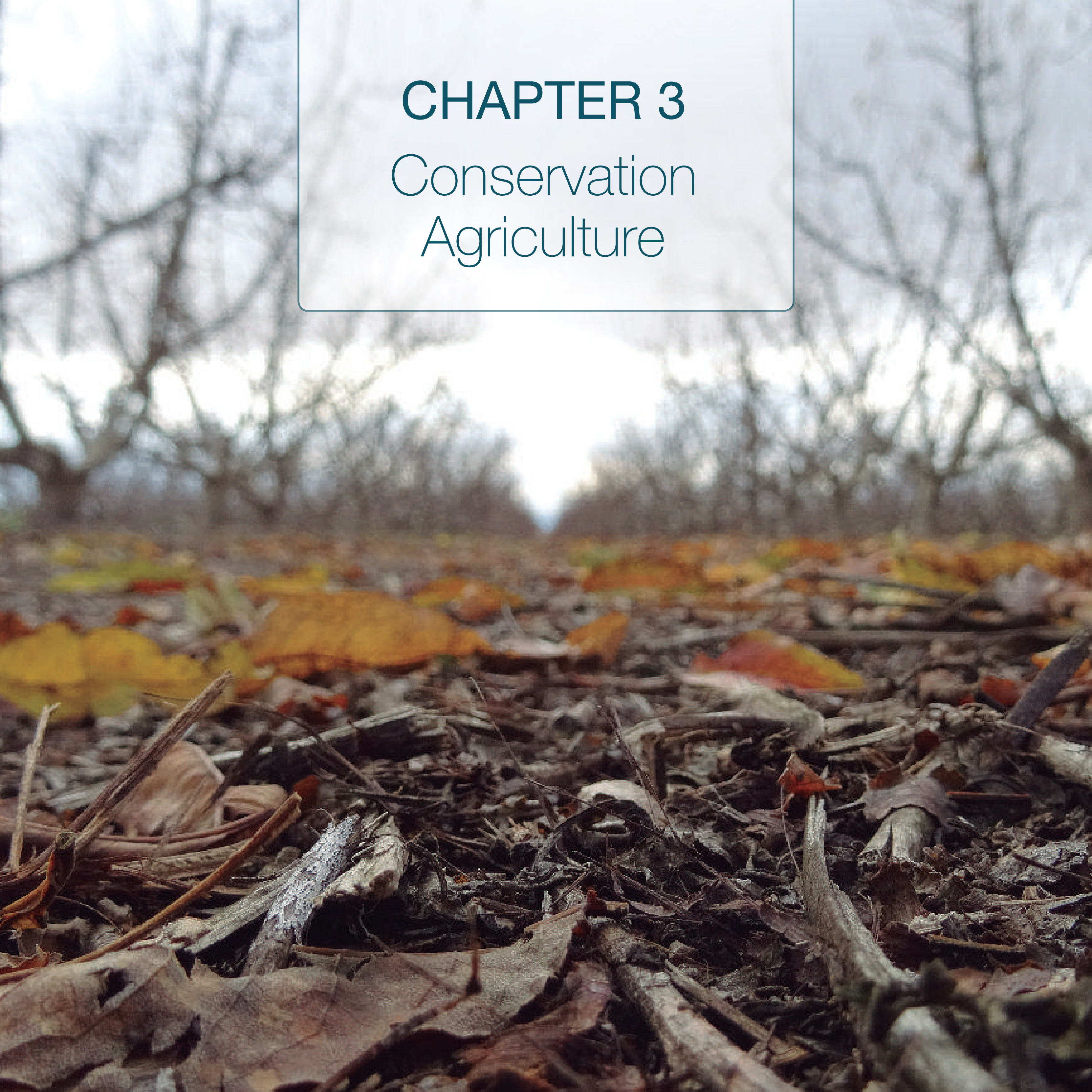
CHAPTER 3

Conservation Agriculture



3.1. Introduction

3.1.1. Origins of Conservation Agriculture in the world

Ancient cultures based their agriculture on sowing on virgin soil with sticks or other pointed elements to make small holes to place seeds (*Derpsch, 1998*). For centuries the soil damage provoked by sowing was minimal, without producing soil losses by preparatory tasks.

In the 1930s, in the central plains of the USA, after years of extreme drought started events of very intense wind erosion known as *Dust Bowl*, where millions tons of soil were lost. These events were filmed by filmmaker Pare Lorentz for the *United States Department of Agriculture* (USDA) in the short documentary film “The Plow That Broke the Plains”, where the tillage was already related to soil erosion (*Lorentz, 1936*). In response to this phenomenon, new tillage equipment was developed in North America that decompressed the soil and controlled the weeds without inverting the soil, which allowed crop residues to remain on the surface. This method expanded dramatically across all dry areas of the United States. In addition to combating soil erosion, it maintained soil humidity. Another important fact was the creation of the US Soil Conservation Service in 1935.

In the following years, this Service stimulated the creation of research teams dedicated to Conservation Agriculture (CA) in many American universities (*Hill et al., 1994*). Also, the publication of the book Plowman’s Folly (*Faulkner, 1943*) increased the interest in the problems of excessive tillage and helped to diffuse CA techniques. During the 1940s, universities, USDA and industry began an intense research effort that soon began to bear fruit: in 1946, the first no-till seed drill (M-21) was developed at Purdue University; in the 1950s the corrugated cutting disc was introduced as well as the treatments with atrazine and paraquat. In the 60s, no-tillage was already presented as a viable technique to be applied on real plots (*McKibben, 1968*).

In Northern European countries, the combination of the negative effects of excessive tillage, particularly on wet soils, with declining rural populations and increased machinery costs, led many researchers to consider a reduction (*Baeumer, 1970*), the Netherlands (*Ouwerkerk and Perdok, 1994*) and the United Kingdom (*Christian, 1994*). A solution were the techniques that needed less labor of the soil, although without the suitable herbicides the adventitious herbs became a limiting factor for the development of these systems of tillage (*Allen, 1981*). The problem was solved with the appearance of the herbicides *paraquat* and *diquat,* developed by *Imperial Chemical Industries* (ICI) in the late 1950s. With these products, it was not necessary to plough the soil any more to control weeds, since they were completely eliminated without causing any risk for the following crops. This made it possible to replace the labors by chemical control of weeds *(Hood et al., 1963; Boon, 1965)*. In this way, the no-till concept arises, making it possible to control the weeds and to sow with an equipment adapted to the presence of crop residues on the surface.

Despite these advances, farmers were still very skeptical about the idea of completely eliminating soil tillage on

the farm, leaving these new practices restricted to the field of research. It was not until mid-1960s that the agronomic and economic advantages of these new techniques were perceived by a broader sector of the agrarian world (*Moody et al., 1961*), and new programs of development and introduction of these systems began in different European countries.

3.1.2. General principles and definitions

CA is one of the most studied and most developed agro-sciences in the world (*Lichtfouse et al., 2010*). Its simplicity and complexity are combined in three basic principles that are based on the achievement of economic benefits for the farmer, environmental improvements of natural resources (air, water, soil,…), biodiversity and the fight against climate change, as well as social benefits such as the maintenance of employment and population in rural areas.

The principles of Conservation Agriculture (Fig. 3.1.) are as follows:

- Minimum soil disturbance. In practice it means no-tillage. At least 30% of the soil must be covered after seeding to effectively protect it against erosion. However, it is recommendable to leave more than 60% of the soil covered to have almost complete control over soil degradation processes.
- Permanent soil cover. In other words, it means to maintain stubble in arable crops and to seed or preserve groundcovers between rows of trees in permanent crops. In this way, soil organic matter and water infiltration into the soil are increasing, weeds are inhibited, and water evaporation from the soil is limited.
- Practicing rotations or crop diversification in annual crops. In this way, pests and diseases are better controlled by breaking cycles that are maintained in monocultures, in addition to including crops that can improve the natural fertility of the soil and biodiversity.

The basis of the benefits that can be obtained thanks to the application of CA in the farms lies in the maintenance of permanent soil cover. Between 30% and 60% of cover significantly reduces soil losses. This justifies the need to keep at least 30% of the land covered during the entire season.

CA is defined as a sustainable agricultural production system that includes a set of agronomic practices adapted to the demands of the crop and the local conditions of each region, whose techniques of cultivation and soil management protect it from erosion and degradation, improve its quality and biodiversity, contribute to the preservation of natural resources such as water and air, without impairing the production levels of the farms.

This definition is aligned with international organizations such as *FAO (2016).* The beneficial effects on the environment derived from CA have been widely studied and disseminated by the scientists for decades. Regarding erosion (*McGregor et al., 1990*), in relation to water-use (*Blanco-Canqui and Lal, 2007*) and its quality (*Jordan and Hutcheon, 1997*), regarding biodiversity improvements (*Valera-Hernández et al*., *1997*) and the fight against climate change (*Lal, 2005; González-Sánchez et al., 2012; Carbonell-Bojollo et al., 2011)*. There are also studies on the economic-productive viability (*Cantero-Martínez et al., 2003; Van den Putte et al., 2010*) and on the need to change the agricultural model due to problems caused by soil degradation (*Bakker et al., 2007; Van-Camp, 2004*).

The most representative agronomic practice of CA in annual crops is no-tillage, which is especially implemented in winter cereals (barley and wheat), spring cereals (corn), legumes in a rotation with cereals (pea, vetch) and oleaginous (sunflower). The most representative agronomic practice in permanent crops is the groundcover, emphasizing its implantation in olives, citrus and almond trees.

CA is an agricultural system that can be considered as global (Fig. 3.2). The expansion of no-till farming is reflected in its rapid acceptance by farmers in all parts

Fig. 3.1. Bases and benefits of Conservation Agriculture. Source: Own elaboration.

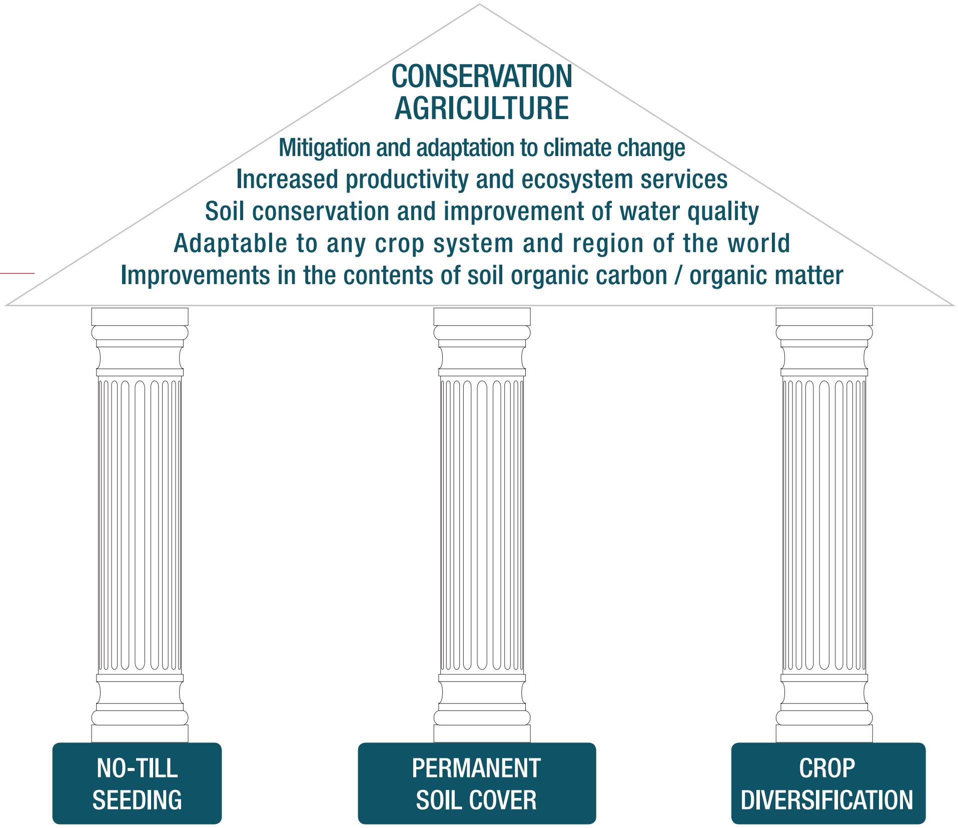
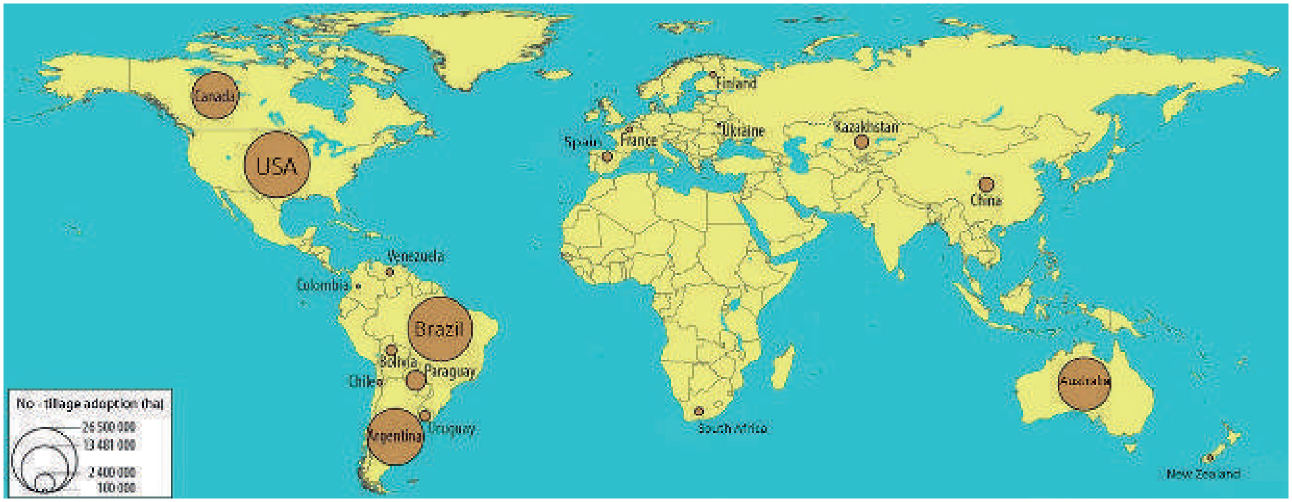


Fig. 3.2. Areas of the countries with the major uses of no-till farming practices. Source: *Laurent, 2015.*



One hectare under CA would compensate emissions equivalent to 14 car journeys from Paris to Berlin.

of the world, from 45 million hectares in 1999 to almost 157 million hectares in 2016 *(FAO, 2016).* The growth margin is wide and imminent in world powers such as China, while constant surface increases are observed in European countries. The reasons of this increase are derived mainly from the economic benefits of CA, based on the drastic reduction of mechanized operations, which lead to reduced consumption of fuels and work time *(González-Sánchez et al., 2010).* The confidence in the maintenance of the productions compared to the conventional tillage has been evidenced by numerous authors (*Basch et al., 2015; González-Sánchez et al., 2015; Kassam et al., 2012; Pisante et al., 2012*).

3.1.3. What is not Conservation Agriculture?

Since the main technical basis of CA is the maintenance of permanent soil cover, which reduces soil erosion and increases soil organic matter, it is necessary to avoid farming techniques based on tillage to prepare the seedbed. It is therefore very important to know what practices meet these requirements and, therefore, can be included in CA. This is particularly relevant at times when we have to respond to global challenges such as climate change, the fight against desertification and soil degradation, and the preservation and improvement of water and biodiversity. The combination of the three pillars of CA can provide the ecosystem services needed to improve the current environmental situation. The lack of terminology in some cases, or the laxity in precision when identifying techniques, lead to a doubtful interpretation of the fundamentals of CA. As an example, small mouldboard ploughs that deepen less than 15 cm, shallower than the traditional that penetrate over 25 cm, are considered as minimum tillage (MT) equipment. Similarly, equipment that prepares the seedbed with only one passage of ploughs in a conventional routine is considered as no-tillage (NT) equipment.

Table 3.1 shows several common techniques and their synonyms with an indication of whether they can be considered as CA.

