Effect of tillage systems on soil aggregation and hydraulic properties in SW Spain

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Abstract
Conservation tillage is particularly important in arid and semi-arid zones, where water is the limiting factor for crop development under rainfed conditions. Conservation tillage improves physical properties and increases organic matter of soils under Mediterranean conditions. This work studies the influence of two tillage systems (traditional tillage, TT, and conservation (reduced) tillage, RT) on soil hydraulic properties and on soil aggregation after 15 years of experimentation. The effect of no-tillage (NT) in a short-term experimentation (4 years) was also considered. In the long-term experiment, the aggregate size distribution (ASD), mean weight diameter (MWD) and aggregation index (AI) values were greater in RT than in TT, although differences were not significant. Water stability (WAS) values for 1-2 mm size aggregates were greater in TT, despite the organic carbon (OC) and $CaCO_3$ contents in these aggregates were greater in RT. However, under our conditions NT seems to have a greater effect on WAS. The increase of this variable in NT respect to TT, was observed after only three years of experimentation. In the long-term experiment, the hydraulic conductivity was higher in TT than in RT for h > -20 mm in agreement with a greater characteristic mean pore radius for h > -20 mm. In the short-term experiment, the lower hydraulic conductivity in NT than in TT suggests a lack of interconnected pores in NT treatment.

Key Words
Soil aggregate stability, conservation tillage, no tillage, traditional tillage, physical properties, soil quality

Introduction
The efficiency of conservation tillage for reducing soil erosion and improving water storage is universally recognised. This is particularly important in arid and semi-arid zones, where water is the limiting factor for crop development under rainfed conditions. In these areas, the management of crop residues is also of prime importance for obtaining sustainable crop productions (Du Preez et al., 2001). The improvement of the soil water profile and hydraulic properties, under conservation tillage, has been reported by Pelegrín et al. (1990) and Moreno et al. (1997) for the conditions of southern Spain. On the other hand, an increase in soil organic matter is a desirable aim as it is associated with better plant nutrition, cultivation and seed performance, and better soil physical properties (greater aggregate stability, reduced bulk density, improved water holding capacity at low suctions, enhanced porosity and earlier warming in spring).
Soil aggregates and their stability have a strong influence on physical properties such as infiltration, hydraulic characteristics, aeration, soil strength, erosion, and the soil's ability to transmit liquids, solutes, gases, and heat. Thus, aggregate stability can provide key information about the capacity of soil to function, which defines soil quality. The aim of this study was to determine the influence of two tillage systems (traditional tillage, TT, and conservation (reduced) tillage, RT) on soil hydraulic properties, dry soil aggregate size distribution and wet aggregate soil stability after 15 years of experimentation. The effect of no-tillage in a short-term experimentation (4 years) is also considered.

Materials and methods
The experiment was established in 1992 at the experimental farm of the Instituto de Recursos Naturales y Agrobiología (CSIC) in the Sevilla province (SW Spain). Soil was classified as Xerofluvent. Climate of the zone is typically Mediterranean, with mild rainy winters (500 mm mean rainfall, average of 1971-2004) and very hot, dry summers. An area of about 2,500 m^2 was selected to establish the experimental plots in 1991. Two tillage treatments were established: TT used in the area for rainfed agriculture (consisted of mouldboard ploughing 30 cm depth, after burning the straw of the preceding crop; straw burning was suppressed since 2003) and a RT characterized by not using mouldboard ploughing, by reduction of the number of tillage operations and leaving the crop residues on the surface (for more details see Moreno et al., 1997). A wheat (*Triticum aestivum*, L.)-sunflower (*Helianthus annuus*, L.) crop rotation was established for both treatments.

In 2005 a fodder pea crop (*Pisum arvense*, L.) was included in the rotation. In 2003 a short experiment was established with a TT and a no tillage (NT, direct drilling) treatments with the same crop rotation as in the long-term experiment. Soil samplings were conducted on October 2007 (0-5, 5-10 and 10-20 cm depths) in the long-term experiment, and in March and October in the short term experiment. Size distribution of dry aggregates was determined using an electromagnetic sieving machine with consecutive sieves of 4, 2, 1, 0.5, 0.25 and 0.05 mm mesh. Aggregate water stability was determined on dry aggregates of 1-2 mm in diameter following the method of Kemper and Rosenau (1986). A tension disc infiltrometer (Perroux and White, 1988) was used to determine in situ the hydraulic conductivity and sorptivity, in the range near saturation ($-120 < h < 0$ mm), using the approach of Ankeny et al. (1991).

