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 the 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 the 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.

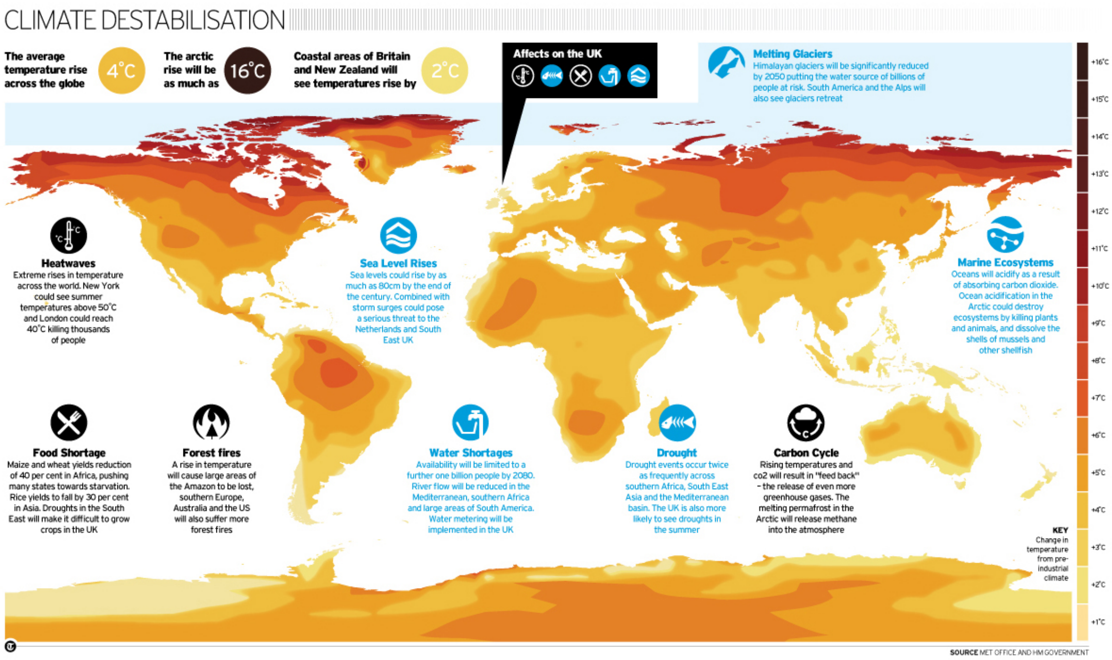


Fig. 1. Global impacts of climate change.

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 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):

• Minimum soil disturbance. In practice it means no-tillage. At least 30% of the soil must be covered after seeding to effectively protect it against erosion. However, it is recommendable to leave more than 60% of the soil covered to have almost complete control over the soil degradation process.

• Permanent soil cover. In other words, it means to maintain stubble in arable crops and to seed or preserve groundcovers between rows of trees in permanent crops. In this way, soil organic matter and water infiltration into the soil are increasing, weeds are inhibited, and water evaporation from the soil is limited.

• Practicing rotations or crop diversification in annual crops. In this way, pests and diseases are better controlled by breaking cycles that are maintained in monocultures, in addition to including crops that can improve the natural fertility of the soil and biodiversity.

Fig. 2. Principles and benefits of Conservation Agriculture.

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.

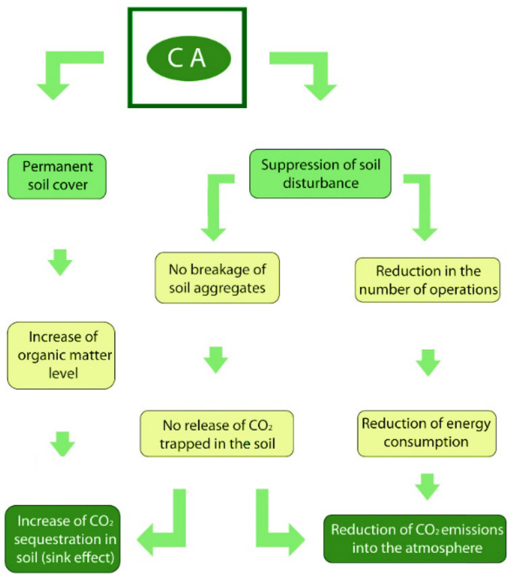


Fig. 3. Mitigating climate change mechanisms through Conservation Agriculture.

