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SHORT-TERM EFFECT OF COVER CROPS ON AGGREGATE STABILITY ASSESSED BY TWO TECHNIQUES

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ABSTRACT

Aggregate stability (AS) is a property closely linked to soil fluid movement. AS can be determined by different methods and can be improved by using cover crops (CC), but the short-term effect of this practice has been little studied. The aim of this study was to evaluate the soil surface aggregate stability of an Argiudoll under no tillage in the Pampas, during the first year after different CC incorporation. AS was determined by using two laboratory techniques: Le Bissonnais and De Leenheer & De Boodt methods, after incorporating different CC (oat, vetch, wheat, oat + vetch) at two different times: after the CC was chemically dried and after the subsequent corn crop harvest. A treatment without CC was also evaluated (fallow between summer crops) as a control. The presence of CC roots improved AS significantly compared to the control, while differences among the various CC were also observed. The presence of corn roots and the residual effect of the decomposition of CC stubble left on the ground also had a positive effect on AS. The various pre-treatments applied by the Le Bissonnais method gave different results: fast wetting of aggregates showed significant differences on AS between the different CC used, whereas slow wetting and mechanical rupture were more effective than fast wetting showing AS differences over time. The results of the De Leenheer & De Boodt method were more erratic and less consistent than those obtained by the Le Bissonnais method.

Key words: Le Bissonnais method, De Leenheer & De Boodt method, soil quality, aggregate size distribution.

CULTIVOS DE COBERTURA: SU EFECTO EN EL CORTO PLAZO SOBRE LA ESTABILIDAD ESTRUCTURAL EVALUADA POR DOS TÉCNICAS

RESUMEN

La estabilidad de agregados (AS) es una propiedad estrechamente relacionada con el movimiento de los fluidos en el suelo. La AS puede determinarse mediante diferentes métodos y puede evolucionar favorablemente utilizando cultivos de cobertura (CC). Sin embargo, el efecto a corto plazo de esta práctica ha sido poco estudiado. El objetivo de este estudio fue evaluar la estabilidad de los agregados superficiales de un Argiudol bajo siembra directa perteneciente a la región Pampeana, durante el primer año después de incorporar diferentes cultivos de cobertura. La AS se determinó después de incorporar distintos CC (avena, vicia, trigo, avena + vicia) en dos momentos diferentes, al secado de los CC y a la cosecha del cultivo de maíz, utilizando dos técnicas de laboratorio: los métodos de Le Bissonnais y de De Leenheer & De Boodt. También se evaluó un tratamiento sin CC (barbecho químico entre cultivos de verano) como control. La presencia de raíces de los CC mejoró significativamente la AS en comparación con el control, mientras que también se observaron diferencias entre los diversos CC. El efecto de las raíces del maíz y el debido a la descomposición de los rastrojos de los CC dejados en la superficie del suelo, también tuvieron un efecto positivo sobre la AS. Los diversos pre-tratamientos del método de Le Bissonnais dieron resultados diferentes: la humectación rápida de los agregados mostró diferencias significativas en la AS entre los diferentes CC utilizados, mientras que la humectación lenta y la disgregación mecánica fueron más efectivos que la humectación rápida para mostrar las diferencias de la AS en el tiempo. Los resultados del método De Leenheer & De Boodt fueron más erráticos y menos consistentes que los obtenidos por el método de Le Bissonnais.

Palabras clave: Método de Le Bissonnais, Método de De Leenheer & De Boodt, calidad del suelo, distribución de agregados.

ABBREVIATIONS

- AS: Aggregate stability
- CC: Cover crops
- CMWD: Change in the aggregate mean weight diameter
- CMWDd: Change in the aggregate mean weight diameter after the CC dried
- CMWDh: Change in the aggregate mean weight diameter after corn harvest
- FW: Fast wetting of aggregates
- LB_{mean}: Average MWD of the three pre-treatments
- MWD: Mean weight diameter
- MWDH: Mean weight diameter of aggregates after being sieved immersed in water
- MWDS: Mean weight diameter of aggregates after dry-sieving
- ST: Stirred water after ethanol pre-wetting of aggregates
- SW: Slow wetting of aggregates

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INTRODUCTION

Land degradation, a process that affects around 33% of the Earth's land surface, remains one of the most important environmental problems (Wall & Six, 2015). An important indicator of land degradation is soil aggregate stability (AS), defined as the resistance of the soil to the energy released by external forces such as rain, runoff and wind (Saygin *et al.,* 2012). AS modifies soil water movement and storage, aeration, biological activity and crop growth, thus affecting a wide range of physical and biochemical processes of natural and agricultural environments. Therefore, maintaining high AS contributes to sustainable land use (Amézketa, 1999). AS may vary with changes in climate and land use. It also varies with the sampling technique used and with the soil moisture content at sampling (Saygin *et al.,* 2012). Methods for AS determination evaluate the degree of aggregate fragmentation when a certain amount of energy is applied to the soil (Amézketa, 1999; Diaz-Zorita *et al.,* 2002; Lal & Shukla, 2004). However, no single methodology is adequate for all soil types and under different management conditions (Le Bissonnais, 1996). The selection of the most appropriate method depends on the aggregate rupture mechanism applied and the type of management of each particular soil type (Saygin *et al.,* 2012). Le Bissonnais (1996) considered four mechanisms of aggregate rupture: compression of entrapped air due to fast wetting, differences in soil expansion during slow wetting, mechanical effects, and dispersion due to the action of physico-chemical factors (Rohošková & Valla, 2004). Gabioud *et al.* (2011) found that, in loamy soils, it is important to consider the effect of the pre-treatment of mechanical disintegration of the Le Bissonnais method, as it simulates the energy impact of rain drops that disperse soil particles when wet. However, the same authors stated that the importance of this form of aggregate dispersion decreases in soils with high vegetation cover. Le Bissonnais (1996) considered that to evaluate the effect of different treatments in soils with high carbon content, fast wetting pre-treatment is more effective than slow wetting. Novelli *et al.* (2013) found that the pre-treatment of mechanical disintegration is the most effective to evaluate the effect of different land uses in Mollisols with high carbon content, while slow wetting presents a better behavior in Vertisols. According to Saygin *et al.* (2012), to assess the AS of sandy-loam soils with different doses of organic amendment, methods that consider various dry-sieving aggregate fractions are more suitable than those which use a single fraction. However, these authors considered that any one mechanism does not allow the description of all soil structural characteristics, since these respond to diverse internal and external factors and their interactions, reflecting the complexity of the aggregate rupture process. Different size aggregates may have different degrees of stability and may respond differently to environmental conditions (rain, wind, irrigation) and management practices (Amézketa, 1999). Lal & Shukla (2004) grouped methods for the determination of AS in three categories: dispersion by turbidimetric techniques, aggregate resistance to raindrop impact, and aggregate size distribution as the result of wet sieving. In the latter, results are influenced by the manner of prior wetting, the aggregate size, the number of sieves used, the intensity of the energy applied during sieving and the type of liquid used to immerse soil samples (Pulido Moncada *et al.,* 2015).

The use of different methods to determine AS makes it difficult to compare results of different studies (Amézketa, 1999). In turn, different soil types react differently to each of the various techniques. For example, Pulido Moncada *et al.* (2015) found a high correlation among estimates of AS determined by different methods (De Leenheer & De Boodt, 1958; Kemper & Rosenau, 1986; Le Bissonnais, 1996) in tropical soils but not in temperate soils. Gabioud *et al.* (2011) compared the methods of Hénin *et al.* (1958) and Le Bissonnais applied to different Pampean soils and found that the degree of association between the results obtained by both techniques was dependent on the soil order. Soil structure and organic matter content are the most dynamic soil properties, and are extremely sensitive to land use changes (Blanco-Canqui & Lal, 2004). Sione *et al.* (2017) determined a greater decrease in carbon content and AS in soils with vertic properties, as the irrigation water quality decreased and the rice frequency increased. Wilson & Paz-Ferreiro (2012) verified a worse AS in Mollisols of Entre Ríos (Argentina) with the increase in agricultural activity.

