higher direct costs (1.7%) in the crop rotation under conservation tillage than conventional tillage. There are 19% lower working costs with conservation tillage than conventional tillage because it requires less labor and machinery. Therefore, there is 26% higher profit margin with conservation tillage than conventional tillage. Further, conservation tillage requires 5.7 hours per ha less for crop rotation than conventional tillage which is almost one fourth of conventional total labor requirement. With conservation tillage, there is 72 liters diesel saving per ha in this crop rotation which is more than 25% of total diesel requirement for conventional tillage.

Table 5.6: Profit Margin Region "Low Mountain range" (plow)
Rape – Wheat – Wheat – Barley (field size 2 ha, farm-field 2 km)

		Rape	Wheat	Wheat	Barley	Crop rotation
Tillage and seeding		plow	plow	plow	plow	
		Seed-bed com.	Seed-bed com.	Seed-bed com.	Seed-bed com.	
		disk harrow plain	disk harrow plain	disk harrow plain	disk harrow plain	
		disk harrow deep	disk harrow deep	disk harrow deep	disk harrow deep	
Yield	dt/ha	36	73	70	63	
Total revenue	Euro/ha	1573	1578	1512	1206	5869
Direct costs	Euro/ha	517	591	551	480	2139
Plant protection	Euro/ha	143	164	135	135	577
Working costs	Euro/ha	678	680	680	673	2711
Profit Margin	Euro/ha	378	307	282	54	1021
Profit Margin per crop	Euro/ha					255
Labor requirement	h/ha	7.70	7.88	7.88	7.69	31.15
Diesel consumption	l/ha	85.82	80.89	80.89	78.14	325.74

Source: Own calculation

Table 5.7: Profit Margin Region "Low Mountain range" (conservation)
Rape – Wheat – Wheat – Barley (field size 2 ha, farm-field 2 km)

		Rape	Wheat	Wheat	Barley	Crop rotation
Glyphosate	g ai ha^{-1}	1800	-	1800	-	
Tillage and seeding		disk harrow plain	disk harrow plain	disk harrow plain	disk harrow plain	
		chisel deep	chisel plain	chisel plain	chisel plain	
		mulch seeder	mulch seeder	mulch seeder	mulch seeder	
Yield	dt/ha	36	73	70	63	
Total revenue	Euro/ha	1573	1578	1512	1206	5869
Direct costs	Euro/ha	517	591	585	480	2173
Plant protection	Euro/ha	143	164	168	135	610
Working costs	Euro/ha	514	522	522	500	2058
Profit Margin	Euro/ha	542	465	406	226	1639
Profit Margin per crop	Euro/ha					410
Labor requirement	h/ha	5.28	5.64	5.64	5.24	21.80
Diesel consumption	l/ha	60.95	50.14	50.14	46.37	207.60

Source: Own calculation

Table 5.8: Profit Margin Region "Low Mountain range" (plow)
Sugar Beet – Wheat – Barley - Radish (field size 2 ha, farm-field 2 km)

		Sugar Beet	Wheat	Barley	Radish	Crop rotation
Tillage and seeding		plow	plow	plow		
		Seed-bed com.	Seed-bed com.	Seed-bed com.	Seed-bed com.	
		seeding	seeder	seeder	seeder	
		disk harrow plain	disk harrow plain	disk harrow plain		
			disk harrow deep	disk harrow deep		
Yield	dt/ha	600	73	63	0	
Total revenue	Euro/ha	2760	1578	1206	0	5544
Direct costs	Euro/ha	816	591	480	79	1966
Plant protection	Euro/ha	265	164	135	0	564
Working costs	Euro/ha	696	680	673	86	2135
Profit Margin	Euro/ha	1248	307	54	-165	1444
Profit Margin per crop	Euro/ha					481
Labor requirement	h/ha	6.09	7.88	7.69	1.20	22.86
Diesel consumption	l/ha	97.75	80.89	78.14	12.12	268.90

Source: Own calculation

Table 5.9: Profit Margin Region "Low Mountain range" (conservation)
Sugar Beet – Wheat – Barley - Radish (field size 2 ha, farm-field 2 km)

		Sugar Beet	Wheat	Barley	Radish	Crop rotation
Glyphosate	g ai ha^{-1}	1800	-	-	-	
Tillage and seeding				disk harrow plain	disk harrow plain	
			Chisel deep	chisel plain	chisel plain	
		mulch seeding	mulch seeder	mulch seeder	mulch seeder	
Yield	dt/ha	600	73	63	0	
Total revenue	Euro/ha	2760	1578	1206	0	5544
Direct costs	Euro/ha	849	591	480	79	1999
Plant protection	Euro/ha	298	164	135	0	597
Working costs	Euro/ha	561	507	500	154	1722
Profit Margin	Euro/ha	1350	480	226	-233	1823
Profit Margin per crop	Euro/ha					608
Labor requirement	h/ha	4.37	5.52	5.24	2.02	17.15
Diesel consumption	l/ha	71.33	51.86	46.37	27.17	196.73

Source: Own calculation

Figure 5.2 presents the costs and profit margins of both crop rotations in North-East region. It was found that the costs are higher with rape-wheat-maize-wheat crop rotation than rape-wheat-barley. But in case of profit margin per crop rotation, it is higher under rape-wheat-barley than rape-wheat-maize-wheat.

Note for the following figures:

R = Winter-Rape; W= Winter-Wheat; B = Winter-Barley; M = Maize; SB = Sugar

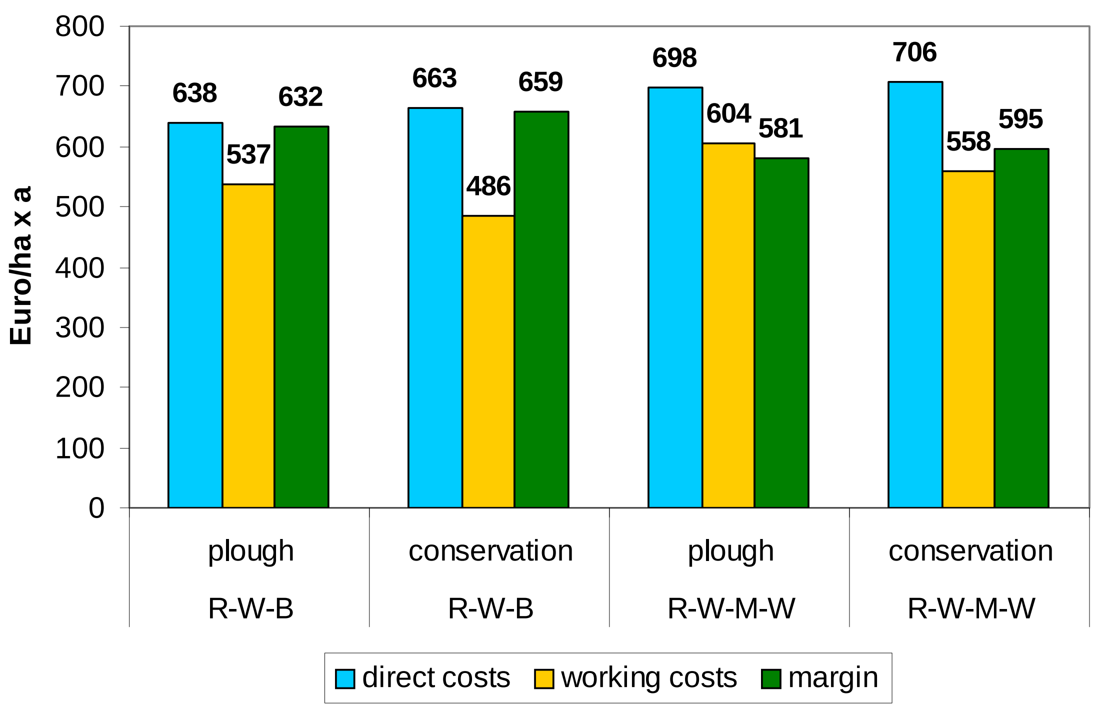


Figure 5.2: Costs and profit margins of selected crop rotations in North-East region with different tillage intensity

Source: Own presentation

Figure 5.3 presents the costs and profit margins of both crop rotations in Low Mountain region. It found that the profit margin is lower with rape-wheat-wheat-barley crop rotation than sugar beet-wheat-barley. Even the profit margin under conventional tillage with crop rotation of sugar beet-wheat-barley is about 16% higher than profit margin under conservation tillage with crop rotation of rape-wheat-wheat-barley. Further, the costs are comparatively lower with rape-wheat-wheat-barley crop rotation than sugar beet-wheat-barley.

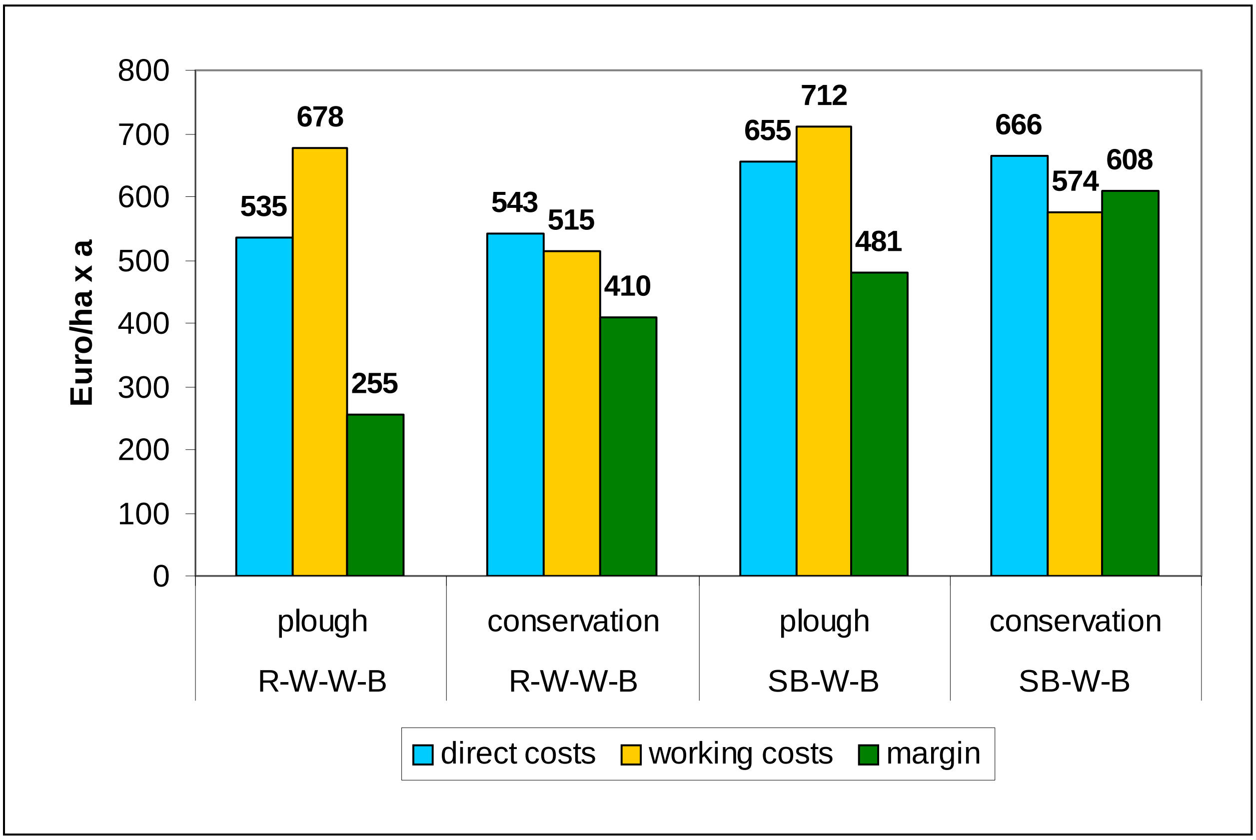


Figure 5.3: **Costs and profit margins of selected crop rotations in Hesse/ Rhineland-Palatinate (Low Mountain) region with different tillage intensity**

