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Methodology for estimating the impact of no tillage on the 4perMille initiative: The case of annual crops in Spain

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ABSTRACT

The 4perMille Initiative aims to mitigate anthropogenic CO_2 emissions through carbon sequestration in soil organic carbon (SOC). Its main objective is to increase the annual amount of C in soils of the world by 0.4%. A new study methodology focused on achieving the regional objectives of 4perMille Initiative through No Tillage (NT) potential application in annual crops has been presented in this paper. It has been based on the modelling of Carbon Sequestration (CS) in Carbon Benefits Project (CBP), an online free tool. For the entire field of study (15 regions in Spain), the annual average is 0.38 Mg of C ha^{-1} yr^{-1}. And the potential CS amounts are almost up to 3 Tg of C per year. CBP is a digital tool which allows to make an online modelling of the evolution of C stocks and Greenhouse Gas (GHG) emissions, derived from using different soil management systems. The comparison between the annual CS through NT and the contents in SOC in annual crops, has allowed to calculate the potential importance of NT, within the regional framework, of the 4perMille Initiative. There are large areas where the stored C could be 2 and up to 3 times over the reference values. What entails that the potential application of NT would represent a significant percentage of the CS objectives of the 4perMille Initiative in Navarra (52%), Castilla-La Mancha (51%), Castilla y León (43%), Aragón (35%), La Rioja (35%), Andalucía (35%) and Cataluña (29%). This methodology for calculating the NT potential over the 4perMille Initiative can be easily replicated in regions and countries around the world.

1. Introduction

Carbon Sequestration (CS) means to store atmospheric carbon forbidding its immediate emission (Baveye et al., 2017). Since the average soil organic matter degradation lasts for centuries, even millennia, increasing soil organic carbon (SOC) through soil conservation practices, is an economically and environmentally interesting option (Lal, 2016). The large-scale application of agricultural practices that allow the sequestration of carbon could even help remove more carbon from the atmosphere than that emitted by the agricultural sector. According to Aertsens et al. (2013), annual agricultural sequestration potential could be equivalent to 37% of all EU emissions per year. In the case of Spain, for the year 2015, the amount of emissions produced by the agricultural sector was 37.4 Tg of C (MAGRAMA, 2018a). If an amount of SOC exceeds that value, the application of these agricultural practices would not only compensate for the emissions produced by the agricultural sector, but they would also mitigate GHG emissions from other sectors (transport, waste, housing, etc.).

The demonstrated benefits of the increase in organic carbon content and CS using appropriate agricultural practices are important for the implementation of the 4perMille Initiative. The 21st Conference of the Parties to the United Nation Framework Convention on Climate Change (COP21) was the origin of both the Paris Agreement and the “4 per Mille Soils for Food Security and Climate” (4perMille Initiative). Signing the 4perMille Initiative is a voluntary choice, with the goal of increasing the annual amount of carbon by 0.4% in the soils of the world. The 4perMille Initiative intends to compensate CO_2 emissions produced worldwide by fossil fuels, through the sequestration of SOC at

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an annual rate of the same magnitude (Baveye et al., 2017). The CS rate of 0.4% comes from the quotient of global carbon emissions (8.9 trillion tons) and the amount of carbon contained in the world's soils (2,400 trillion tons) (Eglin and Cogneau, 2014). Therefore, if a sequestration of 0.4% of the 2,400 trillion tonnes of SOC was reached, a quantity of carbon similar to that emitted by human activity would be removed from the atmosphere. Among the measures to be taken to achieve the objectives of the 4perMille Initiative, those related to agriculture play a very important role. The implementation of soil conservation practices can achieve a CS of approximately 88 Pg in the next 50–75 years (Lal, 2016), compensating for between 20 and 35% of annual emissions of greenhouse gases (Minasny et al., 2017).

Spain has more than 50 million hectares of agricultural area (MAGRAMA, 2018b). Therefore, soil conservation agricultural systems can be an important tool to store much of the SOC established by the 4perMille Initiative. The accumulated SOC in Spanish agricultural land has been estimated at 901.08 Tg (Rodríguez Martín et al., 2016). The same study gives a total amount of 2,819.86 Tg of SOC for all soils in Spain. Thus, in order to achieve the amount established by the 4perMille Initiative in the Spanish agricultural land, a total of 11.28 (2,819.86 × 4/1,000) Tg of SOC should be fixed annually.

SOC sequestration not only helps to remove atmospheric CO2, but it also underpins regulating and provisioning ecosystem services such as soil resistance to erosion (Novara et al., 2011), water retention capacity (Espejo-Pérez et al., 2013), fertility (Carbonell-Bojollo et al., 2011; Repullo et al., 2012) and biodiversity (Holland, 2004; Ogle et al., 2005). Therefore, increasing carbon in the world's soils is one of the main tools to address the threefold challenge which humanity is facing today: climate change, food insecurity and environmental pollution (Lal, 2016). It has been shown that minimal changes in soil C stocks generate very significant effects on both agricultural productivity and the global cycling of greenhouse gases (Post and Kwon, 2000).

The repercussions of SOC dynamics on the mitigation of climate change has led to the use of a multitude of numerical models designed for its study. Among them, it is worth mentioning (Batlle-Aguilar et al., 2011): Century (Parton et al., 1987); DAISY (Hansen et al., 1991); NCSOIL (Molina et al., 1983); CANDY (Franko et al., 1997); RothC (Coleman and Jenkinson, 1996). In addition, digital tools have been implemented to study the evolution of SOC at national and regional levels, by combining the mathematical component of the models, the existing geographic information on land uses; and the rates of C emissions or CS obtained by scientific studies for different soil management. As is the case with GEFSOC Soil Carbon Modeling System (Milne et al., 2007), which studies the evolution of carbon in soil through: modelling with Century and RothC, geographic information on regional land uses through GIS; and the C emission - sequestration coefficients of the Intergovernmental Panel on Climate Change (IPCC) (Álvaro-Fuentes et al., 2010; Wang et al., 2015). Currently, the digital revolution and remote access via web to multiple sources of information has allowed the development of online digital tools that work on this issue. This is the case of the Carbon Benefits Project (CBP, 2019), which allows online modelling of the evolution of C stocks and Greenhouse Gas (GHG) emissions, derived from changing soil management systems in cropland (Milne et al., 2010a, b).

The CBP online free tool is the result of the cooperative work of different entities at an international level. Co-financed by the Global Environmental Facility (GEF) and executed by the United Nations Environment Program (UNEP-DEWA) (Batjes, 2011). CBP has three different monitoring tools: Simple Assessment, Detailed Assessment and Dynamic Modeling. They correspond respectively to a degree of detail of Tier 1, Tier 2 and Tier 3 of the IPCC (IPCC, 2006). Simple Assessment models the flow of C exchange through equations based on three factors: climatic region, land use and soil type (Batjes, 2011). The different categories present in each of these variables have a particular coefficient of C emissions - sequestration, based on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). While in the Detailed Assessment option, the model has been improved with coefficients determined by studies with a greater spatial detail for the three variables indicated before. Finally, the most detailed tool (Dynamic Modeling), does not allow working via web and derives to the download of the GEFSOC Soil Carbon Modeling System software.

