Conservation Agriculture: Making Climate Change Mitigation and Adaptation Real in Europe

ECAF

European Conservation Agriculture Federation

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Executive summary

Agriculture and climate change are closely related. In this report, the European Conservation Agriculture Federation (ECAF) offers its experience and knowledge on how the agricultural sector can respond to climate change through Conservation Agriculture (CA). This experience is based on the development of several European (LIFE) public-funded projects based on the implementation of CA in Europe, and on a literature review on the topic. This document aims to serve as a basis for decision-making based on science and agricultural experimentation in Europe.

Climate change and agriculture

The study of climate is a complex field of investigation and in constant evolution but, since it is influenced by a great number of factors, it is not a static system and therefore it is difficult to forecast its future potential impacts with precision (Fig. 1). However, it is obvious that climate is undergoing rapid changes, where socio-economic development is not corresponding to the limited natural resources. Thus, one of the greatest challenges is to respond to the need to produce enough food, feed and fiber in a sustainable way while satisfying the needs for a growing world population in a changing climate. Agricultural production, and therefore food security, is strongly influenced by changes in rainfall and temperature patterns and other climatic conditions.

In terms of contribution, approximately 10% of greenhouse gases (GHGs) globally emitted come from the European Union (EU). Of these GHGs emitted in Europe, around 10% come from agriculture, which is the fourth largest emitter in the EU after the energy production, transport and industrial combustion sectors. In order to slow down these emissions, the 21st meeting of the Conference of the Parties (COP21) and the 11th meeting of the Conference of the Parties was celebrated at the end of 2015, serving as the *meeting of the Parties with respect to the Kyoto Protocol* (CMP). It concluded with the adoption of a historic agreement to combat climate change and promote measures and investments for a low-carbon, resilient and sustainable future, the so-called Paris Agreement.

Agriculture is a fundamental sector that provides food for both people and animals, produces fibers for the textile sector, and many other products and services essential for the existence of humanity. Like any other economic activity, agriculture is linked to the natural and social environment in which it is developed, and interacts with it. If there is any productive activity that depends directly on the climate and its variability, this is undoubtedly agriculture. A change of temperature and precipitation, or an increase in the concentration of atmospheric CO_2, will significantly affect crop development and performance. At a global level, it is estimated that climate variability is responsible for between 32% and 39% of the variability in yields, an effect that is probably even more pronounced in many regions of Southern Europe.

Today, a multidimensional approach it is essential for measuring agricultural sustainability in order to achieve a balance between preservation and improvement of the environment, social equity and economic viability, and therefore improve the welfare of society. Scientific studies carried out in different agro-ecological regions and countries agree that the less soil is tilled, the more carbon is absorbed and stored in it. Plants absorb carbon dioxide from the air and transform it through the process of photosynthesis into organic carbon. This organic carbon becomes the source for soil organic matter, contributing thus to an enhanced soil fertility and to an improved productive capacity. On the other hand, any action aimed at saving energy and fuel, such as reducing the number of tillage operations, optimizing the use of agricultural inputs and proper execution of operations, directly reduces emissions of greenhouse gases. Therefore, a sustainable agricultural system that responds to these requirements is of particular importance: Conservation Agriculture.

What is Conservation Agriculture?

The principles of Conservation Agriculture are as follows (Fig. 2):

- No or minimum soil mechanical disturbance. In practice, this means no-till seeding and weeding.
- Permanent soil cover. In other words, it means to maintain crop residues and 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

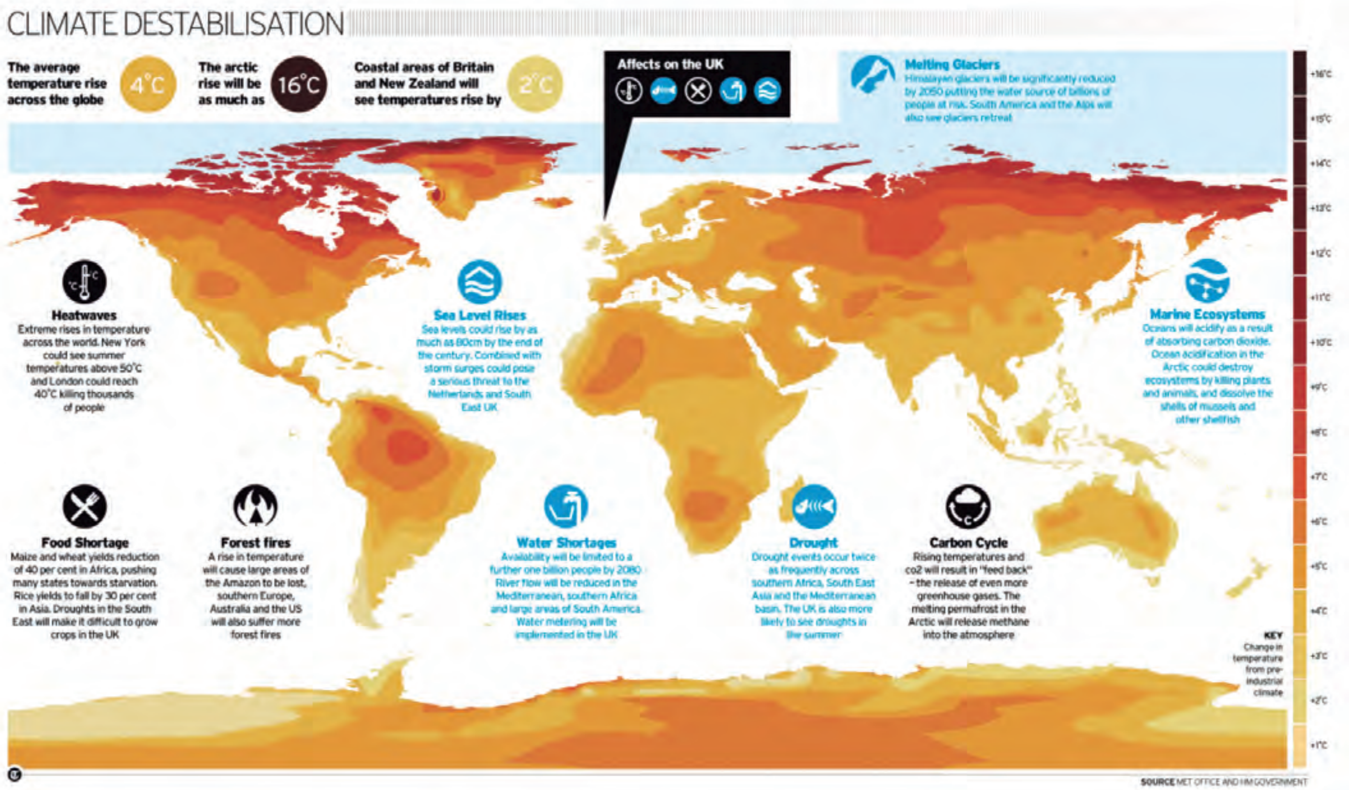


Fig. 1. Global impacts of climate change.

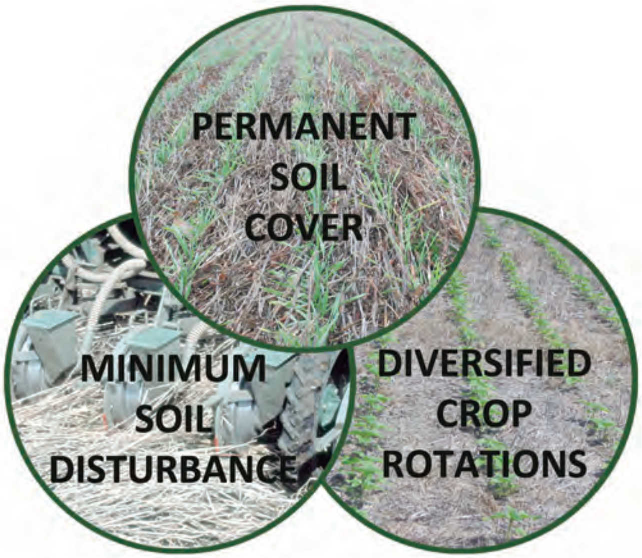


Fig. 2. Principles and benefits of Conservation Agriculture.

For every hectare converted to CA in Europe the emissions of a return flight from London to Athens are removed from the atmosphere.

the soil is limited. 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.

- Cropping system diversification through rotations, sequences and associations involving annuals and perennials. 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.

Conservation Agriculture as an integrated approach towards sustainability

Conservation Agriculture offers a considerable environmental improvement of the agricultural ecosystems, without reducing yields. Almost 20% of the European surface suffers soil losses exceeding 10 tons per hectare per year. Taking into account the low rate of soil formation, losses greater than 1 ton per hectare per year can be considered as irreversible. Conservation Agriculture reduces soil erosion by up to 90% compared to conventional tillage, thus reducing soil degradation.

Comparing Conservation Agriculture to tillage based agriculture, the latter increases emissions of CO_2 into the atmosphere, reducing the content of organic matter of the soil, and therefore affecting its quality and fertility. The implementation of Conservation Agriculture leads to the significant improvement of soil physical and chemical properties resulting in a much better soil structure, increases in soil organic matter (CO_2 sequestration) and biodiversity, improved water infiltration and water holding capacity and reduced runoff and direct evaporation from the soil, thus improving the efficiency of water use and the quality of the water (Table 1).

Table 1. Main environmental benefits of Conservation Agriculture.

For the soil	Reduced erosion
	Increase in soil organic matter
	Improvement of structure and porosity
	Greater biodiversity
	Increased soil fertility
For the air	Fixation of atmospheric carbon in the soil
	Reduced CO_2 emissions into the atmosphere
For the water	Reduced runoff
	Better quality
	Increased water holding capacity

Conservation Agriculture has a double effect on the reduction of greenhouse gases concentration in the atmosphere. On the one hand, the changes introduced by CA (more biomass in form of crop residues and cover crops), increase the carbon content in the soil through higher organic carbon inputs (Fig. 3). And, on the other hand, the drastic reduction of tillage operations along with the minimal mechanical soil disturbance, lead to reduction of the CO_2 emissions resulting from energy savings through less fuel consumption, and the reduction of the mineralization processes of the organic matter.

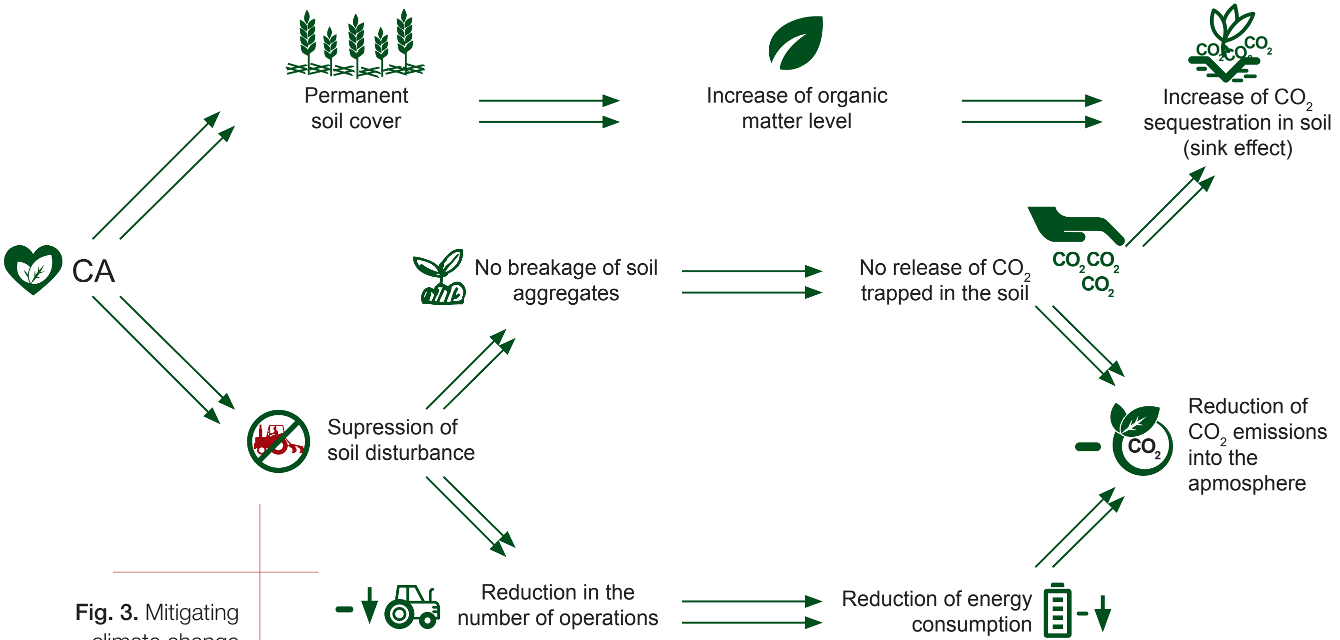


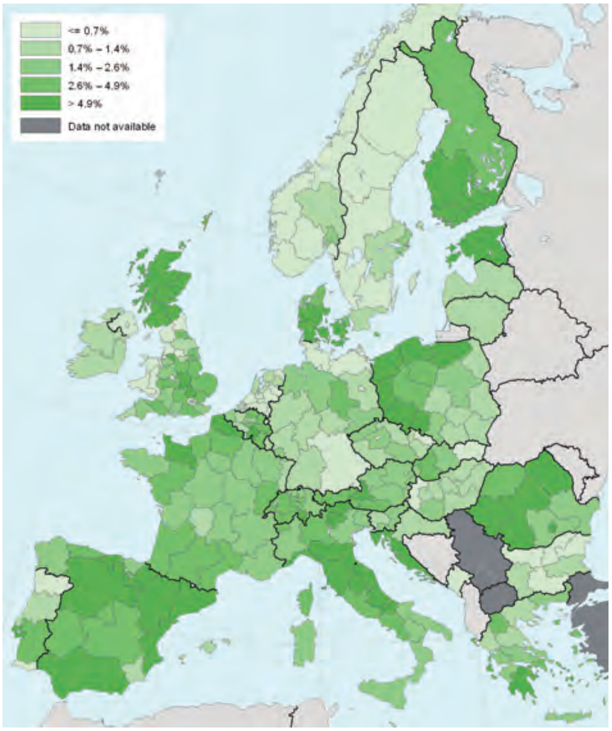
Fig. 3. Mitigating climate change mechanisms through Conservation Agriculture.

Adopting Conservation Agriculture

Conservation Agriculture is one of the most studied agro-sciences in the world, as is practiced on almost 160 million hectares according to FAO. Today, CA is performed in annual crops applying the principles of no-tillage, permanent organic soil cover and crop rotations, while in permanent crops, the CA approach is based on groundcovers between the tree crop rows. CA in annual crops is widespread around the world (Fig. 4), being its adoption rather heterogeneous in Europe (Fig. 5).

Fig. 4. Worldwide no-tillage adoption.

Fig. 5. Share by European regions of annual crops on which no-tillage is applied.



Soil organic carbon fixation through Conservation Agriculture

Different studies in Europe show that during several years of the application of CA principles it is possible to sequester large amounts of CO_2 per hectare and year in annual crops, compared to tillage-based systems. The estimation for EU-28 countries of the potential soil organic carbon (SOC) sequestration through the adoption of CA in annual crops when compared to conventional tillage systems is given in the Table 2.

Table 2. 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**

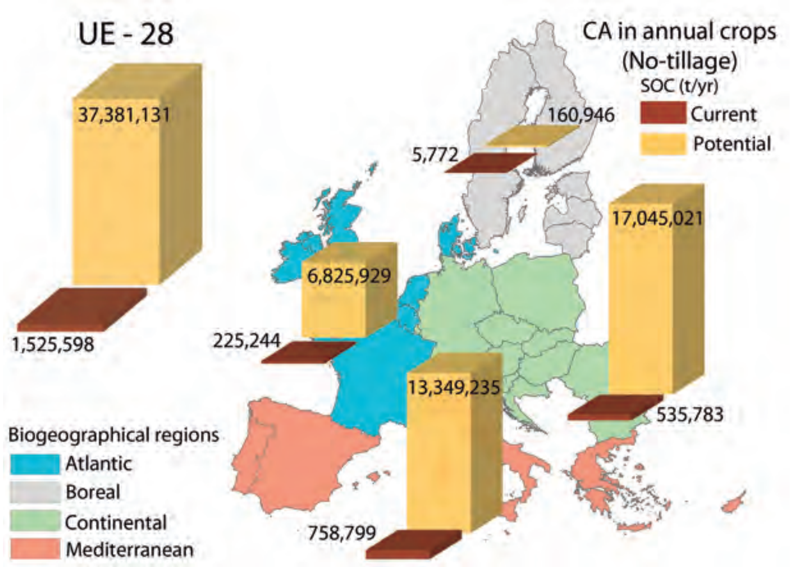
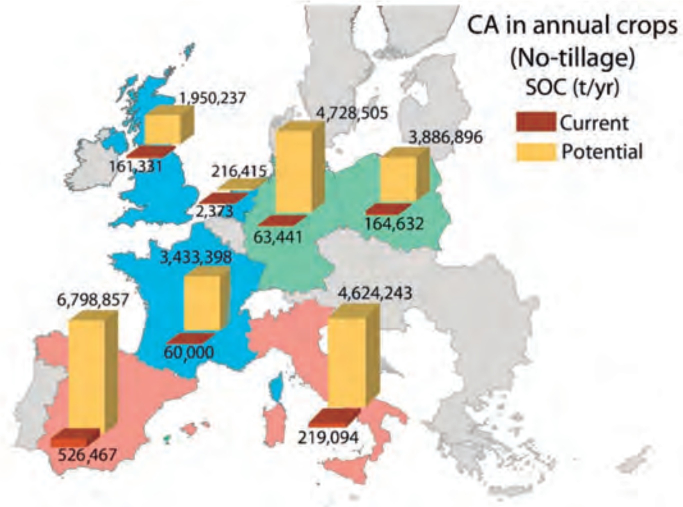


Fig. 6. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 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.



These SOC fixation data are represented by maps for the different biogeographic regions (Fig. 6) as well as for 7 countries in particular (France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom) (Fig. 7).

In relation to CA in permanent crops (groundcovers), there are no official data for Europe as a whole. Due to that, the data of the adoption of this practice derive from reports of the European national associations of Conservation Agriculture. The available scientific data for carbon sequestration, except for France, only address the Mediterranean biogeographic region. However, with due caution, a calculation of the carbon sequestration potential for EU-28 is provided in Table 3.

Table 3. 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})	Groundcover 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**

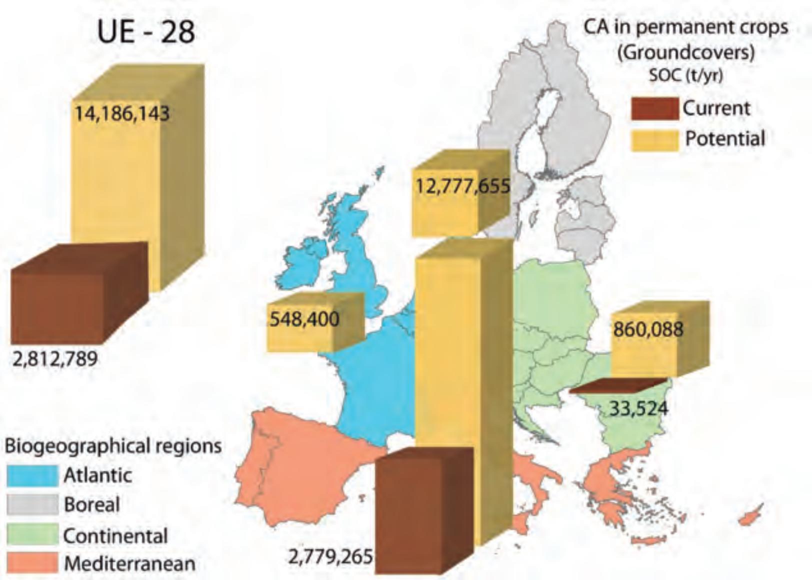
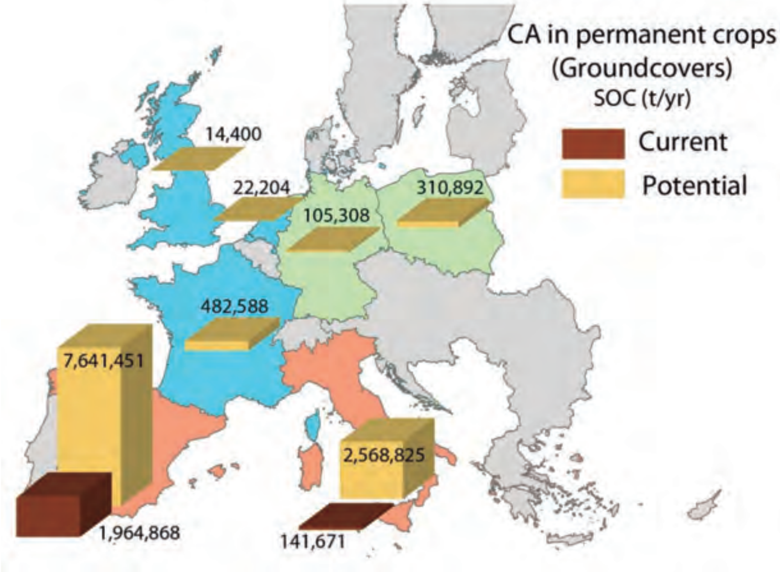


Fig. 8. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 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.



These SOC fixation data are represented by maps for the different biogeographic regions (Fig. 8) as well as for 7 countries in particular (France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom) (Fig. 9).

In order to quantify the CO_2 emission reduction achievable through the values of organic C sequestered in the soil and not released through the microbiological oxidation processes of organic matter, we are using the ratio of 3.7 tons of CO_2 that are generated from 1 ton of C. Therefore, taking into account the increase in soil organic matter (SOM) observed in CA systems (both annual crops and groundcovers in permanent crops) in comparison to the management systems based on tillage, it is possible to calculate the total CO_2 emission offset potential through the implementation of CA in Europe (Table 4).

Implementation of CA in Europe would reduce as much emissions as the closure of 50 coal-fired power plants.

Table 4. 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**

Commitments within the Paris Agreement

The Paris Agreement pursues to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty. To comply with the 40% target compared to 1990, an Emission Reduction is planned in two areas:

- Reduction of 43% compared to 2005 emissions in sectors belonging to the EU Emissions Trading Scheme (ETS).
- Reduction of 30% compared to 2005 emissions in sectors outside the EU ETS (non-ETS) system.

Agriculture is included within the second, counting the reduction of its emissions, within the binding objectives to which each of the Member States has committed (Fig. 10).

The amount of CO_2 sequestered in the soil through the application of the CA, would reach the targets committed by 2030 with greater ease. Considering overall European figures, carbon sequestration that could take place on farm land under Conservation Agriculture would help achieve around 22% of the necessary reductions in the non-ETS sectors by 2030, and almost 10% of the total emissions still allowed in the non-ETS sectors. This achievement would could give the signing member countries some margin in the emission reduction in other sectors such as housing or transport.

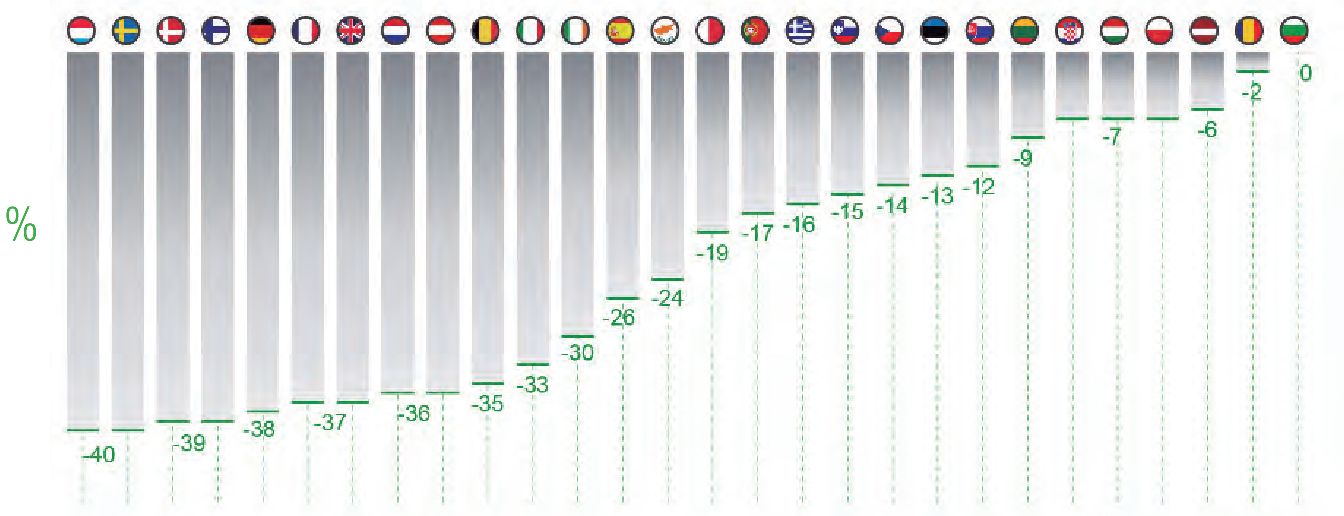


Fig. 10. Percentage reduction of national emissions in sectors outside the EU ETS (non-ETS).

Table 5. 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

Key tools for Conservation Agriculture

Machinery

Since Conservation Agriculture avoids tillage, it is necessary to have adequate equipment to establish the crops in conditions with abundant plant residues. Therefore the development specific machinery, especially for seeding, has had special relevance in the implementation of CA. One of the keys to success in Conservation Agriculture are the direct seeders (no-till drills) and its features, which allow farmers to establish the crops successfully under the divers conditions soil types of soils groundcovers. In general, no-till drills 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 amply fertilizers and plant protection products simultaneously.
- Resistance of its elements to withstand heavy duty conditions.

Plant protection

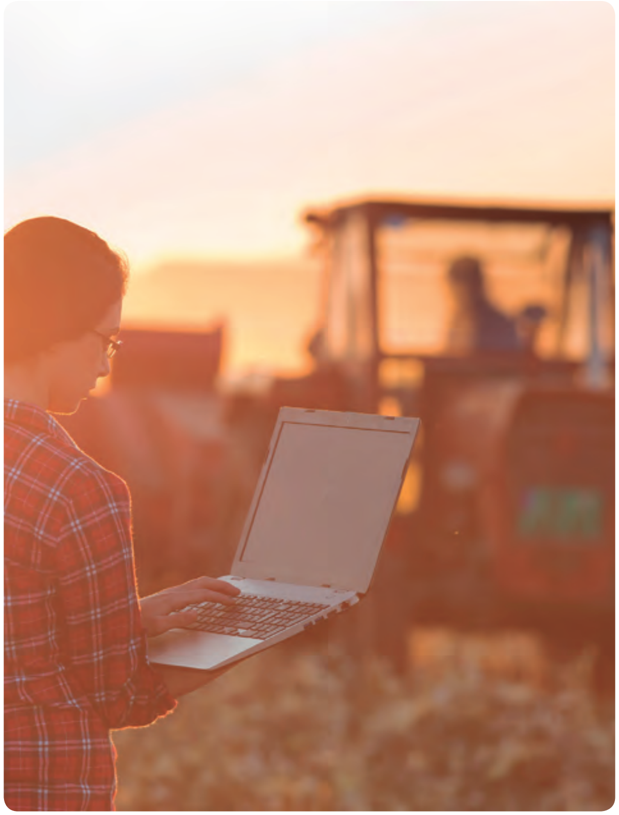
Conservation Agriculture principles, namely crop diversity and rotation and enhanced soil and aboveground biodiversity, help control weeds, pest and diseases. However, some applications of crop protection products may be needed during the season. The numerous plough passes performed in tillage-based agriculture are replaced by an optimized use of phytosanitary treatments. For that reason, herbicides have been, and remain, a crucial element in the development of CA systems. The active ingredients used in the pre-seeding weed control are diverse, but normally glyphosate alone or in combination with other herbicides, such as hormonal ones are a common choice among farmers. Glyphosate controls many weeds and leaves no residue in the soil that could prevent or delay seeding. The low toxicological characteristics of this herbicide, its excellent weed control, and the easy availability of numerous brands commercialized by many companies -since its patent expired in 2000- make treatments with this active ingredient safe, inexpensive and well-known all around the world. Without glyphosate the maintenance and spread of the area under CA in Europe would be at risk, or would depend on the use of other herbicides with a less favourable ecotoxicological profile and at a higher cost to the farmers. It is also important to stress that the application of any plant protection product in CA is much safer when compared to the application in conventional agriculture, as the risk of any off-site transport is much lower and the degradation rate of the products applied is enhanced due to a much higher soil microbial activity.

Facts and figures

Calculations for the following “facts and figures” are based on the total European CO_2 sequestration potential (189 Mt ha^{-1} yr^{-1}) and on the average CO_2 sequestration rate per hectare (1.82 t ha^{-1} yr^{-1}) that could be achieved in Europe by shifting from conventional tillage to Conservation Agriculture the whole European area suitable for CA (103 Mha).

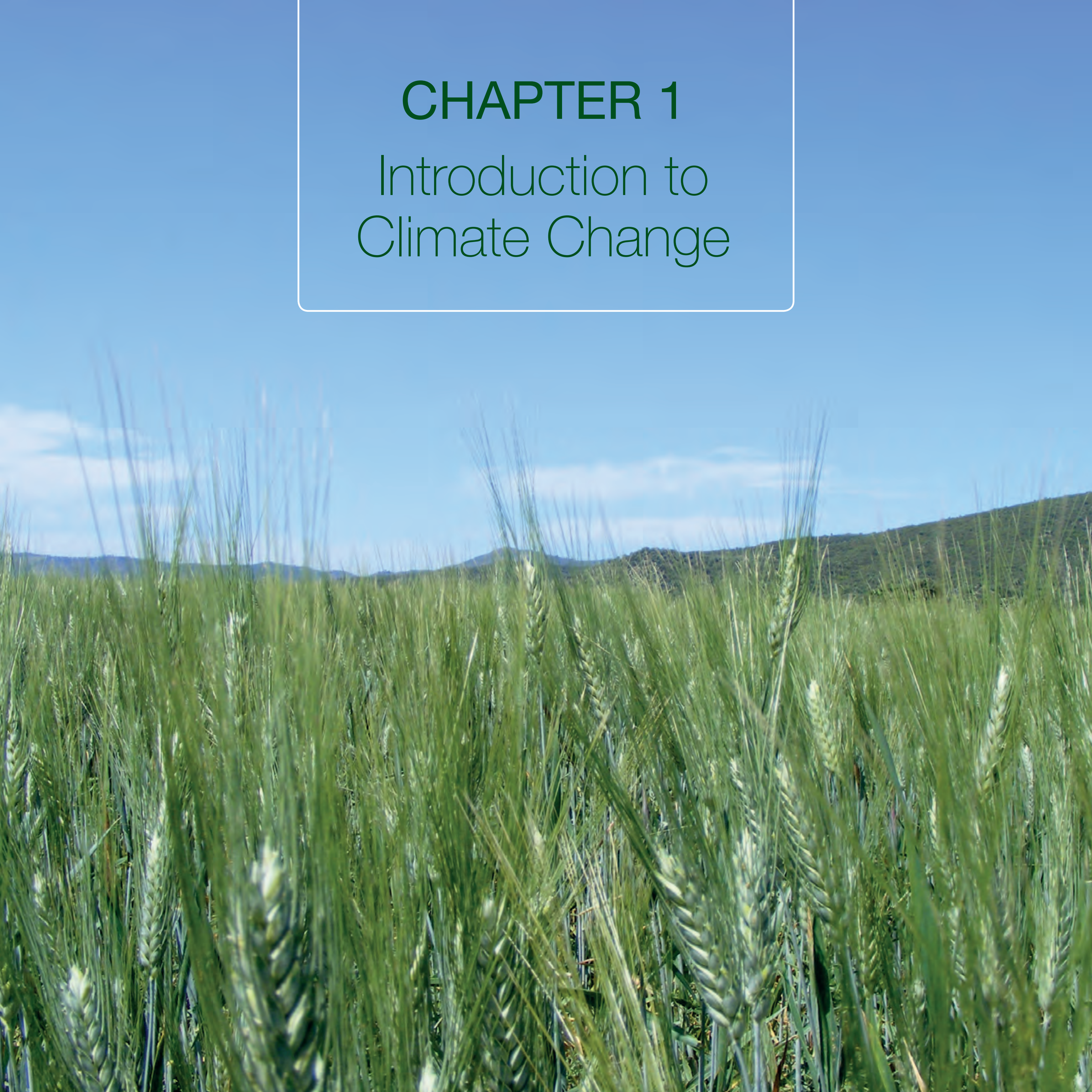
- Just 4 hectares under CA would negate the average annual emissions of a European citizen. (1)
- One hectare under CA would compensate emissions equivalent to 14 car journeys from Paris to Berlin. (2)
- Adoption of CA across Europe would sequester the CO_2 emitted by 18 million households. Or the emissions from electricity generation for 25 million households. (3)
- The carbon sequestration due to the adoption of CA across Europe would be equivalent to the emissions saving obtained by the installation of over 43,000 wind turbines. (3)
- Implementation of CA in Europe would reduce as much emissions as the closure of 50 coal-fired power plants. (3)
- If all European farmland was converted to CA, it would reduce atmospheric carbon by as much as planting 65 million hectares of forest. (3)
- For every hectare converted to CA in Europe the emissions of a return flight from London to Athens are removed from the atmosphere. (2)

According to: (1) Eurostat; (2) Naturefund CO_2 Calculator; (3) EPA Greenhouse Gas Equivalencies Calculator.



