# NO TILLAGE IN RAINFED ARAGON (NE SPAIN): EFFECT ON ORGANIC CARBON IN THE SOIL SURFACE HORIZON

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## Abstract

Conservation tillage has been encouraged as a management alternative to preserve soil and water resources in semiarid Aragon (NE Spain). In fact, its adoption by farmers, and especially of no tillage (NT) systems, has increased in recent years. However, little information concerning the soils on which these techniques are applied is available for this region. The objective of this study was to assess the potential of NT to increase organic carbon content at the soil surface (0-20 cm) in rainfed Aragon. To this aim, 22 pairs of adjacent farm fields under NT and conventional tillage (CT) were comparing in different cereal production areas. The fields were under continuous NT between 5 and 19 years but half were over 10 years. Soil organic carbon (SOC) in NT ranged from 7.06 to 18.53 g $kg^{-1}$ (0-20 cm depth) and was higher than 12 g $kg^{-1}$ in nearly 30% of the fields. These contents represented between 8% less (only one case) and 55% more SOC under NT than under CT with an average gain of 20% in favour of NT. The highest SOC contents were found in the NT fields of longer duration (>10 years) and/or managed with practices that enhance the return of more crop biomass to the soil (complete residue return, cropping intensification and manure application). The identification of the current management practices used by farmers has allowed us to know the diversity of the NT-based cropping systems and the reality of the conservation agriculture in our region. Overall, results from this on-farm study indicate that NT can be recommended as a viable alternative to CT to increase organic carbon at the soil surface in cereal production areas of Aragon.

***Keywords**:* Conservation tillage; soil organic matter; on-farm research; dryland cereal farming; crop residues.

## 1. Introduction

Soil organic carbon (SOC) is a key indicator of soil quality, and also of the entire agricultural system, as it is related to many properties and processes responsible for agricultural productivity and environmental integrity. Even in semiarid regions, where the capacity of soil for agricultural production is limited, the SOC can exert a great influence on soil quality, leading to better physical and chemical soil conditions and increasing, finally, production and economic benefits for the farmer (Carter, 2002; Haynes, 2005; Ogle and Paustian, 2005).

Intensive and continued tillage practices during the 20th century have caused a worldwide decline in SOC with serious environmental and agricultural implications. In the case of Europe, according to the recently adopted Thematic Strategy for Soil Protection (European Commission, 2006), decrease of SOC, together with soil erosion and compaction, are the main soil degradation processes identified. Besides climatic reasons, unsustainable practices of human activities are the most relevant driving forces. This EU communication highlights the need to adopt sustainable management practices, such as conservation tillage, since they can contribute effectively to the solution of agro-environmental problems, of particular interest for the threatened Mediterranean region.

Studies conducted over the past 25 years in different regions of the world have demonstrated the suitability of the conservation tillage, and especially of no tillage (NT), to increase SOC and improve soil quality compared to conventional tillage (CT) systems (West and Post, 2002; Govaerts et al., 2009). These studies also show that the rate and magnitude of change depends on a number of factors such as climate and soil, and interactions with other agricultural practices. At present, it is estimated that NT is practiced on about 117 million hectares world wide but only 1.15 million hectares are in Europe (Derpsch and Friedrich, 2010). In Spain, according to the Spanish Conservation Agriculture Association (AEAC/SV, 2008), 650,000 hectares of agricultural land are under NT. This figure reflects that the rate of adoption of NT is still small in Spain and this despite the fact that the long-term research shows positive results for conservation tillage (Moreno et al., 2010).

Due to particular soil and climate conditions and inappropriate agricultural practices, Aragon (NE Spain) is a region prone to land degradation by wind and water erosion (López et al., 2001; López-Vicente et al., 2008). For this reason, the adoption of conservation tillage practices has been encouraged as an alternative to preserve soil and water in this region. In fact, according to previous results on soil and crop response to conservation tillage in cereal production areas of Aragon (López et al., 2005; Moret et al., 2007; Álvaro-Fuentes et al., 2008, 2009), NT could be regarded as a viable management alternative. Furthermore, a recent survey conducted by the Department of Agriculture and Food of the Government of Aragon (Vallés, 2009) found a very positive perception of the advantages of conservation tillage by farmers and an increasing adoption in the last years, especially of NT. However, this report also highlights the lack of knowledge about the soils on which these techniques are applied.