While, nowadays, the agri-environmental benefits of no-tillage farming and groundcover are widely recognized, many issues lie at the heart of the

Table 3.1. Agricultural practices, their synonyms and eligibility within Conservation Agriculture. Source: Own elaboration.

Crops	Technique	Synonyms	CA?	Observations
Annual	No-tillage	No tilling	Yes	Normally more than 30% of the surface is covered with rop residues or cover crops after sowing.
		Zero tillage	Yes	
	Minimum tillage	Reduced tillage	No	The minimum tillage usually includes 3 or more plough passes, which do not allow to leave more than 30% of the soil covered.
	Strip-till		Yes	Shallow tillage done only in the rows of planting. It is used on monogranous crops (corn, sunflower,…).
Permanent	Groundcovers		Yes	More than 30% of the soil is covered by groundcover.

minimum tillage concept. Minimum tillage should reduce the work on the plots and leave at least 30% of the soil covered after sowing. This requirement is very difficult to meet in most cases, since tillage greatly affects the maintenance of the stubble. In addition, ploughing passes increase the risk of losing crop residues. For example, mouldboard plough, used in conventional agriculture, buries between 90-100% of stubble. The chisel plough, commonly known as chisel, is a primary type plough that is used in minimum tillage, and in a single pass buries about 50% of the residues. As it is not possible to make the seedbed with a single tillage passage, minimum tillage requires the secondary tillage passes (between 2 and 4 or more) which make it impossible to keep at least 30% of the crop residues on the soil.

3.2. No-till

3.2.1. Characteristics

No-till (NT) farming is defined as the agronomic practice of CA in annual crops, where no soil distortion or no mechanical work is done; at least 30% of its surface is protected by living or inert cover, and the sowing is done with machinery enabled to plant on the residues of the previous crop. No-till farming is the best option in order to achieve a high degree of soil conservation in annual crops, in which mechanical work on the soil is completely suppressed.

According to studies *(Márquez-García et al., 2013; Ordóñez-Fernández et al., 2007*) the threshold of 30% of soil cover necessary to protect the soil matches with the one established by *Conservation Technology Information Center* (*CTIC, 2016*).

Table 3.2. Comparison of different agricultural practices regarding environmental problems. Source: *Gonzalez-Sanchez et al. (2015).* * Abbreviations: CT: conventional tillage; GC: groundcovers; NT: no-tillage; MT: minimum tillage. GC 30%: groundcovers present in 30% of the surface between the rows of trees; GC 60%: idem 60%; GC 90%: idem 90%. Effect on the environment: + slightly positive; +++++ very positive; - negative or indifferent.

Crops	Intensity of environmental benefit regarding environmental problems							
	Soil management	Erosion	Soil organic matter	Compaction	Climate change mitigation	Biodiversity	Water quality	Safety of plant protection products application
Annual	CT*	+	+	++	-	-	+	+
	MT	+	+	++	-	++	++	++
	NT	++++	++++	++++	++++	+++	++++	++++
	NT+GC	+++++	+++++	+++++	+++++	+++++	+++++	+++++
Woody	GC 30%	++	++	++	++	++	++	++
	GC 60%	+++	+++	+++	+++	+++	+++	+++
	GC 90%	+++++	++++	+++++	+++++	+++++	+++++	+++++

3.2.2. Adoption of no-tillage in Europe

The application of no-till practices in Europe is about 3.5% of the arable land area, in the countries with a very high application rate, such as Finland, United Kingdom, Romania and Spain (Table 3.3).

Table 3.3. Application of no-till farming in the European Union countries and its comparison with the land planted with annual crops.

	No-till area (ha)	Source	Annual crops area (ha)	Source	Percentage (%)
Austria	28,330	Eurostat, 2010	1,232,040	Eurostat, 2013	2.30
Belgium	270	ECAF, 2017	613,580	Eurostat, 2013	0.04
Bulgaria	16,500	Eurostat, 2010	3,197,800	Eurostat, 2013	0.52
Croatia	18,540	Eurostat, 2010	832,870	Eurostat, 2013	2.23
Cyprus	270	Eurostat, 2010	61,770	Eurostat, 2013	0.44
Czech Republic	40,820	Eurostat, 2010	2,373,890	Eurostat, 2013	1.72
Denmark	2,500	ECAF, 2017	2,184,120	Eurostat, 2013	0.11
Estonia	42,140	Eurostat, 2010	578,660	Eurostat, 2013	7.28
Finland	200,000	ECAF, 2017	1,912,710	Eurostat, 2013	10.46
France	300,000	ECAF, 2017	17,166,990	Eurostat, 2013	1.75
Germany	146,300	ECAF, 2017	10,904,310	Eurostat, 2013	1.34
Greece	7	ECAF, 2017	1,600,950	Eurostat, 2013	0.00
Hungary	5,000	ECAF, 2017	3,560,130	Eurostat, 2013	0.14
Ireland	2,000	ECAF, 2017	999,550	Eurostat, 2013	0.20
Italy	283,923	ECAF, 2017	5,992,540	Eurostat, 2013	4.74
Latvia	11,340	Eurostat, 2010	1,101,650	Eurostat, 2013	1.03
Lithuania	19,280	Eurostat, 2010	2,129,630	Eurostat, 2013	0.91
Luxembourg	440	Eurostat, 2010	60,950	Eurostat, 2013	0.72
Malta	0	Eurostat, 2010	5,290	Eurostat, 2013	0.00
Netherlands	7,350	Eurostat, 2010	670,360	Eurostat, 2013	1.10
Poland	403,180	Eurostat, 2010	9,518,930	Eurostat, 2013	4.24
Portugal	16,050	ECAF, 2017	707,490	Eurostat, 2013	2.27
Romania	583,820	Eurostat, 2010	7,295,660	Eurostat, 2013	8.00
Slovakia	35,000	ECAF, 2017	1,304,820	Eurostat, 2013	2,68
Slovenia	2,480	Eurostat, 2010	165,410	Eurostat, 2013	1.50
Spain	619,373	ECAF, 2017	7,998,655	MAPAMA, 2015	7.74
Sweden	15,820	Eurostat, 2010	2,324,650	Eurostat, 2013	0.68
United Kingdom	362,000	ECAF, 2017	4,376,000	DEFRA, 2016	8.27
Total Europe	**3,162,733**		**90,871,405**		**3.48**

3.2.3. No-till farming in:

3.2.3.1. France

The adoption of NT in France is very low (1.75%), although the aim is to increase it. Thus, in a period of 5 years, significant increases have been found in the use of this technique in different crops (Table 3.4).

The main obstacle to the development of no-tillage in France, despite the benefits it brings to farmers' land and incomes, seems to be related, according to a study by French Ministry of Agriculture, to the economic risk associated when shifting from conventional tillage to no-tillage. Although this period is being gradually, it is necessary for farmers to learn about no-till farming practices. On the other hand, the French agricultural tradition, based on the use of the plough finds it difficult to stop soil tillage. Within the French nation, Basse-Normandy and Nord-Pas-de-Calais regions have the highest percentage of adoption of no-till farming practices in comparison with cultivated land area (Fig. 3.3). On the contrary, Alsace and Limousin regions have the lowest proportion of NT in comparison to the annual crops area.

Table 3.4. Percentage of application of NT regarding the annual crops area in France. Source: *Herault, 2013.*

	2006	2011
Corn	0.2%	0.5%
Sunflower	0.2%	1%
Oilseed rape	0.4%	0.5%
Wheat	3%	4%

3.2.3.2. Germany

No-till farming in Germany has a low application in comparison with the total area of annual crops (1.34%). This percentage is not homogeneous in all federal states, with no application in small federal states (Berlin, Hamburg and Bremen) and maximum in Upper Saxony (Fig. 3.4).

3.2.3.3. Italy

In Italy, the implantation of NT is important, where no-till farming practices are used on almost 5% of the annual crops area. Regarding its internal application, two areas with a greater implantation of NT can be distinguished (Fig. 3.5). On one hand, a larger one, located in the central part of Italy, which includes regions from Liguria to Molise. And another, smaller one located in the Alpine regions of Trento and Bolzano.

3.2.3.4. Netherlands

The Netherlands has a very low NT implantation, slightly higher than 1% of the area covered by annual crops. Although the importance of NT is generally low, in the regions close to the coasts and the internal seas, its use it is somewhat larger (Fig. 3.6). Except in the case of Drenthe, which despite being a region of interior has a NT implantation above average.

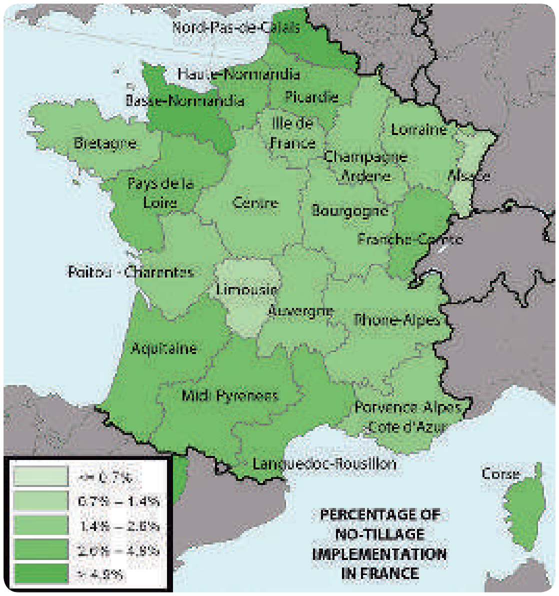


Fig. 3.3. NT percentage in comparison to the total area with annual crops in different French regions. Source: *Eurostat, 2010.*

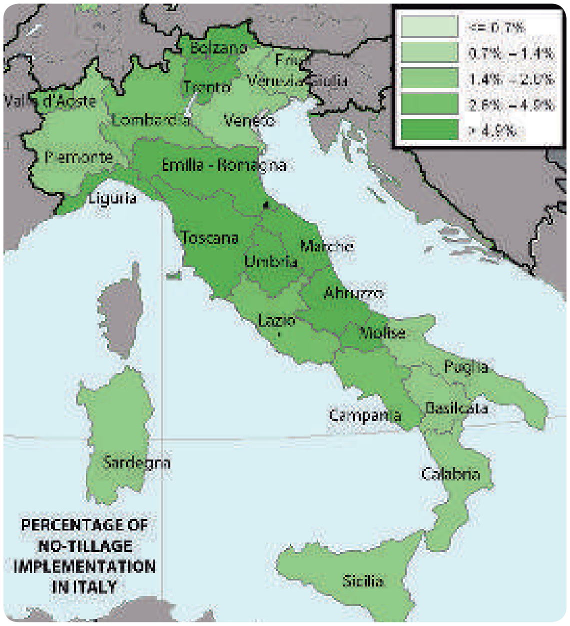


Fig. 3.5. NT percentage in comparison to the total area with annual crops in different Italian regions. Source: *Eurostat, 2010.*

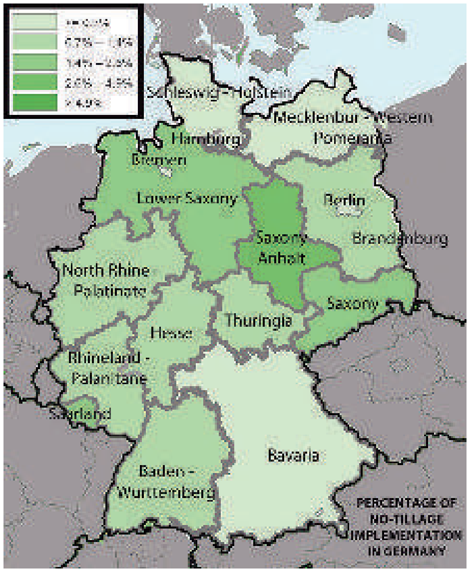


Fig. 3.4. Percentage of application of NT in comparison with the area covered by annual crops in the federal states of Germany. Source: *Eurostat, 2010.*

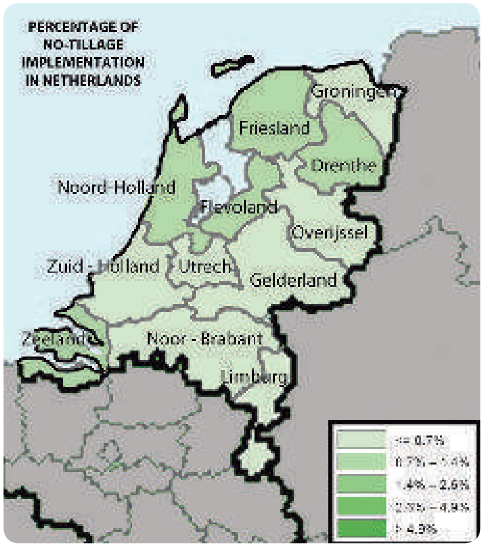


Fig. 3.6. NT percentage in comparison to the total area with annual crops in different Dutch regions. Source: *Eurostat, 2010.*

3.2.3.5. Poland

In Poland, the application of NT has a high adoption rate, 4.24% of total annual crops. That is equivalent to more than 400,000 ha, therefore it is the third country regarding land area under NT of the EU-28, after Spain and Romania. With regard to the distribution of NT practices, it can be seen in the Figure 3.7 that there is a greater adoption rate of NT practices in the western part of the country than in the eastern part, where the balance between hectares in NT and the total annual crop land area is lower.

3.2.3.6. Spain

In the last decade, the area under CA in Spain has been gradually increasing (Fig. 3.8). Currently, 600,000 ha are under no-tillage, while in 2008 there were less than 300,000 ha under this type of farming. This increase was not caused by the creation of new agricultural land, but by converting the farming land under conventional tillage into no-tillage (Fig. 3.9).

At national level, these data show that almost 8% of annual crops area is under NT. Most of this area is located in Castile and Leon (Fig. 3.10), where annual crops are predominant and occupy a large area.

3.2.3.7. United Kingdom

In spite of being the fourth European country regarding the land area in NT, the United Kingdom is the one with the largest proportion of arable land area (8.27%).