CHAPTER 1

Introduction to Climate Change



1.1. Introduction

The study of climate is a complex field of investigation which is in constant evolution due to the large number of factors involved. Therefore, it is not a static system which makes it difficult to determine its effects. Any circumstance that induces temporal and / or spatial fluctuations of one or several components of the climate will cause climatic variation regionally and globally, leading to climate change. As a result of changes in the energy balance, the climate has been subject to variations on all time scales, from decades to thousands and millions of years. There is a scientific, almost generalized consensus, that alterations of the energy consumption and our way of production are generating a global climatic variation, causing not only environmental effects on Earth but also making serious impacts on countries' socio-economic systems.

In recent years, the changes that climate conditions are experiencing and their consequences were some of the most common topics. However, our planet has experienced climate variability not always provoked by human activity, such as the global warming that occurred during the Jurassic Period with average temperatures of 5 ºC above the current ones, the Pleistocene glaciations, where great parts of North America, Europe and North Asia were covered with a thick layer of ice and, more recently, the so-called Little Ice Age that occurred from the 14^{th} to the 19^{th} century.

Climate change is a significant and lasting permutation of local or global climate patterns. The causes that affect

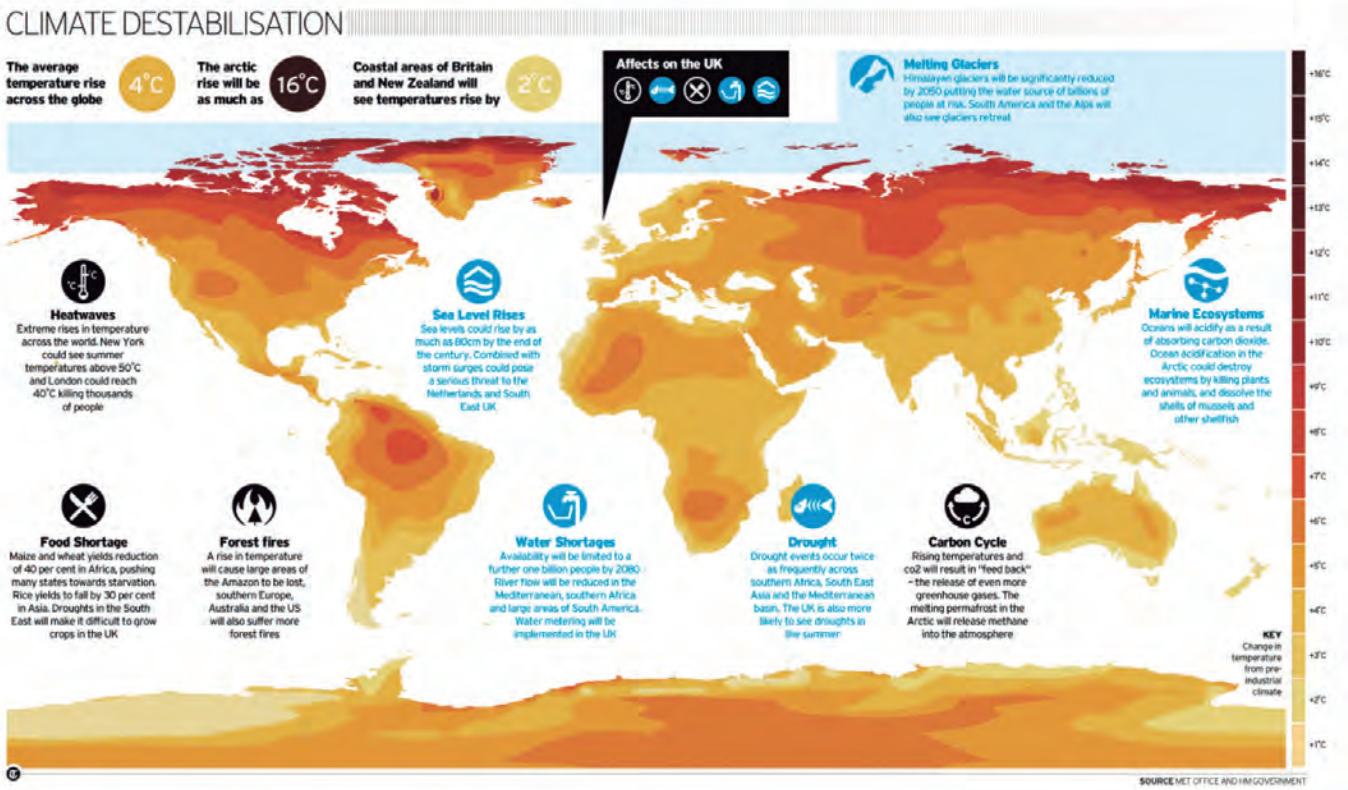


Fig. 1.1. Global impacts of climate change. *Met Office, 2009.*

climate can be natural (energy variations of the sun, volcanic eruptions, ocean circulation, biological processes, etc.) and anthropic (increase in CO_2 emissions and other greenhouse gases, alteration of large parts of soil, etc.). Climate change affects us all, because of its excessive potential impact, with predictions of lack of drinking water, big changes in food production conditions and increase in mortality rates caused by floods, storms, droughts and heat waves. However, these effects not only affect the environment but they also lead to economic and social consequences around the world (Fig. 1.1). Therefore, it is necessary to take a series of measures to mitigate climate change and, at the same time, to adapt to the possible scenarios which are a consequence of global warming.

The United Nations Framework Convention uses the term climate change to refer to changes occurring in the present and only directly or indirectly attributed to human activity which alters the composition of the global atmosphere and can be related to the natural variability of the climate observed over comparable periods. During the meeting, a

The global climate is currently undergoing rapid changes, where economic and social development is not respecting limited natural resources.

very important international treaty about environment was confirmed: the Montreal Protocol, established in 1987, under which members states are obliged to act in the interests of human security, including lack of scientific certainty.

The main achievement of the Convention was to recognize, for the first time, that the problem of climate change is real. It helped raise awareness of all the countries of the issue and encouraged them to start taking measures to avoid it. The United Nations Framework Convention on Climate Change (UNFCCC) entered into force on the 21st of March 1994. Today, a large number of member states makes it almost universal. The 197 countries that have ratified the Convention are called "Parties to the Convention". The Convention is a framework document that has been developed over time in order to discover and establish the most effective strategies in the fight against climate change. Updates have been taking place periodically within the framework of COP22 (Conferences of the Parties). During COP meetings, Parties to the Convention ratify agreements on the reduction of greenhouse gas emissions while evaluating their commitments.

The first addition to the original treaty was the Kyoto Protocol, adopted in 1997 at COP3. This treaty involved the implementation of the Convention, in which industrialized countries have been committed to stabilizing greenhouse gas emissions (CHG). This treaty set binding emission reduction targets for 37 industrialized countries and the European Union, recognizing that they are primarily responsible for the high levels of GHG emissions currently present in the atmosphere, which are the result of burning fossil fuels for more than 150 years.

At the last conference about climate change held in Marrakech (November 7th-18th, 2016), COP22, Parties, including all the countries of the European Union, have reaffirmed their commitment to the fight against climate change by signing the Paris Agreement, which was reached at COP21. They committed to promoting investments in low-carbon, climate-resilient green economy, contributing to economic growth and creating employment. The last two conferences have highlighted the important role that agricultural soils can have as a carbon sink, resulting in the launch of the "4/1000 Initiative: Soils for Food Security and Climate", which is aimed at mitigating GHG levels through an annual increase of 4 per 1000 (0.04%) of the organic carbon in all the planet's soils. The subtraction of atmospheric carbon that can occur in agricultural soils through proper management is particularly important.

1.2. Global impact

The global climate is currently undergoing rapid changes, where economic and social development is not respecting limited natural resources. Global human population growth and the way to feed it without depleting natural resources will undoubtedly be a complex challenge to confront in the constantly changing climatic conditions. The World Commission on Environment and Development drafted the Brundtland report (*Brundtland Inform, 1987*), which states that the path taken by society is destroying the environment which is significantly affecting less developed countries. The concordance between social equality, environmental protection and economic development are fundamental pillars which should be taken into account in the fight against climate change. However, there is still a lot to be done. Progress in international cooperation, near-real-time data exchange, and progress in the science of climate attribution are allowing scientists to investigate the influence of climate change on human activities.

Regarding climate, a recent report has confirmed that the temperatures recorded in 2016 beat all modern records. 2016 has officially been declared the warmest year on record to date (since 1860). It should be noted that at the global level, the warmest years, since records have been kept, were in the period between 1998 and 2009. In the report published by the WMO (the specialized agency of the United Nations), global temperatures from January to September 2016 were 0.88°C above the average temperatures recorded in the period 1961-90 and about 1.2 °C above those of the pre-industrial period (1850-1999). The consequences can be observed in the increase of extreme weather and climate events (Fig. 1.2).

In many Arctic and Subarctic regions of Russia, Alaska and northwest of Canada, values of 3 °C above average were recorded. In the tropics and in 90% of the terrestrial areas of the northern hemisphere, recorded values where of 1 °C above average. However, global surface temperature anomalies were less extreme in the southern hemisphere, but many areas were still 1 °C or more above average in the case of the American continent, Eastern Australia and South Africa. The only area where below-average temperatures were recorded was in the subtropical zone of South America (Argentina, Paraguay and Bolivia).

Continental-scale temperature variability shows that 2016 was the warmest year in North America and Asia. However, Africa was also near to reach record levels in 2016. Asia had its warmest spring and summer while Oceania had its warmest summer and autumn. In the case of the American continent, South America recorded its warmest summer, while North America had its warmest winter. At a global level, it can be seen that the most intense long-term temperature increases occurred in Russia, Western Sahara, Brazil and Canada (Fig. 1.3).

With regard to the climatic data provided by the *WMO (2017)*, Russia recorded the hottest year to date, with temperature values of 2.16 °C above average. China

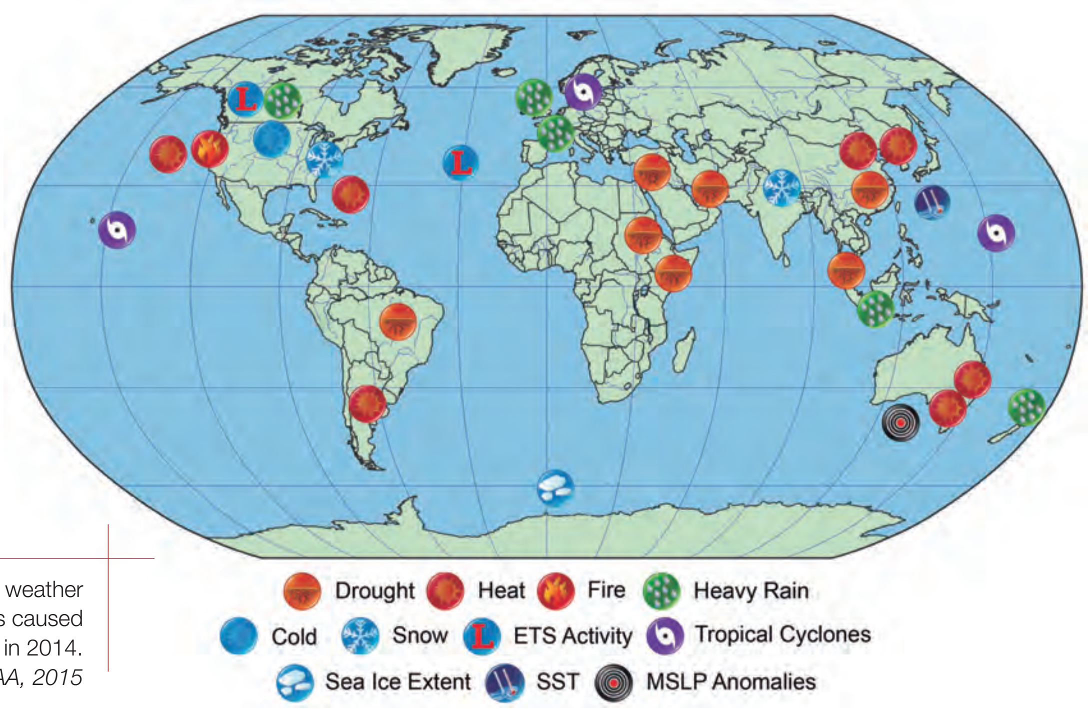


Fig. 1.2. Extreme weather and climate events caused by climate change in 2014. Source: *NOAA, 2015*

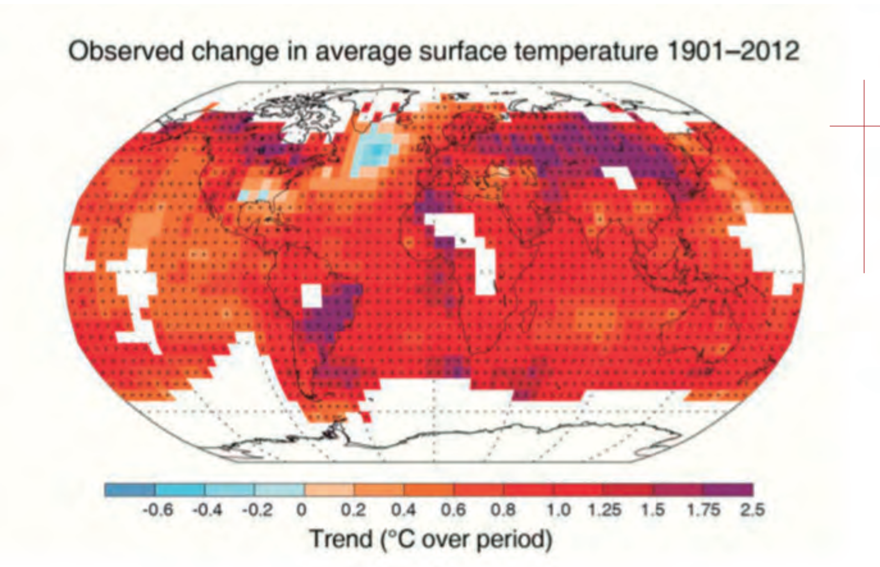


Fig. 1.3. Observed change in average surface temperature 1901-2012. Source: *IPCC, 2014.*

also recorded temperature values different from previous data in 10 provinces.

Africa and Oceania also recorded high temperature values. 2015 was the second warmest year to date. On the other hand, in a few land areas cold conditions were observed. Antarctica is one of the examples, where the positive phase of the Southern Annular Mode lasted several months with the west winds intensifying and contracting towards the Antarctic, which caused a cooling in the Antarctic East and at the same time a warming in the Antarctic Peninsula. In October there was a change towards less extreme values until the end of the year and a warming compared to the continent's average. Some areas of North-East North America reached colder temperatures than normal during the year.

The Intergovernmental Panel on Climate Change *(IPCC, 2014)* predicted that the temperatures at the end of the 21^{st} century will be between 1.1 ºC at best, and 6.4 °C at worst, warmer than at pre-industrial levels in the late 1800s. These may appear to be small thermal increases, but it is worth mentioning that the increase in temperatures propitiating the last ice age on the planet was only 5 °C lower than current temperature. The polar ice cap during the ice age was covering the majority of Europe, Asia and North America.

As temperatures continue to rise, more and more water vapor will evaporate into the atmosphere. On the one hand, this increase in evaporation will affect the freshwater reserves, between 11% and 38% of ecosystems, while increasing the volume of drylands that can be categorised as being at risk of desertification. The disappearance of glaciers will have a negative impact on mountainous streams in areas such as the United Kingdom, Denmark and the United States. This phenomenon will be especially relevant in the southern parts of Europe, leading to longer periods of drought and increasing the frequency of heat waves. On the other hand, rising temperatures will cause an increase in precipitation.

It should be noted that global warming is influencing the temperature of the oceans, which requires more space and therefore increases the volume causing sea level to rise. On the other hand, the melting of glaciers and ice sheets is causing an increased water discharge into the oceans, which increases the risk of landslides and reduces the amount of fresh water.

Analysis of the data shows that sea level rise is currently occurring (Fig. 1.4). In the 20^{th} century, the average sea level rose at a speed of 1.7 mm yr^{-1}. However, observations made by satellite have shown that this increase was around 3 mm yr^{-1} from 1993 onwards. Projected global average sea level rise at the end of the 21^{st} century could be between 26 and 82 centimeters above the current levels, greater than in 2007, when there was an expected increase of between 18 and 59 centimeters. Glaciers and layers of Antarctic ice and Greenland will have particularly significant impacts on coastal areas in the form of flooding, erosion and saltwater intrusion into watersheds.

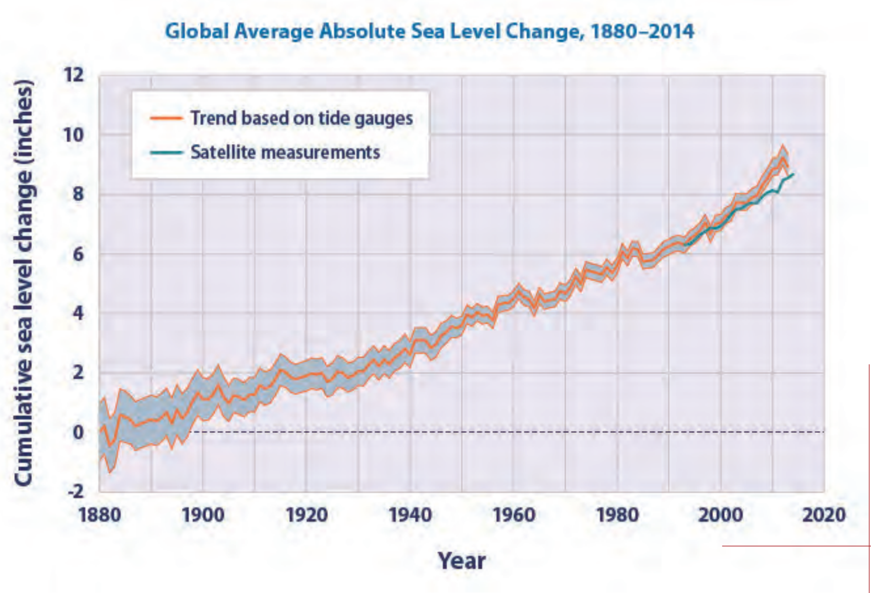


Fig. 1.4. Global Average Absolute Sea Level Change, 1880-2014. Source: *CSIRO, 2015* and *NOAA, 2015.*

Therefore, it is estimated that the Arctic ice melting will continue to rise, which means that, by the end of the summer in the next 15 or 20 years, the melting of the north pole ice sheet will be around 43% at best and 94% at worst. Contrary to the decrease that has occurred in the increase of the surface temperature, sea level rise is accelerating according to the models managed by the IPCC. In all analyzed scenarios it is very likely that the rate of sea level rise will be higher than in the last 40 years. From 1901 to 2010 sea level rose by around 19 centimeters, much faster than in the previous two millennia.

More recent studies predict that due to climate change, more intense and localized precipitation episodes are likely to increase in the coming years. At higher temperature, air masses are able to retain a greater amount of water vapor, which, under changing conditions of pressure or temperature, will precipitate intensely and cause torrential rains in localized areas. The pattern of future precipitation is less clear than that of temperatures. According to the latest research, in the 20th century precipitation increased in the middle latitudes of the northern Hemisphere, decreasing in subtropical and tropical regions. *The IPCC (2014)* predicts that the global concentration of water vapor and precipitation will increase during the 21st century. In the second half of the twenty-first century, winter precipitation is likely to increase in mid-high

latitudes and Antarctica. In low latitudes there will be both regional increases and decreases according to different areas (Fig. 1.5). In most areas, interannual variations are expected.

Therefore, the incidence of climate change will not only affect the total amount of precipitation, but its spatial-temporal distribution patterns will also be modified (Fig 1.6). All of this will lead to more intense and frequent extreme weather conditions, such as floods and storms. According to scientists, these changes cannot be explained if the human impact on climate change is ignored, because human activities may have already had significant effects on ecosystems, agriculture and human health in regions that are sensitive to precipitation changes.

Other less obvious effects of global warming are changes in the distribution of the planet's flora and fauna. However, some of the benefits that climate change could bring with thermal and CO_2 concentrations on ecosystem productivity are positively valued. But, on the other hand, one of the IPCC models determines that higher concentrations of CO_2 could instigate the flora in areas where the limiting factors are water and nutrients, even reversing the beneficial effect.

Regarding fauna, the thermal changes of the climate cause morphological modifications of many animals. This is the case of the polar bear or some species of amphibians that are adapting to the new environmental conditions in order to survive. Examples include the skull size reduction in polar bears, ultimately caused by

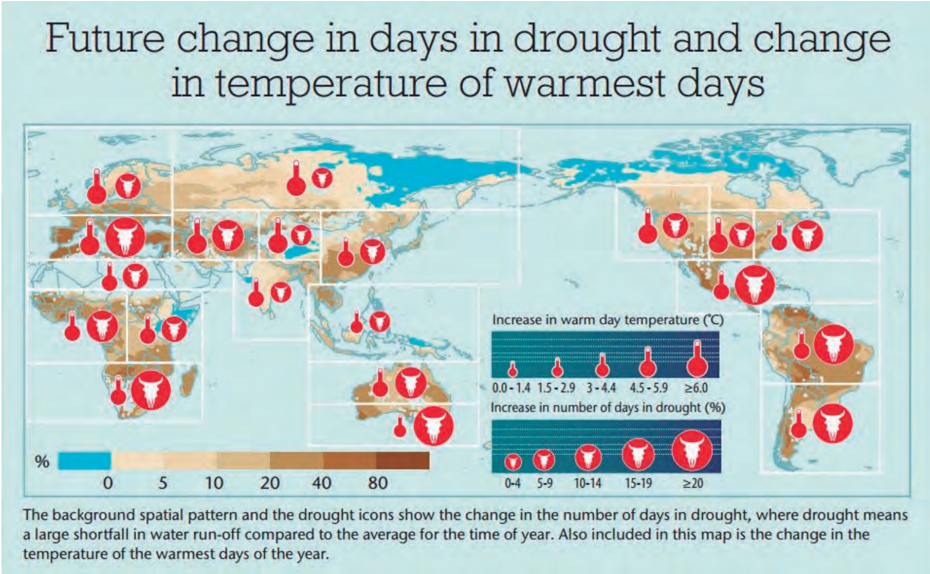


Fig. 1.5. Climate change brings higher temperatures and longer droughts. Source: *Met Office, 2014.*

Legend	
Extreme risk	■
High risk	■
Medium risk	■
Low risk	■
No Data	■

Rank	Country	Rating
1	Somalia	Extreme
2	Mauritania	Extreme
3	Sudan	Extreme
4	Niger	Extreme
5	Iraq	Extreme

Rank	Country	Rating
6	Uzbekistan	Extreme
7	Pakistan	Extreme
8	Egypt	Extreme
9	Turkmenistan	Extreme
10	Syria	Extreme

Fig. 1.6. Water Security Risk Index. Source: *Maplecroft, 2010.*

ice melting, or the rate of parasitic infestation suffered by the lemur population in Madagascar, where parasitic proliferation poses a threat to the species, as well as to public health given that Lemurs are disease vectors for maladies that can affect human beings.

The global temperature rise will affect the variation in the distribution of flora and fauna which will imply expanding the range of diseases carried by the fauna. The search for favorable conditions will allow the proliferation of diseases such as malaria, dengue or yellow fever. It will also affect some species that colonize new regions, either by the escape from their habitat or because the new climatic conditions allow their expansion to new places. This is happening with the arrival of species from the tropical countries to France or Belgium, as is the case of the black widow *(Latrodectus mactans)*.

With regard to the world's main food source, agriculture is extremely vulnerable and plays a key role in mitigating climate change (Fig. 1.7). Among the most serious environmental threats related to agriculture are soil degradation, loss of biodiversity, water quality and availability, and mitigation and adaptation to climate change. In underdeveloped or developing countries, climate change will affect the yield of major crops, leading to additional price increases in crops such as

rice, wheat, maize and soybeans. This also affects the costs of animal feed, resulting in an increase in meat prices.

Long-term climate change effects could affect agriculture in various ways, and almost all of them are a risk to food security for the world's most vulnerable people:

- It would complicate the planning of agricultural activities.

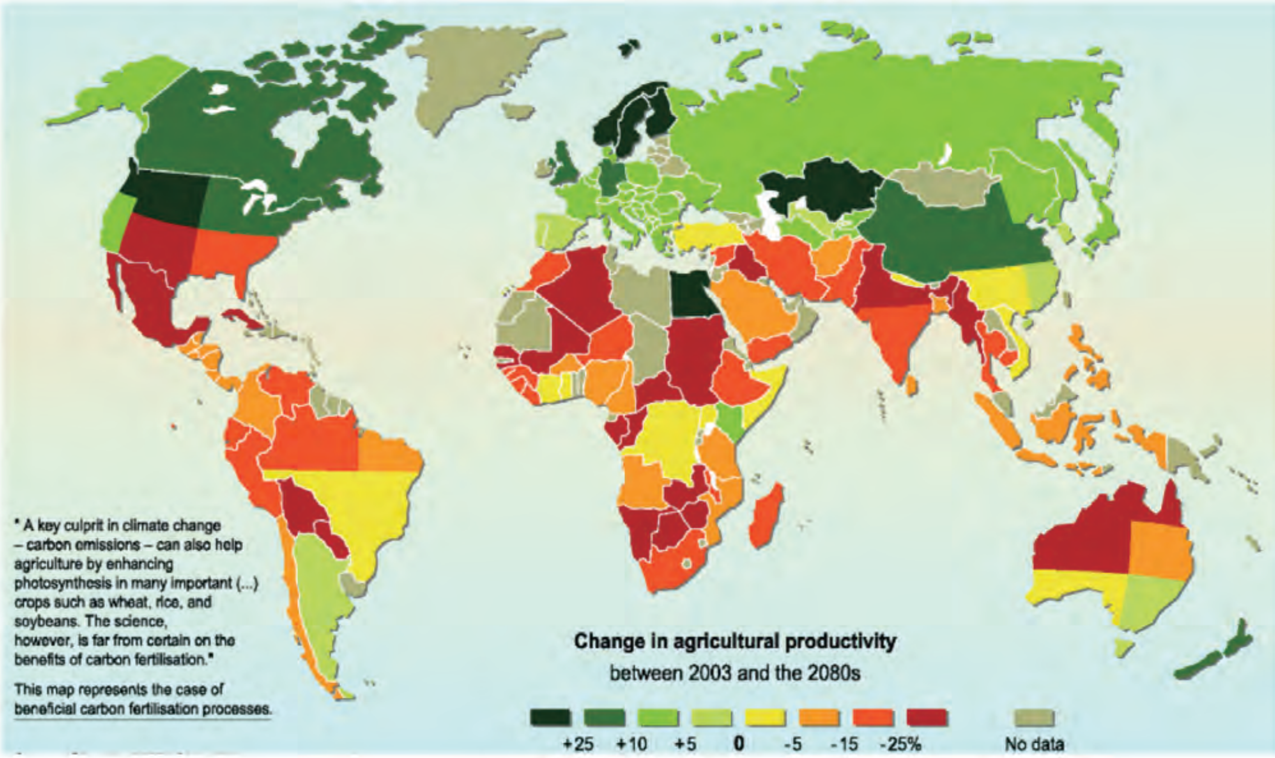


Fig. 1.7. Climate change Impact on agriculture. Source: *Cline, 2007.*

- Increased pressure on fragile farming systems
- Agricultural area loss due to sea level rise.
- Reduction of biological diversity in mangroves and tropical forests.
- Modification of climatic and agro-ecological zones.
- Productive imbalance of food in temperate, cold, tropical and subtropical regions.
- Increase of crops pests and diseases.

Agricultural production, and therefore food security, is influenced by variations in the periods of rainfall, thermal and other climatic conditions. Areas such as Asia and South America are prone to climate change. Extreme climatic events such as storms, floods, droughts, etc., continue to increase and have serious effects on agriculture. It is estimated that their frequency and magnitude will increase and are likely to affect considerably all regions of the planet. There is a serious risk of future conflicts over habitable lands and natural resources. Climate change is affecting the distribution of plants, invasive species, pests and diseases and may increase incidence and geographic location.

1.3. Impact at European level

Just as the climate is changing globally, it is changing in Europe, with different impacts on our health, ecosystems and economy. The effects are likely to be more severe in the coming decades. If the processes that generate them are not mitigated, they could have a very costly impact on human health, ecosystem conservation and the maintenance of goods and infrastructures. The latest climate change report published by the European Environment Agency (Climate Change, impacts and vulnerability in Europe 2016) contains the latest news on the impact of climate change on our continent. These impacts have been estimated through a wide range of observations and simulation models, identifying regions that are experiencing especially severe changes.

It is noted that the main conclusions on the impact of climate change in Europe, published by the European Environment Agency report in 2012, are still valid. Earth's and sea temperatures continue to rise, while precipitation patterns are changing, generally making moist regions more humid, particularly in winter, and making dry regions drier, especially in summer. On the other hand, sea ice extent, the volume of glaciers and snow cover extent are decreasing. Sea level is rising and extreme climatic conditions such as heat waves, heavy precipitation and droughts are increasing in many regions, setting new records for some climatic variables, such as average temperatures in Europe in 2014 and again in 2015, the global sea level in 2015 and the Arctic sea ice extent in winter in 2016. Moreover, the rise in sea level has increased flood risks and contributed to erosion along European coasts.

The observed changes in the climate system are already having wide-ranging impacts on ecosystems, economic sectors and human health and well-being in Europe. Recent studies show that various observed changes in the environment and society, such as changes in forest species, the establishment of invasive alien species and disease outbreaks, have been caused or enhanced by global climate change. Ecosystems and protected areas are particularly suffering from these impacts, threatening their biodiversity and affecting forestry, fishery and agriculture. In response to climate change, many land-based animal and plant species are changing their life cycles and are migrating northwards and / or to higher altitudes. On the other hand, regional extinctions have been observed and various invasive alien species have established themselves or have expanded their range. Regarding marine species, it has been noticed that commercially important fish stocks are migrating northwards.

The increase in heat waves has had significant impacts on human health, especially in the cities of Southern Europe. Heat waves are also increasing the risk of

Fig. 1.8. Biogeographical regions in Europe. *Source: EEA, 2012*

electricity blackouts and forest fires in summer months, therefore affecting transport and tourism. Particularly important was the heat wave that affected southern France in the summer of 2003, which led to a significant increase in mortality of elderly people.