No Tillage (NT) is a Conservation Agriculture practice for annual crops that consists in leaving at least 30% of area covered by plant residues after harvest avoiding soil disturbance (González-Sánchez et al., 2015). NT introduces important changes in soil C dynamics and favours CS (Follett et al., 2001). The scattering of crop residues on the soil surface and the non-mechanical alteration of the soil has as a consequence a reduction in the decomposition rate of the biomass, a decrease in the mineralization of the organic matter and an increase in the SOC (González-Sánchez et al., 2012). Leaving vegetal residues on the soil, leads to the sequestration of the atmospheric CO_2 that had previously been fixed in the vegetative structures by photosynthesis. Therefore, the soil acquires the role of atmospheric CO_2 sink, mitigating the concentrations generated by emissions from other activities (Aguilera et al., 2015). Among the different measures to be applied in agriculture to fight against climate change, Sanz-Cobena et al. (2017) considered that NT practices have a medium potential, just behind the adjustment of nitrogen fertilization or fertirrigation, which have no direct connection with SOC, but with nitrous oxide (another GHG).

There are many studies of the benefits of NT on atmospheric C sequestration in Spanish regions: Castilla y León (De Benito and Sombrero, 2006), Castilla-La Mancha (López-Fando and Pardo, 2011); Andalucía (Carbonell-Bojollo et al., 2015), Aragón (Álvaro-Fuentes et al., 2008), Cataluña (Álvaro-Fuentes et al. 2014), Extremadura (López-Garrido et al., 2011) and Navarra (Virto et al., 2007). However, it is difficult to give a unique sequestration value of different conservative techniques since the magnitude of the response of the NT to CS varies considerably depending on climatic conditions of each area. In a long-term experiment located in the southwest of Spain, López-Bellido et al. (2010) estimated an increase in SOC in the superficial soil horizon (0–10 cm) by establishing NT techniques due to a greater amount of surface residues. In the central part of the Iberian Peninsula, López-Fando et al. (2007), indicate 13% more SOC in no tilled soils than in those under conventional management, in the first 30 cm of the soil. Regarding southern area, Ordonez-Fernandez et al. (2007), evaluated 20% more SOC in the soil under NT, at a depth of up to 26 cm.

The results obtained in most of the studies carried out by Spanish teams on the increase of SOC in NT have been included in three meta-analysis. The first one, prepared by Alvaro-Fuentes and Cantero-Martinez (2010), evaluated 8 studies carried out on national territory under rainfed conditions. The second one (González-Sánchez et al., 2012) reviewed 29 references of studies carried out in Spain, while in the third one (Aguilera et al., 2013), 79 references were made, but, in this case, on an international field, in Mediterranean climate areas.

Most of the studies about the NT effect on carbon sequestration highlight the beneficial effect of the use of this technique on annual crops. Alvaro-Fuentes and Cantero-Martinez (2010) indicated an increase of 0.23 Mg ha^{-1} yr^{-1} of sequestered carbon compared to conventional tillage (CT). González-Sánchez et al. (2012), indicated that C sequestration rates were high in newly introduced systems during the first 10 years, reaching maximum values of 0.85 Mg ha^{-1} yr^{-1}. CS value estimated by Aguilera et al. (2013) was 0.44 Mg ha^{-1} yr^{-1} in Mediterranean climate soils. Therefore, an intermediate CS value to the two works mentioned above.

This article studies the potential sequestration of SOC produced through NT in Spain, determining the quantitative importance of the national implementation of the 4perMille Initiative. To achieve this goal, we have worked with CBP at a regional level providing data to the model on the geographical location of the arable crops of each region and the most up-to-date regional statistics on the areas managed under NT.

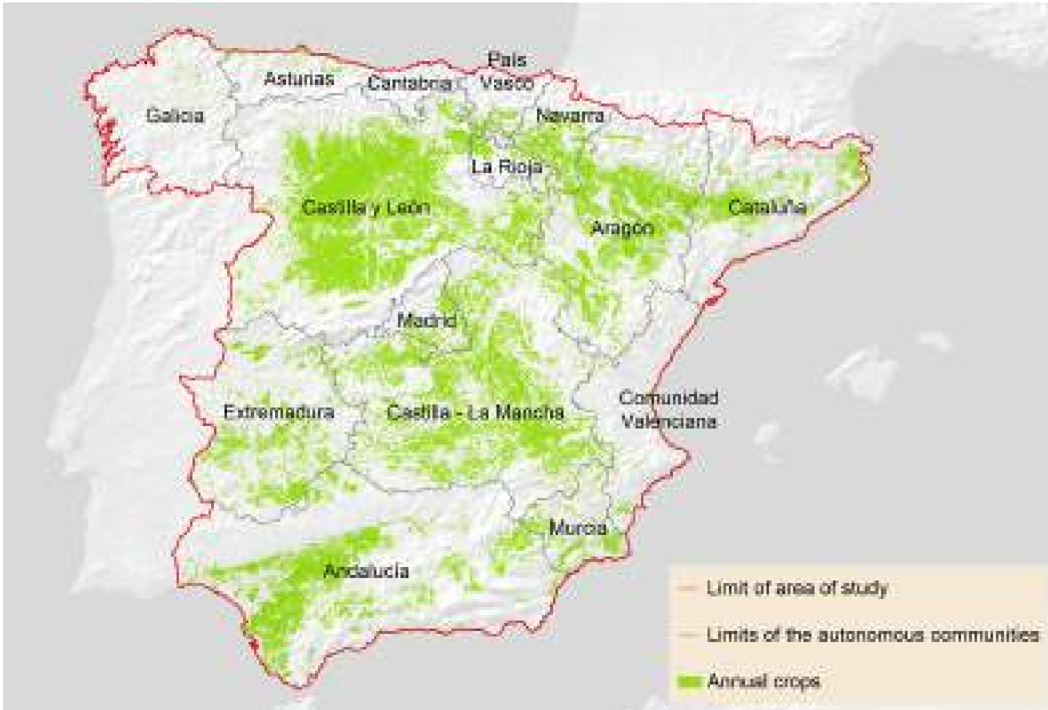

Fig. 1. Study area, location of the studied regions and location of annual crops.

2. Material and methods

2.1. Study area

Modelling of CS has been studied on the Spanish territory located within the Iberian Peninsula. It covers an area of 49,579,200 ha, with altitudes ranging from sea level, to 3479 m in Mulhacén peak. It is included between the parallels 36°00′N, and 43°47′N, and the meridians 9°W and 3°E. Most of the study area is influenced by Mediterranean climate, while the Atlantic climate is restricted to a narrow strip located in the north. It is divided administratively by 15 autonomous communities or regions. There is a great heterogeneity among them in terms of climate, lithology and relief. For this reason, there is also a great heterogeneity among them regarding the distribution (Fig. 1) and typology of the arable crops that are grown in them.

