Journal of Plant Chemistry and Ecophysiology

Open Access

Austin Publishing Group

Research Article

Brachypodium hybridum Plant Cover Improves Water Infiltration in Mediterranean Crop Soils

González Moreno A[1]*, Casanova Pena C[1], Gascó A[2] and Rodríguez Martín JA[1]
[1]Department of Environment, INIA. St. Coruna Km 7.2, 28040 Madrid, Spain
[2]Department of Agricultural and Forest Engineering, University of Valladolid, Spain

***Corresponding author:** Alberto González Moreno, Department of Environment, INIA. St. Coruna Km 7.2, 28040 Madrid, Spain

Received: April 14, 2016; **Accepted:** June 01, 2016; **Published:** June 03, 2016

Abstract

Crop plant cover may be an appropriate solution to avoid soil losses by erosion under Mediterranean climate, where traditional tillage aims to improve rainfall water infiltration, and direct evaporation from bare soil is avoided because plant water transpiration is a major limiting factor for non-irrigated crop productivity. Twelve crop lines of the three *Brachypodium distachyon* complex species with different chromosome number (*B. distachyon*, 2n=10; *B. stacei*, 2n=20; and *B. hybridum*, 2n=30) were grown in a field trial to assess water infiltrability and hydraulic conductivity across crop topsoils considering two different plant cover densities (low cover = 150 plants/m^2; regular cover = 450 plants/m^2), and in a control no-tillage bare soil. Results showed that superficial hydraulic conductivity was significantly higher in *Brachypodium*-covered soils with regular plant density (3.254 ± 0.710 $cm \cdot h^{-1}$) than in the no-tillage bare soil (1.965 ± 0.711 $cm \cdot h^{-1}$). On an extreme ranking basis, yields were $1.89 < k(h_0)$ cm/h < 27.12 under covered soils, and $0.679 < k(h_0) < 4.330$ in the no-tillage bare soil. In conclusion, *B. distachyon* ecotypes can protect soil from being eroded and improve water soil infiltration. The adaptation of *B. hybridum* to Mediterranean environments represents an interesting alternative as cover crop for typical woody agricultural plantations in Mediterranean soil such as olive groves, vineyards, and dry-fruit cropland.

Keywords: *Brachypodium distachyon*; *B. stacei*; *B. hybridum*; Mediterranean agriculture; No-tillage; Plant biomass partition; Soil properties; Soil water content; Topsoil conservation; Unsaturated hydraulic conductivity

Introduction

Soil water infiltrability across soil surface, sorptivity, and diffusivity are relevant physical properties of top soils. Unsaturated water flow through topsoil is involved in water infiltration under light rainfall conditions, and unsaturated hydraulic conductivity [$k(h_0)$] at suction ($h_0>0$) strongly depends on pore geometry, connectivity, and soil volumetric water content (θv). As a result, drying soil primarily replaces water with air in soil pores. Soils in native woods typically show high $k(h_0)$ because of the presence of soil organic matter, the soil-root interface influence, and the existence of preferential flow channels provided by decayed roots [1].

Choosing between conventional tillage and no-tillage agricultural management system is still a dilemma in Mediterranean soils [2]. Olive groves began to be cultivated on no-tillage bare soils from 1979 [3], but other studies have shown that using plant cover was the most effective way to fight against soil erosion and to increase water availability by infiltration during rainy seasons [4]. Spontaneous vegetation associated with a main crop may however turn to bea drawback for the crop yield because of its water consumption, particularly within Mediterranean climate [5].

Consequently, crop plant cover complemented with *Brachypodium distachyon* (L.) P. Beauv., or any of its recently segregated species, may be a good alternative to improve topsoil water infiltration in comparison to plant cover composed by *Secale cereale* (L.) M. Bireb, *Hordeum vulgare* (L.), or spontaneous native vegetation. In fact, some *B. distachyon* complex segregated species have been domesticated over several generations, and commercialized for soil and water conservation purposes in Spanish olive groves [6].

These *Brachypodium* species have also been adopted as model plants to assess the behaviour of temperate cereals, forge grasses, and biofuel grass crops [7,8]. This group includes interesting species that can be grown between crop lines, and may therefore be selected for: (1) short-life cycle growing, as short as 6 weeks [7,9]; (2) self-fertility, ensuring the generation of pure inbred lines within two generation cycles [10]; (3) high germination rate under wild and controlled greenhouse conditions [9,10]; (4) its phylogenetic relationship with economically important *Poaceae* species, such as *Triticum* spp., *Hordeum spp*., and *Oryza sativa*, a tropical cereal with a fully sequenced genome [11-13]; (5) its species-specific chromosome number, which correlates with altitude and latitude [13], resulting that *B. hybridum* 2n=30 ecotypes are frequent in lowland and coastal areas, and in intermediate altitudinal areas, and do not require vernalisation for flowering [10,13-16]; (6) its high root tensile strength compared to other grasses, shrubs, and small trees (*Brachypodium* species ranked second amongst representative Mediterranean plant species of these groups, as reported in Baets et al. [17]).

Certain relationships link the tension infiltrometer, pressure, and soil core estimates of saturated soil $k(h_0)$ [18]. Nonetheless, no references have been found to date addressing *Brachypodium* species plant cover and unsaturated soil $k(h_0)$. This research trial aimed to assess several *Brachypodium* species as plant cover on soils

Citation: González Moreno A, Casanova Pena C, Gascó A and Rodríguez Martín JA. *Brachypodium hybridum* Plant Cover Improves Water Infiltration in Mediterranean Crop Soils. J Plant Chem and Ecophysiol. 2016; 1(2): 1008.

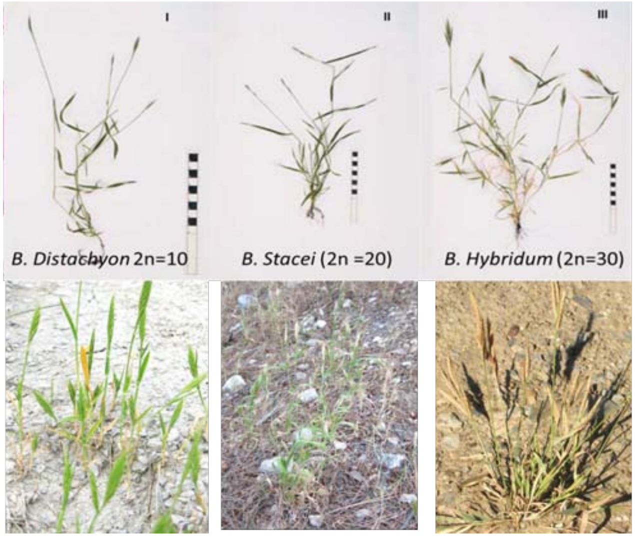

Figure 1: Descriptive images of the three *Brachypodium* spp. ecotypes considered in this essay, grown under standard greenhouse conditions until maturity. Scale in centimeters.

of Mediterranean woody crops interlines, such as olive groves and vineyards, in terms of soil water infiltrability improvement under unsaturated suction conditions.