The little available information on SOC in agrosystems in Aragon has been colleted from small research plots and from single soil types (Álvaro-Fuentes et al., 2009). However, farming practices applied by farmers in their NT fields can be very diverse and differ from those in experimental plots (Blanco-Canqui et al., 2008). For these reasons, direct measurements of SOC under on-farm conditions across a range of soils, microclimate and agronomic practices are necessary to get a broad knowledge of the potential of NT in the region. In order to remedy this lack of information, the objective of this study was to assess the potential of NT to increase SOC in the surface layer by comparing adjacent farm fields of NT and CT across different rainfed cereal areas of Aragon. Likewise, this work allowed us to identify current soil and crop residue management practices used by farmers in the region.

## 2. Materials and methods

A total of 22 pairs of NT and CT farmer fields were selected from rainfed cereal areas of the provinces of Zaragoza (10 pairs of fields), Huesca (11) and Teruel (1) in Aragon (NE Spain, Fig. 1). The fields are located in areas receiving generally from 400 to 700 mm of mean annual precipitation. More specifically, 32% of them are located between isohyets 400 and 500 mm, 50% between 500 and 600 mm and, finally, 18% above 600 mm. The precipitation exceeds 700 mm per year only in one field (741 mm). All soils were medium-textured soils, varying from sandy loam to silty clay loam (Fig. 2). Sand content ranged from 50 to 550 g $kg^{-1}$ (0-20 cm soil depth), silt from 280 to 620 g $kg^{-1}$ and clay from 140 to 370 g $kg^{-1}$. The $CaCO_3$ content varied between 60 and 540 g $kg^{-1}$ but was higher than 200 g $kg^{-1}$ in 80% of the fields.

Two main criteria were considered in the selection of the fields: number of years of continuous NT and proximity of the two fields, NT and CT, in each site. The duration of NT varied between 5 and 19 years but in half of the fields was greater than 10 years. Both fields were contiguous, thus ensuring that soil type and slope were as similar as possible. With regard cropping system, in some sites it was not the same under NT than under CT. Thus, in NT the usual cropping system followed by farmers is the continuous cereal cropping (wheat or barley). In some of these fields (7 of 22) a legume was introduced in rotation with cereal with a varying frequency depending on the site. In the CT fields, legume crop was more unusual (3 of the 22 fields) and, in contrast to NT, in the areas of lower rainfall the traditional farming system is the cereal-fallow rotation (one crop in 2 years).

Three main tillage implements were identified in the study area as primary tillage tools used by farmers in the CT fields: mouldboard plough, chisel and subsoiler. Although the mouldboard plough has been the most traditional implement in the region (López et al., 2001), its use has been reduced in these last years. In fact, in 16 of the 22 fields characterized in the present study the soil was tilled with chisel. However, only in three cases soil management can be considered as reduced tillage since the rest of the soil surface was pulverized by excessive chiselling and soil cover by crop residues was low. In 30% of the CT fields, farmers alternate the use of chisel plough with mouldboard plough or subsoiler.

Soil sampling (0-5 and 5-20 cm depths) was made in three different zones within each field where two soil samples were collected and mixed to make a composite sample. A total of 264 soil samples were taken (22 sites x 2 fields x 2 depths x 3 replicates). Once in the laboratory, the soil was air-dried and ground to pass a 2 mm sieve. Soil organic carbon (SOC) and $CaCO_3$ contents were determined by dry combustion with a LECO analyser (*RC-612* model. LECO Corp., St. Joseph, MI). Soil particle size distribution was obtained by laser diffraction analysis (*Coulter LS230* laser grain-sizer. Coulter Corp., Miami, FL). Six undisturbed soil samples were also taken per depth and field (2 in each of the 3 sampling zones per field) to determine the dry bulk density by the core method.

Within each study site, statistical comparisons between NT and CT were made using one-way ANOVA. As in each of the sites, the two fields were contiguous and sited on similar landscape position and same soil, the three sampling locations (i.e. sampling zones within each field) were used as pseudoreplicates (Christopher et al., 2009). The least significant difference (LSD) test was used to compare treatment means ($P$<0.05).