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).

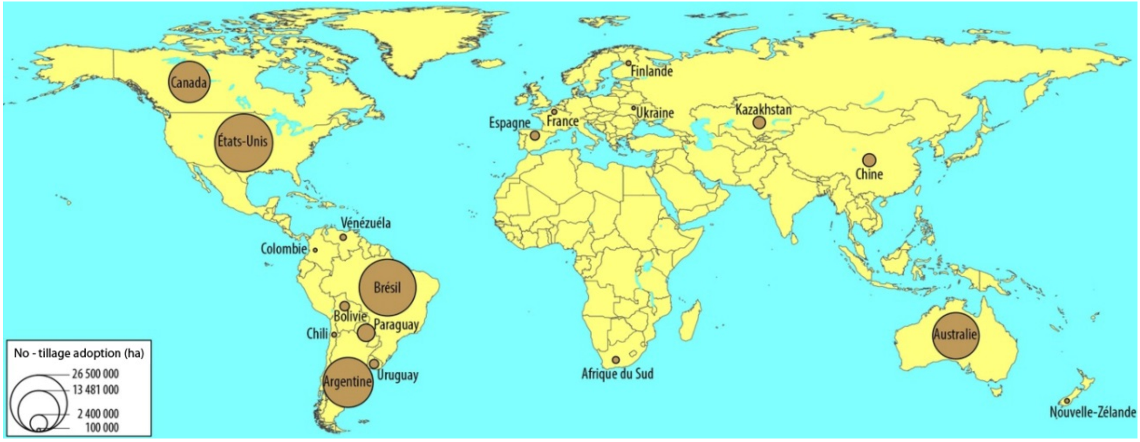


Fig. 4. Worldwide No-tillage adoption.