Materials and Methods

Plant material and layout

Twelve *Brachypodium distachyon*, *B. stacei* and *B. hybridum* lines (four lines per species) were selected to be cultivated along 3 years in soils classified in the large group of the *Haploxeralfs* [19,20], located at "Finca la Canaleja", an experimental field that belongs to the "Instituto Nacional de Investigaciones Agrarias" (INIA), in central Spain near Madrid (latitude = 40º 30' 44" N; longitude = 03º 08' 52" W; altitude=601 m). This area is subjected to a Mesomediterranean type of climate, with average annual atmospheric precipitation of 438 mm, and an average annual temperature of 13.5ºC. The corresponding pedo-climate has a *Xeric* soil moisture regime and a *Mesic* soil temperature regime [21].

These *Brachypodium* species have recently been described as separate species [22,23], namely *Brachypodium distachyon* diploid, 2n=10 (x=5), *Brachypodium stacei*, diploid, 2n=20 (x=10), and *Brachypodium hybridum*, allotetraploid 2n=30 (x=5+10). This group of species was selected because Spain is rich in wild populations [13,15,23,24] that display wide variability in seed characteristics and weight [7] according to environmental diversity. *Brachypodium* species generally show different chromosome base numbers (i.e. diploidy; Catalán et al. [13]), and *B. stacei* and *B. hybridum* tend to be larger than *B. distachyon* [14,23,25,26]. *B. hybridum* does not need vernalisation to flower, and it is therefore able to grow under wider environmental conditions than its diploid *B. distachyon* progenitor (Figure 1).

The 12 *Brachypodium* lines selected to be sown in this trial were the following: (a) four *B. distachyon* (2n=10) lines, labeled D_1, D_2, D_3, and D_4, and selected from central Spanish locations at an altitude of 830-1200 m (Madrid, Guadalajara and Cuenca); (b) two *B. stacei* (2n=20) lines selected in peripheral Spanish locations at altitudes of 42-949 m, labeled T_3 and T_4 (Valencia and Albacete); (c) two other *B. stacei* populations from Iran, labeled A_1 and A_2, which were used as control foreign populations; and (d) four *B. hybridum* (2n=30) lines, labeled H_1, H_2, H_3 and H_4, selected from locations of peripheral Spain at altitudes of 23-759 m (Córdoba, Jaen and Albacete, and between Seville and Huelva).

The crop trial layout consisted of 12 random small rectangular plots (18 x 22 m^2) per *Brachypodium* species and each of the following crop systems: (1) two plant cover crop systems (CC by randomizing the planting of 12 species of the *Brachypodium distachyon* complex in the plot): one considering a low plant density of 150 (±50%) plants/m^2 (LOW CC); and another one considering a regular plant density of 450 (±50%) plants/m^2 (REG CC); (2) a no-tillage system on bare soil (NT). The LOW CC system was obtained from a sowing seed density of 400 seeds/m^2, whereas REG CC was set corresponding to a 1400 seeds/m^2 seed density. Seeds were manually sown. Three increasing doses of nitrogen fertiliser [$NH_4(NO_3)$] were added in the seeding year (0, 100, 200 kg ha^{-1}) after emergence to favour plant establishment and proper growth. Plant cover was evaluated counting the number of plant individuals inside a sampling 12x12 cm^2 small square.

Leaf Weight Ratio (LWR, $g \cdot g^{-1}$) and Specific Root Length (SRL, $cm \cdot mg^{-1}$) were used to discriminate differences between plant/root growth ratios of the assessed *Brachypodium* cytotype species [27,28]. Plant samples were gently washed, and their roots, leaves and stems were separately weighed after being dried in an oven at 75ºC until weight became constant (typically 3 days after placing samples in the oven).

Soil analyses and infiltrability determinations

Twenty-four cylindrical soil samples (10 cm deep; eight corresponding to each NT, LOW CC and REG CC management systems) were air-dried, and standard procedures for soil analyses [29,30] were carried out to determine granulometric fractions (sand between 2 mm and 60 µm, silt fraction between 20-60 µm, fine silt fraction between 2-20 µm, and clay fraction < 2 µm) by the pipette method.

Soil bulk density (BD, $kg \cdot m^{-3}$) and natural water content (NWC, %) were determined by standard soil analysis methods [31]. BD was measured by the core method [32] after collecting soil samples with 10-cm-high stainless steel cylinders that contained a total volume of 340 cm^3. Cylinders were pushed into soil with both ends open using a hydraulic device [29]. Volumetric NWC was determined by drying samples at 105ºC until constant weight [33]. Soil Organic Matter (SOM) was measured by wet oxidation following the Walkley-Black method [34]. Electrical Conductivity (ECe, dS/m at 25ºC) was determined in aqueous saturation extract [35]. Soil analysis results are shown in Table 1.

After infiltration through soil surface, water vertically flows from surface soil to the bottom according to its vertical $k(h_0)$. The flow in unsaturated soil is affected by approximately constant gravity and variable suction ($h_0<0$). The assay to determine infiltrability and vertical unsaturated $k(h_0)$ was carried out using a Decagon minidisk infiltrometer with a 4.5-cm diameter disc, and by exerting a tension of h_0=2 cm. The parameters that were obtained by this infiltrometer

Table 1: Statistical summary of the general descriptive soil properties of the three sets of eight plots that correspond to the following management systems: no-tillage bare soil (NT), low plant density cover (LOW CC) and regular plant density covered (REG CC).

Soil parameter	Treatment	Min	Max	Mean*	Median	SD
SOM (%)	NT	0.18	0.69	0.52a	0.58	0.18
	LOW CC	0.38	0.87	0.52a	0.72	0.15
	REG CC	0.39	0.78	0.55a	0.55	0.15
EC_e (dS/m at 25ºC)	NT	0.121	0.183	0.152a	0.153	0.021
	LOW CC	0.129	0.155	0.149a	0.152	0.008
	REG CC	0.135	0.158	0.148a	0.149	0.010
Clay < 2 µm (%)	NT	12.2	16.4	13.9a	13.9	1.4
	LOW CC	12.6	17.1	13.7a	13.3	1.4
	REG CC	11.2	13.6	12.3b	12.2	0.7
Fine silt 2 - 20 µm (%)	NT	8.7	12.7	10.8a	11.5	1.7
	LOW CC	8.4	11.9	09.6b	9.1	1.3
	REG CC	8.0	10.4	08.8b	8.6	0.7
Coarse silt 20 - 60 µm (%)	NT	12.7	17.4	14.6a	14.3	1.5
	LOW CC	12.8	16.5	13.9ab	13.7	1.1
	REG CC	10.0	13.0	11.7b	11.5	1.0
Sand 0.060 - 2 mm (%)	NT	53.6	64.9	60.6b	60.7	4.1
	LOW CC	53.4	66.6	62.7b	63.8	3.8
	REG CC	64.4	69.5	67.2a	67.4	1.7
NWC (%)	NT	2.21	8.06	5.74a	6.98	2.53
	LOW CC	7.13	8.41	7.85b	7.94	0.52
	REG CC	7.06	8.45	7.54b	7.41	0.48
BD ($kg·m^{-3}$)	NT	1405	1562	1484c	1477	50
	LOW CC	1593	1798	1654b	1667	35
	REG CC	1545	1867	1711a	1687	97