## 3. Results and discussion

### *3.1. Soil organic carbon under no tillage*

Soil organic carbon content in the 0-20 cm depth ranged from 7.06 to 18.53 g $kg^{-1}$ and was higher than 12 g $kg^{-1}$ in nearly 30% of the NT fields (Fig. 3). This value of 12 g $kg^{-1}$ is considered a minimum needed for an optimal agricultural use in Western Europe (Bullock, 1997). It is to expect that from this threshold value, increases in SOC will lead to improved soil quality and increased agricultural productivity. In any case, all studied soils had SOC contents lower than 20 g $kg^{-1}$, in agreement with the levels of SOC estimated for this region in the Map of Topsoil Organic Carbon in Europe (Jones et al., 2005). These contents are comparatively lower than those of other European regions but correspond well to the figures estimated for Southern Europe where a 74% of the land has a surface soil horizon (0-30 cm) with less than 20 g $kg^{-1}$ of organic carbon (Van-Camp et al., 2004). The stratification ratios of SOC (0-5/5-20 cm in depth; Fig. 3) did not reach the threshold value of 2 (Franzluebbers, 2002) possibly due to the continuity of the two considered depths (Moreno et al., 2006). Even so, the highest SOC contents were always found in the surface layer (0-5 cm) with about an average of 40% more carbon stored than at 5-20 cm. This higher concentration in surface layers has been well documented for agricultural soils under NT (West and Post, 2002) and it is due to the crop residue retention on the soil surface and the absence of soil disturbance by tillage.

The number of years with NT seems to be a factor responsible for the differences among fields. In fact, a 50% and 40% of the variability found in SOC was explained by the number of consecutive years under NT for depths of 0-5 and 0-20 cm, respectively (Fig. 4). This suggests that the benefits associated with the adoption of NT will increase with time as observed in other regions of the world (West and Post, 2002; Angers and Eriksen-Hamel, 2008). As explained below, the data point not included in the regression corresponded to a field from which crop residues are removed by the farmer.

Several studies have demonstrated that accompanying agricultural practices to NT, such as crop rotation, crop residue retention or application of manure, can also enhance the SOC storage (Halvorson et al., 2002; Heenan et al., 2004; Dalal et al., 2011). In our study conditions, manure application also appears to play a beneficial role in soils under NT. For example, in Fig. 5a we compare two fields after 13 years of no-till, managed by the same farmer and located in the same agroclimatic zone (mean annual precipitation of 430 mm). The only two differences are that in one of the fields the farmer applies animal manure and in the other does not. The second difference is that, although the two soils are medium textured, the soil without manure has a silt plus clay content greater than the soil with manure (silty clay loam vs. loam texture). As Fig. 5a shows, the SOC content in 0-20 cm depth was 50% higher in the soil with manure even though its texture makes it less suitable for carbon storage than the other soil.

Likewise, results indicate that an adequate management of crop residues is essential for successful NT in rainfed Aragon. In the areas with higher rainfall and hence higher production, farmers remove the straw from the field to prevent later problems with seeding. In some cases, as occurs in the study field with more years under NT (19 years; see Fig. 4), soil cover by residues retained in the field was low (<30%) and, strictly speaking, this would not be a conservation tillage system. In Fig. 5b the SOC in this field is compared with that one of a similar field from a nearby area of slightly less rainfall (676 vs. 741 mm) and where crop residues are always chopped and left on the soil surface. We estimate that, despite the different duration of NT (10 vs. 19 years), the removal of crop residues from the field led to a reduction of 20% of the SOC at 0-20 cm depth.

### *3.2. No tillage versus conventional tillage*

As previously indicated, the cropping system under NT and CT differed in some sites, especially in the driest ones (<500 mm of annual precipitation) where the traditional cereal-fallow rotation under CT is, generally, replaced with the continuous cereal cropping under NT. Therefore, following the remark made by Blanco-Canqui and Lal (2008) in their work on the potential of long-term NT to sequester SOC in the eastern United States, the present study shows data on the effect of NT- and CT-based cropping systems on SOC rather than those of tillage alone. The comparison of both systems was based on the calculation of the relative gain or loss of SOC under NT with respect to CT in each site (i.e., (NT-CT)/CT) and was expressed in Mg C $ha^{-1}$ to take into account the differences in soil bulk density between both tillage systems.

