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Comparing effects of tillage treatments performed with animal traction on soil physical properties and soil electrical resistivity: preliminary experimental results

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Abstract: Soil Compaction results from compressive forces applied to compressible soil by machinery wheels, combined with tillage operations. Draft animal-pulled equipment may also cause soil compaction, but a huge gap exists on experimental data to adequately assess their impacts and, actually, animal traction is an option seen with increasing potential to contribute to sustainable agriculture, especially in mountain areas. This study was conducted to assess the impacts on soil compaction of tillage operations with motor tractor and draft animals. In a farm plot (Vale de Frades, NE Portugal) treatments were applied in sub-plots (30 m x 3 m), consisting in a two way tillage with tractor (T), a pair of cows (C) and a pair of donkeys (D). Undisturbed soil samples (120) were taken before and after operations for bulk density (BD) and saturated hydraulic conductivity (Ks). The relative changes in BD observed after tillage in the 0-0.05 m soil depth increased after operations in all treatments. The increase was higher in the tractor sub-plot (15%) than in those where animal traction was used (8%). Before operation Ks class was rapid and fast in all samples, and after operation this value was reduced to 33% in T, whereas it reached 83% in C. Electrical Resistivity Tomography (ERT) was useful as a tool to identify the alterations caused by tillage operations on soil physical status. These preliminary results confirm the potential of animal traction as an option for mountain agri-environments, yet it requires much wider research to soundly ground its assets.

Keywords: Animal traction, Soil compaction, Saturated hydraulic conductivity, Electrical Resistivity Tomography

1 Introduction

Soil structure degradation, often called soil compaction, is regarded as one of the most serious form of land degradation caused by conventional farming practices which negatively disturbs the soil physical status. According to the European Environmental Agency (2012) compaction is one of the key threats affecting soils. It occurs even in no-tillage systems because of the compressive forces applied to soil by tractor wheels (Batey 2009). Compaction alters soil structure by crushing aggregates or combining them into larger units, increase soil bulk density, and decrease the number of coarse pores (Needham et al. 2004; Delgado et al. 2007). The problem is magnified because, being mainly a sub-surface phenomenon, soil compaction is commonly considered as the type of land degradation most difficult to locate and rationalise. Unlike erosion and salinity that give strong surface evidence of their presence, soil

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compaction requires physical input before it is uncovered and its extent, nature and cause resolved (Mc Garry and Sharp 2003). Soil structure is the way the solid particles and pores are arranged. The pores between aggregates are most important, because not only they distribute air, water and nutrients throughout the soil, but also they are used by plant roots to anchor and sustain a healthy crop above ground. Soil compaction reduces the pore space between aggregates and a compacted soil, where large, continuous soil pores are lost or reduced in size, does not provide adequate space for the storage or movement of air and water, leading to slow permeability to water and to restricted aeration (Mooney and Nipattasuk 2003). Soil compaction, due to the collapse or decrease of pore spaces, is the most common cause of physical restriction for root growth and development. Thus, crop growth, yield and quality are negatively affected causing economic costs to farmers. The economic cost and the difficulty to be detected make soil compaction a serious risk in the global "food security challenge".

The main causes of compaction are compressive forces from tractor tyres and tillage implements (especially mouldboard plough and rotary equipment). Compaction may occur on the surface of the land, within the tilled layer or below it, or even at greater depths (Batey 2009). Traffic of wheeled farm machines is common in most agricultural operations even in zero tillage systems (Tullberg et al. 1990). Soil compaction by wheels is characterised by a decrease in soil porosity localised in the zone beneath the wheel and rut formation at the soil surface (Hamza and Anderson 2005). Tilling, harvesting and spreading of chemicals or fertilisers are the common operations in most farms. Most of these operations are performed by heavy, wheeled machines. In mechanized cropping systems the continual use of tillage implements, especially disc ploughs, disc harrows, mould-board ploughs and rotovators, over long periods of time frequently results in the formation of dense plough pans containing few pores large enough to be penetrated by crop roots.

Methodological approaches for assessing soil compaction are all focused on changes in soil physical status after enduring compressive forces. Soil physical properties related to air and water storage and movement are currently assessed (porosity, soil water characteristic curve, hydraulic conductivity, and air permeability), as these properties largely reflect the impacts of those forces on key soil functions. Measurement of parameters describing soil mechanical behaviour, such as shear strength and resistance to penetration, is also commonly used in soil compaction (Horn and Fleige 2003). Geophysical methods are increasingly applied in soil compaction studies, as non-invasive and less time and labour consuming (e. g., electrical resistivity tomography – ERT (Besson et al. 2004) and apparent electrical conductivity – EC_a (Al-Gaadi 2012; Brevik and Fenton 2004). ERT has been used to study the spatial and temporal variability of many soil physical properties (Samouelian et al. 2005). It has been also applied to detect the effects of tillage in soil physical properties (Besson et al. 2013; Rossi et al. 2013), to describe soil tilled layer (Besson et al. 2004), to estimate soil water content (Samouelian et al. 2005; Seladji et al. 2010; Dafonte et al. 2013) and saturated hydraulic conductivity (Farzamian et al. 2015). Electric conduction occurs within the water-filled pores and at the surface of clay particles. Consequently, electrical resistivity would depend on soil bulk density and more generally on soil structural status (Besson et al. 2004).

