SJSS
SPANISH JOURNAL OF SOIL SCIENCE

Evaluation of plant waste used as mulch on soil moisture retention

Evaluación de residuos vegetales utilizados como acolchado sobre la retención de humedad de suelos

Avaliação de resíduos de plantas utilizadas como cobertura morta ("mulch") sobre a retenção de umidade do solo

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Received: 25.01.2016 | **Revised:** 03.03.2016 | **Accepted:** 10.03.2016

ABSTRACT

Soil mulching is a technique commonly used in arid and semi-arid areas to prevent erosion and reduce evaporation of soil water. In this study, an experiment quantified the effect of three organic wastes (shredded date palm leaf (*Phoenix dactylifera*), cereal straw, and pine bark) used as mulch on moisture retention in two soils with different textures, S1 (loam) and S2 (silty loam). Each soil was added to a height of 15 cm in square containers 31 cm wide and 20 cm high. The treatments were administered a day after soil saturation with water by covering each soil with 2 cm of mulch. Soils without mulching were used as control treatments. The experiment took place inside a greenhouse until a total loss of soil moisture was achieved. Temperature (T) and relative humidity (RH) values were measured throughout the experiment. During the first 16 days, high and practically constant evaporation was observed in the soils without mulching (1813 g H_2O/day per m^2 in S1 and 1792 g H_2O/day per m^2 in S2). Linear regressions were established to quantify the water loss over time in each treatment. The results show that all three organic byproducts were effective in reducing water loss in both soils, with significant differences observed between pine bark and the other two materials. The palm leaf was as effective as the cereal straw, so it is considered appropriate for use as a mulching material in areas like ours where its abundance and ease of use provide further environmental benefits.

RESUMEN

*El uso de acolchados en suelos es una técnica usada habitualmente en zonas áridas y semiáridas, para evitar los procesos erosivos y reducir la evaporación del agua. En este estudio, se plantea un experimento para cuantificar el efecto de tres residuos orgánicos (hoja de palmera datilera triturada (*Phoenix dactylifera*), paja de cereal (heno) y corteza de pino), como materiales de acolchado, sobre la retención de humedad de dos suelos de diferente textura, S1 (franco) y S2 (franco-limoso), saturados inicialmente con agua. Se emplearon recipientes de 31 x 31 cm de lado y 20 cm de altura, llenándose con suelo los primeros 15 cm. Los tratamientos se establecieron aplicando, a cada suelo, una capa de 2 cm de cada residuo orgánico, teniendo como referencia suelo sin acolchado. El experimento se realizó en invernadero, controlando los valores de Temperatura (T) y Humedad Relativa (HR) ambiente, hasta pérdida total del agua inicial de los suelos. Se observó una elevada evaporación en los suelos sin acolchado, en los primeros 16 días, prácticamente constante de 1813 g agua/día x m^2 en el suelo 1 y de 1792 g agua/día x m^2 en el suelo 2. Se establecieron regresiones lineales para cuantificar la pérdida de agua con el tiempo, en cada tratamiento considerado. Los resultados demuestran que los tres subproductos orgánicos fueron efectivos para reducir la pérdida de agua en ambos suelos, observándose diferencias estadísticamente significativas entre el uso de la corteza de pino y los otros dos materiales. La hoja de palmera tuvo una efectividad similar a la de la paja de cereal, por lo que se considera*

DOI: 10.3232/SJSS.2016.V6.N2.05

adecuada su utilización como acolchado en zonas como la nuestra, en las que por su abundancia, disponibilidad y facilidad de uso, supone un beneficio ambiental añadido.