Urban areas, where four out of five Europeans live, are being tested in order to determine their exposure to heat waves, floods and sea level rise. Those areas are usually not well prepared for the afore mentioned phenomena.

In addition to the climate change impacts, it should be borne in mind that in the near future such effects will interact with other socio-economic developments, such as population growth and increased urbanisation across Europe.

Climate change is affecting all regions in Europe, but the impacts are not uniform. Southern and Central Europe are increasingly suffering from heat waves, forest fires and droughts. The Mediterranean area is becoming increasingly dry, making it even more vulnerable to drought and fires. On the other hand, Northern Europe is clearly becoming an increasingly humid area and floods in winter may be more frequent. The most significant impacts are projected to occur in the different European biogeographical regions (Fig. 1.8). As can be seen although the negative effects predominate, there are some positive variations observed in Northern Europe.

Arctic region

- Temperatures rise much larger than global average
- Decrease in Arctic sea ice coverage
- Decrease in Greenland ice sheet
- Decrease in permafrost areas
- Increasing risk of biodiversity loss
- Some new opportunities for the exploitation of natural resources and for sea transportation
- Risks to the livelihoods of indigenous peoples

Boreal region

- Increase in heavy precipitation events
- Decrease in snow, lake and river ice cover
- Increase in precipitation and river flows
- Increasing potential for forest growth and increasing risk of forest pests
- Increasing damage risk from winter storms
- Increase in crop yields
- Decrease in energy demand for heating
- Increase in hydropower potential
- Increase in summer tourism

Atlantic region

- Increase in heavy precipitation events
- Increase in river flow

- Increasing risk of river and coastal flooding
- Increasing damage risk from winter storms
- Decrease in energy demand for heating
- Increase in multiple climatic hazards

Continental region

- Increase in heat extremes
- Decrease in summer precipitation
- Increasing risk of river floods
- Increasing risk of forest fires
- Decrease in economic value of forests
- Increase in energy demand for cooling

Mediterranean region

- Large increase in heat extremes
- Decrease in precipitation and river flow
- Increasing risk of droughts
- Increasing risk of biodiversity loss
- Increasing risk of forest fires
- Increased competition between different water users
- Increasing water demand for agriculture
- Decrease in crop yields
- Increasing risks for livestock production
- Increase in mortality from heat waves
- Expansion of habitats for southern disease vectors
- Decreasing potential for energy production
- Increase in energy demand for cooling
- Decrease in summer tourism and potential increase in other seasons
- Increase in multiple climatic hazards
- Most economic sectors negatively affected
- High vulnerability to spillover effects of climate change from outside Europe

Mountain regions

- Temperature rises larger than European average
- Decrease in glacier extent and volume
- Upward shift of plant and animal species
- High risk of species extinctions
- Increasing risk of forest pests
- Increasing risk from rock falls and landslides
- Changes in hydropower potential
- Decrease in ski tourism

Coastal zones and regional seas

- Sea level rise
- Increase in sea surface temperatures
- Increase in ocean acidity
- Northward migration of marine species
- Risks and some opportunities for fisheries
- Changes in phytoplankton communities
- Increasing number of marine dead zones
- Increasing risk of water-borne diseases

The increase in heat waves has had significant impacts on human health

1.4. National scale climate change impacts

1.4.1. France

Climate change has different impacts in France, ranging from affecting ecosystems to the health of the population. The factors that have the greatest impact on the health of French people are heat waves, allergies and exotic diseases. The southeastern part of the country, located in the Mediterranean region, will be mostly affected by the increase in the frequency, amplitude and duration of heat waves. In addition to the direct effects of heat on people at risk (patients, babies, the elderly, etc.), heat waves provoke the development of allergic reactions, such as rhinitis, conjunctivitis and asthma attacks. The worrying fact is that concentration of pollen could quadruple by the year 2050. Another possible consequence is the expansion of exotic species, such as the tiger mosquito, carrier of tropical diseases like dengue, which is estimated to become widespread in France by 2050.

Agriculture is another important sector affected by climate change. Particularly serious may be the effects on the Bordeaux wine fields, where grapes are ripening 15-20 days earlier than normal. This is benefiting the harvest right now, but by 2050, it is expected that drought and high temperatures could damage leaves and grapes, consequently reducing wine quality.

Furthermore, electro-nuclear production will also be affected by climate change because nuclear power plants need water to feed their turbines and cool their reactors. Reducing river flows and increasing the temperature of water, by reducing rainfall and increasing evapotranspiration, may jeopardize the proper functioning of such plants. In fact, 28 °C is the established temperature limit of river waters used in electro-nuclear production processes, and the activity of the reactors should be stopped or reduced when the limit is exceeded.

The impact of climate change on biodiversity in France depends on species. Some will benefit from the increase in temperature by finding new territories, while others will gradually change their distribution migrating northwards, so they might disappear from the country, or even become extinct if the change is too extreme. The flora is the most affected by abrupt heating, especially the one that has its habitat in the high altitude bioclimatic areas, since they do not have the possibility to expand northwards. The consequences do not only affect environment, but also local economies. For example, in Aquitaine, where the extensive Landes forest is likely to be particularly affected by increased aridity and drought, there are 74,000 forestry-related jobs (40,000 silviculturists + 34,000 jobs related to direct work).

1.4.2. Germany

According to a study by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety *(Zebisch et al., 2005)*, the most

widespread risks of climate change are related to flooding processes, predicting highly damaging effects. These events will cause serious problems in agriculture and infrastructures and are especially strong in the area of the Alps.

Regarding water availability problems, the southwestern regions of the country have the greatest vulnerability to climate change, because those are the areas with the most arid territory and the poorest soils. This part of Germany will be more affected by water scarcity due to the expected decrease in precipitation in summer, followed by greater evaporation which is the consequence of temperature increase. Agriculture and forestry will be particularly affected by the lack of water and the rise of diseases and pests, which will benefit from a more favorable climate for them. It is precisely in this zone of the south-west of Germany that maximum temperatures have been recorded year after year. Temperatures are expected to continue rising, causing problems, and having negative impact on human health. Also, new climatic conditions could increase the risk of forest fires.

In addition to the aforementioned agricultural and forestry sectors, the major river transport sector in Germany is expected to be highly affected by extreme climate events (extreme storms and precipitation) as well as extreme heat waves in summer. The effects would affect both the traffic flow and the infrastructures which would be affected by important fluctuations in the water levels of the rivers.

In the Alpine region, in addition to the risk of floods, endemic species of flora with a very restricted distribution might disappear, because they have a low capability of adaptation to rapid climate changes. Furthermore, animal species will have less possibilities of migration, due to the fragmentation of the territory. Moreover, winter tourism is expected to get affected by climate change, because of reduced snowfall in ski resorts.

Northwestern Germany has the lowest vulnerability to climate change, where conditions for agriculture may be even improved, as well as coastal areas, which, despite being threatened by rising sea levels, could benefit from the increase of sunny days and temperatures, which would improve summer tourism and increase the agricultural yield.

1.4.3. Italy

Italy is also expected to be affected by climate change, with heterogeneous consequences due to the intrinsic characteristics of the country. The most important consequences according to *Sgobbi and Carraro, (2008)*, will be located in the Alpine region, the Po basin, coastal areas and regions at risk of desertification.

In the Alpine region, an increase in temperatures is anticipated, with the consequent reduction in the amount of snowfall and even complete lack of it. This will seriously affect the winter tourism industry. On the other hand, as the attractiveness of the alpine ecosystems diminishes, summer tourism can be affected as well. Furthermore, composition of plant and animal species will be altered, which will tend to go higher in both altitude and latitude, thus leading to a loss of biodiversity. Moreover, climate change will increase the probability of forest fires.

On the other hand, the risk of floods and landslides in the Po river basin is expected to increase, due to increased torrential precipitation and the melting of the alpine mountains. These floods, in addition to the economic cost and human lives, can result in the spread of water-related diseases and pollution. Moreover, it can also increase an important risk of deterioration and / or disappearance of the large cultural patrimony of the region.

Coastal areas are important assets for Italy, with many economic activities linked to tourism, agriculture and industry. Sea level is expected to raise in such areas, as well as an increased incidence of extreme weather events. In addition to impacts on human activities, further coastal erosion and a decline in biodiversity are also expected.

About 5.5% of Italian territory (16,500 km^2) is currently at risk of desertification. This area is mainly located in five regions: Apulia, Basilicata, Calabria, Sicily and Sardinia. It is predicted that climate change will worsen the risk of desertification already observed in these areas, leading to greater soil degradation. Agriculture, livestock and tourism will be significantly affected. Urban areas will have problems with electricity and water supply, while in natural ecosystems the risk of fires will be even greater.

1.4.4. Netherlands

The expected climate changes in the Netherlands concern temperature, precipitation, evaporation, and weather extremes *(Schipper et al., 2014)*. How the climate changes largely depends on the temperature increase across the globe and on the changes in air flow patterns in Western Europe, accompanying changes in wind speed and direction. Table 1.1 provides an overview: on the left are the results for the target year 2050 and on the right, for the year 2100.

All climatic models' scenarios have the same results, where climate change keep emerging to some degree:

- The warming persists, so mild winters and warm summers occur more frequently. (Fig. 1.9)
- On average, the winters are wetter and extreme amounts of rainfall increase (Fig. 1.9)
- The intensity of extremely heavy rainfall in summer increases while the number of rainy summer days actually decreases.
- The calculated changes in wind climate are small if compared to the natural unpredictability.
- Forecasts for changes in precipitation patterns for coastal areas are different to forecasts for the interior.
- The sea level rise is a very important risk for particular conditions of Netherlands.

1.4.5. Poland

In Poland, the effects of climate change are expected to be reflected in the increase and intensity of extreme weather events: droughts, winds and hail. Most of the Polish regions will be affected by wind storms, increasing the risks of infrastructure and the integrity of people.

Regarding precipitation, in eastern Poland, the rainless period has been prolonged up to 5 days per decade. This area has been affected by several droughts in recent decades. At the same time, in most of the Polish regions, an increase in the number of days per decade with heavy precipitation events have been observed. The combination of these two phenomena is especially dangerous for agriculture, which could be affected by reduced availability of water and loss of crop due to flooding.

On the other hand, the southwest of Poland is expected to be the most affected by the effect of rising temperatures due to climate change. In fact, heat waves have been recently affecting this part of the country. Rising temperatures, in most of Poland, have led to a decrease in the number of cold and very cold days.

Generally speaking, forecasts show that climate change will produce an overall increase in temperatures across the country. This increase will be reflected in all climatic factors based on this variable. For example, there are less days with a minimum temperature below 0 °C, while there are more days with maximum temperature above 25 °C. Regarding precipitation, forecasts estimate longer periods without precipitation, more frequently maximum rainfall events, and shorter periods of snow cover.

1.4.6. Spain

As regards to Spain, given its geographical and socio-economic characteristics, it is especially vulnerable to climate change. In the last century, the average temperature has been increased by 1.5 ºC, which is twice the global thermal average. The models predict that Spain has a greater risk of heat waves, fires and floods. The temperature will increase by 3 and 4 ºC during winter and by 5 and 7 ºC in the summer. These conditions will be more pronounced in the peninsular

Table 1.1. Results of climatic models for the Netherlands. Source: *Shipper et al., 2014.*

		2050				2100			
		G	G+	W	W+	G	G+	W	W+
Global rise in temperature		+ 1ºC	+ 1ºC	+ 2ºC	+ 2ºC	+ 2ºC	+ 2ºC	+ 4ºC	+ 4ºC
Changes in air flow patterns Western Europe		no	yes	no	yes	no	yes	no	yes
Winter	Average temperature	+ 0.9ºC	+ 1.1ºC	+ 1.8ºC	+ 2.3ºC	+ 1.8ºC	+ 2.3ºC	+ 3.6ºC	+ 4.6ºC
	Coldest winter day of the year	+ 1.0ºC	+ 1.5ºC	+ 2.1ºC	+ 2.9ºC	+ 2.1ºC	+ 2.9ºC	+ 4.2ºC	+ 5.8ºC
	Average precipitation	+4%	+7%	+7%	+14%	+7%	+14%	+14%	+28%
	Number of wet days (≥0.1 mm)	0%	+1%	0%	+2%	0%	+2%	0%	+4%
	Highest day-average wind speed per annum	0%	+2%	-1%	+4%	-1%	+4%	-2%	+8%
Summer	Average temperature	+ 0.9ºC	+ 1.4ºC	+ 1.7ºC	+ 2.8ºC	+ 1.7ºC	+ 2.8ºC	+ 3.4ºC	+ 5.6ºC
	Warmest summer day of the year	+ 1.0ºC	+ 1.9ºC	+ 2.1ºC	+ 3.8ºC	+ 2.1ºC	+ 3.8ºC	+ 4.2ºC	+ 7.6ºC
	Average precipitation	+3%	-10%	+6%	-19%	+6%	-19%	+12%	-38%
	Number of wet days (≥0.1 mm)	-2%	-10%	-3%	-19%	-3%	-19%	-6%	-38%
	Potential evaporation	+13%	+8%	+7%	+15%	+7%	+15%	+14%	+30%
Sea level	Absolute increase (cm)	15-25	15-25	20-35	20-35	35-60	35-60	40-85	40-85

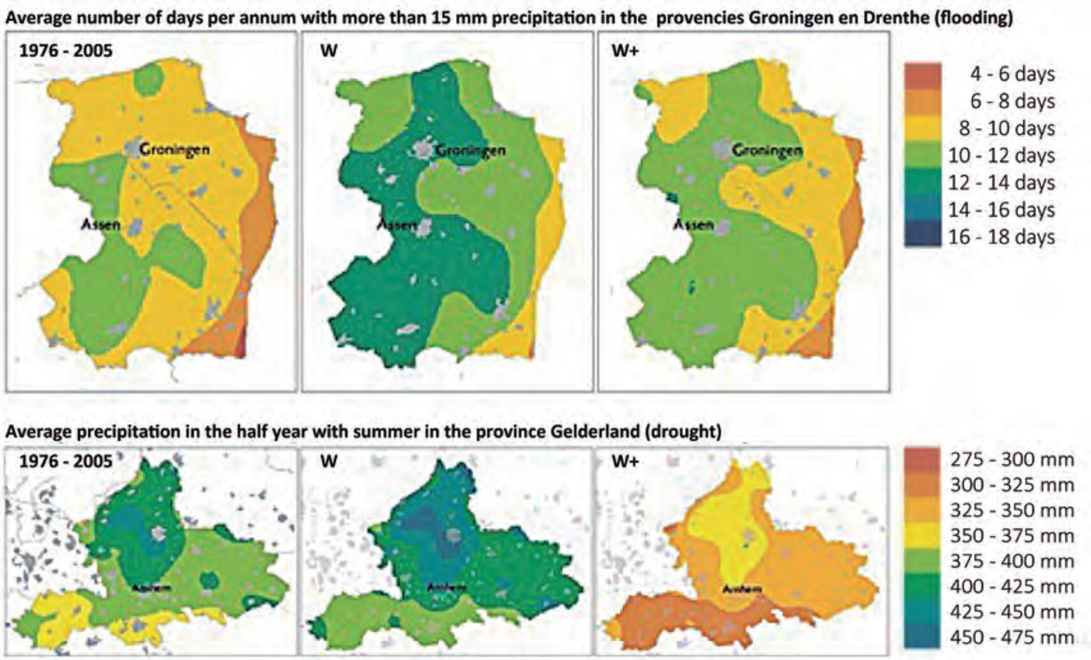


Fig. 1.9. Predictions of flooding and drought days in different regions of Netherlands. Source: *Schipper et al., 2014.*

interior than in the coastal areas. The frequency of maximum temperatures will increase which will affect water resources by decreasing its amount and time periodicity.

The year 2015 was one of the warmest years on record in Spain and the year 2016 has been even warmer than the previous one. Between May and September 2016, the peninsula was affected by a heat wave during the month of May that set a new monthly record. The temperatures reached 42.6 ºC at Lanzarote airport and Valencia surpassing by 6 ºC the previous maximum temperatures recorded in May. Spain's longest heat wave recorded lasted from June to July (from 27 to 22, respectively). November and December were exceptionally warm months in Spain. Unprecedented high temperatures were recorded in December.

Regarding sea level, in areas such as the Cantabrian and Atlantic coasts, sea level rise has an annual rate of 1 to 1.5 mm and 0.7 mm in the Mediterranean part. The increase of the oceans, which has rates between 10 and 68 cm, will cause the disappearance of the deltas of the rivers. In addition, during the last century the Pyrenean glaciers have experienced a retreat of 75%.

The models project for Spain a progressive reduction of precipitations that will be more pronounced in the second part of 21^{st} century. Reductions of more than 20% of surface and groundwater resources could be reached, especially in the south, 5% in the north half, and near 10% in the southwest between 2011-2040, until reaching, in the last third of the century (2070-2100), reductions in average annual precipitation from 15% to 25% in the regions of the northern half and 20% to 30% in the southern third of the peninsula. On the other hand, irregularities in floodwaters in the interior and Mediterranean basins will increase. Erosive processes will also increase, aggravating the desertification conditions where they already exist.

In 2015, January was a rainy month in great part of northern Spain. Between 20 and 24 March, 300 mm of rain fell in some areas of the province of Castellón. In northern Spain, snowfall has been reduced by 50% since 1975. Active glaciers in the Pyrenees have lost almost 90% of their area since the beginning of the 20th century. Only eighteen of the thirty-four glaciers described in 1982 persist.

Regarding agriculture, global warming has already altered the duration of the growing season of crops in much of the peninsula. In other words, it advances the time of flowering and harvest of the cereals by a few days. These changes are likely to continue in many regions.

Climate change will reduce agricultural production although the effects will not be the same in all areas. Due to the global concentrations of CO_2 in the atmosphere, temperatures will increase, and this will positively affect cultivated plants, stimulating photosynthesis. However, in the south of the peninsula these temperature scenarios will increase the rate of evapotranspiration which will negatively affect the photosynthetic rates, increasing the irrigation needs in some cases. Simultaneously, the temperature rise will lead to an increase in phytopathologies due to harmful insects.

The extent of pests and diseases of crops is variable according to Spanish geography. Changing temperatures can lead to displacement towards higher latitudes of some diseases. All these factors will cause fluctuations in crop yields and local food supply.

1.4.7. United Kingdom

A representative selection of threats and opportunities for the United Kingdom are summarised in Figure 1.10 (*DEFRA, 2012*). This lists potential risks according to whether they are regarded as a threat or opportunity; classifies each risk according to a broad 'order of magnitude' score from either an economic, social or environmental perspective; and also indicates whether confidence in the direction and magnitude is "low", "medium" or, "high".

A clear example of the changes taking place in the climate of the United Kingdom was heavy precipitation in the winter of 2013/2014 (Fig. 1.11). Many UK areas were struck by floods as a consequence of extreme storms. In southern England extreme precipitation caused widespread flooding, electricity blackouts and major disruptions to transport systems. Economically, the most affected areas were Somerset, Devon, Dorset and Cornwall in the southwest and the Thames Valley in the southeast of England.

Fig. 1.10. A selection of potential risks (threats and opportunities) for the UK based on the Medium emissions scenario. Source: *DEFRA, 2012.*

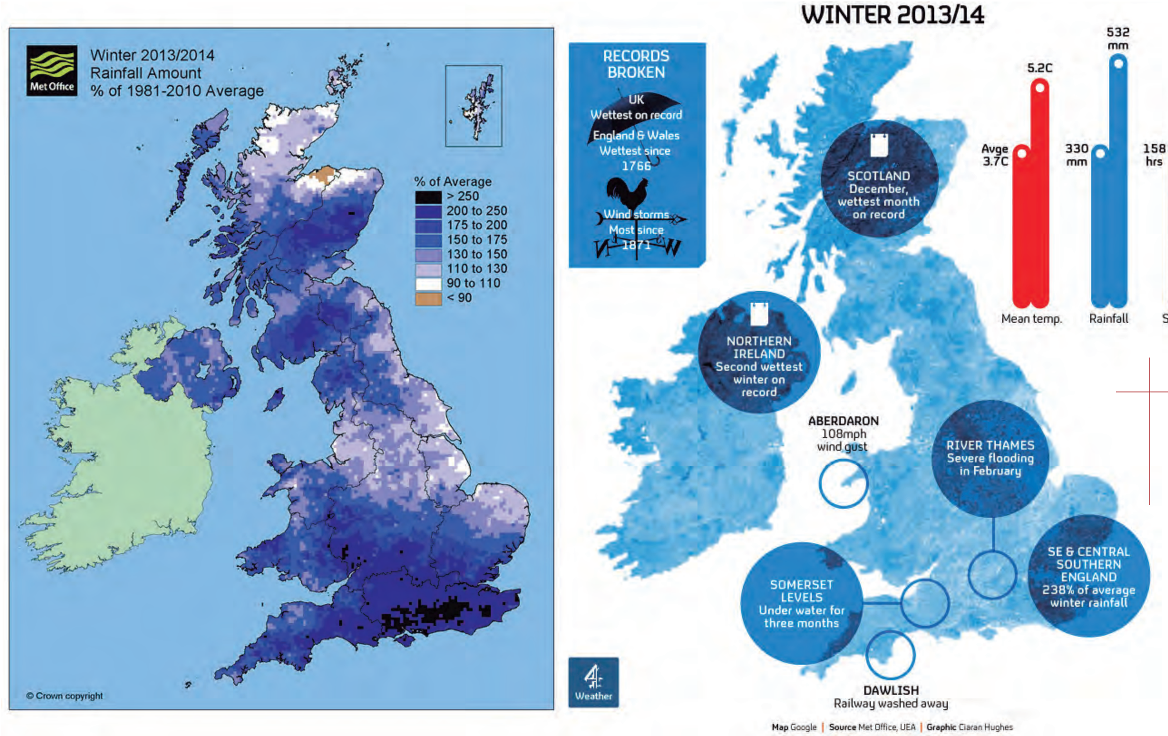


Fig. 1.11. Precipitation in the UK during the winter of 2013/2014 and its most important effects. Source: *Met Office, 2014* and *www.channel4.com, 2014.*

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CHAPTER 2
Agriculture and Climate Change

2.1. Relationship between climate change and agriculture

The agricultural sector contributes to climate change and is affected by it. However, agriculture can act as a mitigating activity because CO_2 emissions can be reduced due to the use of less productive factors, and because, if properly managed, soil can fix carbon.

In 2012, approximately 10% of global greenhouse gas (GHG) emissions came from the European Union (EU). Of these GHGs emitted by the EU, about 10% came from agriculture, which is the fourth largest emitter activity in the EU, behind the energy, transport and industrial combustion sectors *(European Environment Agency, 2011).*

For the end of the 21^{st} century, the vast majority of climate models point to global warming (from 2 °C to 5 °C) and to an increase in global precipitation ranging from 5% to 25% (*IPCC, 2007*). Furthermore, there are projected changes in the distribution, intensity and frequency of extreme phenomena such as heat waves and droughts. However, large regional differences should be taken into account. In Europe, the *CLIMATECOST* project modeled the changes in crop productivity of different European agro-climatic regions. For this purpose, a set of projected scenarios for different representative emission paths and different climate models for the 2080s have been considered.

2.2. Climate change effects on agriculture

If there is any productive activity that depends directly on the climate and its variability, it is undoubtedly agriculture. Changes in temperature and precipitation patterns and increases in the concentration of atmospheric CO_2, will significantly affect crop development. Global climate variabilities are estimated to be responsible for 32% to 39% of yield variability (*Ray et al., 2015*), an effect that is more pronounced in areas such as The Iberian Peninsula.

While some aspects of climate change, such as increased growth seasons and rising temperatures may be beneficial, lack of water availability as well as extreme weather conditions will more often have negative impacts and adverse effects on agriculture. However, climate change may pose opportunities or risks for the agricultural sector depending on the considered area, based on the climatic characteristics of the region, crops and potential changes that may occur. The effect of climate change on a region's crops can be positive or negative depending on climate characteristics, current crops and potential changes.

As an example, the production of cereals at an African continental scale in 2080 (Fig. 2.1) is projected to be higher in the equatorial areas and lower in the tropical areas. At first glance, the effects seem to be balanced, but in fact, tropical areas are very vulnerable because they are already arid (perimeters of the Sahara and Kalahari deserts). Reducing harvests in these areas could pose a significant risk to the food supply.

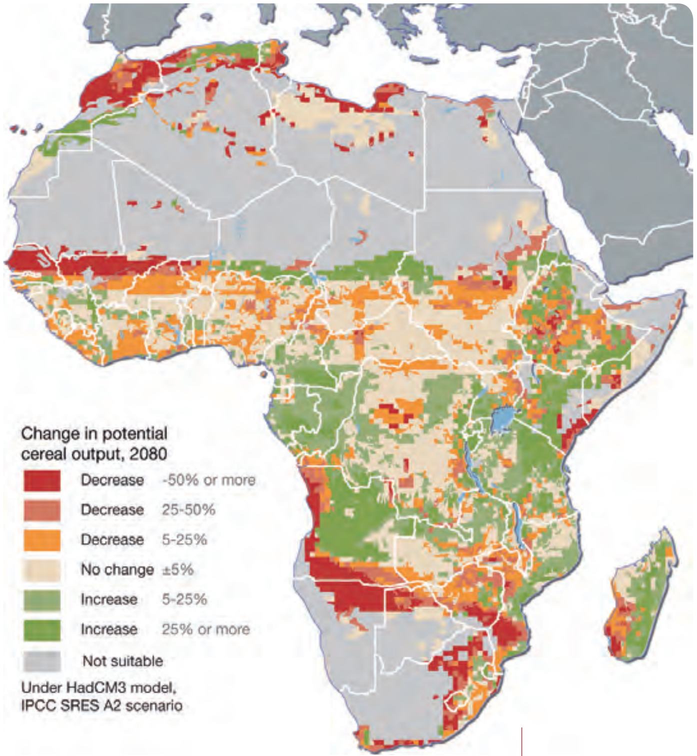


Fig. 2.1. Model of climate change effects on cereal crops in Africa. *Source: Geothinking, 2012.*

Another model, designed to predict global food supply security (Fig. 2.2), shows, in general, an increase in food supply insecurity, especially in tropical areas where current food supply problems will be accentuated.

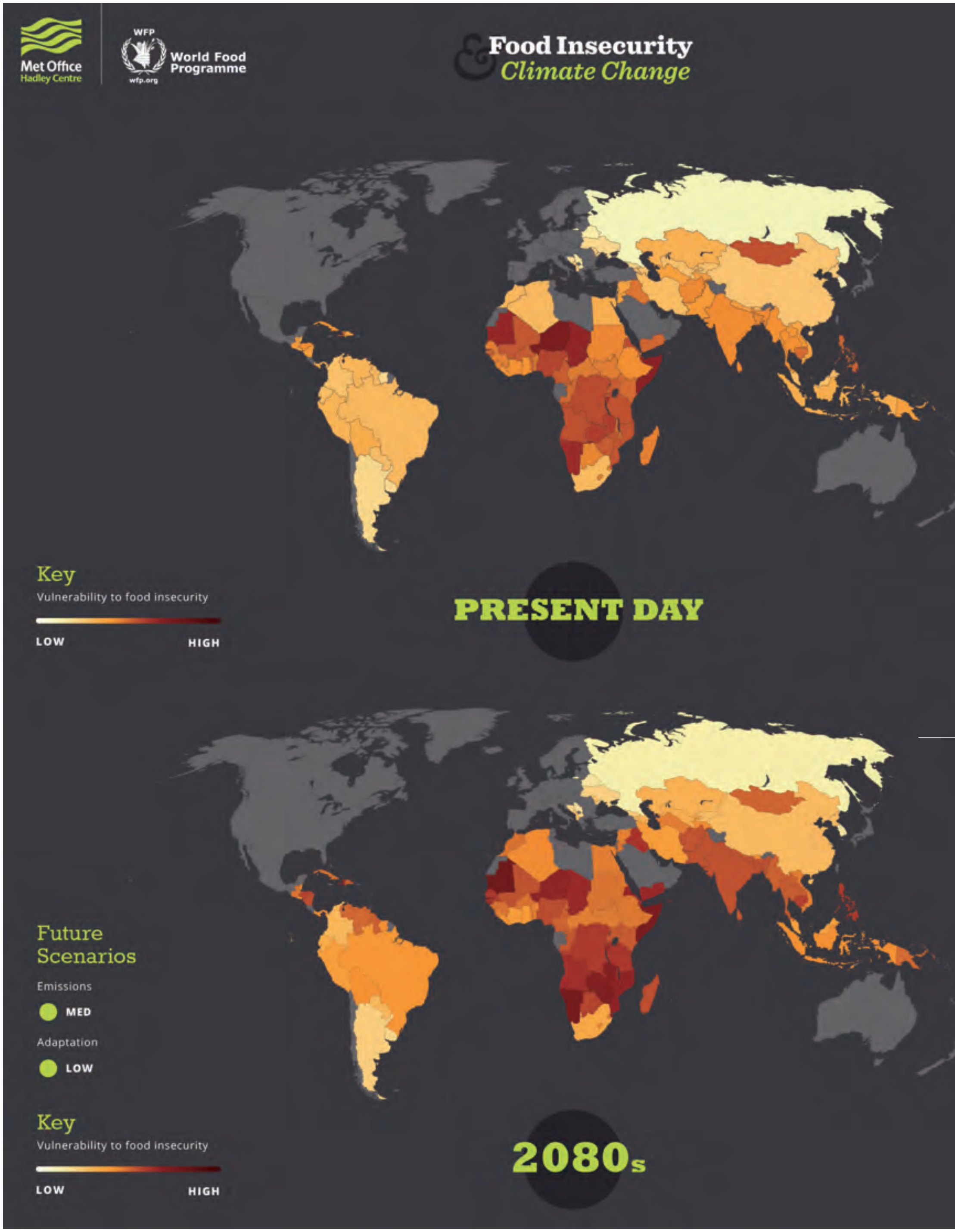


Fig. 2.2. Comparison between current food insecurity and that expected in the 2080's (considering medium emissions and low adaptation). Source: *Global Food Insecurity Index (Met Office and World Food Program)*.

Regarding Europe, the northern regions will experience warmer, drier summers and wetter winters, in addition to sea level rise. This will result in longer growing seasons, but also an increased risk of flooding. Meanwhile, the Mediterranean regions will be affected mostly by high temperatures and by the decrease in precipitation, with more torrential rainfall events. All this will lead to a decrease in the soil surface suitable for cultivation, not only because of adverse climatic conditions, but also because of the increase in erosion, soil loss and water quality due to extreme rainfall events.

At first sight, it could be considered that the increase in CO_2 concentration in the atmosphere could favor agricultural productivity, increasing its biomass and water-use efficiency; nevertheless recent studies point out that the direct CO_2 phenomena occur in crop conditions where the plants are influenced by other limiting factors that lead to lower final productions. The temperature increase of 1 to 3 ºC, results in a lower water availability for the plant, an increase in the incidence of crop pests and diseases, and worsening soil and water quality. The Table 2.1 summarizes the possible positive and negative effects that climate change could have on the productive capacity of crops.

Obviously, the potential positive and negative effects described in Table 2.1 will not occur in all regions but will largely depend on the variations produced by climate change with regard to the baseline conditions of each region.

A quick analysis of the situation might show that, in general, there would be changes in the zoning and productivity of crops, resulting in a shift of the optimal areas of development to more northern areas, establishing a new map of crops, in which the colder countries will take over the agricultural role that hot and temperate countries had until now.

Table 2.2 shows the degree of certainty for each of the risks and opportunities posed by climate change in Europe according to the considered agro-climatic zone.

