

# The Iberian Montado/Dehesa in face of climate change: Soil effects (bulk density and hydraulic conductivity)

## O Montado/Dehesa Ibérico face às alterações climáticas: Efeitos no solo (massa volúmica aparente e condutividade hidráulica)

Rui Bajouco<sup>1,\*</sup>, Cláudia Penedos<sup>1</sup>, Jorge Velez<sup>2</sup>, Sandra Velez<sup>2</sup> and Carlos Alexandre<sup>1,2</sup>

<sup>1</sup> MED – Mediterranean Institute for Agriculture, Environment and Development, University of Évora, Pólo da Mitra, Apartado 94, 7006-554 Évora, Portugal

<sup>2</sup> Department of Geosciences, University of Évora, Largo dos Colegiais, nº 2, 7004-516 Évora, Portugal

(\*E-mail: rnbst@uevora.pt)

<https://doi.org/10.19084/rca.28395>

### ABSTRACT

A sustainable management of the soil is an imperative for all land use systems. The LIFE Montado-Adapt project proposed to implement several soil conservation and protection practices, in order to fight landscape and climate change in the Montado/Dehesa Iberian agro-silvo-pastoral system. This work showcases an evaluation of the effect of some soil protection measures, such as soil reduction/zero tillage and improvement of the pastures, in 4 pilot areas of the project, on 2 soil physical parameters: soil hydraulic conductivity ( $k_s$ ) and soil bulk density (BD). After 3 years, a  $k_s$  decrease was observed, 22% (0.61 Log<sub>10</sub>  $k_s$ ), being more accentuated in areas with livestock cattle exist, reaching to 37% (0.83 Log<sub>10</sub>  $k_s$ ). Contrary to  $k_s$ , BD increased in areas where livestock pasture occurs, between 12 and 4%, a consequence of livestock trampling. In areas where pastures do not occur, a decrease was observed, 3 and 4%, consequence of the no-tillage policy of soils, which promotes a better root development, accumulation of organic matter and soil aggregation. Even after 3 years, the soil conservation and protection practices seem to promote changes both  $k_s$  and BD of the soils.

**Keywords:** cattle traffic, soil compaction, under trees canopy, open field, sustainable soil management.

### RESUMO

A gestão sustentável do solo é um imperativo para todos os sistemas de uso do território. O projeto LIFE Montado-Adapt propôs-se a implementar medidas de conservação e proteção do solo, por forma a combater a alteração da paisagem e as alterações climáticas do sistema agro-silvo-pastoril Montado/Dehesa Ibérico. Neste trabalho avaliou-se o efeito de medidas de conservação do solo, como redução/não mobilização e a melhoria das pastagens, em 4 áreas piloto do projeto, sobre 2 características físicas do solo: Condutividade hidráulica do solo ( $k_s$ ) e massa volúmica aparente (MVA). Ao fim de 3 anos, observou-se a diminuição de  $k_s$ , na ordem dos 22% (0.61 Log<sub>10</sub>  $k_s$ ), sendo mais acentuada nas áreas com gado de pastagens chegou aos 37% (0.83 Log<sub>10</sub>  $k_s$ ). Ao contrário do  $k_s$ , a MVA aumentou nas áreas onde ocorre gado pastagens, entre 12 e 4%, sendo possível consequência do pisoteio do gado. Nas áreas onde não ocorrem pastagens, a diminuição, na ordem dos 3 e 4%, consequência da não mobilização dos solos, promovendo um maior enraizamento vegetal, acumulação de matéria orgânica e agregação do solo. As práticas de conservação e proteção do solo parecem promover alterações, ao fim de 3 anos tanto na  $k_s$  como na MVA.

**Palavras-Chave:** pisoteio do gado, compactação do solo, sob a copa das árvores, áreas abertas, gestão sustentável do solo.