The different patterns of root growth of different plant species as well as their physiology and functioning modify the soil structure differently (Amézketa, 1999). According to Lynch & Bragg (1985) and Oades (1993), to maintain AS, monocot plants are better than dicot plants, and pastures are better than cereals due to greater biomass production (Amézketa, 1999). Soil fauna and flora, including plant and animal residues, are also intrinsically associated with soil aggregation (Blanco – Canqui & Lal, 2004). It has been found that root exudates associated with organic substances derived from the activity of soil microorganisms are more important in stabilizing macroaggregates than the carbon derived from aboveground plant residues (Blanco-Canqui & Lal, 2004). The presence of active roots and biological activity promote the occurrence of hydrophobic substances in aggregates (Jaramillo, 2003), which produce a decrease in the sudden rupture of aggregates due to entrapped air as water permeates more slowly, thus increasing AS (Hallett & Young, 1999). The stubble C:N ratio also influences soil aggregation. A low C:N ratio favors residue decomposition, which will temporarily facilitate aggregate formation. On the other hand, plant residues that breakdown more slowly will have a gradual but more persistent effect on aggregation (Blanco-Canqui & Lal, 2004). This coincides with the results of Bossuyt *et al.* (2001), who found greater AS on the surface soil after the addition of stubble residue, which was greater with residues with high C:N ratios. In recent years, cover crops (CC) have been used to improve soil organic carbon content (Sainju *et al.,* 2007; Restovich *et al.,* 2011), to promote soil nutrient balance and retention (Kaspar *et al.,* 2007; Beltrán *et al.,* 2016) and to control erosion (Wilhelm *et al.,* 2010), among others. CC supply carbon to the soil from root exudates and decomposition, which leads to a significant and rapid increase in AS but, apparently, to no changes in total carbon content (Amézketa, 1999). Conversely, this author also remarks that there is evidence of aggregate stability loss due to root grow (Reid & Goss, 1981; Reid *et al.*, 1982; Caron *et al.*, 1992). Nevertheless the overall effects of roots over aggregate stability is positive.

CC are sown between two harvest crops and are not grazed, harvested or incorporated into the soil. These crop residues remain on the soil surface, protecting the soil and releasing nutrients as a result of aerial and root biomass degradation (Scianca *et al.,* 2006). The inclusion of CC in agricultural systems under no tillage reduces water and wind erosion (Zhu *et al.,* 1989; Blanco-Canqui *et al.,* 2013), creates better conditions for the development of physical, chemical and biological soil properties (Fronning *et al.,* 2008; Blanco-Canqui *et al.,* 2011), and competes strongly with weeds (Teasdale *et al.,* 2007). The use of CC in the Pampas has been promoted as a complement to no tillage, especially in soybean monoculture systems (Álvarez *et al.,* 2010). Kabir & Koide (2002) and Liu *et al.* (2005) found an increase in aggregate average size and stability in plots with CC. The effect of CC on soil properties has been studied mainly in the medium and long term (Villamil *et al.,* 2006; Blanco-Canqui *et al.,* 2011; Steele *et al.,* 2012), but there is little information about the impact of CC on soil quality over shorter periods (1-3 years) (Mukherjee & Lal, 2015). The De Leenheer & De Boodt (1958) technique has been widely used in Argentina to determine the effect of different land uses on AS (Chagas *et al.,* 1995; Cacchiarelli *et al.,* 2008; Castiglioni *et al.,* 2013). However, in response to the number of destruction mechanisms contemplated by the Le Bissonnais method, this methodology seems more sensitive to better discriminate the short-term effects caused by the incorporation of new management techniques. Under the assumption that CC can generate significant changes in AS in the short term, the aim of this study was to evaluate the soil surface AS of an Argiudoll under no tillage in the Pampas (Argentina), during the first year after incorporating different CC, by using two laboratory techniques.

MATERIALS AND METHODS

Location of the study area, climatic and soil characteristics

The study was conducted in a paddock in "La Fe" farm, located in the San Antonio de Areco district (Province of Buenos Aires, Argentina; 34º12'18"S, 59º32'46" W). The annual mean temperature is 16.5°C (period 1967-2015), and the mean annual rainfall 1084 mm (period 1882-2015), 75% of which falls in spring-summer. The soil is a fine, illitic, very deep, thermal Abruptic Argiudoll (Soil Survey Staff, 2010), of the Capitán Sarmiento series (INTA, 2009). The surface horizon has a silty loam texture (clay: 261 g kg^{-1}; silt: 616 g kg^{-1} and sand: 123 g kg^{-1}), pH is 5,6, electrical conductivity 0,4 dS m^{-1}, cation exchange capacity 14,3 cmol + kg^{-1} and mean surface carbon content 19,0 g kg^{-1}.

Characteristics of the experiment

During the ten years before the experiment, the paddock had been cropped continuously under no tillage, with summer crops (corn and soybean) and winter fallow or winter annual pasture. After the soybean harvest, the following CC were sown in June 2014 under no tillage: oat, wheat, vetch and oat + vetch. A control treatment that consisted of a winter fallow covered with stubble from the previous crop and then cropped was included. The CC cycle was interrupted after flowering in September 2014 with 4 L ha^{-1} glyphosate (48% active ingredient), to ensure high total dry matter production without compromising corn optimum sowing date. Corn was sown by no tillage in December 2014, at a density of 72000 plants ha^{-1} and 0,70 m between rows and harvested in June 2015. Glyphosate treatment was not able to control the weed *Conyza sumatrensis* ("rama negra"), which appeared only in the control plots, so weed control was complemented with manual weeding.

Table 1. Surface (0-5 cm) soil particulate and total soil organic carbon (%) of the different treatments.

Tabla 1. Carbono orgánico particulado y total (%) superficial (0-5 cm), correspondientes a los distintos tratamientos.

Treatment	Particulate organic carbon	Total organic carbon
O	0,25	1,87
O+V	0,33	1,94
W	0,26	1,87
V	0,30	1,94
C	0,23	1,82

Treatment: Oat (O); oat + vetch (O + V); wheat (W); vetch (V); control
Tratamientos: Avena (O); avena + vicia (O + V); trigo (W); vicia (V); control (C).

The experiment had a randomized block design with three replications. Soil sampling (five subsamples per experimental unit) was carried out in the surface layer (0-5 cm) with spade at two times: after the CC was chemically dried and after the subsequent corn harvest. The average values of surface (0-5 cm) soil particulate and total soil organic carbon for each treatment are in **Table 1**.

Determination of aggregate stability

AS was analyzed using two methods: the Le Bissonnais method (1996) and the De Leenheer & De Boodt method (1958), which differ in the treatments applied to aggregates to evaluate their resistance to external forces and in the aggregate fractions used. In the laboratory, samples were manually broken up following natural fracture lines and roots and plant residues were removed. Then, samples were dried at room temperature and AS was determined.

Le Bissonnais method

The application of the Le Bissonnais method comprises three sample pre-treatments: 1) fast wetting (FW), which evaluates the degree of aggregate rupture due to the effect of compressing the enclosed air; 2) stirred water after ethanol pre-wetting (ST), which evaluates the mechanical disruption occurred by stirring previously wetted aggregates. In this case, the aggregate mechanical cohesion is analyzed independently of the rupture effect caused by the FW pre-treatment; 3) slow-wetting (SW), which evaluates the aggregate rupture due to differential swelling and, to a lesser degree, due to air compression, through slow wetting by capillarity.