Source: Own presentation

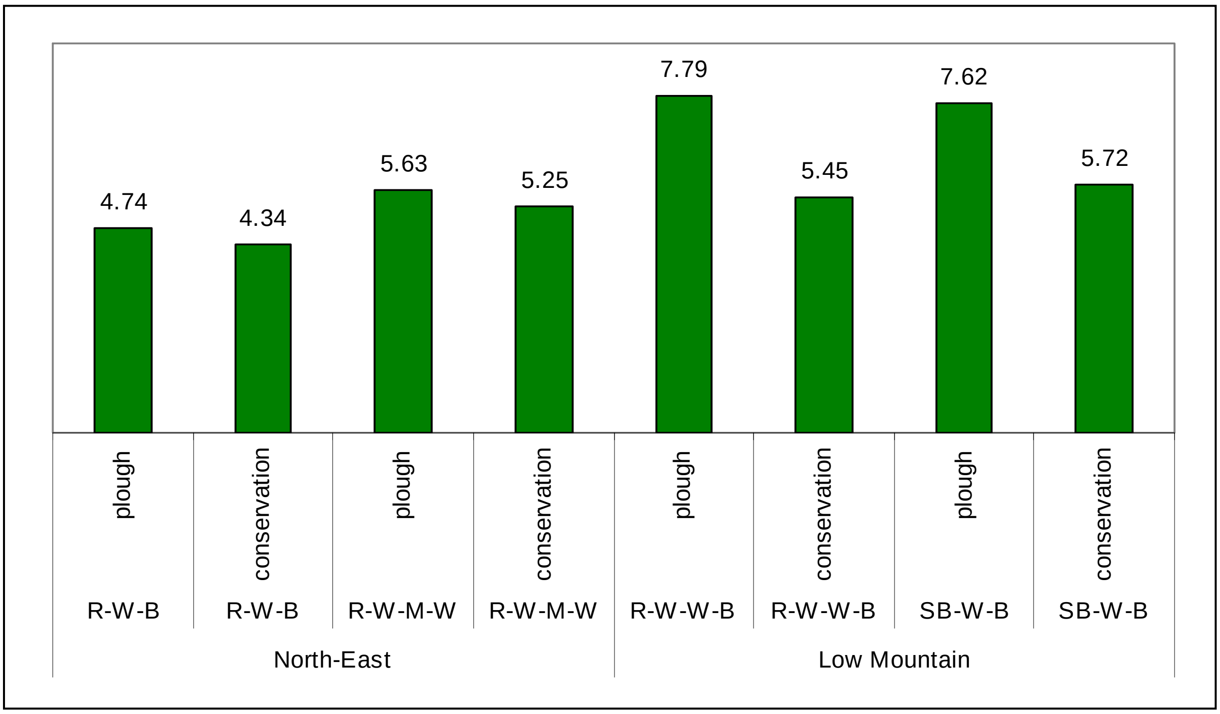


Figure 5.4: **Average working time (hours ha^{-1}) of selected crop rotation under consideration of different tillage intensity**

Source: Own presentation

Figure 5.4 shows the labor requirements of both regions with different crop rotations. Crop rotation of rape-wheat-wheat-barley in Low Mountain region has highest labor requirements i.e. 7.8 hours ha^{-1}. Whereas rape-wheat-barley in North-East region requires lowest labor i.e. 4.34 hours ha^{-1} which is 44% lower of highest labor requirement. In both regions, it was found that the crop rotations in Low Mountain region require comparatively more labor than the crop rotation in North-East region.

Figure 5.5 shows the profit margin per labor unit of the examples in both regions with different crop rotations. Crop rotation of rape-wheat-barley under conservation tillage in North-East region has highest values i.e. 152 Euro ha^{-1} and the lowest value was noticed under conventional/ plow conditions in rape-wheat-wheat-barley in Low Mountain. North-East region has almost higher profit margin per labor unit in conservation and conventional tillage than Low Mountain.

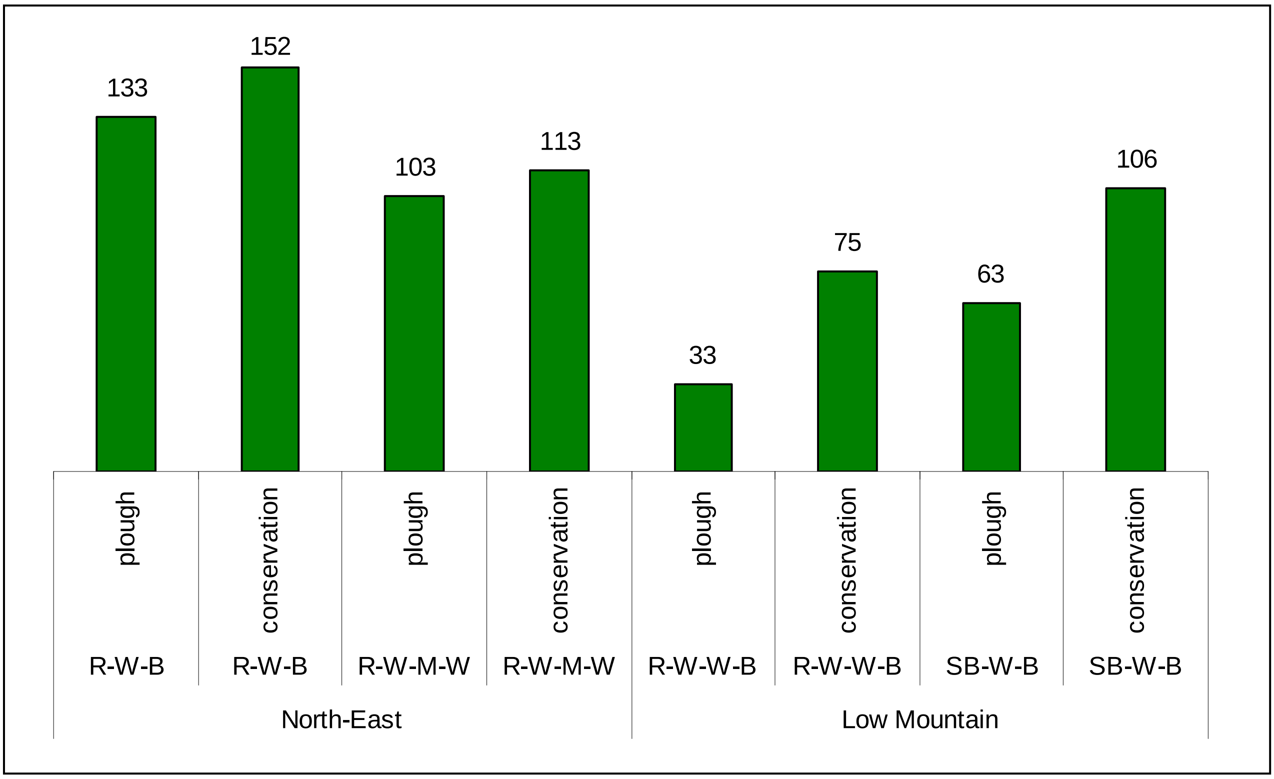


Figure 5.5: Profit margins per labor hour (Euro ha^{-1}) of selected crop rotation under consideration of different tillage intensity

Source: Own presentation

5.3 Potential long-term benefits from the conservation tillage with herbicide use

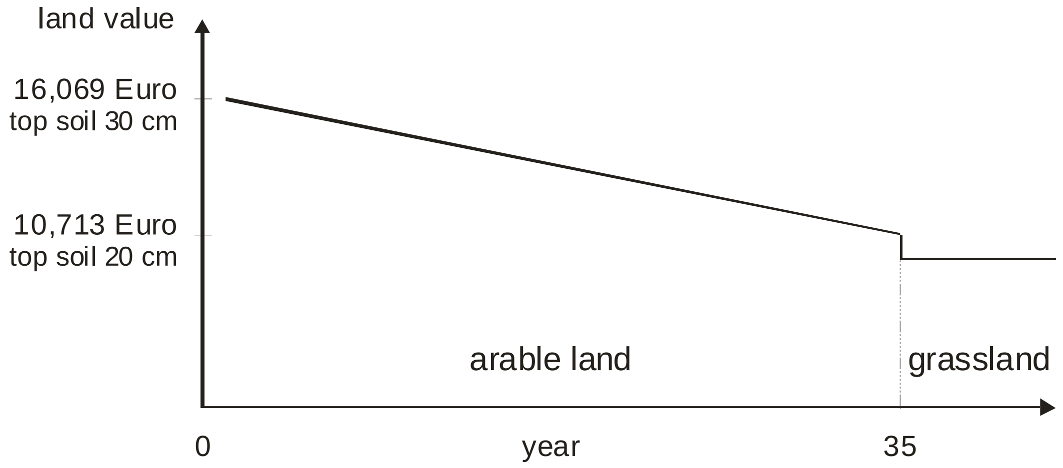
Conservation tillage offers different benefits in the reduction of production costs and soil erosion, decrease of GHG emissions and water runoff. Thereby it helps to mitigate climate change as well as to improve the soil biodiversity and carbon sequestration etc. This part is concentrating on the potential benefits from reduction of soil erosion and CO_2 emission. The long-term economic and environmental advantages from conservation tillage were analyzed from the scenario for a 40-year period.