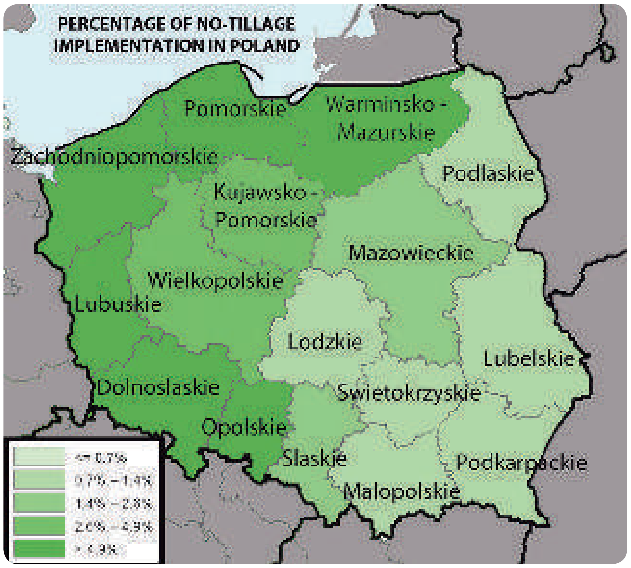


Fig. 3.7. NT percentage in comparison to the total area with annual crops in different regions of Poland. Source: *Eurostat, 2010.*

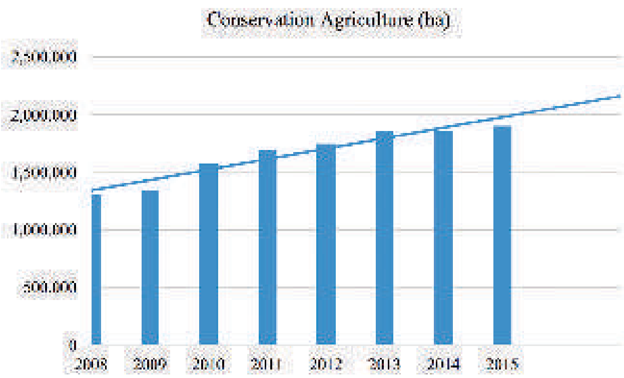


Fig. 3.8. Evolution of CA in Spain. Source: *MAPAMA (2009 to 2016).*

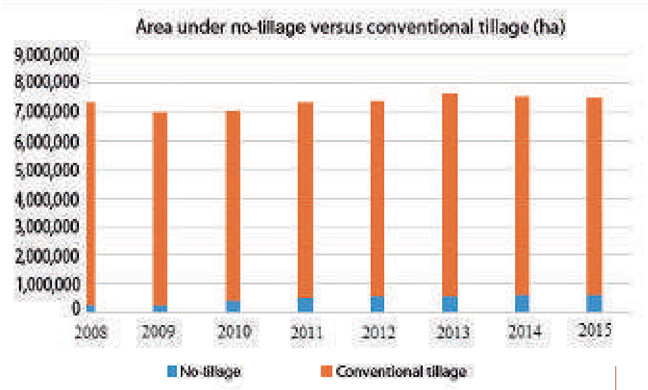


Fig. 3.9. Comparison of surface in no-till farming to conventional tillage in Spain. Source: *MAPAMA (2009 to 2016).*

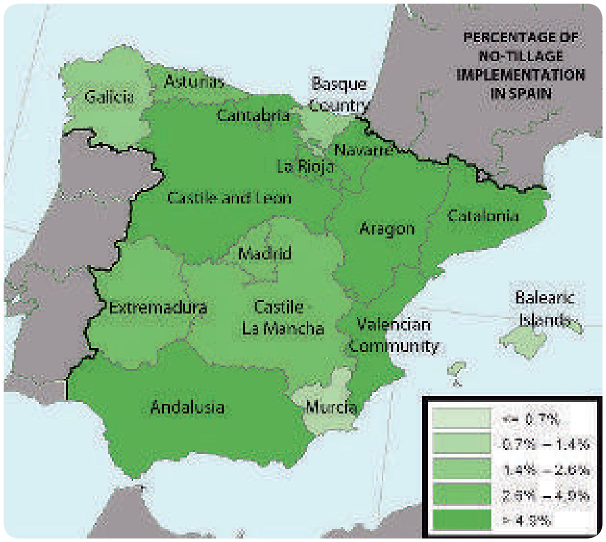


Fig. 3.10. Percentage of NT application regarding the annual crops area in the autonomous communities of Spain. Source: *Eurostat, 2010.*

This important rate of adoption of NT practices takes place mainly in the Scottish regions (Fig. 3.11) and to a lesser extent in most regions of England. On the other hand, Northern Ireland and Wales have surprisingly low number of hectares under this farming practice.

3.3. Groundcovers

3.3.1. Characteristics

It is the most representative agronomic practice of CA in permanent crops, whereby the soil surface between the rows of trees remains protected from the water erosion generated by the direct impact of raindrops. At least 30% of the soil surface is protected by a groundcover.

3.3.2. Adoption of groundcovers in Europe

Information about the adoption of groundcovers in woody crops in Europe is very small. In fact, the data of the area on which this technique is used, come from reports of the different national associations of Conservation Agriculture. The total land area in Europe is over 2 million ha (Table 3.5), which is mainly found in the countries of the Mediterranean area.

3.3.3. Groundcovers in:

3.3.3.1. Italy

The application of groundcovers in Italy is encouraged by administrations within the framework of a set of Conservation Agriculture aids (Fig. 3.12). Although the area of woody crops with groundcovers exceeds 100,000 ha, it is less than 6% of the almost 2 million and a half hectares of permanent crops in Italy, consequently the potential to increase the area of implementation of groundcovers is very high.

In Italy, many different soil management systems are carried out in permanent crops. The reasons for the implementation of groundcovers are the protection of farming soil from erosion, the preservation of the environment, the reduction of production costs and the enhancement of the quality of the fruits. Where water competition is not limiting (over 700 mm per year with regular distribution, north of Italy), groundcovers have been used as soil management system in many orchards (i.e. vineyards, apples, pears). Groundcover is usually limited to the inter-row area but in some periods (the humid season) it can be also extended to the line of trees, in which case it can also be an agronomic tool to reduce the excessive vigour of the trees.

In the absence of irrigation during the hottest months and in southern Italy, competition for water could occur during flowering, fruit formation and development (in olives and vineyards), limiting the final yield. To avoid this competition a temporary groundcover (seeded or natural vegetation) is usually grown from early autumn to mid-spring which is often the wettest period, and it is controlled during the hottest period through herbicide

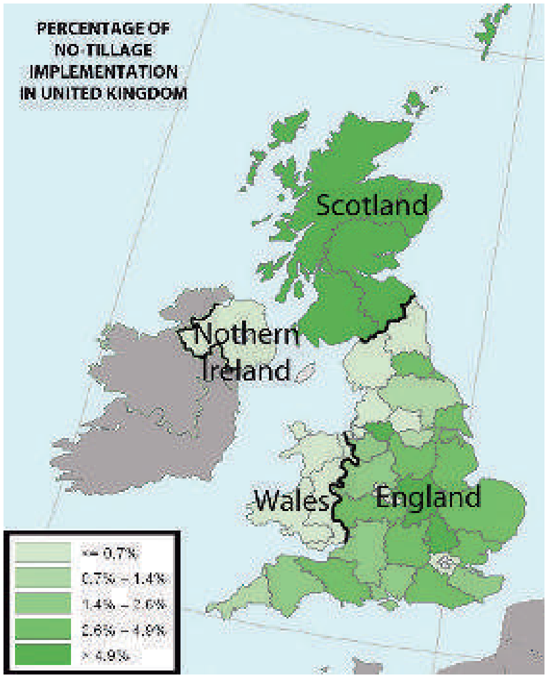


Fig. 3.11. NT percentage in comparison to the total area with annual crops in different regions of the United Kingdom. Source: *Eurostat, 2010*.

Fig. 3.12. Regions with aid to adoption of Conservation Agriculture in Italy. *Source: ECAF, 2017.*

Table 3.5. European Union countries in which groundcovers are adopted, area under this technique and its comparison with the woody crops area.

Country	Groundcovers surface (ha)	Source	Permanent crops surface (ha)	Source	Percentage (%)
Slovakia	18,810	ECAF, 2017	26,130	Eurostat, 2013	71.99
Portugal	32,950	ECAF, 2017	895,590	Eurostat, 2013	3.68
Hungary	65,000	ECAF, 2017	214,430	Eurostat, 2013	30.31
Italy	132,900	ECAF, 2017	2,409,780	Eurostat, 2013	5.52
Greece	483,340	ECAF, 2017	1,040,140	Eurostat, 2013	46.47
Spain	1,275,888	ECAF, 2017	4,961,981	MAPAMA, 2015	25.71
Rest of countries	0		3,357,030		0
Total EU-28	**2,008,888**		**12,905,081**		**15.57**

application or chopping it 2–3 times during the period of major nutrient demand.

Different mixes of crop species, including leguminous, are used in different areas. Normally, where soils have low fertility (especially in the south), species of legumes are introduced into the herbaceous mix of the groundcover to supply nitrogen required from trees. In specific farms, positive results have been obtained with self-seeding legumes which germinate when the first rains arrive in the autumn, grow during winter time and end crop cycle in the early spring, leaving residues on the soil surface. On the other hand, fibrous root system of grasses is better to improve soil structure and, generally, they add more organic matter than legumes *(Stagnari et al., 2014)*.

3.3.3.2. Spain

In Spain, the implementation of groundcovers has been increasing in the last 10 years, as it happens with NT in annual crops. (Fig. 3.13). Of the nearly 5 million hectares of permanent crops in Spain, more than a quarter have groundcovers. In other words, it is half of the hectares of Europe on which this technique has been implanted.

As for Europe, Spain has the largest area of permanent crops with groundcovers. Within the regions of Spain, Andalusia has the largest amount of hectares with groundcovers (Fig. 3.14). These covers are mainly located in olive groves, the predominant crop in this community. In fact, Andalusian region has the largest olive oil production in the world.

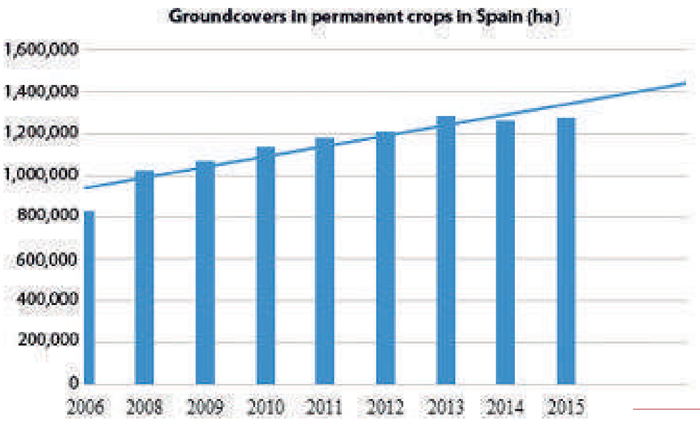


Fig. 3.13. Evolution of groundcovers in permanent crops in Spain. Source: *MAPAMA (2009 to 2016).*

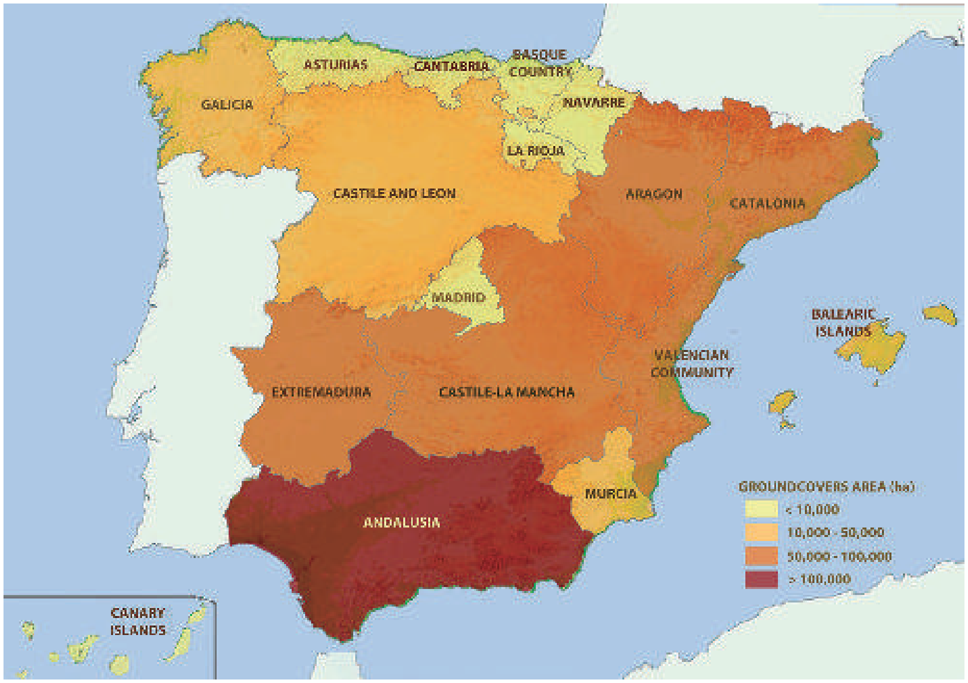


Fig. 3.14. Area of permanent crops with groundcovers in different regions of Spain. Source: *MAPAMA (2009 to 2016).*

3.4. Essential tools for Conservation Agriculture

3.4.1. No-till seeder

Since Conservation Agriculture avoids tillage, it is necessary to have adequate tools to seed in conditions with abundant crop residues. Therefore the development of mechanization, especially of machinery for seeding, has had special relevance in the implementation of CA. One of the keys to success in Conservation Agriculture is the no-tillage seeding machine and its accessories which allow farmers to seed under optimum conditions on different types of soils and the different cover crops.

In general, no-till seeders must have the following characteristics:

- Enough weight to penetrate under compact soil conditions and cover crops.
- Ability to open a groove wide and deep enough to place the seed at the adequate depth. It will be different if it is used for fine (~ 3 cm) or thick (~ 5 cm) seed.
- Possibility to regulate the rate and spacing of seeds of different size and ensure their adequate covering.
- Possibility to easily modify its settings to adapt to different crops and to apply fertilizers and plant protection products simultaneously.
- Resistance of its elements to withstand heavy duty conditions.

Similar to conventional seed drills, seeders used for crop establishment under CA conditions can be classified based on several aspects.

- Seed distribution system (mechanical or pneumatic).
- Seed size (coarse or small grains).
- Distance between seeding rows.
- Residue cutting and furrow opening devices (tines or disc seeders).

Table 3.6. Changes in the use of agricultural machinery while shifting from conventional to Conservation Agriculture (no-tillage). Source: Own elaboration.

Conventional agriculture	Conservation Agriculture
High energy requirements (fuel and manufacturing of implements).	It does not require tillage, avoidance of soil disturbance.
Necessary to do several primary and secondary soil tillage passes for seed bed preparation.	Integrated weed management based on crop rotations, permanent soil cover and herbicides.
Mechanical weed control, in addition to chemical control.	Reduces working hours on the field up to 50%, less use of the tractor.
Dependence on tillage equipment.	Significantly improves energy use efficiency and productivity.
Many hours of field work for both labour and machinery.	In most cases, there is a reduction of more than 50% of fuel consumption.

3.4.1.1. Functions of no-till seeder

The aim is to place the seed correctly in order to establish the crop well and help its growth. Therefore, a no-till seeder must perform the following functions.

a) Handling crop residues and pre-opening of the seed furrow

The only mechanical disturbance of the soil is performed in the seed furrows in order to place the seed in optimal conditions for germination. To do this, there are tools which allow to remove or cut through the crop residues before the furrow openers act on the ground.

Fig. 3.15. Cutting disc.

In order to cut the residues along the seeding row different types of discs are normally employed that range from single, flat coulter and completely vertically oriented discs to wavy discs, notched discs to inclined single discs and staggered double discs. Figure 3.15. shows one of those cutting discs.

Another way to handle considerable amounts of crop residues to guarantee correct seed placement, to facilitate emergence and to help warming the soil environment around the seed under cool conditions is to remove the residue from the seeding row attaching so-called row cleaners (Fig. 3.16) in front of the furrow

Fig. 3.16. Stubble sweeper mounted on the sowing train.

Fig. 3.17. Seeder equipped with single disc opener and lateral depth control wheel.

openers. This option is particularly interesting for the seeding of wide row crops (e.g. maize, sunflower, sugar beet, etc.).

Under dry conditions, penetration is hampered by the high resistance that the soil offers to the cutting action of the discs. To overcome this, the options are to increase the pressure that each seeding unit can apply onto the soil surface or to mount specially designed cutting discs in front of the row openers. The most commonly used disc types for this purpose are notched discs. Whether working directly in front of the openers or between the tractor and the seeder, both opening and seeding discs have to be perfectly aligned. In some regions, the preferred option to deal with dry and hard-to-penetrate soil conditions is the use of tine openers that, depending on their design, can cause much more soil disturbance when compared to disc openers.

b) Seed furrow opening and placement

Depending on the soil and residue conditions the seed furrow opening and seed placement can also be performed as a stand-alone operation without the use of a pre-opener tool. Seed furrow openers can normally be classified into two groups: disc coulters or tines (knife coulters).

Discs

Seed furrow openers can be single or double. In both cases they are inclined with respect to the soil surface and mounted in the forward direction. Some disc-based systems have also a slight angle relative to the direction of displacement. Single-disc machines usually do not have a front cutter, since the discs perform the cutting and opening functions of the sowing furrow (Fig. 3.17). The outer edge of the disc can be smooth or grooved, the latter one cuts the straw better. Laterally to the discs a tube guides the seeds to the bottom of the seed furrow. The pressure to force the discs into the soil is either performed mechanically (springs) or pneumatically. Enough pressure has to be guaranteed to achieve the desired seeding depth. Depth control of seed placement is normally performed by (a) side or back wheel(s), either of rubber or metallic, which limits the working depth.