2.2. CBP tool

To obtain the CS data through CBP, the Detailed Assessment tool has been used. For this, CBP needs the introduction of 4 different parameters:

a) Types of crops and their surface (Legume, Forage, Sunflower or Cereal)
b) Soil types (sandy, very clayey, slightly clayey, etc.)
c) Types of climate (warm and dry, warm and humid, cold and dry, cold and humid, etc.)
d) Types of soil management (Tillage or Non-tillage)

For each of the options of each of the 4 parameters, CBP has a particular coefficient given by the developers of the application with expert judgment. So in CBP the information of these 4 parameters and the model must be entered, from the combination of the corresponding coefficients it manages to calculate a regional CS.

The Detailed Evaluation has been modeled at 10 years in two different ways. First, simulating the CS using NT. And then, simulating the CS in CT. The difference between the two is the CS which potential has been achieved in 10 years. Subsequently, it has been divided by 10 to obtain the annual CS. CBP offers a level of results corresponding to a Tier 2. Since this tool uses more specific CS calculation coefficients than the general ones used in Tier 1 (which are general globally). Subdividing between different CS rates for different management, climates and soil management. Based on work done in detail on the ground, giving results with a greater degree of reliability. For correct operation of CBP, it is necessary to introduce two variables at regional scale: spatial distribution of the crops to be analysed and the extent occupied by each type of crop to be studied. As the present work has been carried out on the sequestration potential through NT, the spatial distribution of annual crops within each region has had to be entered into the tool. And also the most current and detailed possible information regarding the surface of the annual crops suitable to be handled by NT. Thus, CBP working with easily accessible sources of information today. The replicability of the methodology presented in this research in any other area is possible because CBP has been implemented with data of CS in soils around the world. In this way, a workflow has been established at a regional scale (Fig. 2), which allows obtaining CS through CBP in any region of the planet. For the whole area of this study, the sequestration data of the Spanish regions were added. Then, it was compared to the estimated carbon in the soil in order to calculate the possible achievement of the 4perMille goal.

2.3. Input data in CBP: extent occupied by each type of crop

For modelling the potential CS is necessary to introduce in CBP the area occupied by those crops which are suitable to be managed under this agricultural system. According to González-Sánchez et al. (2017), these crops have been considered cereals with the exception of rice, legumes, sunflower and forage crops. This information has been obtained from the Spanish Survey on Crops Area and Yield for 2017 (MAGRAMA, 2018c) in which detailed and updated information of the surface occupied by different crops is collected at a regional level. In general, this type of survey is available in a large number of countries. Otherwise, this information can also be obtained in databases such as Eurostat or Faostat. Table 1 shows the surface on a regional scale of the

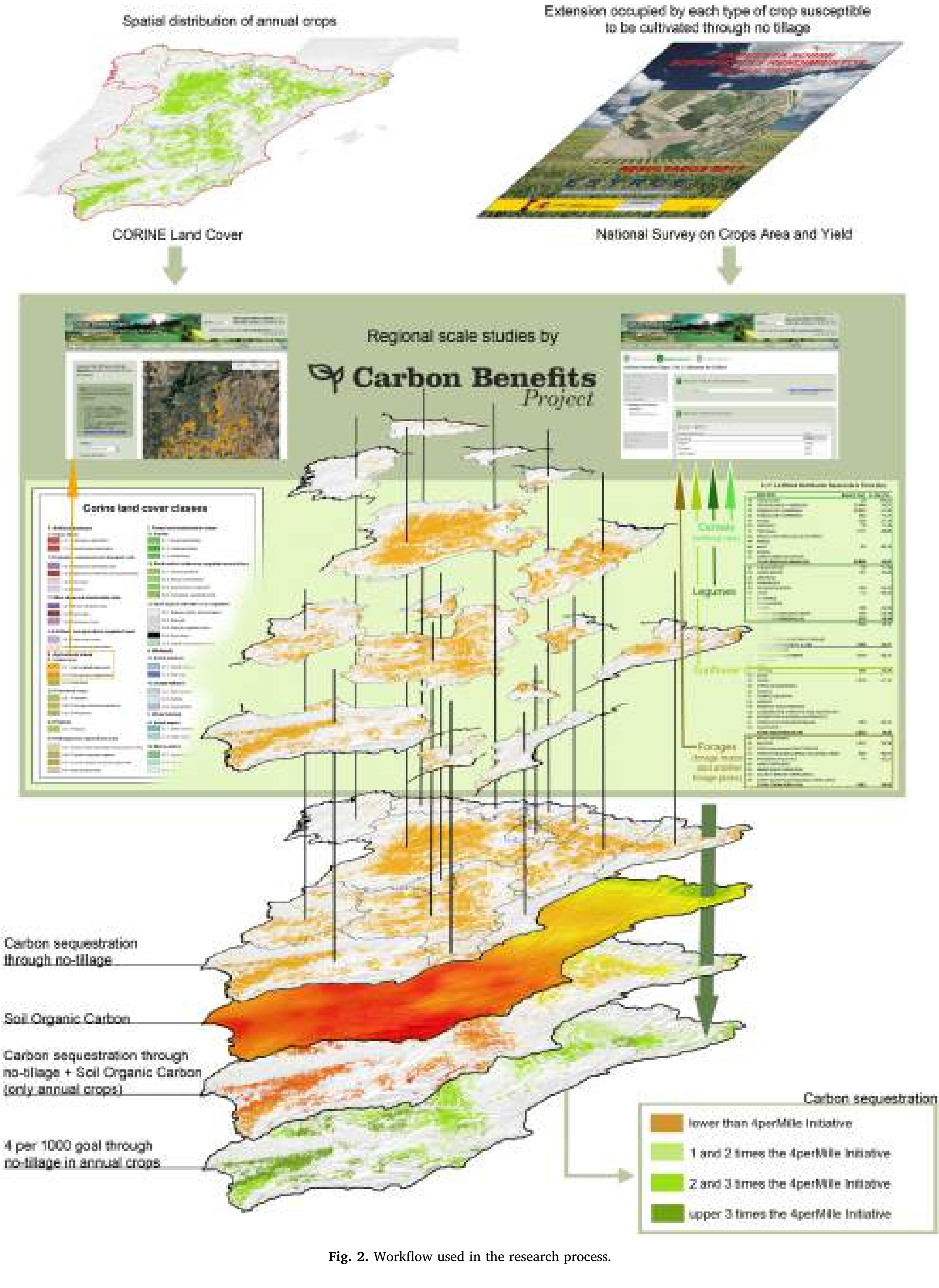

Fig. 2. Workflow used in the research process.

Table 1
Area of the crops that have been considered as suitable to be cultivated through NT in each autonomous community (MAGRAMA, 2017b).