*Significant differences at the 95% level of significance (LSD test) are labeled by different letters; SD = standard deviation.

device were: (1) Infiltration Velocity (InfVel), that is, infiltration rate or infiltrability (i, $mm·s^{-1}$); and (2) Accumulative Infiltration (InfAcum), i.e. infiltration (I, $litre·m^{-2}$ = mm), as determined by the following formula:

$$i = dI/dt = V\, d\theta_v/dt$$

Where t is time and θ_v is the volumetric water content ($m^3·m^{-3}$) in the soil profile affected by water infiltration, with a soil volume per m^2 of soil surface equal to V (mm).

Infiltration (I, mm) can be estimated in dry soils by the equation proposed by Zhang [36], which uses the two first terms of the equation addressed by Philip [37], that is:

$$I = S·t^{1/2} + B·t$$

Where S is called sorptivity, a parameter that is approximately equal to cumulative infiltration during the first unit of time, i.e. a measure for the capacity of soil to absorb water; B is a parameter related to the unsaturated hydraulic conductivity [$k(h_0)$] at suction h_0 that is estimated by the following equation:

$$k(h_0) = A/B$$

Where A is the a-dimensionless van Genutchten parameter [38,39], which depends on soil type, suction value, and the diameter of the infiltrometer disc. Considering a sandy loam soil texture such as the one found in the experimental field, suction h_0=2 cm, and the diameter of the infiltrometer disc (4.5 cm), the van Genutchten parameter value resulted A = 4.24.

Unsaturated $k(h_0)$ was estimated considering the above formula [36] by computing the measured InfAcum *vs.* the square root of time, and by fitting the results with the dimensional formula $L·T^{-1}$, which conveniently resulted in $k(h_0)$ in units of $mm·s^{-1}$ or $cm·h^{-1}$ ($1\ mm·s^{-1} = 360\ cm·h^{-1}$).

Statistical and geostatistical analysis

A standard statistical analysis (mean, median, standard deviation, etc.) was carried out to describe the different analysed parameters. Differences between experimental groups were first determined by analysis of variance (ANOVA). However, these statistical analyses ignore spatial variability, which may be the result of differences among plots characteristics widespread the experimental field; for example, not very big differences in SOM or clay content may significantly affect unsaturated $k(h_0)$ value.

Simple geostatistical techniques based on semi-variograms determination have increasingly been used to analyze the spatial pattern of soil variables [40-42]. Experimental semi-variograms were calculated to analyze spatial autocorrelation of edaphic variables, and to determine the spatial dependence range [43,44]. The spatial correlation range should be interpreted as the separation distance beyond which observations are not spatially dependent [41,42,45]. Normally, a wide range expresses a major area of influence, which is also attributed to intrinsic properties [46,47]. Unsaturated soil $k(h_0)$ was mapped by Ordinary Kriging (OK) based on the parameters that derived from the spherical model fitted to semi-variance data. The prediction accuracy of the unsaturated soil $k(h_0)$ map was evaluated by the cross-validation technique, which removes each data location, one at a time, and predicts the associated data value. Cross-validation analysis served to compare measured and predicted values. Spatial errors are so determined by making a comparison between the experimentally measured $k(h_0)$ values and the estimated $k(h_0)$ values obtained from the spatial model. These errors reflect unsaturated $k(h_0)$ variability among field trial plots, as indicated by standard deviations of original data, and by the uncertainty that is inherent to interpolating from a widely dispersed site [48-50]. As a result, kriging-estimated errors are considered a covariate to avoid the variability attributed to environmental factors that affected experimental field plots. The residuals of Kriging analyses, as a random component and a new independent variable, provide short-scale information of the variation of unsaturated soil $k(h_0)$. These differences in the kriged values of unsaturated $k(h_0)$ were therefore used as a covariate in a new ANOVA performance.

Results

Soil characterization

Topsoils of field plots were not homogeneous (Table 1). At the 95% level of probability confidence, the Shapiro-Wilks test nevertheless showed no significant differences in Soil Organic Matter (SOM) and salinity, estimated by the EC of the saturated

Table 2: Standard statistical summary of the cumulative infiltration of water in soil (I) and unsaturated hydraulic conductivity [$k(h_0)$] of topsoil in the three sets of eight plots that correspond to the following management systems: no-tillage bare soil (NT), low plant density cover (LOW CC) and regular plant density cover (REG CC).

Soil parameter	Treatment	Min	Max	Mean*	Median	SD
I (cm)	NT	0.169	0.602	0.328b	0.283	0.145
	LOW CC	0.175	0.961	0.440ba	0.583	0.245
	REG CC	0.316	1.130	0.726a	0.650	0.273
$k(h_0)$ ($cm \cdot h^{-1}$)	NT	0.679	2.906	1.965b	2.080	0.711
	LOW CC	0.849	3.311	2.303b	2.122	0.831
	REG CC	2.292	4.330	3.254a	3.165	0.710

*Significant differences at the 95% level of significance (LSD test) are labeled by different letters; SD = standard deviation.

Table 3: Statistics of the measured *vs.* estimated values of field unsaturated hydraulic conductivity, $k(h_0)$ in $cm \cdot h^{-1}$, through top soils covered with 12 lines of different *Brachypodium distachyon*, *B. stacei* and *B. hybridum* cover crops.

***Brachypodium* cytotypes**			**Measured values**		**Estimated values**		**Spatial errors**	
Pl	Family	n	mean	SD	mean	SD	mean	SD
2n = 10	D_4	11	2.578	0.664	2.528	0.631	0.050	0.744
	D_3	11	2.361	1.133	2.629	0.801	-0.268	0.997
	D_2	11	2.692	0.989	2.583	0.673	0.109	1.093
	D_1	11	2.716	1.233	2.867	0.785	-0.151	1.132
2n = 20	A_2	11	2.792	1.093	2.577	0.722	0.215	0.537
	A_1	11	2.228	0.955	2.497	0.964	-0.254	0.732
	T_2	11	3.225	1.898	2.961	0.946	0.265	1.461
	T_1	11	3.047	2.555	3.149	1.240	-0.102	2.394
2n = 30	H_4	11	3.077	1.516	2.797	1.180	0.280	1.550
	H_3	11	2.870	1.511	3.020	1.083	-0.150	1.235
	H_2	11	3.379	1.236	2.904	0.934	0.475	0.902
	H_1	11	2.468	0.988	2.900	0.829	-0.432	0.777
Total		**132**	**2.794**	**1.382**	**2.795**	**0.789**	**-0.001**	**1.211**

extract, among the soils of these plots, located low terrace of River Henares; although significant differences were observed in particle size and water content. These differences were not however enough to explain the differences that were found in Bulk Density (BD) figures among the three sets of field plots which soil cover properties resulted different. Therefore, the treatment of these soils may have been responsible for an increased BD in the no-tillage bare soils (NT) compared with the low plant cover (LOW CC) and regular plant cover crops (REG CC). In summary, these soils are classified in the large group of Haploxeralfs.