Table 2.1. Possible positive and negative effects of climate change. Source: *Iglesias et al., 2007.*

Change factor	Potential positive effects	Potential negative effects
Temperature rise	• Longer growth periods. • Faster growth times. • New crops in cold areas.	• Increased thermal stress due to ambient temperatures. • Increase in weeds, pests and diseases. • Problems with flowering and curdling due to vernalization damage.
Precipitation variations	• Increased productivity. • Decreased demand for water. • Increased guarantees of water supply.	• Increased flooding and salinization. • Increased frequency of droughts. • Increase in weeds, pests and diseases. • Increased erosion.
Increased GHG concentrations	• Increase in fertilization due to the higher concentration of atmo-spheric CO_2.	• Negative effects of other gases.

Just 4 hectares under CA would negate the average annual emissions of a European citizen.

2.3. The impact of agriculture on climate change

Agriculture, traditionally, has carried tillage operations. Until a few decades ago, tillage, due to the scarce means available to farmers, did not pose a serious problem on soil sustainability. However, development and adaptation of powerful machinery to the agricultural sector have led to more intense tillage actions, both in depth within the edaphic profile and in the extension of tilled surface. Bearing in mind that this development has made it possible to provide the world's population with food as it had not been previously achieved, the processes of intensification of agricultural activity have increased soil vulnerability to erosion, what has led to annual substantial soil losses, on a global scale, therefore, drawing a worrisome

Table 2.2. Degree of certainty for risks and opportunities posed by climate change in Europe. Source: *Iglesias et al, 2007.*

Consequences of Climate Change	Type of weather				
Description	**Boreal**	**Atlantic**	**Continental**	**Alpine**	**Mediterranean**
RISK					
Changes in crop area, due to a decrease in optimal conditions for its development		Medium	Medium	Medium	High
Decreased crop productivity		Medium	Medium	Medium	Medium
Increased risk of agricultural pests, diseases, weeds	High	High	High	Medium	High
Decreased crop quality		Medium	Medium		High
Increased risk of flooding	High	High	High	High	
Increased risk of drought and water shortage		High	High	High	High
Increased irrigation needs		Medium	High		High
Deterioration of water quality	High	High		High	
Soil erosion, salinization, desertification	High	Medium	High	High	High
Loss of glaciers and permafrost (soils with ice, which act as a water reservoir)	Medium			High	
Deterioration of the conditions for livestock production	High	Low	Low	High	Medium
Sea level rise	High	High	High		High
OPPORTUNITIES					
Changes of crops distribution to increase agriculture in optimal conditions	High	Medium	High	High	Medium
Increased crop productivity	Medium	Medium		High	
Water availability	High	High		Medium	
Decreased energy costs for greenhouses	Medium	Medium	Medium		Medium
Improvement of livestock productivity	High	High	High	High	

horizon to ensure the food supply for world population in continuous growth.

In addition to facilitating erosion, tillage decreases the organic carbon stored in the soil. This is because organic carbon is released when ploughing and, through oxidation, it becomes CO_2 and is no longer available for crops. Soil can act as an atmospheric carbon sink (Fig. 2.3) if tillage is removed and is permanently covered, what allows the accumulation in the edaphic profile of the atmospheric carbon that crops have got from the atmosphere though photosintesis. On the opposite, when soil is tilled, the process is reversed, there are losses of soil carbon and levels of CO_2 in the atmosphere are increased. This favours climate change which, as explained in the previous section, has an impact on the crops.

One of the consequences of management systems based on tillage is the reduction of the soil sink effect, whose direct consequence is the reduction of the organic carbon content, the main component of organic matter. This organic matter is fundamental in all the processes that occur in the soil and affects its quality, because it improves soil structure, fertility and water holding capacity, and it is, therefore, widely accepted as an indicator of soil quality. Several authors agree that soil alteration through tillage is one of the main causes of soil organic carbon decline *(Six et al., 2004). Reicosky (2011)* argues that intensive agriculture has contributed to the loss of 30% to 50% of soil organic carbon in the last two decades of the 20th century.

Another consequence of intesive tillage is the production of higher emissions of CO_2 into the atmosphere,

both in short-term (inmediately after tillage) and long-term (during the crop season). This is because tillage stimulates the production and accumulation of CO_2 in the porous structure of the soil through processes of mineralization of organic matter. The mechanical action of tillage breaks soil aggregates, with the consequent release of CO_2 stored in the soil and its subsequent emission into the atmosphere *(Pisante et al., 2015).*

Finally, as shown in Figure 2.3, in addition to the CO_2 emissions from soil aggregates breakdown, tillage also implies a higher consumption of fossil fuels, since it includes greater number of tillage passes and a higher mechanical resistance of the soil. Consequently, more emissions are released into the atmosphere, with the potential effect on global climate change.

2.4. International initiatives

In recent years, the attention of decision-makers in the fight against climate change and its consequences has increased the interest in this issue, although there have been some conflicts and reluctance from some people, until scientific evidences have persuaded them.

Scientists were the first to raise the alarm about the threats of climate change. Since the beginning of the nineteenth century natural changes began to be discovered in the paleoclimate and the natural greenhouse effect was identified. From the mid-twentieth century onwards, the increase in CO_2 concentrations in the atmosphere was observed, an increase that has continued up until the present day.

The actions taken at the global level in the fight against climate change by countries members of the IPCC are shown in chronological order in Table 2.3.

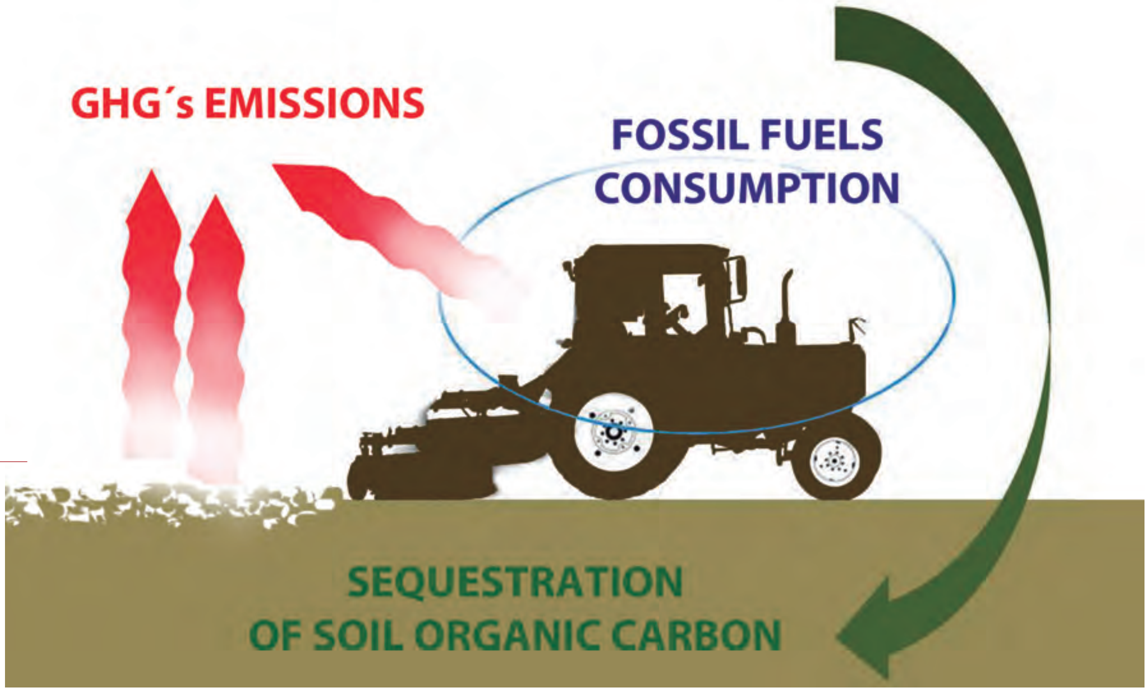


Fig. 2.3. Main greenhouse gasses fluxes and related processes in agriculture, Source: Own elaboration.

The 21st session of the Conference of the Parties (COP21) and the eleventh session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) were held in Paris at the end of 2015. COP21 concluded with the adoption of a landmark agreement to fight climate change and take measures and investments for a low-carbon, resilient and sustainable future.

The main objective of the agreement was to keep the temperature rise in this century below 2 °C above pre-industrial levels and to encourage joint efforts to limit temperature rise even below 1.5 °C, greatly reducing the risks and impacts of climate change. In addition, the agreement sought to strengthen the capacity of society to address the consequences of climate change, while providing developing countries with better and more permanent international aid for the adaptation.

The restoration of degraded agricultural land and the increase in soil carbon emissions play an important role in addressing the threefold challenge of food security, the adaptation to climate change of food systems and people, and the mitigation of human emissions. In this context, the "4/1000 Initiative: Soils for Food Security and Climate", launched by the Government of France at COP21, makes sense.

The 4/1000 Initiative aims to ensure that agriculture plays an important role in the climate change mitigation and adaptation. With the annual growth of 4/1000 (0.4%) of soil organic carbon (SOC), it is sought to show that even a small increase in carbon storage in soils is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term goal of limiting the global average temperature increase to a maximum of 1.5 or 2 °C. By joining the "4/1000 Initiative", stakeholders are committed to making a transition to resilient agriculture through sustainable soil management, that generates jobs and gains, and ensures sustainable development.

At COP22 (Marrakesh, 2016) progress has been made in drafting the implementation rules, or manual, of the Paris Agreement. The agreement requires a significant improvement in the transparency of actions, including, among others, the measurement and accounting of emission reductions or the provision of funding to address climate change, and technology development and transfer.

It also includes designing communications on adaptation, which is the main vehicle for sharing individual adaptation efforts and meeting needs within the framework of the Paris Agreement.

Table 2.3. Chronology of global actions on climate change. Source: *website of the United Nations Framework Convention on Climate Change (UNFCCC). http://unfccc.int/.*

Climate process in retrospect	
1979	The first World Climate Conference is held.
1988	The Intergovernmental Panel on Climate Change (IPCC) is established.
1990	The first IPCC evaluation report is published. The IPCC and the second World Climate Conference call for a global treaty on climate change. Negotiations of the General Assembly of the United Nations begin on a framework convention.
1991	The first meeting of the Intergovernmental Negotiating Committee (ICN) is held.
1992	The ICN adopts the text of the Climate Convention. At the Rio de Janeiro Earth Summit, the UN Framework Convention on Climate Change (UNFCCC) is now ready for signature in conjunction with the Convention on Biological Diversity (UNCBD) and the Convention to Combat Desertification (UNCCD).
1994	The United Nations Framework Convention on Climate Change enters into force.
1995	The first Conference of the Parties (COP1) is held in Berlin.
1996	The secretariat of the Convention is established to support the actions of the Convention.
1997	The Kyoto Protocol is officially adopted at COP3 in December.
2001	The third IPCC evaluation report is published. The Bonn Agreements are adopted following the 1998 Buenos Aires Plan of Action. The Marrakech Accords are adopted at COP7, which details the rules for implementing the Kyoto Protocol. The Buenos Aires Program of Work on adaptation and response measures at COP10 is agreed.
2004	The Work Program of Buenos Aires on adaptation and response measures at COP10 is agreed.
2005	Kyoto Protocol enters into force. The first meeting of the Parties on the Kyoto Protocol (CMP1) is held in Montreal. In accordance with the requirements of the Kyoto Protocol, the Parties start negotiations on the next phase of the Kyoto Protocol under the Special Working Group on Further Commitments of Annex I Parties under the Kyoto Protocol (GTE- PK).
2006	The Nairobi work program is adopted.
2007	The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) is published. The public is sensitized about the science of climate change. At COP13, the Parties agree on the Bali Road Map, which marks the path towards an improved situation after 2012 through two working streams: the Ad Hoc Working Group on New Commitments under the Kyoto Protocol (GTE-PK) and another working group established under the Convention, the Ad Hoc Working Group on Long-term Cooperation (AWG-LCA).
2009	The drafting of the Copenhagen Accord at the COP15 in Copenhagen begins. The Conference of the Parties “takes note” of it and subsequently countries submit non-binding emission reduction pledges or promises of mitigation measures.
2010	The Cancun Agreements are drafted and widely accepted by the COP at COP16. In these agreements the countries formalize the promises they had made in Copenhagen.
2011	Seventeenth Conference of the Parties (COP17) in Durban, South Africa.
2012	Eighteenth Conference of the Parties (COP18) in Doha, Qatar. The Doha amendment on the Kyoto Protocol is adopted by the WPC at WPC 8. A number of decisions are made to open a door to greater ambition and action at all levels.
2013	The key decisions taken at COP19 / CMP 9 in Warsaw include decisions on the progress of the Durban Platform, the Green Fund for Climate and Long-term Finance, the Warsaw Framework for REDD Plus and the International Mechanism for Loss and Damage. Under the Durban Platform, Parties agree to submit “planned national contributions”, known as INDC.
2014	At COP20 hold in Lima in 2014, Parties adopt the “Call to Action in Lima”, which develops key elements of the next agreement in Paris.
2015	In December 2015, intensive negotiations are held within the framework of the Ad Hoc Group on the Durban Platform for Action for the period 2012-2015, culminating in the adoption of the Paris Agreement (COP21).
2016	As a continuation of the Paris Agreement the COP22 is celebrated in Marrakech.

Scientists were the first to raise the alarm about the threats of climate change

2.5. Agriculture and the Paris Agreement in numbers

The Paris Agreement *(UN, 2015)* aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

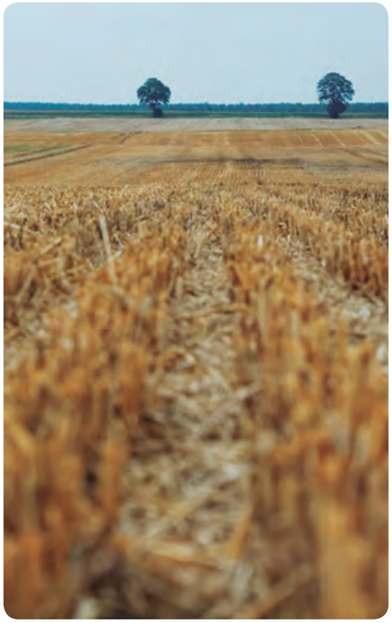
1. Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
2. Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and
3. Making finance flows consistent with a pathway towards climate-resilient development and low greenhouse gas emissions.

The EU has committed itself to a binding target of reducing greenhouse gas emissions by 40 % from 1990 levels by 2030. With this commitment, the EU intends to:

- Take measures to achieve its long-term goal of reducing emissions by 80-95% by 2050.
- Make a fair and ambitious contribution to the new international climate agreement, to take effect in 2020.

To achieve reduction target of at least 40% by 2030, compared to 1990 levels, a reduction in emissions has been planned in two areas:

- EU Emissions Trading System (ETS) sectors should reduce emissions by 43% by 2030 compared to 2005.
- EU non-Emissions Trading System (non-ETS) sectors should reduce emissions by 30% by 2030 compared to 2005.



Agriculture is a non-ETS sector and, by reducing its emissions, it collaborates to reach the binding objectives to which each of the Member States has committed in non-ETS sectors (Fig. 2.4) (Table 2.4).

In Table 2.4 are shown figures of emissions and reduction of emissions for non-ETS sectors and specifically for agriculture, where the implementation of CA would have a direct impact.

Fig. 2.4. Percentage reduction of national emissions from sectors not included in the EU ETS (non-ETS). Source: *Euroefe, 2017.*

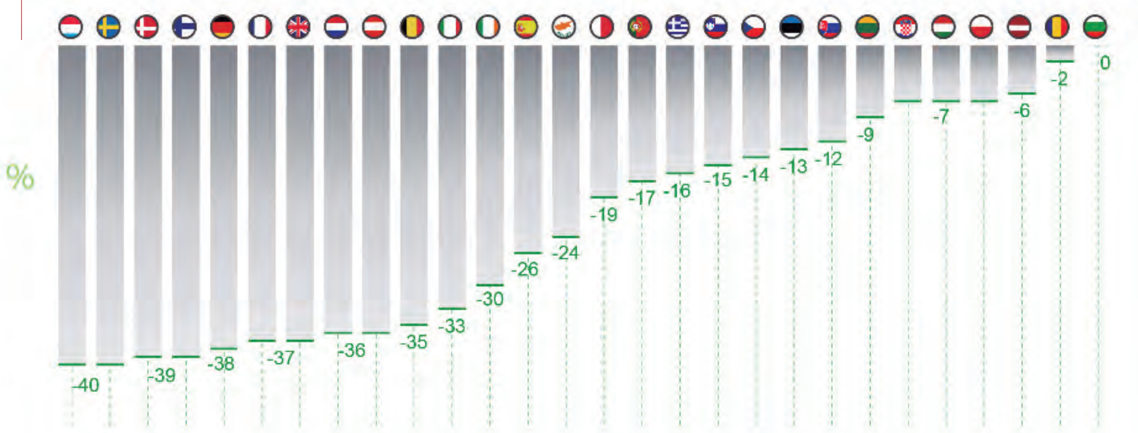


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Table 2.4. 2005 non-ETS emissions in 28 EU member countries, binding reductions of member countries and emission commitments by 2030. *Sources: Eurostat, 2016a; Eurostat, 2016b; EC, 2016 and own calculations.*

	Non-ETS emissions in 2005 (t)	Agriculture emissions in 2005 (t)	Reduction (%)	Non-ETS Reduction (t)	Non-ETS emissions by 2030 (t)	Agriculture reduction (t)	Agriculture emissions by 2030 (t)
Austria	56,670,000	7,017,070	36	20,401,200	36,268,800	2,526,145	4,490,925
Belgium	78,200,000	10,243,990	35	27,370,000	50,830,000	3,585,397	6,658,594
Bulgaria	24,570,000	5,023,300	0	0	24,570,000	0	5,023,300
Croatia	16,820,000	2,951,820	7	1,177,400	15,642,600	206,627	2,745,193
Cyprus	4,180,000	630,240	24	1,003,200	3,176,800	151,258	478,982
Czech Republic	62,550,000	8,334,900	14	8,757,000	53,793,000	1,166,886	7,168,014
Denmark	40,080,000	10,965,760	39	15,631,200	24,448,800	4,276,646	6,689,114
Estonia	5,430,000	1,083,230	13	705,900	4,724,100	140,820	942,410
Finland	33,600,000	6,413,810	39	13,104,000	20,496,000	2,501,386	3,912,424
France	395,590,000	78,482,950	37	146,368,300	249,221,700	29,038,692	49,444,259
Germany	468,440,000	62,919,510	38	178,007,200	290,432,800	23,909,414	39,010,096
Greece	61,780,000	8,769,530	16	9,884,800	51,895,200	1,403,125	7,366,405
Hungary	46,380,000	6,127,520	7	3,246,600	43,133,400	428,926	5,698,594
Ireland	47,520,000	19,192,190	30	14,256,000	33,264,000	5,757,657	13,434,533
Italy	329,140,000	33,124,200	33	108,616,200	220,523,800	10,930,986	22,193,214
Latvia	8,520,000	2,270,810	6	511,200	8,008,800	136,249	2,134,561
Lithuania	10,780,000	3,747,480	9	970,200	9,809,800	337,273	3,410,207
Luxembourg	10,130,000	637,120	40	4,052,000	6,078,000	254,848	382,272
Malta	1,030,000	102,900	19	195,700	834,300	19,551	83,349
Netherlands	122,880,000	18,746,440	36	44,236,800	78,643,200	6,748,718	11,997,722
Poland	176,010,000	29,322,120	7	12,320,700	163,689,300	2,052,548	27,269,572
Portugal	49,530,000	7,297,630	17	8,420,100	41,109,900	1,240,597	6,057,033
Romania	73,030,000	19,756,660	2	1,460,600	71,569,400	395,133	19,361,527
Slovakia	22,300,000	3,113,680	12	2,676,000	19,624,000	373,642	2,740,038
Slovenia	11,850,000	1,781,970	15	1,777,500	10,072,500	267,296	1,514,675
Spain	233,840,000	38,086,750	26	60,798,400	173,041,600	9,902,555	28,184,195
Sweden	42,900,000	7,228,670	40	17,160,000	25,740,000	2,891,468	4,337,202
United Kingdom	414,710,000	45,813,070	37	153,442,700	261,267,300	16,950,836	28,862,234
Total Europe	2,848,460,000	439,185,320		856,550,900	1,991,909,100	127,594,678	311,590,642

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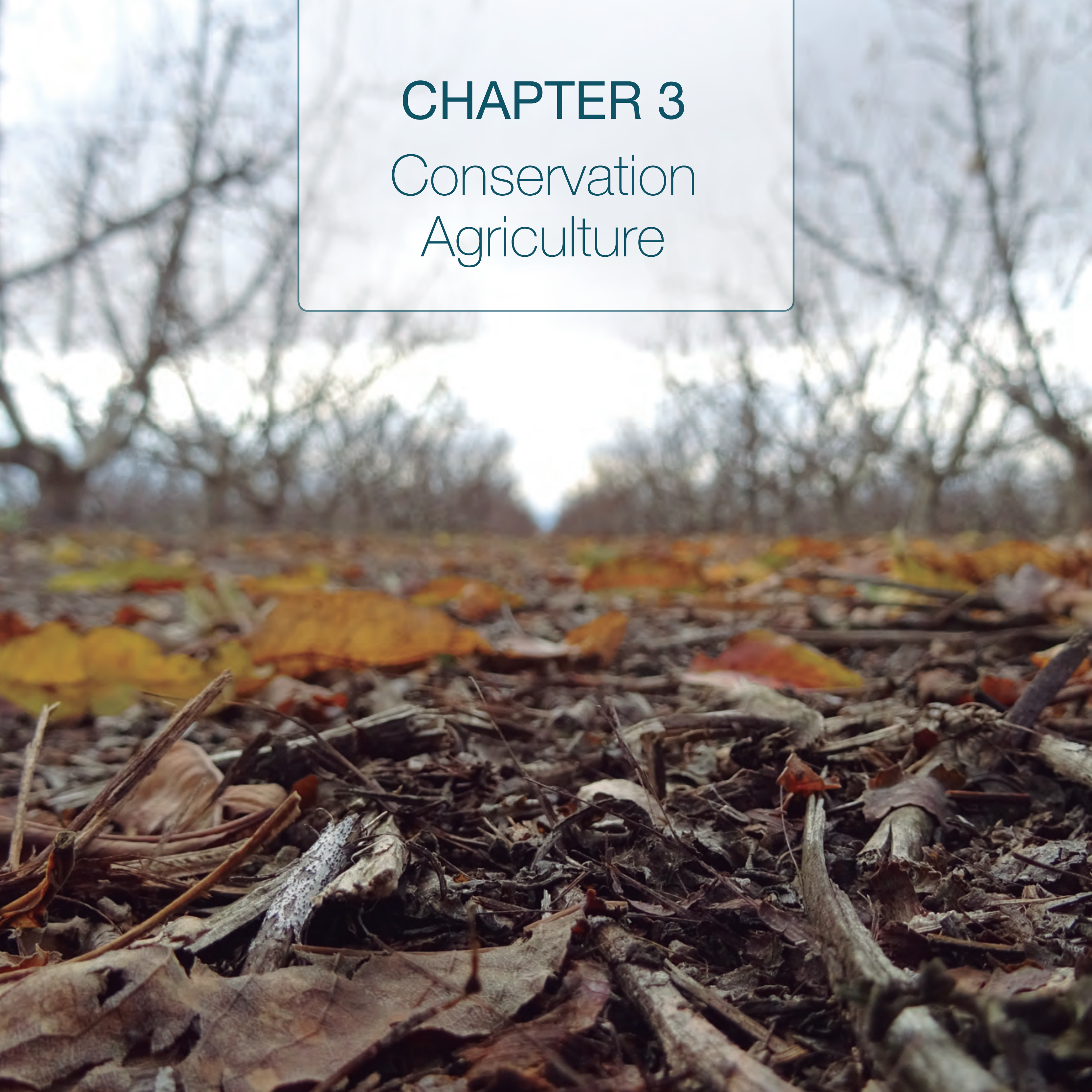
CHAPTER 3

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:

- No or minimum soil mechanical disturbance. In practice, this means no-till seeding and weeding.
- Permanent soil cover. In other words, it means to maintain crop residues and 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. 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.
- Cropping system diversification through rotations, sequences and associations involving annuals and perennials. 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.

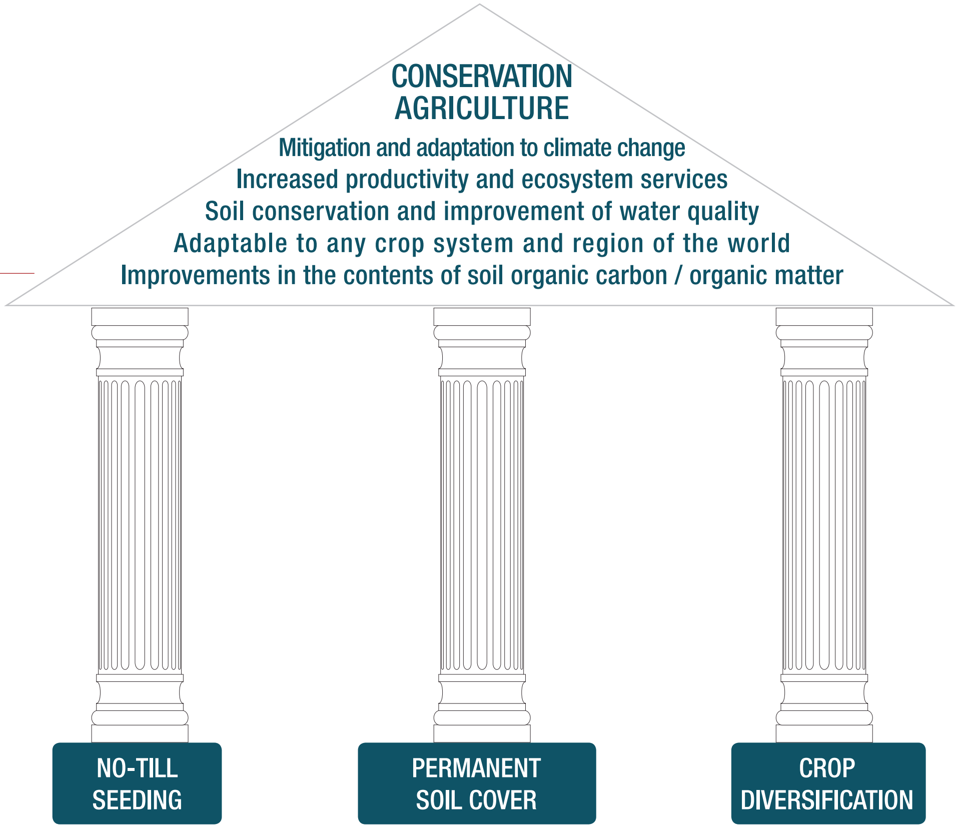


Fig. 3.2. Areas of the countries with the major uses of no-till farming practices. Source*:* *Laurent, 2015.*

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 manage-ment	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.

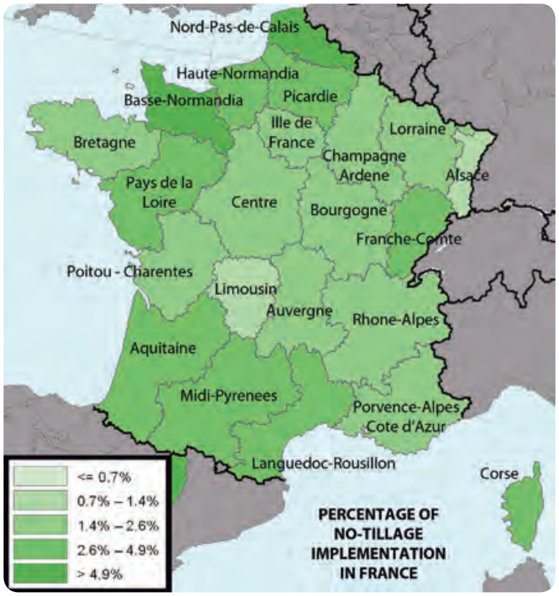


Fig. 3.3. NT percentage in comparison to the total area with annual crops in different French regions. Source: *Eurostat, 2010.*

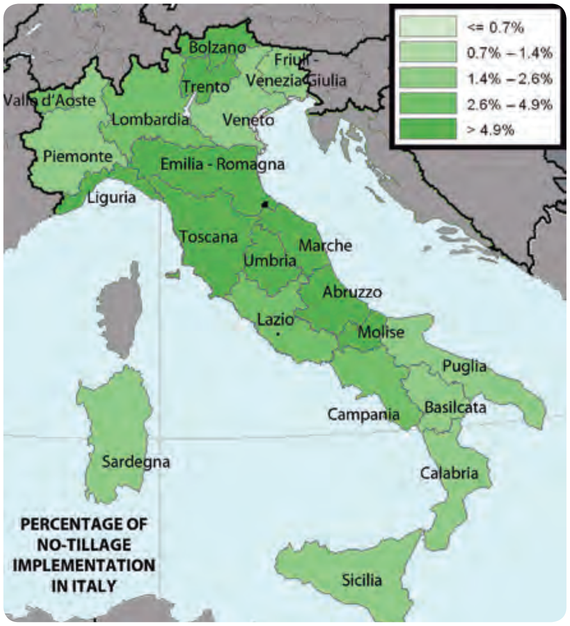


Fig. 3.5. NT percentage in comparison to the total area with annual crops in different Italian regions. Source: *Eurostat, 2010.*

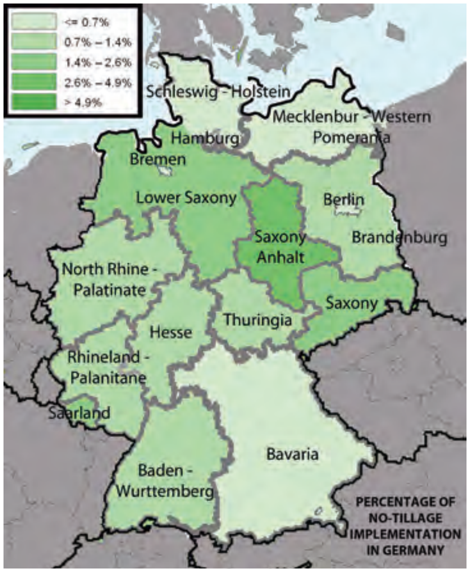


Fig. 3.4. Percentage of application of NT in comparison with the area covered by annual crops in the federal states of Germany. Source: *Eurostat, 2010.*

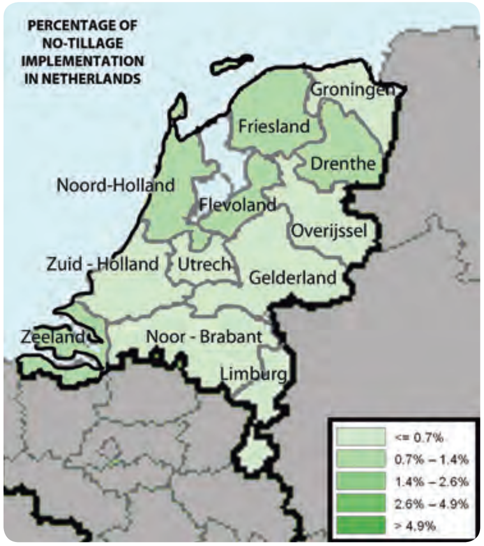


Fig. 3.6. NT percentage in comparison to the total area with annual crops in different Dutch regions. Source: *Eurostat, 2010.*

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%).