Results and discussion

In the long-term experiment the aggregate size distribution (ASD), mean weight diameter (MWD) and aggregation index (AI) values were slightly greater in RT than in TT, although differences were not significant (Figure 1). On the contrary, water stability (WAS) values for field-moist 1-2 mm size aggregates were greater in TT, despite the organic carbon (OC) and $CaCO_3$ contents in these aggregates were greater in RT (OC, 12.4 g kg^{-1} in TT, and 14.0 g kg^{-1} in RT; $CaCO_3$, 136 g kg^{-1} in TT and 190 g kg^{-1} in RT, values at 0-5 cm depth).

Aggregation is a temporal variable property, product of interactions of the soil biota, mineral and organic components, that is affected by soil use and management. For example, increasing loads, and soil density, can enhance the relative water stability. Earthworm activity, greater under RT, can also alter the structural stability by either a stabilizing or a disrupting effect on soil aggregates, depending on the soil texture and mineralogy, an aspect to be studied under our conditions. Other possible cause could have been the effect of the straw burning carried out in previous years in the TT treatment.

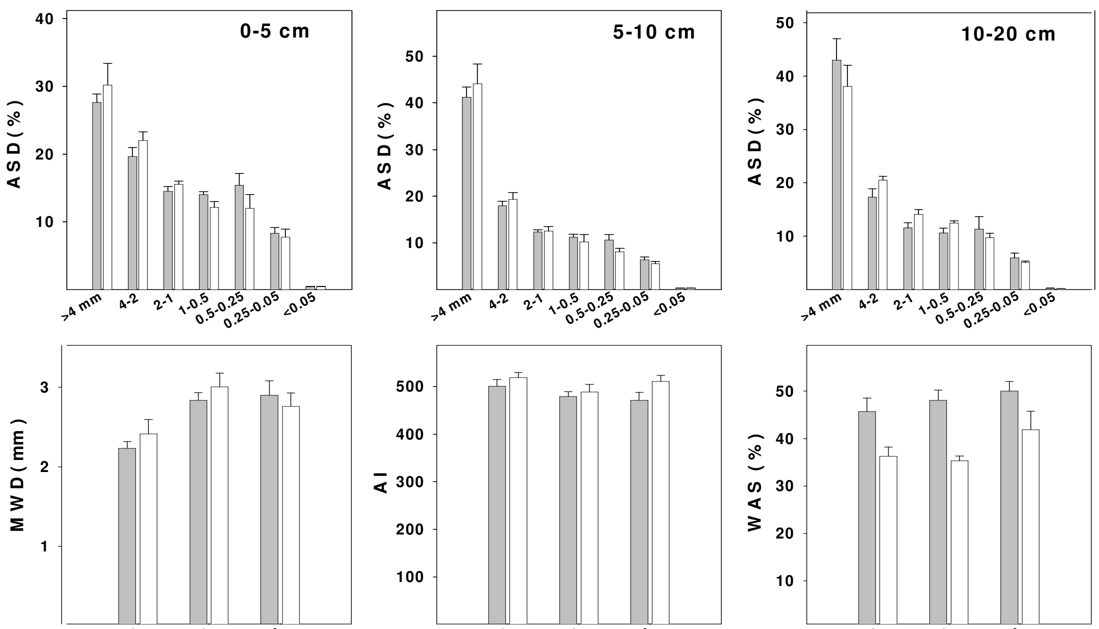

Figure 1. Dry aggregate size distribution (ASD), mean weight diameter (MWD), aggregation index (AI) and water stability of air-dry 1-2 mm size aggregates (WAS) of TT (grey bars) and RT (white bars) treatments in the long-term experiment. (mean values ± standard error).

In the short-term experiment the aggregate size distribution (ASD), mean weight diameter (MWD) and aggregation index (AI) values were similar in both treatments (traditional tillage, TT and no-tillage, NT), data not shown.