5.3.1 Benefits from reduction in soil erosion

Different studies confirmed that conservation tillage is an appropriate tool to reduce soil erosion. According to Mosimann *et al.* (2009), the amount of soil loss also depends on types of the crops. In case of sugar beet and potato lead to 50 tons $ha^{-1}year^{-1}$ soil loss, while in case of cereals it is only 10 tons $ha^{-1}year^{-1}$. In worst case for sugar beet, soil loss can be 90 to 170 tons $ha^{-1}year^{-1}$(Richter, 1998). The calculation of soil losses in this study based on the crop rotation with sugar beet, winter wheat and winter barley (SB-WW-WB) from Low Mountain region. Based on the comprehensive literature analysis it can be assumed that the soil erosion potential is about an average 23 tons $ha^{-1}year^{-1}$ (sugar beets 50 tons $ha^{-1}year^{-1}$, winter wheat and winter barley 10 tons $ha^{-1}year^{-1}$ each). If arable land loses one tone soil $ha^{-1}year^{-1}$ then it loses 0.0125 cm topsoil $ha^{-1}year^{-1}$ (Umweltbundesamt, 2013). Therefore, without conservation tillage, SB-WW-WB crop rotation loses 0.29 cm topsoil $ha^{-1}year^{-1}$. In case of a 40-year period, it would lead to the loss of about 12 cm topsoil ha^{-1}. If farmers will work under conventional tillage conditions, it would cause about 23 tons of soil losses $ha^{-1}year^{-1}$ that still can increase over time. Herewith, soil erosion leads to nutrients losses that are additionally influenced by leaching and soil erosion. The empirical analysis shows that soil loss of 23 tons $ha^{-1}year^{-1}$ would lead to extra costs of 11 Euro $ha^{-1}year^{-1}$ only due to pure nutrition loss.

From different scenarios, it was found that increasing the soil loss quantity decrease the life span of arable land. The soil loss can be higher than 23 tons $ha^{-1}year^{-1}$ due to harvesting of sugar beets and wind erosion etc. In case of soil loss of 25 tons $ha^{-1}year^{-1}$ in our assumption, within 32 years, 10 cm topsoil will be eroded and land can be use only as grassland. If soil loss increase to 27 tons $ha^{-1}year^{-1}$, then land with 30 cm topsoil would be useful as arable land only 30 years. Whereas, in some special cases, if soil loss increase to 30 and 35 tons $ha^{-1}year^{-1}$ then, land would be productive only till 27 and 23 years respectively.

For Low Mountain regions, the assumed purchase price for arable land is about 16,069 Euro ha^{-1} (HSL, 2013). Hence, ownership of this land implies for the farmer an asset value of 16,069 Euro. Presuming that only 30 cm of topsoil can be appropriate as an arable land, then soil loss by 0.29 cm $ha^{-1}year^{-1}$ will lead to vanishing of 30 cm topsoil in around 100 years. In addition, 30 cm topsoil has a value of 16,069 Euro ha^{-1}, so the value of one cm topsoil can be specified with 536 Euro. As a result, a loss of 0.29 cm topsoil would be equivalent to a loss of 155 Euro $ha^{-1}year^{-1}$. In 35 years, the asset depreciation will achieve 5,356 Euro ha^{-1}. After 35 years, land can lose 10 cm topsoil from 30 cm topsoil ha^{-1}, so the land is not suitable as arable land anymore and can be used as grassland only (Fig. 5.6).



note: Grassland (EMZ < 30) = 9,080 Euro/ha

Figure 5.6: Loss of land value by soil erosion

Example: purchase value land Hesse

Soil erosion: 0.29 cm year^{-1} = 23 t soil loss ha^{-1}year^{-1}

Source: Own presentation

Moreover, the expected 23 tons ha^{-1}year^{-1} soil loss will also decline the profit margin. Table 5.10 shows the calculated effects of soil erosion on profit margin with conventional tillage. The results from the previous section confirm that conservation tillage results in profit increase to 127 Euro ha^{-1}year^{-1} compared to conventional tillage in a SB-WW-WB crop rotation (tables 5.8 and 5.9). This difference can achieve 6,392 Euro ha^{-1} under decreasing profit margins in 40 years (table 5.10). In case of a 0.29 cm topsoil loss, after 35 years only 20 cm topsoil would be left. The land would not be suitable for the arable purposes and has to be converted into grassland. The current Common Agricultural Policy (CAP) of the European Union contains direct payment of 260 Euro ha^{-1}year^{-1} for grassland in Germany. After subtraction of 80 Euro ha^{-1}year^{-1} for maintenance costs, a profit margin amounts 180 Euro ha^{-1}year^{-1} for grassland.

Empirical analysis shows that in case of conventional tillage the losses from different components - like nutrient loss, land value reduction, diesel consumption and reduction in profit margins - lead to the total loss of 461 Euro ha^{-1}year^{-1}. Conservation tillage, in turn, has a huge potential for sustainable agriculture in the future.

Table 5.10: Impacts of soil losses on profit margins (assumptions)

Year	Profit margin loss in % from initial year	with soil loss profit margin Euro ha^{-1}	without soil loss profit margin Euro ha^{-1}	Difference in profit margin Euro ha^{-1}
1	2	471	481	10
2	4	462	481	19
3	6	453	481	28
4	8	444	481	37
5	10	435	481	46

6	11	426	481	55
7	13	418	481	63
8	15	409	481	72
9	17	401	481	80
10	18	393	481	88
11	20	385	481	96
12	22	377	481	104
13	23	370	481	111
14	25	363	481	118
15	26	355	481	126
16	28	348	481	133
17	29	341	481	140
18	30	334	481	147
19	32	328	481	153
20	33	321	481	160
21	35	315	481	166
22	36	308	481	173
23	37	302	481	179
24	38	296	481	185
25	40	290	481	191
26	41	284	481	197
27	42	279	481	202
28	43	273	481	208
29	44	268	481	213
30	45	262	481	219
31	47	257	481	224
32	48	252	481	229
33	49	247	481	234
34	50	242	481	239
35	51	237	481	244
36	grassland	180	481	301
37	grassland	180	481	301
38	grassland	180	481	301
39	grassland	180	481	301
40	grassland	180	481	301
sum		12,848	19,240	6,392

Assumptions: soil loss 23 tons $ha^{-1}year^{-1}$
Increasing losses for profit margins
20 cm topsoil after 35 years only use for grassland

Source: Own calculation

5.3.2 Reduction of CO_2 emissions through conservation tillage

Reduced tillage has direct and indirect impacts on CO_2 emission. Generally, one liter diesel burning releases 2.682 kg CO_2 in the environment (EIA, 2013). Reduced tillage helps to reduce the requirement of diesel quantity. Table 5.11 presents the reduction of CO_2 emission with conservation tillage over conventional tillage with different crop rotation in North-Eastern and Low Mountain regions of Germany. The crop rotations in Low Mountain region have more reduction in CO_2 emission than North-Eastern region because in the example with intensive plowing there is higher saving in diesel consumption than North-East region. In Hesse and Rhineland-Palatinate, the average farm size is 43 ha and 34 ha; whereas in Mecklenburg Western Pomerania is 287 ha (Statistisches Bundesamt, Landwirtschaftszählung 2010). In case of Low Mountain range region, farm size as 39.5 hectares is considered while for North-Eastern region, it is 287 ha. In North-Eastern region, there is about 35 metric tons CO_2 emission reduction in two crop rotations per farm whereas, in Low Mountain range region, CO_2 emission reduction per farm is only 20 metric tons. The main reason is that North-Eastern region has about 7 times larger farms than Low Mountain range. In Europe, light vehicles as normal car produce 135.7g CO_2 km^{-1} in 2011 (EC, 2014). As an average a normal car covers about 15000 km distance per year. Therefore, it produces about 2 metric tons CO_2 per year. It shows that a normal car produce CO_2 in the environment for 7 to 10 years can be compensated with reduction of CO_2 emission by adopting conservation tillage in the North-East per farm.

Table 5.11: Reduction of CO_2 emission through different crop rotation with conservation tillage

Particulars	Reduction in diesel quantity due to conservation tillage in liters	CO_2 emission per liter diesel in kg	Total CO_2 emission reduction per ha/crop rotation in kg
North -East			
(a) R-W-B/ha	21.52	2.682	52.35
(b) R-W-M-W/ha	26.09	2.682	69.97
(c) R-W-B per farm (in kg)			15,312.31
(d) R-W-M-W per farm (in kg)			20,082.54
Low Mountain			
(a) R-W-W-B/ha	118.14	2.682	316.85
(b) SB-W-B/ha	72.17	2.682	193.56
(c) R-W-W-B per farm (in kg)			12,515.65
(d) SB-W-B per farm (in kg)			7,645.62

Source: Own calculation

Carbon sequestration under conservation tillage results as reduction of carbon emission by 0.5 tone carbon $ha^{-1}year^{-1}$ (Tebrügge and Epperlein, 2007). One ton carbon contains 3.7 tons CO_2, therefore conservation tillage reduces 1.85 tons CO_2 $ha^{-1}year^{-1}$ (Basch *et al.,* 2012). For evaluation of the external effects of CO_2 emission, the auction price for CO_2 pollution rights is used as a basis. In 2013 at the European Energy Exchange (EEX), the auction price for one ton of CO_2 was 4.40 Euro in average (EEX, 2013). Therefore, the auction price for reduced CO_2 ha^{-1} through carbon sequestration was 8 Euro $ha^{-1}year^{-1}$ and in 40 years, it will be 320 Euro ha^{-1}. Less diesel consumption in the SB-WW-WB crop rotation leads to reduction of CO_2 emission by 0.065 tons $ha^{-1}year^{-1}$ (table 5.11, 193.56 kg /3 years). This diminution multiplied by the low auction price in 2013 (EEX, 2013) results in a cost-saving effect of 0.29 Euro $ha^{-1}year^{-1}$. In short, the conservation tillage provides a positive environmental response through the external effects of reduced CO_2 emission.

5.4 Interim conclusions

Summarizing this chapter one can conclude that conservation tillage could be more profitable than conventional tillage. However, in some cases it has lower yields. It is also helpful to reduce the labor pressure and diesel consumption. Therefore, it has direct impacts on CO_2 emission reduction in the environment. Conventional tillage raises more soil and nutrient losses as well as high soil erosion, which makes the land for arable purposes not suitable. Conventional tillage in erosion areas could create the problems not only for farmers but also for the environment because it is an energy intensive practice and high process related CO_2 emissions. Conservation tillage, in turn, provides higher profit margins, more sustainable agriculture production and good agricultural practice. From farm analysis, it can be concluded that conservation tillage is not only economical for human beings, but is also favorable for the environment. The results from economic analysis of this study are more actual and precise to the results from literature review. The calculations were performed basis on the experience of plant production consultants from specific regions. On the basis of their knowledge, it was possible to create typical regional production methods to compare with different tillage systems and different plant protection strategies.

6 Summary and Conclusions

Soil erosion is one of the major problems for sustainable agriculture in the world because it not only reduces the soil productivity but also creates many other problems. There are about 1643 million hectares in the world that are affected by soil erosion through water and wind. From this problem, Europe and especially Germany is also affected. In some extreme cases of cereal production, there are about 10 tons $ha^{-1}year^{-1}$ soil losses whereas the soil formation rate is only 0.3 to 1.4 tons $ha^{-1}year^{-1}$. Conservation tillage can be a tool to face this problem. There is around 125 million ha area in the world. To adopt properly conservation tillage, it requires long time and different machineries and appropriate use of herbicides. Glyphosate, in that circumstance, is one of the main herbicides to control weeds.