RESUMO

*O uso de cobertura morta do solo ("mulch") é uma técnica comumente usada em áreas áridas e semi-áridas para evitar a erosão e reduzir a evaporação de água do solo. Neste estudo, realizou-se um ensaio para quantificar o efeito de três resíduos orgânicos (folha de palmeira moída (*Phoenix dactylifera*), palha de cereais (feno) e casca de pinheiro), na retenção de humidade em dois solos de textura diferente, S1 (textura franca) e S2 (textura franco-limosa), inicialmente saturados com água. Utilizaram-se recipientes paralelopipédicos com 31 cm de lado e 20 cm de altura, tendo-se adicionado água a cada solo até uma altura de 15 cm. Os tratamentos foram instalados um dia após a saturação do solo adicionando-se 2 centímetros de altura dos diferentes tipos de cobertura morta sobre cada um dos solos. Os solos A e B sem cobertura foram usados como tratamento testemunha. O ensaio realizou-se em estufa, e prolongou-se até perda total da água inicial do solo. Ao longo do ensaio foram controlados os valores da temperatura (T) e da Humidade Relativa (HR). Nos primeiros 16 dias, observou-se uma permanente e elevada taxa de evaporação nos solos sem cobertura morta de 1.813 g de água/m^2/dia e 1792 g de água/m^2/dia no S1 e S2, respetivamente. Estabeleceram-se regressões lineares para quantificar a perda de água durante o ensaio, em cada tratamento considerado. Os resultados mostraram que os três resíduos orgânicos foram eficazes na redução da perda de água em ambos os solos, tendo-se observado igualmente diferenças significativas entre o uso de casca de pinheiro e os outros dois materiais. A folha de palmeira foi tão eficaz como a palha de cereais, sendo por isso considerada adequada para usar como cobertura morta em áreas como a nossa, pela sua abundância, disponibilidade e facilidade de uso, para além dos benefícios ambientais que acarreta.*

KEY WORDS
Palm leaf, cereal straw, pine bark, soil water

PALABRAS CLAVE
Hoja de palmera, paja de cereal, corteza de pino, agua del suelo

PALAVRAS-CHAVE
Folha de palmeira, palha de cereais, casca de pinheiro, água do solo

1. Introduction

Soil protection, preventing erosion and reducing water loss from evaporation, is fundamental in arid and semi-arid areas due to water shortages, long periods with high temperatures and occasional torrential rainfalls. In these cases, cultural practices should be applied to avoid the degradation of soil, increase infiltration, reduce the rate of water circulation and help reduce erosion (Moradi et al. 2015). The technique of mulching is one of these practices, and it is commonly used to protect soil and as a cultivation technique in both intensive farms (Contreras et al. 2006) and organic farming (Cánovas et al. 1993; Altieri 1999). Synthetic or natural materials can be used as mulch, (Zribi et al. 2015), as well as organic byproducts, crop-, pruning-, or clearing remains, woodchips and pine bark, all of which favor increased soil fertility (Haynes 1980); natural inorganic materials, such as sand or gravel, are also possible.

Using plant waste in mulches can bring numerous advantages. Several studies indicate that they can reduce erosion processes (Rees et al. 2002; Kuncheva 2015), improve physical properties (Jordán et al. 2010; Daraz et al. 2014; Moradi et al. 2015), reduce crusting, regulate temperature, favor water infiltration (up to 30% with respect to bare soil) and conserve soil moisture (Zribi et al. 2011), permit more efficient water use and irrigation (Ducrocq 1990), increase fertility and nutrient availability (Tian and Brussaard 1997; Neilsen et al. 2002), increase organic matter, the cation exchange capacity, the presence of soil fauna and stimulate biological activity in the soil (Jodaugiené et al. 2010), decrease soil compaction and favor gas exchange (Brouder and Gómez-McPherson 2014), and reduce the development of adventitious weeds, favoring the growth of plants and their productivity (Chalker-Scott 2007; Bajgai et al. 2014; Tosic et al. 2014). Mulch must be used in a way that all of its potential advantages are optimized; for example, cereal straw facilitates aeration and the entry of water into the soil, but because it decomposes slowly and has a low nitrogen content, adding some type of supplementary fertilizer to the soil to facilitate its subsequent mineralization is considered necessary.

In contrast, inappropriate use of mulch must be avoided, because this could result in excess moisture within the root zone and situations of anoxia or, conversely, making it too difficult for water to penetrate it and reach the soil (González 2014). Therefore, an adequate cover must be established in terms of both the type of waste and the thickness employed (Nagaya and Lal 2008). Furthermore, the practice of mulching must be governed with criteria of sustainability, valuing aspects such as the availability of the material, reuse of local byproducts, socio-economic development, no waste generation, environmental synergisms, etc.