	Regional crops area suitable to be cultivated through NT (ha)				
Region	Cereals	Legumes	Sunflower	Forage crops	Total
Andalucía	636,034	62,213	259,477	56,637	1,014,361
Aragón	913,070	18,500	9,390	33,724	974,684
Asturias	205	530	0	8,221	8,956
Castilla - La Mancha	1,380,757	165,197	160,909	57,586	1,766,669
Castilla y León	2,056,682	167,505	253,178	104,965	2,582,330
Comunidad Valenciana	27,200	845	1,264	2,087	31,396
Cantabria	821	124	0	4,441	5,386
Cataluña	316,415	11,321	1,074	52,498	381,308
Extremadura	242,870	16,378	11,897	35,548	306,693
Galicia	35,069	996	0	69,748	105,813
La Rioja	55,512	2,106	352	68	58,038
Madrid	83,247	7,932	373	2,025	93,577
Murcia	60,334	1,771	3	492	62,600
Navarra	191,718	6,384	3,080	6,611	207,793
País Vasco	47,255	2,746	741	242	50,984

crops that have been considered as suitable to be cultivated by NT. The data entered in Table 1 has been introduced manually in the CBP Detailed Assessment tool through drop-down menus in which different types of crops can be selected.

2.4. Input data in CBP: spatial distribution of the crops

The spatial information with the location of the annual cropland was obtained from the CORINE Land Cover (CLC) project. This project is framed in Coordination of Information on the Environment program (CORINE), promoted by the European Commission in 1985 for the assessment of environmental quality in Europe (Muñoz-Rojas et al., 2011). The result of this project is the periodic generation of the European database of land occupation at a scale of 1:100,000. CLC includes 44 different land cover classes, distributed into five main classes: Artificial surfaces, Agricultural areas, Forests and semi-natural areas, Wetland and Water (Heymann, 1994). In general, digital cartographies of land used in the regions do not distinguish between different types of arable crops. This happens also in CLC, where the agrarian uses are divided into annual crops, woody crops and mixtures of annual and woody crops. The data that is entered is shp files. Finally, the annual crops are classified into three categories: Non-irrigated arable land, Permanently irrigated land and Rice fields. NT in rice fields is proven to produce more GHG emissions than crops under conventional management (Sanchis et al., 2012). For this reason, rice fields have not been taken into account in this research. Specifically, the information about the land occupation is the one corresponding to the year 2018. Therefore, it contains geographic data with very recent information on the distribution of annual crops in each Spanish region (Fig. 1).

2.5. CBP modeling

In addition to entering in CBP the spatial distribution of the crops to be analysed and the extent occupied by each type of crop to be studied are entered, it is necessary to select between different soil management systems and different destinies of the stubble generated after harvest. This allows to model the carbon sequestration that occurs in NT and CT.

CBP allow calculate CS in the soil for a period of years to 0–30 cm depth. In our case, CBP calculates CS in the soil within a period of 10 years (2020 to 2030). The simulation of land management in CBP was carried out for the period between 2020 and 2030. Process is based on coefficients associated to: carbon content in vegetative structures for each type of crop, soil management and stubble management. With the objective of calculating the potential CS in NT, the No tillage options in soil management have been selected and the Retained option, as stubble destination.

As has already been mentioned, in CLC, there is no distinction between types of annual cultivated crop. So the CS data generated by CBP refers to the conditions related to the locations of annual crops in CLC, including the surface data by type of crop from national surveys. Therefore, the potential sequestration data obtained refers to the set of all crops at the regional level. From this total potential sequestration value, the average potential sequestration per hectare has been calculated. This allows geographically referencing the potential increase in carbon that could occur when NT is implemented and comparing it with the geographic SOC data present in each location. The SOC increment has been compared to the objectives of the 4perMille Initiative.

2.6. Comparison between CS and SOC content

The SOC increment has been compared to the objectives of the 4perMille Initiative. To make the comparison described above between SOC content in soil and the increment calculated by CBP, it is necessary to have a digital map with SOC content. For this, an interpolation of the SOC map calculated for the Iberian regions of Spain in Rodríguez Martín et al. (2016) has been carried out. The Inverse Distance Weighting (IDW) interpolation method in QGIS was used measuring the SOC content in 1 km × 1 km grid. This has allowed having the constant content of SOC within the territory to be able to compare it with the increment calculated in CBP. It was represented graphically to know the locations with the greatest CS potential through the application of NT. A data extraction and modification similar to the one presented here on the map of Rodríguez Martín et al. (2016), had been previously used (Pardo et al., 2017) on the same map and for the same purpose.

In order to relate the potential of CS through NT to the amount of C in the soil, a SOC content map of the study area was generated on a 1 km × 1 km grid (Fig. 3). The total number of cells generated was 506,400, covering the entire Spanish territory of the Iberian Peninsula. In any case, the existence of a strip located in the north can be clearly observed. It runs through the peninsula from west to east and shows high levels of carbon in soil (higher than 90–100 Mg ha^{-1}), while in the rest of the territory the values are low or very low. Map of SOC stock in the study area looks very similar to the map from which it has been extracted and modified to obtain a continuous data of the stock SOC (Rodríguez Martín et al., 2016). In the same way, the results are very similar to those presented in Pardo et al. (2017) for the C stock in the Mediterranean coastal provinces on the Iberian Peninsula. As well as with the results obtained in a study of the C stock from edaphic data for the same study area of the present work (Rodríguez-Murillo, 2001). With respect to C stock of researches at the regional level, there are also coincidences regarding the results (Rodríguez-Lado and Martínez Cortizas, 2015; Calvo de Anta et al., 2015; Álvaro-Fuentes et al., 2011;

Fig. 3. Map of SOC stock in the study area extracted and modified by Rodríguez Martín et al. (2016).

Albaladejo et al., 2013; Muñoz-Rojas et al., 2012). At an international level, the result obtained has similar characteristics to the maps recently used to study the repercussions of different actions on the 4perMille initiative (Minasny et al., 2017).

3. Results

3.1. Regional carbon sequestration

The potential amount of C retained annually in the soils of the crops studied, that is, those suitable to be managed under NT, are shown in Fig. 4 for each region. These results correspond to the potential sequestration that may be achieved annually in the areas listed in Table 1. In addition to the calculated CS data, the figure shows the error percentage that CBP calculates for the obtained results. In this regard, it should be noted that the CBP provides a measure of uncertainty about the results of CS, which follows the error detection method recommended by the IPCC. The final result of the calculated sequestration in all study area reaches almost 3 Tg of C a year, but it is uneven between regions. In fact, 6 out of 15 studied regions (Castilla y León, Castilla-La Mancha, Aragón, Cataluña, Andalucía and Navarra) account for more than 90% of the total estimated annual SOC sequestration. If the entire area that is suitable to cultivation through NT is taken into account, the average rate of CS through NT is 0.38 Mg of C ha^{-1} yr^{-1}.

Once the amount of C that can be retained in the soil by NT in each region was known, the rate of sequestration per unit of regional surface of the crops suitable to be handled with this technique has been calculated (Fig. 5). As the modelling using CBP is based on edaphic and climatic characteristics, in Fig. 5 each coefficient has been represented in reference to the average data of these variables in each region. It is observed that in a narrow range of the sequestration rate (0.2 to 0.4 Mg of C ha^{-1} yr^{-1}) 8 regions are located (Asturias, Aragón, Castilla y León, Madrid, Castilla-La Mancha, Murcia, Extremadura and Andalucía). The surfaces of crops suitable to be cultivated by NT of these regions account for almost 90% of the total area of these crops in the study area. In the regions of Navarra, Rioja, Cataluña and Comunidad Valenciana the sequestration rate is two time higher (0.7 to 0.9 Mg of C ha^{-1} yr^{-1}), while the País Vasco and Cantabria have even higher rates. In contrast, Galicia, has very low CS rate. A certain north-south gradient seems to be observed in the CS between regions. With relatively higher values in the northernmost regions. Associated with a rainier climate and with less basicity, except in the case of Galicia, which has lower values of CS. In a general way, towards the south the rates of CS are reduced, at the same time that the basicity of the land increases and the precipitation is reduced.