Dominantly applied to assess the effects of mechanized and tractor pulled agricultural practices on soil structural degradation, extensively reported in literature, the above mentioned methods are also applied in other research contexts such as that of animals wandering over the soil. In fact, compaction is also caused by compressive forces acting on soil under the hooves of livestock or other animals, as it is the case of animal trampling (da Silva et al. 2003). Effects of grazing animals on soil physical properties are described by Drewry et al. (2008). Soil compaction caused by grazing animals through hoof action may be more widespread within the paddocks as compared to that caused by mechanical implements, which is limited to the wheel (Drewry 2006; Sigua and Coleman 2008). This comparison draws the attention to the difference between localized impacts and widespread impacts on soil in an area subject to compressive forces over the ground. Actually, data lack in literature regarding the effects of draft animals acting in timely tillage operations. Under these circumstances, it can be hypothesized, but it is far from being fully parameterized, that the moving load represented by animals pulling tillage equipment determines a localized impact with discontinuous spatial pattern. Besides, animal traction operations are performed at a lower speed and with a lower load over the soil, when compared with tractor pulled operations, these two factors affecting soil structural degradation under mechanized conditions. For mechanized soil management, speed depends on the type of implement to get a better result: 5 to 7 $km.h^{-1}$ for a moulboard plough or 5 to 10 $km.h^{-1}$ for a cultivator (Ortiz-Cañavate 2012). However, these factors were not yet extensively appraised in their consequences for soil compaction under animal traction. This is a relevant gap of information in the context of mountain agriculture, where animal traction played, and may keep playinga major role, towards the sustainability of these areas, taking into account its three pillars namely: environment, economy and society.

Technological improvement and mechanization of agriculture during the 20th century in Europe, together with the depopulation of rural areas following steadily migration to urban areas, greatly reduced the need of working animals (Ivankovic et al. 2002; Beretti et al. 2005). This process was somewhat slower in the southern European countries due to a late industrialization, but soon followed the European trend, mainly in the last three decades (Aranguren-Mendez et al. 2001; Colli et al. 2013). In spite of this ongoing process, in mountain areas of Northeast Portugal, working animals, such as donkeys and, in a much smaller scale, cattle, are still kept for draft purposes. Here, draft animals are a major source of energy in these small-holding farming systems, essentially meeting power demands of agricultural activities. They also play a key role in the social and economic support of a declining and ageing human population, considering their unique characteristics for sustainable animal production under such environments (Hoffmann 2010). Mostly native breeds, these animals are nowadays threatened (or have already disappeared from some mountain areas), according to their risk status classification, based on the actual low number of individuals recorded in the official studbooks (Colli et al. 2013; FAO 2007). Especially in mountain areas, the actual trend towards the full replacement of animal by motorized traction in farming operations represents not only a major loss of biodiversity, but also the loss of historic, cultural and genetic heritage (Beja-Pereira and Ferrand 2005; Hodges 2006). The preservation of livestock breed diversity should be regarded as a genetic insurance especially when considering the increasing environmental changes. Hence there is need for adaptation to an ever changing environment, resistance to diseases or response to market requirements (Simianer 2005; Bennewitz et al. 2006). Along with the reasons referenced above, the conservation of endangered local breeds calls for sustainability in support of the local economies and human populations in marginal areas, as well as protection of ecological value, allowing improvement and preservation of the agro-biodiversity (Gandini and Villa 2003).

This paper is grounded on the above set of arguments on the actual and future role of draft animals in mountain farming systems as key elements of their sustainability. The research takes into consideration the extensive lack of data regarding the impacts on soil compaction due to tillage operations performed with animal traction. An experimental field research was carried out in NE Portugal in order to fill this information gap, and support foreseen developments for preserving mountain agri-environments. The research specifically aimed at: (i) comparing a field plot, tillage operations performed with two types of draft animals (cows and donkeys), their effects on soil physical properties in relation to soil compaction status; (ii) testing the performance of ERT in detecting changes in near surface soil physical properties as affected by the tillage treatments tested.

2 Material & Methods

2.1 Study area

The agricultural plot where the study was carried out is located at Vale de Frades, village, in the Municipality of Vimioso in NE, Portugal (41°38'46.3 "N 6°29'47.7" W (Figure 1). The soil of the site was classified as Dystrict Regosol according to the World Reference Base for Soil Resource (WRB, 014) developed over a slate bedrock, with loam texture (15% clay content) and low organic matter content (1.8%) (Agroconsultores e Coba 1991). The agricultural field is flat and homogeneous with an average elevation of 700 m above sea level. The plot has been used for mixed farming including cereal or forage in the winter period and potatoes in summer. The climate of the region is Csb – Warm Summer Mediterranean climate according to the Köppen climate classification (Köppen 1936). The average precipitation is about 800 mm per year with a typical Mediterranean seasonal distribution (hot dry summers) and the average annual temperature is around 12 °C % (Agroconsultores e Coba 1991).

2.2 Tillage operations

The field experiment was conducted in June 2015 during an extreme hot day, the soils showing gravimetric water content of 8.08% ±0.041.

The plot was divided in 5 sub-plots of 30 m x 3m (Figure 2) in order to apply the treatments. Three different implements were considered (Figure 3), a Roman plough that turns over the soil; a 5 tine cultivator and a 9 tine cultivator, which are bound to cut the soil, the first and second for use with animal traction, the third one for use with a tractor. Five different treatments were applied (Figure 3): Tractor + Cultivator (Treatment 1), Cows + Roman plough (Treatment 2), Cows + Cultivator (Treatment 3), Donkeys + Roman plough (Treatment 4) and Donkeys