Seed opener with double discs open the seed furrow in a V-shape by the combined action of both discs (Fig. 3.18). The drop tube is located between them, through which the seeds are conducted to the bottom of the furrow. If there is a large amount of crop residues, this system usually requires a cutting disc, therefore it requires more weight than the single disc seeder to reach the same depth. Today also very common are the so-called "staggered" double disc openers, which consist also of two V-shaped discs being one of them smaller in diameter. This solution was found to better handle residues.

Fig. 3.18. Seed drill equipped with double disc opener.

Fig. 3.19. Sowing train in a single grain planting machine.

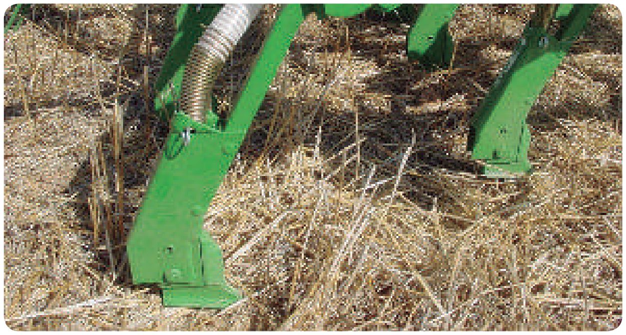


Fig. 3.20. Seed drill equipped with tines.

Tine or knife coulters

The second large group of seeders are those that use tines or knifes to create the seed furrow. They are different from the previous ones because they act on the ground exerting the vertical cut upwards, forcing the tines into the soil, which considerably reduces the necessary weight/pressure to achieve the desired seeding depth. The angle of attack of the tines is constant regardless the working depth, which allows the row to be opened evenly. This coulter type adapts better to stony terrains than those equipped with discs, although they can also have some inconveniences

Fig. 3.21. Detail of row closure using double disc.

such as blockage with already a low amount of crop residues, especially when not chopped.

c) Row closure

Once the seed has been placed, it is necessary to cover it with fine soil that is tight enough to absorb the soil moisture and begin the germination process. The row closure is usually carried out by press wheels, whether single or double, made of either rubber, hardened nylon or metal.

Some machines mount rakes after the press wheels in order to smoothen the soil surface and the residues on top of it thus leaving the row covered with aggregates trying to avoid crusting.

3.4.1.2. Pre-planting operations

In order to facilitate the work of the seeder, the seedbed must present homogeneous conditions for a correct establishment of the crop. The same applies under CA

Fig. 3.22. Detailed system spreader of residues in the cereal harvester.

Fig. 3.23. Rear crop residue spreader detail.

farming where in addition to the soil we have to manage crop residues. The management of the crop residues has to guarantee its uniform distribution as sudden changes in the amount of groundcover can pose serious challenges to the quality of the seed placement by drills even well adapted to changing conditions. For this purpose, the necessary accessories must be available on the harvester allowing to chop and spread uniformely the crop residues (Fig. 3.22 and 3.23).

During the harvest, it is necessary to take into account the next crop in the rotation, the type of seeder and the management of the groundcover, in order to opt for a higher or lower cut and a finer or coarser chopping of the residues of the harvested crop.

3.4.2. Sustainable use of plant protection products in Conservation Agriculture

3.4.2.1. What are plant protection products? Their regulation in Europe

They are chemical mixtures containing one or more active substances and other ingredients, whose purpose is to protect crops and their products from harmful organisms. Substances that destroy plants, regulate or inhibit germination are also considered to be plant protection products.

Plant protection products contribute to increasing yields in agriculture, controlling weeds through herbicides, as well as pests and diseases through insecticides and fungicides that help ensure good quality food. In order to ensure that their use does not have an adverse effect on plant production and does not present risks to humans, animals or the environment, and to be able to sell and use plant protection products it is necessary to have an authorization of a strict risks evaluation according to Regulation (EC) No 1107/2009, applicable in the European Union. There are also Community rules defining maximum residue levels (MRLs) for plant protection products in food and feed, such as Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum amounts of pesticide residues in food and feed of plant and animal origin and amending Council Directive 91/414/EEC, where the maximum residue level (MRL)

Plant protection products contribute to increasing yields in agriculture is defined as "*the upper legal level of a concentration for a pesticide residue in or on food or feed set in accordance with this Regulation, based on good agricultural practice and the lowest consumer exposure necessary to protect vulnerable consumers*". Nowadays, there is an initiative at European level which includes, among other rules, Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing the framework for community action to achieve sustainable use of pesticides.

3.4.2.2. Adventitious herbs. General features

Adventitious herbs, commonly known as weeds, are plants which are considered undesirable in a particular situation. They are characterized by their high dispersibility, persistence and competitiveness. In general, they diminish crop yields, and in many cases in the processes of harvesting and commercialization, they have a negative impact by reducing the price that the farmer receives for their product.

Weeds are as old as the agriculture itself, and they have being adapting to the different farming systems which have been introduced, while some species were disappearing and other ones appearing. It is necessary to have a comprehensive approach to these herbs, taking into account their biology, knowledge of the interaction of weeds with the crop and the adoption of appropriate measures in order to control them.

Before establishing any strategy to control weeds, it is necessary to identify which species are truly harmful, taking into account the historically problematic ones in each plot. In order to act correctly, it is advisable to follow the evolution of the different species of weeds through periodic surveys.

The knowledge about different species is important to adopt the correct control measures. The moment of weeds germination is a factor to take into account. In some cases, delaying the main crop establishment is desirable, by choosing a short cycle variety, since the majority of weeds will have been germinated, and could be controlled by applying herbicides in pre-seeding operations. The latency periods of the seeds of weeds that allows them to remain in the soil for several years without germinating, is another factor to consider especially for planning the crop rotations.

The last, and perhaps the most important, within biology, is the life cycle and its reproduction. In fact, the control strategy is very different if weeds are annual herbs that are reproduced by seeds, in which case it is essential to prevent them from reaching maturity because they would leave the soil seeded for several years. In this case, the appropriate control strategy is to apply herbicides with great displacement power to the reproductive organs, to avoid the maturation of seeds that can be used for reproduction.

The interaction of unwanted species with the crop is another factor to take into account. As mentioned above, weeds adapt to different cropping systems so their populations are never constant over time. Grass species, for example, increase greatly when the cereal is cultivated on the same plot for several years in a row. The establishment of wide rotation strategies is always advisable.

The adoption of appropriate measures for weeds control is very varied. In fact, preventive measures must be

taken into account, such as the use of seeds free of weeds, which have good quality and grow fast to ensure rapid coverage of the soil, avoiding new germination of adventitious herbs. It is important to avoid as much as possible the breeding and grazing because cattle is a source of weeds infestation, since many seeds are viable after passing through the digestive system of the animals.

Monitoring of perennial weed populations and their control is relevant, since they can easily become a problem in the absence of tillage. However, they are easy to control with an appropriate herbicide. On the other hand, the rotation of crops is a very effective measure for the weeds control. It has enormous agronomic and economic advantages. Crops rotation allows the use of different herbicides with completely different modes of action that improve the control of weeds and significantly reduce the risk of resistant herbs.

Managing the date of seeding the main crop helps to control weeds. In some cases, the delay of the seeding would allow having many weeds germinated before, so herbicides could be used to control them before the establishment of the main crop. While, there are other cases, in which the advance of the seeding date would favour to cover the soil and prevent the germination of weeds. Proper separation between rows of crops helps to cover the soil better and control weeds.

Finally, the rational use of herbicides that are authorized in each crop is a tool to be taken into account for the control of weeds. Herbicides should be used strictly following the authorized uses written on the label of each product.

3.4.2.3. Control of weeds in Conservation Agriculture

The way of preparing the land for sowing and the strategies used to control weeds before sowing (pre-seeding) reduce organic matter and biodiversity in soils. Tillage-based agriculture uses passes of various ploughs to control weeds and prepare the seedbed where the crop will be cultivated. This last soil management system leaves the soil bare with no groundcover to protect it against erosion, not only caused by rainfall, but also by wind. Intensive tillage has caused constant erosion processes that have resulted in the loss of the most fertile layer of soil. In the European Union, 970 million tonnes of soil are lost every year (*Panagos et al., 2015*).

CA, on the other hand, promotes a way of cultivating based on the maintenance of permanent soil cover, which would help to protect the soil against the erosion, improve water quality and crops water balance, fix CO_2 (carbon) in the soil and increase biodiversity. All this, allowing the sustenance of the farmers, through improvements in productivity and the sustainability of the sector that is able to convince population to remain in rural areas.

This profound transformation in soil management also requires technological improvements. Specific CA seeders are used, such as those described in the previous section, intensive tillage is avoided, and plant protection products are used to control weeds. Therefore, herbicides have been, and remain, an essential element in the development of CA systems.

The correct use of herbicides is one of the critical factors for the economic success of the crop, both in conventional agriculture and in CA. The safety of their use is sufficiently guaranteed by the scientific evidence, as well as by the measures included in the current legislation. Regarding plant protection products, European legislation is very demanding, paying particular attention to the protection of the applicator, consumer and the environment. In addition, the improvements in biodiversity and soil promoted by CA result in a safe and optimized use of the inputs that are available to farmers. In fact, according to recent reviews of scientific papers, the principles of CA, no-tillage, crop rotations and permanent soil cover produce less weed infestation in CA *(Nichols et al., 2015).* CA systems tend to accumulate seeds near the soil surface where they are most prone to germinate but are also exposed to the adverse climate conditions, and the animal predation, that might make them not germinate. This balance reduces weeds in no-till farming.

Among the products used before the crop seeding, glyphosate alone or in combination with other other hormonal herbicides, is the most common choice among farmers. Glyphosate controls many of the weeds on the fields where CA is practiced and leaves no residue on the soil that can prevent or delay plantings. The low toxicological profile of this active substance, its excellent weed control, its wide availability of numerous brands made by many companies, since its patent expired in 2000, make treatments with this base inexpensive and well-known in all the world, recognized as an essential product to control weeds. Without glyphosate the cultivation hectares in CA could be reduced and the use of other herbicides with a less favorable ecotoxicological profile and a higher cost to the farmer would increase.

According to data from the International Association for the Plant Protection Sciences, the average price to distributor of glyphosate remains unchanged, around € 3.5 l^{-1}. Pre-seeding treatments, which are carried out instead of tillage, usually do not exceed 1.5 $l\ ha^{-1}$

of glyphosate, which means that a cost of herbicide control of weeds in pre-seeding process is 5.25 € ha^{-1}. In conventional agriculture, a mouldboard pass is required, as well as cultivator and spring cultivator passes. In the case of minimum tillage, a chisel plough and a spring cultivator passes are needed. On the other hand, the no-till is correctly prepared using only one herbicide pass (glyphosate alone, or in combination with other herbicides according to the weeds found). Based on CA, which is the most economical way to prepare the soil for seeding, 154 € more per hectare were spent on conventional tillage, and 73 € more on minimum tillage (*Arnal, 2014*).

Furthermore, the consumption of fuel for weeds control in pre-seeding operations is highly reduced, as can be seen in Table 3.7, which includes the fuel consumption of different implements. It should be noted that the farmer would either use a mouldboard plough or a chisel, at least two passes or a disc harrow or cultivator. This represents not less than 30 ha^{-1} of diesel fuel consumption, which can reach 40 l ha^{-1}, compared to the scarce 1 l ha^{-1}, consumed by the sprayer equipment of plant protection products. Fuel saving which, in addition to the economic benefit for the farmer, mentioned above, means a reduction in the emission of greenhouse gases (GHG) for about 3.03 kg CO_2 equivalent ha^{-1} per liter of fuel.

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Table 3.7. Operations and associated fuel consumption. CA stands for Conservation Agriculture; CT stands for Conventional Tillage. Source: *LIFE + Agricarbon project.*

Operation	Fuel consumption (l ha^{-1})	Soil management system
Mouldboard plough	22.5±4.1	CT
Chisel	14.1±0.8	CT
Disc harrow	7.7±1.1	CT
Cultivator	6.4±1.5	CT
No-till seeder	7.7±1.0	CA
Conventional seeder	6.0±1.6	CT
Spraying equipment of plant protection products	1.1±0.3	CT and CA
Fertilizer	0.9±0.4	CT and CA
Combine harvester	11.4±0.9	CT and CA

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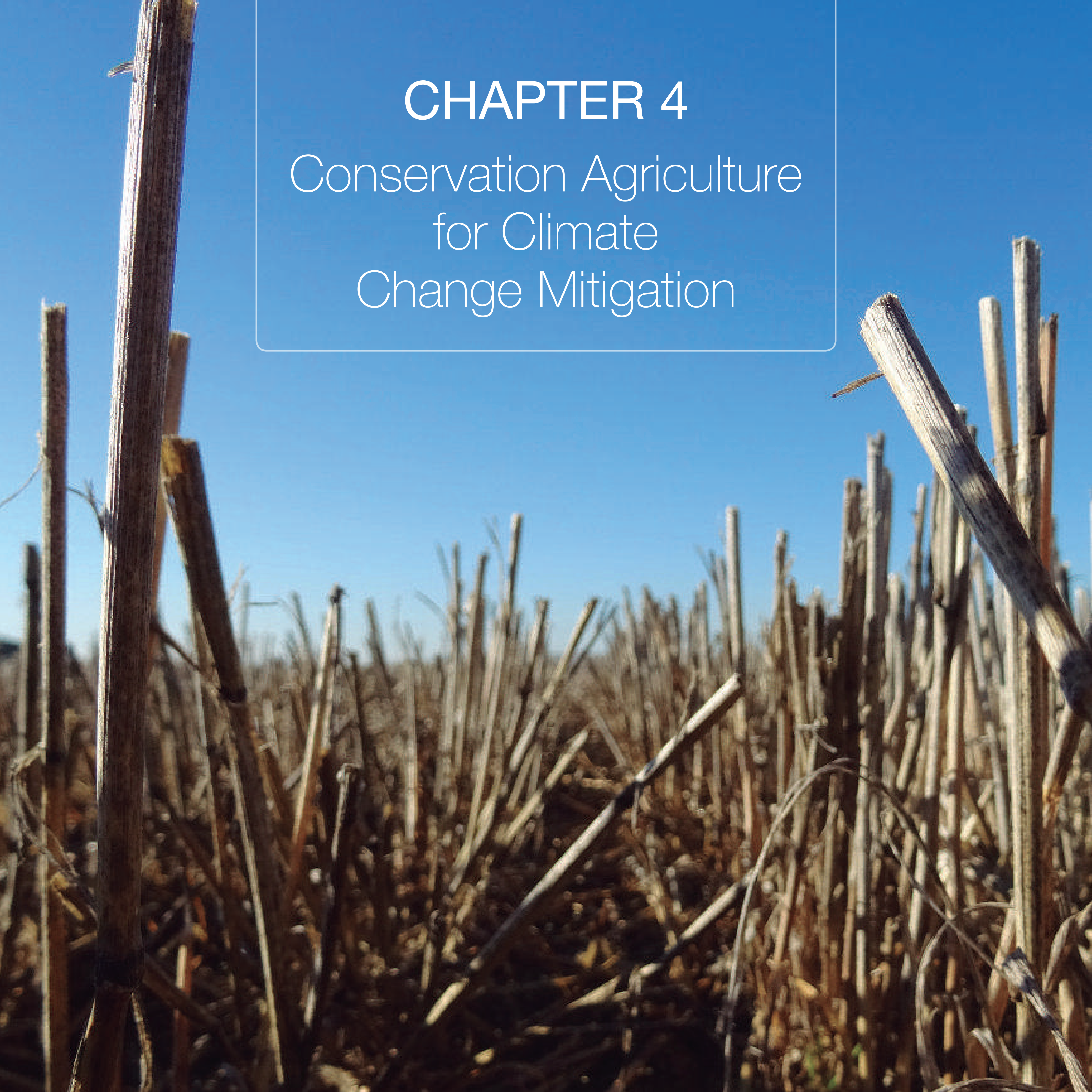
CHAPTER 4

Conservation Agriculture for Climate Change Mitigation



4.1. Introduction

Although the soil management system based on mechanized tillage introduced more than half a century ago made European agriculture progress, it is now unsustainable, because it emits greenhouse gases (GHG) and does not contribute to the conservation and improvement of natural resources, such as air, soil and water.