There are different meanings for conservation tillage, like in American continent; conservation tillage is mainly used for no or zero tillage, whereas in Europe, it is referred as reduced tillage or mulch tillage. Reduced tillage is more familiar and favorable for Europe because climate conditions are more suitable for reduced tillage than no-tillage. Therefore, there is limited area under no-tillage in Europe. Conservation tillage has very positive impact on soil and its productivity. Most of the studies show that farmers are more profitable with conservation tillage than conventional tillage even though they have lower yields in some cases. It is because this reduces operating costs, which can compensate for lower yield. Most of the countries, except Europe at initial stage, produce relatively higher yields with conservation tillage. However, Europe has potential for economic and environmental sustainability due to reduction of labor units and diesel use in conservation tillage. In Asia and Africa, farmers are adopting conservation tillage to increase the yield and their current economic benefits. A series of studies confirmed that conservation tillage helps to achieve sustainability with clear environmental perspective through reduction in soil erosion, mitigating climate change through increasing albedo surface, decline of GHG emission, increase water infiltration rate and maintenance of soil biodiversity. In spite of positive outcomes from conservation tillage, its adoption rate is very slow. The reason for this could be the expensive machineries and small farm sizes.

In Germany, there is about 17% of the total area affected by soil erosion. Among all the states in Germany, Bavaria has the highest effected area under soil erosion, whereas about 39% area is covered by conservation tillage. There are some specific positive impacts of conservation tillage over conventional tillage in Germany that is confirmed by different studies (Table 6.1):

- There is no significant impact on yield. Nevertheless, there are 5% to 10% higher profit margins than conventional tillage because there is more than 20% of savings in production costs.
- There is a 30% reduction in diesel consumption and a 25% reduction in labor use, which makes the savings of about 2-hour ha^{-1}.
- It increases about 30% of soil organic carbon and higher carbon sequestration.
- It reduces 4% to 11% of GHG emission ha^{-1} $year^{-1}$.
- There is more than 50% of reduction in soil erosion: reduces loss in nutrients and plant protection chemicals through a reduced amount of soil washout; and 3 times higher infiltration rate: absorbs more rainfall which reduces soil erosion.

- It enhances the soil biodiversity through higher abundances of earthworms.
- In conservation tillage, glyphosate is an essential tool in weed management programs especially to control resistant weeds like black grass.

The study with key finding is listed in the table as Annex I.

Table 6.1: Results from the literature survey

Category	Criteria	Results
Environmental Impacts	Soil organic matter and emission of CO_2 and N_2O gas	• Soil Organic Carbon increased at top soil (10% to 70%) and higher Carbon sequestration • Reduction of CO_2 & N_2O gas emissions (4% to 11%) • Minimize up to 10% fossil energy consumption
	Soil erosion or compaction, water runoff	• Reduction in soil loss (50 to 88%) • Avoid the subsoil compaction due to less traffic intensity which reduces water runoff and soil erosion because compacted soil become less able to absorb rainfall • More than three time higher infiltration rate • Reduction in nutrient loss
	Soil Biodiversity enhancement	• More than 50% higher earthworms' abundance (110 earthworms pro m^2 higher in average) • Proportion of deep burrowing earthworms *Lumbricus terrestris* was increased up to 55% (33 earthworms pro m^2 higher).
Social Impacts	Time saving	• More than 25% reduction in labor use • Saving of 2 h $ha^{-1}year^{-1}$
Economic Impacts	Farm-income (Costs, Yield and Gross margin)	• More than 20% saving in production costs. • About 30% reductions in diesel consumption. • There is no significant long term yield difference. • Higher gross margin (5 to 10%)

The own empirical research consists of two components: An interview with experts and a cost-benefit-analysis. The expert discussions also confirmed that conservation tillage saves the time and labor and is suitable for erosion areas in Germany. So reduced and mulch tillage are more familiar for Germany in comparison with some other European countries where no-till is more popular. Weed control is the main challenge because the traditional method for weed control is plowing. Therefore, herbicide use, especially glyphosate, is very important in conservation tillage.

Some key messages from the cost-benefit analysis (data for crop rotations in selected examples):

- There is no significant difference in yields between conservation and conventional tillage. However, higher profit margins occur in conservation tillage system, because it requires less labor and working costs.
- In North-East Germany, there are up to 4% higher direct costs with conservation tillage but 7% to 10% lower working costs, 9% to 12% lower diesel consumption and 7% to 9% lower labor requirement in comparison to conventional tillage. This leads to 2% to 4% higher profit margins with conservation tillage. There is about 1.5 hour ha^{-1} time saving with conservation tillage.
- In Low Mountain region, there are about 2% higher direct costs with conservation tillage while 19 to 24% lower working costs, 26% to 33% lower diesel consumption and 25% to 30% lower labor requirement in comparison to conventional tillage. Therefore, there is 26% to 60% higher profit margin with conservation tillage. There is about 5.7 hour ha^{-1} time saving with conservation tillage. The saved time could be helpful for the farmers to spend more time with family, community etc. that would be helpful to make their social contacts stronger than before.
- In North-Eastern region, full quantity of plant protection as well as deep chisel is used in conservation and conventional tillage. Therefore, there is less difference in working costs, labor requirements and diesel consumption between both tillage systems.
- In low mountain region, almost no deep chisel was used in conservation tillage; therefore, conservation tillage is more labor and diesel saving in this region than North-Eastern region.
- Conservation tillage reduces diesel consumption and increases carbon sequestration; therefore, it also reduces approximately 1.85 tons CO_2 $ha^{-1}year^{-1}$. Whereas an average car produces about 2 tons CO_2 $year^{-1}$ which can be almost compensated with reduction of CO_2 $ha^{-1}year^{-1}$ with reduced tillage over conventional tillage.
- Conventional tillage could provoke soil erosion and as a result high topsoil losses (in average 0.29 cm $year^{-1}$). After some years, land with high erosion would not be suitable for arable purposes anymore and the farmers have to convert their arable land into grassland.
- Nutrients loss due to soil erosion costs approximately 11 Euro $ha^{-1}year^{-1}$ in average (pure nutrient price only).
- There is also a land value loss because of soil erosion and reduction of topsoil surface (asset depreciation).

Finally, it can be concluded that conventional tillage is not suitable for agriculture and environment on the arable land with erosion hazard, because it is not possible to sustain fertile soils. On the other hand conservation tillage is the best option for Germany with significant advantages in erosion areas over conventional tillage that is practiced and soil fertility is sustained. Against the background of the soil protection act Germany, conservation tillage is a soil conservation and sustainable farming practice because it prevents soil compaction and soil erosion, promotes soil biological activity, and sustains its beneficial qualities. The findings from this study can also be used for some countries of Europe which have similar climatic conditions to Germany. Conservation tillage significantly reduces the number of tillage, but in the process leads to an increased frequency of weed growth. This can be successfully prevented and controlled with a sustainable application of the broad spectrum selective and total (glyphosate) herbicides.

References

Abdalla, M., Osborne, B., Lanigan, G., Forristal, D., Williams, M., Smith, P. and Jones, M.B. (2013): Conservation tillage systems: a review of its consequences for greenhouse gas emissions. *Soil Use and Management, 29.*199-209.

AGRAVIS (2013): Pflanzenschutzpreisliste. Ed. AGRAVIS Raiffeisen AG, Münster.

AMI (2014). Markt Bilanz. Ed. Agrarmark Informations-Gesellschaft, verschiedene Produkte, Bonn.

Andruschkewitsch, R., Geisseler, D., Koch, H.J. and Ludwig, B. (2013): Effects of tillage on contents of organic carbon, nitrogen, water-stable aggregates and light fraction for four different long-term trials. *Geoderma, 192:* 368-377.

Aurich, A.M., Gandorfer, M., Gerl, G. and Kainz, M. (2009): Tillage and fertilizer effects on yield, profitability, and risk in a corn-wheat-potato-wheat rotation. *Agronomy Journal, 101(6):* 1538-1547.

AuW (2007): Maßnahmenübersicht Ackerland RL AuW/2007. http://www.umwelt.sachsen.de/ umwelt/natur/21030.htm

Baker, C. J., Saxton, K. E. and Ritchie, W. R. (2002): No-tillage seeding: science and practice, 2nd edn. Oxford, UK: CAB International.

Basch, G., Geraghty, J., Streit, B. and Sturny, W.G. (2008): No-tillage in Europe-state of the art: constraints and perspectives. In: Goddard, T., Zoebisch, M.A., Gan, Y., Ellis, W., Watson, A. and Sombatpanit, S. (Eds.), No-Till Farming Systems Book. Special Publication No 3. World Association of Soil and Water Conservation, Thailand, pp. 159-168.

Basch, G., Kassam, A., González-Sánchez, E.J. and Streit, B. (2012): Making sustainable agriculture real in CAP 2020: The role of conservation agriculture. ECAF, Brussels, 43 pp.

Basso, B., Sartori, L., Bertocco, M., Cammarano, D. and Martin, E.C. (2011): Economic and environmental evaluation of site-specific tillage in a maize crop in NE Italy. *Eur. J. Agron., 35 :* 83-92.

BGR (2013): Bodenerosion durch Wind hat mehrere Ursachen. Bundesanstalt für Geowissenschaften und Rohstoffe http://www.bgr.bund.de/DE/Themen/Boden/Ressourcenbewertung-management/ Winderosion/Bodenerosion_node.html.

Bhatia, A., Sasmal, S., Jain, N., Pathak, H., Kumar, R. and Singh, A. (2010): Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. *Agriculture, Ecosystems and Environment, 136 (3-4):* 247-253.

Bischoff, T. (2010). Nährstoffe in die Pflanze bringen. Reduzierte Bodenbearbeitung. *DLZ-Spezial, Mit Mulch- und Direktsaat zum Erfolg.* 84-87.

Blanco, H. and Lal, R. (2010): Soil and water conservation. Principles of Soil Conservation and Management. Springer. p. 2.

Blum, W. E. H. (2005): Urban soils and the European soil thematic strategy. Soils of Urban, Industrial, Traffic, Mining and Military Areas SUITMA 2005 Cairo. Available on http://ticri.inplancy.fr/

urban_soils.en/index.php/SUITMA_2005_Cairo_Urban_soils_and_theEurpean_soil_thematic_strate-gy.

BMELV (2013): Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten. VI Düngemittel, Pflanzenschutz, Schädlingsbekämpfung. http://www.bmelv-statistik.de/de/statistisches-jahrbuch/kap-c-landwirtschaft

Bossche, A., Bolle, S., Neve, S. and Hofman, G. (2009): Effect of tillage intensity on N mineralization of different crop residues in a temperate climate. *Soil & Tillage Research, 103:* 316-324.

Brenes Muñoz, T., Lakner, S. and Brümmer, B. (2012): Economic growth of farms: An empirical analysis on organic farming. Paper presented *International Association of Agricultural Economists (IAAE) Triennial Conference*, Foz do Iguaçu, Brazil, 18-24 August, 2012

CEC (2006): Thematic strategy for soil protection. In: Technical Report COM 231. Commission of the European Communities, Brussels, Belgium.