3.2. Comparison between CS and SOC content

Fig. 6 shows the potential influence of NT application on the studied territory according to the objectives of 4perMille Initiative. It represents the ratio, per thousand, between the annual CS data obtained through CBP, with the content in SOC in each of the cell square of 1 km × 1 km of the Fig. 3. It can be observed how annual crop lands, in general, have a capacity of CS higher than that indicated by the 4perMille Initiative (Fig. 6). There are large areas where the C stored could be 2 and up to 3 times over the reference values. On the other hand, the cells in which the expected CS values are not reached are scarce. These are concentrated on the northern part of the Iberian Peninsula and in a dispersed way. As can be seen in Fig. 6, the largest number of cells is within the range in which the potential CS would be between 2 and 3 times the objective of the 4perMille Initiative. There are also numerous cells in which the values are between 1 and 2 times higher than those established as the objective, as well as those in which values are 3 times higher. Within the latter, cells have been calculated in which the C increase has meant more than 7 times the 4perMille rate.

In order to observe the results of the modelling at regional level, the 4perMille rate has been related in each cell with the existing SOC. The adjustment of this data is shown for each of the regions in Table 2 and Fig. 7. The table also shows minimum, maximum and average data, as well as the number of crop cells per region. It should be highlighted the existence of regions with a small area of annual crops, such as the extreme case of Cantabria. In Fig. 7 it can also be observed the different dynamics that occur in Galicia and Asturias with respect to the rest. In general, it has been noticed that the greatest increase occurs in those areas where the C content is lower. This increase becomes lower when the C content is higher like in Galicia and Asturias regions. With average SOC contents of 145 and 115 Mg ha^{-1}, respectively.

Through the cells of the map in Fig. 3, it has been possible to calculate the current SOC content in the surface layer of soil (0–30 cm) in the studied regions (Table 3). That has allowed relating the annual potential CS through the NT in each region, with its objectives of the 4perMille Initiative. In summary, what is represented as the percentage that would be the potential application of the NT on the global objectives to be achieved in each region. There is a high disparity between regions regarding the application of this measure to achieve the level of carbon retention that corresponds to the 4perMille Initiative. There are regions where 50% of the established objectives would be exceeded (Navarra and Castilla y León) while there are others that would not reach even 1% (Galicia and Asturias).

4. Discussion

4.1. Carbon sequestration in study area

Potential CS through NT calculated by CBP for the whole study area amounts annually almost 3 Tg of C. That is more than a third of what could be sequestered in all the soils of Spain. And it would be close to the 3.6 Tg of C that should be reached in all agricultural land. This means an average sequestration rate of 0.38 Mg of C ha^{-1} yr^{-1}. This result is in line with those reflected in different meta-analysis that groups most of the experiences carried out in the study territory on the increase in SOC when applying NT with respect to conventional cultivation. Most of the studies of the NT effect on the sequestration of SOC highlight the beneficial effect of the use of this technique on annual crops. Alvaro-Fuentes and Cantero-Martinez (2010), evaluated 8 studies carried out on Iberian Peninsula under rainfed conditions and indicated an increase of 0.23 Mg ha^{-1} yr^{-1} of sequestered C compared to conventional tillage. González-Sánchez et al. (2012), who reviewed 29 references of studies carried out in Spain, indicated that C sequestration rates were high in newly introduced systems during the first 10 years, reaching maximum values of 0.85 Mg ha^{-1} yr^{-1}. CS value estimated by Aguilera et al. (2013) was 0.44 Mg ha^{-1} yr^{-1}, through 79 references in

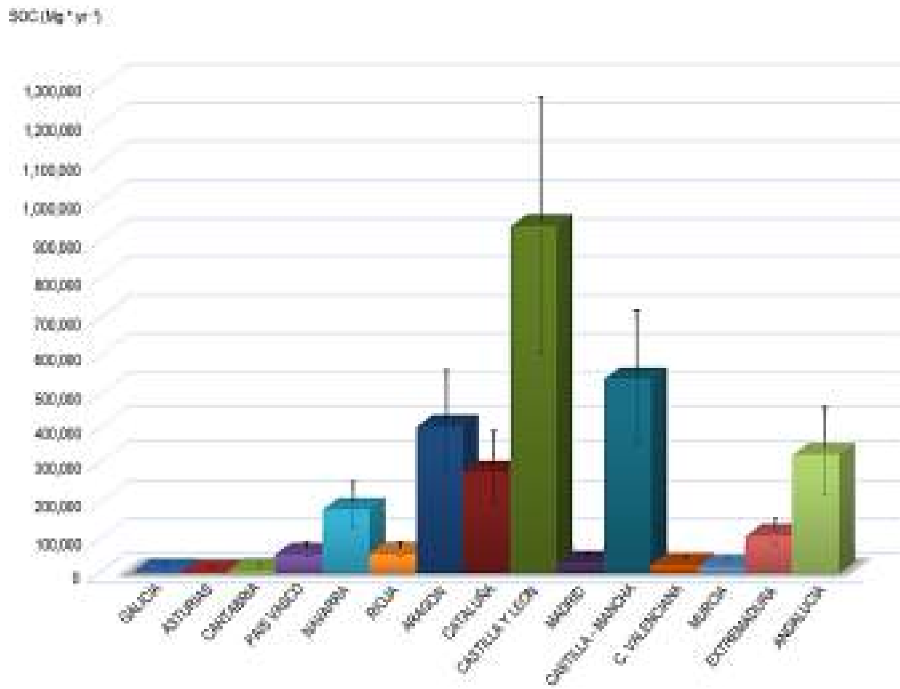

Fig. 4. Annual carbon sequestration in each region. Bars shows error percentages that CBP calculates for the obtained results.