Regarding climate change, one of the consequences of management systems based on tillage is the reduction of the soil sink effect, which leads to a decrease in the organic carbon (OC) content. OC is the main component of organic matter (OM) and it is widely accepted as an indicator of soil quality *(Podmanicky et al. 2011)*, as it is capital in all soil processes, improving its structure, fertility and water holding capacity.

The reasons for this decrease are:

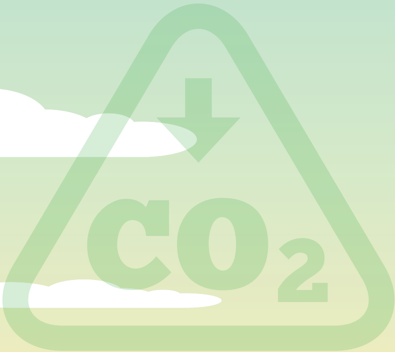
- The lower input of OM in the form of crop stubble.
- The higher humus mineralization rate caused by tillage. Tillage facilitates the penetration of air into the soil and therefore

the mineralization of humus, a process that includes a series of oxidation reactions, generating CO_2 as the main byproduct. One part of CO_2 gets trapped in the porous space of the soil, while the other part gets released into the atmosphere through diffusion mechanisms between zones of the soil with different concentration.

- The higher rate of erosion, which causes significant losses of OM and minerals. In conventional agriculture, the preparation of soil for sowing leaves the soil exposed to erosive agents for a long period of time.

Furthermore, the burning of stubble is a common practice in conventional agriculture in some areas. *Heenan et al. (2004)* estimated losses of 8.2 t ha^{-1} in the surface horizon of a Chromic Luvisol soil continuously tilled with cereal crop and in which stubble was burned. On the contrary, they recorded increase of 3.8 t ha^{-1} using no-tillage system (NT).

For all that reasons, many authors agree that soil disturbance by tillage is one of the main causes of organic carbon reduction in the soil (*Balesdent et al., 1990, Six et al., 2004; Olson et al., 2005*). *Reicosky (2011)* argues that intensive agriculture has contributed to the loss of between 30% and 50% of soil OC in the last two decades of the 20^{th} century. *Kinsella (1995)* estimates that, in only 10 years of tillage, 30% of the original OM was lost. In Europe, there are several estimations of carbon (C) loss in agricultural soils, so *Janssens et al. (2003)* estimated a loss of 300 Tg of C per year in European agricultural area extending to the Ural Mountains. Using a similar methodology, *Vleeshouwers and Verhagen (2002)* estimated an average loss of 78 Tg of C per year in the European Union. In a study at European level, *Janssens et al., (2005)*, calculated that the average annual rate of OC losses in agricultural soils in Spain was 47 kg ha^{-1}, which means that 79.8 Gg of C are lost in the national area every year. *Ordoñez-Fernández et al., (2007)* observed in Spain that ten years of continuous tillage, caused a decrease of 18% in OM content in the first 20 centimeters of a vertisol.



Adoption of CA across Europe would sequester the CO_2 emitted by 18 million households. Or the emissions from electricity generation for 25 million households.

Another consequence of the intensive work on the soil in the tillage-based agriculture are higher CO_2 emissions. Tillage has a direct influence on soil CO_2 emissions both in the short term (immediately after tillage) and in the long term (during the growing season). It stimulates the production and accumulation of CO_2 in the porous structure of the soil through the processes of mineralization of OM. The mechanical action of tillage involves a breakdown of the soil aggregates, with the consequent release of CO_2 trapped inside the soil which is therefore emitted into the atmosphere. Among the first studies on CO_2 emissions during tillage are those carried out by *Reicosky and Lindstrom (1993)* and *Reicosky (1997)* in the central area of the USA. These authors showed that the increase in CO_2 observed just after tillage was the result of changes in soil porosity and, therefore, it is proportional to the intensity of tillage.

On the other hand, the different agricultural practices (tillage, application of fertilizers and amendments, irrigation, plant protection products treatments...) need the use of fossil fuels, especially diesel, to be carried out, implying unavoidable GHG emissions. Thus, conventional tillage implies a greater consumption of fossil fuels in comparison with Conservation Agriculture, which leads to a higher atmospheric pollution, due to the emissions of CO_2, with the consequent negative effect on climate change.

Therefore, mitigation actions in the agricultural sector must be aimed at fixing C in the soil, while reducing GHG emissions. Thus, the agricultural practices that farmers have to adopt in order to achieve this dual purpose, should respect the following principles:

- Use soil management practices that increase the OM content in soils and thus enhance the sink effect.
- Reduce soil disturbance in order to reduce GHG emissions from the soil.
- Reduce fuel consumption and use more energy efficient processes to reduce the GHG emissions associated with them.

Scientists all over the world agree that the less the soil is tilled, it absorbs and stores more C, and therefore synthesizes more OM, which in the long run increases its productive capacity. In addition, it is verified that leaving crop residues on the surface and the no mechanical disturbance of soil, reduce the decomposition rate of stubble; decrease the mineralization of soil OM, due to a less aeration and lower possibility of the microorganisms to access it; and increase soil C. At the same time, no-till farming decreases the CO_2 released into the atmosphere, because tillage oxygenates the land in excess, which favors the oxidation of carbon that is emitted as CO_2.

On the other hand, it is well-known that all energy processes lead to the emission of CO_2. Therefore, all actions aimed at saving energy and fuel, such as reducing the amount of tillage, optimizing the use of agricultural inputs and executing operations correctly, reduce GHG emissions.

4.2. Conservation Agriculture as a climate change mitigation method

Conservation Agriculture (CA) represents a perfect solution to all of the aforementioned issues, contributing to climate change mitigation by reducing atmospheric GHG concentration. On the one hand, the changes introduced by CA related to the C dynamics in the soil, lead directly to an increase in soil C and create sinks of C. On the other hand, the drastic reduction in the amount of tillage and the mechanical non-alteration of the soil, reduce CO_2 emissions derived from the energy saving and the reduction of the mineralization processes of the OM (Fig. 4.1).

4.3. Sink effect in Conservation Agriculture

CA, by leaving crop residues on the soil surface, induces a dynamics of OM analogous to that produced in natural ecosystems. Therefore, CA increases the vertical stratification of OM. This stratification is taken as a quality recovery index of the agricultural soils degraded by tillage (*Franzluebbers, 2002; Moreno et al., 2005*). One important part of this humified OM on the soil surface is incorporated into the soil by earthworms, whose population is favoured by CA (*Cantero-Matínez et al., 2004; Bescansa et al., 2005*).

On the other hand, the less the soil is tilled, it absorbs and stores more C, which has previously been fixed into the plant thanks to photosynthesis, synthesizing more OM, which, in the long run increases soil productive capacity, and at the same time decreases CO_2 emissions.

In a study developed by *Lal (2004),* it is estimated the potential C fixation of an evetual global migration to CA systems, concluding that if on 1,500 million ha, the practices based on tillage were replaced by CA practices, between 0.6 and 1.2 Pg of C would be fixed per year.

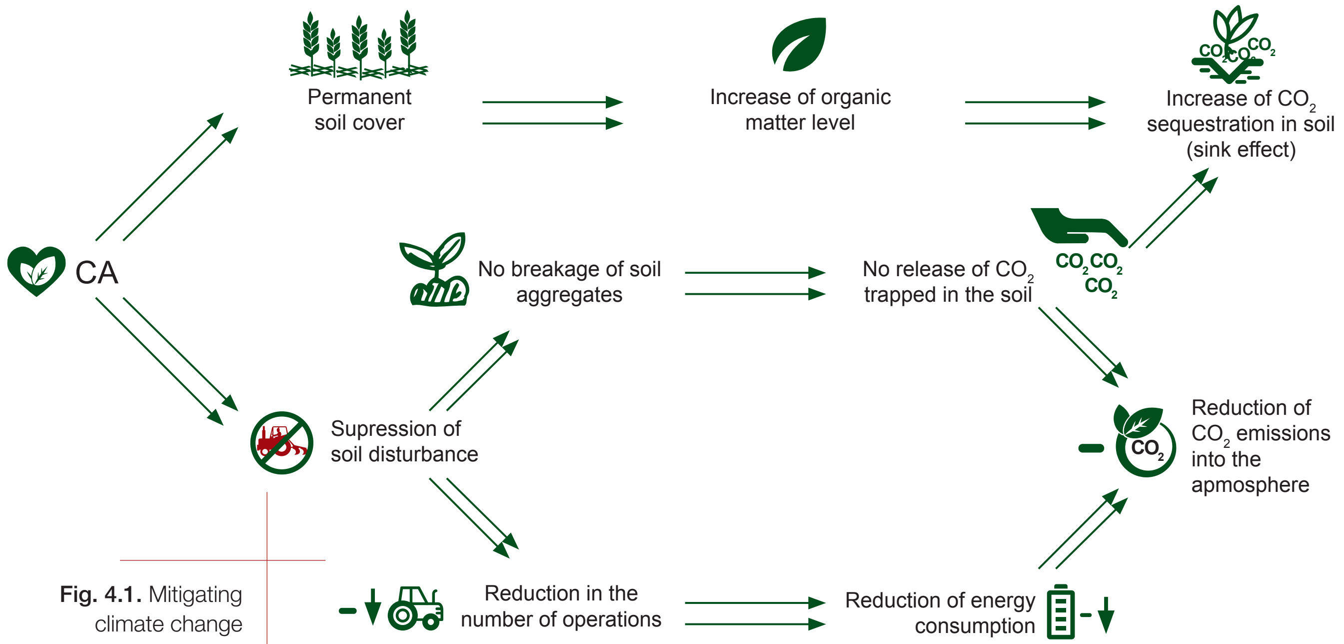


Fig. 4.1. Mitigating climate change mechanisms in Conservation Agriculture. Source: own elaboration.

4.4. Reduction of CO_2 emissions from soil in Conservation Agriculture

The adoption of Conservation Agriculture implies a drastic reduction of tillage operations, a reduction that could completely eliminate mechanical disturbance of soil using no-till practices. This reduction impacts on the volume of CO_2 emissions that occurs on the one hand, due to the breakdown of soil aggregates and the subsequent gas exchange that takes place after tillage, and on the other, the consumption of diesel and energy derived from the soil management.

CO_2 emissions derived from the mechanical action on the soil are directly related to the stability of its aggregates. Under natural conditions, OM is encapsulated inside the aggregates, and it is not accessible to the attack of the microorganisms present in the soil. The less stable an aggregate, the lower its resistance to alteration processes that may cause its breakage and, therefore, the OM inside it may be more easily accessible to microorganisms, favoring the processes of mineralization and CO_2 generation as a by-product which would be emitted into the atmosphere.

The adoption of alternative CA practices has allowed not only greater control of soil erosion but also a decrease in OM losses and CO_2 emissions as a result of non-soil disturbance. The non-alteration of soil promoted by conservation practices, improves its structure, increasing the stability of the aggregates against the processes of disaggregation, allowing a greater protection of the OM against the attacks of the edaphic microfauna, and maintaining "trapped" in the porous space of the soil, the CO_2 resulting from the mineralization processes of OM.

Therefore, the reduction of tillage reduces and slows the decomposition of crop residues, storing the atmospheric CO_2 (fixed in the structure of the plant and returned to the ground in the form of crop residue) in the soil. In this way, the soil will have the function of storing atmospheric CO_2, thus helping to mitigate the GHG emissions generated by other activities.

In research carried out in the United States *(Reicosky et al., 2007)*, the short-term effects on CO_2 emissions of two soil management systems were evaluated, one of which was based on the use of mouldboard plough and the other one on no-tillage. The investigations resulted in a higher emission in both the short and medium term of the conventionally tilled plots in comparison with the no-tillage plots, with values that were 3.8 times higher in tilling processes, when the tillage was more superficial (10 cm), than those quantified in no-tillage and, in the case of deeper tillage (28 cm), emissions were 10.3 times higher than with no-tillage. Fig. 4.2 shows research done by *Reicosky (1997),* which compared accumulated CO2 emissions from tilled soils for 5 hours after tillage with the emissions of a soil managed using no-till practices .

In experiments carried out in Spain by *Carbonell-Bojollo et al.* (2011), soils under no-tillage emitted a lower amount of gas in comparison with the tilled soils. Specifically, during the sowing operations, plots under soil management based on tillage,

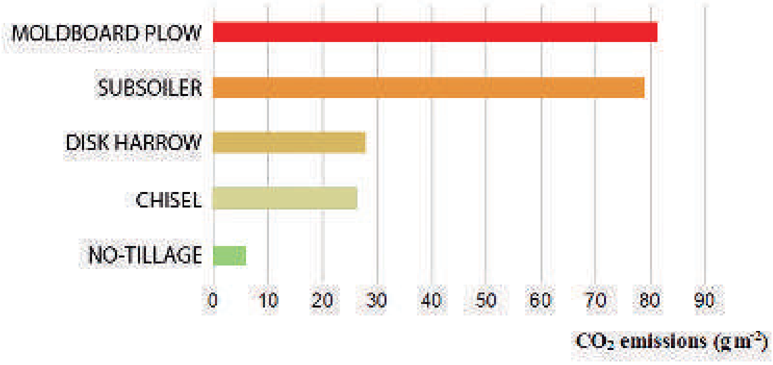


Fig. 4.2. Accumulated CO_2 emissions (g m^{-2}) 5 hours after the tillage. Source: *Reicosky (1997).*

Table 4.1. Daily CO_2 emissions produced during the sowing operations and maximum differences between the evaluated management systems (CT: Conventional Tillage, NT: No-tillage). Source: *Carbonell-Bojollo et al. (2011).*

Crops	Seedtime	Daily CO_2 emissions (kg ha^{-1})		Maximum emission difference (Hours after operation)
		CT	NT	
Pea	17/01/2007	8	3	75% (4 h)
Wheat	17/12/2007	14.6	10	41% (4 h)
Sunflower	24/03/2009	23	5	49% (4 h)
Pea	27/11/2009	33	21	34.5% (4 h)

emitted between 34% and 75% more CO_2 than those managed under no-tillage, with emission peaks 4 hours after the tillage (Table 4.1).

Based on a study comparing different soil management systems, *Prior et al. (2000)* concluded that the increase in CO_2 emissions after tillage is related to the depth of the operation and to the degree of soil disturbance. This coincides with the results obtained by *Carbonell-Bojollo et al. (2011)* (Fig. 4.3), who compared the two systems and observed that tillage with mouldboard plough, which reached up to 40 cm in depth, was the one that produced the largest emissions. Results showed that CO_2 emissions produced after tillage with mouldboard plough and disc harrow were respectively 10.5 and 6.7 times higher than the emissions produced in the plots under no-till practices.

In other studies, it was observed that, in the long term, the average emissions were lower in the no-tillage plots than in the plots under conventional tillage practices. In the short term, the flow of CO_2 in no-till practices were low and constant throughout the study because soil was not disturbed in this system. From the beginning until 48 hours after tillage, the accumulated CO_2 emissions in the conventional tillage system was 45 g CO_2 m^{-2}, however, for the same period CO_2 emissions in no-tillage system reached values of 24 g CO_2 m^{-2}, which were 40% lower than in the conventional tillage system *(Álvaro-Fuentes et al., 2007).*

4.5. CO_2 emissions related to energy consumption

Energy savings are another CO_2 emissions reduction mechanism through CA. The practical application of CA is based on the elimination of tillage, therefore, this system requires a lower amount of energy than conventional tillage, which consumes more fuel in the preparation of the seedbed. Fuel consumption is connected with the performed soil operations, the greater the number of operations, the greater the fuel consumption.

In the end, energy consumption turns into CO_2 atmospheric emissions. Using the values of the conversion coefficients given by Lal (2004), which assumes that the consumption of 1 MJ in any energy process results in the emission of 20 g of equivalent C, it is possible to estimate the difference between CO_2 emissions from conventional agriculture and CA, due to the performance of different operations, based on their fuel and energy consumption.