Soil samples dried at 40 ° C for 24 hours and sieved through 5 and 3 mm mesh sieves were subdivided in 6 g sub-samples to which the different pre-treatments were applied. This was done in triplicate for each pre-treatment and each experimental unit. In FW, soil samples were immersed in distilled water for 10 minutes, whereas in ST they were saturated in ethanol for 30 minutes and then transferred to an Erlenmeyer flask with distilled water and agitated by turning the flask 10 times in a full circle, and in SW they were wetted by capillarity with distilled water for 60 minutes. Aggregates were then sieved with a 0,05 mm-mesh sieve while immersed in ethanol with a Feodoroff shaker. The aggregates retained in the sieve were oven-dried at 40 ° C for 48 h. Then, they were air-sieved through a column of sieves to obtain the size distribution of dried aggregates: >2 mm, 2-1 mm, 1-0,5 mm, 0,5-0,2 mm, 0,2-0,1 mm and 0,1-0,05 mm. The fraction <0,05 mm was calculated as the difference in weight between the soil retained in the different sieves and the initial weight of the soil sample. Mean weight diameter (MWD) was calculated using the following formula (1):

MWD=[[3,5*(% weight >2 mm)]+[1,5*(% weight 2-1 mm)]+[0,75*(% weight 1-0,5 mm)]+[0,35*(% weight 0,5-0,2 mm)]+[0,15*(% weight 0,2-0,1 mm)]+[0,075*(% weight 0,1-0,05 mm)]+[0,025*(% weight<0,05 mm)]]/100 (1)

More details can be found in Le Bissonnais (1996).The MWD values calculated for each pre-treatment were also averaged as (FW + ST + SW)/3, to obtain a value that summarized the results of all pre-treatments (LB_{mean}) (Le Bissonnais & Arrouays, 1997; Chenu *et al.,* 2000).

AS classes were described following Le Bissonnais (1996), where: MWD <0,4 = very unstable, 0,4-0,8 = unstable, 0,8-1,3 = average, 1,3-2,0 = stable and >2,0 = very stable. Finally, to study the effect of each treatment on the distribution of different aggregate fractions, the percentage of soil mass was calculated for the following aggregate categories: 5-2 mm (>2), 2-0,2 mm (2-0,2) and less than 0,2 mm (<0,2).

De Leenheer and De Boodt method

In this method, AS is determined as the change in the aggregate mean weight diameter (CMWD), which is the difference between the mean weight diameter of aggregates after dry-sieving (MWDS) and the mean weight diameter of aggregates after being sieved immersed in water (MWDH):CMWD = (MWDS - MWDH). For dry-sieving, 8; 4,8; 3 and 2 mm-mesh sieves were used, yielding three fractions of aggregate sizes: 8-4,8; 4,8-3 and 3-2 mm. MWDS was calculated using the following formula (2):

MWDS=[[6,4*(% weight 8-4,8 mm)]+[3,9*(% weight 4,8-3 mm)]+[2,5*(% weight 3-2 mm)]]/100 (2)

Prior to wet-sieving, dry-sieved aggregates from each of the three categories were drip-wetted to field capacity. The mass of soil of each aggregate fraction used was equal to the proportion of soil obtained for each category after dry sieving, totaling a 100 g sample. This was done in triplicate for each experimental unit. Samples were wetted with 0,25 mm drops applied from a 30 cm height. After wetting, samples were placed in a saturated humid environment for 24 hours. Then, they were placed in the sieve of appropriate size, within a battery of sieves with mesh sizes of 4,8 mm, 3 mm, 2 mm, 1 mm, 0,5 mm and 0,25 mm. The sieves were then immersed in water, where a mechanical device made them oscillate up and down for 5 minutes. Subsequently, aggregates were placed in aluminum pans and oven-dried at 50 ° C to constant weight. The mass of the soil fractions 8-4,8 mm, 4,8-3 mm, 3-2 mm, 2 – 1 mm, 1-0,5 mm and 0,5-0,25 mm was thus obtained, while the mass of the <0,25 mm fraction was determined as the difference between the total weight of the original sample (100 g) and the sum of the weights of all other fractions. MWDH was calculated using the following formula (3):

MWDH=[[6,4*(% weight 8-4,8 mm)]+[3,9*(% weight 4,8-3 mm)]+[2,5*(% weight 3-2 mm)]+[1,5*(% weight 2-1 mm)]+[0,75*(% weight 1-0,5 mm)]+[0,375*(% weight 0,5-0,25 mm)]+[0,125*(% weight<0,25 mm)]]/100 (3)

Finally, CMWD was calculated as follows:

CMWD = (MWDS - MWDH)

To evaluate the effect of each treatment on the distribution of different aggregate categories, it was calculated the percentage of soil mass retained in each sieve after wet-sieving for the aggregate fractions >4,8 mm (>4,8), 4,8-3 mm (4,8-3) and 3-2 mm (3-2) and the mass of aggregates 2-0,25 mm (2-0,25) and <0,25 mm (<0,25).

To compare the values obtained by the two methods between all treatments, the CMWD for each pre-treatment of the Le Bissonnais method (1996) and their mean was determined by subtracting the corresponding MWDS, whose value was 4 mm because 100% of the sample was retained by the 5 and 3 mm-mesh sieve, from the MWD values of FW, SW, ST and LB_{mean}. Larger CMWD values mean lower AS.

Temporal assessment of aggregate stability

We next compared the AS values between the time the CC was dried and the corn harvest was completed. The CMWDh / CMWDd ratio for each plot was calculated with data obtained by each of the two methods, where CMWDh is the value of the change in the aggregate mean weight diameter after corn harvest and CMWDd is the value of the change in the aggregate mean weight diameter after the CC dried. Ratio values near 1 meant slight differences in AS between sampling dates, whereas values >1 meant higher CMWDh and therefore a loss in AS at corn harvest in relation to the moment when the CC was dried, and values <1 meant that AS increased at corn harvest.

Statistical analysis

To compare the effect of different treatments on AS and on aggregate distribution by both techniques, we used a one-way ANOVA for each sampling date as well as for the comparison of results between sampling times for each treatment. ANOVA assumptions (normality, heterogeneity of variances, independency) were met in all cases. Given the existence of significant statistical differences, means were compared using the Tukey test ($p < 0,05$). Pearson correlation analysis was used to establish the degree of association between AS results obtained with both methods and between aggregate distribution and MWD/CMWD. All statistical analyses were performed with Infostat (Di Rienzo *et al.,* 2015).