## INTRODUCTION

According to the European Environmental Agency, the agro-silvo-pastoral Montado/Dehesa systems, are classified as High Nature Value Farming Systems (Paracchini *et al.*, 2008). Combining biodiversity and the pursue of farming on certain types of land and the conservation of regional farming systems (Berrahmouni & Regato, 2007), the Montado/Dehesa systems through agriculture and forestry are targets of public policies concerning the provision of goods supply (Pinto-Correia *et al.*, 2011). Over the last decades the Montado/Dehesa systems have faced several perturbations, such as intensification and/or extensification, that have led to the landscape change (Pinto-Correia, 1993) and served, both ways, as a menace to their ability for goods supply. Covering nearly 4 million ha of the southwestern Iberian Peninsula and being a system of high importance in the southern European region, due to its economic, social and environmental value; the conservation and management optimization are of great concern in an era of climate change and need of maximum optimization of goods production (Pinto-Correia *et al.*, 2011).

Measures for soil conservation and protection, aiming to fight the effects of climate change, such no/reduced-tillage and bio-diversification/improvement of pasture plants were applied in 12 pilot areas distributed between Alentejo (Portugal), Extremadura and Andalusia (Spain), and monitored between 2018 and 2021 (EU-Life, 2016). The LIFE Montado-Adapt project aimed to “promote the adaptation of the Montado/Dehesa system in Portugal and Spain...to mitigate the consequences of climate change...” (LIFE Montado-Adapt, 2022), by evaluating the effects of such soil conservation practices regarding the soil carbon sequestration, promoting water infiltration and soil water retention.

This work presents an assessment of the changes of soil saturated hydraulic conductivity ( $k_s$ ) and bulk density (BD), prior and after the soil conservation practices took place, between 2018 and 2021, in 4 of the project pilot areas.

## MATERIALS AND METHODS

### Study sites

Pilot areas used in this work were (Life Montado-Adapt, 2022): Dehesa of Guijo, Malpartida de Plasencia, Cáceres, Spain (n=6, L3); *Dehesa of Boyal de la Piedra*, Villasbuenas de Gata, Cáceres, Spain (n=6, L4); National Forest of Cabeção, Mora, Portugal (n=8, L8); Ribeira Abaixo, Santa Margarida da Serra, Grândola, Portugal (n=6, L12).

In the four showcased pilot areas, measures such reduced or no tillage, diversified plantation and improved pastures took place, as described by the LIFE Montado-Adapt (2022). In Table 1 are presented some general characterization of the presented pilot areas.

**Table 1** - General conditions and characteristics of the presented pilot areas (LIFE Montado-Adapt, 2022)

pilot area	L3	L4	L8	L12
plot (ha)	6.15	3.8	3.2	4.08
cattle	+	+	-	-
Soil textural classe	Loam	Sandy-loam Loamy-sand	Sandy	Loam Silty-loam
Tree species	<i>Quercus rotundifolia</i> L. <i>Quercus suber</i> L.			

### Soil sampling and analysis

Random sampling occurred in two moments the first between January-March of 2018 and the second between June and July of 2021. The soil sampling involved two strata: under the canopy of trees (UC) and open field (OF), outside the canopy influence. Each pilot area had six to eight sampling sites. In each site, two collection points were carried out along the N-S axes, about 1 m from the trunk under the tree canopy and about 2 m apart from each other in the open field areas, with cylinders, of 100 cm<sup>3</sup>.

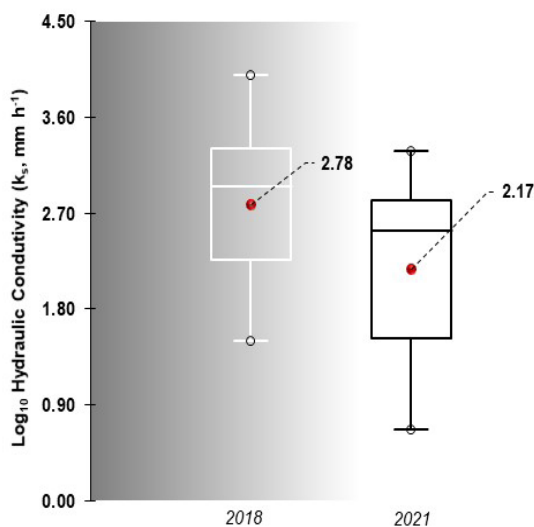
The cylinder samples were used to determine the soil bulk density, BD, (g cm<sup>-3</sup>) and the saturated hydraulic conductivity (CaCl<sub>2</sub> 0.005M),  $k_s$  (mm h<sup>-1</sup>), in a laboratory permeameter using the Eijkelkamp® apparatus, with the constant head method.