The production volume of organic plant waste is very high. If used properly, it would both increase in value and the available resources would be utilized better.

This paper proposes to analyze the effectiveness of three plant wastes used as mulch, on soil water retention over time, analyzing possible differences between them and the evaporation in an unprotected soil as reference. This study contributes to appropriate soil management techniques, improving soil protection and valuing plant byproducts.

2. Materials and methods

In order to isolate uncontrollable exterior climatic factors, the experiment was conducted inside a greenhouse. Two LOG 32 data logger sensors monitored the relative humidity and temperature, taking a measurement of these every hour throughout the entire trial. In all, 2300 measurements were taken.

For the experimental design, 32 plastic containers were used. Each container was 20 cm tall, with a square base 27 cm wide, and 31 cm wide at the top. Each container had five drainage holes in its base to release gravitational water at the beginning of the experiment.

Two anthrosols were sampled from agricultural terraces in the northern part of the municipality of Elche. The terraces had been used for dozens of years but today are abandoned. After their sampling, the soils were air dried, homogenized, and sieved through a 0.5 cm mesh to eliminate coarse matter, characterizing them afterwards following the methodology referenced by UNE standards (AENOR 2001a, 2001b, 2001c, 2001d, 2001e, 2008), MAPA (1986), and various authors. Their textures were determined by the Bouyoucos method (Gee and Bauder 1986), pH (1:2.5, w/v) in distilled water, electric conductivity in 1:5 (w/v) aqueous extract, oxidizable organic matter (oxOM) by oxidation with potassium dichromate (Nelson and Sommers 1982), Kjeldahl nitrogen (Bremmer and Mulvaney 1982), P by the Burriel-Hernando method (Díez 1982), Na, K, Ca, and Mg exchangeable ammonium acetate extract (Blakemore et al. 1987), and Fe, Mn, Cu, and Zn available in DTPA extract. The characteristics of both soils (average value ± σ) are shown in **Table 1**.

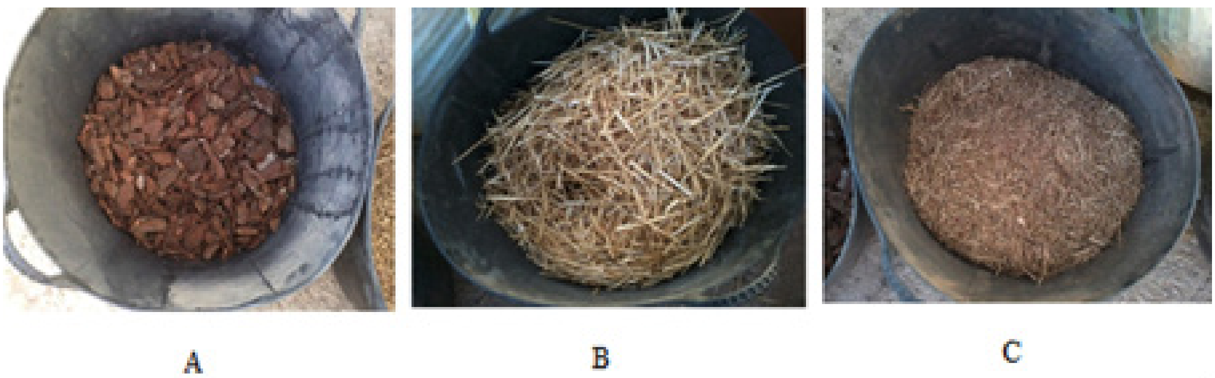
Each soil had a different texture, affecting their water adsorption capacity. The pH in both was basic due to the presence of very high levels of alkaline carbonate and alkaline earth metals, with a quantified percentage of equivalent carbonate percentages in soil 1 of 70% and high concentrations of available calcium and sodium related with the pH values and very high electrical conductivity (EC). The organic matter content, N and P, was very low in both and lacked available Fe, Mn, Cu, and Zn. In view of the results (**Table 1**), the soils, limestone in nature, presented the typical characteristics and problems of the semi-arid Mediterranean such as a low fertility and high salinity.