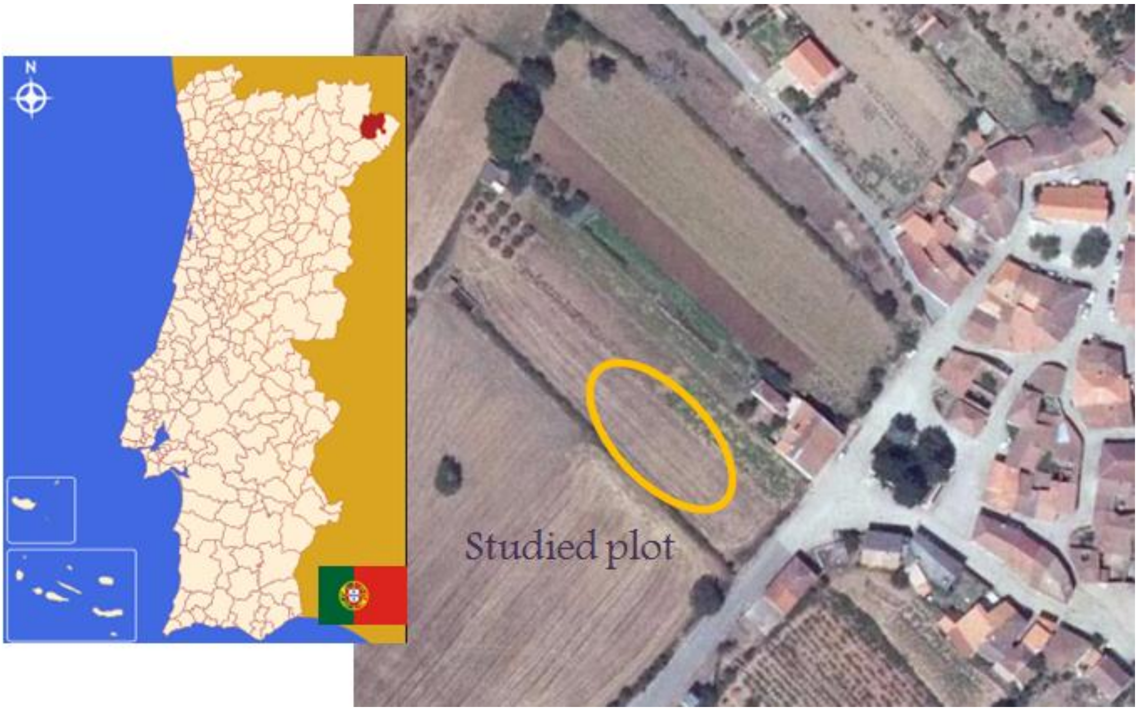

Figure 1: Location of the experimental site: the studied plot in Vale de Frades village, in the Municipality of Vimioso, NE Portugal

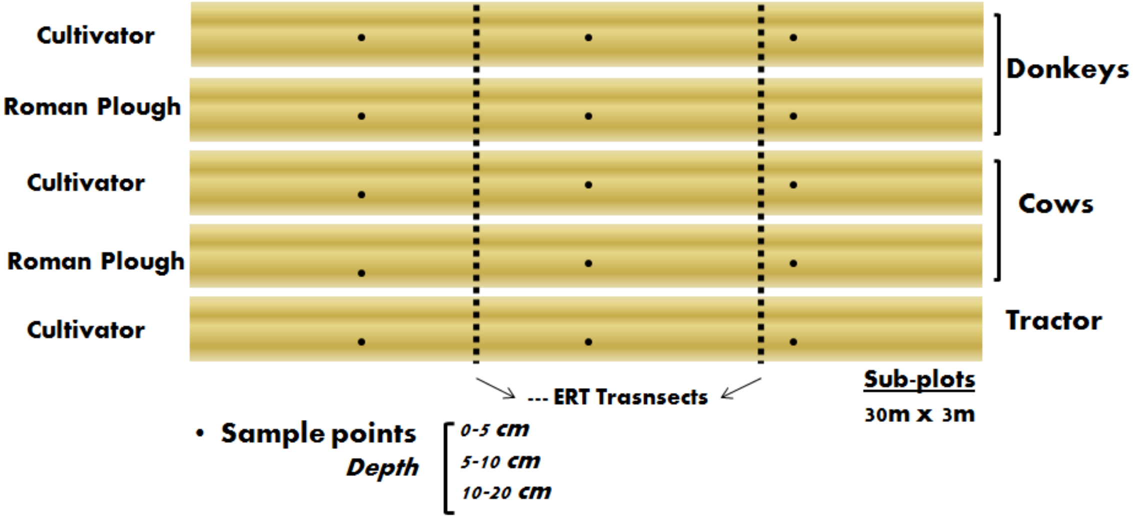

Figure 2: Field experiment scheme: treatments, soil sampling and ERT transects

+ Cultivator (Treatment 5). Each treatment comprised a two-way passage along the plot length, performed on the respective sub-plot.

The tractor used in this study was a New Holland TN 75 A (2745 kg) – 53.7 kW tractor with 7.50 - 16 front tires and 14.9 - 28 rear tires. The animals used in this study were: a pair of adult working *Mirandês* jennies and a pair of adult working *Mirandês* cows, with a combined weight of the animals of approximately 700 kg and 1200 kg, respectively. Both pairs were driven by the respective owners, following the indications of the researchers, ensuring the correct passage of the animals and equipment in the subplots defined.

The cultivator pulled by the tractor was a 9 tine cultivator with a weight of 360 kg, and a ground clearance 0.46 m. The working width was 2.20 m and the working depth ranged from 0.15 m to 0.30 m. The cultivator pulled by the animals was a 5 tine cultivator with scarifier shovels with a weight of 30 kg. The Roman plough pulled by the animals had a covering shovel and it weight was 30 kg.

Figure 3: Traction means and implements used in the field experiment: the 9 tine cultivator pulled by a tractor (A), the *Mirandesa* cows (B) and *Mirandês* donkeys (C), the 5 tine cultivator (D), and the roman plough (E)

2.3 Soil sampling and analysis

Undisturbed soil samples were taken using a 100.10^{-6} m^3 core, in each one of the 5 subplots where treatments under test were applied, at 3 depths (0-0.05 m, 0-0.10 m, 0.10-0.20 m), at 3 points along the subplots (in the middle and about 7 m from the edges). Bulk density (BD), porosity (P), soil water content (SWC) and coarse fragments (CF) were determined in a total of 90 samples, 45 collected in the morning before the treatments and 45 in the afternoon after the treatments (Figure 2). Moreover, using also 100.10^{-6} m^3 cores at the collection points indicated above, 30 undisturbed soil samples (15 samples before and 15 samples after the operations) were taken at 0-0.05 m in order to assess surface permeability or, synonymously, saturated hydraulic conductivity (Ks).