The addressed differences in particle size distribution (Table 1) among these topsoils were consistent with continental heteromeric sediments from fluvial deposition, and also with the residual accumulation of sand in topsoil because of the natural pedogenesis of their A-Bt-Ck soil horizons sequence. The increase in BD from the NT to LOW CC and REG CC plots was in accordance with both the increase in sand content and the decrease in clay and silt contents. However, soil compaction maybe partially explained by the tension of water that is exerted during soil desiccation, promoted by the presence of Brachypodium plants density and their corresponding water consumption.

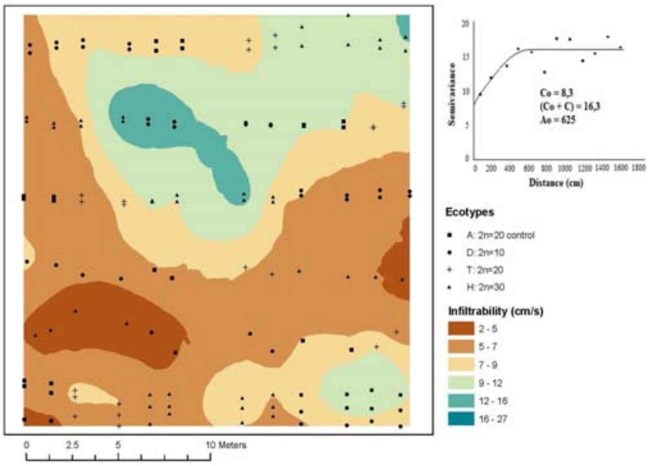

Figure 2: Kriging map of infiltrability ($cm \cdot h^{-1}$) for the field trial design and semivariogram of the experimental values.

Soil hydraulic conductivity and infiltration

Cumulative infiltration of water in soil (I) and unsaturated topsoil $k(h_0)$ significantly increased with *Brachypodium* plant cover (Table 2), which did not agree with the previously reported increased soil compaction provided by BD figures (Table 1) on the basis of the 24 field trial samples that were analysed (NT, LOW CC, REG CC). This surely occurred by the influence of secondary permeability, caused by adsorbed water on vertical surfaces of small root channels and dependant on vegetation cover density and developed root systems.

Table 3 shows the relations obtained by classical statistical and spatial approach analyses for cumulative water infiltration (I) in soil, and unsaturated $k(h_0)$, across the topsoils of the experimental field plots, and on the basis of 132 determinations equally distributed by the designed treatments (LOW CC, REG CC; data not shown). As a result, infiltration (I) ranged from 0.47 to 5.03 cm showing no significant differences among the 12 lines of the three *Brachypodium* species by the classical ANOVA test. Unsaturated $k(h_0)$ ranged from 1.89 to 27.1 $cm \cdot h^{-1}$; extreme values were identified close to the coloured zones on the map (Figure 2), and significant differences among the three *Brachypodium* species within CC treatments (LOW CC, REG CC) were addressed by classical ANOVA (Table 4).

Ranking differences were observed for I and $k(h_0)$ among different species and management treatments (NT, LOW CC, REG CC), which can be partially explained by the influence of soil granulometric particle distributions, the presence of crop cover, and the soil compaction effect on (I) and $k(h_0)$. The spatial pattern in the geostatistical analysis was described in dissimilarity terms of the observed data according to the distance in between. The semivariogram (Figure 2) showed the degree of spatial continuity for $k(h_0)$ across spatial locations, and the spatial dependence given by the scale range. This scale range displayed a spatial influence at a 6.25 m distance, which considered the distance of spatial dependence between field measurements. The spatial variability of water infiltration rate through topsoil surface could be affected by intrinsic traits of soils, such as structure, texture, and SOM content; as well as by extrinsic ones, like agricultural practices (e.g. tillage), seed density, or type of the species used as plant cover.

Table 4: Analysis of variance for unsaturated soil hydraulic conductivity ($k(h_0)$, $cm{\cdot}h^{-1}$)by ploidy, $NH_4(NO_3)$ fertilization, and plant density as sources of variation. *Kriging* residuals of the plots were used as a covariate alternative to perform the 2nd ANOVA, which improved the field trial error term by a 41.1% (44760/108889).

Factor	ANOVA	df	Mean square	P-value	Contribution
Ploidy	Without covariate	2	209407	0.151	6.24%
	With covariate	2	139781	0.047	1.97%
N-fertilization	Without covariate	2	72781	0.415	2.17%
	With covariate	2	77339	0.191	1.09%
Plant density	Without covariate	1	2962550	0.000	88.34%
	With covariate	1	5129	0.736	0.07%
Covariate	Without covariate	-	-	-	-
	With covariate	1	6842430	0.000	96.24%
Error	Without covariate	110	108889		
	With covariate	110	44760		

Table 5: Number of plants sampled in the two tested seed density values, and plant biomass partition main parameters measured for *Brachypodium hybridum* (2n=30) plants.

	Mean	Range	SD
Plant density / Number of samples*			
LOW CC		6 - 9 (11 - 28)	± 0.03
REG CC		18 - 31 (19 - 46)	± 0.03
Plant biomass partition			
Volume	0.055	0.014 - 0.099	± 0.027
Weight	0.102	0.028 - 0.191	± 0.052
Specific root length (SRL),cm/mg	1.308	0.784 - 2.029	± 0.424
Leaf weight ratio (LWR), g/g	0.413	0.484 - 0.552	± 0.026
Steam weight ratio (SWR) ,g/g	0.300	0.286 - 0.319	± 0.013
Root weight ratio (RWR),g/g	0.287	0.153 - 0.228	± 0.038
Aerial weight ratio (AWR),g/g	0.713	0.771 - 0.872	± 0,039

*Number of plants sampled in 400 cm^2 of soil surface for 2 years. Values in parentheses are the number of plants in year 2. SD = standard deviations.

Kriging process estimates were calculated by the weighted sums of the adjacent topsoil $k(h_0)$ values.