With the exception of only one case, the SOC under NT was always higher than under CT (ratio>0) (Fig. 6). These values represent between 1 and 55% more SOC with NT, averaging about 20%. The lowest differences (ratios close to 0) corresponded to the sites with the NT fields of shorter duration (5-7 years). As long-term studies show (West and Post, 2002; Christopher et al., 2009), increases in SOC with the adoption of NT is time-dependent and less than 10 years is usually not enough time to produce a marked accumulation of SOC with respect to a CT management. The ratio values of 0.10-0.20 (Fig. 6), which represent SOC increments between 10 and 20% in NT with respect to CT, generally corresponded to the sites where the straw is frequently or continuously removed from the NT fields. Also, they were obtained in cases where the CT system is actually a reduced tillage management (chiselling as primary tillage and crop residues retained in the field), an increasingly common practice in some areas of Aragon.

The highest differences in SOC between NT and CT (Fig. 6), i.e. ratios >2, generally reflect the use in the NT fields of improved practices such as total residue return, manure application or intensification of cropping system. For example, after 10 years of annual cereal cropping with NT the SOC in the 0-20 cm depth was increased in 55% with respect to that in the adjacent CT field under the traditional cereal-fallow rotation (Fig. 7). In other study site, a 25% more SOC was stored in the surface layer in a 13-yr NT field under a cereal-legume rotation than in the CT field under a continuous cereal cropping (Fig. 7). Likewise, in another location, the combination of animal manure application and NT during 10 years led to an increase of 32% in SOC with respect to the contiguous CT field without manure addition (Fig. 7).

The above results are in agreement with those compiled in scientific literature reviews (e.g., Jarecki and Lal, 2003; Govaerts et al., 2009) and suggest that the use of these improved practices (complete residue return, cropping intensification and rotation, and manure application) may be strategies for increasing SOC in NT vs. CT soils. Also, similarly to the meta-analysis studies conducted by Alvarez (2005) and Angers and Eriksen-Hamel (2008) for a wide range of soils, climate and tillage practices, other site characteristics such as precipitation or soil texture do not seem to explain the differences in SOC under NT and CT among the study sites. Probably, a higher impact of the NT duration, cropping intensity or crop residues management could be masking the effect of other influential factors.

The depth of soil sampling can greatly affect the conclusions about the SOC sequestration rates (Angers and Eriksen-Hamel, 2008; Blanco-Canqui and Lal, 2008; Christopher et al., 2009). In this sense, it is important to remember that the results obtained in the present study come from the superficial horizon of the soil (0-20 cm) and that the whole soil profile must be considered to reach conclusions about the potential of NT to sequester SOC vs. CT systems. However, this evident remark does not question the environmental benefits of NT derived from the higher accumulation of organic matter on the soil surface. Among them, an enhanced structural stability of soil and, therefore, a lower soil susceptibility to two main degradation processes that affect agricultural lands of semiarid Aragon, wind and water erosion (López et al, 2001; Álvaro-Fuentes et al., 2008).

## 4. Conclusions

Results from this on-farm study indicate that NT can be recommended as a viable alternative to CT to increase organic carbon at the soil surface (0-20 cm) in rainfed cereal areas of Aragon (NE Spain). On average, 20% more SOC was stored under NT than under CT. The highest SOC contents were found in the NT fields of longer duration (>10 years) and/or managed with practices that enhance the return of more crop biomass to the soil (complete residue return, cropping intensification and manure application). The identification in this study of the current management practices used by farmers has allowed us to know the diversity of the NT-based cropping systems and to be aware of the reality of the conservation agriculture in Aragon. The increasing interest of farmers for NT could help to reduce the risk of soil degradation in the study area but further studies should consider the whole soil profile to correctly evaluate the potential of NT to sequester SOC.

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## Figure legends

Figure 1. Location of the study sites and average annual rainfall isohyets (mm).

Figure 2. Soil texture class triangle showing the percentages of sand (2000-50 μm), silt (50-2 μm) and clay (<2 μm) of the study soils in the depth of 0-20 cm.