Table 1. Soil characterization and analysis results

	Soil 1	Soil 2
Clay (%)	21 ± 1	21 ± 1
Silt (%)	30 ± 2	68 ± 2
Sand (%)	49 ± 2	11 ± 1
USDA classification	Loam	Silty loam
pH	8.4 ± 0.1	8.0 ± 0.1
EC (mS/cm)	1.18 ± 0.02	2.23 ± 0.02
oxOM (%)	0.50 ± 0.06	0.30 ±0.05
Equivalent carbonate (%)	70 ± 2	52 ± 2
N (%)	0.020 ± 0.005	0.035 ± 0.005
P (ppm)	5.5 ± 0.2	2.0 ± 0.1
Na (g/kg)	0.61 ± 0.03	0.29 ± 0.03
K (g/kg)	0.12 ± 0.02	0.28 ± 0.01
Ca (g/kg)	3.66 ± 0.01	7.64 ± 0.09
Mg (g/kg)	0.32 ± 0.01	0.44 ± 0.04
Cu (ppm)	0.31 ± 0.03	0.48 ± 0.03
Fe (ppm)	0.53 ± 0.03	0.44 ± 0.04
Mn (ppm)	1.68 ± 0.05	0.26 ± 0.02
Zn (ppm)	0.36 ± 0.03	0.31 ± 0.03

Three types of organic byproducts were used (**Photograph 1**). Two of them are commonly used as mulch: pine bark and cereal straw, and the third, shredded palm leaf, was selected for being a novel material capable of being used for this purpose.

Pine bark is used very much in gardening; in this case, the bark came from Pinus halepensis. The average sizes of the fragments varied between 3.9 x 1.8 cm for the largest and 1.5 x 0.9 cm for the smallest ones. When applying the mulch layer, the fragments blended fairly well, and the surface became homogenized in an acceptable manner. The average size of the strands of cereal straw (hay) was 9.3 ± 2.0 cm long with a diameter of approximately 0.2 cm, and this was the lightest of the wastes. Shredded palm leaf (previously air-dried) is readily available in the area, and came from trimming *Phoenix dactylifera*. This is the only waste that required being shredded beforehand (MTD chipper



Photograph 1. Pine bark (A), cereal straw (B), and crushed palm leaf (C) wastes.

shredder model 465), producing average size fragments of 4.0 ± 1.6 cm long with thicknesses less than 0.1 cm. Covering the soil produced a fairly homogenous layer, similar to that of the cereal straw.

The wastes were characterized following the UNE-EN-ISO 13000 standards of soil improvers and cultivation substrates (AENOR 2001a, 2001b, 2001c, 2001d, 2001e, 2008), and the characteristics are shown in **Table 2**. It is worth noting that the palm leaf presented the greatest electrical conductivity and had a slightly higher ash content than the other materials.

Each soil was introduced into 16 containers, filled to a height of 15 cm, and then weighed. Each soil was saturated with irrigation water and given 24 h to shed the excess. Subsequent to this, a 2-cm high layer of mulch was applied. This was indicated as time 0. The data was collected by weighing the container contents on a scale until day 95, the last day of data collection. The treatments combined the use of the organic waste and both types of soils. Four containers were prepared for each treatment with each type of soil: 4 control samples had no mulch cover, 4 samples had a pine park cover, 4 samples had a cereal straw cover, and 4 samples had a shredded palm leaf cover. The containers were randomly distributed in an area within the greenhouse, in such a way that they were not affected by their arrangement, and containers with the same contents were not placed adjacent to one another.

Table 2. Waste analysis results

	Pine bark	Cereal straw	Date palm leaf
Density (g/cm^3)	0.25 ± 0.02	0.07 ± 0.01	0.12 ± 0.01
EC (mS/cm)	0.474 ± 0.005	0.788 ± 0.005	2.28 ± 0.02
Organic material (%)	94.5 ± 0.3	94.8 ± 0.3	93.2 ± 0.3
Ash contents (%)	5.5 ± 0.3	5.2 ± 0.3	6.8 ± 0.3

Different statistical treatments were applied to the data. The standard deviation value was used in the soil and waste characterization tables, and also to represent the range of variation in the evolution of the hydric contents of the soils in the distinct treatments. Analysis of variance (ANOVA), along with Tukey's test, was used to quantify whether there were statistically significantly differences between treatments with respect to the parameter analyzed and the time that transpired until achieving complete loss of moisture in the soils. Linear regressions were also applied between the loss of water and the experimentation time, evaluating the goodness of fit by the R coefficient and the resulting F value.