Chatskikh, D., and Olesen J.E. (2007): Soil tillage enhanced CO2 and N2O emissions from loamy sand soil under spring barley. *Soil and Tillage Research, 97.* 5-18.

Chatskikh, D., Olesen J.E, Hansen, E., Elsgaard, L. and Petersen, B. (2008): Effects of reduced tillage on net greenhouse gas fluxes from loamy sand soil under winter crops in Denmark. *Agriculture, Ecosystems & Environment, 128:* 117-126.

Chen, H., Marhan, S., Billen, N. and Stahr, K. (2009): Soil organic-carbon and total nitrogen stocks as affected by different land uses in Baden-Württemberg (southwest Germany). *Journal of Plant Nutrition and Soil Science, 172:* 32-42.

Corine (1994): Soil erosion risk and important land resources in the southern regions of the European Community. Available on http://www.eea.europa.eu/publications/CORO-soil

Davin, E.L., Seneviratne, S.I., Ciais, P., Olioso, A. and Wang, T. (2014): Preferential cooling of hot extremes from cropland albedo management. *PNAS* Early Edition. 1-9.

Deike, S., Pallutt, B., Melander, B., Strassemeyer, J. and Christen, O. (2008): Long-term productivity and environmental effects of arable farming as affected by crop rotation, soil tillage and strategy of pesticide use: a case-study of two long-term field experiments in Germany and Denmark. *European Journal of Agronomy: 29:* 191-199.

Derpsch, R. (2001): Conservation tillage, no-tillage and related technologies. In: García-Torres L., Benites, J. and Martínez-Vilela A. (Eds.), Conservation Agriculture, a Worldwide Challenge, Proceedings of the First World Congress on Conservation Agriculture, Madrid, 1-5 October, 2001, Vol. 1, pp. 161-170, http://www.rolf-derpsch.com.

Derpsch, R., Friedrich, T., Kassam, A. and Li, H. (2010): Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering 3:* 1-25.

DLG (2000): Die neue Betriebszweigabrechnung. Ed. DLG e.V., Arbeiten der DLG, Band 197, Frankfurt/M.

Dumanski, J., Peiretti, R., Benetis, J., McGarry, D. and Pieri. C. (2006): The paradigm of conservation tillage. Proceedings World Assoc. *Soil and Water Conserv., P1*: 58-64.

EC (2014): Energy efficiency and specific CO2 emissions (TERM 027) - Assessment published Jan 2013.

EEA (2000): Down to earth: Soil degradation and sustainable development in Europe-A challenge for the 21st century. *Environmental issue series No. 16.* European Environment Agency Copenhagen.

EEX (2014): Emission Spot Primary Market Auction Report 2013. Available on https://www2.eex.com/en/Download/Market-Data/EU%20Emission%20Allowances%20-%20EEX

EIA (2013): Frequently Asked Questions. How much carbon dioxide is produced by burning gasoline and diesel fuel? http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=10

Erhard, M., Böken, H. and Glante, F. (2003): The assessment of the actual soil erosion risk in Germany, based on CORINE land-cover and statistical data from the main representative survey of land use. OECD Expert Meeting on Soil Erosion and Soil Biodiversity Indicators, Rome, 25-28 March, 2003.

Ernst, G. and Emmerling, C. (2009): Impact of five different tillage systems on soil organic carbon content and the density, biomass, and community composition of earthworms after a ten year period. *European Journal of Soil Biology, 45:* 247-251.

European Commission (2009): Flow diagram - 1107 process for renewal of active substance. Download on 5 Dec. 2013 from http://www.pesticides.gov.uk/Resources/CRD/Migrated-Resources /Documents/F/flow%20diagram%20-%201107%20process%20for%20renewal%20of %20 active%20 substance.pdf

FAO (2011). CA Adoption Worldwide: FAO-CA available online http://www.fao.org/ ag/ca/6c.html

FAO (undated) Conservation agriculture. available online http://www.fao.org/agriculture/crops/ thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/conservation-agriculture/en/

Franchini, J.C., Debiasi, H., Balbinot Junior, A.A., Tonon, B.C., Bouc¸ J.R., Oliveira, M.C. and Torres, E. (2012). Evolution of crop yields in different tillage and cropping systems over two decades in southern Brazil. *Field Crops Research 137*: 178-185.

Friedrich,T., Derpsch, R. and Kassam, A. (2012): Overview of the global spread of conservation agriculture, *Field Actions Science Reports, Special Issue 6,* 2012.

Garvert, H., Schmitz, P.M. and Ahmed, M.N. (2013): Agro-economic analysis of the use of glyphosate in Germany. *Outlooks on Pest Management*, *April, 2013:* 81-85.

Gehring, K. (2010): Institut für Pflanzenschutz, Bayerische Landesanstalt für Landwirtschaft, Freising: Konkurrenten unerwünscht. Reduzierte Bodenbearbeitung. *DLZ-Spezial, Mit Mulch- und Direktsaat zum Erfolg:* 72-75.

Gianessi, L. P. (2013): The increasing importance of herbicides in worldwide crop production. *Pest Management Science: 69:* 1099-1105.

Grimm, M., Robert, J. and Montanarella, L. (2002): Soil erosion risk in Europe. European Commission Directorate General Joint Research Centre, Institute for Environment & Sustainability, European Soil Bureau.

Gruber, S., Pekrun, C., Möhring, J. and Claupein, W. (2012): Long-term yield and weed response to conservation and stubble tillage in SW Germany. *Soil and Tillage Research, 121:* 49-56.

Gunreben, M. (2004): Soil quality standards in respect of water and wind erosion in Lower Saxony, Germany. Briefing Papers Of the second SCAPE workshop in Cinque Terre (IT), 13-15 April 2004. *SCAPE-Soil Conservation and Protection for Europe*. Available on the World Wide Web http://eusoils.jrc.ec.europa.eu/projects/scape/CT_book.pdf

Hermann, W. (2008): Strip-Till – Streifenlockerung bei Zuckerrüben und Mais eine Alternative zur Mulch- und Direktsaat. Bodenbearbeitung Sonderheft, Boden verbessern Ertrag steigern: Ökologisch und Pfluglos. *LOP:* 45-47.

Hobbs, P.R., Sayre, K. and Gupta, R. (2008): The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences 363:* 543-555.

HSL (2013): Kaufwerte Landwirtschaftlicher Grundstücke in Hessen. Ed.. Hessisches Statistisches Landesamt, M I 7 – j/13, Wiesbaden.

Huang, G.B., Zhang, R.Z., Li, G.D., Li, L.L., Chan, K.Y., Heenan, D.P., Chen, W., Unkovich, M.J., Robertson, M.J., Cullis, B.R. and Bellotti, W.D. (2008): Productivity and sustainability of a spring wheat-field pea rotation in a semi-arid environment under conventional and conservation tillage system. *Field Crops Res., 107:* 43-55.

Ingenieurbüros Feldwisch (undated): Bodenerosion. http://www. ingenieurbuero-feldwisch.de/ bodenerosion.htm

International Assessment of Agricultural Science and Technology for Development (IAASTD): (2008). Agriculture at a cross-roads. Washington, DC: Island Press. http://www.unep.org/dewa/ agassessment/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20Report%20% 28 English%29.pdf

Jacobs, A., Helfrich, M., Hanisch, S., Quendt, U., Rauber, R. and Ludwig, B. (2010): Effect of conventional and minimum tillage on physical and biochemical stabilization of soil organic matter. *Biology and Fertility of Soils, 46:*671–680.

Jones, A., Panagos, P., Barcelo, S., Bouraoui, F., Bosco, C., Dewitte, O., Gardi, C., Erhard, M., Hervás, J., Hiederer, R., Jeffery, S., Lükewille, A., Marmo L., Montanarella, L., Olazábal, C., Petersen, J.-E., Penizek, V., Strassburger, T., Tóth, G., Van Den Eeckhaut, M., Van Liedekerke, M., Verheijen, F., Viestova, E. and Yigini, Y. (2012): The state of soil in Europe. A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report – SOER 2010. European Commission Joint Research Centre, Institute for Environment and Sustainability.

Joschko, M., Barkusky, D., Rogasik, J., Fox, C., Rogasik, H., Gellert, R., Buchholz, B., Ellmer, F., Reinhold, J. and Gerlach, F. (2012): On-farm study of reduced tillage on sandy soil: effects on soil organic carbon dynamic and earthworm abundance. *Archives of Agronomy and Soil Science, 58:sup1,* 252-260.

Joschko, M., Gebbers, R., Barkusky, D., Rogasik, J., Höhn, W., Hierold, W., Fox, C. and Timmer, J. (2009): Location-dependency of earthworm response to reduced tillage on sandy soil. *Soil and Tillage Research, 102:* 55–66.

Kairis, O., Karavitis, C., Kounalaki, A., Salvati, I. and Kosmas, C. (2013):The effect of land management practices on soil erosion and land desertification in an olive grove. *Soil Use and Management.* Article first published online: 1 AUG 2013 DOI: 10.1111/sum.12074

Kassam, A., Friedrich, T. and Derpsch, R. (2010): Conservation Agriculture in the 21st century: A Paradigm of Sustainable Agriculture. Proceedings of the European Congress on Conservation Agriculture: Towards Agro-Environmental Climate and Energetic Sustainability. Madrid, 19-68.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, R., Emilio, B., González-Sánchez, E.J., and Serraj, R. (2012): Conservation agriculture in the dry Mediterranean climate. *Field Crop Res, 132:*7-17.

Khakbazan, M. and Hamilton, C. (2012): Economic evaluation of tillage management practices at the watershed scale in Southern Manitoba. *Soil & Tillage Research 118*:40-51.

Kiani, S. and Houshyar, E. (2012): Energy Consumption of Rainfed Wheat Production in Conventional and Conservation Tillage Systems. *International Journal of Agriculture and Crop Sciences, 4 (5):*213-219.

Kihara, J., Bationo, A., Mugendi, D. N., Martius, C. and Vlek, P. L. G. (2011): Conservation tillage, local organic resources and nitrogen fertilizer combinations affect maize productivity, soil structure and nutrient balances in semi-arid Kenya. *Nutr. Cycl. Agroecosyst. 90:*213-225.

Klarhölter, T. (2010). Mulchsaat beginnt im Kopf - Reduzierte Bodenbearbeitung. *DLZ-Spezial Mit Mulch- und Direktsaat zum Erfolg:* 62-63.