Soil moisture was assessed gravimetrically (oven-dry soil at 105° C for 48 h), bulk density being determined with the oven-dry soil mass and the cylinder volume. Porosity was calculated assuming 2.65.10^3 kg·m^{-3} as particle density. Oven-dried samples were sieved (2 mm) and coarse fragments mass determined.

Soil saturated hydraulic conductivity was measured in a lab close-circuit constant head permeameter, measurements starting after 48 h saturation and performed at 24 h intervals in 4 sequent days. Initial permeability was taken as the first measurement after saturation and final permeability as the average of the last 3 measurements, the former not being considered in data analysis. Soil core area and length were 20.10^{-4} m^2 and 0.05 m, respectively. Mean water head during measurements was 0.027 m ±0.32.10^{-2}. The measured water level difference was used for every sample to calculate the saturated hydraulic conductivity (Ks), according to Hillel (1998):

$$Ks = \frac{V * L}{A * t * h}$$

V = volume of water flowing through the sample (cm^3).
Ks = permeability coefficient or “K-factor” (cm/h).
h = water level difference between inflow and outflow through sample cylinder (cm).
L = length of the soil sample, constant (cm).
A = cross-section area of the sample, constant (cm^2).
t = time used for measuring the water volume V (h).

Values obtained and expressed as described above for soil surface saturated hydraulic conductivity were classified according to USC/USDA classification.

2.4 Tomography

Electrical Resistivity Tomography (ERT) is an active geophysical method which measures the electric potential differences at specific locations while injecting a controlled electric current at other locations. ERT survey was carried out using a Terrameter SAS 1000 device (ABEM). In order to assess tractor and animals passage and tilling, ER was measured in a long 2 transects perpendicular to the traffic direction (Figure 1), using 40 steel electrodes spaced 0.4 m, the total length of each profile line was 16 m, using Wenner array, the effective depth was 3.39 m. ERT measurements were carried out: before and after the operations, in each transect. The data obtained during ERT field measurements were classically presented as apparent resistivity pseudo-sections. The resistivity data obtained from the field were then inverted using RES2DINV 3.59 software (Loke 2010), which is based on the regularized least-squares optimization method (Loke and Barker 1996).

2.5 Statistics

Basic descriptive statistics were calculated for each data set of the soil physical properties determined. Two-way ANOVA (using factors timing – before and after tillage operations, and treatment – the defined combinations traction vs. implement) were performed to statistically compare these effects on each soil physical property (SWC, BD, P, CF and Ks), at each sampling depth, and ERT measurements at 0.8 m and 0.23 m depths, followed by Tukey mean separation method, when applicable.

3 Results & Discussion

The results of the physical soil properties (by depth) which were assessed before and after tillage operations are shown in Table 1 and Table 2. Soil water content (SWC) showed a statistically significant decrease of the global plot average, at 0-0.05 m depth, from 9.4% to 5.8%, when comparing the sample collection timing (in the morning, before operations, and in the afternoon, after operations), affected by the high temperature prevailing along the day. SWC showed also statistically significant differences

Table 1: Comparison of treatments mean (± standard deviation) of the soil physical properties studied, before and after tillage operations, by depth: A 0-0.05 m, B 0.05-0.10 m and C 0.10-0.20 m (SWC – soil water content; BD – bulk density; P – porosity; CF – coarse fragments)

A

	SWC (%)		BD (g/cm^3)		P (%)		CF (%)	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Treatment 1	11.83±3.58	6.32±6.34	0.97±0.03	1.12±0.04	63.49±1.06	57.93±1.65	18.78±2.01	21.70±7.56
Treatment 2	8.41±3.59	3.02±2.72	1.07±0.21	1.17±0.01	59.71±7.98	55.87±0.29	18.08±2.93	19.72±0.51
Treatment 3	10.47±5.82	4.26±1.27	1.05±0.05	1.13±0.03	60.31±1.71	57.44±1.01	18.17±1.71	24.89±4.45
Treatment 4	6.73±0.50	6.60±4.77	1.12±0.05	1.25±0.08	57.82±1.97	52.87±3.01	21.52±1.61	24.93±4.60
Treatment 5	9.77±3.97	8.91±1.37	1.15±0.16	1.19±0.04	56.77±5.99	55.89±1.40	22.05±5.34	26.50±7.29

B

	SWC (%)		BD (g/cm^3)		P (%)		CF (%)	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Treatment 1	16.52±1.04	10.27±7.31	1.06±0.03	1.02±0.05	59.81±1.05	61.45±1.93	17.88±1.97	17.48±0.56
Treatment 2	15.33±3.27	9.55±2.36	1.00±0.07	1.12±0.04	62.08±2.67	58.31±1.46	17.76±3.37	24.44±5.98
Treatment 3	15.71±0.53	10.48±2.88	1.00±0.06	1.08±0.05	62.19±2.14	59.35±1.82	16.91±1.95	18.94±0.50
Treatment 4	15.37±0.91	13.13±2.69	1.16±0.10	1.16±0.18	56.33±3.95	56.11±6.95	21.29±6.42	21.14±2.47
Treatment 5	15.30±1.47	15.53±1.82	1.11±0.07	1.05±0.07	58.27±2.78	60.58±2.48	26.29±4.09	18.89±1.55