The results in the map (Figure 2) show areas with high $k(h_0)$ values, which were associated with higher plant density, and with a 70-cm distance spatial resolution. Spatial errors determined by comparing experimentally measured and estimated $k(h_0)$ values obtained from the spatial model are shown in Table 3. The effects of different factors on the $k(h_0)$ values, by either considering kriging-estimated errors as a covariate (obtained by the geostatistical analysis) or not, are shown in Table 4. In the first case, only plant density proved statistical significance, with an 88.3% contribution factor. No differences due to either the species type factor or nitrogen fertilization factor were detected. However, when tKriging process residual values were considered as a covariate, differences were attributed to the species type factor because the covariate removed soil properties contribution due to the existing spatial variability in the experimental field. Even though plant cover density had no effect on unsaturated $k(h_0)$, *B. hybridum* showed a significantly higher unsaturated $k(h_0)$ across topsoils than the other two species.

Brachypodium biomass partition assessment

The four *B. hybridum* lines had bigger seeds than the *B. stacei* and *B. distachyon* lines. As a result, their seed germination was better and their crops were more viable in dry habitats. In fact, *B. hybridum* individuals were also the biggest plants, and were affected by certain genetic gigantism; i.e. their plants had a high leaf proportion on a dry weight basis, and they obtained higher root system/aerial part ratio values (Table 5) and a longer specific root length (SRL = 13.08 ± 4.24 $km{\cdot}kg^{-1}$).

Discussion

Brachypodium plant cover of croplands may play a relevant role in Mediterranean agricultural soils. For example, only 11.4% of Spanish agricultural soil can be used for optimum olive grove farming, and about a 44% cropland area is estimated to be affected by desertification [51], mainly because of soil erosion on slope land. Increasing soil water infiltrability and conductivity establishing a plant cover between the rows of woody crops, such as olive groves, vineyards, and other dry-fruit tree orchards [3], significantly reduces surface runoff and soil erosion [52],

A relation has been found between other cover crops, such as *Sulla* and *Atriplex* shrubs, and water content in soils [53], but the effectiveness of plant cover to reduce soil erosion has not yet been fully achieved when used to protect soils of woody crops in Mediterranean environments because of the existing water competition against the main crop, e.g. olive trees [3] or vineyards [54]. Nevertheless, a genuine crop cover based on autochthonous mountain species has previously been assayed providing good soil erosion reduction in olive groves [55]. In this essay, a cover crop based on the three species of the *Brachypodium distachyon* complex was designed to examine the association of its species and polyploid occurrence (*B. hybridum*) with its adaptation to environmental aridity [56].

B. distachyon can display certain germination success depending on both soil water content retained in its micro-pores and the surface of soil particles at suction, as provided by the matric water potential as follows: 2% germinated seeds < -1.5 MPa $<\Psi_m< -0.05$ MPa $< 50\%$ germinated seeds [57]. This property affects seed germination and the viability of the different *Brachypodium* species and ecotypes here in selected as cover crops. Non-dormant seeds were germinated at suitable temperature and matric potential [58], similar to BdTR4A and BdTR4B lines of *Brachypodium distachyon sensu lato* reported in Filiz et al. [59]. In fact, *B. distachyon* seeds maintain a high germination rate under wild conditions, and a high auto-seeding capacity for these BdTR4A and BdTR4B lines that belong to the *B. hybridum* species (2n=30 cytotype; Vogel et al. [60]). Temperature was identified as the major driver of their growth rate [61]. In addition, *Brachypodium pinnatum* and *Brachypodium sylvaticum* seeds are able to remain viable in the ground for 5 years [62].

The plant density of the cover crop provided by the tested *Brachypodium distachyon* complex species resulted statistically significant, with an 88.3% contribution to the unsaturated $k(h_0)$ value of the covered sandy loam compacted soil (Table 4). These results confirmed those addressed by Hooke and Sandercok [63], and by Ruiz-Colmenero et al. [54]. Nevertheless, soil infiltration responds to a complex mechanism that involves organic matter content change, aggregated stability [64], total porosity [65] and pore space connectivity [66], all of which result in increased available water capacity [67,68] and soil water infiltration [69].

The statistical significance shown for BD corresponded to the tested NT, LOW CC and REG CC treatments. BD generally addresses the effects of decreasing pore volume and the size of the pores through which water moves. Nevertheless, infiltrability and unsaturated $k(h_0)$ increased correlatively with soil compaction, which could be attributed to the development of secondary permeability, linked to the surfaces generated by the appearance of mini-cracks and root channels, where adsorbed water moved according to differences in matric water potential. The increase in unsaturated $k(h_0)$ after cropping *Brachypodium hybridum* plants for 2 years (2n=30), compared with single inbred lines, was similar to that reported by Rahman [70] for a sandy soil of SE Burkina Faso. The unsaturated $k(h_0)$ in the no-tillage bare soil treatment (NT) decreased and fell within the 0.679-2.906 $cm{\cdot}h^{-1}$ range, which is in accordance to a soil compaction value of BD = 1562 ± 50$kg{\cdot}m^{-3}$. Similar data have been previously reported to reduce rooting [71,72].

Soil compaction decreases the volume of pores in quantity and size terms; both consequences lower infiltration rates and unsaturated hydraulic conductivity [73-75]. Although dry BD in NT plots was lower than BD for LOW CC and REG CC, unsaturated $k(h_0)$ and cumulative infiltration were also lower in NT plots than for plant cover treatments. This apparent paradox could be attributed to the disaggregation effect of soil structure by rain erosivity and soil erosion ability under bare soil conditions after a dry summer, when the first storm episodes clog pores and soil is affected by sealing when it becomes wet, and by crusting when it is dry [2,4].

Macro-pores volume and soil strength both limit root elongation rates in soil. Soil compaction hinders root growth, thus it is a soil quality-related parameter [76]. BD for the three treatments (NT, LOW CC and REG CC) showed mechanical impedance for both root and shoot growth [77]. The localised soil compaction position determines root and, subsequently, shoot growth responses. The root system of *Brachypodium* spp. is similar to that of wheat [78], which is mainly cultivated under similar climate conditions to those of the herein considered experimental fields, and corresponds in plant density and soil sand content. Nitrogen fertilization was not statistically significant for the sets of plots located in the trial field because the *B. distachyon* complex species had no such avidity for the fertiliser, and its root system was able to colonize relatively poor soils without further aid [7,79]. Nevertheless, using *Brachypodium hybridum* as a cover crop helped reduce net leaching nitrate-N losses, as previously reported by Delgado and Bausch [80] in soils covered by malting barley and winter rye crops.

Hydraulic conductivity showed spatial variability. The second ANOVA was performed using the residual values obtained by Kriging to reduce this spatial soil disturbance, and to separate the species type and ploidy factors of *Brachypodium distachyon*. Significant differences in unsaturated $k(h_0)$ linked to the species type and ploidy level of the plant lines were difficult to assess. Nevertheless, the individuals of *B. hybridum* (2n=30) displayed better root system development (Table 5) compared with *B. distachyon* (2n=10) and *B. stacei* (2n=20) individuals; as well as a higher absolute average unsaturated $k(h_0)$ value was also addressed.