Figure 2 shows the results of the water stability of air-dry aggregates in two sampling date. Under our conditions NT seems to have a greater effect on water stability of aggregates than RT, both in comparison with the respective TT treatment. We have observed an increase of this variable, in NT respect to TT, after only four years of experimentation.

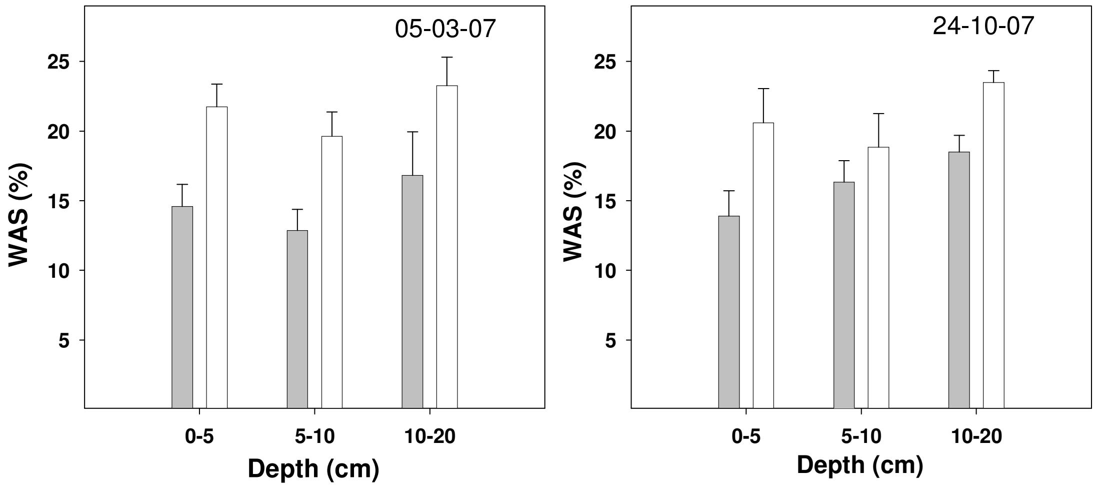

Figure 2. Water stability of air-dry 1-2 mm size aggregates in two dates in the short-term experiment. TT (grey bars) and NT (white bars). (mean values ± standard error).

In Figure 3 are shown the results of hydraulic conductivity (K), sorptivity (S) and characteristic mean pore radius (λ_m) measured in situ at the soil surface in the long- and short-term experiment. The hydraulic conductivity (Figure 3a) was significantly higher ($p<0.05$) in TT than RT for h > -20 mm in the long-term experiment.