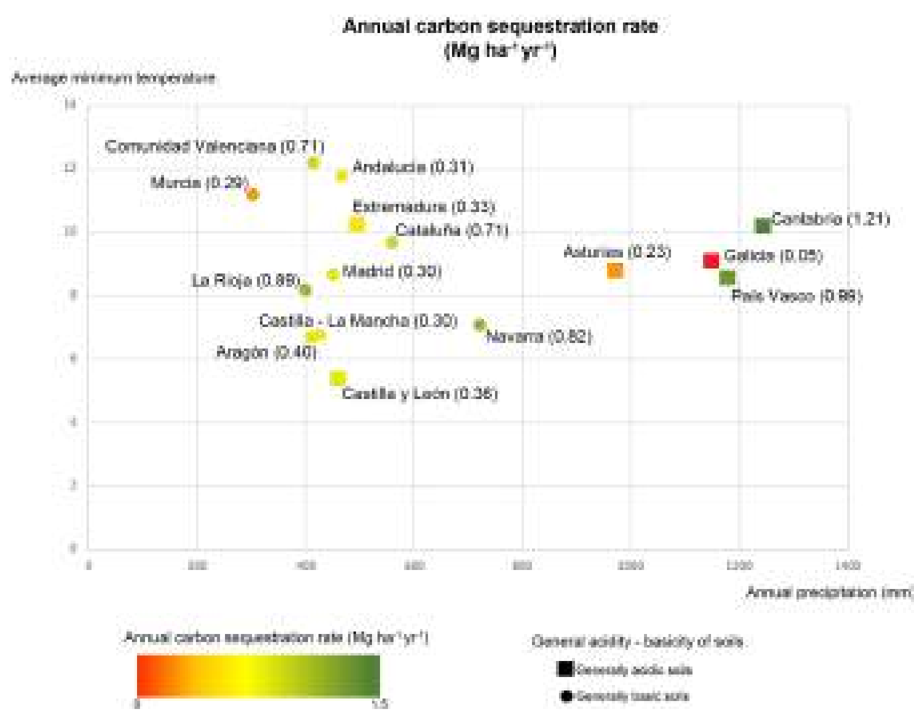

Fig. 5. Annual carbon sequestration rate in each region. It has been referenced by representative climatic and edaphic variables.

Mediterranean climate areas.

The data obtained through CBP is fully reliable, both globally and for most regions (Fig. 4). It must be taken into account that the regions that have a potential CS closer to bibliographic data are those that have the largest extensions of annual crops (Table 1). Therefore, those regions are more important for the quantification of CS. In this regard, Fig. 5 reflects how there are a majority of regions where CS rate is between 0.2 and 0.4 Mg of C ha^{-1} yr^{-1}. This explains why among the wide range of CS rates at the regional level, the average for the whole territory is 0.38 Mg of C ha^{-1} yr^{-1}). In addition to the weather, soil texture is also important for CS. In soils under cultivation of the study area, High Activity Clay Soils (IPCC, 2006) stand out. Those are characterized by having a high clay content and promoting long-term stabilization of organic matter. Therefore, they are good receptors for carbon released from plant residues (Iranmanesh and Sadeghi, 2019). CBP takes the spatial distribution of the soils from Batjes (2010).

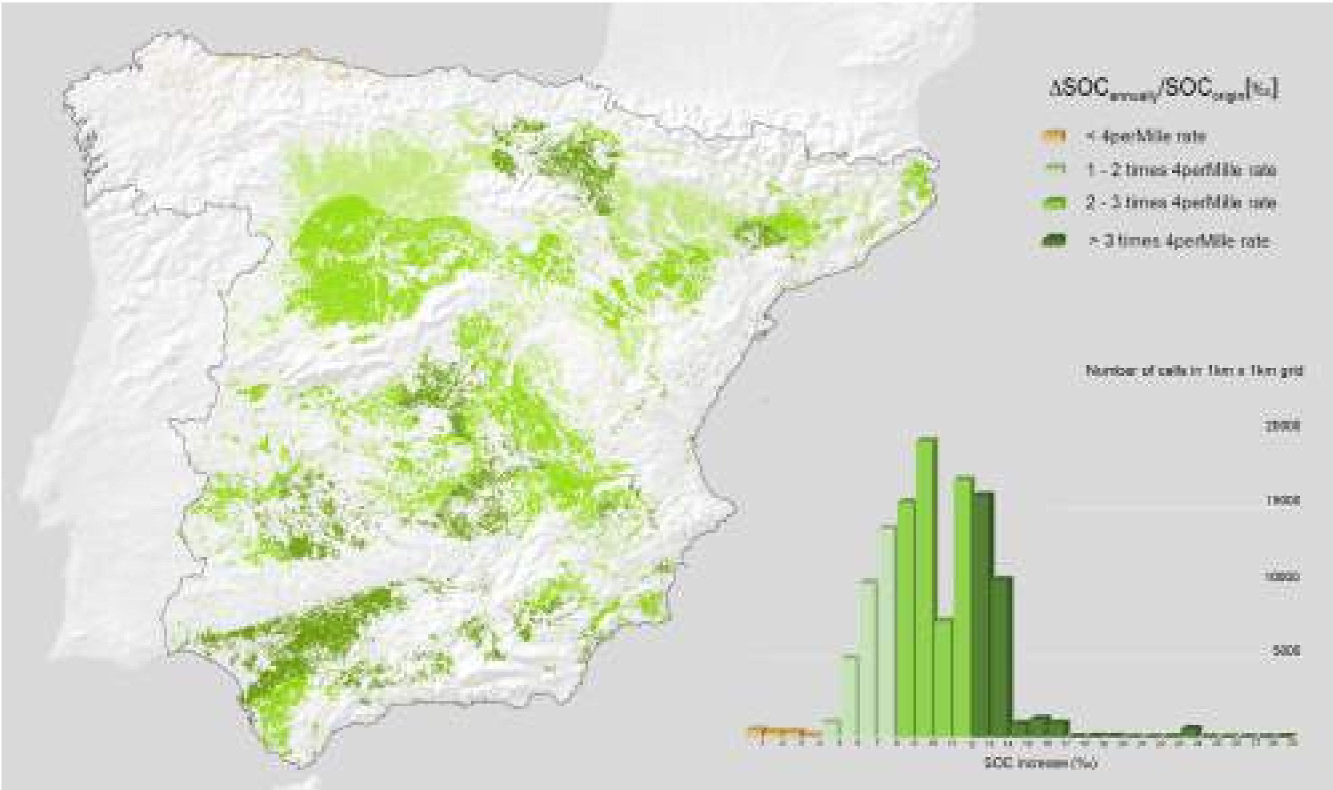

Fig. 6. Map with the increase in SOC in relation to the 4perMille Initiative rate and distribution of these results by grids of the map.

4.2. Carbon sequestration in Mediterranean regions

If the Mediterranean regions are distinguished by their maritime influence according to González-Sánchez et al. (2012), they can be divided into continental Mediterranean (Navarra, La Rioja, Aragón, Castilla y León, Madrid, Castilla-La Mancha and Extremadura) and maritime Mediterranean (Cataluña, Comunidad Valenciana, Murcia and Andalucía). González-Sánchez et al. (2012), established an increase in the C sequestration capacity of soils under NT compared to conventional management in continental Mediterranean climate of 0.72 Mg of C ha^{-1} yr^{-1} and in maritime Mediterranean climate of 0.29 Mg of C ha^{-1} yr^{-1}. In this case, through the modelling carried out by CBP, the results have been 0.37 Mg of C ha^{-1} yr^{-1} and 0.42 Mg of C ha^{-1} yr^{-1}, respectively. Region by region, the value of González-Sánchez et al. (2012) is very similar for Murcia and Andalucía, but it is half of what has been obtained in Cataluña and Comunidad Valenciana, which have similar values to those exposed by these authors for the continental regions. In contrast, according to CBP, regions of continental Mediterranean, such as Castilla y León, Castilla-La Mancha, Aragón, Extremadura and Madrid, have a significantly lower CS rate than what is established in González-Sánchez et al. (2012) for this type of climate zone. Navarra and La Rioja have CS rates close to what is established by the authors, quite similar to the 0.85 Mg of C ha^{-1} yr^{-1} established as the maximum value in their study.