Differences in biomass partition results could be attributed to soil compaction, as previously reported by Atwell [81] for wheat plants that grew in compacted soils in the U.K., where the RWR/SWR ratio was limited due to seminal root axes growth inhibition. Ecotypes of *Brachypodium hybridum* 2n=30 tend to be larger than ecotypes of *Brachypodium distachyon* 2n=10 [26]. Spanish *Brachypodium hybridum* grows faster and produces more biomass than polyploid lines [16,25]. The allotetraploid *Brachypodium hybridum* generally adapts better to drought conditions than the diploid *Brachypodium distachyon* due to its eco-physiological performance, including gas exchange, photosynthesis [2] and its "escapist" strategy to cope with aridity situations associated with water stress [56]. Plants with long roots and vast aerial green cover have also shown advantages for soil and water conservation, such as *Brachypodium hybridum* and the shrub *Atriplex halimus*, which have previously been addressed to increase soil macro-porosity [53,82]. Root growth is also proportional to the development of the aerial part [83]. Therefore, big plants develop big root systems, which improves soil water infiltration because the necessary preferential channels for water movement are precisely provided by root growth. This has already been shown for two commercial varieties of *B. distachyon* (Ibros and Zulema), which have been tested for interlines plant cover in olive groves in Spain [15]. *B. hybridum* also increased Soil Organic Matter content (SOM) near the root channel surface after 2 years of crop growing thanks to dead root decomposition and root channels abundance.

Conclusion

In summary, *B. distachyon* ecotypes can protect soil and improve water soil infiltration. The cover of *Brachypodium distachyon*, *B. stacei* and *B. hybridum* plants positively affects soil properties and water conservation by reducing rain erosion effects. The aerial part of vegetation acts as a protective shelter against rainwater drop tapping, which would otherwise pull off and move soil fine particles of organic matter and clay. The hidden-half root part acts as a swelling and shrinking agent during wetting and drying processes, which increases soil-connected macro-pores where water moves. The use of residual values that derive from geostatistical analyses ensures relations between soil infiltration and plant cover density. Spatial analysis can be a new method for evaluating soil characteristics variability in plant breeding essays. A long developed Specific Root Length (SRL, $km{\cdot}kg^{-1}$) is significant for increasing macro-porosity from death gross and medium roots, where water moves and is adsorbed on the surface of these root channels; whereas soil organic matter increases from fine roots decomposition. The adaptation of *B. hybridum* to Mediterranean environments characterizes this species as an interesting alternative to be used as a cover crop in woody crops, such as olive groves, vineyards or dry-fruit croplands.

Acknowledgements

This research has been supported by Project RTA2009-0082-00-00. We are also grateful to the Spanish Ministry of Science and Innovation for funding Project CGL2013-43675-P. We also wish to thank and gratefully remember Consuelo Soler, who led the project until 2013 (R.I.P.). We are grateful to J.M. Gascó (Polytechnic University of Madrid) and Angeles Tirado Torralvo (INIA) for technical assistance, to Pilar Catalán (University of Zaragoza) for

providing us with photographs of *B. distachyon*, *B. stacei* and *B. hybridum*, and for contributing to early versions of the manuscript with valuable comments.

References

1. Huck MG, Klepper B, Taylor HM. Diurnal variations in root diameter. Plant Physiol. 1970; 45: 529.

2. Ruiz-Colmeneroa M, Bienesa R, Marquesc MJ. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil Till Res. 2011; 117: 211-223.

3. Pastor M, Castro J, Humanes MD, Muñoz. Sistemas de manejo del suelo en olivar de Andalucía. *Edafología*. 2001; 8: 75-98.

4. Martín MH, Pastor M. Comparación de los sistemas de siega química y mecánica para el manejo de cubiertas de veza (*Vicia sativa* L.) en las interlíneas de los olivos. Actas/Sociedad Española de Malherbología, Congreso 1995, Huesca 14, 15 y 16 de noviembre de 1995. Instituto de Estudios Altoaragoneses. 1995; 235-238.

5. Hammer K, Gladis T, Diederichsen A. Weeds as genetic resources. Plant Genetic Resources Newsletter 1997; 111: 33-39.

6. Soler C, Casanova, Rojo A. Desarrollo de cubiertas vegetales a partir de gramíneas seleccionadas para su explotación en tierras de olivar. Actas Horticulturales. 2004; 41: 97-100.

7. Mur LA, Allainguillaume J, Catalán P, Hasterok R, Jenkins G, Lesniewska K, et al. Exploiting the *Brachypodium* tool box in cereal and grass research. New Phytol. 2011; 191: 334-347.

8. Catalan P, Chalhoub B, Chochois V, Garvin DF, Hasterok R, Manzaneda AJ, et al. Update on the genomics and basic biology of *Brachypodium*. Trends in Plant Science. 2014; 19: 414-418.

9. Garvin DF, Gu YQ, Hasterok R, Hazen SP, Jenkins G, Mockler TC, et al. Development of genetic and genomic research resources for *Brachypodium distachyon*, a new model system for grass crop research. Crop Sci. 2008; 48: 69-84.

10. Vogel JP, Tuna M, Budak H, Huo N, Gu YQ, Steinwand MA. Development of SSR markers and analysis of diversity in Turkish populations of *Brachypodium distachyon*. BMC Plant Biology. 2009; 9: 88.

11. Barker NP, Clark LG, Davis JI, Duvall MR, Guala GF, Hsiao C, et al. Phylogeny and subfamilial classification of the grasses (*Poaceae*). Ann Mo Bot Gard. 2001; 373-457.

12. Catalán P, Kellogg EA, Olmstead RG. Phylogeny of *Poaceae* subfamily *Poöideae* based on chloroplast ndhF gene sequences. Mol Phylogenet Evol8. 1997; 150-166.

13. López-Alvarez D, Manzaneda AJ, Rey PJ, Giraldo P, Benavente E, Allainguillaume J, et al. Environmental niche variation and evolutionary diversification of the *Brachypodium distachyon* grass complex species in their native circum-Mediterranean range. American Journal of Botany. 2015; 102: 1-16.

14. Draper J, Mur LA, Jenkins G, Ghosh-Biswas GC, Bablak P, Hasterok R, et al. *Brachypodium distachyon*. A new model system for functional genomics in grasses. Plant Physiol. 2001; 127:1539-1555.

15. Hammami R, Jouve N, Cuadrado A, Soler C, González J. Prolamin storage proteins and alloploidy in wild populations of the small grass *Brachypodium distachyon* (L.) P. Beauv. Plant Syst Evol. 2011; 297: 99-111.

16. Opanowicz M, Vain P, Draper J, Parker D, Doonan JH. *Brachypodium distachyon*: making hay with a wild grass. Trends in Plant Sci. 2008; 13: 172-177.

17. Baets S, Poesen JA, Knapen GG, Barberá, Navarro JA. Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant Soil. 2007; 294: 169-183.