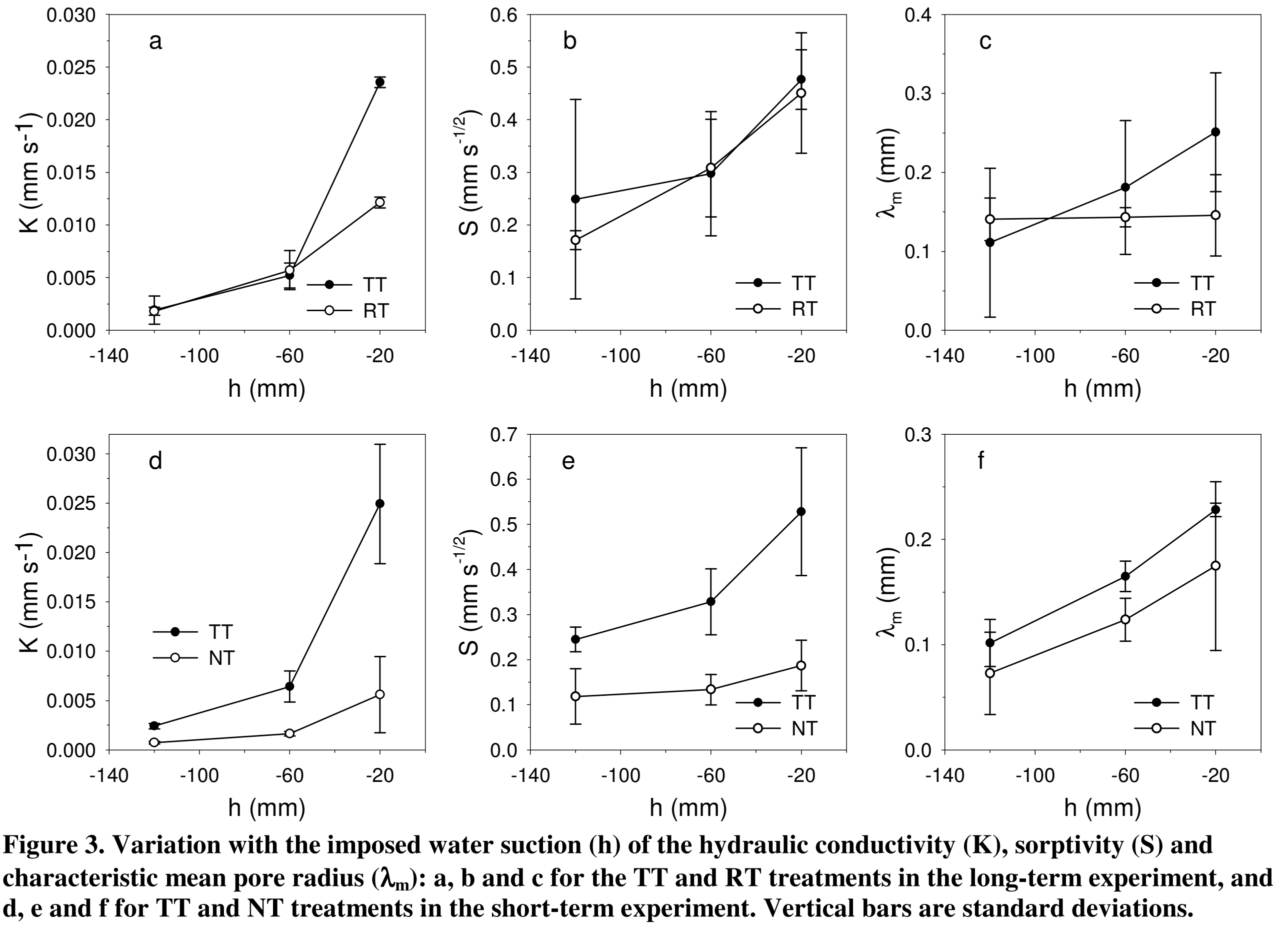

Figure 3. Variation with the imposed water suction (h) of the hydraulic conductivity (K), sorptivity (S) and characteristic mean pore radius (λ_m): a, b and c for the TT and RT treatments in the long-term experiment, and d, e and f for TT and NT treatments in the short-term experiment. Vertical bars are standard deviations.

Sorptivity was similar under both treatments (Figure 3b). Differences in hydraulic conductivity between the two treatments can be attributed to a different soil consolidation, and in agreement with a characteristic mean pore radius greater in TT than in RT for h > -60 mm (Figure 3c). These results are similar to those found by Moreno et al. (1997) three years after this long-term experiment was established.
In the short-term experiment K, S and λ_m values (Figures 3d, 3e and 3f, respectively) were higher

(significantly different at $p<0.05$ for K and S) in the TT treatment than in the NT treatment in the range $-120 < h < 0$ mm. The lower hydraulic conductivity in NT than in TT is in apparent contradiction with the fact that λ_m was not significantly different between treatments, and suggests a lack of interconnected pores in NT treatment as reported by Angulo-Jaramillo et al. (1997).

Conclusions

In the long-term experiment, the aggregate size distribution (ASD), mean weight diameter (MWD) and aggregation index (AI) values were slightly greater in RT than in TT, although differences were not significant. Water stability (WAS) values for 1-2 mm size aggregates were greater in TT, despite the organic carbon (OC) and $CaCO_3$ contents in these aggregates were greater in RT.
On the contrary, under our conditions NT seems to have a greater effect on water stability of aggregates. We have observed an increase of this variable, respect to TT, after only four years of experimentation.
In the long-term experiment, the hydraulic conductivity was higher in TT than in RT for $h > -20$ mm in agreement with a greater characteristic mean pore radius for $h > -20$ mm. In the short-term experiment, the lower hydraulic conductivity in NT than in TT suggests a lack of interconnected pores in NT treatment.

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