4.3. Carbon sequestration in Atlantic regions

In the case of CS in regions of the Atlantic climate, there are big differences between the rates charged by CBP for the western regions (Galicia and Asturias), with respect to the eastern ones (Cantabria and

Table 2
Exponential Fit Equations, Coefficient of Determination, data domain (X min, X max) and average of annual C sequestration rate per SOC at origin (Y mean) and number of point data used (N) for each region.

Region	Equation	R^2	X min	X max	Y mean	N
Andalucía	Y = 32.424 exp(−0.0371 X)	0.95	13.48	37.15	12.59	17,538
Aragón	Y = 19.940 exp(−0.0180 X)	0.99	38.47	78.42	7.84	15,506
Asturias	Y = 05.461 exp(−0.0087 X)	0.99	97.54	134.11	2.02	718
Castilla - La Mancha	Y = 25.552 exp(−0.0311 X)	0.99	19.19	53.46	10.36	27,756
Castilla y León	Y = 20.920 exp(−0.0207 X)	0.97	30.55	119.97	8.08	38,124
Comunidad Valenciana	Y = 52.140 exp(−0.0263 X)	0.99	24.75	52.64	20.97	991
Cantabria	Y = 38.517 exp(−0.0116 X)	0.99	75.17	101.93	15.22	17
Cataluña	Y = 27.229 exp(−0.0138 X)	0.99	45.61	104.26	10.78	5,780
Extremadura	Y = 29.228 exp(−0.0322 X)	0.99	19.15	45.59	11.09	7,653
Galicia	Y = 01.024 exp(−0.0071 X)	0.99	101.82	172.56	0.37	495
La Rioja	Y = 41.944 exp(−0.0174 X)	0.99	52.18	62.83	14.62	1,066
Madrid	Y = 30.122 exp(−0.0365 X)	0.99	24.20	37.55	10.97	2,016
Murcia	Y = 30.277 exp(−0.0383 X)	0.99	18.86	30.93	10.63	2,461
Navarra	Y = 34.453 exp(−0.0157 X)	0.99	52.31	95.26	13.14	3,453
País Vasco	Y = 38.819 exp(−0.0144 X)	0.99	61.61	90.80	14.31	750

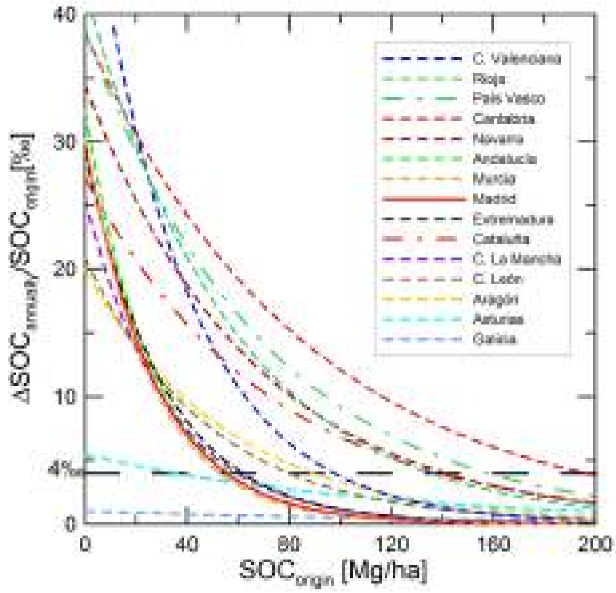

Fig. 7. Regional curves with the relation between 4perMille rate and existing SOC in each grid.

País Vasco). According to González-Sánchez et al. (2017), the average CS through the NT for the European Atlantic regions is 0.32 Mg of C ha^{-1} yr^{-1}. Being Asturias the region with an average CS data closest to this rate. In addition to being very near to 0.2 Mg of C ha^{-1} yr^{-1} calculated in a meta-analysis of the effect of the NT on CS in France (Arrouays et al., 2002), where the Atlantic climate predominates. However, the data of the País Vasco is very close to that of its neighboring regions located in the Mediterranean climate. The disparity with the reference datum of Atlantic climate may be due to the fact that annual crops are located in the south of the region where there is a great influence of the Mediterranean climate. A similar case occurs in Cantabria, but this time the CS rate is extremely high compared to that of the neighboring regions (Galicia y Aturias). This can be due to various causes:

- Little extension of crops in which to make the comparison between NT and CT. Therefore, the presence of a very high data of CS in a particular location can generate a CS overestimation calculated at the regional level.
- The few annual crops in Cantabria are located in a transit zone from the Atlantic climate to the Mediterranean climate.
- Less information about the CS rate in the Atlantic climate regions compared to the Mediterranean climate.

In any case, due to the large amount of carbon stored in the soils of Cantabria, the relative importance for the implementation of NT for the achievement of the 4perMille Initiative in this region is very limited.

4.4. *Effects on the 4perMille initative*

The beneficial effect of NT adoption on the achievement of the objectives of the 4perMille Initiative in the territory shown in Fig. 6 is in line with the results shown around the world (Minasny et al., 2017). The cells in which the objectives of the 4perMille Initiative are not achieved are scarce. These cells are located scattered along the northern fringe of the study area. This situation is similar to two meta-analisys conducted in France (Arrouays et al., 2002) and Canada (VandenBygaart et al., 2008). More abundant are the records ranged between 1 and 2 times the intended objectives, which are according to those observed by Powlson et al. (2012) in UK and Johnson et al. (2005) in USA. The largest number of cells in the territory has a CS between 2 and 3 times as advocated by the Initiative, similar to the case of the South Eastern USA (Franzluebbers, 2010) and North Eastern Italy (Piccoli et al, 2016). Finally, there is also a large abundance of cells that exceed the 4perMille rate by more than 3 times, as in the case of a study conducted in Central Italy (Mazzoncini et al., 2011). At regional level, CS data estimated in relation to the 4perMille Initiative (Fig. 6) are in accordance with what has been stated in local experiments on C retention through NT. For example, with values predominantly between 1 and 2 the objective of the Initiative in Castilla y León (De Benito and Sombrero, 2006), between 2 and 3 in Cataluña (Álvaro-Fuentes et al., 2014) and Madrid (Hernanz et al., 2009) and more than 3 in Andalucía (Carbonell-Bojollo et al., 2015).