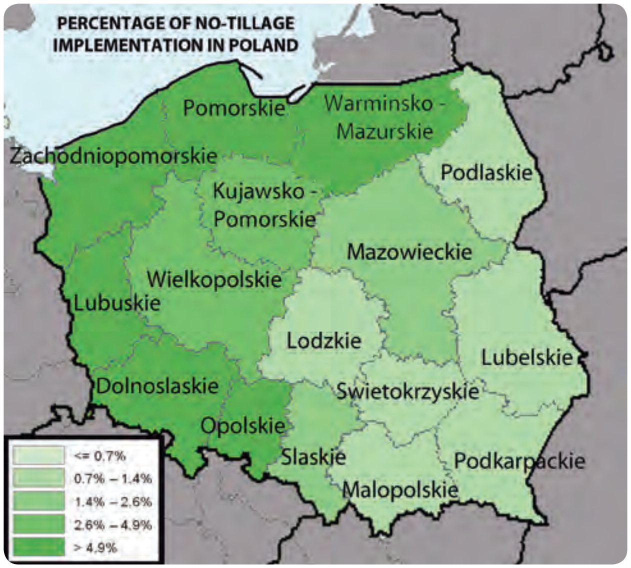


Fig. 3.7. NT percentage in comparison to the total area with annual crops in different regions of Poland. Source: *Eurostat, 2010.*

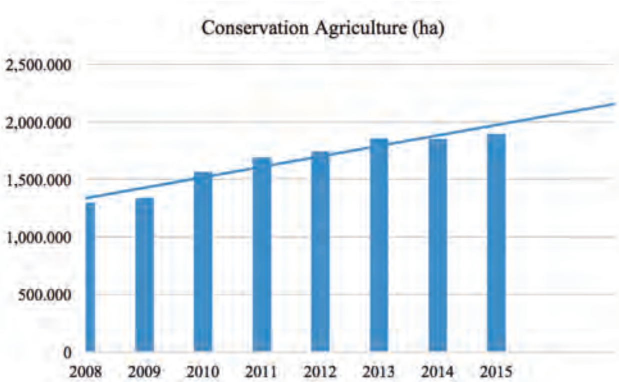


Fig. 3.8. Evolution of CA in Spain. Source: *MAPAMA (2009 to 2016).*

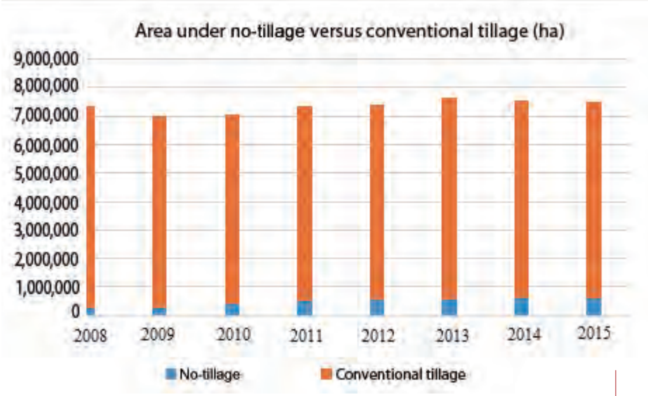


Fig. 3.9. Comparison of surface in no-till farming to conventional tillage in Spain. Source: *MAPAMA (2009 to 2016).*

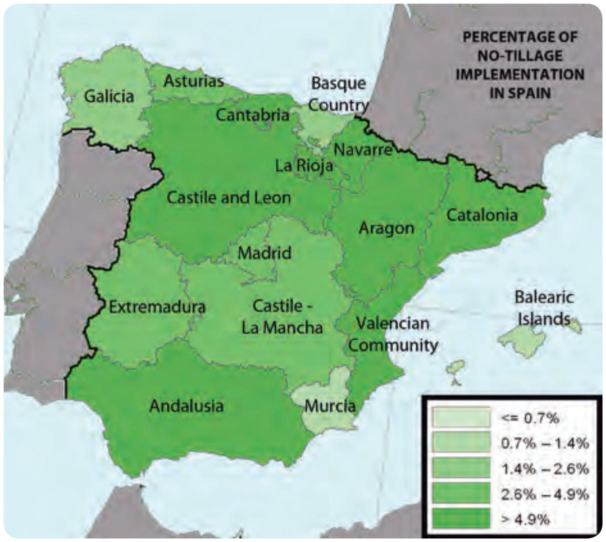


Fig. 3.10. Percentage of NT application regarding the annual crops area in the autonomous communities of Spain. Source: *Eurostat, 2010.*

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

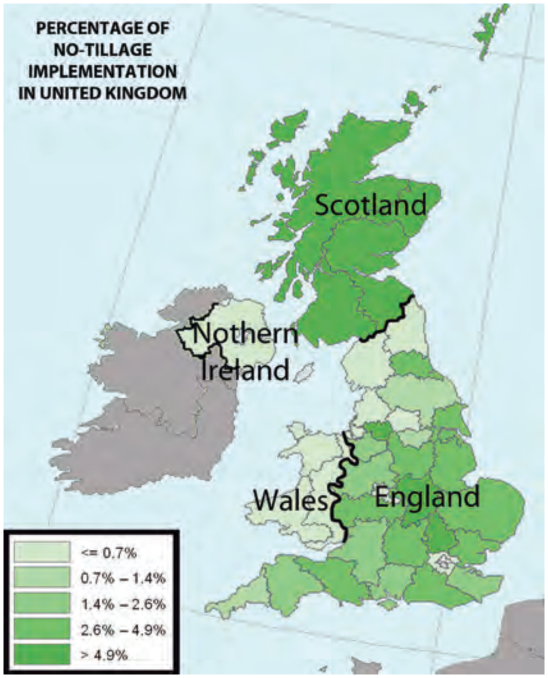


Fig. 3.11. NT percentage in comparison to the total area with annual crops in different regions of the United Kingdom. Source: *Eurostat, 2010*.

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.

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.

Fig. 3.15. Cutting disc.

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

Fig. 3.20. Seed drill equipped with tines.

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

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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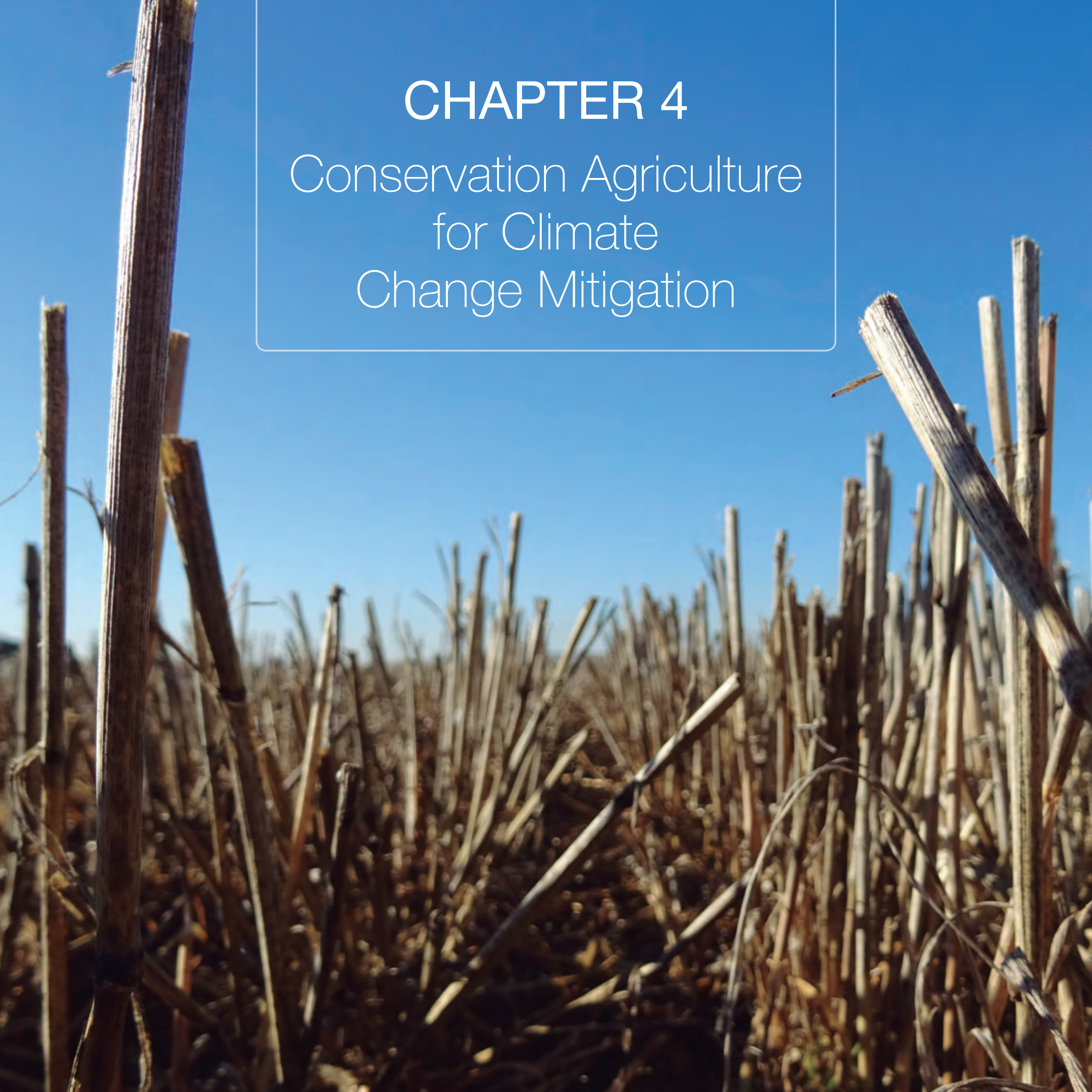
CHAPTER 4

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:

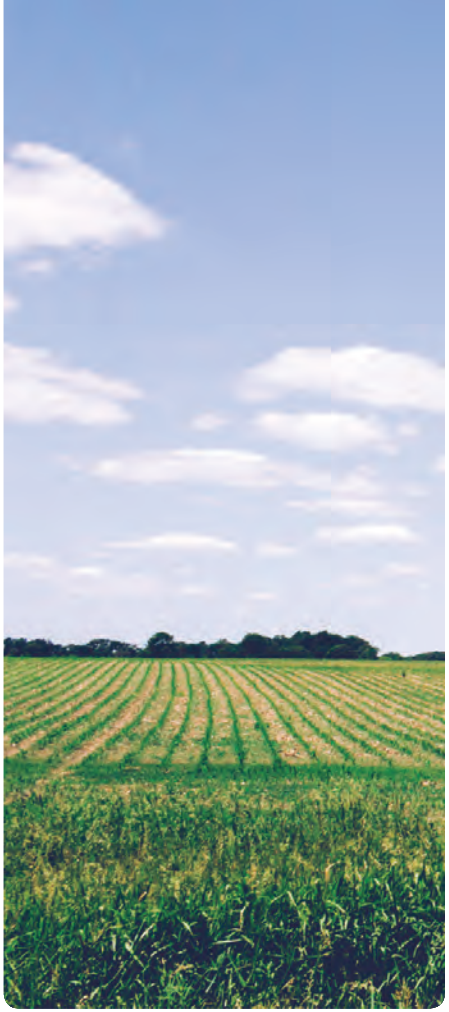
- The lower input of OM in the form of crop stubble.
- The higher humus mineralization rate caused by tillage. Tillage facilitates the penetration of air into the soil and therefore

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.

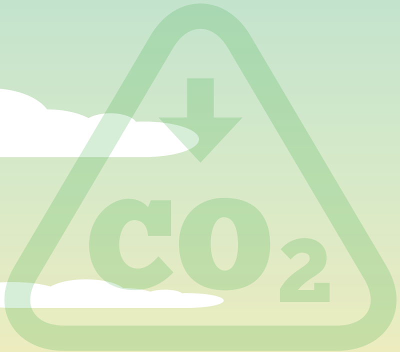
- The higher rate of erosion, which causes significant losses of OM and minerals. In conventional agriculture, the preparation of soil for sowing leaves the soil exposed to erosive agents for a long period of time.

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 20th 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.

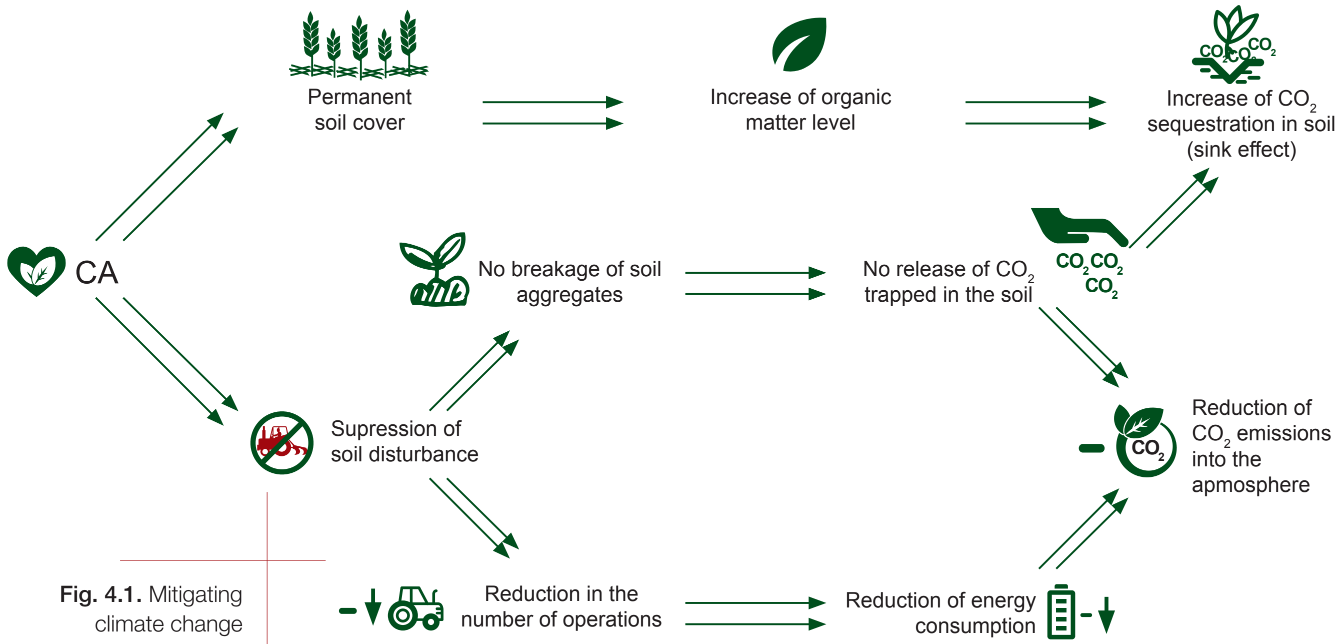


Fig. 4.1. Mitigating climate change mechanisms in Conservation Agriculture. Source: own elaboration.

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,

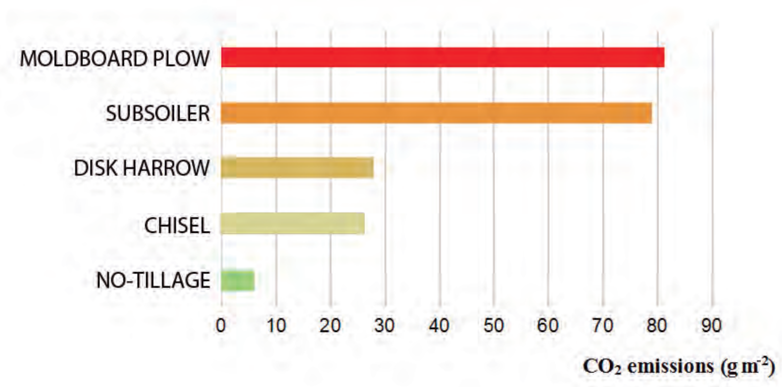


Fig. 4.2. Accumulated CO_2 emissions (g m^{-2}) 5 hours after the tillage. Source: *Reicosky (1997).*

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.

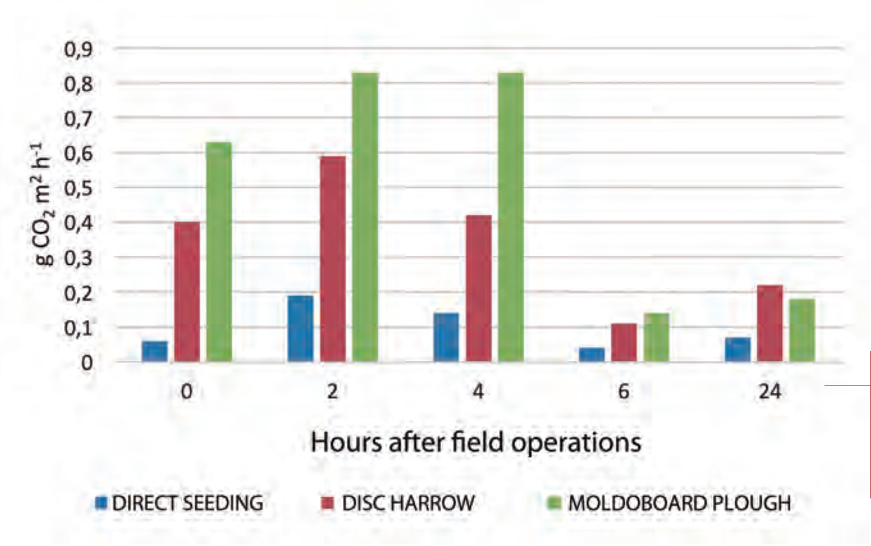


Fig. 4.3. Increase of CO_2 emissions per hour during the tillage operations on the soil in the different cropping systems. (Each value represents the average of 14 readings). Source: *Carbonell-Bojollo et al., (2011).*

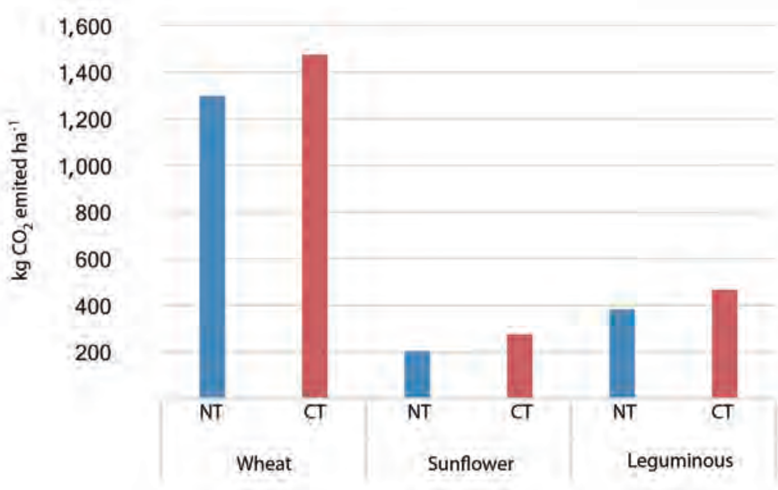


Fig. 4.4. CO_2 emissions for each crop as a result of the energy consumption in the performed farming operations: no-tillage (NT) and Conventional-tillage (CT). Source: *LIFE + Agricarbon Project, 2014.*

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).

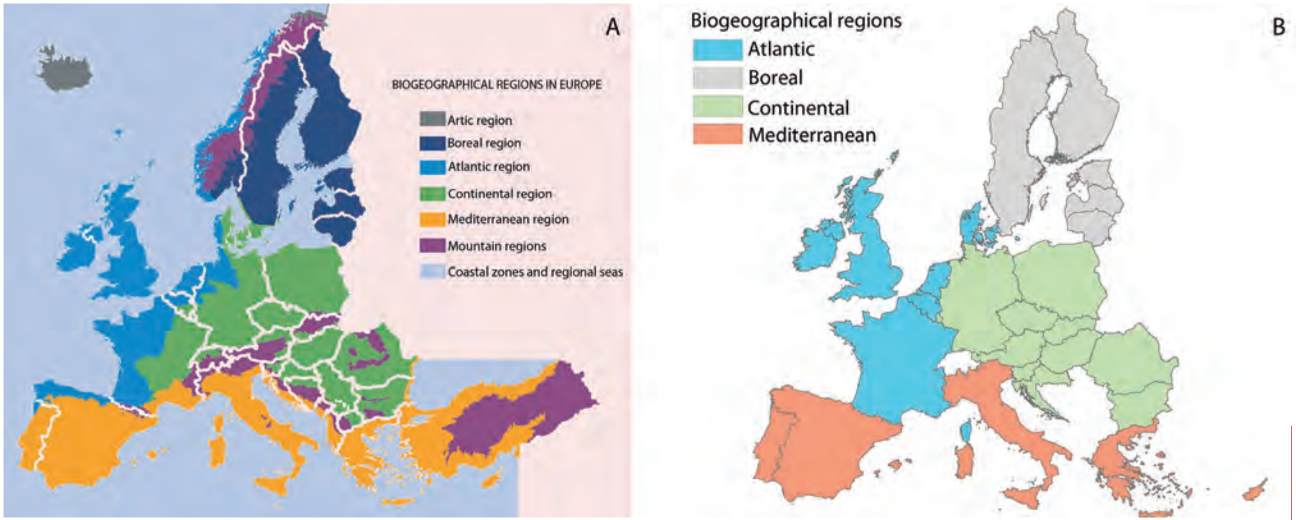


Fig. 4.5. Classification of European countries (B) according to the European biogeographic region (A) (EEA, 2012), they belong to.

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**

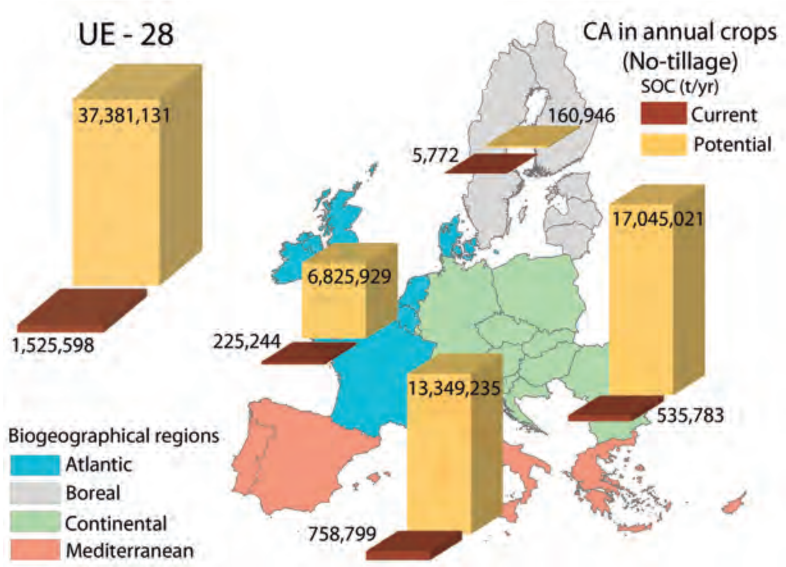


Fig. 4.6. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

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.

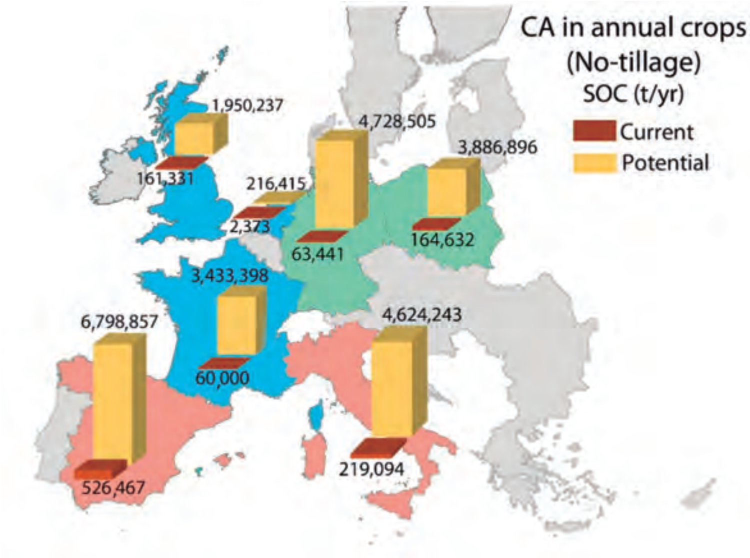


Table 4.5. Area under CA in permanent crops (groundcovers)in Europe, carbon sequestration potential per biogeographic region or country, and actual and potential carbon/CO_2 fixation through groundcovers (1 ton of Corg corresponds to 3.7 tons of CO_2).

	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**

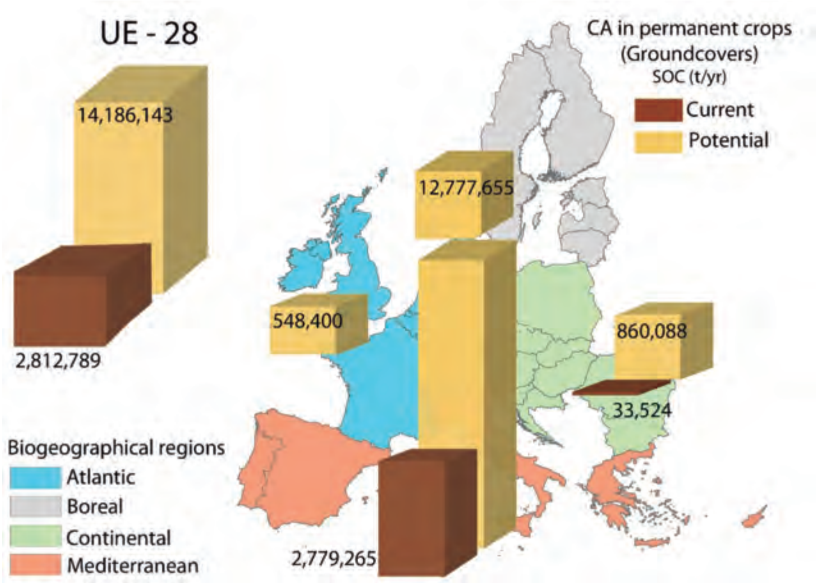
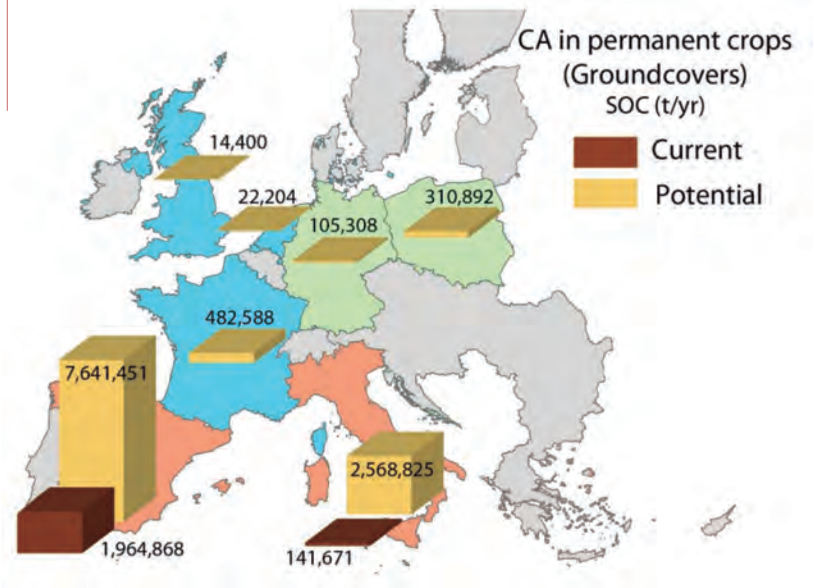


Fig. 4.8. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

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**

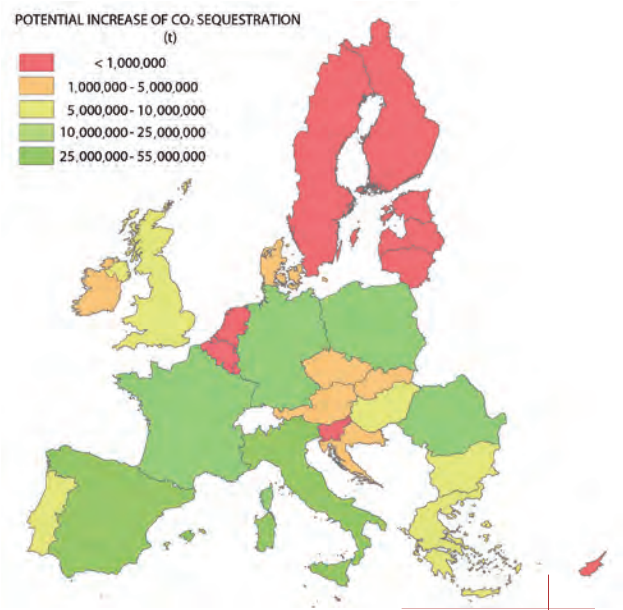


Fig. 4.10. Potential increase (potential – current) of CO_2 sequestration in Europe through CA.

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. 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

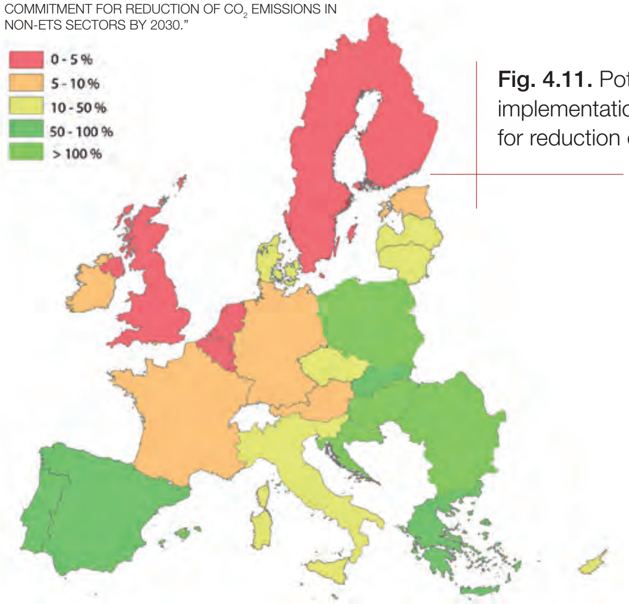


Fig. 4.11. Potential CO_2 sequestration due to the implementation of CA as a percentage of the commitment for reduction of CO_2 emissions in non-ETS sectors by 2030.

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%).

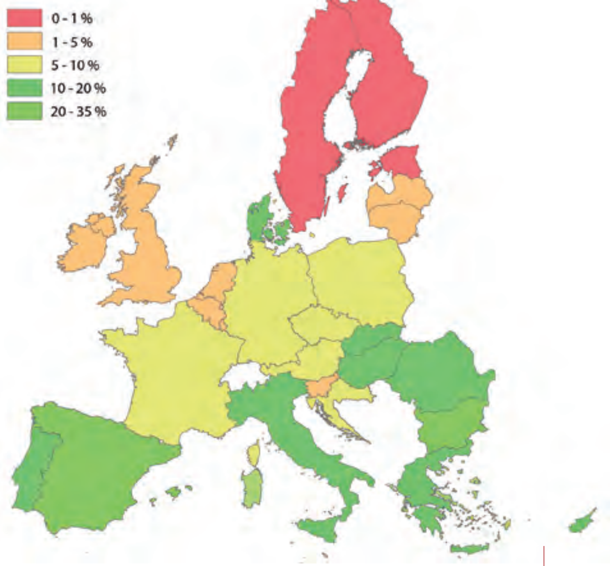


Fig. 4.12. Potential CO_2 sequestration due to the implementation of CA as a percentage of allowed CO_2 emissions in non-ETS sectors by 2030.