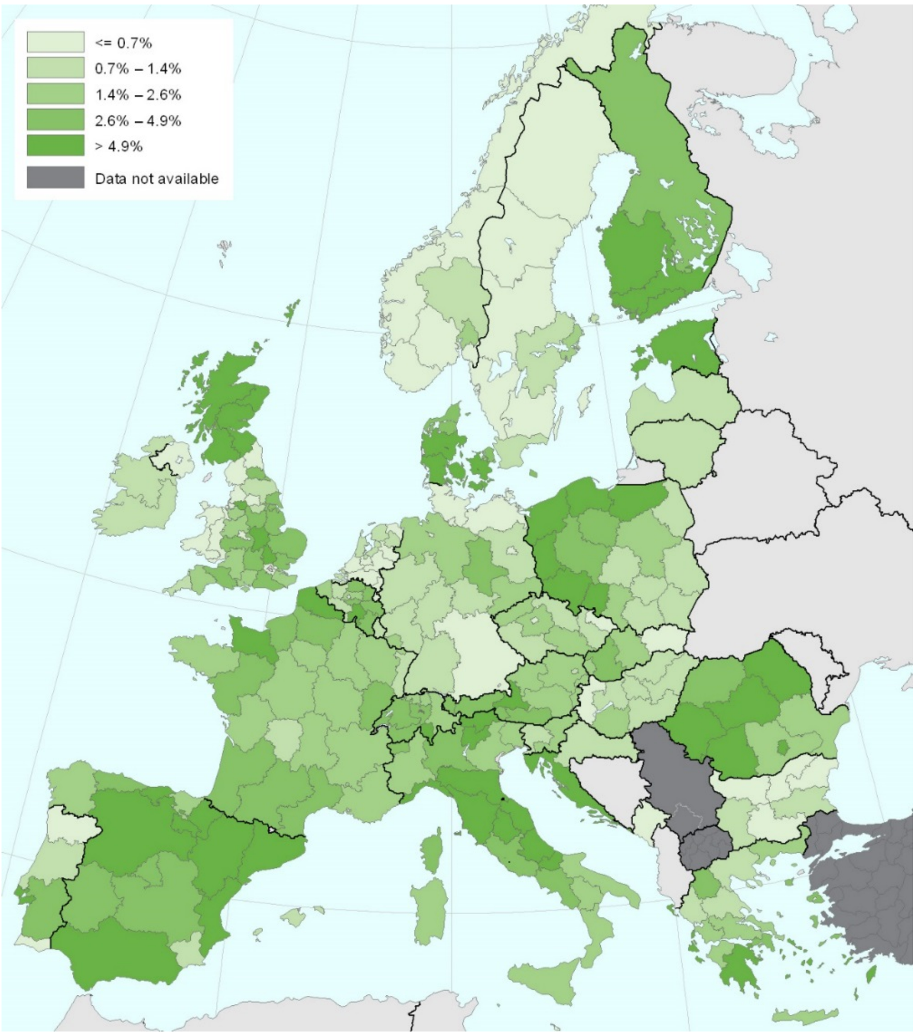


Fig. 5. Share by European regions of annual crops on which no-tillage is applied.