Klik, A., Trümper, G., Baatar, U., Strohmeier,,S., Liebhard, P., Deim, F., Moitzi, G., Schüller, M., Rampazzo, N., Mentler, A., Rampazzo-Todorovic, G., Brauner, E., Blum, W., Köllensperger, G., Hann, S., Breuer, G., Stürmer, B., Frank, S., Blatt, J., Rosner, J., Zwatz-Walter, E., Bruckner, R., Gruber, J., Spieß, R., Sanitzer, H., Haile, T.M., Selim, S., Grillitsch, B., Altmann, D., Guseck, C., Bursch, W. and Fürhacker. M. (2010): Einfluss unterschiedlicher Bodenbearbeitungssysteme auf Kohlenstoffdynamik, CO2-Emissionen und das Verhalten von Glyphosat und AMPA im Boden. Abschlussbericht. Forschungsprojektnr.: 100069, GZ BMLFUW-LE.1.3.2/0130-II/1/2006, im Auftrag des BMLFUW in Kooperation mit den Bundesländern Niederösterreich und Steiermark. S. 299.

Klute, A. (1982): Tillage effects on hydraulic properties of soil: A review. In: Predicting tillage effects on soil physical properties and processes. P.W. Unger and Van Doren, D.M. (eds.) ASA Special Publication No.44:29-43.

Koch, W. (1992): Impact of weeds on developing countries. Proceedings of the *1st international Weed Control Congress (Vol. 1):* 127-133.

Körschens, M., Rogasik, J., Schulz, E., Böning, H., Eich, D., Ellerbrock, R., Franko, U., Hülsbergen, K. J., Köppen, D., and Kolbe, H. (2004): Humusbilanzierung: Methode zur Beurteilung und Bemessung der Humusversorgung von Ackerland. (Humus balance method: method for evaluating and quantifying the humus supply of agricultural soils). *VDLUFA* Standpunkt. Bonn (Germany): *VDLUFA:* 12.

KTBL (2014): Verfahrensrechner Pflanze. Ed. Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt.

Küstermann, B., Munch, J.C. and Hülsbergen, K.J. (2013): Effects of soil tillage and fertilization on resource efficiency and greenhouse gas emissions in a long-term field experiment in Southern Germany. *European Journal of Agronomy. 49:* 61-73.

Lahmar, R. (2010): Adoption of conservation agriculture in Europe -Lessons of the KASSA project. *Land Use Policy*, *27:* 4-10.

Lal, R. (1975): Role of mulching techniques in tropical soil and water management. *IITA Technical Bulletin No. 1*, Ibadan, Nigeria.

Lal, R. (1983): No-till farming: Soil and water conservation and management in the humid and subhumid tropics. *IITA Monograph No. 2*, Ibadan, Nigeria.

Lal, R. (1986): No-tillage and minimum tillage systems to alleviate soil related constraints in the tropics. In: No-tillage and surface tillage agriculture: The tillage revolution. M. A. Sprague and G.B. Triplett (eds.) pp. 261-317. John Wiley, New York.

Lal, R. (2003): Soil erosion and the global carbon budget. *Environment International*, 29: 437-450.

Lal, R. (2004): Soil carbon sequestration to mitigate climate change. *Geoderma* 123: 1-22.

Liu, S., Yang, J.Y., Zhang, X.Y., Drury, C.F., Reynolds, W.D. and Hoogenboom, G. (2013): Modelling crop yield, soil water content and soil temperature for a soybean–maize rotation under conventional and conservation tillage systems in Northeast China. *Agricultural Water Management, 123:* 32-44.

Liu, X., Zhang, S., Zhang, X., Ding, G. and Cruse, R.M. (2011): Soil erosion control practices in Northeast China: A mini-review. *Soil & Tillage Research, 117:* 44-48.

Loibl, B. (2013): Erfahrung aus langjährigen Praxisversuchen zur Bodenbearbeitung. AK Konservierende Bodenbearbeitung und Direktsaat Baden-Württemberg, 27.02.2013, Hohenheim. Download on 25 November, 2013 from http://www.ltz-bw.de/pb/site/lel/get/documents/MLR.LEL/PB5 Documents/ltz_ka/pdf/l/Loibl%20Technik%20und%20Herbizidstrategien%20bei%20pflugloser%20Boden bearbeitung%20-%20aus%20Sicht%20der%20Praxis.pdf?attachment=true

Lopes-Bermudes, F., Tobar, P., Javier, P. F. and Romero, A. (1998): Regional economic and social approaches to desertification. MEDALUS III Regional indicators, second annual report 65-80 in N. J. Yassoglou (1999) History and development of desertification in the Mediterranean and its contemporary reality. Conference proceeding on Desertification in Europe: mitigation strategies, land-use planning from 31 May to 10 June 1999, Alghero, Sardinia, Italy.

Lorenz, M., Fürst, C. and Thiel, E. (2013): A methodological approach for deriving regional crop rotations as basis for the assessment of the impact of agricultural strategies using soil erosion as example. *Journal of Environmental Management, 127:* p. 37-S47.

Lütke-Entrup, N. and Kivelitz, H. (2010): Gestaltung der Fruchtfolge Schlüsselfunktion für Effizienz und Wirtschaftlichkeit im Pflanzenbau. Fachbereich Agrarwirtschaft Soest, Fachhochschule Südwestfalen. Download from http://www.landwirtschaft.sachsen.de/landwirtschaft/download/Luetke_Entrup _Fruchtfolge_2010.pdf dated on 3 December, 2013.

Mäder, P. and Berner, A. (2012): Development of reduced tillage systems in organic farming in Europe. *Renew. Agric. Food Syst. 27:* 7-11.

Maiorano, A., Blandino, M., Reyneri, A. and Vanara, F. (2008): Effects of maize residues on the Fusarium spp. infection and deoxynivalenol (DON) contamination of wheat grain. *Crop Protect. 21:* 182-188.

McCarthy, J. R., Pfost, D. L. and Currence, H.D. (1993): Conservation tillage and residue management to reduce soil erosion. *Agric Publ G-1650*. University of Missouri, Missouri, USA.

McConkey, B.G., Campbell, C.A., Zentner, R.P., Peru, M. and VandenBygaart, A.J. (2012): Effect of Tillage and Cropping Frequency on Sustainable Agriculture in the Brown Soil Zone. *Prairie Soils & Crops Journal- Long Term Studies*, 5:51-58. www.prairiesoilsandcrops.ca

Mikanová, O., Šimon, T., Javùrek, M. and Vach, M. (2012): Relationships between winter wheat yields and soil carbon under various tillage systems. *Plant soil Environ., 58,(12): 5*40-544.

Mitchell, J. P., Carter, L., Munk, D., Klonsky, K., Hutmacher, R., Shrestha, A., DeMoura, R. and Wroble, J. (2012): Conservation tillage systems for cotton advance in the San Joaquin Valley. *California Agriculture 66(3):*108-115.

Moitzi, G., Schüller, M., Szalay, T., Wagentristl, H., Refenner, K., Weingartmann, H., Boxberger, J. and Gronauer, A. (2013): Energy consumption and energy efficiency of different tillage systems in the semi-arid region of Austria. *Agricultural Engineering, 4:* 25-33.

Mosimann, T., Bug, J., Sanders, S. and Beisiegel, F. (2009): Bodenerosionsdauerbeobachtung in Niedersachsen 2000-2008. Methodik, Erosionsgeschehen, Bodenabträge und Anwendung der Ergebnisse, Geosynthesis 14, Hannover, p. 101.

Mosimann, T., Groß, J., and Meer, U. (2003): Erosion und Stoffhaushalt in Landwirtschaftsgebieten: GIS- Gestützte Modellierung Unterstützt Das Moderne Landnutzungsmanagement. http://www.uni-hannover.de/en/universitaet/veroeffentlichungen/unimagazin/ausgaben/2003-3-4/index.php?action

Mueller, L., Kay, B.D., Deen, B., Hu, C., Zhang, Y., Wolff, M., Eulenstein, F. and Schindler, U. (2009). Visual assessment of soil structure: Part II. Implications of tillage, rotation and traffic on sites in Canada, China and Germany. *Soil and Tillage Research, 103:* 188-196.

Ngwira, A., Aune, J. and Mkwinda, S. (2012): On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research. 132:*149-157

Ngwira, A.R., Thierfelder, C. and Lambert, D.M. (2012): Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renew. Agr. Food Syst. FirstView*: 1-14.

Opara-Nadi, O.A. (1993): Conservation tillage for increased crop production. In Soil Tillage in Africa: Needs and Challenges, Soil resources, management and conservation service Land and Water Development Division, FAO, Rome, 1993. Issue 69.

Peigne, J., Ball, B.C., Roger-Estrade, J. and David, C. (2007): Is conservation tillage suitable for organic farming? A review. *Soil Use and Management 23:*129-144.

Piegholdt, C., Geisseler, D., Koch, H.J. and Ludwig, B. (2013): Long-term tillage effects on the distribution of phosphorus fractions of loess soils in Germany. *Journal of Plant Nutrition and Soil Science, 176:*217-226.

Putte, A., Govers, G., Diels, J., Gillijns, K. and Demuzere, M. (2010): Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. *Eur. J. Agron.*, 22: 231-241.

Reicosky, D. (2001): Conservation Agriculture: Global environmental benefits of soil carbon management. In: García-Torres, L., Benítes, J., and Martínez-Vilela, A. (eds.) Conservation Agriculture - *A Worldwide Challenge: 3-12.*

Reicosky, D. and Archer, D.W. (2007): Moldboard plow tillage and short-term carbon dioxide release. *Soil and TillageResearch 94:* 109-121.

Richter, G. (1998): Bodenerosion und Bodenschutz. Darmstadt.

Rockström., J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. and Damgaard-Larsen, S. (2009): Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil and Tillage Research, 103:* 23-32.

Rogler, H. and Schwertmann, U. (1981): Rainfall erosivity and isoerodent map of Bavaria. *Zeitschrift für Kulturtechnik und Flurbereinigung, 22:* 99-112.

Saharawata, Y.S., Singh, B., Malik, R.K., Ladha, J. K., Gathala, M., Jat, M.L. and Kumar V. (2010): Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. *Field Crops Research, 116 (3):* 260-267

Sattler, C. and Nagel, U. J. (2010): Factor affecting farmers' acceptance of conservation measures- A case study north eastern Germany. *Land Use Policy: 27:* 70-77.

Schaper, E.U. (2010): Pfluglos am Hang. *DLZ-Spezia, Mit Mulch- und Direktsaat zum Erfolg:* 14.

Schmidt, W., Götze, H, Hänsel, M., Zimmer, J., Dittmann, B., Berger, T. and Kroschewski, B. (2012): Hinweise zur pfluglosen Bodenbearbeitung im Ökologischen Landbau auf leichten Böden im Hinblick auf die Bodenstruktur. Download from http://lelf.brandenburg.de /media_fast/4055/Oeko_FF_Gueterfelde_Bodenphysik_Schmidt_LfULG_07062012d.pdf dated on 15 November 2013.

Schmitz, P. M. and Garvert, H. (2012): Die ökonomische Bedeutung des Wirkstoff Glyphosat für den Ackerbau in Deutschland. *Journal für Kulturpflanzen,* 64: 150-162.