18. Reynolds WD, Bowman BT, Brunke RR, Drury CF, Tan CS. Comparison of tension Infiltrometer, pressure Infiltrometer, and soil core estimates of saturated hydraulic conductivity. Soil Sci Soc Am J. 2000; 64: 478-484.

19. Soil Survey Staff. Keys to soil taxonomy, twelfth edition. Natural Resources Conservation Service, NRCS, United States Department of Agriculture, Natural Resources Conservation Service, National Survey Center, Lincoln, Nebraska, USA. 2014.

20. Soil Survey Staff. Illustrated guide to soil taxonomy, version 2. U.S. Department of Agriculture, Natural Resources Conservation Service, National Survey Center, Lincoln, Nebraska, USA. 2015.

21. Elias F. Encín , soil and climate . Volume 17 , Monograph INIA . Department of Ecology delInstituto National Agricultural Research , Madrid. 1977.

22. Catalán P, Muller J, Hasterok R, Jenkins G, Mur LA, Langdon T, et al. Evolution and taxonomic split of the model grass *Brachypodium distachyon*. Annals of Botany. 2012; 109: 385-405.

23. Catalán P, López-Álvarez D, Bellosta C, Villar L. Updated taxonomic description, iconography and habitat preferences of *Brachypodium distachyon*, *B. stacei* and *B. hybridum* (*Poaceae*. Anales del Jardín Botánico de Madrid. 2016; 73: 28.

24. López-Alvarez D, López-Herranz ML, Betekhtin A, Catalán P. A DNA barcoding method to discriminate between the model plant *Brachypodium distachyon* and its close relatives *B. stacei* and *B. hybridum* (*Poaceae*). PLoS ONE. 2012; 7: 51058.

25. Scoles G, Filiz E, Ozdemir B, Budak F, Vogel J, Tuna M, et al. Molecular, morphological, and cytological analysis of diverse *Brachypodium distachyon* inbred lines. Genome. 2009; 52: 876-890.

26. Schwartz CJ, Doyle MR, Manzaneda AJ, Rey PJ, Mitchell-Olds T, Amasino RM. Natural variation of flowering time and vernalization responsiveness in *Brachypodium distachyon*. Bioenergy Research. 2010; 3: 38-46.

27. Poorter H, Remkes C. Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. *Oecologia*. 1990; 83: 553-559.

28. Ryser P. The mysterious root length. Plant Soil. 2006; 286: 1-6.

29. Gee GW, Bauder JW. Particle-size analysis. Klute A, editor. In: Methods of soil analysis, Part 1. Physical and mineralogical methods, 2nd edn, American Society of Agronomy ASA, and Soil Science Society of America SSSA, Madison, WI, USA.1986; 383-411.

30. Gee GW, Or D. Particle-size analysis. Dane JH, Topp GC, editors. In: Methods of soil analysis. Part 4 - Physical methods, Soil Science Society of America SSSA, Madison, WI, USA. 2002; 255-293.

31. Klute A, editor. Methods of soil analysis. Part 1.2nd Edn. Agron. Monogr. 9. ASA and SSSA, Madison WI, USA. 1986.

32. Blake GR, Hartge KH. Bulk density by core method. Klute A, editor. In: Methods of soil analysis. Part 1. 2nd Edn. Agron. Monogr. 9. ASA and SSSA, Madison, WI, USA. 1986.

33. Gardner WH. Water content. Klute A, editor. In: Methods of soil analysis. Part 1.2nd Edn. Agron. Monogr. 9. ASA and SSSA, Madison, WI, USA. 1986.

34. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. Black CA, editor. In: Methods of soil analysis. Part 3. Chemical methods, Soil Science of America and American Society of Agronomy, Madison, WI, USA. 1996; 961-1010.

35. Rhoades JD. Salinity: Electrical conductivity and total dissolved solids. Sparks DL, editor. In: Methods of soil analysis. Part 3. Chemical methods. American Society of Agronomy ASA and Soil Science Society of America SSSA books series No. 5, Madison, WI, USA. 1982; 417-436.

36. Zhang R. Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. Soil Sci. Soc. Am. J. 1997; 61: 1024-1030.

37. Philip J. The theory of infiltration: 1. The infiltration equation and its solution. Soil Sci. 1957; 8: 345-358.

38. van Genuchten MT. A Closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci Soc Am J. 1980; 44: 892-898.

39. van Genuchten MT, Nielsen D. On describing and predicting the hydraulic properties of unsaturated soils. Annals of Geophys. 1985; 3: 615-628.

40. Odumo B, Carbonell G, Angeyo H, Patel J, Torrijos M, Rodríguez Martín J. Impact of gold mining associated with mercury contamination in soil, biota sediments and tailings in Kenya. Environ Sci Pollut R. 2014; 21: 12426-12435.

41. Rodríguez Martín JA, Álvaro-Fuentes J, Gonzalo J, Gil C, Ramos-Miras JJ, Grau Corbí JM, et al. Assessment of the soil organic carbon stock in Spain. Geoderma. 2016; 264: 117-125.

42. Rodríguez Martín JA, Nanos N. Soil as an archive of coal-fired power plant mercury deposition. J Hazard Mater. 2016; 308: 131-138.

43. Nanos N, Grigoratos T, Rodríguez Martín J, Samara C. Scale-dependent correlations between soil heavy metals and As around four coal-fired power plants of northern Greece. Stoch Env Res Risk A. 2015; 29: 1531-1543.

44. Rodríguez Martín JA, Carbonell G, Nanos N, Gutiérrez C. Source Identification of Soil Mercury in the Spanish Islands. Arch Environ Con Tox. 2013; 64: 171-179.

45. Solgi E, Solgi M, Rodríguez Martín JA. Spatial variability of heavy metal concentrations in vineyard soils on Malayer Plains (Iran). Environmental Forensics. 2016; 17: 87-96.

46. Goovaerts P. Geostatistics for natural resources evaluation. Oxford University Press, USA. 1997.

47. Rodríguez Martín J, Vazquez de la Cueva A, Grau Corbí J, Martínez Alonso C, López Arias M. Factors controlling the spatial variability of mercury distribution in Spanish topsoil. Soil Sediment Con. 2009b; 18: 30-42.

48. Mirzaei R, Esmaili-Sari A, Hemami M, Rezaei H, Rodríguez Martín J. Levels and Variability of Metals in Soils of the Province of Golestan (Iran). Arch Environ Con Tox. 2014; 67: 617-629.

49. Rodríguez Martín J, Carbonell Martín G, López Arias M, Grau Corbí J. Mercury content in topsoils, and geostatistical methods to identify anthropogenic input in the Ebro basin (Spain). Span J Agric Res. 2009a; 7: 107-118.

50. Zamani-Ahmadmahmoodi R, Bakhtiari AR, Rodríguez Martín JA. Spatial relations of mercury contents in Pike (Esox lucius) and sediments concentration of the Anzali wetland, along the southern shores of the Caspian Sea, Iran. Marine Pollution Bulletin. 2014; 84: 97-103.