Soil  $k_s$  values were  $\log_{10}$  transformed to overcome environmental variability and obey normality assumptions. Statistical analysis for data description, means T-test ( $\alpha=0.05$ ) were performed using the XLSAT Microsoft® software.

## RESULTS AND DISCUSSION

### Soil Hydraulic conductivity, $k_s$

The observed  $k_s$  decreased on average 22%, since the first sampling in 2018, Figure 1, with statistical significance ( $\alpha=0.05$ ,  $p=0.005$ ,  $n=26$ ). With the L3 and L4 areas showing the highest soil  $k_s$  reduction, 37% and 30% since 2018 (2.25 and 2.35  $\text{mm h}^{-1}$ ), respectively. It must be noted that these areas are subjected to high livestock grazing pressure, which has been shown to be a cause of soil compaction and soil permeability reduction (Chandler *et al.*, 2018).

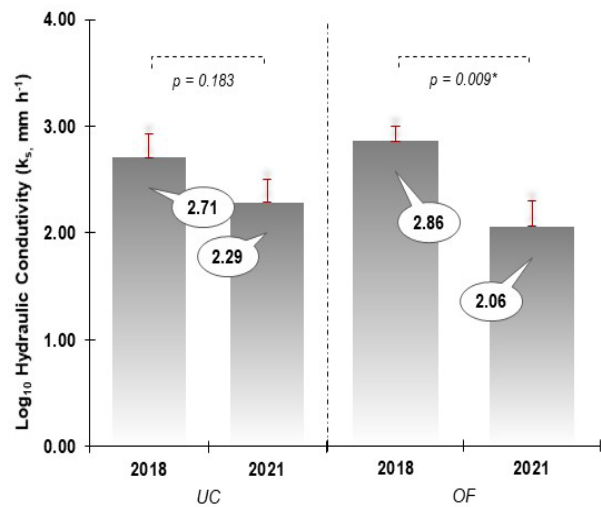


**Figure 1** - BoxPlot's representation of the soil hydraulic conductivity,  $k_s$  ( $\text{Log}_{10}$ ,  $\text{mm h}^{-1}$ ), of the 2018 and the 2021 sampling, the means are in bold.

Nevertheless, L8 and L12 areas also presented a decrease, 16 and 13% (2.84 and 3.46  $\text{mm h}^{-1}$ ), respectively, since 2018. In these cases, the reduced or even no tillage management may have a significant role, especially in L8, where the soil samples are of sand texture. Although seasonal effects on  $k_s$  (and also on bulk density) are not fully understood, they may have played a role in results obtained

(Hu *et al.*, 2012). However, it can be relevant that higher reduction in  $k_s$  was observed in the L3 and L4 areas, which are grazing areas.

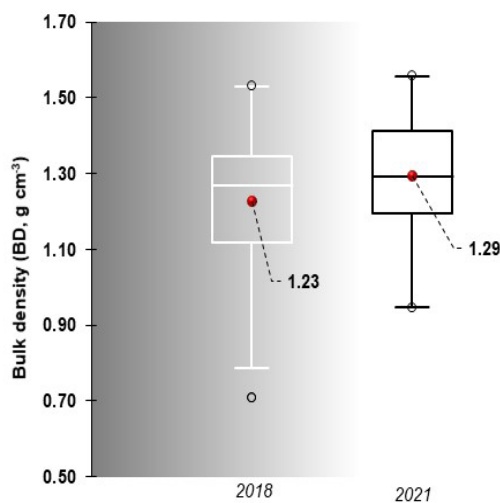
When assessing the changes in  $k_s$  values under and out of tree canopy influence, although there was a trend for a decrease in all pilot areas, the differences were only statistically significant in the OF areas, Figure 2, where a decrease of nearly 28% was observed. This stresses that soils in OF areas are more prone to stand negative impacts related to cattle, people and machinery traffic, namely due to potentially more traffic intensity in these areas, among other factors.



**Figure 2** - Bars and standard errors of the effects of the soil conservation practices system implantation on soil hydraulic conductivity,  $k_s$ , under (UC,  $n=13$ ) and outside (OF,  $n=13$ ) of tree canopy influence ( $*\alpha=0.05$ , significance level).