Schmitz, P.M., Ahmed, M.N., Garvert, H. and Hesse, J.W. (2011): Agro-economic analysis of the use of glyphosate in Germany. *Agribusiness-Forschung Nr.28;* Ed. Institute für Agribusiness, Gießen.

Schmitz, P.M., Hesse, J.W. and Garvert, H. (2013): Cross Compliance und Greening – Gibt es Vorteile für landwirtschaftliche Betriebe bei Verzicht auf Direktzahlungen? *Agribusiness-Forschung Nr.29;Ed.* Institute für Agribusiness, Gießen.

Schneider, M. (2010): Pfluglos sparen. Reduzierte Bodenbearbeitung. *DLZ-Spezial, Mit Mulch- und Direktsaat zum Erfolg:* 94-98.

Shäfer, W., Sbresny, J. and Thiermann, A. (2010): Methodik zur Einteilung von landwirtschaftlichen Flächen nach dem Grad ihrer Erosionsgefährdung durch Wasser gemäß § 2 Abs. 1 der Direktzahlungs-Verpflichtungenverordnung in Niedersachsen. – Stand: Januar 2010, Hannover (LBEG).

Sharma, P., Abrol, V. and Sharma, R.K. (2011): Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed subhumid inceptisols, India. *Europ. J. Agronomy 34*: 46-51.

Sheid, I. (2010): Wirkung von pflanzenbaulichen Maßnahmen zur Erosionsminderung auf die Wirtschaftlichkeit sowie Stoff- und Energieflüsse am Beispiel von Ackerbaubetrieben in Rheinland-Pfalz. *Masterthesis*. Zentrum für Qualitätssicherung in Studium und Weiterbildung Fernstudium Umweltschutz, Universität Rostock.

Singh, K.P., Prakash, V., Srinivas, K. and Srivastva, A.K. (2008): Effect of tillage management on energy-use efficiency and economics of soybean (Glycine max) based cropping systems under the rainfed conditions in North-West Himalayan Region. *Soil & Tillage Research 100*: 78-82.

Soane, B.D., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F. and Roger-Estrade, J. (2012): No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil and Tillage Research, 118:* 66-87.

SoCo (Sustainable agriculture and soil conservation) (2009): Soil-friendly farming systems and practices: Fact sheet no. 5: Conservation agriculture. Available on: http://eusoils. jrc.ec.europa.eu/projects/ SOCO/FactSheets/ENFactSheet-05.pdf.

Statistisches Bundesamt (2010): Landwirtschaftszählung - Bodenbearbeitung, Bewässerung, Landschaftselemente - Erhebung über landwirtschaftliche Produktionsmethoden (ELPM), FS 3 Heft 5, Wiesbaden.

Stocking, M. A. and Murnaghan, N. (2001): Handbook for the field assessment of land degradation. Earthscan Publications Ltd., London.

Tabatabaeefara, A., Emamzadeh, H., Varnamkhasti, G. M., Rahimizadeh, R. and Karimi, M. (2009): Comparison of energy of tillage systems in wheat production. *Energy 34 (1):* 41-45.

Tebrügge, F., and Düring, R. A. (1999): Reducing tillage intensity – a review of results from a long-term study in Germany. *Soil Tillage Res. 53:* 827-831.

Tebrügge, F., and Epperlein, J. (2007): The importance of the conservation agriculture within the framework of the climate discussion. http://www.ecaf.org/docs/ecaf/positionpaperco2ecaf.pdf

The Guardian (2011): Sandstorm kills eight in German pile-up: http://www.theguardian. com/world /2011/apr/09/sandstorm-kills-eight-german-pile-up.

Ulrich, S., Tischer, S., Hofmann, B. and Christen, O. (2010): Biological soil properties in a long-term tillage trial in Germany. *Journal of Plant Nutrition and Soil Science, 173:* 483-489.

Umweltbundesamt (2013): Was sind die Folgen von Bodenerosion durch Wasser? http://www. umweltbundesamt.de/themen/boden-landwirtschaft/bodenbelastungen/erosion

USDA NRCS (US Department of Agriculture Natural Resources Conservation Service) (2003): Interpreting the soil conditioning index: A tool for measuring soil organic matter trends. Tech Note No. 16. Soil Quality Institute. Auburn, AL. p. 6.

Usman, K., Khan, S.M., Awan, I., Ghulam, S., Khan, M.U., Khan, M.A. and Rehman, A. (2012): Tillage and seed rate impact on wheat yield, soil organic matter and total soil nitrogen under rice-wheat cropping system in Northwestern Pakistan. *The Philippine Agricultural Scientist, 95(2):* 160-168.

Vakali, C., Zaller, J.G. and Köpke, U. (2011): Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. *Soil and Tillage Research, 111:* 133-141.

Verch, G., Kächele, H., Höltl, K., Richter, C. and Fuchs, C. (2009): Comparing the profitability of tillage methods in Northeast Germany-A field trial from 2002 to 2005. *Soil and Tillage Research, 104:* 16-21.

Verheijen, F.G.A., Jones, R.J.A., Rickson, R. J. and Smith, C.J. (2009): Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews, 94: 1–4:*23-38.

Vogeler, I., Rogasik, J., Funder, U., Panten, K. and Schnug, E. (2009): Effect of tillage systems and P-fertilization on soil physical and chemical properties, crop yield and nutrient uptake. *Soil and Tillage Research, 103:* 137-143.

Volk, M., Möller, M. and Wurbs, D. (2010): A pragmatic approach for soil erosion risk assessment within policy hierarchies. *Land Use Policy, 27:* 997-1009.

Young, D. and Schillinger, W. (2012): Wheat farmers adopt the undercutter fallow method to reduce wind erosion and sustain profitability. *Soil & Tillage Research, 124:* 240-244.

Zhang, M., Wang, F., Chen, F., Malemela, M.P. and Zhang, H. (2013): Comparison of three tillage systems in the wheat-maize system on carbon sequestration in the North China Plain. *Journal of Cleaner Production, 54:* 101-107.

Zotarelli, L., Zatorre, N.P., Boddey, R.M., Urquiaga, S., Jantalia, C.P., Franchini, J.C. and Alves, B.J.R. (2012): Influence of no-tillage and frequency of a green manure legume in crop rotations for balancing N outputs and preserving soil organic C stocks. *Field Crops Research, 132*: 185-195.

Annex I: Key results of different studies related to conservation tillage in Germany

Category	Criteria	Results	Source	Time period
Environmental	Soil organic matter and emission of CO_2 & N_2O gas	-After 5 years, slightly pH increased in conservation tillage. -Increased soil organic matter among all tillage systems but slightly higher under conservation tillage.	Vogeler et al, (2009)	8 years, Braunschweig
		-Soil Organic Carbon increased to about 10 to 24% higher at top soil. -After topsoil, SOC significantly decreased.	Ernst and Emmerling (2009)	10 years, Southern Eifel
		-43% higher SOC and total Nitrogen at 0-20 cm soil depth.	Chen et al, (2009)	2 years, Baden - Wuerttenberg
		-23 to 36% higher SOC and 14 to 29% higher Total N under conservation tillage up to 15 cm soil depth -Higher microbial biomass and more CO_2 sequestration	Ulrich et al, (2010)	37 years, Leipzig
		-70% higher SOC and 55% higher total N under conservation tillage	Jacobs et al, (2010)	37 years, Goettingen
		-There is no significant difference in organic carbon, but Potassium and magnesium were significantly higher under conservation tillage.	Bischoff (2010)	12 years, Saxony-Anhalt
		-More than 30% higher SOC at 0-15 cm soil depth and more than double humus under conservation tillage than conventional tillage.	Joschko et al, (2012)	12 years, Brandenburg
		-About 7% higher ratio of organic carbon and total N -More than 50 and 40% higher organic carbon and total N respectively at 0-5 cm soil depth -higher water extractable organic carbon and carbon sequestration	Andruschkewitsch et al, (2013)	18-25 years, Eastern & Southern Germany
		-Change of SOC at 0-8 cm soil depth was 258 to 290 kg/ha which increased more than ten times at soil depth of 8-18 cm. -Reduction of CO_2 & N_2O gas emissions by 11 and 4% respectively. -Saving of energy 1.20 GJ/ha/year; - Minimize 35% diesel fuel and up to 10% fossil energy.	Küstermann et al, (2013)	9 years, Scheyern Southern Germany

	Soil erosion or compaction, water runoff	-Reduce surface runoff due to increase more than three times higher infiltration rate.	Vogeler et al, (2009)	8 years Braunschweig
		-Avoid the subsoil compaction due to less traffic intensity.	Mueller et al, (2009)	More than 10 years, Dedelow
		-More than 60% reduction in soil loss.	Volk et al, (2010)	Saxony,*USLE Meth.*
		-Reduction in soil erosion up to 75%.	Mosimann et al, (2009)	10 years, Lower Saxony
		-Mulch and no-tillage had significant impact on soil erosion because it improves the soil structure and quality.	Scheid (2010)	Rheinland-Pfalz
		-18 to 46% higher soil aggregate stability (Organic Farming). -30 to 50% higher penetration resistance.	Vakali et al, (2011)	3 years, South West Germany
		-10 to 25% higher humus. -10 to 25% higher soil aggregate stability. -Almost double no. of macropores. -38% higher infiltration rate. -About 70% reduction in soil loss.	Schmidt et al, (2012	8 years, Sachsen
		-More than 50% reduction in soil loss.	Piegholdt et al, (2013)	8 years, East and South Germany
		- Soil erosion can be reduced up to 80 to 88% through conservation tillage (Scenario).	Lorenz et al, (2013)	Dresden
		-More than 50% reduction in soil loss	Loibl (2013)	17 years, Saxony
	Soil Biodiversity enhancement	-About 53% higher earthworms abundance. -Proportion of deep burrowing *Lubriscus terrestris* was increased.	Joschko et al, (2009)	10 years, Brandenburg
		- 38 earthworms/m^2 were higher than conventional tillage.	Ernst and Emmerling (2009)	10 years, Southern Eifel
		-Higher enzyme activities at upper soil layer. -More than 80 earthworms/m^2 higher under reduced tillage but no significant difference between conventional and no tillage.	Ulrich et al, (2010)	37 years, Leipzig
		-Increased earthworms' quantity (Farmer).	Klarhölter (2010)	Klein Escherde