RESULTS AND DISCUSSION

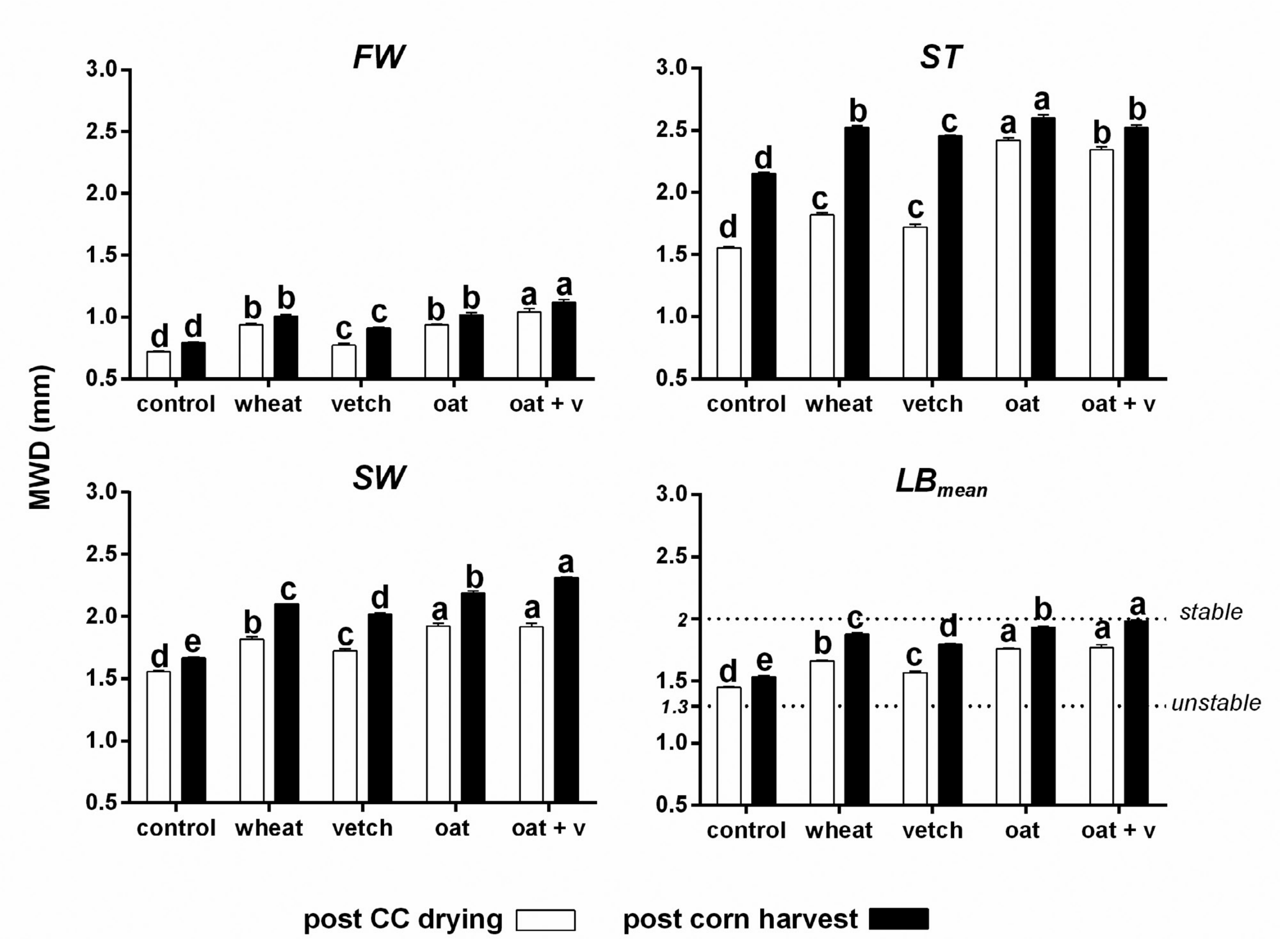
Le Bissonnais method

Under all treatments and across both sampling times, average AS was stable (i.e. within the limits of LB_{mean} values of 1,3-2,0 mm, **Figure 1**).

Aggregate stability after a cover crop cycle

One cycle with CC caused significant differences in soil AS regardless of the type of CC, as all plots with CC had higher MWD ($p < 0,05$) than controls (**Figure 1**). CC presented significant differences in MWD regarding each pre-treatment. Plots under oat, oat + vetch and wheat modified their relative MWD ranks according to the pre-treatment implemented. Considering the timing of samples, differences among treatments can only be assigned to the effect of CC roots. Since roots and their rhizosphere affect aggregate behavior through exudates, physical protection and activity of macro and microorganisms, different plant species affect aggregation differently as a consequence of the different properties, exudates and functioning of their roots (Bronick & Lal, 2005). In the soil subjected to SW, the CC that most improved AS were oat and oat + vetch (**Figure 1**), whereas in the soil subjected to FW, the best results were those obtained with oat + vetch, and in the soil subjected to ST, the CC that most improved AS was oat. Vetch was the CC that always showed the worst AS results. Legumes are rich in labile carbon, which is easily degraded (Blanco-Canqui & Lal, 2004), a fact closely associated with the dynamics of microbial respiration (De Gryze *et al.,* 2006), resulting in a rapid decrease in AS. In this study, the C/N ratio of vetch and oat was 13,7:1,0 and 29,2:1,0 respectively. Thus, the low root C/N ratio of vetch and, as a consequence, fast stubble mineralization and high but short-lived biological activity, may explain the lower AS values. Restovich *et al.* (2011) found that, in a Pampas Argiudoll, after a year with a CC, plots with oat had the most favorable effect on surface AS, measured with the method proposed by Douglas & Goss (1982). However, the results from plots with other CC species (brome grass, barley, ryegrass, oat + vetch, vetch, canola and forage turnip) did not differ from that obtained with a winter fallow. The possible reason for the differences found in the present study was the different method used to determine AS. Dapaah & Vyn (1998) also reported AS increases in the first 7 cm of a loam and sandy-loam soil, one year after sowing the CC. These authors also found a greater persistence of the favorable effect of ryegrass than of red clover or radish.

The order of MWD values obtained for each pre-treatment was: FW <SW <ST, in inverse pro-



FW: fast wetting. SW: slow wetting. ST: mechanical disintegration. LBmean: average. Oat + Vetch (oat + V). Different lowercase letters within a given pre-treatment and sampling time = statistically significant differences between treatments (Tukey's test p <0,05). Dotted horizontal lines indicate stable and unstable limits.

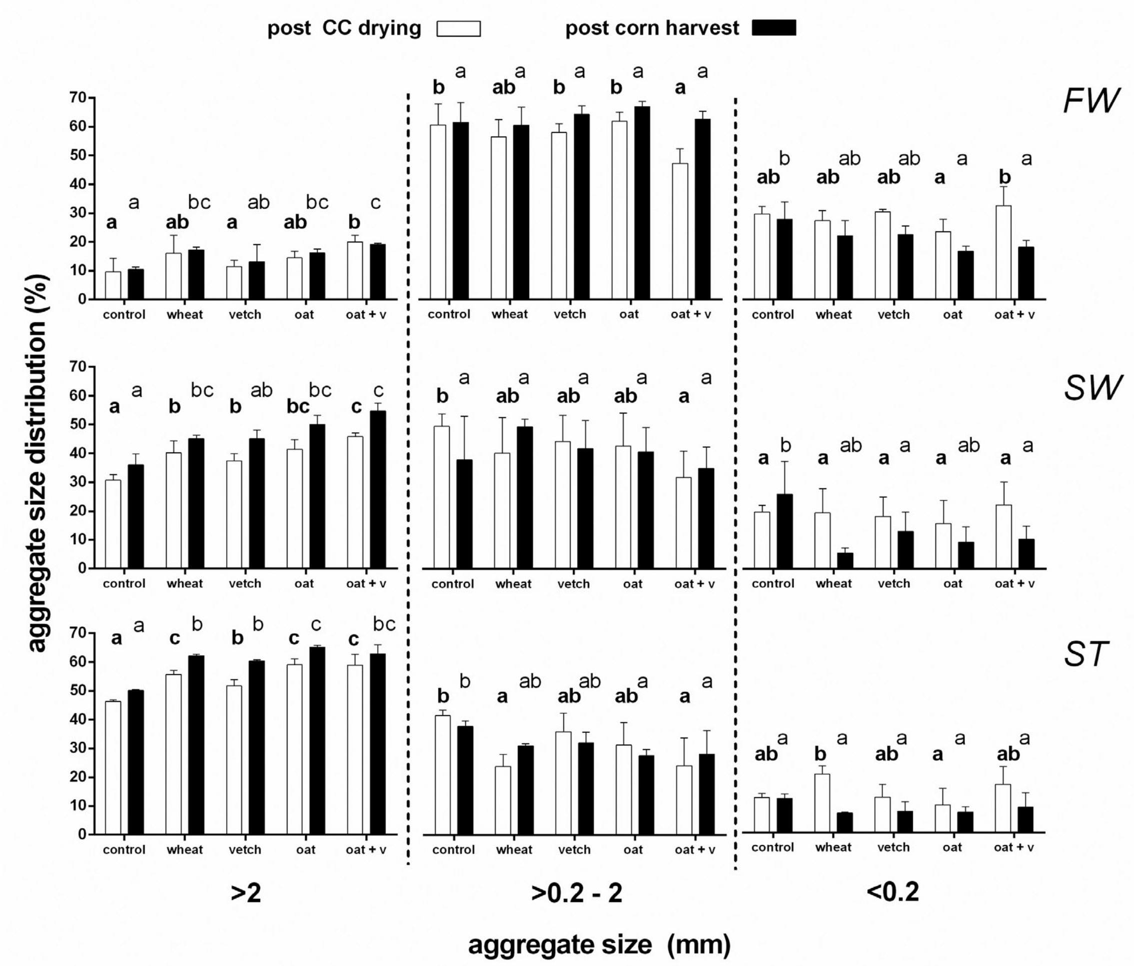
FW: humedecimiento rápido. SW: humedecimiento lento. ST: disgregación mecánica. LBmean: promedio. Wheat: trigo. Vetch: vicia. Oat: avena. Oat + V: avena + vicia. Letras minúsculas diferentes dentro de un pretratamiento y un mismo tiempo de muestreo = diferencias estadísticas significativas entre tratamientos (prueba de Tukey p <0,05). Las líneas de puntos horizontales indican los límites estables e inestables de los agregados.