3. Results

Table 3 indicates the average times that the different treatments took to completely lose their initial moisture and the result of applying two-way ANOVA. It is evident that the mulches significantly increased ($p = 0.001$) the resistance to water loss in both soils with respect to the control treatment, with the pine bark the material that retained moisture the longest, with a significant difference ($p = 0.05$) detected between the effectiveness of this byproduct and the cereal straw.

Table 3. Effect of the mulching material and type of soil on the time transpiring until the soils dried (days)

	Drying time (days±σ)	
	Soil 1	Soil 2
Control	42 ± 4	56 ± 7
Pine bark	81 ± 8 (a)	94 ± 2 (a)
Cereal straw	69 ± 3 (b)	84 ± 4 (b)
Palm leaf	73 ± 1 (ab)	88 ± 4 (ab)
F (corrected)	55.6***	
F (mulch)	106***	
F (soil)	72.6***	
F (soil x mulch)	2.17 ns	

*, **, and *** indicate a significance level at p = 0.05, 0.01, and 0.001, respectively. In the columns, average values with the same letters are statistically equal to p = 0.05 (Tukey's).

The F value (soil x mulch) indicates that there was no statistically significant effect of each mulch on the difference of drying time between either soil, which varied between 13 and 15 days in all cases. This difference was due to the distinct water retention capacity of the soils, which manifested itself in the different initial moisture percentage, following saturation, which was 20.1 ± 0.4 for the group of soil 1 (n = 16) and 23.1 ± 0.6 for the average of soil 2 (n = 16), values that are distinct from each other with statistical significance p = 0.001 (F = 300).

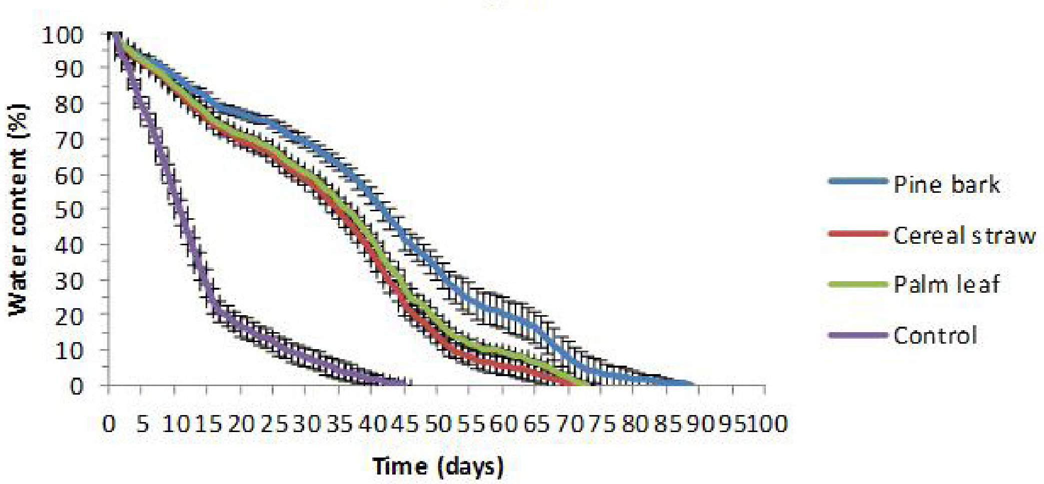


Figure 1. Variation in the water retention times of the various mulches in soil 1 (loam).