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 %

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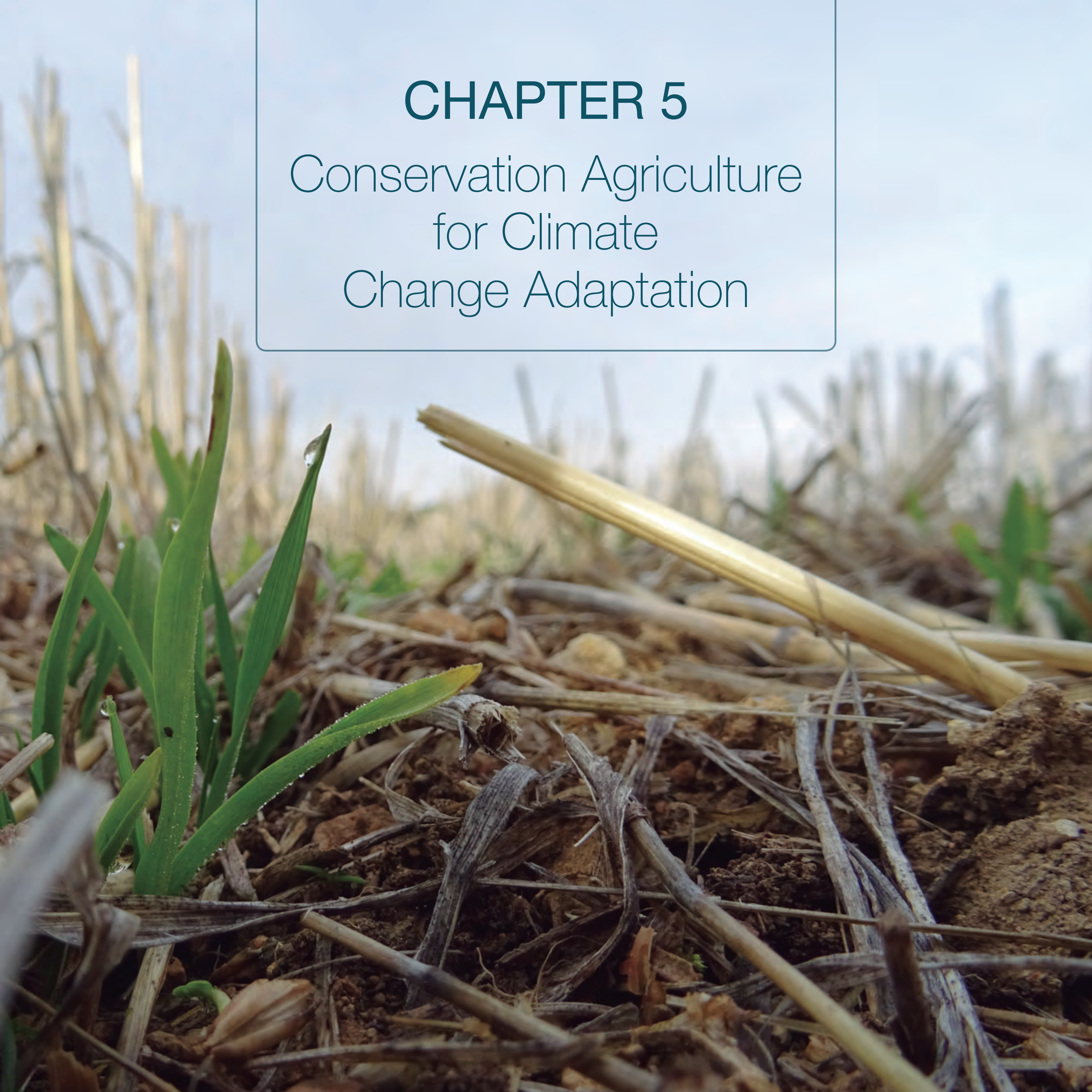
CHAPTER 5

Conservation Agriculture for Climate Change Adaptation



5.1. Introduction

As described in previous chapters, climate change impacts on all types of ecosystems, especially on the agricultural ones. In addition to the environmental consequences that this phenomenon generates, it has a great influence on the economic and social areas, taking into account the great interrelation they have with human activities.

Therefore, it is not only important to adopt strategies to mitigate phenomena which increase climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to reduce their vulnerability to the potential consequences of global warming, favouring the adaptation of crops to new climatic scenarios.

The term “adaptation” refers to all adjustments that need to be made in a system (in our case, in the agricultural system) to better respond to actual or anticipated changes resulting from climate change, and taking advantage of the opportunities given by the new climatic scenarios.

Farmers, in their daily work, have always had to make decisions to adapt their crops to the changing weather conditions that can occur in different seasons. So far, these decisions have been based on the *crop pattern alteration* or changes in crop management, but it seems that these measures will not be enough to face the expected short and medium term impacts, which are the consequences that climate change will have on agricultural ecosystems.

The adaptation strategies must be related to the expected changes according to the considered agroclimatic region, because the measures that can be adopted in a region of continental climate will be completely different from those adopted in a region with a subarctic climate. Adaptation means looking for strategies at the local level to respond to a global problem. The areas in which such strategies can be encompassed in the agricultural sector range from the means of agricultural and livestock production, market structure, risk assessment of climate change in the farm or the space related to the public support instruments.

Previous chapters have already cited the regional consequences of climate change in agro-climatic regions and the risks that this will have on agricultural ecosystems. In the present chapter, an analysis of these effects will be carried out taking into account the climate phenomenon and the solutions to some of these effects will be provided by Conservation Agriculture.

5.2. Key factors for adaptation of agricultural ecosystems to climate change: increased resilience

The options for adapting crops to the scenarios caused by climate change will increase the resilience of the ecosystems in which they are developing. The term “resilience” refers to the responsiveness of the medium to a disturbing agent or a harmful condition, minimizing the impact of such a situation and adapting to it.

In order to establish the premises for adaptation strategies based on increasing resilience of agricultural ecosystems, the effects of climate change on these ecosystems and the climate phenomenon that causes those effects must be identified first, because the measures which should be adopted have to respond effectively to those changes. The ways to respond could be, either mitigating them directly, or creating a response in the environment and natural resources on which it depends, counteracting the negative effects.

Table 5.1 summarizes the main expected effects on the agricultural ecosystems of the different phenomena of climate change, in each of the factors involved in agricultural production.

Table 5.1. Main effects of climate change on the factors involved in agricultural production. Source: *UNEP/Grid-Arendal and The Spanish Ministry of Agriculture, Food and Environment (MAGRAMA, 2009).*

CLIMATE PHENOMENON	CROPS	WATER RESOURCES	SOIL	AIR
TEMPERATURE CHANGE	Increased production in colder environments Decreased production in warmer environments Increased incidence of pests	Reduction of water supply	Increased soil temperature in warmer environments	Increased evapotranspiration demand in warmer environments
HEAT WAVES / HOT PERIODS	Reduction of production in hot regions Increased fire risk	Increased demand for water	Reduction in moisture content in the soil profile Release into the atmosphere of carbon stored in the soil	Increased evapotranspirative demand
EVENTS OF HEAVY PRECIPITATION	Damage to crops Cultivation difficulties because of waterlogging	Adverse effects on surface and ground water quality Pollution of water supplies	Increased erosion Reduction in organic matter content	
DROUGHT	Crop damage and loss Increased fire risk	More widespread water stress	Soil degradation Increased erosion Reduction in organic matter content Release into the atmosphere of carbon stored in the soil	Increased evapotranspirative demand
CYCLONES AND CYCLONIC SEASONS	Crop damage and loss		Soil degradation Increased erosion Reduction in organic matter content	

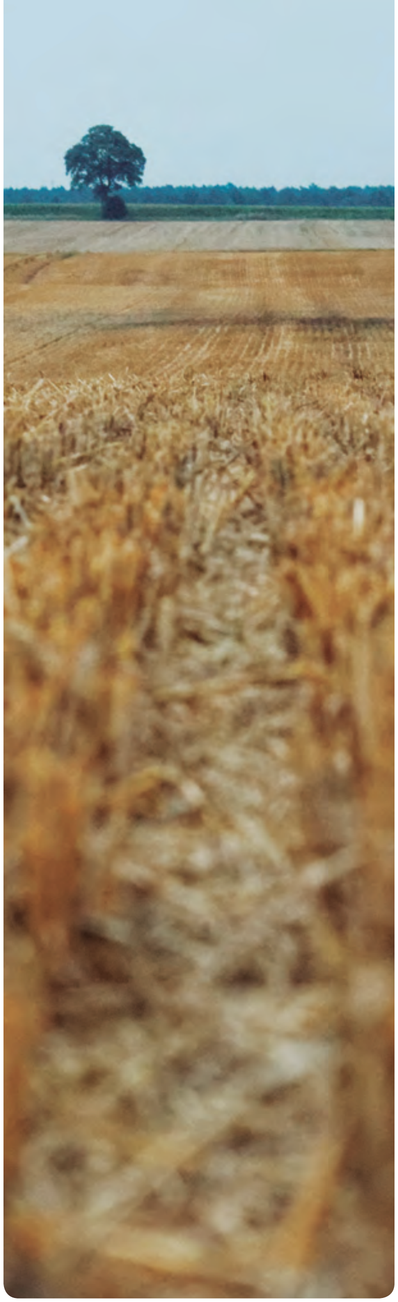
Taking into account the expected effects, it is possible to undertake various actions aimed at improving the quality of natural resources and biodiversity, which will result in an increase in the resilience of agricultural ecosystems, improving adaptation of crops to climate change (Table 5.2). In many cases, as will be seen a posteriori, many of these actions can be carried out implementing Conservation Agriculture practices, thus constituting not only a feasible tool to mitigate the effects of climate change, as described in the previous chapter, but also, as a measure of adaptation to its effects.

Table 5.2. Possible actions to increase resilience of agrarian ecosystems and agricultural techniques whose application involves adaptation of these actions. Source: Own elaboration.

Natural Resource	Actions to increase resilience	Agricultural techniques
WATER	Increased infiltration Reduced runoff Optimization of water use Improvement of soil water balance	Conservation Agriculture Deficit irrigation Precision farming Improvement of irrigation infrastructures and pipelines Use of irrigation monitoring systems Implantation of green filters, buffer strips, vegetation in the margins of the plot (multi-functional margins)
SOIL	Reduced runoff Increase in organic carbon (organic matter) Improvement of structure Increased soil fertility	Conservation Agriculture High flotation tires Soil health cards
BIODIVERSITY	Increase in the epigeal fauna Improvement of conditions for the habitability of steppe birds Increase in pollinating species	Conservation Agriculture Use of integrated fighting Implantation of green filters, buffer strips, vegetation in the margins of the plot (multi-functional margins)
CROPS	Increased resistance to drought Escape from water stress Reduction of weed invasion Reduced incidence of pests and diseases	Crop rotation Use of varieties resistant to drought Advancement of planting date Use of native varieties Crop cycle variation Use of integrated fighting

5.3. Conservation Agriculture: basis for crops adaptation to climate change

According to *Lal (2010),* Conservation Agriculture is a good strategy not only to mitigate climate change, but also to adapt agricultural ecosystems to their effects, by increasing crop resilience facing climatic variations. Thanks to its implantation, erosion is reduced, the quality and fertility of the soil is improved and the erosion is reduced, allowing the crop to have more water in dry periods. All this makes the responsiveness to climate changes greater and therefore crops under Conservation Agriculture systems have a better capacity of adaptation.



5.4. Conservation Agriculture and water resource improvement

As water is a scarce and in many cases a limiting resource, it is fundamental to manage the agricultural production system (Fig. 5.1) for the maximum harnessing of available water. So, in irrigated agricultural production systems, both agronomic and hydraulic strategies should aim to improve aspects such as the distribution and efficiency of irrigated water, while in the rainfed land, these strategies should be focused on maximizing the uptake of water and its use by plants.

The adoption and development of Conservation Agriculture practices lead to a number of benefits in the management of water used in the agricultural ecosystem, as well as increasing the availability of this resource for the crops and improving of its quality (Fig. 5.2).

Regarding advantages offered by Conservation Agriculture related to adaptation to climate change, this management system will be particularly interesting in ecosystems with a decrease in water resources availability or in those regions, in which, due to the increase of extreme precipitation events, the phenomena of runoff are increased.

On the basis of studies published by the European Environment Agency (EEA, 2012), it is expected, at European level, a reduction in precipitation in the Mediterranean and Continental regions. Therefore, there will be an increased demand for water resources in agriculture in the Mediterranean regions, which will make them especially vulnerable to the lack of water. On the other hand, an increase in extreme precipitation events in the Atlantic regions is expected, which will affect water quality and erosion.

Regarding water balance of the soil-cropping system, the existing studies determine that CA systems improve the uptake, conservation and use of available water in the soil by the crops, thanks to the fact that it favours

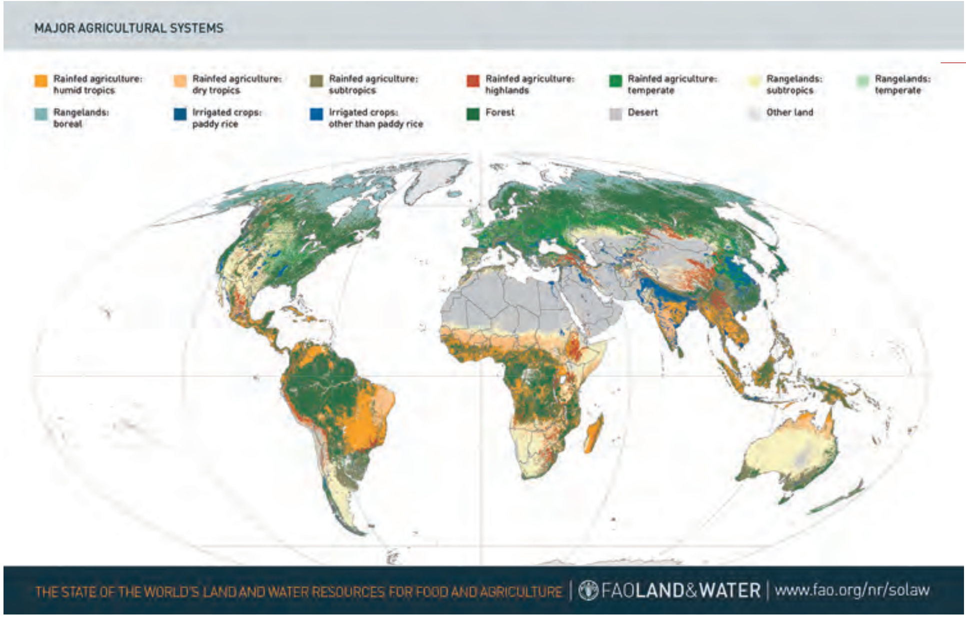


Fig. 5.1. Major agricultural systems. Source: *FAO, 2011.*

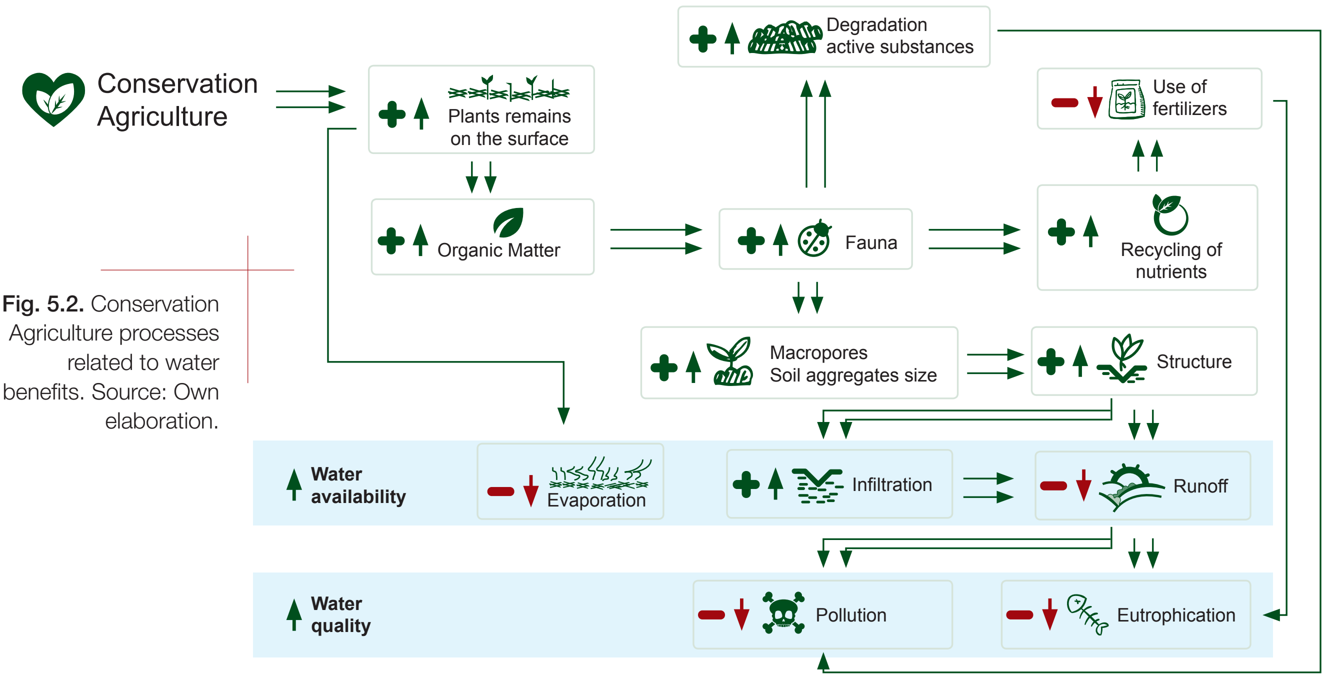


Fig. 5.2. Conservation Agriculture processes related to water benefits. Source: Own elaboration.

The carbon sequestration due to the adoption of CA across Europe would be equivalent to the emissions saving obtained by the installation of over **43,000** wind turbines.

infiltration, reduces runoff, increases water holding capacity and reduces evaporation. All this is achieved due to the maintenance of crop residues, which effects are described in Table 5.3.

Thus, thanks to the maintenance of crop residues on the soil, which could be either residues of the previous crop or living cover crops that maintain their root systems, the direct impact of raindrops is minimized, the infiltration is improved and the runoff is reduced. The greater the soil coverage the greater the reduction in water runoff.

5.4.1. Reduced runoff and increased infiltration and water-retention capacity

In Conservation Agriculture, runoff is reduced due to an increase in water infiltration because of the structural improvements stemed from Conservation Agriculture techniques along with the large amount of crop residues on the soil that slows the flow of water on the surface, preventing the formation of crusts which limit the infiltration of water.

Thus, due to the presence of soil covers, the speed of the water on soil surface decreases, reducing the runoff and increasing infiltration. In addition, having the soil covered protects it from the direct impact of raindrops, which are responsible for aggregates disintegration in bare soils, thereby producing a surface crusting, that limitis water infiltration and increases water runoff.

Several studies at the global level analyse the reduction of runoff occurring in Conservation Agriculture systems, with a decrease of 67% in no-till in annual crops (*Kertész et al., 2010*) and 43% using groundcovers in permanents crops (*Márquez et al., 2010*).

On the other hand, the increase in the infiltration rate that occurs in soils managed under Conservation Agriculture practices, improves water availability after rain periods, which is not the case in soils managed under a tillage-based system *(De Vita et al., 2007)*. Therefore, several studies have analysed the effects of soil management on dynamics and conservation of water.

According to *López-Garrido (2010),* in soils under Conservation Agriculture practices, the volumetric water

Table 5.3. Effects of permanent soil covers on edaphic moisture. Source: Own elaboration.

Effects	Direct causes	Indirect causes
Increase in infiltration-reduction of runoff	Greater retention of rainwater in permanent soil covers.	Through the increase of OM, soil struture is improved.
	Protection of the soil against the impact of raindrops.	Increased soil fauna (earthworms), which generate galleries and pores, favoring the circulation of water.
Reduction of evaporation	No direct incidence of radiation on wet soil.	
	Reduction of evaporation to the atmosphere.	

content of the first 20 cm is higher than in soils under CT practices. In addition, *Muriel et al. (2005)* concluded that CA techniques not only allow a greater retention of water in the soil profile, especially in the first 30 cm of depth, but also slow down the water discharge rate, which has a positive impact on the development of spring-summer crops, where the limiting factor of production is undoubtedly the lack of water. Fig. 5.3 shows the evolution of moisture contents for two soil management systems (NT: no-tillage and CT: conventional tillage). It not only shows higher water recharge given in NT system, but also greater soil discharge in the second part of the growing season, because in that case, and thanks to the greater availability of water, the crop is able to better satisfy the growing evapotranspiration demand which occurs in spring and summer.

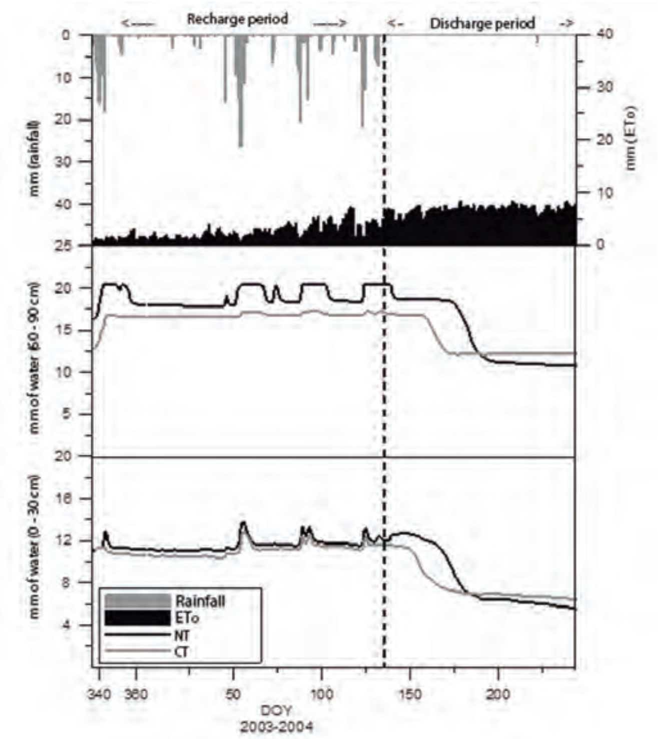


Fig. 5.3. Evolution of moisture content in two soil management systems. (NT: no-tillage and CT: conventional tillage). Source: *García-Tejero et al. (2010).*

Troccoli et al. (2009b) at CREA-CER carried out a field trial on a monoculture of durum wheat comparing conventional tillage and no-till systems. At the 14th year of experiment they assessed the soil moisture with gravimetric method during the 2009 growing season at four soil depths from April to June, and reported an average moisture content of the soil significantly higher in no-till (13% dry mass basis) than in conventional tillage (10%) management (Fig. 5.4), equivalent to about 22 mm of water savings.

5.4.2. Reduction of water evaporation

Conservation Agriculture systems prevent the direct incidence of radiation on moist soil and reduce water evaporation into the atmosphere. As a result, rainfed crops can better withstand stress conditions, as *Moreno et al. (1997)* and *Murillo et al. (1998)* found under conditions of Andalusian dryland, where spring and summer temperatures are high. This positive effect is especially noticeable in dry years.

Thus, Conservation Agriculture systems, by keeping the soil unaltered and covered by crop residues, cause a decrease in soil water evaporation during periods of high temperatures, and this means that the soil stays wetter during the spring and early summer (*Márquez et al., 2007*).

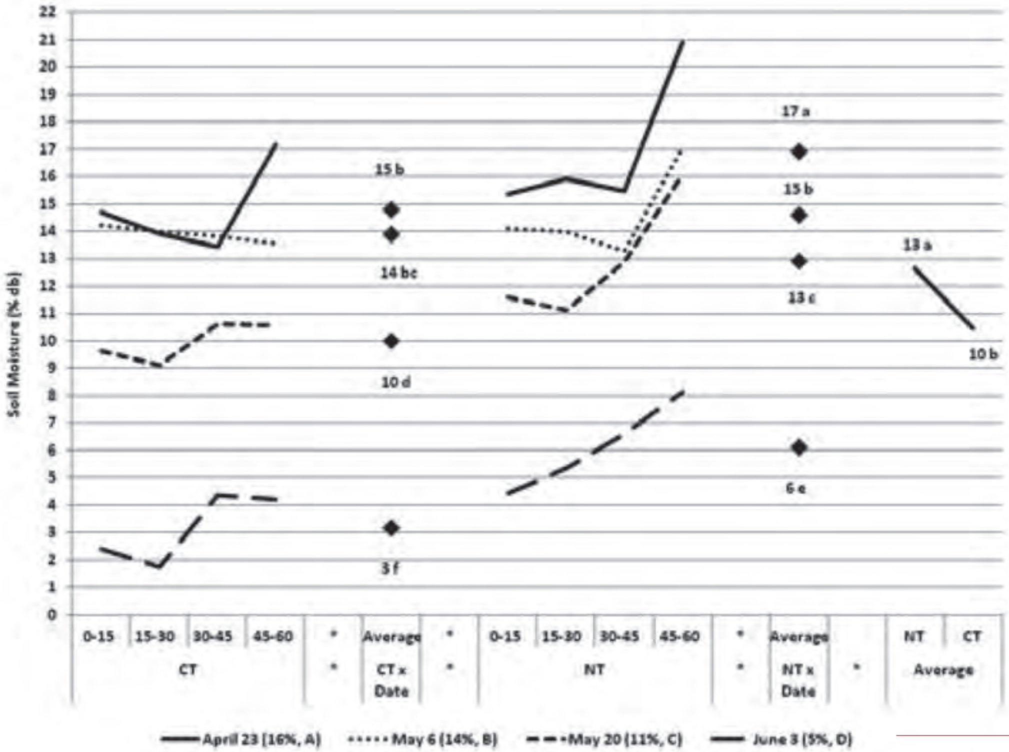


Fig. 5.4. Trend of soil moisture for a monoculture of durum wheat grown in no-tillage (NT) and conventional tillage (CT) systems. Source: *Trocoli et al. (2009a).*

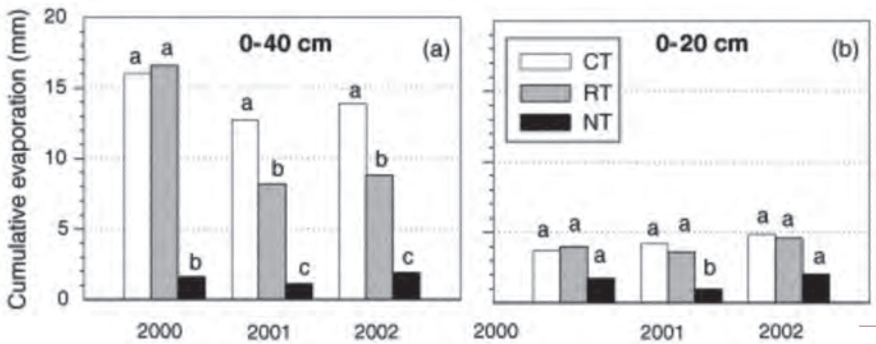


Fig. 5.5. Cumulative evaporation of soil water measured 24 hours after primary (a) and secondary (b) soil management practices. CT: conventional tillage, RT: reduced tillage, NT: no-tillage. Source:

Moret et al. (2006) observed, during three periods of long fallow (16-18 months), that soil, under an intensive tillage system with mouldboard plough, lost by evaporation 14 times more water than in NT system, in the 24 hours after the first tillage operations, (Fig. 5.5).

This improvement in water use efficiency is a key factor in adapting crops to future climatic scenarios with lower, more erratic precipitation and higher temperatures.

5.5. Conservation Agriculture and soil improvement

One of the keys to increase the resilience of the agricultural ecosystems that are possible thanks to adoption of Conservation Agriculture is the substantial improvement that occurs in the physical-chemical properties of the soils on which these agricultural practices are implemented. Soils with a better structure and less erosion, will respond better to events of intense rainfall. On the other hand, soils with a greater content of organic matter and greater natural fertility, are more and better prepared to respond to adverse climatic conditions that contribute to their degradation. Fig. 5.6 shows the processes through which Conservation Agriculture improves this resources.

5.5.1. Reduction of erosion

CA maintains permanent soil covers which minimize the direct impact of the raindrops on the soil, increase the infiltration and reduce soil erosion. The greater the coverage of the soil, the more effective reduction of erosion is. Therefore, soil management operations should leave as much crop residue as possible on the soil surface, in order to protect it and prevent erosion. Studies carried out by the Spanish Association for Conservation Agriculture Living Soils (AEAC.SV) shows that with 30% of soil covered, erosion decreases, and with 60% of soil covered, erosion almost completely disappears (Fig. 5.7).

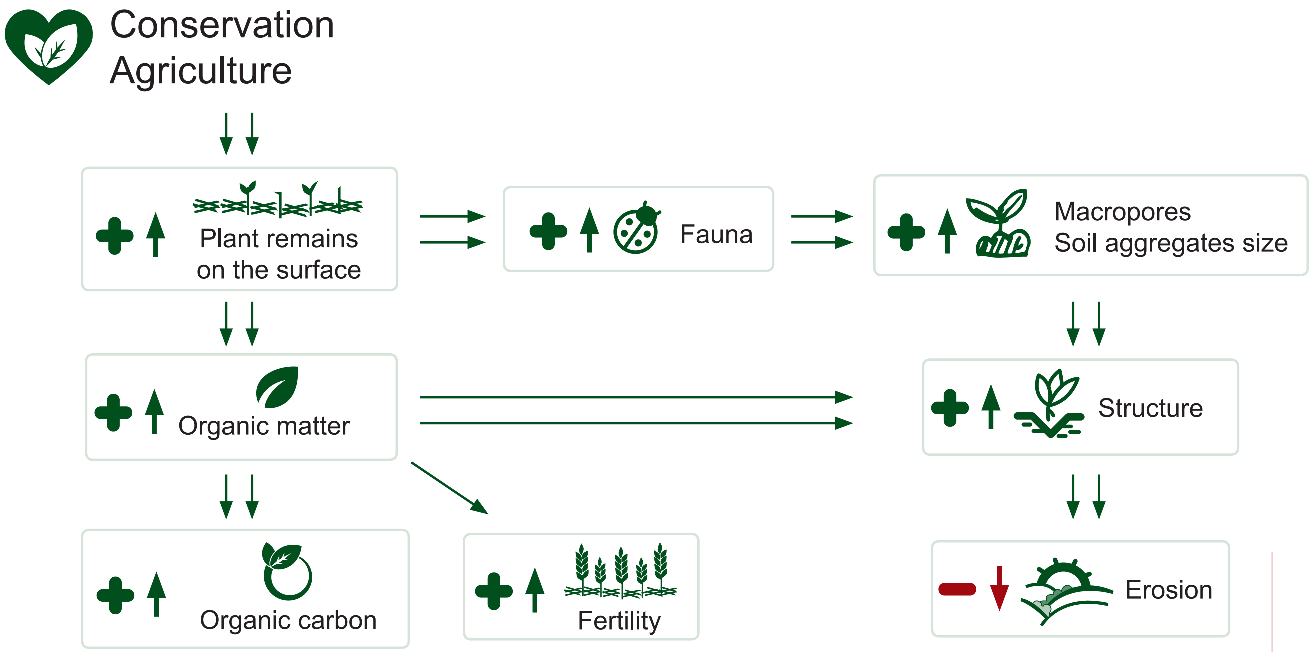


Fig. 5.6. Conservation Agriculture processes related to soil benefits. Source: Own elaboration.

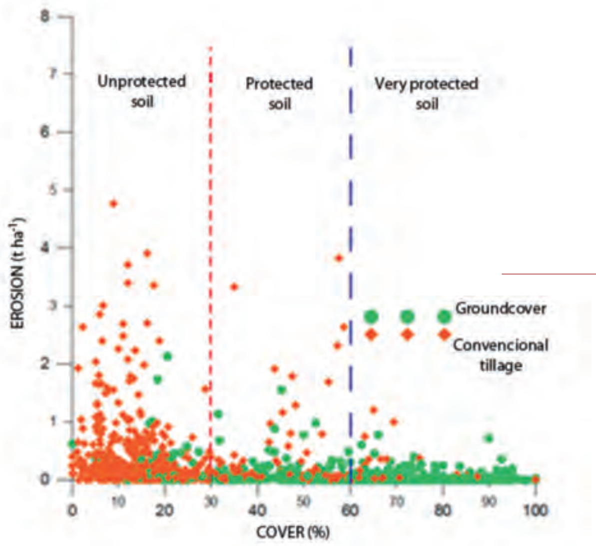


Fig. 5.7. Soil erosion related to the percentage of surface covered by crop residues. Source: AEAC.SV.

Based on this premise, investigations carried out in other countries certify erosion reductions of more than 90% in the case of no-tillage (NT) (*Towery, 1998*), and more than 60% in minimum tillage (*Brown et al., 1996*). More recent studies (*Kertész et al., 2010*) show erosion reductions in NT of up to 98.3%.