Figure 1. Aggregate mean weight diameter (MWD) for the various pre-treatments and the mean (LBmean) for the different treatments for two sampling times using the Le Bissonnais (1996) method.

Figura 1. Diámetro medio ponderado de los agregados (MWD) para los diversos pretratamientos y su promedio (LBmean), correspondiente a los diferentes tratamientos, en dos momentos de muestreo y utilizando el método de Le Bissonnais (1996).

portion to the amount of energy applied on soil aggregates. In turn, the MWD order of the CC was related to the pre-treatment considered (**Figure 1**). The different order of CC importance under FW and SW compared with ST after a single CC cycle may be due to the fact that the results of the first two tests were conditioned by soil hydrophobicity, which increases rapidly with greater biological activity (Cosentino *et al.,* 2006; De Gryze *et al.,* 2006). Other author working in the same CC experiment showed that FW and SW presented a higher determination coefficient with soil hydrophobicity (R^2: 0,82, 0,75, respectively), measured by the repellency index, than the ST pre-treatment (R^2: 0,36) (Fernández, 2016). By contrast, mechanical disintegration is more associated with edaphic organic carbon content, which has a slower response to land use changes.

By analyzing different crop successions under no tillage in different soils of the Pampas, Novelli (2013) and Kraemer (2015) also found that FW was the main destabilization mechanism of aggregates, followed by SW and ST. This agrees with the findings of Le Bissonnais (1996), who also mentioned the importance of FW in silty soils. The effect of FW is comparable to that of a high intensity storm or irrigation by flooding (Amézketa, 1999), which generate aggregate explosion by slaking. In contrast, the effect of SW is similar to a gentle rain, where aggregates break by, for example, differential swelling. SW has proved very useful to compare different treatments in soils with low structural stability (Ojeda *et al.,* 2008), whereas the use of FW is more effective in soils with high levels of organic carbon (Le Bissonnais, 1996). In turn, pre-wetting of aggregates with ethanol (ST) allows determining the degree of mechanical cohesion of wet soil. However, Le Bissonnais (1996) mentioned that although each pre-treatment corresponds to specific conditions of initial soil water content, wetting rate and energy applied, results show the same trend. In coincidence with our results, this author also suggested that the relative position within the higher to lower scale of AS values can vary according to the pre-treatment. Nevertheless, while Le Bissonnais (1996) considered that the use of only one pre-treatment may be more effective to discriminate treatment effects, in the present study no single AS pre-treatment was best to account the CC effect. It can be con-



Pre-treatments: FW: fast wetting. SW: slow wetting. ST: mechanical disintegration. Oat + Vetch (oat + V), Different lowercase letters above the bars for the same aggregate fraction and same sampling time indicate statistically significant differences between treatments (Tukey's test p <0,05),
Pre-tratamientos: FW: humedecimiento rápido. SW: humedecimiento lento. ST: disgregación mecánica. Wheat: trigo. Vetch: vicia. Oat: avena. Oat + V: avena + vicia. Letras minúsculas diferentes sobre las barras para la misma fracción de agregados y en el mismo momento de muestreo, indican diferencias estadísticas significativas entre los tratamientos (prueba de Tukey p <0,05).

Figure 2. Aggregate size distribution (%) for two sampling times for each treatment and pre-treatment using the Le Bissonnais method (1996).

Figura 2. Distribución de agregados (%) en dos momentos de muestreo para cada tratamiento y pre-tratamiento, utilizando el método de Le Bissonnais (1996).

cluded that, with heavy rains or with irrigation by flooding, aggregate resistance to rupture will be greater under a CC of oat + vetch, while with a rainfall of moderate intensity, no difference in aggregate response between oat and oat + vetch treatments would be found. The mechanical resistance of moist soil would not be different between wheat and vetch treatments.

In agreement with Pulido Moncada *et al.* (2015) and other authors in soils of temperate climate (D'Haene *et al.,* 2008; Leroy *et al.,* 2008), the intensity of the energy applied on soil aggregates with the three pre-treatments generated different patterns of aggregate size distribution (**Figure 2**). This distribution pattern was essentially due to the amount of soil lost from the >2 mm fraction, which decreased with decreasing energy intensity (**Figure 2**). In addition, the relative proportion of the 2-0,2 mm and <0,2 mm aggregate fractions (between 66 and 69% and between 34 and 31%, respectively) did not vary significantly among pre-treatments. This confirms that the greatest sensitivity to soil disintegration as a consequence of the energy applied in the various pre-treatments was mainly in >2 mm aggregates. The only significant correlation coefficients between MWD and >2 mm aggregates (**Table 2**), showed that the >2 mm aggregate fraction was the only one that explained the significant differences in MWD values. This is also in agreement with that found by Cosentino *et al.* (2006), who considered that this difference response is due to the hierarchical nature of the soil structure. The percentage weight of each aggregate fraction in the different treatments was also significantly different (**Figure 2**), although MWD had greater ability to discriminate the effect of CC on the soil structure (**Figure 1**).

Table 2. Correlation coefficients between the aggregate mean weight diameter of the different pre-treatments of the Le Bissonnais method, with the aggregate size distribution for the two sampling times.

Tabla 2. Coeficientes de correlación entre el diámetro medio ponderado de los agregados correspondientes a los distintos pretratamientos del método de Le Bissonnais, con la distribución por tamaño de agregados para las dos fechas de muestreo.

Pre-treatments	Aggregate size		
	>2	2-0,2	<0,2
	Post CC drying		
FW	0,96**	-0,66ns	-0,09ns
SW	0,95*	-0,78ns	-0,09ns
ST	0,94*	-0,63ns	-0,04ns
	Post corn harvest		
FW	0,99**	0,21ns	-0,91*
SW	0,98**	-0,01ns	-0,88*
ST	0,99**	-0,95*	-0,93*

Pre-treatments: FW: fast wetting. SW: slow wetting. ST: mechanical disintegration. *(p<0,05); **(p<0,01); ns(not significant).
Pre-tratamientos: FW: humedecimiento rápido. SW: humedecimiento lento. ST: disgregación mecánica. *(p<0,05); **(p<0,01); ns(no significativo).

Aggregate stability after a cover crop followed by a corn crop

AS differed significantly between the two sampling times (p <0,05) and an improvement in the soil structural condition was found in all treatments (**Figure 1**). With FW, the rank order from lowest to highest in the scale of MWD values was also equal for both sampling times, while the remaining pre-treatments were better able to capture AS changes over time. Both LB_{mean} and SW showed a relative decline in AS with oat as compared to oat + vetch. These two pre-treatments showed a statistically different effect of all treatments on AS, a fact not observed in the results obtained on the first sampling date. Under ST, a relative improvement of AS was observed with wheat in relation to vetch, while no differences in MWD were found between wheat and oat + vetch. As previously mentioned, this behavior may be due to the different C/N ratio of cereal grasses with respect to legumes, and to the method used to break the aggregates for AS determination. ST aggregate rupture depends on the cohesion generated by the soil organic carbon (Kraemer, 2015), which also depends on a high C/N ratio. The percentage distribution of aggregate sizes (>2, 2-0,2 and <0,2) showed a behavior (**Figure 2**) similar to the results from the first sampling time (after drying of the CC). However, the mean proportion of soil with >2 mm aggregates was higher in SW (46%) and ST (60%) than in the first sampling (39% and 54%, respectively). The proportion in weight of the 2-0,2 mm and <0,2 mm aggregate fractions, although similar among pre-treatments, was different from that determined in the first sampling. After the corn crop, results obtained were 75-79% for the 2-0,2 mm fraction and 25-21% for the <0,2 mm fraction. These results confirm the idea of an improvement of AS after the corn harvest.