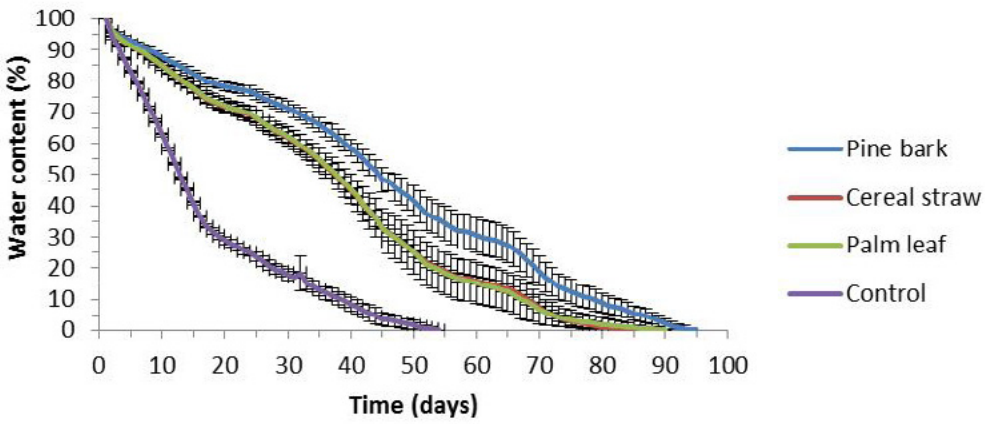


Figure 2. Variation in the water retention times of the various mulches in soil 2 (silty-loam).

Figures 1 and 2 show the water loss tendency in both soils over time, expressed as average value of each mulching treatment and the confidence intervals represented as error lines calculated from the standard deviation.

Temperature and relative humidity data recorded in the greenhouse throughout the experiment are shown in **Figures 3 and 4**. **Figure 5** shows the joint evolution of the average of both of these factors. In this sense, it is expected that high temperatures favor evaporation while high relative humidities hinder it.

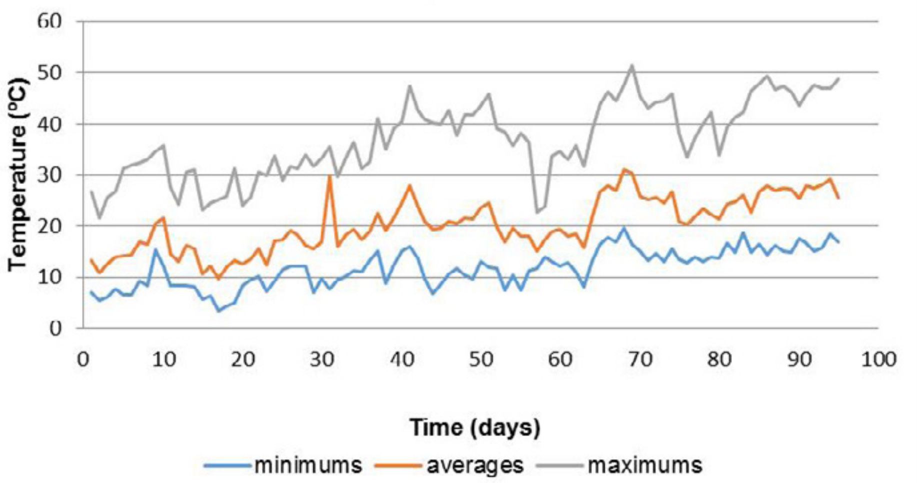


Figure 3. Temperature evolution during the experiment.

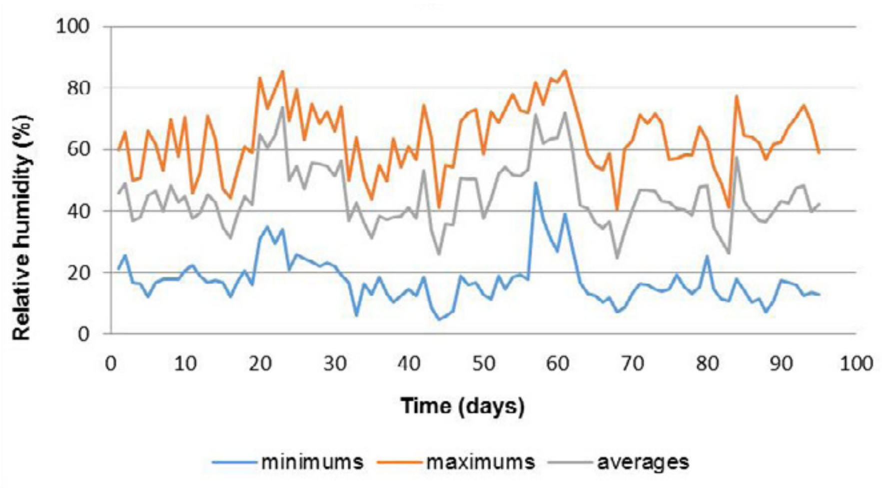


Figure 4. Relative humidity evolution during the experiment.