C

	SWC (%)		BD (g/cm^3)		P (%)		CF (%)	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Treatment 1	17.45±1.04	14.75±1.81	1.00±0.03	1.05±0.06	62.26±1.23	60.51±2.08	21.51±3.25	23.11±1.54
Treatment 2	18.03±1.38	12.77±5.29	1.26±0.10	0.98±0.08	52.43±3.61	62.74±3.10	17.71±0.97	18.91±1.81
Treatment 3	16.29±0.93	12.51±2.95	1.09±0.10	1.04±0.09	58.82±3.79	60.67±3.23	18.41±3.03	20.39±3.17
Treatment 4	15.09±0.83	15.33±1.25	1.17±0.04	1.21±0.14	56.03±1.48	54.71±5.47	20.62±3.51	22.31±1.87
Treatment 5	17.63±2.02	17.05±1.64	1.23±0.05	1.11±0.15	53.59±2.02	58.46±5.63	25.61±2.72	22.57±3.60

Table 2: Comparison and classification of treatments mean (± standard deviation) saturated hydraulic conductivity (Ks), before and after tillage operations, at 0-0.05 m soil depth

Ks (cm/h)				
	Before	**Classification**	**After**	**Classification**
Treatment 1	26.04±8.40	Very Fast	13.33±4.18	Fast
Treatment 2	13.14±9.05	Fast	7.67±6.51	Mod. Fast
Treatment 3	23.73±26.92	Fast	5.52±1.66	Moderate
Treatment 4	24.32±13.25	Fast	22.29±5.01	Fast
Treatment 5	10.16±2.05	Mod. Fast	4.61±2.52	Moderate

between the surface layer and deeper soil depths, as the global plot average of the 0-0.05 m depth was 7.63%±4.17 while for the 0.05-0.10 and 0.10-0.20 m depths the average was 13.72%±3.59 and 15.69%±2.70, respectively. Taking into account the different treatments, SWC decreased in all of them after operations for the 0-0.05 m depth and in 4 treatments for the 0.05-0.10 m depth, except in Treatment 5 (Donkeys + Cultivator) where SWC values were unchanged. Bulk density (BD) increased and Porosity (P) decreased after operations in the 5 treatments for the 0-0.05 m depth. Tillage operations may produce soil compaction which alters soil structure by smashing aggregates or merging them into bigger fragments, increases BD and decreases the number of coarser pores (Horn et al. 1995; Delgado et al. 2007). CF measured before treatments was considered moderate in the studied soil. CF increased in the 5 treatments for 0-0.05 cm depth, 19.72% before treatments to 23.55% after treatments. Treatment 3 (Cows + Cultivator) was the treatment which caused the highest increment (18.17% to 24.89%) and Treatment 2 (Cows + Roman plough) which caused the lower one (18.08% to 19.72%). These results were expected due to the more pronounced effects of tillage operations in the surface layer, clearly corroborated by field evidence, expressed not only in structural changes and compaction but also in particles grain size distribution in the topsoil profile.

Soil compaction caused by tillage operations may also lead to reduce permeability to water (Mooney and Nipattasuk 2003). After operations, a consistent decline on saturated hydraulic conductivity or permeability (Ks) was observed in all treatments, yet not statistically significant, leading to a drop in the class of the average in 4 out of the 5 treatments (except in Treatment 4), down to two classes in Treatment 3 (Table 2). Following Ks classification by USC/USDA, before operations 100% of the samples fell on the moderately-fast and higher classes, whereas after operations only 60% of the samples were classified similarly, the remaining 40% ranking as moderate or moderately slow (Figure 4a). Comparing animal with motorized traction, results show that samples