Results showed that MWD was better at discriminating the treatment effect on AS than the distribution of the different aggregate fractions. Similarly to that observed after the first sampling time, in all pre-treatments, significant correlations were observed between the MWD of the different pre-treatments and the proportion of >2 mm aggregates (**Table 2**). However, a significant reduction was also corroborated between the percentage of <0,2 mm aggregates and the MWD obtained by the different pre-treatments (**Table 2**).

De Leenheer and De Boodt method

Aggregate stability after a cover crop cycle

No changes in soil structure in response to the different treatments were detected by soil dry-sieving (**Table 3**). MWDH only showed significant differences between treatments with the highest (oat) and lowest (vetch) MWDH value. The CMWD values indicated a positive effect on the soil structure of the two cereal grasses (oat and wheat), compared to the legume (vetch) and its consociation with oat (oat + vetch). There were no significant differences in CMWD between treatments and the control (**Table 3**). When comparing these results with the MWD LB_{mean}, substantial differences were found (**Figure 1**). Although by both methods oat proved to be the best CC at improving soil AS, results from the De Leenheer & De Boodt method showed equal AS values under wheat and oat, worse AS values under vetch and oat + vetch, and no differences under the control, results that differ from those determined with MWD LB_{mean}.

As already mentioned, when applying the Le Bissonnais method, and depending on the energy applied in the various pre-treatments, the relative location of the different treatments in the scale of AS values could change. By comparing the MWDH values obtained by the De Leenheer & De Boodt method (**Table 3**) with the MWD of the pre-treatments of the Le Bissonnais method (**Figure 1**), we found that the former produced less aggregate disaggregation values than the latter. Fan *et al.* (2007) affirmed that the pressure exerted by entrapped air in fast-wetted aggregates is in the order of megapascals, while the energy of a raindrop impact is in the order of kilopascals. In the De Leenheer & De Boodt method, for wet sieving, aggregates were immersed after they had been previously soaked and then allowed to stand for 24 hours. Lado *et al.* (2004) found that fast wetting of presoaked aggregates causes less rupture than when dry. Coinciding with our results, Pulido Moncada *et al.* (2015) also found less aggregate destruction in temperate climate soils, when using the De Leenheer & De Boodt method. This behavior is the result of certain characteristics of the last method mentioned: use of a larger range of aggregate sizes, less energy applied by using drop-dripping and greater moisture content when aggregates were submerged for wet sieving (Pulido Moncada *et al.,* 2015). As a consequence, this technique did not have the same ability to discriminate among different treatments as the Le Bissonnais method and generated different arrangement of the aggregates on the AS scale. In this sense, the only favorable effect on the soil structure found with De Leenheer & De Boodt method was in the oat and wheat treatments. No significant correlations were found between MWDH (De Leenheer & De Boodt method) and MWD values (Le Bissonnais method).

When comparing the two methods, different authors obtained different results. Pulido Moncada *et al.* (2015) found a high significant negative correlation between the results obtained by the De Leenheer & De Boodt method and those from the FW and SW pre-treatments of the Le Bissonnais method. In Belgian loamy soils, D'Haene *et al.* (2008) found a significant correlation between the results of the former methodology and the SW pre-treatment of the Le Bissonnais method. In turn, and contrary to our conclusions, in Belgian sandy loam soils, Leroy *et al.* (2008) considered that the De Leenheer & De Boodt method was more effective than the FW and ST pre-treatments of the Le Bissonnais method at showing the effect of the addition of different doses of organic amendment.

The largest differences between treatments in the percentage of soil retained after wet-sieving was found in the 3-2 mm aggregate fraction (**Table 3**). Those under cereal grasses as cover crop (oat and wheat) had the lowest soil mass loss, while those under legumes (vetch and oat + vetch) or winter fallow presented the greatest loss, although differences between the latter were not significant (**Table 3**). It should be noted that the aggregate fraction used in the Le Bissonnais method was not effective at showing differences between treatments when using the De Leenheer & De Boodt method, as no significant difference was found in the percentage of soil retained in that category. This shows that different laboratory procedures differentially affect the value of each aggregate fraction and consequently the overall results of such tests.

The fraction of aggregates of soil material (2-0,25 mm and <0,25 mm) detached from the larger categories had a different capacity to separate treatment effects. Thus, <0,25 mm was not a variable that helped distinguish the effect of the CC or winter fallow. The variations in the 2-0,25 mm aggregate fraction, on the other hand, were the mirror image of the variations in the 3-2 mm fraction. Cereal grass cover crop treatments (oat and wheat) yielded the lowest amounts in the 2-0,25 mm fraction, while those under legumes (vetch and oat + vetch) or winter fallow showed the greatest weight increases. Consequently, the 3-2 mm fraction proved the most fragile, whereas the next lower category (2-0,25 mm) was more effective than the <0,25 mm at separating the effect of the various treatments. The highest coefficients of correlation between CMWD and the various aggregate categories that lost or gained soil material were those for fractions that best differentiated treatment effects (**Table 5**).

Aggregate stability after the corn crop

Similarly to the results from the first sampling time, MWDS did not allow distinguishing the treatments. The MWDH values after the corn harvest showed a more favorable effect of the cereal grass CC (wheat) on soil AS than that of the legume

Table 3. Soil aggregate stability of different treatments determined by De Leenheer & De Boodt method, sampled after the cover crop was dried.

Tabla 3. Estabilidad estructural de los diferentes tratamientos, determinada por el método de De Leenheer & De Boodt, correspondiente al secado de los cultivos de cobertura.

Treatment	MWDS mm	MWDH mm	CMWD mm	>4,8 %	4,8 – 3,0 %	3,0 – 2,0 %	2,0 – 0,25 g	<0,25 g
O	4,55 a	4,43 b	0,11 a	97,67 bc	97,68 a	93,94 b	1,19 a	2,23 a
O+V	4,52 a	4,36 ab	0,16 b	96,50 a	98,22 a	87,84 a	3,30 b	2,27 a
W	4,50 a	4,39 ab	0,11 a	97,77 c	98,01 a	93,17 b	1,55 a	1,99 a
V	4,45 a	4,29 a	0,16 b	96,63 ab	97,65 a	87,65 a	3,35 b	2,47 a
C	4,52 a	4,38 ab	0,14 ab	97,57 abc	97,39 a	88,20 a	2,96 b	2,35 a

MWDS: mean weight diameter of dry-sieved aggregates. MWDH: mean weight diameter of wet-sieved aggregates. CMWD: Difference in the mean weight diameter of aggregates between MWDS and MWDH. >4,8: proportion in the weight of aggregates retained in the 8-4,8 mm fraction. 4,8-3: proportion in the weight of aggregates retained in the aggregate 4,8-3 mm fraction. 3-2: proportion in the weight of aggregates retained in the 3-2 mm fraction. 2-0,25: weight of the soil retained in the 2-0,25 mm-mesh sieves. <0,25: weight of soil aggregates <0,25 mm. Oat (O); oat + vetch (O + V); wheat (W); vetch (V); control (C). Different lowercase letters within a given variable mean statistically significant differences between treatments (Tukey's test p <0,05).

WDS: diámetro medio ponderado de los agregados correspondiente al tamizado seco. MWDH: diámetro medio ponderado de los agregados correspondiente al tamizado húmedo. CMWD: diferencia en el diámetro medio ponderado de los agregados entre MWDS y MWDH. >4,8: proporción en peso de la fracción de agregados de 8 a 4,8 mm. 4,8-3: proporción en peso de la fracción de agregados de 4,8 a 3 mm. 3-2: proporción en peso de la fracción de agregados de 3 a 2 mm. 2-0,25: peso del suelo retenido entre los tamices con abertura de malla de 2 a 0,25 mm. <0,25: peso de los agregados del suelo <0,25 mm. Avena (O); avena + vicia (O + V); trigo (W); vicia (V); control (C). Letras minúsculas diferentes dentro de una misma variable significan diferencias estadísticas significativas entre los tratamientos (prueba de Tukey p <0,05).