Fig. 7 and Table 2 show different adjustments made for each regions. The decreasing exponential fits indicate a higher CS potential when initial SOC is lower (Berhe et al., 2007). It can be seen that there are cases of certain similarity between the different adjustments made in regions. Taking advantage of this circumstance to facilitate the discussion of the results, the curves of the 12 regions have been grouped into 3 (Fig. 8). In the case of Galicia and Asturias, they have not been grouped, as they are very different from the others, and from each other. This is because they have a very low CS rate, being the relationship established with the SOC, practically linear. In Cantabria, the case is the opposite. The exceptional high rate of CS, possibly due to a small number of records for calculation using CBP, makes it independent from others. In this case it can be seen that even with an extreme amount of SOC, the CS would remain within the limits of the 4perMille Initiative. Clusters A (Cataluña and Comunidad Valenciana) and B (La Rioja, Navarra y País Vasco) are located below the Cantabria

Table 3
Relationship between annual carbon sequestration through NT potential application and the 4‰ carbon currently stored in each region of study area (0–30 cm deep).

Region	Annual C sequestration through potential NT application (Mg)	Total regional SOC (Tg)	4‰ Total regional SOC (Mg)	Relationship between Potential sequestration and 4‰ Total regional SOC (%)
Andalucía	318,779	230.5	922,096	34.57
Aragón	394,143	277.4	1,109,440	35.53
Asturias	2,067	137.4	549,528	0.38
Castilla - La Mancha	522,939	256.4	1,025,504	50.99
Castilla y León	932,878	537.0	2,148,148	43.43
Comunidad Valenciana	22,329	92.5	369,853	6.04
Cantabria	6,543	60.2	240,816	2.72
Cataluña	271,225	233.6	934,500	29.02
Extremadura	100,892	142.4	569,780	17.71
Galicia	5,622	419.1	1,676,280	0.34
La Rioja	51,387	36.3	145,312	35.36
Madrid	28,226	27.7	110,754	25.49
Murcia	18,017	33.7	135,020	13.34
Navarra	171,251	82.2	328,860	52.07
País Vasco	50,482	69.6	278,587	18.12

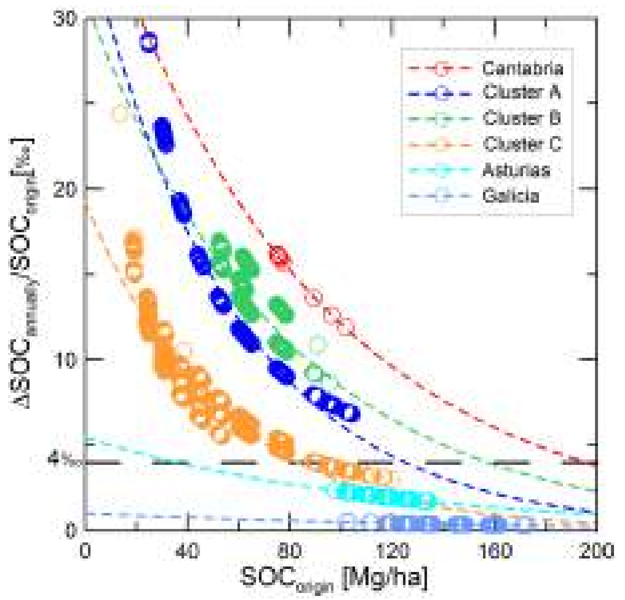

Fig. 8. Groups between regions by the similarity of the curves obtained in Fig. 7.

curve. In Cluster A the rates of CS are higher than in Cluster B and, therefore, the steepest slope. It also highlights the fact that in Cluster A, the SOC data has a greater distribution range than in Cluster B. In both cases, these are regions with a low or moderate area of annual crops. In Cluster C (other regions) there is a reduced CS with respect to the rest, but it abounds in places where the starting SOC is low. This makes it be a very important scenario for the achievement of the 4perMille Initiative, furthermore, the regions with the largest annual crop area are located there.

Table 3 shows that in 3 regions the application of the NT would represent more than 40% of the CS that should be necessary in the total region to comply with the 4perMille Initiative. In these regions, there are already studies that confirm the benefits of the application of the NT to achieve CS: Navarra (Virto et al., 2007), Castilla-La Mancha (López-Fando and Pardo, 2011) and Castilla y León (De Benito and Sombrero, 2006). Likewise, there are researches that encourage NT systems to fix carbon in soil in spite of being regions where there are less benefits of its use ranging between 40 and 15% of Initiative objective (Table 3): Aragón (Álvaro-Fuentes et al., 2008), Andalucía (Carbonell-Bojollo et al., 2015), Cataluña (Álvaro-Fuentes et al. 2014), Madrid (Hernanz et al., 2009) and Extremadura (López-Garrido et al., 2011).

The greatest interest in the 4perMille Initiative is in those areas where a high degree of CS is combined with a low level of SOC. In these low carbon areas, it is where policy makers should encourage the practice of NT. On the other hand, in regions that still have a high CS rate have a high SOC content, this measure is not as interesting as regards the fight against climate change. The SOC content will depend on the climatic and edaphic conditions, as well as the agricultural management that the soil has suffered (Batjes, 2011). The application of measures such as NT, will reduce the carbon deficiencies of those soils where CT has been carried out more profusely. In this sense, the results obtained show that in those typically agricultural regions, there is greater potential for the 4perMille Initiative. Since there has been a gradual decline in carbon content due to agricultural intensification.

5. Conclusions

In present paper, a new study methodology has been presented on the achievement of the regional objectives of CS with respect to the 4perMille Initiative. Specifically, the potential effect of the application of NT on annual crops has been studied. It has been based on the modelling of CS through CBP and its subsequent comparison with the currently stored SOC. As a result of the work, the average annual CS over a 10-year study period in 15 regions of Spain has been obtained. Using CBP it is possible to calculate the potential CS of a region at Tier 2 level. For the entire field of study, the annual average is 0.38 Mg of C ha^{-1} yr^{-1} and the potential CS amounts annually to almost 3 Tg of C for the whole surface considered. What is more than a third of what should be sequestered in all soils of Spain and it would be close to the 3.6 Tg of C that should be reached for all agricultural land.

Obtaining a continuous map of the SOC content on the territory, as a premise for comparison with CS data, has allowed us to observe a clear NW-SE gradient. The ratio per thousand between the annual CS and the contents in SOC, has allowed to calculate the potential importance of NT, within regional framework, of the 4perMille Initiative. In fact, abundant information on this aspect has been obtained for the 15 studied regions. It has been seen that annual crop lands generally have a capacity of CS higher than that indicated by the 4perMille Initiative. There are large areas where the stored C could be 2 and up to 3 times over the reference values. On the other hand, the cells in which the expected CS is not reached are scarce. In particular, the potential application of NT would represent a significant percentage (30–50% approximately) of the CS objectives of the 4perMille Initiative in Navarra, Castilla-La Mancha, Castilla y León, Aragón, La Rioja, Andalucía and Cataluña.

Spatial location of annual crops, agricultural statistics data and a map of the stored SOC are easily collected for regions and countries around the world. Therefore, this methodology for calculating the potential of the NT over the 4perMille Initiative can be easily replicated. Regarding the drawbacks, it has been observed that in regions with a low annual crop presence, CBP has calculated CS higher than expected in the bibliographic references. Possibly, because of a low input of data to run the model. On the other hand, when there is an abundance of records with which modelling is performed, the obtained results are in clear agreement with what was observed in the scientific works.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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