At the global level, some studies on C emission values related to energy consumption in the pre-seeding operations have been carried out. Based on their results, it has been estimated that 35.3 kg ha^{-1} of C emissions are released in conventional tillage, 7.9 kg ha^{-1} in minimum tillage based on the use of chisel plough, and 5.8 kg ha^{-1} in a management system based on no-tillage, implying a reduction of 83.57% in emissions compared to conventional agriculture (*Lal, 2004*).

In energy analysis carried out in different areas of Spain, energy savings of CA system compared to conventional tillage varied between 5% and 50% depending on the region and crop *(Hernanz-Martos et al., 1997*).

In a recent study carried out in Spain, within the LIFE + Agricarbon (LIFE08 ENV/E/000129) project: "Sustainable agriculture in carbon arithmetics" (Fig. 4.4) in raifed crops (rotation wheat/ sunflower/leguminous plants), during four agricultural seasons, there were compared the energy consumption and other data related to the performance of agricultural operations of plots under no-tillage with that of plots under conventional tillage. Results showed a positive balance in terms of energy consumption and CO_2 emissions of CA in comparison with CT. Thus, in the plots where no-tillage was introduced, CO_2 emissions linked to energy consumption were reduced by an average of 12% in wheat, 26.3% in sunflower and 18.4% in leguminous plants. It means that in the plots under no-tillage, in one season, there were emitted 176 kg of CO_2 ha^{-1} less in wheat, 73 kg of CO_2 ha^{-1} less in sunflower and 86 kg of CO_2 ha^{-1} less in leguminous crops.

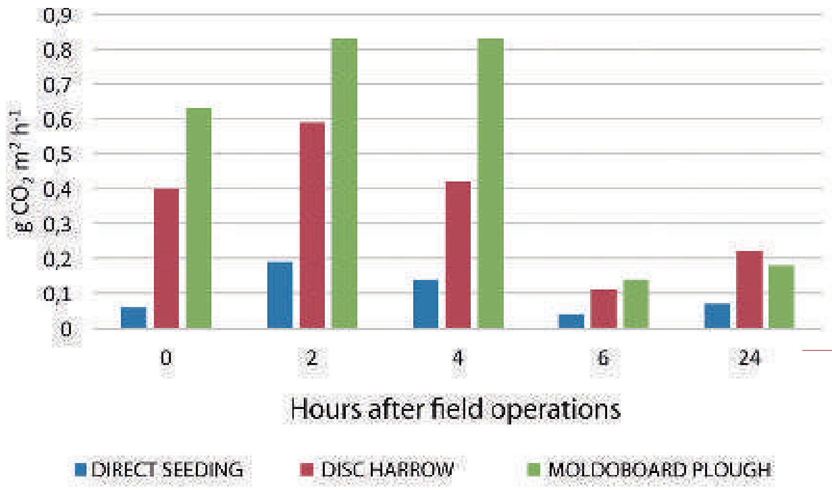


Fig. 4.3. Increase of CO_2 emissions per hour during the tillage operations on the soil in the different cropping systems. (Each value represents the average of 14 readings). Source: *Carbonell-Bojollo et al., (2011).*

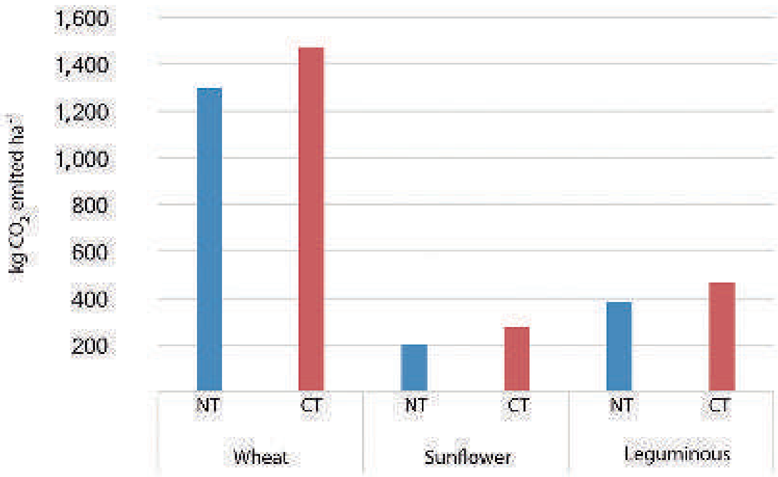


Fig. 4.4. CO_2 emissions for each crop as a result of the energy consumption in the performed farming operations: no-tillage (NT) and Conventional-tillage (CT). Source: *LIFE + Agricarbon Project, 2014.*

4.6. Climate change mitigation through Conservation Agriculture in Europe

4.6.1. Increasing soil organic carbon

Climate change mitigation through CA is based on the three main factors that have been discussed in the previous sections (sink effect, reduction of emissions from the ground and reduction of emissions from the use of agricultural machinery). The sum of the first two processes, an increase in the carbon sink effect in the soil and a decrease in CO_2 atmospheric emissions from the soil, leads to a net increase of soil organic carbon (SOC). This increase is measured in tons of carbon in soil that accumulate per hectare and year (t ha^{-1} $year^{-1}$).

The increase in soil organic carbon in no-tillage in comparison with conventional tillage at a European general scale (EU-15) is 0.4 t ha^{-1} yr^{-1} (*Freibauer et al., 2004; Smith et al., 2005)*. While for groundcovers, there is no general data on this scale. The closest approximation is provided by *Freibauer et al. (2004),* which indicates an increase of 0.3 to 0.8 t ha^{-1} yr^{-1}. But this information refers to cover crops, which are arable crops that are not aimed at being harvested, but at protecting the soil from erosion and loss of nutrients. Groundcovers are grassland between the rows of woody crops. In this case, there is only information at European level for the Mediterranean biogeographical region. In particular, the recent work of *Vicente-Vicente et al. (2016),* in which by means of meta-analysis it has been determined that the groundcover increases SOC; 1.1 t ha^{-1} yr^{-1} in olive groves, 0.78 t ha^{-1} yr^{-1} in vineyard and 2.0 t ha^{-1} yr^{-1} in almond groves.

In order to obtain more detailed data on climate change mitigation through the application of CA on European agricultural soils, a bibliographic review has been made. This review has been carried out in selected countries. Data obtained have been extrapolated to the different biogeographic regions of Europe (Fig. 4.5a).

For this purpose, each European country has been allocated in one of the four main biogeographic regions (Boreal, Continental, Atlantic and Mediterranean) (Fig. 4.5b).

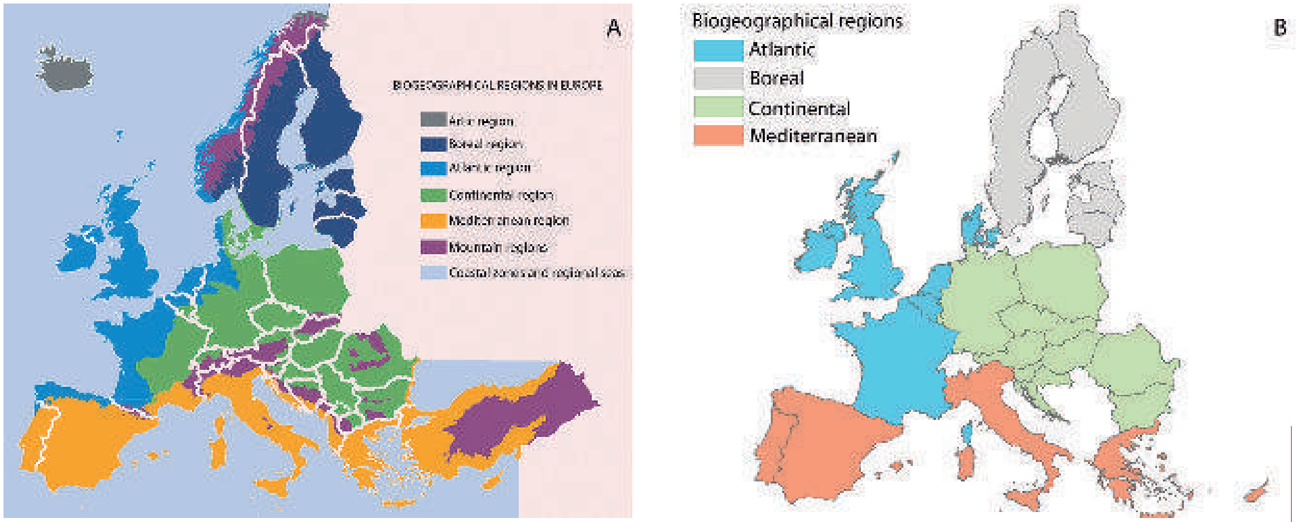


Fig. 4.5. Classification of European countries (B) according to the European biogeographic region (A) (EEA, 2012), they belong to.

In particular, in the continental, Atlantic and Mediterranean biogeographical regions there have been selected two countries to carry out the bibliographic review . While in the Boreal region data from one country have been collected. These countries are:

- Boreal Region: Sweden.
- Continental Region: Germany and Poland.
- Atlantic Region: France and the United Kingdom.
- Mediterranean Region: Spain and Italy.

SOC increase data for each country have been obtained, preferably, from articles that by way of global analysis or meta-analysis give a general data of SOC increase at national level. If this type of study does not exist for a given country, this increase has been obtained from the average of the results obtained in comparative studies between CA and conventional tillage carried out in that country. Table 4.2 summarizes the SOC increase data obtained for each of the studied countries.

Regarding CA in annual crops (NT) data, it should be noted that the carbon increase calculated for NT in Germany as the average of results of comparative studies, is very similar to the value determined by *Neufeldt (2005)* for NT in comparison with conventional tillage in the German federal state of Baden-Wurttemberg (0.44t ha^{-1} $year^{-1}$). Regarding groundcovers, as in the study of Europe in general, the availability of SOC increase data is small. And there are no data in the countries of the Boreal and Continental regions, as in the case of the United Kingdom.

An arithmetic mean of values obtained for the countries included in each biogeographic region (shown in Table 4.2) was calculated. Result has been considered as the sequestration value that can be applied to the rest of countries included in each region (Table 4.3). In the case of NT, an average of the values obtained for the countries located within each biogeographic region has been calculated, with the exception of the Boreal region, where data from Sweden where directly considered.

Regarding CA in permanent crops (groundcovers), it was more difficult to obtain a value for SOC increase, except in the Mediterranean region where it has been calculated using average values of Spain and Italy. It is noteworthy that this average is very similar to the average value presented by *Vicente-Vicente et al. (2016)* for olive orchards, vineyard and almond orchards: 1.29 t ha^{-1} yr^{-1}.

In the Atlantic region, it has been taken as SOC increase value in groundcovers the figure for France (0.4 t ha-1 yr-1) since no information was found in the United Kingdom. In the case of the Continental region, the French value has also been used, since it coincides with the figure for SOC increase in NT in this region and is within the 0.3 - 0.8 t ha^{-1} yr^{-1} range provided by *Freibauer et al. (2004)* and it is also similar to the 0.4 t ha^{-1} yr^{-1} that are generally produced in Europe by avoiding tillage (*Freibauer et al., 2004, Smith et al., 2005*).

Finally, no increase of SOC has been considered for CA in permanent crops in Boreal countries because no data has been found for these crops in the region.

Figures presented in tables 4.2 and 4.3 make it possible to calculate values for the current and potential SOC increases, at national and European level, due to the implementation of CA. For this, the mentioned figures have to be linked with the current area under CA in annual crops and with the total area of annual crops (Table 4.4); as well as with the current area under CA in permanent crops and with the total area of permanent crops (Table 4.5). Figures displayed in Table 4.4 are graphically represented in Figures 4.6 and 4.7, while figures in Table 4.5 are graphically shown in Figures 4.8 and 4.9.

Table 4.2. Increase of SOC in soils under CA in comparison with soils under conventional tillage in the studied countries.

Biogeographical region	Country	CA Practice	Increase of soil organic carbon (t ha^{-1} yr^{-1})	Source
BOREAL	SWEDEN	NO-TILLAGE	0.02	Average of pair-wise comparisons
		GROUNDCOVERS	NA	
CONTINENTAL	GERMANY	NO-TILLAGE	0.43	Average of pair-wise comparisons
		GROUNDCOVERS	NA	
	POLAND	NO-TILLAGE	0.41	Average of pair-wise comparisons
		GROUNDCOVERS	NA	
ATLANTIC	FRANCE	NO-TILLAGE	0.20	Arrouays et al., 2002
		GROUNDCOVERS	0.40	Arrouays et al., 2002
	UNITED KINGDOM	NO-TILLAGE	0.45	Average of pair-wise comparisons
		GROUNDCOVERS	NA	
MEDITERRANEAN	ITALY	NO-TILLAGE	0.77	Average of pair-wise comparisons
		GROUNDCOVERS	1.07	Average of pair-wise comparisons
	SPAIN	NO-TILLAGE	0.85	González-Sánchez et al., 2012
		GROUNDCOVERS	1.54	González-Sánchez et al., 2012

Table 4.3. Increase of SOC in soils under CA in comparison with soils under conventional tillage for European biogeographic regions.

Biogeographical region	CA Practice	Increase of soil organic carbon (t ha^{-1} yr^{-1})
BOREAL	NO-TILLAGE	0.02
	GROUNDCOVERS	ND
CONTINENTAL	NO-TILLAGE	0.42
	GROUNDCOVERS	0.40
ATLANTIC	NO-TILLAGE	0.32
	GROUNDCOVERS	0.40
MEDITERRANEAN	NO-TILLAGE	0.81
	GROUNDCOVERS	1.30

Table 4.4. Area under CA in annual crops in Europe, carbon sequestration potential per biogeographic region or country and actual and potential carbon/CO_2 fixation through CA in annual crops (1 ton of Corg corresponds to 3.7 tons of CO_2).