(vetch), with no differences between the remaining treatments (**Table 4**). The CMWD values, on the other hand, were different from those obtained after the first sampling time, as plots covered with oat, oat + vetch and wheat had greater AS, the controls presented the worst structural condition, and those covered with vetch had an intermediate value (**Table 4**). Although treatment differentiation by the MWD LB_{mean} (Le Bissonnais method) was better than with CMWD (De Leenheer & De Boodt method), results from the second sampling time had a higher association than those from the first sampling, with correlation coefficients for the relationship between methods being between 0,70 and 0,75 (p <0,01).

Significant differences in the percentage of the different aggregate fractions retained or accumulated after wet sieving were found between the two sampling times (**Tables 3** and **4**). The amounts of >4,8 mm and 4,8-3 mm aggregate fractions were the only ones that explained the differences in AS between treatments. Plots under wheat retained more >4,8 mm aggregates than controls, while those under oat and oat + vetch lost less soil material than controls, but in the 4,8-3 mm aggregate size. Contrary to the results from the first sampling, those from the second sampling showed no significant differences in the degree of persistence of 3-2 mm aggregates between treatments. The weight of 2-0,25 mm and <0,25 mm aggregates did not allow differentiating between treatments either. As a result, when establishing the degree of correlation between CMWD and the fractions that lost and gained soil material, we found differences between the results from the two sampling dates (**Table 5**). In the second sampling, changes in CMWD were explained mainly by the >4,8 mm, 4,8-3 mm and <0,25 mm aggregates fractions (**Table 5**).

Table 5. Correlation coefficients between the change in the aggregate mean weight diameter of the De Leenheer & De Boodt method, with the aggregate size distribution for the two sampling times.

Tabla 5. Coeficientes de correlación entre el cambio en el diámetro medio ponderado de agregados del método de De Leenheer & De Boodt, con la distribución por tamaño de agregados para las dos fechas de muestreo.

	Aggregate size				
	>4,8	4,8-3,0	3,0-2,0	2,0-0,25	<0,25
	Post CC drying				
CMWD	-0,83**	-0,03ns	-0,89**	0,84**	0,78**
	Post corn harvest				
CMWD	-0,62*	-0,74**	-0,14ns	0,47ns	0,71**

CMWD: change in the aggregate mean weight diameter of the De Leenheer & De Boodt method. *(p<0,05); **(p<0,01); ns(not significant).
CMWD: cambio en el diámetro medio ponderado de agregados del método de De Leenheer & De Boodt. *(p<0,05); **(p<0,01); ns(no significativo).

Table 4. Soil aggregate stability of different treatments measured by De Leenheer & De Boodt method, sampled after the corn harvest.

Tabla 4. Estabilidad estructural de los diferentes tratamientos determinada por el método De Leenheer & De Boodt, correspondiente a la cosecha de maíz.

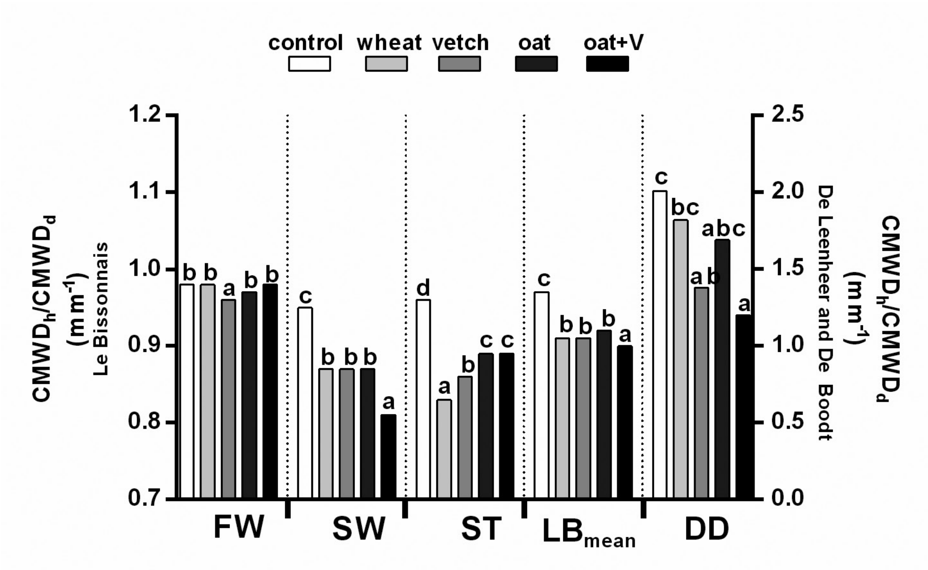
Treatment	MWDS	MWDH	CMWD	>4,8	4,8 – 3,0	3,0 – 2,0	2,0 – 0,25	<0,25
	mm	mm	mm	%	%	%	g	g
O	4,78 a	4,59 ab	0,19 a	95,97 ab	97,06 b	89,12 a	2,21 a	3,14 a
O+V	4,72 a	4,53 ab	0,19 a	95,25 ab	97,76 b	92,08 a	1,66 a	3,18 a
W	4,83 a	4,63 b	0,20 a	97,64 b	95,20 ab	8212 a	3,35 a	3,50 a
V	4,60 a	4,38 a	0,22 ab	94,99 ab	96,10 ab	90,40 a	2,74 a	3,47 a
C	4,70 a	4,42 ab	0,28 b	94,17 a	93,33 a	85,40 a	4,22 a	4,14 a

MWDS: mean weight diameter of dry-sieved aggregates. MWDH: mean weight diameter of wet-sieved aggregates. CMWD: Difference in the mean weight diameter of aggregates between MWDS and MWDH. >4,8: proportion in the weight of aggregates retained in the 8-4,8 mm fraction. 4,8-3: proportion in the weight of aggregates retained in the aggregate 4,8-3 mm fraction. 3-2: proportion in the weight of aggregates retained in the 3-2 mm fraction. 2-0,25: weight of the soil retained in the 2-0,25 mm-mesh sieves. <0,25: weight of soil aggregates <0,25 mm. Oat (O); oat + vetch (O + V); wheat (W); vetch (V); control (C). Different lowercase letters within a given variable mean statistically significant differences between treatments (Tukey's test p<0,05).
WDS: diámetro medio ponderado de los agregados correspondiente al tamizado seco. MWDH: diámetro medio ponderado de los agregados correspondiente al tamizado húmedo. CMWD: diferencia en el diámetro medio ponderado de los agregados entre MWDS y MWDH. >4,8: proporción en peso de la fracción de agregados de 8 a 4,8 mm. 4,8-3: proporción en peso de la fracción de agregados de 4,8 a 3 mm. 3-2: proporción en peso de la fracción de agregados de 3 a 2 mm. 2-0,25: peso del suelo retenido entre los tamices con abertura de malla de 2 a 0,25 mm. <0,25: peso de los agregados del suelo <0,25 mm. Avena (O); avena + vicia (O + V); trigo (W); vicia (V); control (C). Letras minúsculas diferentes dentro de una misma variable significan diferencias estadísticas significativas entre los tratamientos (prueba de Tukey p <0,05).

Relationship between sampling times

Differences in AS (CMWDh/CMWDd ratio) were found between the results obtained by the two methods used (**Figure 3**). All the pre-treatments applied in the Le Bissonnais method showed AS improvement after the corn harvest (second sampling time), as in all cases the ratio was <1 (CMWDh <CMWDd), which means a better structural condition (this can also be seen in **Figure 1**). By contrast, the results from the De Leenheer & De Boodt method showed that, in all treatments, CMWDh increased in relation to CMWDd, resulting in significantly lower AS in this second sampling.