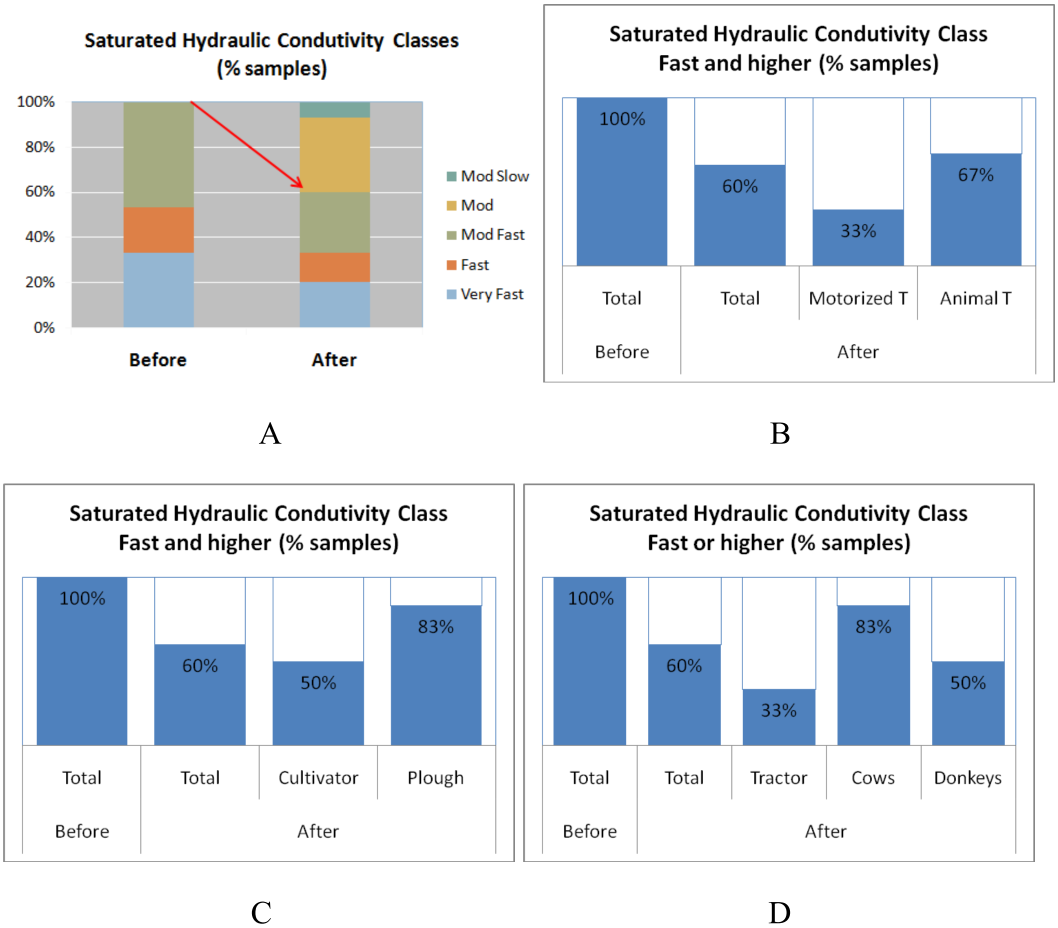

Figure 4: Effects of treatments on Saturated Hydraulic Conductivity class distribution at surface soil layer (0-0.05 m depth): A – Operations global effect; B – Motorized and Animal Traction effects; C – Implement effect; D – Traction mean effect

with Ks classified as fast and higher, in the tractor sub-plot, were in a far lower proportion than the reference after operations (Figure 4b). In contrast, the proportion of samples taken in the animal traction sub-plots with Ks classified as fast and higher was slightly larger than reference after operations (Figure 4b). Seemingly, the detrimental effect on surface soil saturated hydraulic conductivity caused by the tractor pass was not verified on animal traction treatments, globally considered. In what concerns the effect of implements applied in the experiment, in sub-plots where cultivators were used, the proportion of samples with Ks classified as fast and higher was below the reference, while in those where the Roman plough was used, that proportion raised (Figure 4c). This result is relevant because the Roman plough is specifically pulled by animals. Evaluating the effect on Ks of traction means (tractor, cows and donkeys), it was observed that samples classified as fast and higher decreased more after operations in the tractor and in the donkeys sub-plots than in the cows sub-plots. (Figure 4d). For the range of traction means that were tested in the experiment, cows rank last in terms of impact on surface soil hydraulic conductivity and donkeys were less performing to this respect, a result not consistent with their comparably lower weight. Short-scale soil variability, not assessed in this study, may help explaining these results. Additionally Figure 5 depicts the relative changes in bulk density (BD) observed after operations in the 0-0.05 m soil depth. BD increased after operations in all treatments, averaging globally + 10%. The increase was much higher in the tractor sub-plot than in those where animal traction was used. Relative changes in BD after operations were similar when comparing treatments using cows with donkeys, or applying different implements. It should be noted that relative changes after operations calculated with Ks values were sharper than in BD, averaging globally – 46%, meaning that structural disturbance by tillage operations is greatly reflected in pore arrangement and, therefore, in water flow velocity through the soil. Results obtained for BD and Ks are globally consistent with surface soil disturbance observed after tillage operations, in this study quantified for the specific case of those performed with animal traction.

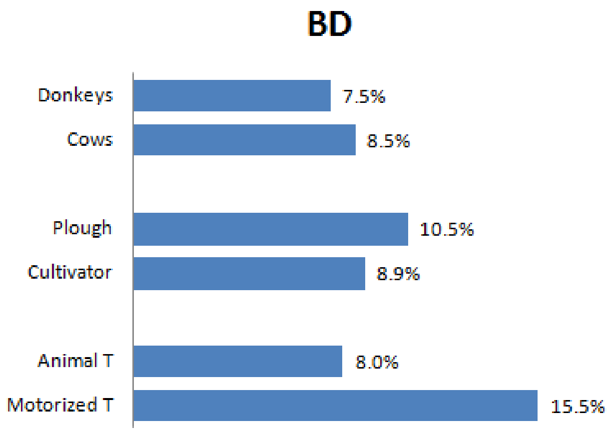

Figure 5: Relative changes in Bulk Density at 0-0.05 m depth after tillage operations: Traction, Implement and Animal effects

Electrical Resistivity Tomography (ERT) results are presented in Figure 6. The distance between the 2 transect was 16 m and the plot is a mixed-farming field, regularly cultivated, a priori considered homogeneous. However, the 2 transects showed important differences in ERT measurements. The first transect presented an average of 718.83 Ω•m before operations, and 706. 67 Ω•m after operations , while the second transect showed an average of 522.88 Ω•m before and 506.44 Ω•m after operations. SWC in the sample area of the second transect averaged 14% , against 11% in the sample area of the first transect; which may explain the significantly lower ERT results in the second transect. In order to assess the effects caused by tractor tyres track and animal pass in ERT, measurements obtained at 0.08 m and 0.23 m were studied (Figure 7). At 0.08 m depth, the mean ER in the first transect decreased from 727.35 Ω•m before to 690.12 Ω•m after operations, while in the second transect it decreased from 548.94 Ω•m to 521.73 Ω•m. The mean ER in the first transect at 0.23 m decreased from 709.93 Ω•m to 694.42 Ω•m and in the second one from 545.90 Ω•m to 522.08 Ω•m. Besson et al. (2004, 2013) found that in the tractor tyre track compacted areas ER values are lower than in the non-compacted ones. In this study, however, the decrease in ER after operations was not statistically significant at the two depths, which can be explained by the fact that measurement were taken in a warm day, and the variation of SWC between the morning, (9.4% before operations), and in the afternoon (5.8% after operations) may affect the ERT measurements. Moreover, with that low moisture content the soil was less prone to compaction caused by tractor and animal pass over ground. The authors found in a similar study with tractors, and the soil at field capacity, that ER suffered a reduction of about 35% (at 0.05 m) in the compacted areas (tyre tracks), comparing measurements before and after tractor pass (García-Tomillo et al. 2015). At 0.08 m depth, the mean ER values of most treatments decreased in the two transects, except in the Cows + Roman plough treatment (Treatment 2) in transect 1, the same pattern being found at 0.23 m depth (Figure 7).