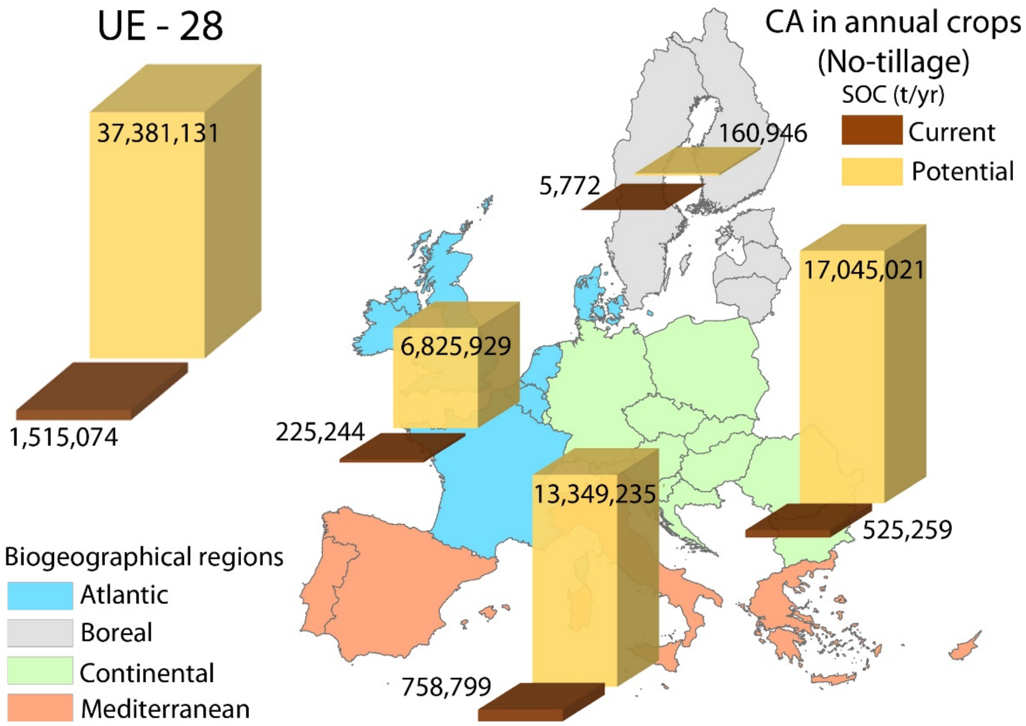
SOIL ORGANIC CARBON FIXATION THROUGH CONSERVATION AGRICULTURE

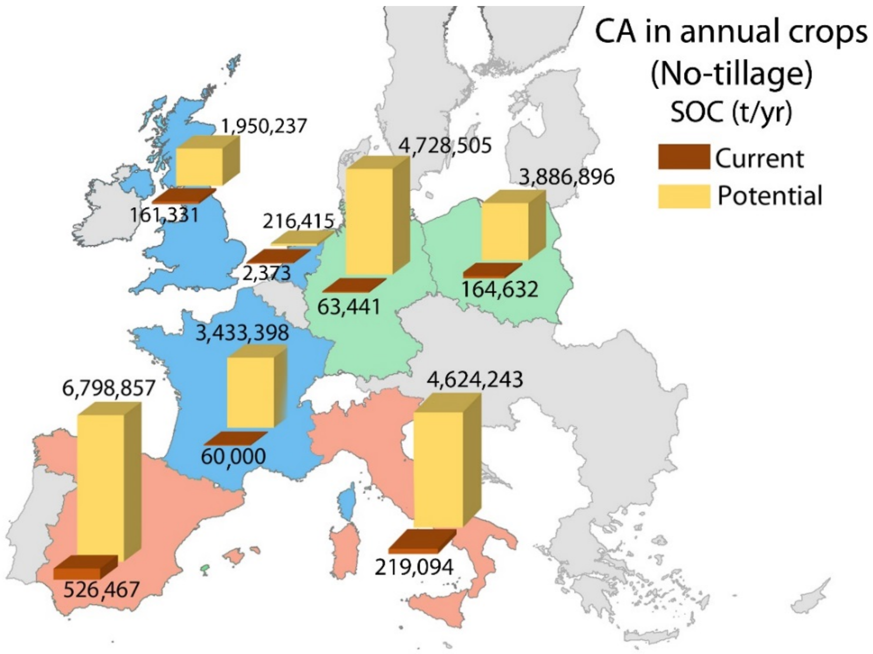
Different studies in Europe show that during several years of the application of CA principles it is possible to sequester large amounts of CO_2 per hectare and year in annual crops, compared to tillage-based systems. The estimation for EU-28 countries of the potential soil organic carbon (SOC) sequestration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

Country	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	10,000	4,210	15,436	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			3,137,733	1,515,074	5,555,271	90,871,405	37,381,131	137,064,146

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)

Country	**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})**	**Groundcover 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

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).