### Soil Bulk Density, BD

The soil bulk density increased on average 5% since 2018 (1.23  $\text{g cm}^{-3}$ ), Figure 3, but no statistical significance was observed. Wherein L3 area showed the higher increase, 12%, since 2018 (1.16  $\text{g cm}^{-3}$ ) while L4 and L8 only increased 4 and 5% (1.37 and 1.20  $\text{g cm}^{-3}$ ), respectively. However, L12 area decreased 4% in relation to the observed 2018 BD (1.20  $\text{g cm}^{-3}$ ), with no statistical significance. It must be noted that the L8 had an outlier, prompted by the presence of a stone in the collecting cylinder. Without this outlier, the L8 area BD also decreases, nearly 3% ( $n=5$ ).



**Figure 3** - BoxPlot's representation of the soil Bulk density, BD ( $\text{g cm}^{-3}$ ), of the 2018 and the 2021 sampling, the means are in bold.

The average soil BD increase in the L3 and L4 areas may be the effect of the livestock high density in these pilot areas (Chandler, et al, 2018), which is not observed in the L12 and L8 (without the outlier).

## REFERENCES

- Berrahmouni, N. & Regato, P. (2007) - Cork oak forest landscapes: a whole world beyond cork. In: Berrahmouni, N.; Escuté, X.; Regato, P. & Stein, C. (Eds.) - *Beyond cork — a wealth of resources for people and nature: lessons from the Mediterranean*. WWF Mediterranean Programme, Madrid, pp 8–16.
- Chandler, K.; Stevens, C.; Binley, A. & Keith, A. (2018) - Influence of tree species and forest land use on soil hydraulic conductivity and implications for surface runoff generation. *Geoderma*, vol. 310, p. 120-127. <https://doi.org/10.1016/j.geoderma.2017.08.011>
- EU-Life (2016) - *EU-Life public database, European Commission, LIFE-Montado-adpat on LIFE Public Database. MONTADO & CLIMATE; A NEED TO ADAPT*. [https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=5658](https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=5658) [cit. 2022-04-10].
- Hu, W.; Shao, M.A. & Si, B.C. (2012) - Seasonal changes in surface bulk density and saturated hydraulic conductivity of natural landscapes. *European Journal of Soil Science*, vol. 63, p. 820-830. <https://doi.org/10.1111/j.1365-2389.2012.01479.x>
- LIFE MONTADO-ADAPT (2022) - *Montado & Climate, a need to adapt*. <https://www.lifemontadoadapt.com/index.php> [cit. 2022-04-10].
- Paracchini, M.; Petersen, J.; Hoogeveen, Y.; Bamps, C.; Burfield, I. & van Swaay, C. (2008) - *High nature value farmland in Europe: an estimate of the distribution patterns on the basis of land cover and biodiversity data*. European Commission, Joint Research Centre, Institute for Environment and Sustainability, Office for Official Publications of the European Communities, Luxembourg.
- Pinto-Correia, T. (1993) - Threatened landscape in Alentejo, Portugal: the 'montado' and 'agro-other-silvo-pastoral' systems. *Landscape and Urban Planning*, vol. 24, n. 1-4, p. 43-48. [https://doi.org/10.1016/0169-2046\(93\)90081-N](https://doi.org/10.1016/0169-2046(93)90081-N)
- Pinto-Correia, T.; Ribeiro, N. & Sá-Sousa, P. (2011) - Introducing the montado, the cork and holm oak agroforestry system of Southern Portugal. *Agroforestry Systems*, vol. 82, p. 99–104. <https://doi.org/10.1007/s10457-011-9388-1>

There were no observed statistical significant changes in the samples collected in the UC or OF sites, with the soil conservation practices.

## CONCLUSION

The soil conservation practices may already be stressing its effects on soil physical properties, such  $k_s$  and BD, especially in the areas where no livestock pressure exists. The decrease in soil permeability may be an effect of the reduced/no tillage practices, leading to a more stable and aggregated soil superficial horizon, which also promotes a lower BD, due to trees and plant roots development, especially in areas without cattle, people, machinery traffic.

## ACKNOWLEDGMENTS

Rui Bajouco and Claudia Penedos were supported by LIFE15 CCA/PT/000043 MONTADO & CLIMATE; A NEED TO ADAPT.