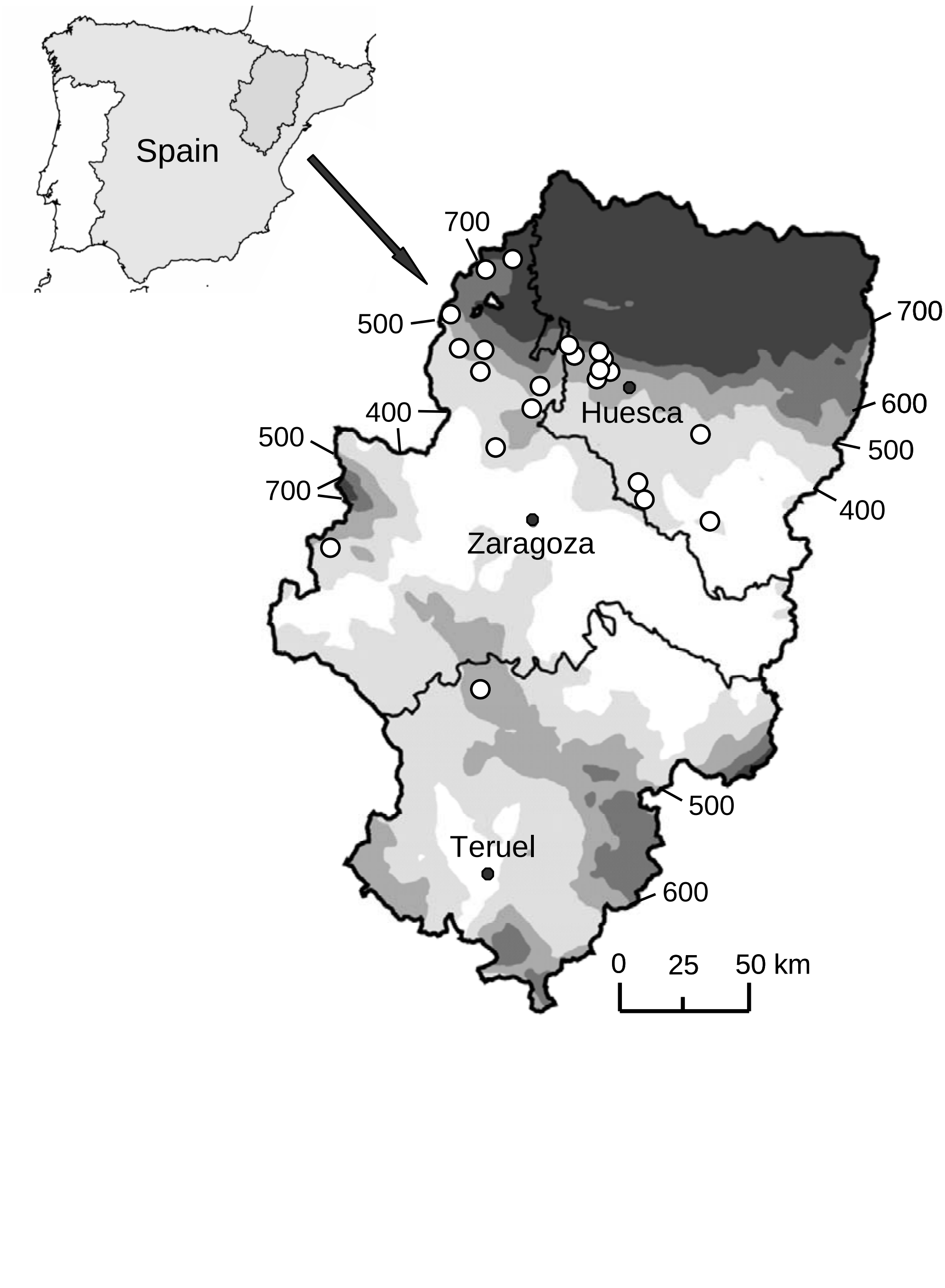
Figure 3. Distribution of no tillage fields according to soil organic carbon content at 0-20 cm depth. The stratification ratio (SR) is the organic carbon content at 0-5 cm depth divided by that at 5-20 cm depth.