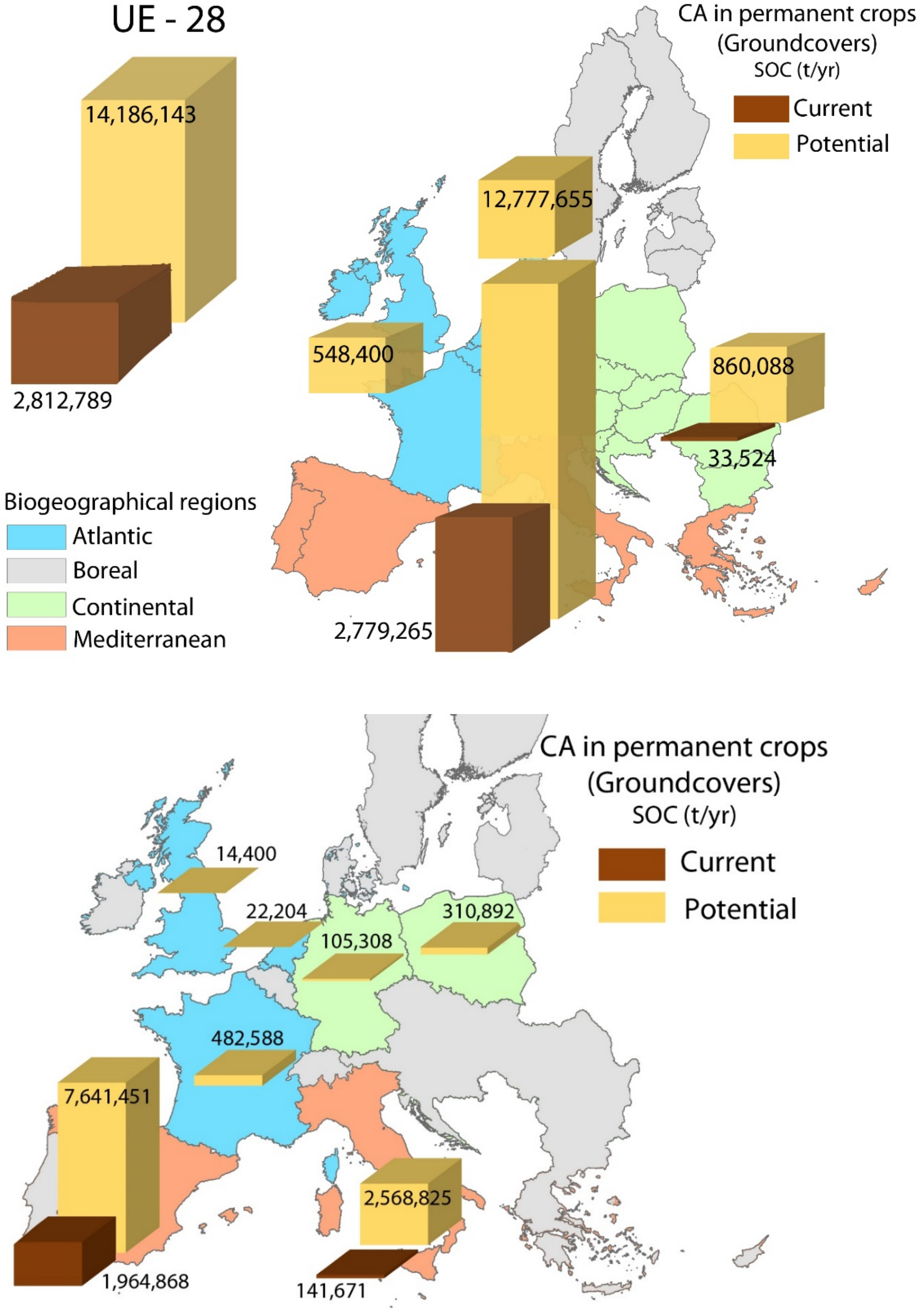


Fig. 9. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom.

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).

Table 4. Current and potential fixation of CO_2 in Europe.

	Biogeographical region	**Current CO_2 fixation through CA (t yr^{-1})**	**Total Potential CO_2 fixation through CA (t yr^{-1})**	**Remaining Potential for CO_2 fixation 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	43,024	2,052,459	2,009,435
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		15,868,829	189,080,005	173,211,176

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).

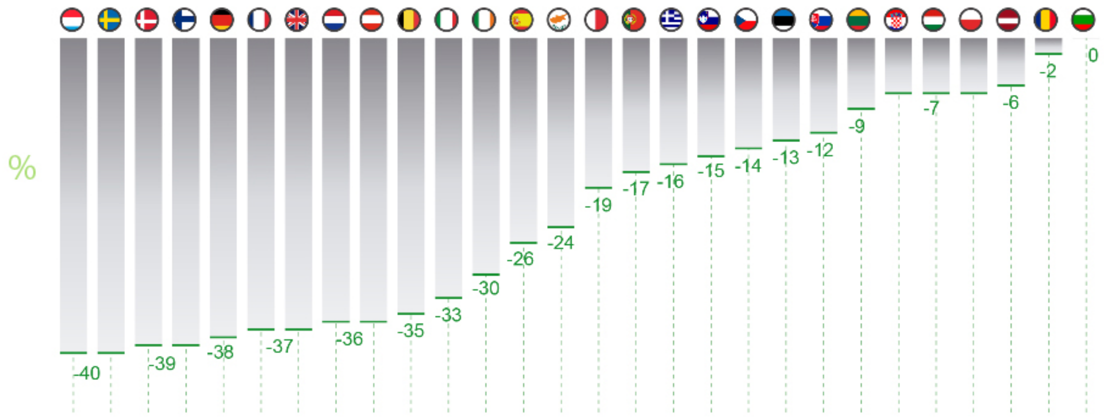


Fig. 10. Percentage reduction of national emissions in sectors outside the EU ETS (non-ETS).

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.

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

Data are based on the potential of CO_2 sequestration in Europe (189 M t ha^{-1} yr^{-1}) and on the average yearly CO_2 sequestration that can be achieved by the implementation of CA (1.82 t ha^{-1} yr^{-1}). This amount results of dividing the CO_2 sequestration in Europe by the area susceptible to be managed under CA (103 M ha).

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

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

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.

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.

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

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

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