Figure 8 depicts the relative changes in ERT (A) at 0.08 m depth (A) and at 0.23 m after the tillage operations. At 0.08 m depth, treatments using cows caused only 1% ER

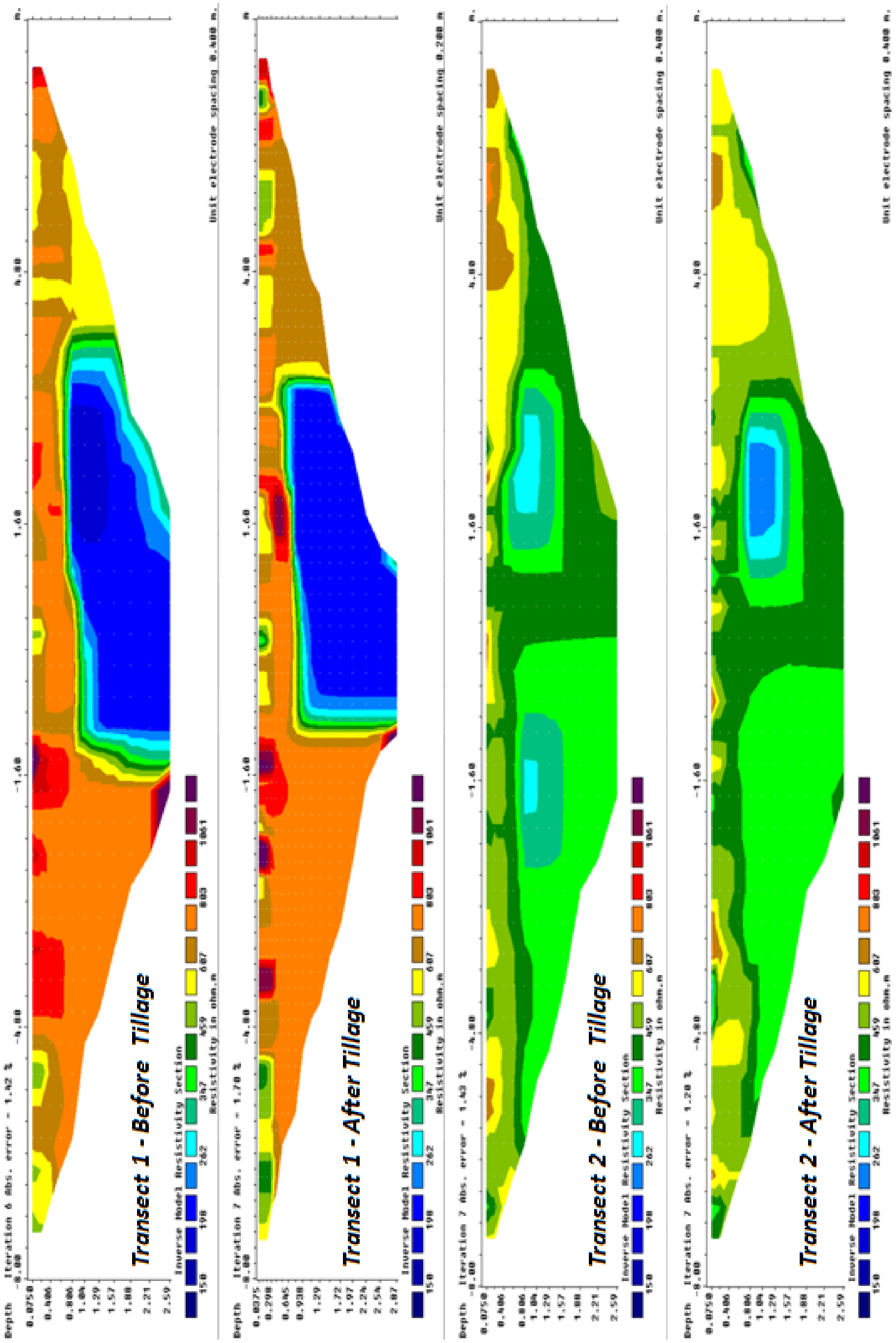

Figure 6: Electrical Resistivity profiles in the 2 transects (using inverted RES2DINV), before and after operations

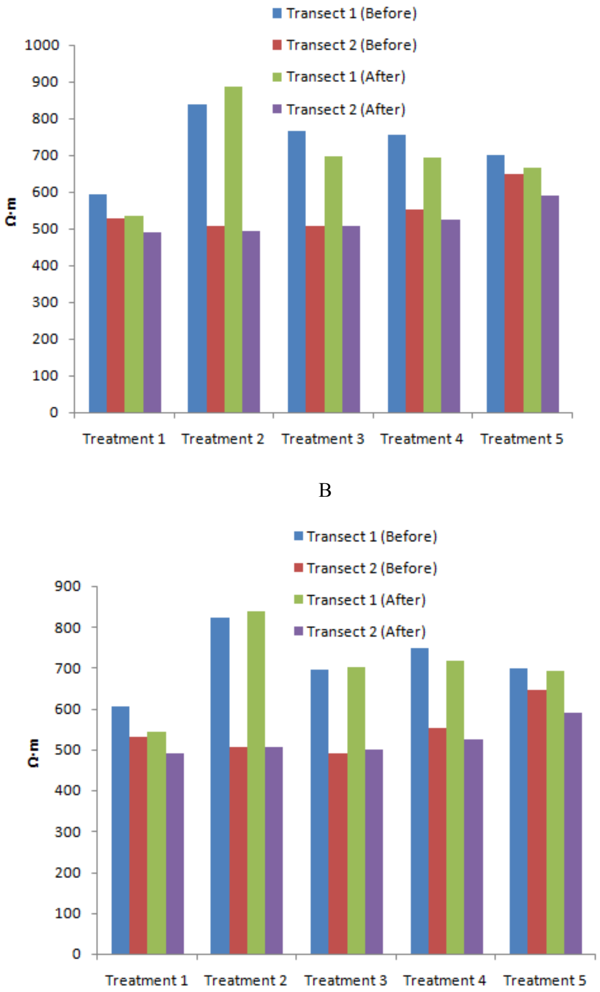

Figure 7: Electrical Resistivity means in the 2 transects and the 5 treatments, before and after operations, at 0.08 m (A) and 0.23 m (B) soil depths