The maintenance of permanent soil covers also plays an important role in reduction of wind erosion. According to the results obtained by *Fryear (1985),* in a soil whose surface was covered by 20% of crop residues, the soil loss was reduced by 57%. In soils whose surface was covered by 50%, erosion was reduced by 95% (Fig. 5.8).

Regarding the influence of groundcovers on the reduction of erosion in permanent crops, there are many studies carried out in Spain, a country where CA practice is widely extended within the European context. In Spain there are several investigations in woody crops that study the influence of groundcovers in the reduction of erosion. Thus, *Márquez et al. (2013)* quantified average erosion reductions of up to 80.4% in olive groves, *France et al. (2000, 2006)* found soil losses three times lower in CA systems compared to the tillage plots and, finally, *Martínez Raya et al. (2010)* observed erosion rates almost 10 times higher in tillage systems compared to CA ones for almond tree orchards.

5.5.2. Increased soil organic matter and soil fertility

The reduction of erosion due to the implantation and development of Conservation Agriculture, leads to an increase in the organic matter content in the soil, which, in addition to being the basis of the C sink effect, improves soil quality, enhances the chemical and physical fertility of the soil, favours the development of the structure or aggregates, thus increasing soil resistance to erosion and favouring water infiltration. In addition, thanks to the ability of humus to retain cations and adsorb heavy and harmful elements, organic matter acts as a water filter, improving its quality.

Soil organic matter is an integrator of several soil functions and as such is a key component of soil quality and of the delivery of many ecosystem services (*Palm et al., 2014*). Conservation Agriculture practices of no-tillage and residue maintenance

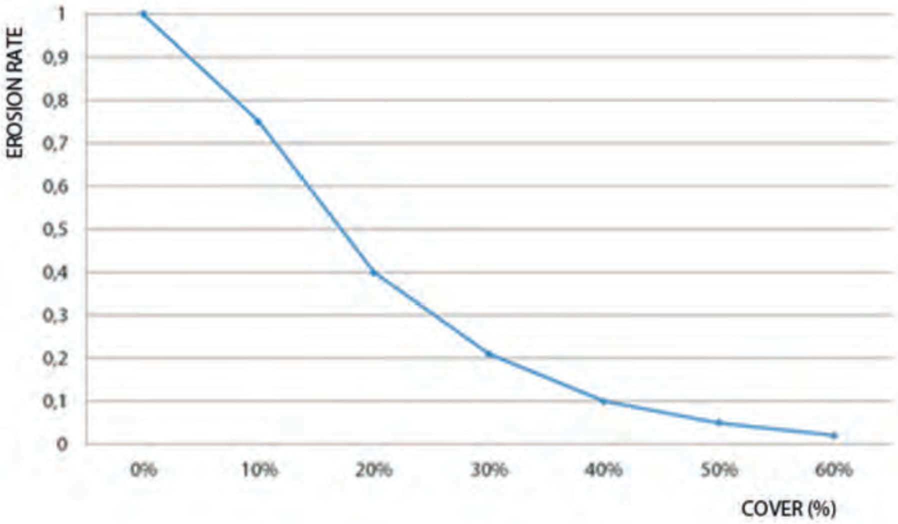


Fig. 5.8. Reduction of the rate of wind erosion according to the percentage of crop residues. Source: *Fryrear (1985).*

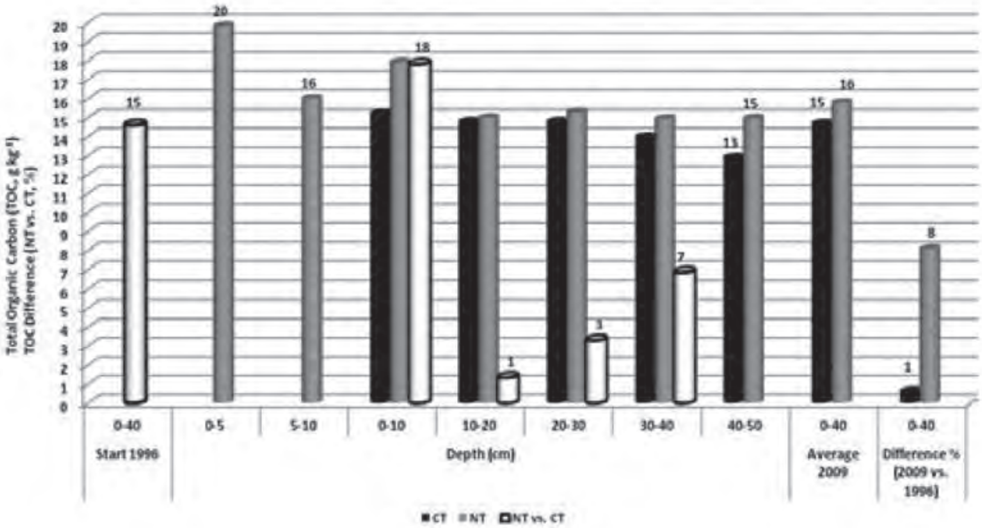


Fig. 5.9. Trend along soil profile of total organic carbon (TOC) values for no-tillage (NT) and conventional tillage (CT) systems. Source: *Troccoli et al., 2009a.*

are key-points to conserve or increase soil organic matter in the topsoil which in turn provides energy and substrate for soil biota activities and their contributions to soil structure and nutrient cycling, as well as many other soil processes and ecosystem services (*Brussaard, 2012*).

Scientific evidences show that due to the improvement in moisture regime over the growing season and soil storage of water and nutrients, as well as to the introductions of legume cover crops and build-up of soil organic matter, crops under CA require less fertilizer and pesticides to feed and protect the main crop (*Lafond et al., 2008; Crabtree, 2010; Lindwall and Sonntag, 2010*). Good mulch cover provides 'buffering' against extreme temperatures at the soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimizing a potential cause of yields limitation (*Kassam et al., 2012*).

5.6. Conservation Agriculture and the improvement of soil biodiversity

Soil biodiversity plays a key role in fertility, nutrient absorption by plants, biodegradation processes, the elimination of hazardous compounds and natural pest control. In other words, richer and more biologically diverse soils have greater capacity to respond to extreme phenomena resulting from climate change that can worsen their degradation, such as the incidence of heavy precipitation, temperature increase or the geographical displacement of pests and diseases, among others.

One of the environmental benefits of the adoption of Conservation Agriculture practices for agrarian ecosystems is the improvement of biodiversity in general, and in the soil in particular. In other words, under soil conservation practices, soil biota is enriched, allowing better recycling of nutrients and helping to control pests and diseases (*Holland, 2004*).

The implementation of CA benefits various groups of microorganisms (bacteria, fungi, protozoa, nematodes, etc.) which live in no-tilled soils. *Muñoz et al. (2007)* found significant differences in the number of microorganisms from the beginning to the end of the study about microorganisms in the soil under several management systems, which were always in favour of conservation systems. Thus, according to the mentioned study, the soil maintained using no-till practices had 50% more microorganisms than the soil under conventional tillage. Fig. 5.10 shows the number of microorganisms present in the soil in several soil management systems, including several no-till alternatives based on a larger amount of crop residues and a greater number of years of implantation (*Muñoz et al., 2009*). It should be noted that a direct consequence of the increase of microorganisms in the edaphic profile is the increase of the structural soil stability. Thus, large amounts of organic matter involved in the implementation of techniques such as no-tillage or groundcovers contribute to increasing microbial activity, which improves the stability of aggregates.

Another populations benefited by the implementation of Conservation Agriculture and whose activity supposes an improvement of the fertility of the soil and its structural stability, are earthworms. These living beings have great importance especially in productive ecosystems,

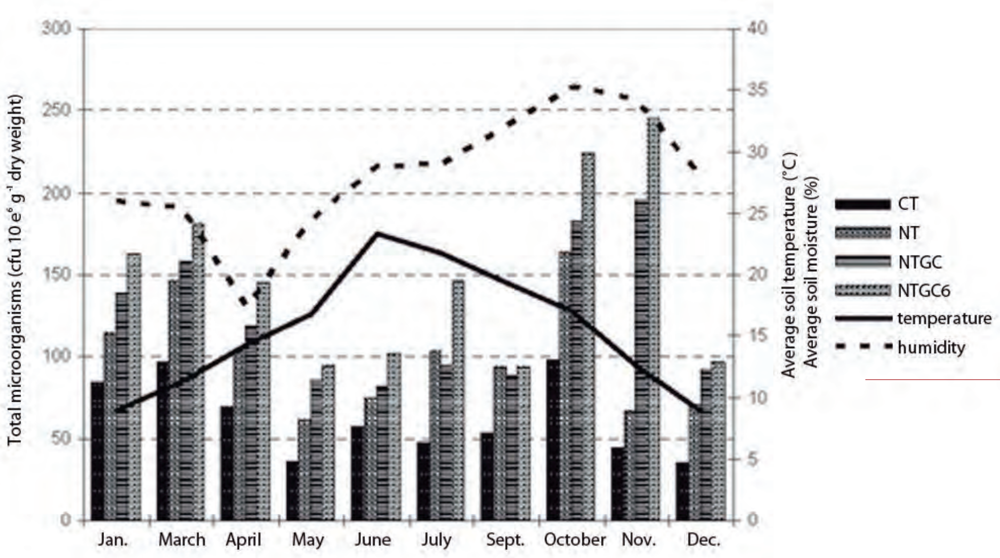


Fig. 5.10. Average soil temperature, average soil moisture content and average amount of microorganisms in each soil management system throughout the year. (CT: conventional tillage, NT: no-till, NTGC: no-till with winter groudcover, NTGC6: no-till with winter groundcovers during 6 years of implantation). Source: *Muñoz et al. (2009).*

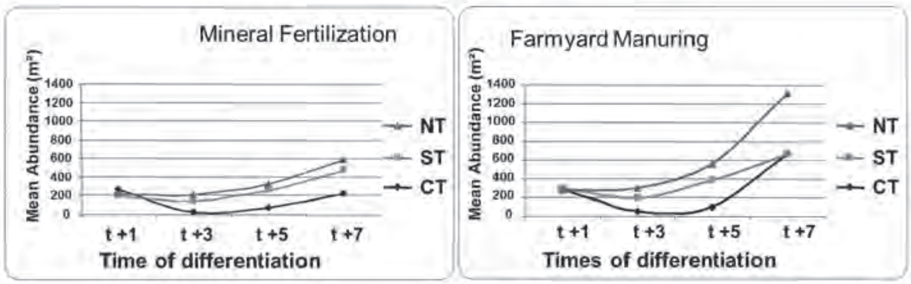


Fig. 5.11. Evolution of earthworm abundance under three treatments (CT: conventional tillage, ST: superficial tillage, NT: no tillage) according to mineral fertilization and farmyard manuring. Source: *Piron et al. (2010).*

due to their influence on the decomposition of organic matter, soil structure development and nutrient cycle. In addition, earthworms reduce bulk density and increase water infiltration, with the consequent advantages discussed previously related to the improvement of soil moisture content. It is verified that CA increases the activity of earthworms, because of lower soil disturbance and the increase in organic matter. Thus, studies by *Piron et al. (2010)* in France (Fig. 11), which made comparison between three management systems (no-tillage, superficial tillage and conventional tillage) with two fertilization strategies (mineral and organic fertilization), showed that in all cases, after 7 years of research, earthworm populations were superior in Conservation Agriculture than in conventional tillage.

5.7. Strategies in the agronomic management of crops: Conservation Agriculture and crop rotation

The increase in temperature during the critical periods of the crop, the changes in the monthly distribution of precipitation and the reduced soil water holding capacity because of climate change, could reduce productivity and crop quality. Therefore, one of the measures that can be taken to deal with these risks is the diversification of crops, praticing the crop rotations on the farm, which is one of the fundamental pillars of implementation and development of CA. In this way, pests and diseases are better controlled, breaking cycles that are maintained in monocultures, in addition to incorporating crops that can improve the natural fertility of the soil and biodiversity.

But crop rotation not only brings benefits for the optimized management of water and soil moisture, it also offers other advantages that help the agrarian ecosystem to be more and better prepared for the variety climatic scenarios caused by global warming, and, therefore, to be more sustainable. The following advantages can be highlighted:

- The establishement of crop rotations that explore different edaphic horizons and have different water needs, promotes synergies between them, improving the medium and long term productions in the global computation.
- Rotation is used to reduce pests and diseases in the cropping system and to control weeds.
- Rotations can also provide benefits, such as better soil quality (deeper roots, root exudates), better distribution of nutrients in the soil (deep root crops mobilize deeper nutrients), and increased biological activity.
- Through the rotations, the periods of high labour demand can be reduced and farming operations can be better distributed throughout the year, if, for example, sowing and harvesting dates for the different crops involved in the rotation do not coincide in time.

- Crop rotations can reduce the risk created by extreme weather events such as droughts or floods and their negative effects, since their incidence does not equally affect all crops. In this case, rotation represents a way to diversify risk.
- Crop rotations can balance the production of crop residues by alternating crops that produce few and/or easily degradable residues with crops that produce many and/or more long-lasting residues.

Therefore, the rotation of crops promoted by CA increases the resilience of the agricultural ecosystem, improving soil properties in general, while increasing the crop potential to obtain higher yields.

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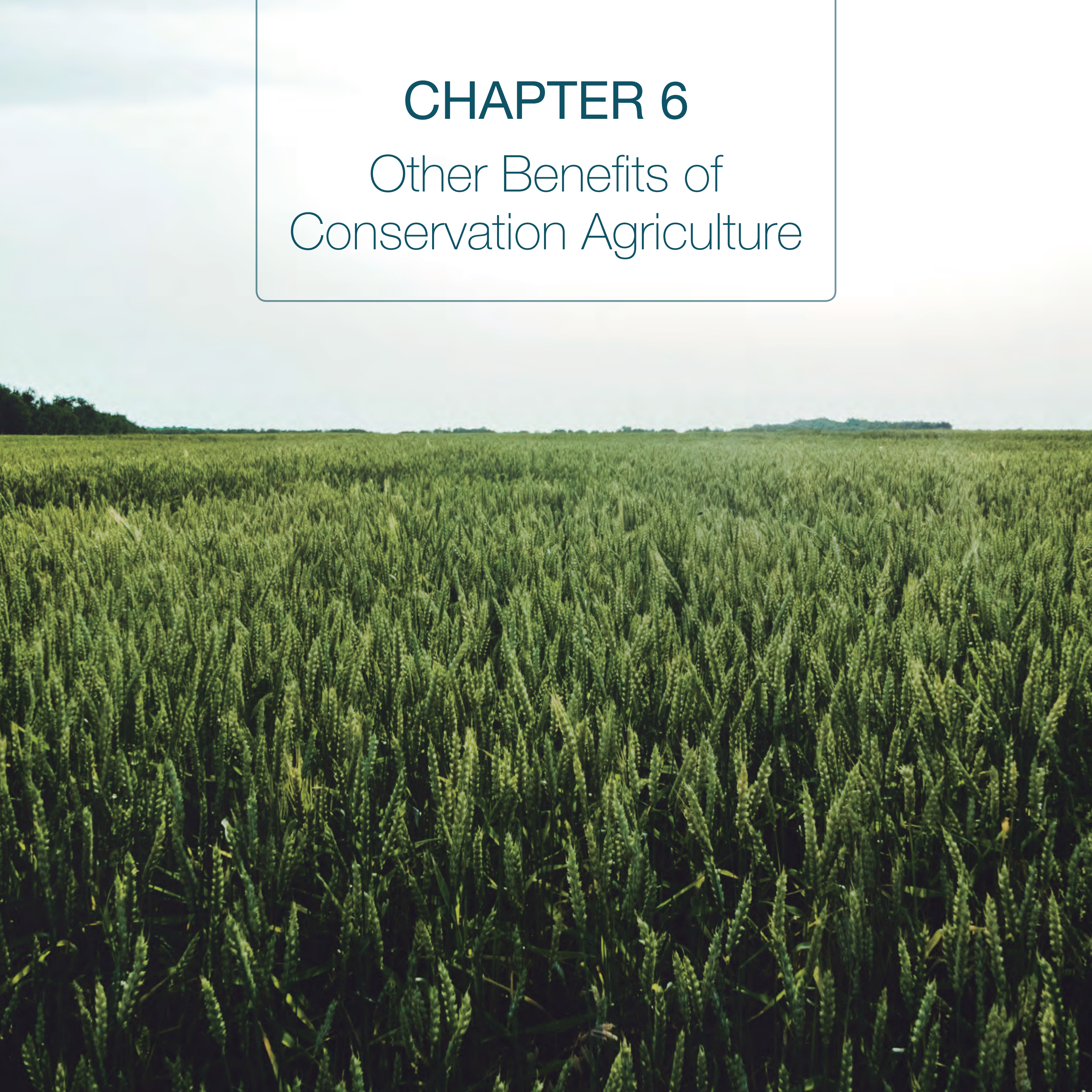
CHAPTER 6

Other Benefits of Conservation Agriculture



6.1. Introduction

The benefits of Conservation Agriculture (CA) related to improvement of atmospheric quality have been extensively developed in previous chapters. However, sustainability in agriculture includes other fields. A system can be sustainable if it is so for all the environment (not only at the atmospheric level), and if it has agronomic, economic and social benefits. All these facts make Conservation Agriculture the model of agriculture that best fits the definition of sustainable development provided by the United Nations World Commission on Environment and Development (WCED) in the Brundtland Report (1987): "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

This chapter will analyse agricultural sustainability, from different points of view:

- Environmental: Agriculture is an activity with a clear influence on the environment. The systems used must improve protection, conservation and, where possible, natural resources.
- Economic: It cannot be forgotten that agriculture is the farmer's sustenance. The economic benefits of farms are vital for their sustainability. Agricultural systems should aim to maximize these benefits through lower production costs and / or increased incomes (either through improved product quality, increased production or both).
- Social: The agrarian activity itself, and that of the agro-industries that are established in the surroundings of the farms producing raw materials, are the means to fix

the rural population. Therefore, the social sustainability aspect of agriculture aims at the adoption of production systems that can improve the welfare of farmers and the population linked to agricultural activities. Another aspect that should be taken into account, from the social point of view, is the demand for food produced under certain quality and food safety standards. The model of agriculture that needs to be implemented should not neglect these social requests.

- Agronomic: Crops must be managed in order to maintain or improve the properties of the agrarian ecosystem in which they are growing, avoiding its degradation and improving its physicochemical properties, which can increase production. An agricultural model is sustainable from the agronomic point of view if it allows the implantation and the correct development of crops in the long term without degrading the environment in which they are developed.

Conservation Agriculture increases benefits and is sustainable in all the cases mentioned above. This chapter will discuss the benefits that CA provides to soil and water. It should be noted that these benefits, as will be shown below, do not reduce yields.

6.2. Soil benefits

6.2.1. Reduction of erosion

The main environmental problem caused by the current agricultural model based in tillage is the degradation of agricultural soils due to erosion and compaction processes. There are around 106 Mha (16% of Europe's area-excluding Russia) affected by water erosion, and 42 Mha affected by wind erosion all around Europe. According to *Jones et al. (2012a)* soil losses are higher than 10 t ha^{-1} yr^{-1} in almost 20% of Europe's surface area. There are also studies carried out by the Joint Research Center (*Bosco et al., 2015; Jones et al., 2012b*) that have estimated that mean soil losses from water erosion are of 2.76 t ha^{-1} yr^{-1} for the EU-27 (Fig. 6.1). In areas where soil loss is higher than 1 t ha^{-1} yr^{-1} these losses can be considered as irreversible over a period of between 50 and 100 years (*Huber et al., 2008)* due to the low soil formation rate.

Control of erosion can be improved by changing agricultural practices. When, for example, permanent soil cover is increased, soil loss rates are reduced exponentially *(Gyssels et al., 2005)*. This results from the fact that the maintenance of the crop residues on the ground acts as a protective layer that dissipates the energy of the rain drops and minimizes their direct impact on the soil thus avoiding its disintegration, reducing the runoff, and, consequently, greatly reducing soil loss. In addition, the decomposition of the roots of the cover crops in annual crops, or of the groundcovers in permanent crops, opens channels that favour a greater infiltration reducing the runoff, and therefore, the associated erosive processes. *(Martínez Raya, 2005)*. The effectiveness of soil protection against erosion is directly related to the coverage of the soil and, therefore, to the less burial of crop remains through tillage operations.

Although there are variations depending on soil type and local conditions, there is a general consensus in the scientific literature that Conservation Agriculture techniques (no-tillage, groundcovers) reduce soil erosion up to 90% in comparison with conventional tillage (CT) (*Towery, 1998*). Specifically, *Gómez et al., (2004)* found that CA implantation reduced 20% the probability of soil losses in a range of between 5 and 12 t ha^{-1} yr^{-1} in studies carried out in the Mediterranean area.

Other studies at European level have focused on how CA practices influence the C factor (crop management factor –groundcover–, dimensionless) of the soil loss equation (RUSLE), determining that the application of no-till techniques (NT) or groundcover (GC) can reduce its average value by 19.1% *(Panagos et al., 2015)*, which implies a decrease in the calculation of soil loss. Fig. 6.2 shows the reduction in C factor due to the presence of crop residues in the EU countries.

6.2.2. Increase in organic matter content

Tillage practices such as overturning increase CO_2 emissions, decreasing the amount of organic matter (OM) in the soil *(Schlsinger and Andrews, 2000; Lal, 2004; Álvaro-Fuentes et al., 2007; Cabrera, 2007; Lopez-Garrido et al., 2019)*. In cultivated soils OM can progressively decrease, with a large part being removed annually (harvest) and much of it being lost by mineralization if the tillage is very aggressive, such as the one that CT causes *(Wallace, 1994; Causarano et al., 2008)*.

OM has a great influence on soil physical, chemical and biological properties, necessary for the development of its functions *(Bauer and Black, 1994; Magfoffand Weil, 2004)*. The loss of OM from a soil, in addition to a negative effect on the balance between the different carbon pools, also affects the quality of the soil and its fertility can be seriously compromised.

Organic matter is fundamental for the physical fertility of a soil because it improves the formation and stability of aggregates *(Gajri et al., 2002)*. OM is considered as a source of energy for plants and soil organisms *(Brady and Weil, 2002)* with the amount, diversity and activity of the macro and mesofauna of the soil and microorganisms being directly related to the amount of OM *(González et al., 2004)*.

High contents of OM improve the cohesion between the different elements of the soil, which increases their adhesion properties and, for this reason, this parameter can be considered as an indicator of soil health status. In CA, crop residues are slowly degraded, resulting in an increase in soil OM content. Its increase in the first

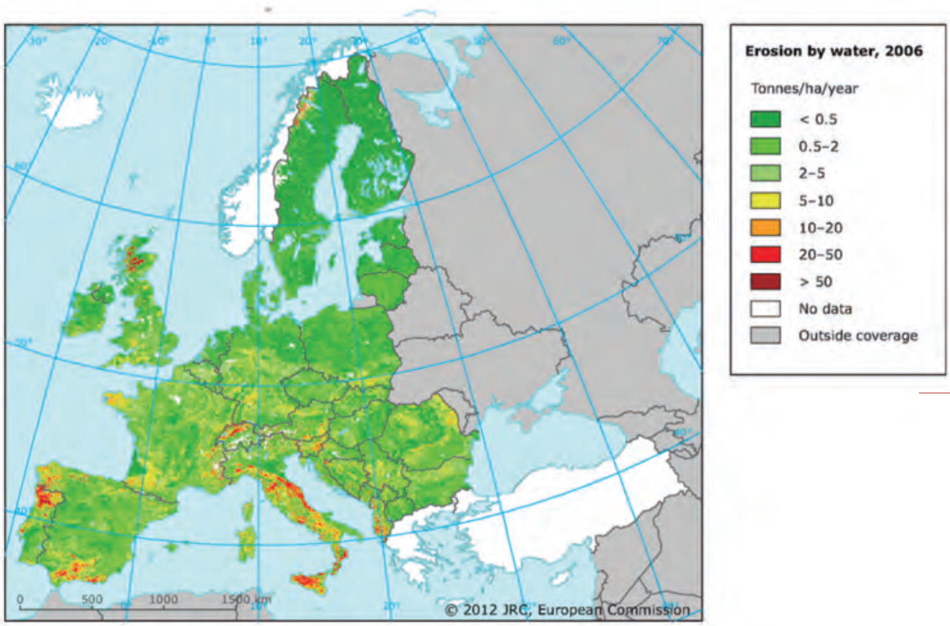


Fig. 6.1. Estimation of soil erosion by water in cultivated land. Source: *JRC/ Bosco et al. (2015).*

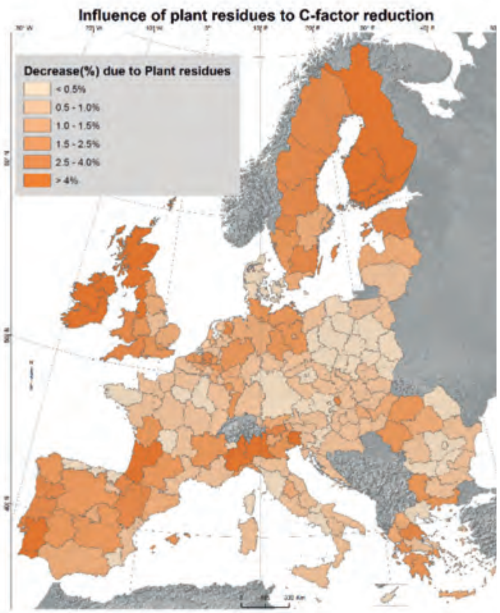


Fig. 6.2. Influence of crop residues in C factor of the RUSLE equation. Source: *Panagos et al., (2015)*.

If all European farmland was converted to CA, it would reduce atmospheric carbon by as much as planting 65 million hectares of forest.

centimeters of the soil surface increases the nutrient reserves *(González, 1997; Rhoton, 2000)*, which can be released gradually and at a different rate than in tilled soils *(Fox and Bandel, 1987).*

In a study about CA where the influence of soil management on soil OM content was evaluated, *Giráldez et al. (2003)* verified that the OM content increased throughout the soil profile, compared to the CT system in which its percentage was reduced. In addition it was observed that the main causes that induce the different amount and distribution of OM in the soil profile are the type and amount of surface stubble and the climatology of the area.

6.2.3. Improvement of soil structure

The *Thematic Strategy for Soil Protection (COM (2012) 046)* identifies soil compaction as one of the main threats to soil. This is due to the fact that the overall deterioration of the edaphic structure happens because soil compaction limits root growth, storage capacity, fertility, biological activity and stability. In addition, if precipitation is strong, it is impossible for water to easily seep into the soil. Consequently, the high volume of runoff water increases the risk of erosion and, according to some experts, has been one of the triggers of some of the last floods in Europe (*EEA, 2001*). Soil compaction occurs when it is subjected to mechanical pressure, such as the use of heavy machinery and excessive grazing, especially if the soil is wet (*Huber et al., 2008*).

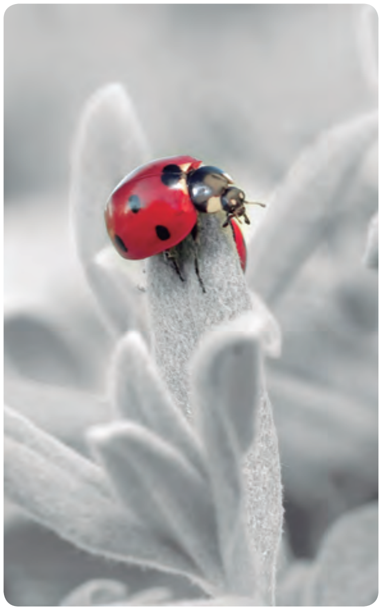
Another factor that affects the soil structure is the formation of superficial crusts, which are responsible for the loss of edaphic structural stability (*Micó et al., 2006*).

A series of benefits on the physical properties of the soil, which contributes to the improvement of soil structure are achieved through the implementation of CA. Thus, by keeping the soil unchanged by suppressing tillage operations, the generation of galleries resulting from root degradation, together with the higher amount of earthworms in a soil under CA, form so-called biopores. Water infiltrates in depth through these preferential channels.

In addition, the properties related to soil structure, such as aggregate size distribution, weighted average diameter and aggregation index, are improved thanks to CA *(López-Garrido et al., 2010)*. It also improves the stability of aggregates 1-2 mm in diameter in wet soils.

On the other hand, it is proven that OM is crucial in all the processes that occur in the soil and in particular for its quality, since it improves its structure, fertility and water storage capacity, being therefore widely accepted as an indicator of soil quality *(Podmanicky et al., 2011)*. The increase in soil OM content improves its structure and favors structural stability. Therefore, CA, due to the increase of OM that its practice implies, contributes to the structural improvement of the soil.

6.2.4. Greater biodiversity



Soil biodiversity tends to be higher in forests, prairies and undisturbed soils rather than in cultivated ones. The implementation of a field with natural vegetation involves a series of changes in the soil. The intensification of agrarian activity, derived from the tillage conducted in conventional agriculture, leads to a potentiation of these changes, decisively affecting the biodiversity of soil inhabitants, including epigeous fauna, which tends to disappear.

Regarding biodiversity, agricultural soils under CA can be considered intermediate between the two above mentioned extremes *(Kladivko, 2001)*. Thanks to the presence of a permanent soil cover, CA practices influence a series of parameters and characteristics of soil that improve the conditions to give food and shelter to many animal species during critical periods of their life cycle, thus, a large number of species of birds, small mammals, reptiles, earthworms, etc. Additionally, the interrelations between diverse parameters also improve the conditions for the development of aquatic life in water bodies close to CA plots (Fig. 6.3).

López-Fando (2010) carried out the analysis of both own and others research. This analysis shows the great importance of the characterization of microflora

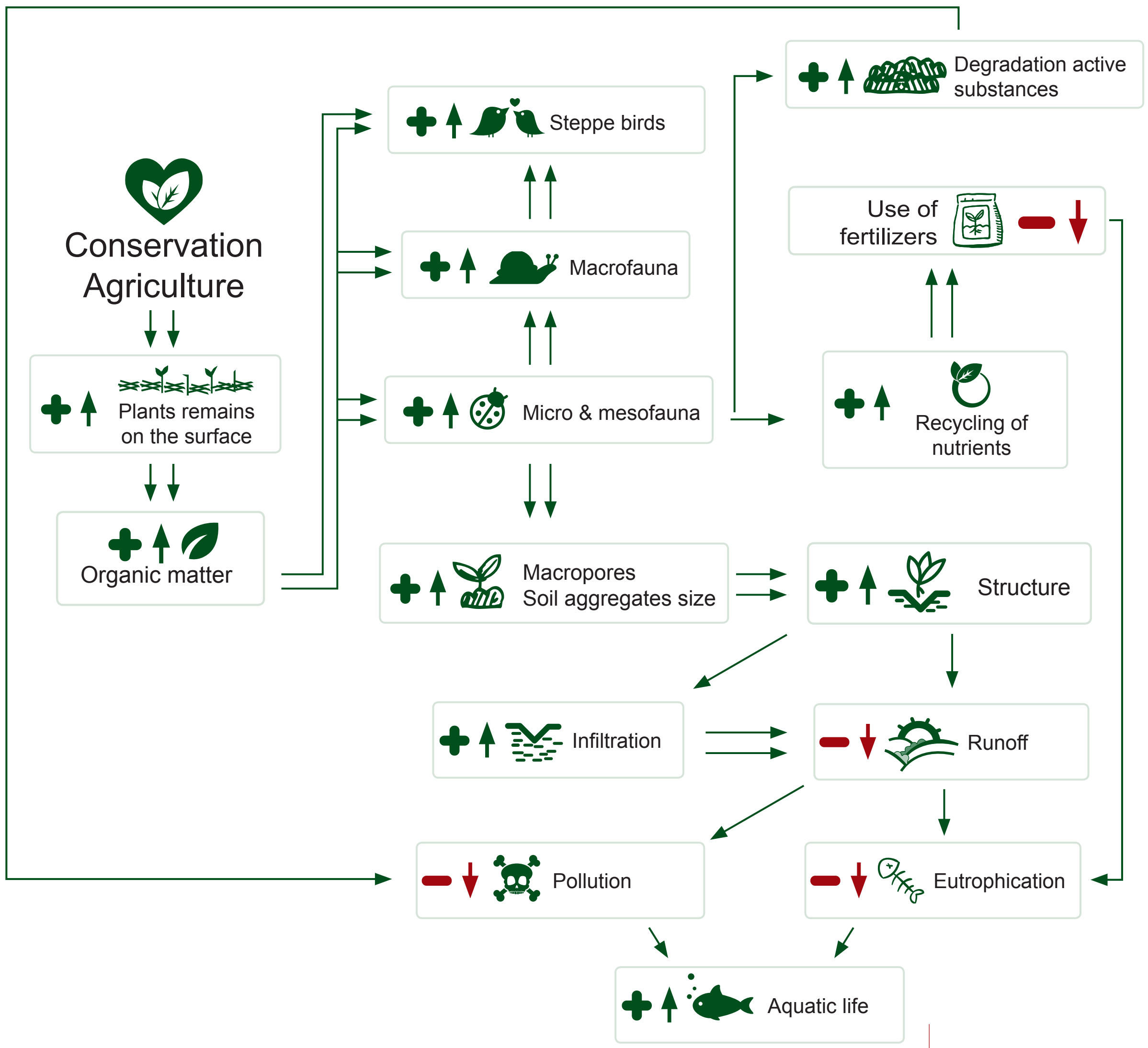


Fig. 6.3. Improvement of biodiversity due to changes promoted by the implementation of CA.

and edaphic fauna, with special reference to the study of their function in the different levels of organization in the trophic system. In particular, the seasonal dynamics and structure of soil organisms communities accuse changes in use. These studies have shown that CA can be an effective means of conserving and enhancing biodiversity.