	Biogeographical region	Increase of soil organic carbon (t ha^{-1} yr^{-1})	NT current area (ha)	Current SOC fixed (t yr^{-1})	Current CO_2 fixed (t yr^{-1})	NT potential area (ha)	Potential SOC fixed (t yr^{-1})	Potential CO_2 fixed (t yr^{-1})
Austria	Continental	0.42	28,330	11,927	43,731	1,232,040	518,670	1,901,791
Belgium	Atlantic	0.32	270	87	320	613,580	198,084	726,308
Bulgaria	Continental	0.42	16,500	6,946	25,470	3,197,800	1,346,225	4,936,160
Croatia	Continental	0.42	18,540	7,805	28,619	832,870	350,626	1,285,627
Cyprus	Mediterranean	0.81	270	219	803	61,770	50,085	183,646
Czech Republic	Continental	0.42	40,820	17,185	63,010	2,373,890	999,372	3,664,363
Denmark	Atlantic	0.32	2,500	807	2,959	2,184,120	705,107	2,585,391
Estonia	Boreal	0.02	42,140	843	3,090	578,660	11,573	42,435
Finland	Boreal	0.02	200,000	4,000	14,667	1,912,710	38,254	140,265
France	Atlantic	0.20	300,000	60,000	220,000	17,166,990	3,433,398	12,589,126
Germany	Continental	0.43	146,300	63,441	232,617	10,904,310	4,728,505	17,337,853
Greece	Mediterranean	0.81	7	6	21	1,600,950	1,298,104	4,759,713
Hungary	Continental	0.42	5,000	2,105	7,718	3,560,130	1,498,761	5,495,456
Ireland	Atlantic	0.32	2,000	646	2,367	999,550	322,688	1,183,190
Italy	Mediterranean	0.77	283,923	219,094	803,344	5,992,540	4,624,243	16,955,559
Latvia	Boreal	0.02	11,340	227	832	1,101,650	22,033	80,788
Lithuania	Boreal	0.02	19,280	386	1,414	2,129,630	42,593	156,173
Luxembourg	Continental	0.42	440	185	679	60,950	25,659	94,083
Malta	Mediterranean	0.81	ND	ND	ND	5,290	4,289	15,727
Netherlands	Atlantic	0.32	7,350	2,373	8,700	670,360	216,415	793,520
Poland	Continental	0.41	403,180	164,632	603,650	9,518,930	3,886,896	14,251,954
Portugal	Mediterranean	0.81	16,050	13,014	47,718	707,490	573,656	2,103,407
Romania	Continental	0.42	583,820	245,779	901,191	7,295,660	3,071,362	11,261,662
Slovakia	Continental	0.42	35,000	14,734	54,026	1,304,820	549,309	2,014,135
Slovenia	Continental	0.42	2,480	1,044	3,828	165,410	69,635	255,329
Spain	Mediterranean	0.85	619,373	526,467	1,930,379	7,998,655	6,798,857	24,929,141
Sweden	Boreal	0.02	15,820	316	1,160	2,324,650	46,493	170,474
United Kingdom	Atlantic	0.45	362,000	161,331	591,548	4,376,000	1,950,237	7,150,870
Total Europe			**3,162,733**	**1,525,598**	**5,593,861**	**90,871,405**	**37,381,131**	**137,064,146**

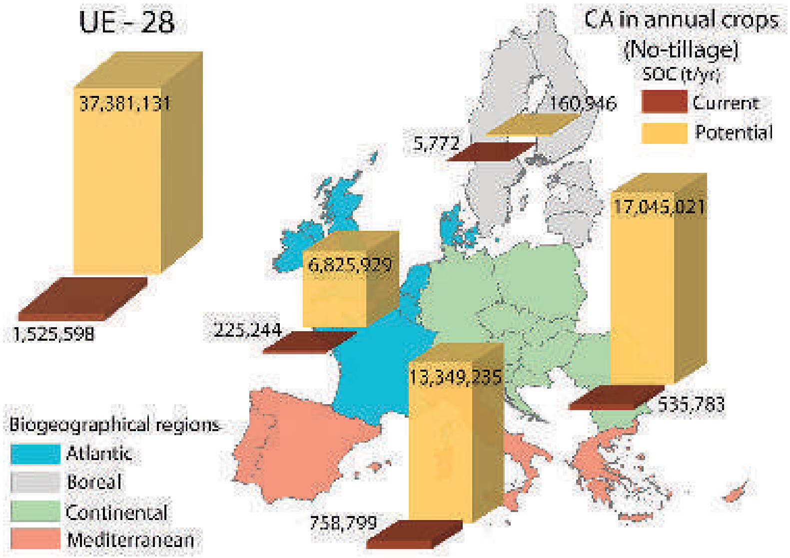


Fig. 4.6. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 4.7. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom.

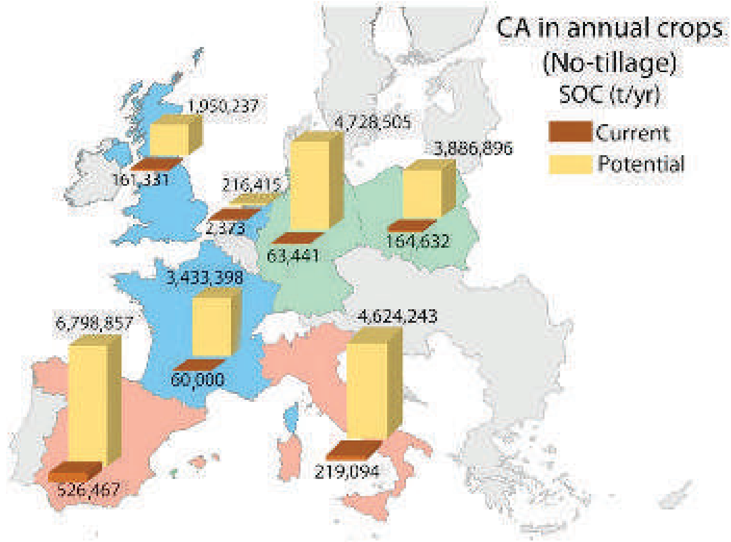


Table 4.5. Area under CA in permanent crops (groundcovers)in Europe, carbon sequestration potential per biogeographic region or country, and actual and potential carbon/CO_2 fixation through groundcovers (1 ton of Corg corresponds to 3.7 tons of CO_2).

	Biogeographical region	Increase of soil organic carbon (t ha^{-1} yr^{-1})	Ground-cover current area (ha)	Current SOC fixed (t yr^{-1})	Current CO_2 fixed (t yr^{-1})	Ground-cover potential area (ha)	Potential SOC fixed (t yr^{-1})	Potential CO_2 fixed (t yr^{-1})
Austria	Continental	0.40	ND	ND	ND	80,190	32,076	117,612
Belgium	Atlantic	0.40	ND	ND	ND	38,170	15,268	55,983
Bulgaria	Continental	0.40	ND	ND	ND	143,070	57,228	209,836
Croatia	Continental	0.40	ND	ND	ND	100,290	40,116	147,092
Cyprus	Mediterranean	1.30	ND	ND	ND	32,980	42,973	157,567
Czech Republic	Continental	0.40	ND	ND	ND	60,100	24,040	88,147
Denmark	Atlantic	0.40	ND	ND	ND	32,320	12,928	47,403
Estonia	Boreal	ND	ND	ND	ND	6,210	ND	ND
Finland	Boreal	ND	ND	ND	ND	7,020	ND	ND
France	Atlantic	0.40	ND	ND	ND	1,206,470	482,588	1,769,489
Germany	Continental	0.40	ND	ND	ND	263,270	105,308	386,129
Greece	Mediterranean	1.30	483,340	629,792	2,309,237	1,040,140	1,355,302	4,969,442
Hungary	Continental	0.40	65,000	26,000	95,333	214,430	85,772	314,497
Ireland	Atlantic	0.40	ND	ND	ND	2,530	1,012	3,711
Italy	Mediterranean	1.07	132,900	141,671	519,462	2,409,780	2,568,825	9,419,027
Latvia	Boreal	ND	ND	ND	ND	13,000	ND	ND
Lithuania	Boreal	ND	ND	ND	ND	44,120	ND	ND
Luxembourg	Continental	0.40	ND	ND	ND	1,670	668	2,449
Malta	Mediterranean	1.30	ND	ND	ND	1,650	2,150	7,883
Netherlands	Atlantic	0.40	ND	ND	ND	55,510	22,204	81,415
Poland	Continental	0.40	ND	ND	ND	777,230	310,892	1,139,937
Portugal	Mediterranean	1.30	32,950	42,934	157,424	895,590	1,166,954	4,278,830
Romania	Continental	0.40	ND	ND	ND	446,760	178,704	655,248
Slovakia	Continental	0.40	18,810	7,524	27,588	26,130	10,452	38,324
Slovenia	Continental	0.40	ND	ND	ND	37,080	14,832	54,384
Spain	Mediterranean	1.54	1,275,888	1,964,868	7,204,514	4,961,981	7,641,451	28,018,653
Sweden	Boreal	ND	ND	ND	ND	7,390	ND	ND
United Kingdom	Atlantic	0.40	ND	ND	ND	36,000	14,400	52,800
Total Europe			**2,008,888**	**2,812,789**	**10,313,559**	**12,905,081**	**14,186,143**	**52,015,859**

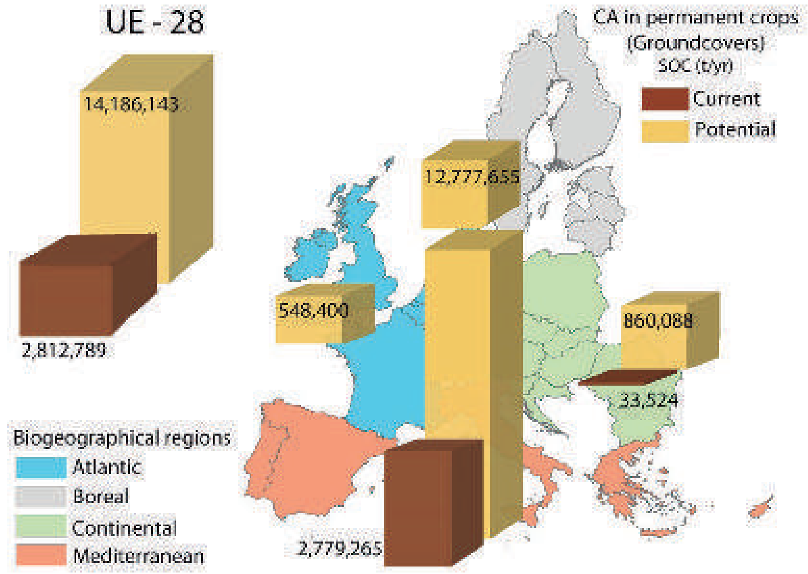
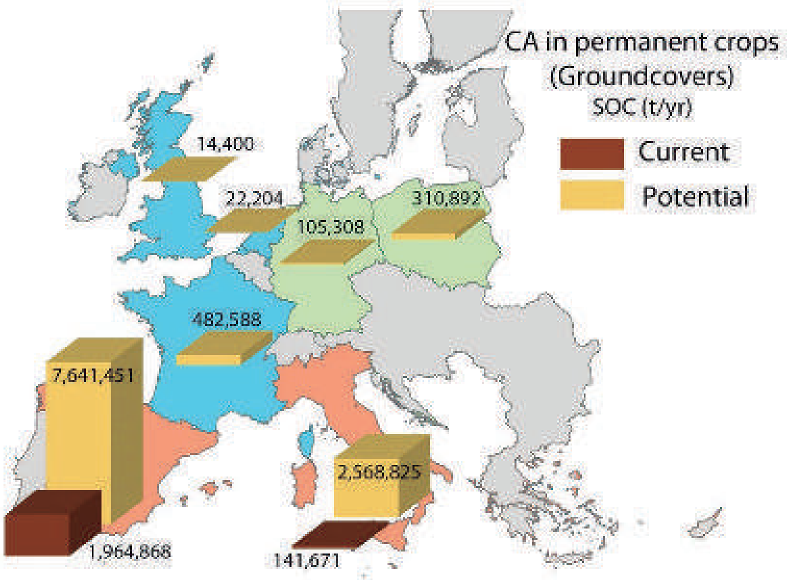


Fig. 4.8. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 4.9. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom.



4.6.2. CO_2 sequestration produced by carbon fixation

In order to estimate the sequestered CO_2 on the basis of the amount of organic C fixed in the soil, it has been taken into consideration that 1 ton of C generates 3.7 tons of CO_2 through microbiological oxidation processes that take place in the soil *(Tebruegge, 2001)*. Therefore, taking into account the increase in OC observed in CA systems in comparison with management systems based on tillage, it is possible to calculate, the amount of CO_2 which will not be emitted due to the implementation of conservation systems (Table 4.6) (Fig. 4.10).

Table 4.6. Current and potential fixation of CO_2 in Europe.

	Biogeographical region	Current CO_2 fixed through CA (t yr⁻¹)	Potential CO_2 fixed through CA (t yr⁻¹)	Increase CO_2 fixed through CA (Potential - current) (t yr⁻¹)
Austria	Continental	43,731	2,019,403	1,975,672
Belgium	Atlantic	320	782,291	781,971
Bulgaria	Continental	25,470	5,145,996	5,120,526
Croatia	Continental	28,619	1,432,719	1,404,101
Cyprus	Mediterranean	803	341,213	340,410
Czech Republic	Continental	63,010	3,752,510	3,689,499
Denmark	Atlantic	2,959	2,632,794	2,629,835
Estonia	Boreal	3,090	42,435	39,345
Finland	Boreal	14,667	140,265	125,599
France	Atlantic	220,000	14,358,615	14,138,615
Germany	Continental	232,617	17,723,982	17,491,365
Greece	Mediterranean	2,309,258	9,729,155	7,419,897
Hungary	Continental	103,051	5,809,954	5,706,902
Ireland	Atlantic	2,367	1,186,900	1,184,533
Italy	Mediterranean	1,322,806	26,374,586	25,051,780
Latvia	Boreal	832	80,788	79,956
Lithuania	Boreal	1,414	156,173	154,759
Luxembourg	Continental	679	96,532	95,853
Malta	Mediterranean	0	23,611	23,611
Netherlands	Atlantic	8,700	874,935	866,234
Poland	Continental	603,650	15,391,891	14,788,241
Portugal	Mediterranean	205,142	6,382,238	6,177,096
Romania	Continental	901,191	11,916,910	11,015,719
Slovakia	Continental	81,614	2,052,459	1,970,844
Slovenia	Continental	3,828	309,713	305,885
Spain	Mediterranean	9,134,893	52,947,794	43,812,901
Sweden	Boreal	1,160	170,474	169,314
United Kingdom	Atlantic	591,548	7,203,670	6,612,122
Total Europe		**15,907,420**	**189,080,005**	**173,172,585**

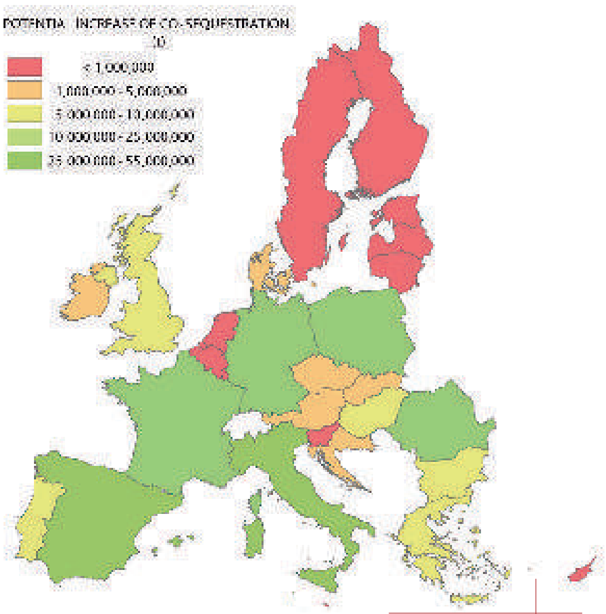


Fig. 4.10. Potential increase (potential – current) of CO_2 sequestration in Europe through CA.

4.6.3. Contribution to the commitments of the Paris Agreement

By signing the Paris Agreement, EU Member States have committed to reduce GHG emissions by at least 40% below 1990 levels by 2030. This reduction is intended to be achieved both through economic sectors that are part of the EU emissions trading system (the so-called ETS sectors) and, also, through the rest of economic sectors, which have more difficulties entering the EU emissions trading system (non-ETS sectors), including agriculture. And also, through the rest of economic sectors, which have more difficulties entering the EU emissions trading system (EU ETS), including agriculture. The EU-28 is committed to reduce GHG emissions in the non-ETS sectors by 30% below 2005 non-ETS sectors emission levels by 2030. This reduction commitment is not homogeneous, but each country has to apply a different percentage related to its non-ETS sectors emissions in 2005. See Table 2.4 in Chapter 2.

In the previous section (4.6.2.) it has been estimated the potential increase in CO_2 sequestration that can be achieved in EU-28 countries by shifting from the conventional farming system to Conservation Agriculture. Based on these figures it is possible to calculate to what extent the change in the agricultural system could contribute to achieving the Paris Agreement commitments, through carbon sequestration in the soil.

Calculations referred to in the previous paragraph are presented in Table 4.7, where two different percentages are shown in the last two columns:

- Data displayed in the penultimate column shows the relationship between potential CO_2 sequestration through CA and the reduction of emissions that must be achieved in the non-ETS sectors by 2030 (Fig. 4.11). In some countries (Croatia, Hungary, Poland and Romania) the implementation of CA would not only mean achieving the established reduction targets of non-ETS sectors, but also producing extra carbon sequestration. In general, the application of CA to the entire European agricultural area suitable for the implementation of this system would help to achieve around 22% of reductions by 2030.
- In the last column it is presented the percentage that CO_2 sequestration that would be reached

Table 4.7. Existing relationship between CO_2 sequestration that would occur in the soil when conventional farming system is substituted by Conservation Agriculture on the entire surface, and the emission reduction to be achieved in the non-ETS sectors by 2030. And with respect to Non-ETS emissions allowed by 2030.