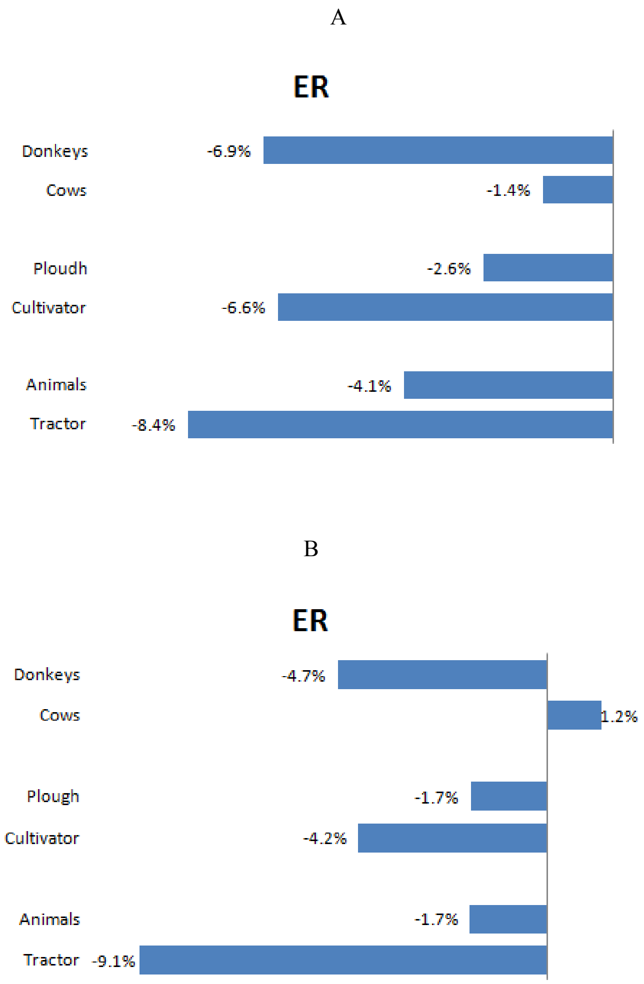

Figure 8: Relative changes in ER after tillage operations (A) at 0.08 m depth (B) and at 0.23 m

decrease as compared with those using donkeys where ER change reached – 7%, the same value being found in treatments applied with cultivator, and – 3% in those applied with the Roman plough (pulled by animals). Comparing animal vs. motorized traction, the latter caused a ER decrease of 8% against a smaller change of – 4% for animal traction. Although with a pattern of results similar to that described, for 0.23 m depth, it can be observed that the effect of animal traction treatments on ERT changes was globally lower than at 0.08 m depth (– 2%) but, on the contrary, the tractor treatment still affected ERT measurements at this depth with the highest relative change (– 9%). Traffic over the soil and tillage lead to an increase of BD (and a decrease of porosity) to which corresponds a decrease in ER (Besson et al. 2004) and the ERT data obtained were consistent with that. These results are also consistent with the consequences of soil disturbance induced by farm operations to water flow through the soil, as assessed by saturated hydraulic conductivity. However, the relationship between ER and BD can also be weakened when additional time-dependent variables interact with soil electrical resistivity, such as the soil moisture. Moreover, ERT measurements allowed detecting effects caused by operations performed with motorized traction, reaching deeper in soil than those with animal traction.

4 Conclusions

Assessment of soil physical properties allowed estimating the impacts caused by the different treatments compared in the experiment, focused on animal vs motorized traction in an agricultural plot. Results suggest the potential of animal traction as an option for mountain agri-environments, yet requiring deeper research to soundly ground its assets. In fact, in spite of the differences in bulk density and saturated hydraulic conductivity changes associated to farm operations, that clearly indicate lower impact on soil when performed with animal traction as compared with those performed with motorized traction, the experiment was not statistically conclusive. Additionally, outcomes of the experiment showed the need for further research inorder to clear differentiate the impacts induced by cows from those induced by donkeys, the two most relevant draft animal species in the Portuguese mountain areas.

Results indicate that Electrical Resistivity Tomography (ERT) was able to detect the disturbance caused by tillage operations on soil physical status under field experimental conditions, even though lacking statistical significance ERT measurements were broadly consistent either with the field perception of operations impact on soil or with bulk density and saturated hydraulic conductivity data obtained. Time-dependent variables, as soil moisture, and short-scale soil spatial variability, are hardly controlled in the field, and they may extensively condition ER measurements when farm operations inducing light soil disturbance are compared, and this was the case of animal traction treatments tested in the experiment. However, heavier soil disturbance is better reflected in ER changes so as to allow differentiating tractor pulled operations from those pulled by draft animals, and detecting their deeper reaching effects in soil.

Due to the lack of experimental research on the topic, results obtained in this study are regarded as a starting point to better understand the impacts of animal traction in a key resources for mountain farming systems, as it is the case of soil. The promising results obtained open not only a challenging research path but should also raise awareness for the potential contribution of animal traction to ecosystems services provided by mountain agriculture. Their valorization should, as well, have the adequate consideration within the policy framework being built up for mountain agri-environments sustainability.

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