51. Montanarella L. Soil at the interface between agriculture and environment. Agriculture, Environment, Rural development: Facts and Figures - A Challenge for Agriculture. Report for the European Commission. 1999.

52. Lee KH, Isenhart TM, Schultz RC, Mickelson SK. Multispecies riparian buffers trap sediment and nutrients during rainfall simulations. J Environ Quality. 2000; 29: 1200-1205.

53. Chisci GC, Bazzoffi P, Pagliai M, Pellegrini S, Vignozzi N. Association of *Sulla* and *Atriplex* shrub for the physical improvement of clay soils and environment protection in central Italy. Agricultural Ecosystem and Environment. 2001; 84: 45-53.

54. Ruiz-Colmenero M, Bienes R, Eldridge DJ, Marques MJ. Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. CATENA. 2012; 104: 153-160.

55. VH. Durán Z, JR. Francia M, CR. Rodríguez P, A. Martínez R, B. Cárceles R. Soil erosion and runoff prevention by plant covers in a mountainous area (SE Spain): implications for sustainable agriculture. Environmentalist J. 2006; 26: 309-319.

56. Manzaneda AJ, Rey PJ, Bastida JM, Weiss-Lehman Ch, Raskin E, Mitchell-Olds T. Environmental aridity is associated with cytotype segregation and polyploidy occurrence in *Brachypodium distachyon (Poaceae)*. New Phytol. 2012; 193: 797-805.

57. Evans JR, Etherington CE. The effect of soil water potential on seed germination of some British plants. New Phytologist. 1990; 115: 539-548.

58. Taylor JR, Roundy BA, Allen PS, Meyer SE, Eggett DL. Soil water sensor accuracy for predicting seedling emergence using a hydrothermal time model. Arid Land Res and Manage. 2007; 21: 229-243.

59. Filiz E, Ozdemir BS, Budak F, Vogel JP, Tuna M, Budak H. Molecular, morphological, and cytological analysis of diverse *Brachypodium distachyon* inbred lines. Genome. 2009; 52: 876-890.

60. Vogel JP, Garvin DF, Mockler TC, Schmutz J, Rokhsar D, Bevan MW, et al. Genome sequencing and analysis of the model grass Brachypodium distachyon. Nature. 2010; 463: 763-768.

61. Matos DA, Cole BJ, Whitney IP, MacKinnon KJ, Kay SA, Hazen SP. Daily changes in temperature, not the circadian clock, regulate growth rate in *Brachypodium distachyon*. PLoS ONE. 2014; 9: 100072.

62. Thompson K, Band SR, Hodgson JG. Seed size and shape predict persistence in soil. Func Ecol. 1993; 7: 236-241.

63. Hooke J, Sandercock P. Use of vegetation to combat desertification and land degradation: Recommendations and guidelines for spatial strategies in Mediterranean lands. Landscape and Urban Planning. 2012; 107: 389-400.

64. Tisdall JM, Oades JM. Organic matter and water-stable aggregates in soils. J Soil Sci. 1982; 33: 141-163.

65. Reeves DW. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage Research. 1997; 43: 131-167.

66. Schwen A, Bodnerb Schollb GP, Buchanc GD, Loiskandla W. Temporal dynamics of soil hydraulic properties and the water-conducting porosity under different tillage. Soil Till Res. 2011; 113: 89-98.

67. Hudson BD. Soil organic matter and available water capacity. Journal of Soil and Water Conservation. 1994; 49: 189-194.

68. Franzluebbers AJ. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil & Tillage Research. 2002; 66: 197-205.

69. Ankeny MD, Ahmed M, Kaspar TC, Horton R. Simple field method for determining unsaturated hydraulic conductivity. Soil Science Society of America Journal. 1991; 55: 467-470.

70. Rahman GA. A study of infiltration rate in South West region of Burkina Faso. Australian Journal of Basic and Applied Sciences. 2010; 4: 1349-1357.

71. Valentine TA, Hallett PD, Binnie K, Young MW, Squire GR, Hawes C, et al. Soil strength and macropores volume limit root elongation rates in many UK agricultural soils. Annals of Botany. 2012; 110: 259-270.

72. McKenzie N, Coughlan K, Cresswell H. Soil physical measurement and interpretation for land evaluation. CSIRO Publishing, Collingwood, Victoria, Australia. 2002.

73. Vogel HJ, Babel U. Soil Space Diversity and Its Dynamics: Qualitative and Quantitative Considerations Biodiversity. Benckiser G, Schnell S, editors. In: Agricultural Production Systems, CRC Taylor and Francis Group, Boca Raton FL, USA. 2006; 41-68.

74. Horgan GW, Ball BC. Simulating diffusion in a Boolean model of soil pores. European Journal of Soil Science. 1994; 45: 483-491.

75. Horgan GW. Mathematical morphology for soil image analysis. European Journal of Soil Science. 1998; 49: 161-173.

76. Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE. Soil quality: A concept, definition, and framework for evaluation. Soil Sci Soc Amer. J. 1997; 61: 4-10.

77. Cook A, Marriott CA, Seel W, Mullins CE. Effects of soil mechanical impedance on root and shoot growth of *Lolium perenne* L, *Agrostis capillaris* and *Trifolium repens* L. Journal of Experimental Botany. 1996; 47: 1075-1084.

78. Chochois V, Vogel JP, Watt M. Application of *Brachypodium* to the genetic improvement of wheat roots. Jof Exp Bot. 2012; 63: 3467-3474.

79. Benavente E, García-Toledano L, Carrillo JM, Quemada M. Thermographic imaging: assessment of drought and heat tolerance in Spanish germplasm of *Brachypodium distachyon*. Procedia Environmental Sciences. 2013; 19: 262-266.

80. Delgado JA, Bauch W. Potential use of precision conservation techniques to reduce nitrate leaching in irrigated crops. Journal of Soil and Water Conservation. 2006; 60: 379-387.

81. Atwell BJ. The effect of soil compaction on wheat during early tillering. I.Growth, development and root structure. New Phytologist. 1990; 115: 29-35.

82. Walker DJ, Lutts S, Sánchez-García M, Correal E. *Atriplex halimus* L.: Its biology and uses. J Arid Environ. 2014; 100-101: 111-121.

83. Eissenstat DM, Wells CE, Yanai RD, Whitbeck JL. Building roots in a changing environment: implications for root longevity. New Phytologist. 2000; 33-42.

J Plant Chem and Ecophysiol - Volume 1 Issue 2 - 2016
Submit your Manuscript | www.austinpublishinggroup.com

Citation: González Moreno A, Casanova Pena C, Gascó A and Rodríguez Martín JA. *Brachypodium hybridum* Plant Cover Improves Water Infiltration in Mediterranean Crop Soils. J Plant Chem and Ecophysiol. 2016; 1(2): 1008.