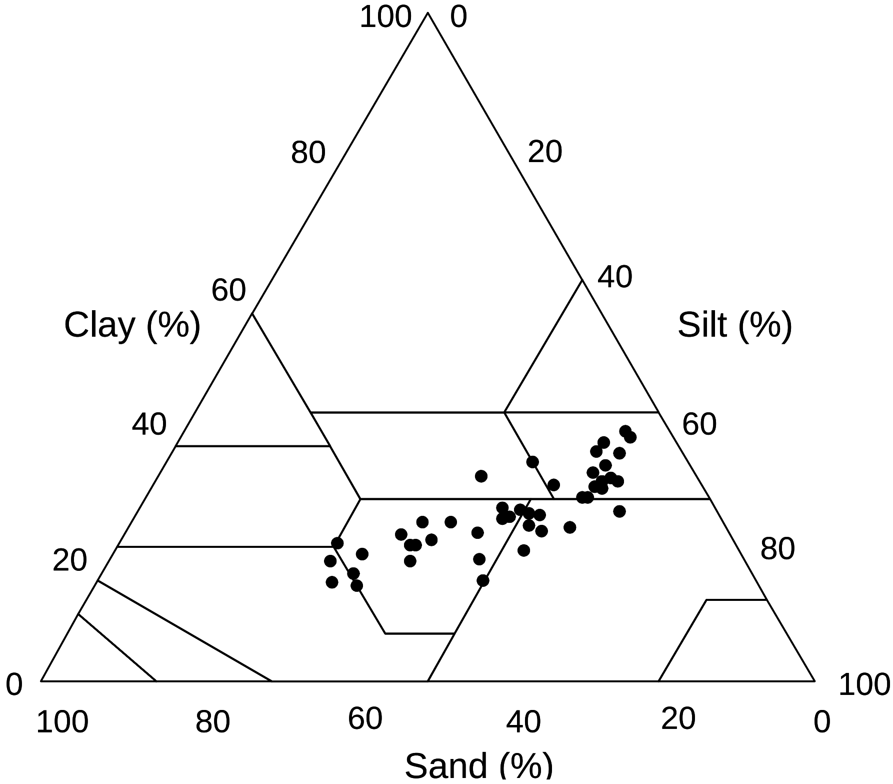
Figure 4. Relationship between the duration of continuous no tillage management and the soil surface organic carbon, SOC (0-5 cm depth). The point represented by a white circle was not included in the regression analysis (see comments in the text).

Figure 5. Soil organic carbon (SOC) in four no tillage fields under similar soil and climate conditions (within each graph A and B) but with the following management differences: A) 13 years under no tillage with and without application of manure; B) 10 years leaving the cereal straw in the field and 19 years removing the straw. Within each graphic (A and B) and soil depth, columns with different letters are significantly different ($P<0.05$).

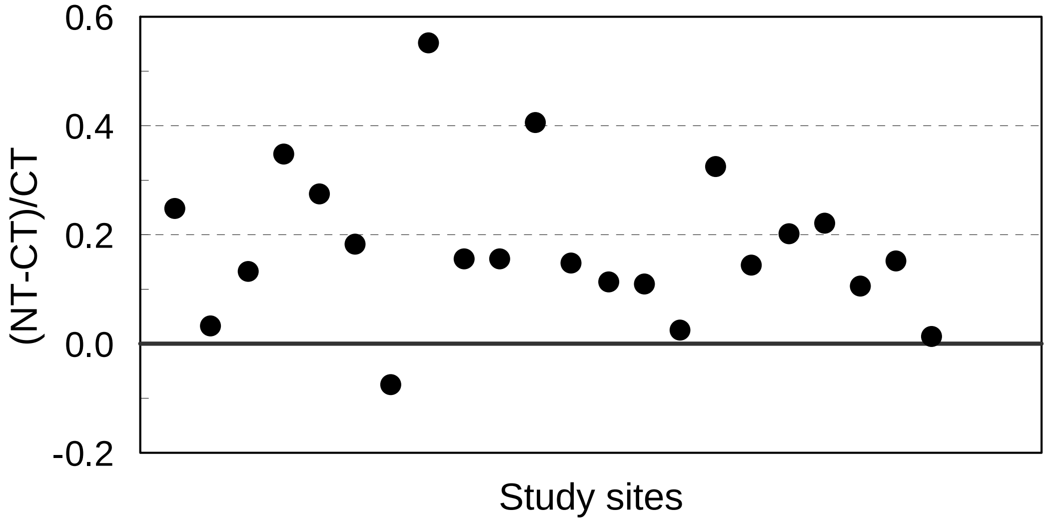
Figure 6. Relative difference in soil organic carbon content (0-20 cm; Mg $ha^{-1}$) between no tillage (NT) and conventional tillage (CT) in 22 study sites from different cereal production areas of Aragon.