		-31% shoot mass of barley decreased but weed shoot mass increased by 65% (Organic Farming).	Vakali et al, (2011)	3 years, South West Germany
		-Higher abundance of deep-burrowing *Lubriscus terrestris* earthworms under conservation tillage.	Joschko et al, (2012)	12 years, Brandenburg
		-More than 100% higher earthworms/m^2. -7 times higher deep digger earthworms/m^2.	Schmidt et al, (2012	8 years, Sachsen
		-More than three times higher no. of earthworms/m^2	Loibl (2013)	17 years, Saxony
Social	Labor Time	-More than 25% reduction in labor use.	Hermann (2009)	2 years, Stuttgart
		-Slightly reduction in labor requirement. -Saving of 2h/ha/year.	Aurich et al, (2009)	12 years, Munich
Economic	Farm-income (Costs, Yield and Gross margin)	-More than 20 and 40% reduction in operating costs and fuel quantity respectively.	Hermann (2008)	2 years, Stuttgart
		-Lower yield and production costs but non-significant difference. -Slightly higher returns with high quantity of fertilizers. -Lower returns and higher production costs in wheat after corn. -20% reduction in fuel quantity.	Aurich et al, (2009)	12 years, Munich
		-6% higher wheat yield after rape. -An average net returns in Barley was 55 to 111€/ha whereas conventional -7€. -About 30% reduction in costs in all crops. -Net returns were higher in cold as well as dry weather conditions	Verch et al, (2009)	3 years, Northeast Germany
		-About 10% lower in Grain yield	Mueller et al, (2009)	More than 10 years, Dedelow
		-No significant difference in yield among tillage systems, but there was lower yield under no tillage only.	Vogeler et al, (2009)	8 years, Braunschweig
		- A saving of about €100/ ha and 60 liters of diesel/ ha/ year. There was no requirement for new machines in mulch tillage practices	Schaper (2010)	Lower Saxony
		-There was no difference in yield among tillage systems.	Joschko et al, (2012)	12 years, Brandenburg

		-Average yield was lowered by 1.4 t/ha but higher gross margin i.e. 59- 163€/ha. -65€/ha saving in tillage work.	Schneider (2010)	3 years, Soest, Guelzow Freising, Braunschweig
		-Saving of 24 to 66% costs in tillage works/ha. -25 to 36% saving in machinery costs/ha. -33 to 44% saving in diesel quantity/ha. -Lower process costs except WW-WW crop rotation. -Up to 5 % yield was higher in mulch tillage, but lower in no-tillage.	Lütke Entrup and Kivelitz (2010)	7 years,Soest, Guelzow
		-Lower relative yield up to 7.3% under no-tillage. -Higher yield, emergence of plants and crop density under reduced tillage. -higher weeds density.	Gruber et al, (2012)	12 Years, SW Germany
		-No significant difference in yield among tillage systems. -No effects of more nitrogen fertilization -Wheat had average higher yield under mulch tillage (two year average)	Andruschkewitsch et al, (2013)	18-25 years, Eastern & Southern Germany
		-16% higher yield in winter wheat compared to Germany mean yield. -Generally yield was relatively lower than conventional tillage.	Piegholdt et al, (2013)	7 years, East and South Germany
		-There was no significant difference in yield. -About 7 to 13% increase in yield with N fertilization. -Saving of 30 l/ha/year or 35% diesel fuel.	Küstermann et al, (2013)	9 years, Scheyern Southern Germany
		-In sugar beet 5% reduction in costs per ha and no significant difference in yield. -About 5% higher gross margin, but 17% lower with no tillage. -In wheat 8 to 15% reduction in costs and 6 to 10% higher gross margin	Loibl (2013)	17 years, Saxony

Nr. 33	SCHMITZ, P.M., P. MAL UND J.W. HESSE: The Importance of Conservation Tillage as a Contribution to Sustainable Agriculture: A spezial Case of Soil Erosion. 2nd Revised Edition. 2015	30 Euro
Nr. 32	SCHMITZ, P.M., P. MAL UND J.W. HESSE: The Importance of Conservation Tillage as a Contribution to Sustainable Agriculture: A spezial Case of Soil Erosion. 2014	30 Euro
Nr. 31	SCHMITZ, P.M., B. KAISER, A. MÄRKER, R. SCHRÖCK UND J.W. HESSE: Bundesweite Befragung von Absolventen der Haushalts- und Ernährungswissenschaften. 2014	30 Euro
Nr. 30	SCHMITZ, P.M. UND P. MOLEVA: Bestimmungsgründe für das Niveau und die Volatilität von Agrarrohstoffpreisen auf internationalen Märkten – Sind Biokraftstoffe verantwortlich für Preisschwankungen und Hunger in der Welt? 2013	40 Euro
Nr. 29	SCHMITZ, P.M., J.W. HESSE und H. GARVERT: Cross Compliance und Greening – Gibt es Vorteile für landwirtschaftliche Betriebe bei Verzicht auf Direktzahlungen? 2013	25 Euro
Nr. 28	SCHMITZ, P.M., M.N. AHMED, H. GARVERT UND J.W. HESSE: Agro-Economic Analysis of the use of Glyphosate in Germany, 2012	30 Euro
Nr. 27	SCHMITZ, P.M., A. MATTHEWS, N. KEUDEL, S. SCHRÖDER UND J.W. HESSE: Restricted availability of azole-based fungicides: impacts on EU farmers and crop agriculture, 2011	30 Euro
Nr. 26	SCHRÖDER, S.: Die neue EU-Qualitätspolitik für Agrarerzeugnisse – Eine Befragung anhand der Choice-Based-Conjoint-Analyse, 2011	30 Euro
Nr. 25	SCHMITZ, P.M.: Die Bedeutung nachwachsender Rohstoffe am Standort Deutschland, 2. aktualisierte und erweiterte Auflage, 2010	27 Euro
Nr. 24	SCHMITZ, P.M.: Bedeutung des AgriFoodBusiness am Standort Deutschland, 3. aktualisierte und erweiterte Auflage, 2010	30 Euro
Nr. 23	SCHMITZ, P M. und J. W. HESSE: Das verfassungsrechtliche Aus des Absatzfonds – Ökonomische Bewertung und Entwurf einer Nachfolgelösung, 2009	17 Euro
Nr. 22	SCHMITZ, P.M.: Bedeutung des AgriFoodBusiness für den Standort Deutschland, 2008	20 Euro
Nr. 21	HESSE, J.W., S. MAAS, K. SCHMITZ und P.M. SCHMITZ: Das Waren-geschäft im genossenschaftlichen Verbund: Fakten, Trends und Chancen, 2007	20 Euro
Nr. 20	SCHMITZ, P.M.: Die Bedeutung Nachwachsender Rohstoffe am Standort Deutschland, 2008	17 Euro
Nr. 19	SCHMITZ, P.M. und J.W. HESSE: Analyse und Bewertung des Milchlieferstreiks in Deutschland, 2008	20 Euro
Nr. 18	FISCHER, C.: The European Beer Market and Strategic Implications for the Main Players, 2002	15 Euro

Nr. 17	DILLENBURG, M.: Konzepte zur Honorierung ökologischer Leistungen der Landwirtschaft - ein Literaturüberblick im Rahmen des Teilprojektes A4 Sonderforschungsbereich 299 der Justus-Liebig-Universität Gießen, 2002	10 Euro
Nr. 16	MÜLLER, M. und K. SCHMITZ: Measuring Preferences for Landscape Functions – An Application of the Adaptive Conjoint Analysis, 2002	10 Euro
Nr. 15	SCHMITZ, P.M.: Wirtschaftliche Auswirkungen einer Kulturlandschaftsprämie, 2002	18 Euro
Nr. 14	MÜLLER, M. und P.M. SCHMITZ: Bewertung von Landschaftsleistungen in der Verbandsgemeinde Daaden, 2000	15 Euro
Nr. 13	MÜLLER, M. und P.M. SCHMITZ: Bewertung von Landschaftsleistungen in der Verbandsgemeinde Rennerod, 2000	15 Euro
Nr. 12	SCHMITZ, K.: Agrarmarketing: Förderung der regionalen Vermarktung in der kritischen Analyse, 2000	18 Euro
Nr. 11	DILLENBURG, M., K. SCHMITZ, P.M. SCHMITZ und S. WIEGAND: Wettbewerbsfähigkeit der sächsischen Landwirtschaft, 1999	20 Euro
Nr. 10	KIßLING, M. und P. M. SCHMITZ: Zur Analyse der Kosten und des Nutzens des chemischen Pflanzenschutzes in der deutschen Landwirtschaft aus gesamtwirtschaftlicher Sicht, 1999	12 Euro
Nr. 9	KIßLING, M.: Analyse, Bewertung und Kommunikation des Einsatzes transgener Pflanzen in der Landwirtschaft, 1999	18 Euro
Nr. 8	SARX, R.: Optimierung der Logistik in der Ernährungswirtschaft durch Supply-Chain-Management. Analyse des ECR-Elements am Beispiel eines mittelständischen Unternehmens der Brauindustrie, 1999	18 Euro
Nr. 7	KUHL, M. und P.M. SCHMITZ: Auswirkungen der Währungsunion auf die internationale Agrarwirtschaft. Die erwarteten Wirkungen auf den Agrarhandel, 1998	20 Euro
Nr. 6	WRONKA, T.C.: Was ist der Preis für Umwelt? Möglichkeiten und Grenzen des kontingenten Bewertungsansatzes, 1998	30 Euro
Nr. 5	SCHMITZ, P.M.: Das EU-Agribusiness im Globalisierungs- und Transformationsprozeß, 1998	20 Euro
Nr. 4	FISCHER, C.: Ansätze zur Verbesserung der Wettbewerbsfähigkeit im Importhandel von Lebensmitteln, 1997	35 Euro
Nr. 3	VON DEM BUSSCHE, P.: Agribusiness 2010: Herausforderungen für die deutsche Landwirtschaft und ihre Partner auf globalen Märkten. Aus der Sicht der Landwirtschaft, 1997	10 Euro
Nr. 2	STÖHR, R.: Agribusiness 2010: Herausforderungen für die deutsche Landwirtschaft und ihre Partner auf globalen Märkten. Aus der Sicht des Agraraußenhandels, 1997	10 Euro
Nr. 1	WIEGAND, S.: Bürger in und um Leipzig bewerten ihre Umwelt. Monetäre Bewertung der Kulturlandschaft am Beispiel der Stadt Leipzig und des Kreises Leipziger Land, 1996	12 Euro

Die Forschungsberichte können zum angegebenen Preis zzgl. Versandgebühr und MWSt. gegen Rechnung über das Institut für Agribusiness bezogen werden:

Institut für Agribusiness
Senckenbergstraße 3
35390 Gießen
Tel.: +49 (0)641-99 37070
Fax +49 (0)641-99 37069
E-Mail: info@agribusiness.de
www.agribusiness.de

DER Online-Stellenmarkt für Fach- und Führungskräfte!

agrarzeitung | jobs

Wirtschaft
für die Landwirtschaft

Gut. Neu. Besser.

AgriJob ist jetzt 'agrarzeitung | jobs'.

Am 1. April 2011 ging AgriJob in die Online-Stellenbörse 'agrarzeitung | jobs' über.

'agrarzeitung | jobs' ist der Stellenmarkt für Fach- und Führungskräfte in der Agrar- und Ernährungswirtschaft - branchenspezifisch und zielgenau.

Gehen Sie am Besten gleich auf **www.agrarzeitung.de/jobs**

Eine Kooperation von VDL, IAB und 'agrarzeitung | online'

Institut für Agribusiness

VDL Berufsverband Agrar Ernährung Umwelt

agrarzeitung | online
Wirtschaft
für die Landwirtschaft