When comparing between sampling times (Le Bissonnais method), the controls showed a better structural condition after a corn crop (second sampling time). The CMWDh/CMWDd ratio in all pre-treatments, except FW, was significantly lower in the plots under a CC than in the controls (**Figure 3**). This means there was also an improvement in the soil structural condition after the second sampling due to the CC residual effect. These results suggest that this improvement could be influenced by the decomposition of the CC material that remained on the soil surface. Moreover, we observed differences in the residual effect of the various CC on the soil structure, with different results according to the pre-treatment. According to Bronick & Lal (2005), the combined effect of the different biochemical composition and amount of plant residues added to the soil influences AS differently. In the present study, greater residual effect was observed under wheat with ST, under oat + vetch with SW, while with FW only vetch favored AS, and if LB_{mean} was considered, O + V was the most important. The results obtained by the De Leenheer & De Boodt method also showed significant differences in AS between sampling times. These results show that the structural soil condition deteriorated after the corn crop (second sam-



Pre-treatments of the Le Bissonnais method: FW: fast wetting. SW: slow wetting. ST: mechanical disintegration. LBmean: average of all pre-treatments. DD: De Leenheer & De Boodt method. Oat + Vetch (oat + V). Different lowercase letters above bars for the same pretreatment of the Le Bissonnais method or for the De Leenheer & De Boodt method indicate statistically significant differences (Tukey's test p <0,05) between treatments.

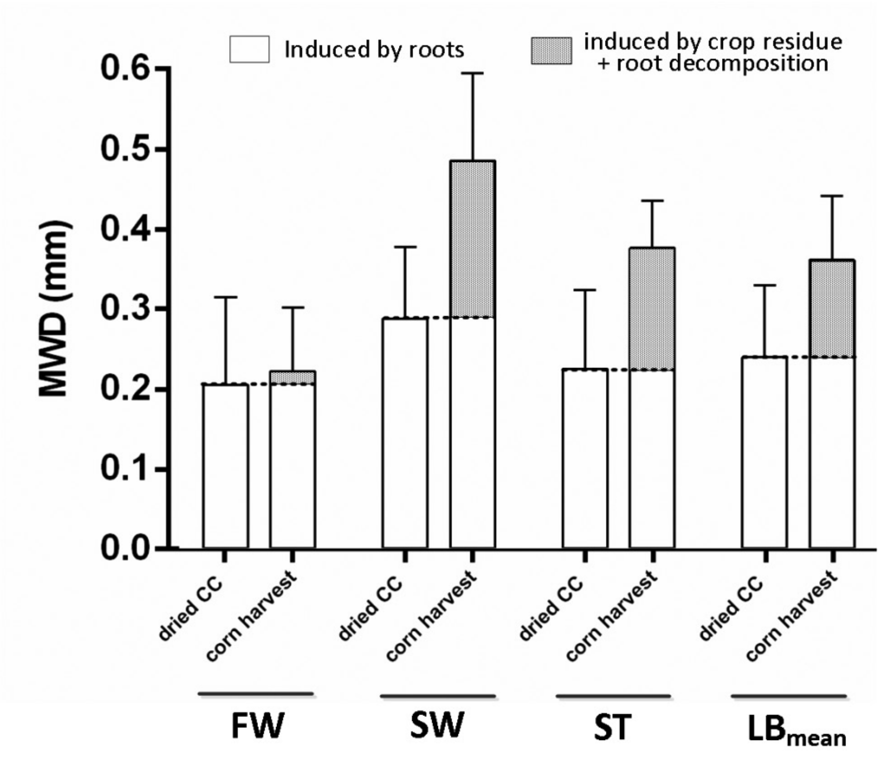
Pre-tratamientos del método de Le Bissonnais: FW: humedecimiento rápido. SW: humedecimiento lento. ST: disgregación mecánica. LBmean: promedio de los pre-tratamientos. DD: Método De Leenheer & De Boodt. Wheat: trigo. Vetch: vicia. Oat: avena. Oat + V: avena + vicia. Letras minúsculas diferentes sobre las barras para el mismo pre-tratamiento del método Le Bissonnais o para el método De Leenheer & De Boodt, indican diferencias estadísticas significativas (prueba de Tukey p <0,05) entre tratamientos.

Figure 3. CMWDh / CMWDd ratio (CMWDh = CMWD after a corn crop harvest; CMWDd= CMWD after a cover crop cycle dried) determined by two methods: Le Bissonnais (1996) and De Leenheer & De Boodt (1958).

Figura 3. Relación CMWDh / CMWDd (CMWDh = CMWD después de la cosecha de maíz; CMWDd = CMWD después del secado de los cultivos de cobertura) determinada por dos métodos: Le Bissonnais (1996) y De Leenheer & De Boodt (1958).

pling date, **Figure 3**). However, there was also a significant residual effect of some CC (vetch and oat + vetch), which compensated for the negative effect of the corn crop (**Figure 3**). **Figure 4** shows the difference between the MWD of the CC treatments and the control for both sampling dates and for each pre-treatment (Le Bissonnais method). The increase in AS observed after the CC was dried was due to the effect of the CC roots, which added new carbon sources to the soil, while the standard deviation indicated differences in the effect of the CC. As previously stated, after the corn harvest, this increase was not only due to crop root activity but also to the quality and quantity of CC surface residues, which through decomposition, generated a carbon flow into the soil. In this case, the size of the standard deviation also reflects the variability between the different CC used.

This Figure shows that the magnitude of these AS increases depends on the pre-treatment used. Aggregate rupture through FW is related to slaking, hydrophobicity and biological activity, processes that are conditioned by the presence of active roots. Large amounts of organic materials are incorporated into the soil during the CC growing period, from root exudates and root death (Liu *et al.,* 2005). These carbon forms contribute to the generation of active polysaccharides, which promote soil microbiological activity, which in turn is capable of producing mucilaginous substances that generate more stable structures (Liu *et al.,* 2005). In agreement, Blanco-Canqui & Lal (2004) argue that root exudates and the organic substances derived from microbiological activity have a greater role in stabilizing soil aggregates than the one of the carbon flow from



FW: fast wetting; SW: slow wetting; ST: mechanical disintegration; LB_{mean}: average for two sampling times: after the cover crop was dried (dried CC) and after the subsequent corn harvest (corn harvest). Error bars correspond to standard deviations.
FW: humedecimiento rápido; SW: humedecimiento lento; ST: disgregación mecánica; LBmean: promedio para dos momentos de muestreo: después del secado de los cultivos de cobertura (dried CC) y después de la cosecha del maíz (corn harvest). Las barras de error corresponden al desvío estándar.

Figure 4. Average increase in structural stability as the difference between mean MWD of CC treatments and the control (Le Bissonnais method) for each pre-treatment.

Figura 4. Incremento promedio en la estabilidad estructural determinado como la diferencia entre la MWD media de los tratamientos con CC y el control (método de Le Bissonnais) para cada pre-tratamiento.

surface residues. Furthermore, Kabir & Koide (2002) also found AS improvement in corn plots after a winter crop, compared to fallow-corn plots. These authors attributed these differences to the winter crop as a host to mycorrhiza, which favored the subsequent colonization of the corn roots, causing greater AS. Mycorrhizae have a positive influence on the soil structure due to the production of glomalin, its protective physical effect and as a carbon source for other microorganisms (Kabir & Koide, 2002). The results from the second sampling showed that the difference in AS was significantly higher with SW and ST than with FW (**Figure 4**), as these pre-treatments respond to organic carbon content (Le Bissonnais, 1996; Kraemer, 2015), which is regulated by the quantity and quality of stubble provided by the various CC. On the other hand, the lower sensibility of FW indicates also the fragility of these soils to slaking, overshadowing the effects of CC on AS.

CONCLUSION

The results of the present study allowed observing the impact of CC roots on AS improvement in the short term. They also showed the effect of different species on this soil property and the favorable residual impact of CC on the soil structure. The Le Bissonnais (1996) method was more useful and consistent to separate treatment effects, but no single pre-treatment was considered better than the others. Although FW allowed separating the effect of cereal grasses, legumes and cereal grass-legume consociations on the soil structure on both sampling dates, the other two pre-treatments were able to capture significant structural changes between sampling dates. On the other hand, results obtained with the De Leenheer & De Boodt (1958) method were more erratic and less consistent, probably because this method applies less rupture energy to soil aggregates.

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