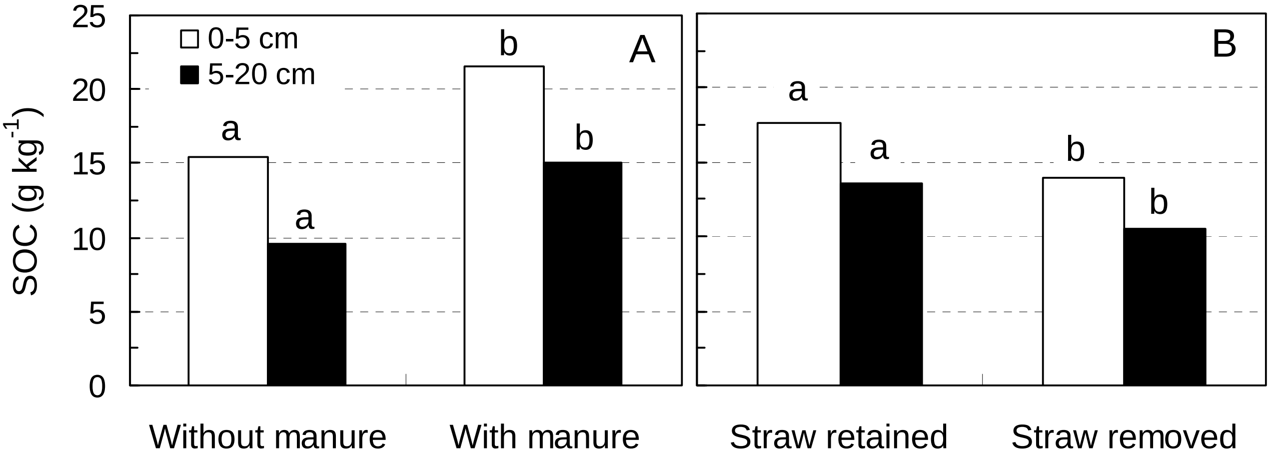
Figure 7. Effect of no tillage- and conventional tillage-based cropping systems on soil organic carbon (SOC, 0-20 cm depth) at three different sites of cereal agriculture in Aragon. Columns with different letters within the same study site are significantly different ($P<0.05$). NT, no tillage; CT, conventional tillage; CC, continuous cropping; CF, cereal-fallow rotation.


Spain
700
500
400
500
700
Huesca
Zaragoza
700
600
500
400
500
Teruel
600
0
25
50 km

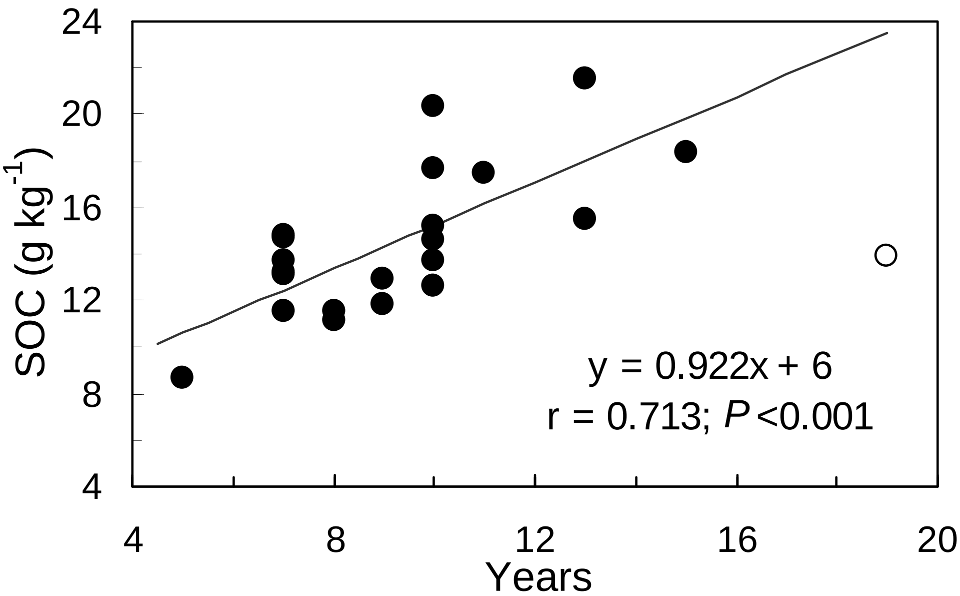


100
0
80
20
60
40
Clay (%)
Silt (%)
40
60
20
80
0
100
100
80
60
40
20
0
Sand (%)