There are research studying the influence of the application of CA on the micro, meso, macro and mega fauna, in addition to those mentioned in the chapter on the properties of CA to favor the adaptation of crops to the effects of climate change through the improvement of soil resilience. Table 6.1 shows the influence of the application of CA in the population of different types of living organisms.

6.2.5. Increase in natural fertility

There are various processes which occurrence lead to the degradation or loss of soil quality and quantity such as erosion, salinization, contamination, drainage, acidification, loss of structure, compaction or a combination of them. Inadequate human uses of soil can lead to one or several of these processes, which negatively affect soil quality and, therefore, its productive capacity or natural fertility. One of the examples of inadequate land use is agricultural practice based on intensive tillage because it contributes to degradation phenomena mentioned above. As a result, bad agricultural practices do not optimize the use of fertilizers because they adversely affect the OM content and do not return extracted nutrients.

In general, when the soil ceases to be tilled and the stubble is integrated into the productive management of the crops, soil parameters that have been traditionally used to evaluate soil fertility (OM, nitrogen-phosphorus-potassium availability) are favorably evolved. For all this, CA aims to improve soil fertility because the slow decomposition of crop residues produces a surface layer rich in compost, which, through its mineralization, provide crops with nutrients (*Roldán et al., 2003; Riley et al., 2005; Diekow et al., 2005*).

6.2.5.1. Conservation Agriculture and organic matter

The dynamics of OM play a very important role in the natural fertility of the soil. It mineralizes, providing nutrients to the plants and together with the clay, constitutes the colloidal fraction of the soil, responsible for its chemical fertility and the development of the structure or aggregates that increase the resistance of the soil against erosion *(Ordóñez Fernández, 2010).*

Particulate OM is a fraction of soil OM. It is closely related to the development of the soil structure and can be very easily destroyed by tillage (*Mrabet et al., 2001*). For this reason, dynamics of OM in CA, where ground cover is slowly degraded, are similar to that produced in natural ecosystems.

Increases in the OM content which is produced in the soil when implementing CA practices have been verified in several studies on this topic, already mentioned in the chapter 5. Percentage increases for these studies are shown in Table 6.2.

Table 6.1. Increase in the population of different types of living organisms thanks to the implementation of Conservation Agriculture.

Class / subclass / animal studied	Type of fauna	Conservation Agriculture Practice	Increase	Source
Arachnida	Macrofauna	Groundcovers	++	*Campos et al., (2002)*
Clitellata (earthworms)	Macrofauna	No-tillage	+++	*Cantero et al., (2004)*
Malacostraca (moisture cochineal)	Macrofauna	No-tillage	+++	*Alfaress (2002)*
Mites	Microfauna	No-tillage	+	*Perdue and Crossley (1989)*
Mollusks (snails and slugs)	Macrofauna	No-tillage	+	*Wolters and Ekschmitt (1997)*
Myriapods	Macrofauna	No-tillage	+	*Wolters and Ekschmitt (1997)*
Nematodes	Microfauna	No-tillage	++	*López-Fando and Bello (1995)*
Springtails	Macrofauna	No-tillage	++	*Shearin et al., (2007)*
Steppe birds (thistle)	Megafauna	No-tillage	++	*Cantero-Martínez et al., (2007)*

Table 6.2. Increase of organic matter content in the soil thanks to the implementation of Conservation Agriculture.

Conservation Agriculture Practice	Increased organic matter compared to conventional tillage (depth)	Years of study	Source
No-tillage	+15% (25 cm)	21 years	*Lacasta et al. (2005)*
No-tillage	+6.1 t ha^{-1} (30 cm)	16 years	*López Fando and Pardo (2011)*
No-tillage	+40% (30 cm)	19 years	*Ordóñez et al. (2007)*
Groundcovers	+45% (25 cm)	4 years	*Márquez et al. (2013)*

6.2.5.2. Conservation Agriculture and availability of nitrogen, phosphorus and potassium

Many long-term studies on the benefits of CA for soil nitrogen *(Lacasta Dutoit and Meco Murillo, 2005*; *Sombrero et al., 2006; Ordóñez-Fernández et al., 2007)* mark the increase of this nutrient in no tilled soils (Table 6.3). However, the intensity and extent of these differences in the soil profile depend on the climate, type of soil and crop rotation on the farm. In any case, there is some controversy about the influence of soil management on the nitrification, denitrification and volatilization processes that are, in the end, those that determine the availability of nitrogen in the soil for the plant. The rotation of crops with leguminous plants, a necessary practice in CA, significantly enriches the soil with organic nitrogen which, in the long run and due to the mineralization processes, is made available to crops. Therefore, this achievement, together with the other improvements provided by CA in relation to the rest of nutrients, make this practice one to be considered to enhance soil fertility.

Regarding phosphorus, the continuous management of soils in CA leads to a greater efficiency of phosphate fertilizer, increasing the concentration and availability of phosphorus, due to the stratification of OM in the surface horizon (*Phillips, 1985*). *Ordóñez et al., (2007), Bravo et al., (2007)* and *Saavedra et al., (2007)* noticed that, after more than 19 years of NT, the concentrations of phosphorus and potassium available for the crop were higher in the superficial horizon than those in CT.

6.3. Benefits for the water

Taking into account that a third of the water used in Europe goes to the agricultural sector, that agriculture affects both the quantity and the quality of water available for other uses and that in the EU there is an increasing demand by citizens and environmental organizations for cleaner rivers, lakes, groundwater and coastal beaches, it goes without saying that water management in agriculture is crucial.

Soils play a key role in the water balance of crops, due to their storage capacity according to their physical, chemical and biological characteristics. Thus, any management practice that increases soil quality, through the increase of OM, the improvement of its structure and of its biodiversity, will positively result in its capacity for water storage.

Table 6.3. Increased N content in the soil thanks to the implementation of Conservation Agriculture.

Conservation Agriculture Practice	Increase in N compared to conventional tillage	Years of study	Source
No-tillage	+26%	15 years	*Lacasta Dutoit and Meco Murillo (2005)*
No-tillage	+25%	10 years	*Sombrero et al. (2006)*

In general, CA systems contribute to a greater accumulation of water in the soil profile, motivated by the following reasons:

- Runoff is considerably reduced and infiltration is increased.
- It reduces the pollution of surface water, thereby improving its quality.
- There is an increase in the storage capacity of the soil due to the produced structural or biological changes.
- The evaporation of water from the soil is reduced.

As discussed in chapter 5, these processes have a direct impact in the adaptation of agricultural systems to climate change, but implementation of CA brings additional benefits to water.

6.3.1. Improvement of surface and groundwater quality

Tillage based conventional farming practices contribute to the deterioration of surface water quality (*Blevins et al., 1990; Sharpley et al., 1993; Douglas et al., 1998; Fleming and Cox, 1998*). In a study, *Christensen (1995)* classifies the following as potential pollutants that have the greatest impact on aquatic ecosystems, in descending order: sediments, nutrients, pathogens, OM, heavy metals and plant protection products. Thus, entrainment of soil particles, due to water erosion, contaminate riverbeds, worsening conditions for species survival in aquatic ecosystems. On the other hand, fertilizers and plant protection products are used on crops to increase their yield. When transported by runoff water, sediments become the main pollutant of surface waters.

CA techniques reduce runoff, and, therefore, reduce the risk of contamination by both suspended soil particles and plant protection products dissolved in the runoff water.

Comparison of no-tillage with conventional tillage has also shown that the transport of herbicides in surface waters is reduced by 70%, that of sediments by 93% and the runoff is also reduced by 69% (*ECAF, 1999*). As a result, studies on no-tillage in dry land crops, observed between 2% and 18% of soil water increases. All these data make us see that CA techniques prevent, to a large extent, water pollution, improving water quality.

6.3.2. Reduction of diffuse pollution

It would appear that increases in rainwater infiltration could increase nitrogen leaching. The studies carried out by *Kertész et al. (2010)* on no-tillage and by *Márquez et al. (2008)* in groundcovers show how the structural improvements, focused on a better relationship between the macro and micropores of the soil, increase the retention capacity of fertilizers in the shallow pores of the soil and facilitate the assimilation of this element by the plant, reducing losses of nutrients dissolved in runoff and adsorbed in the sediment.

According to the data collected in these investigations, no-tillage reduces nitrogen loss by almost 89%, phosphorus by 95.6% and potassium by almost 79%. In the case of groundcovers, the reductions are 38% in the case of nitrogen, 52% in the case of phosphorus (Fig. 6.4) and 57% in the case of potassium.

Regarding nitrogen, *Goss et al., (1993)* verified that in no-tilled plots, losses by leaching were 21% lower than those in tilled plots (Fig. 6.5). Approximately 95% of the nitrogen was present in the water infiltrated in the tilled plots, implying that most of this element was leached.

The implementation of CA, therefore, largely retains fertilizers and plant protection products in the area in which they are applied, until they are used by the crop or decomposed into other inactive components. Thus, conservation techniques not only greatly reduce runoff, but also lead to a sharp decrease in the amount of fertilizers, herbicides, etc. dissolved in the runoff water or adsorbed by the sediment.

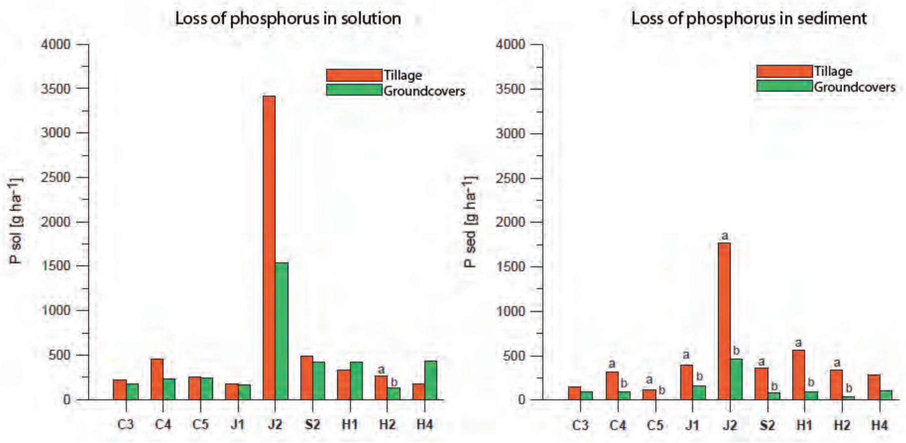


Fig. 6.4. Concentration of phosphorus in solution and associated to sediment in two management systems in olive grove. *Source: Márquez et al., (2008).*

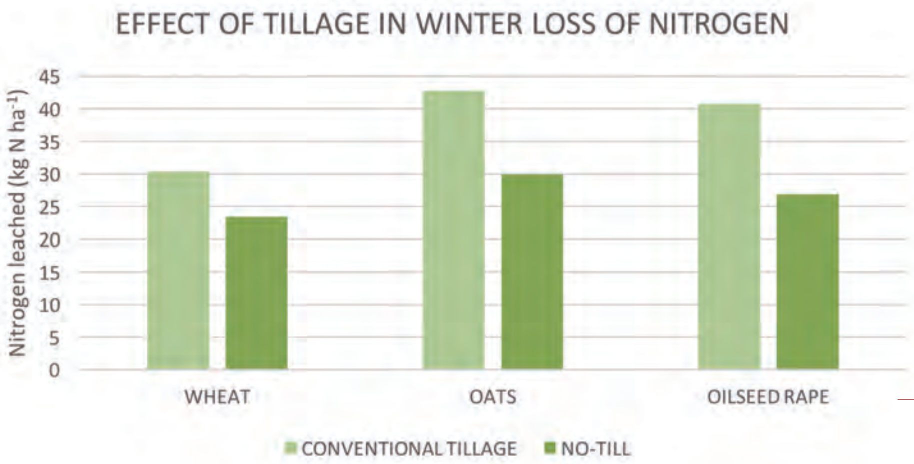


Fig. 6.5. Effects of soil management systems on the leaching of Nitrogen (kg ha^{-1}). Source: *Goss et al. (1993).*

6.4. Economic benefits

The implementation of CA systems entails several economic benefits, some of them are direct and easily quantifiable, such as the improvement of the accounting results of the operation. Some other, such as the cost for public administrations derived from the erosion, pollution, loss of biodiversity or the impact on CO_2 emissions are indirect but not less important.

The main direct economic benefit to the farmer comes from the reduction of production costs since the yield of the crops under CA is similar to conventional systems *(Domínguez Giménez, 1997)*. *Tebrügge and Böhrnsen (2001)* surveyed the opinions of 111 farmers in 7 European countries (Switzerland, Germany, Denmark, UK, Italy, Netherlands and Portugal) and found that reduced working time and lower costs were the dominant reasons for adopting no-till.

There are several studies in Spain in different agroclimatic situations that support the reduction of costs. *González-Sánchez (2010),* obtains that the variable costs of sunflower crop in NT are 250.50 € ha^{-1} compared to 323.50 € ha^{-1} of the crop managed by CT. Also, the cost of durum wheat in CT was 501.74 € ha^{-1} compared to the costs of 458 € ha^{-1} in NT farming system.

Within the framework of the LIFE + Agricarbon project, the CT and NT systems supported by precision agriculture (CA+PA) were analyzed. The profitability of the NT has been considerable, because, while maintaining yields, it showed cost saving compared to conventional management systems. In each campaign, the estimated cost savings were: 59.6 € ha^{-1} on wheat, 72.7 € ha^{-1} on sunflower and 62.0 € ha^{-1} on leguminous plants (Fig. 6.6). In percentages, the cost savings were 9.5% on wheat, 21.6% on sunflower and 15.4% on leguminous crops.

If we take into account that the hourly yield (h ha^{-1}) has decreased by an average of 60% in the CA+ PA systems compared to the CT systems, the benefit obtained per hectare increases even more. Other study that can serve as reference, and which underpin the figures obtained in LIFE + Agricarbon project, was carried out by *Crochet et al. (2008)*. This study compared labour, herbicide and mechanization costs for crop establishment by no-till and ploughing (Table 6.4) and showed the total of these costs for no-till was 50% of that for ploughing.

This cost reduction, while maintaining the income, in comparison with CT practices, implies a greater profitability for the farmer and therefore an improvement of their economy. Hence, there can be made great progress, considering the rate of implementation of CA techniques in Europe. According to data in chapter 3 of this report, the NT hectares of the main extensive arable crops represent only 3.48% of the total area of these crops, as opposed to the countries with higher implantation rate, such as Argentina, where its adoption is above 80%. External and intrinsic factors make farmer reluctant to change. Market uncertainty, strict regulation, future uncertainty - which creates immobility - investments with medium to long-term returns, etc. are some of the causes that explain this behavior.

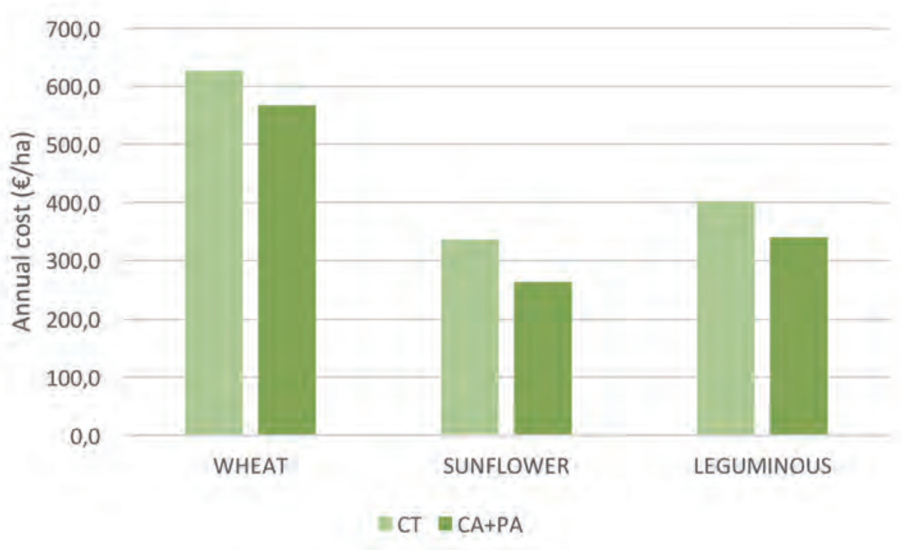


Fig. 6.6. Evaluation of costs (€ ha-1) obtained in the plots under conventional tillage (CT) and no-till+precision agriculture (CA+PA). Source: LIFE + Agricarbon.

Table 6.4. Cost of crop establishment for conventional and no-till treatments in France. Mechanisation cost includes equipment depreciation, maintenance and operating cost. Source: *Crochet et al., 2008.*

Tillage system	Labour cost (€ ha^{-1})	Herbicide (€ ha^{-1})	Mechanization[1] (€ ha^{-1})	TOTAL (€ ha^{-1})
Plough, cultivate, drill	31	2	134	167
Spray, direct drilling machine	10	7	67	84

Regarding permanent crops, *Gil Ribes et al. (2007)* have carried out economic profitability studies on olive groves in Spain, comparing four management systems: CT (harrow, cultivator, roller compactor), NT (suppression of labor and bare soil by herbicide treatments), spontaneous groundcover and sown GC, both mechanically mowed. The cost reduction in the spontaneous GC system with respect to the CT system was around 18 € ha^{-1}, while the sowing GC system, meant approximately 20 € ha^{-1} higher cost than in CT. It should be noted that, in all cases, the highest costs corresponded to the use of machinery, which were around 50%, resulting in the reduction of overall costs in CA systems, due to the reduction in working time. This decrease is greater if the mechanical control of the cover is replaced by a chemical control (which is also more economical).

The benefits of CA systems in permanent crops, mainly those obtained maintaining groundcovers, have been better perceived by the farmers, which has resulted in their greater implementation. According to data in chapter 3 of this report, groundcovers represent 15.6% (2,008,888 ha) of total amount of hectares (12,905,081 ha).

In the analysis of the cost-efficiency relationship, one also needs to take into account that the implementation of these practices by a farmer who previously carried out a conventional management system based on tillage, requires an initial investment in the case that he decides to purchase the necessary equipment. The higher cost the farmer would have to face is the no-till seeder, which can vary between € 18,000 and € 50,000 depending on the characteristics of the sowing train and the working width. Return on this investment will depend on the number of working hours per year, so it may be advisable for small producers to contract the services of an external company to carry out the sowing operation. An alternative for those farmers who do not want to make a significant initial investment is to subcontract the operations, and there are already companies in the market that can provide services that can respond to this type of demand. On the other hand, in the first years it is necessary for the farmer to be trained and informed appropriately in order to reduce the risks and problems that could arise when shifting the system. In any case, it is clear that the higher investment cost is returned by the increase in the profit margin obtained by changing the management system, which means that these practices not only bring environmental benefits, but also economic ones.

6.5. Social benefits

The reduction of costs and the improvement of the profitability increase the competitiveness of the farms and therefore their sustainability, fixing population in the rural environment and creating wealth. If an activity is not economically sustainable, it cannot be socially sustainable.

A study carried out by *Arnal Atares (2014)* shows the noticeable reduction of working time in crops. Adding all the working hours in the crop's agricultural operations (with the exception of the harvester which is rented), Arnal estimated that the average working time required for the analyzed crops (extensive herbaceous) was 7.50 h ha^{-1} in the case of conventional management, 5.75 h ha^{-1} in minimum tillage and 3.90 h ha^{-1} in NT management system, which means a decrease of 1.75 h ha^{-1} in minimum tillage and 3.6 h ha^{-1} in NT systems compared to CT (Fig. 6.7). This reduction implies that NT management uses 52% of the time required in conventional agriculture.

In 2013 there were 10,841,000 farms in EU-28 (*Eurostat, 2013*) and, as showed in Fig. 6.8, the majority of the employed labor is familiar, integrating the farmer and relatives, who often do not receive adequate remuneration from the performed work due to the low profitability of farms. The reduction of working hours per hectare thanks to CA in addition to the reduction of costs, allows more time for other activities both inside and outside the farm (family, training, leisure, activities for the community, etc.) improving the economic and welfare conditions of farmers and their families.

The decrease in the number of working hours per hectare should not lead to a decrease of employment in

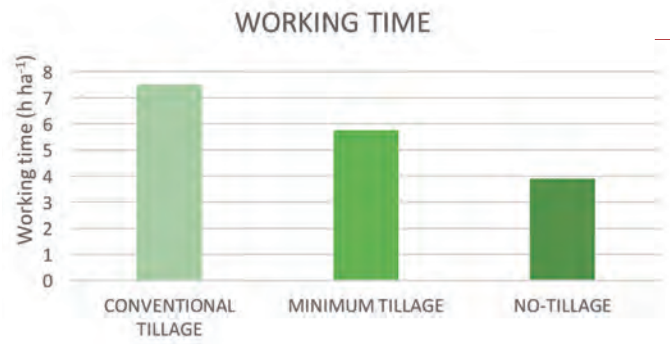


Fig. 6.7. Working time dedicated to agricultural operations in the analyzed systems, conventional tillage (CT), minimum tillage (MT) and no-tillage (NT). Source: *Arnal Atares, 2014.*

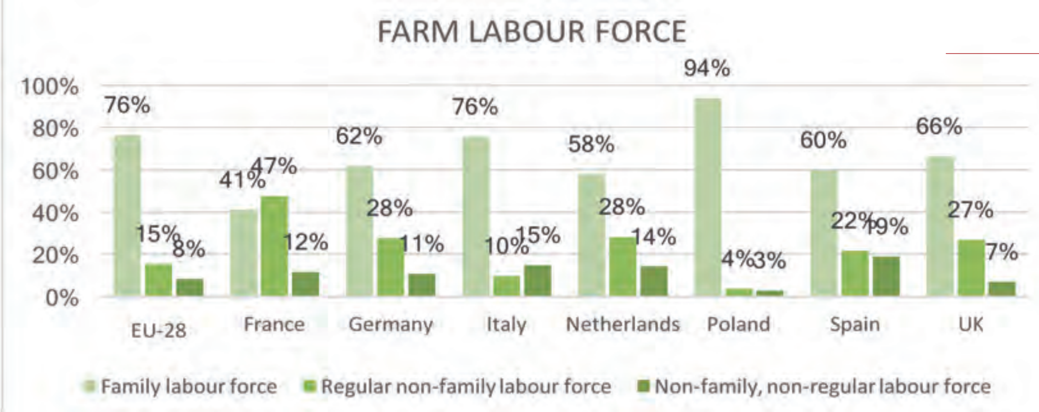


Fig. 6.8. Distribution of annual work units (AWU) according to the type of worker. Source: *Eurostat, 2013.*

rural areas where CA is implemented, since the greater use of technology induces indirect and more qualified work (machinery dealers, workshops, supplies, etc.), transferring employment from the agricultural sector to other sectors of higher added value.

Another important aspect related to society is that, due to the more complete training skills of CA farmers, their environmental awareness will be greater and they will have a deeper knowledge about the risks that agricultural activity entails and about the techniques to reduce them.

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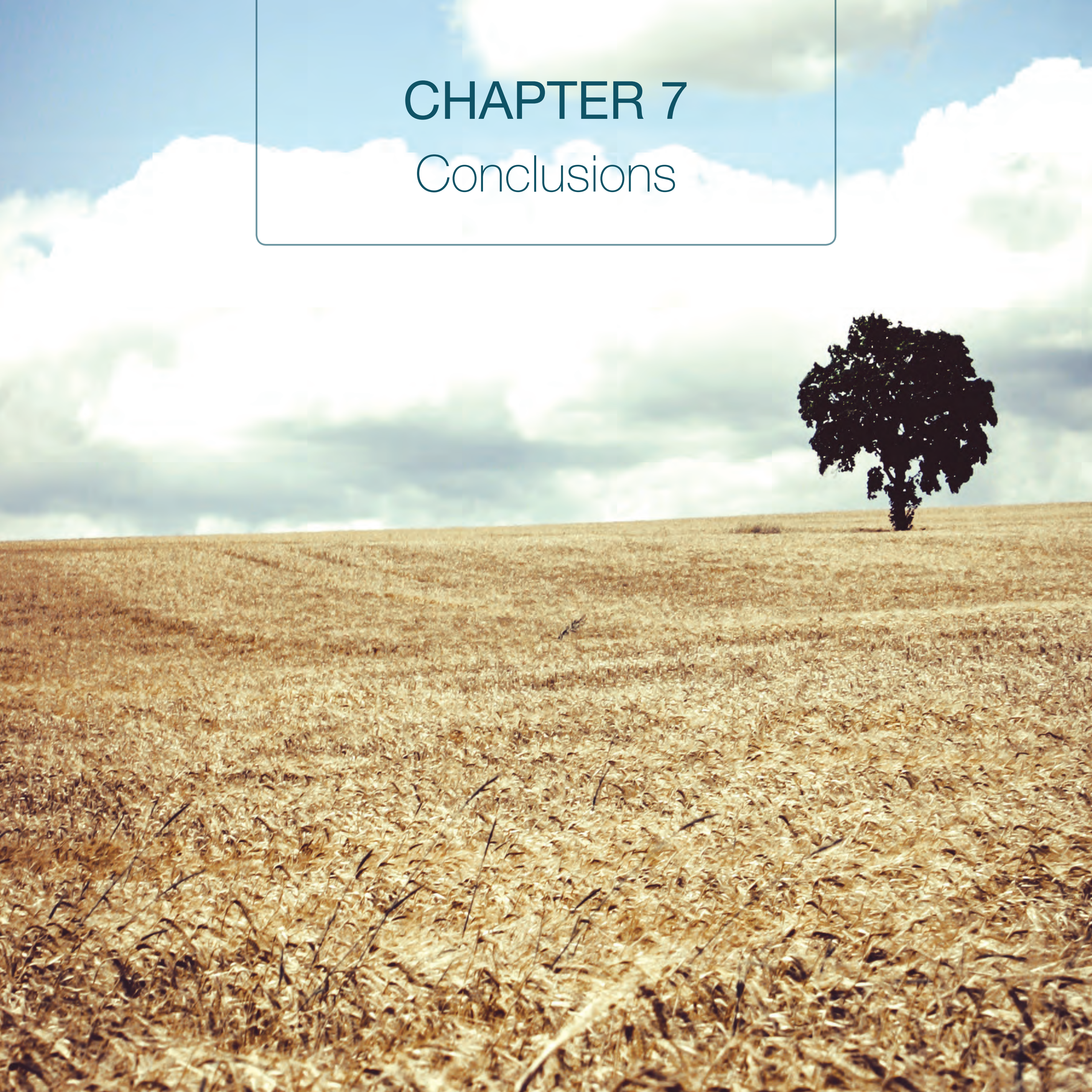
CHAPTER 7
Conclusions



Conclusions

1. Conservation Agriculture is a sustainable farming approach based on three interlinked principles: (1) Continuous minimum mechanical soil disturbance; (2) Permanent organic soil cover; and (3) Diversification of crop species grown in sequences and/or associations. In practical terms, no-tillage is the term frequently used to refer to Conservation Agriculture in annual crops, whereas leaving groundcovers in-between tree rows is the case for permanent crops.

2. Conservation Agriculture has multiple environmental benefits, such as reducing soil erosion up to more than 90%, improving the quality of soil and water, increasing biodiversity, mitigating and adapting to climate change, among others. At the same time, Conservation Agriculture helps improve farmers' profits and competitiveness.

3. Climate change is a global threat, whose impact will adversely affect agricultural production also in Europe. The lower amount of precipitation, periods with excess rainfall and prolonged drought periods, together with the increase in temperature, will negatively impact the European countryside. Through Conservation Agriculture, these effects can be mitigated. Indeed, research confirms that Conservation Agriculture helps mitigate climate change by sequestering carbon in the soil and helps adapt through water saving as a consequence of less evaporation from the soil.

4. Carbon sequestration rates vary within the European continent. In the Mediterranean, the CO_2 stored in the soil through Conservation Agriculture can be up to 3 tons per hectare and year, whereas this rate is around 1.5 tons in the Continental region, 1 ton in the Atlantic, and only around 0.1 ton in the Boreal region. In

permanent crops, maintaining a groundcover in comparison with conventional agriculture, is capable to sequester more than 5 tons of CO_2 per hectare and year in the Mediterranean region, while in the Continental and Atlantic ones, this rate is approximately half.

5. International treaties, such as the Paris Agreement (COP21, 2015) and the Initiative 4 per 1000, identify the improvement of the management of agricultural soils as a key factor to mitigate climate change. In this context, around 100 of the 187 signatory countries have included land-related measures in their reduction plans. In the Paris Agreement, the European countries have committed themselves to reduce non - emissions trading system (non-ETS) emissions by 30% by 2030 which means over 856 M tons of CO_2. Therefore, non-ETS emissions in EU-28 by 2030 should not exceed 1,991 M tons.

6. Conservation Agriculture can contribute to reduce GHG emissions by storing CO_2 as organic carbon in the soil. The total figure would be around 190 M tons of CO_2. This means that carbon sequestration through the practice of Conservation Agriculture, at European level, could account for almost 10% of the EU non-ETS allowed emissions by 2030, and for over 22% of the commitments in non-ETS GHG reduction.

7. Conservation Agriculture is a holistic approach that promotes sustainable intensification of agricultural production, and therefore needs essential technologies and innovative solutions for its application on the field. The application of Conservation Agriculture implies a change in the management of the soils, since tillage is not used neither to eliminate adventitious vegetation nor to prepare the seedbed. Therefore, it is necessary to use seeding machines adapted to work on soils with a solid seedbed and groundcovers, and to control weeds with plant protection products instead of ploughing.

8. There are diverse types of no-till drills on the market adapted to the different European soil conditions, and to different cover crops and amount of residues that can occur in the rotations. In addition, broad-spectrum herbicides with a low ecotoxicological risk, such as glyphosate-based herbicides, are essential tools to control weeds, avoiding soil degradation caused by intensive tillage, commonly performed in conventional and organic agriculture.

9. Conservation Agriculture uses inputs in a more efficient way, which also leads to economic savings for farmers and environmental benefits through less off-site transport of nutrients and plant protection products. According to studies, through Conservation Agriculture, the farmer can save 24% of the total costs of cultivation in comparison with conventional tillage, and about 9% compared to minimum tillage. Conservation Agriculture is a win-win option for farmers, as yields are maintained or even increased, with lower production costs.