	(A) Non-ETS emissions allowed by 2030 (t yr^{-1})	(B) Reduction of emissions by 2030 from non-ETS compared to 2005 (t yr^{-1})	(C) Potential of CO_2 fixed through CA (t yr^{-1})	Percentage of (C) over (B) (%)	Percentage of (C) over (A) (%)
Austria	36,268,800	20,401,200	2,019,403	9.90	5.57
Belgium	50,830,000	27,370,000	782,291	2.86	1.54
Bulgaria	24,570,000	0	5,145,996	-	20.94
Croatia	15,642,600	1,177,400	1,432,719	121.69	9.16
Cyprus	3,176,800	1,003,200	341,213	34.01	10.74
Czech Republic	53,793,000	8,757,000	3,752,510	42.85	6.98
Denmark	24,448,800	15,631,200	2,632,794	16.84	10.77
Estonia	4,724,100	705,900	42,435	6.01	0.90
Finland	20,496,000	13,104,000	140,265	1.07	0.68
France	249,221,700	146,368,300	14,358,615	9.81	5.76
Germany	290,432,800	178,007,200	17,723,982	9.96	6.10
Greece	51,895,200	9,884,800	9,729,155	98.43	18.75
Hungary	43,133,400	3,246,600	5,809,954	178.96	13.47
Ireland	33,264,000	14,256,000	1,186,900	8.33	3.57
Italy	220,523,800	108,616,200	26,374,586	24.28	11.96
Latvia	8,008,800	511,200	80,788	15.80	1.01
Lithuania	9,809,800	970,200	156,173	16.10	1.59
Luxembourg	6,078,000	4,052,000	96,532	2.38	1.59
Malta	834,300	195,700	23,611	12.06	2.83
Netherlands	78,643,200	44,236,800	874,935	1.98	1.11
Poland	163,689,300	12,320,700	15,391,891	124.93	9.40
Portugal	41,109,900	8,420,100	6,382,238	75.80	15.52
Romania	71,569,400	1,460,600	11,916,910	815.89	16.65
Slovakia	19,624,000	2,676,000	2,052,459	76.70	10.46
Slovenia	10,072,500	1,777,500	309,713	17.42	3.07
Spain	173,041,600	60,798,400	52,947,794	87.09	30.60
Sweden	25,740,000	17,160,000	170,474	0.99	0.66
United Kingdom	261,267,300	153,442,700	7,203,670	4.69	2.76
Total Europe	1,991,909,100	856,550,900	189,080,005	22.07	9.49

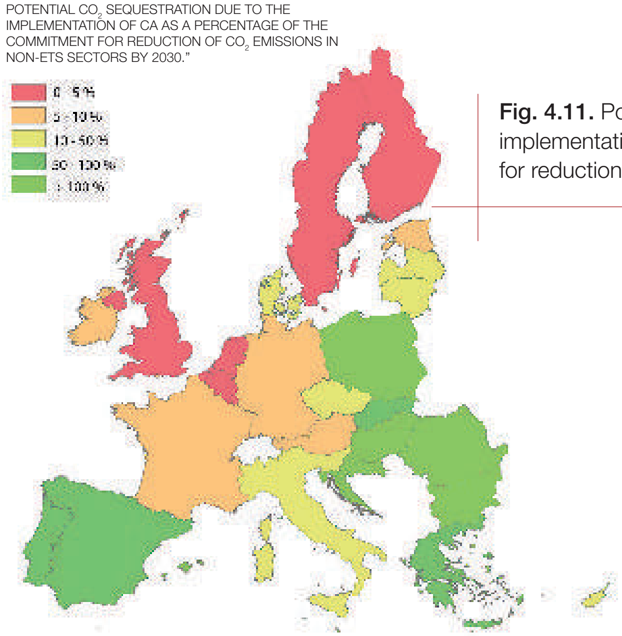


Fig. 4.11. Potential CO_2 sequestration due to the implementation of CA as a percentage of the commitment for reduction of CO_2 emissions in non-ETS sectors by 2030.

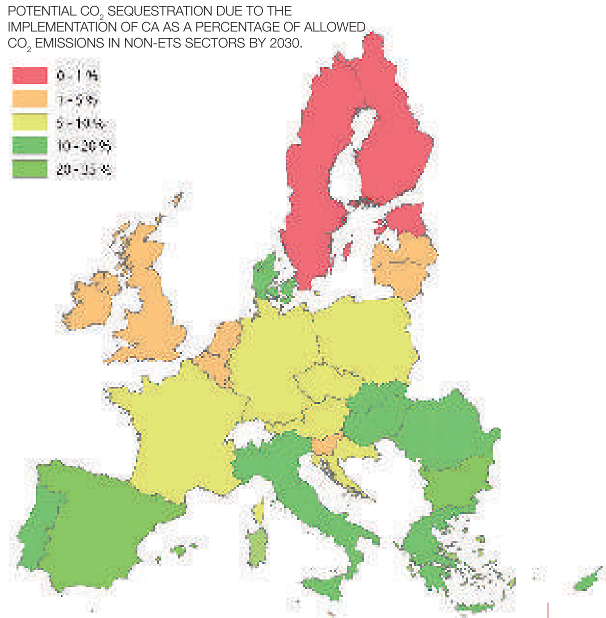


Fig. 4.12. Potential CO_2 sequestration due to the implementation of CA as a percentage of allowed CO_2 emissions in non-ETS sectors by 2030.

thorugh the implementation of CA over the EU-28 agricultural area suitable for this agricultural system would represent in relation to the overall allowed emissions in the non-ETS sectors by 2030 (Fig. 4.12). The amount of CO_2 fixed in the agricultural soils would allow countries to achieve their Paris Agreement reduction targets by 2030 more easily. At European level, CO_2 sequestration thanks to the implementation of CA would account for almost 10% of the maximum emissions allowed, what could give some scope for reducing emissions in other non-ETS sectors, such as housing, transport, etc.

Similarly to the information showed in Table 4.7 for non-ETS sectors, in Table 4.8 the potential increase in CO_2 sequestration that can be achieved in EU- 28 countries by shifting from the conventional farming system to Conservation Agriculture is linked to the commitments of the Paris Agreement in agriculture. As can be seen, at European level, the shift to CA not only allows to reach the commitment of European CO_2 emissions reduction in agriculture, but also achieves an important potential (almost 50% of commited reduction for agriculture) to offset emissions from other sectors. This reduction is not homogeneous. There are countries where the overall implementation of CA would allow agriculture to become a climate change mitigating sector (more than 100% in percentage of C over B) and others, where agriculture would continue to be an emitting sector (less than 100%).

Table 4.8. Comparison of potential CO_2 sequestration due to the shift from conventional tillage to Conservation Agriculture in all the surface suitable for CA with the reduction of emissions to be achieved in agriculture by 2030 and with emissions allowed in agriculture by 2030.

	(A) Agriculture emissions allowed by 2030 (t yr^{-1})	(B) Reduction of emissions by 2030 from agriculture compared to 2005 (t yr^{-1})	(C) Potential of CO_2 fixed through CA (t yr^{-1})	Percentage of (C) over (B) (%)	Percentage of (C) over (A) (%)
Austria	4,490,925	2,526,145	2,019,403	79.94	44.97
Belgium	6,658,594	3,585,397	782,291	21.82	11.75
Bulgaria	5,023,300	0	5,145,996	-	102.44
Croatia	2,745,193	206,627	1,432,719	693.38	52.19
Cyprus	478,982	151,258	341,213	225.58	71.24
Czech Republic	7,168,014	1,166,886	3,752,510	321.58	52.35
Denmark	6,689,114	4,276,646	2,632,794	61.56	39.36
Estonia	942,410	140,820	42,435	30.13	4.50
Finland	3,912,424	2,501,386	140,265	5.61	3.59
France	49,444,259	29,038,692	14,358,615	49.45	29.04
Germany	39,010,096	23,909,414	17,723,982	74.13	45.43
Greece	7,366,405	1,403,125	9,729,155	693.39	132.07
Hungary	5,698,594	428,926	5,809,954	1354.53	101.95
Ireland	13,434,533	5,757,657	1,186,900	20.61	8.83
Italy	22,193,214	10,930,986	26,374,586	241.28	118.84
Latvia	2,134,561	136,249	80,788	59.29	3.78
Lithuania	3,410,207	337,273	156,173	46.30	4.58
Luxembourg	382,272	254,848	96,532	37.88	25.25
Malta	83,349	19,551	23,611	120.76	28.33
Netherlands	11,997,722	6,748,718	874,935	12.96	7.29
Poland	27,269,572	2,052,548	15,391,891	749.89	56.44
Portugal	6,057,033	1,240,597	6,382,238	514.45	105.37
Romania	19,361,527	395,133	11,916,910	3015.92	61.55
Slovakia	2,740,038	373,642	2,052,459	549.31	74.91
Slovenia	1,514,675	267,296	309,713	115.87	20.45
Spain	28,184,195	9,902,555	52,947,794	534.69	187.86
Sweden	4,337,202	2,891,468	170,474	5.90	3.93
United Kingdom	28,862,234	16,950,836	7,203,670	42.50	24.96
Total Europe	**311,590,642**	**127,594,678**	**189,080,005**	**148.19**	**60.68**

4.7. Mitigation summary sheets

4.7.1. Europe

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	90,871,405 ha
	CA IN ANNUAL CROPS SURFACE:	3,162,733 ha
	CURRENT SOC FIXATION:	1,525,598 t yr^{-1}
	POTENTIAL SOC FIXATION:	37,381,131 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	12,905,081 ha
	CA IN PERMANENT CROPS SURFACE:	2,008,888 ha
	CURRENT SOC FIXATION:	2,812,789 t yr^{-1}
	POTENTIAL SOC FIXATION:	14,186,143 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	4,338,387 t yr^{-1}
	POTENTIAL SOC FIXATION:	51,567,274 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	15,907,420 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	189,080,005 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	173,223,524 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 -EQ BY 2030 COMPARE TO 2005:	856,550,900 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	22.07 %
	NON-ETS GHG EMISSIONS BY 2030:	1,991,909,100 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	9.49 %

4.7.2. France

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	17,166,990 ha
	CA IN ANNUAL CROPS SURFACE:	300,000 ha
	CARBON FIXATION RATE:	0.20 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	60,000 t yr^{-1}
	POTENTIAL SOC FIXATION:	3,433,398 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	1,206,470 ha
	CA IN PERMANENT CROPS SURFACE:	ND
	CARBON FIXATION RATE:	0.40 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	ND
	POTENTIAL SOC FIXATION:	482,588 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	60,000 t yr^{-1}
	POTENTIAL SOC FIXATION:	3,915,986 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	220,000 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	14,358,615 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	14,138,615 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	146,368,300 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	9.81 %
	NON-ETS GHG EMISSIONS BY 2030:	249,221,700 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	5.76 %

4.7.3. Germany

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	10,904,310 ha
	CA IN ANNUAL CROPS SURFACE:	146,300 ha
	CARBON FIXATION RATE:	0.43 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	63,441 t yr^{-1}
	POTENTIAL SOC FIXATION:	4,833,813 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	263,270 ha
	CA IN PERMANENT CROPS SURFACE:	ND
	CARBON FIXATION RATE:	0.40 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	ND
	POTENTIAL SOC FIXATION:	105,308 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	63,441 t yr^{-1}
	POTENTIAL SOC FIXATION:	4,833,813 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	232,617 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	17,723,982 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	17,491,365 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	178,007,200 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	9.96 %
	NON-ETS GHG EMISSIONS BY 2030:	290,432,800 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	6.10 %

4.7.4. Italy

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	5,992,540 ha
	CA IN ANNUAL CROPS SURFACE:	283,823 ha
	CARBON FIXATION RATE:	0.77 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	219,094 t yr^{-1}
	POTENTIAL SOC FIXATION:	4,624,243 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	2,409,780 ha
	CA IN PERMANENT CROPS SURFACE:	132,900 ha
	CARBON FIXATION RATE:	1.07 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	141,671 t yr^{-1}
	POTENTIAL SOC FIXATION:	2,568,825 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	360,765 t yr^{-1}
	POTENTIAL SOC FIXATION:	7,193,069 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	1,322,806 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	26,374,586 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	25,051,780 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	108,616,200 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	24.28 %
	NON-ETS GHG EMISSIONS BY 2030:	220,523,800 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	11.96 %

4.7.5. Netherlands

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	670,360 ha
	CA IN ANNUAL CROPS SURFACE:	7,350 ha
	CARBON FIXATION RATE:	0.32 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	2,373 t yr^{-1}
	POTENTIAL SOC FIXATION:	216,415 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	55,510 ha
	CA IN PERMANENT CROPS SURFACE:	ND
	CARBON FIXATION RATE:	0.40 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	ND
	POTENTIAL SOC FIXATION:	22,204 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	2,373 t yr^{-1}
	POTENTIAL SOC FIXATION:	238,619 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	8,700 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	874,935 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	866,234 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	44,236,800t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	1.98 %
	NON-ETS GHG EMISSIONS BY 2030:	78,643,200 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	1.11 %

4.7.6. Poland

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	9,518,930 ha
	CA IN ANNUAL CROPS SURFACE:	403,180 ha
	CARBON FIXATION RATE:	0.41 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	164,632 t yr^{-1}
	POTENTIAL SOC FIXATION:	3,886,896 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	777,230 ha
	CA IN PERMANENT CROPS SURFACE:	ND
	CARBON FIXATION RATE:	0.40 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	ND
	POTENTIAL SOC FIXATION:	310,892 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	164,632 t yr^{-1}
	POTENTIAL SOC FIXATION:	4,197,788 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	603,650 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	15,391,891 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	14,788,241 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	12,320,700 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	124.93 %
	NON-ETS GHG EMISSIONS BY 2030:	163,689,300 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	9.40 %

4.7.7. Spain

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	7,998,655 ha
	CA IN ANNUAL CROPS SURFACE:	619,373 ha
	CARBON FIXATION RATE:	0.85 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	526,467 t yr^{-1}
	POTENTIAL SOC FIXATION:	6,798,857 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	4,961,981 ha
	CA IN PERMANENT CROPS SURFACE:	1,275,888 ha
	CARBON FIXATION RATE:	1.54 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	1,964,868 t yr^{-1}
	POTENTIAL SOC FIXATION:	7,641,451 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	2,491,335 t yr^{-1}
	POTENTIAL SOC FIXATION:	14,440,307 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	9,134,893 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	52,947,794 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	43,812,901 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	60,798,400 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	87.09 %
	NON-ETS GHG EMISSIONS BY 2030:	173,041,600 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	30.60 %

4.7.8. United Kingdom

CONSERVATION AGRICULTURE IN ANNUAL CROPS		
	ANNUAL CROPS SURFACE:	4,376,000 ha
	CA IN ANNUAL CROPS SURFACE:	362,000 ha
	CARBON FIXATION RATE:	0.45 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	161,331 t yr^{-1}
	POTENTIAL SOC FIXATION:	1,950,237 t yr^{-1}
CONSERVATION AGRICULTURE IN PERMANENT CROPS		
	PERMANENT CROPS SURFACE:	36,000 ha
	CA IN PERMANENT CROPS SURFACE:	ND
	CARBON FIXATION RATE:	0.40 t ha^{-1} yr^{-1}
	CURRENT SOC FIXATION:	ND
	POTENTIAL SOC FIXATION:	14,400 t yr^{-1}
CONSERVATION AGRICULTURE		
	CURRENT SOC FIXATION:	161,331 t yr^{-1}
	POTENTIAL SOC FIXATION:	1,964,637 t yr^{-1}
	CURRENT CO_2 SEQUESTRATION:	591,548 t yr^{-1}
	POTENTIAL CO_2 SEQUESTRATION:	7,203,670 t yr^{-1}
	POTENTIAL INCREASE OF CO_2 SEQUESTERED:	6,612,122 t yr^{-1}
COMMITMENT OF PARIS AGREEMENT		
	REDUCTION OF NON-ETS EMISSIONS OF CO_2 - EQ BY 2030 COMPARE TO 2005:	153,442,700 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	4.69 %
	NON-ETS GHG EMISSIONS BY 2030:	261,267,300 t yr^{-1}
	POTENTIAL SEQUESTRATION THROUGH CONSERVATION AGRICULTURE:	2.76 %

4.8. References

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