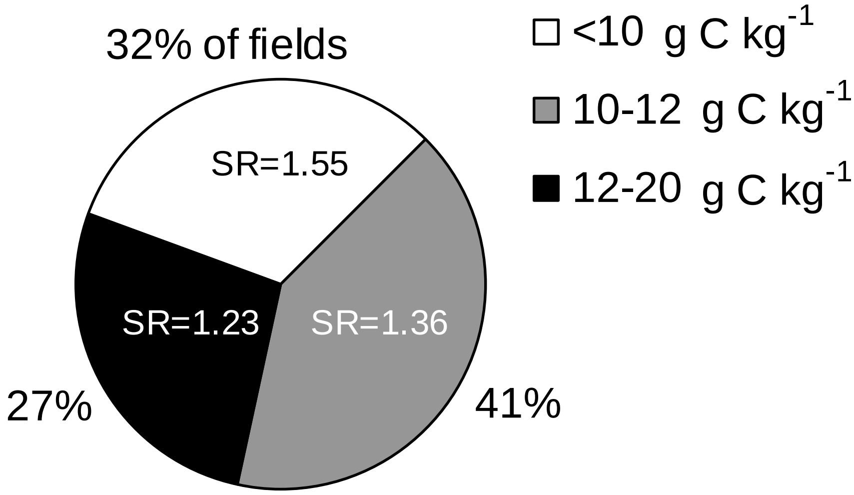

0.6
0.4
0.2
0.0
-0.2
(NT-CT)/CT
Study sites



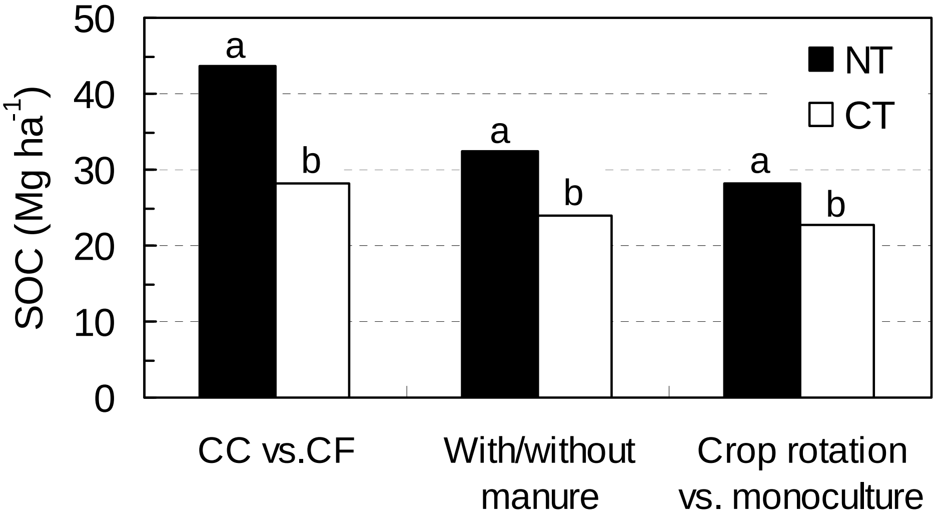
SOC (g kg$^{-1}$)
25
20
15
10
5
0
0-5 cm
5-20 cm
A
B
a
a
b
b
a
a
b
b
Without manure
With manure
Straw retained
Straw removed



24
20
16
12
8
4
SOC (g kg-1)
y = 0.922x + 6
r = 0.713; P<0.001
4
8
12
16
20
Years



32% of fields
SR=1.55
SR=1.23
SR=1.36
27%
41%
<10 g C kg-1
10-12 g C kg-1
12-20 g C kg-1



50
40
30
20
10
0
SOC (Mg ha-1)
a
b
a
b
a
b
NT
CT
CC vs.CF
With/without manure
Crop rotation vs. monoculture