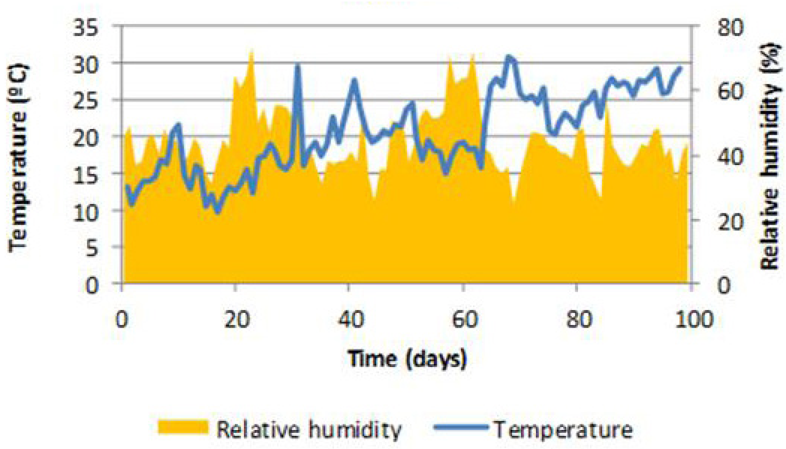


Figure 5. Evolution of the averages of temperature and relative humidity during the experiment.

4. Discussion

The data represented in **Figures 1 and 2** show a large decrease in water in both soils without mulch, which was practically constant during the experiment's first 16 days. The average evaporation velocities for soil 1 was 174 g/day per container (1813 g/day per m^2) and 172 g/day per container (1792 g/day per m^2) for soil 2, which represents water loss of approximately 80% of the total water retained in soil 1 and 75% of soil 2. Such a loss, for the same time interval, is equivalent to a moisture content variation (DSM) between 25.1 and 6% for soil 1 and between 30.1 and 11% for soil 2. If it is kept in mind that the field capacity for medium textured soils is usually between 15 and 30% of the dry weight of the soil and that the wilting point for the same type of soils is usually within the interval of 5 to 15% (Ducrocq 1990), it can be said, quite roughly, that the water loss observed in the soils without mulch during the first 16 days may correspond with the fraction of the water available or water useful for plants.

From day 17 onward, the evaporation velocities of the control soils diminished and became fairly constant until reaching 5% moisture. During this interval, water losses were quantified at 29.3 g/day per container (306 g/day per m^2) in soil 1 and 42.1 g/day per container (439 g/day per m^2) in soil 2.

As in the control soils, after the first 16 days, the mulch treatments seemed to mark a turning point and a tendency that the evaporation losses were conditioned by temperature and relative humidity. It is interesting to note that this behavioral change in the moisture loss occurred when the initial content of soil water in had only reduced by approximately 20% versus 75-80% of the control treatments for both soils. During the experiment's final days, the quantity of water remaining in the soil, no matter the treatment, was very low (< 5%) and its retention high, so this can be considered a residual fraction.

Table 4 shows, with high statistical significance, the positive effects from using the mulching materials on maintaining soil moisture. A 20% moisture loss (DSM) in them was taken as reference, and the data was expressed in days that transpired until the soils in each treatment had lost 20% of their initial water. It can seen that by applying the organic material, the time it took to lose 20% of the moisture in soil 1 was extended between 2 and 3 times, while for soil 2 it was a bit more than double.

Table 4. Effect of the mulching material on the time it takes (days) for the soils to lose 20% of the initial water

	Drying time (days ± σ)	
	Soil 1	**Soil 2**
Control	16 ± 1	27 ± 2
Pine bark	60 ± 5	68 ± 4
Cereal straw	45 ± 2 (a)	53 ± 2 (a)
Palm leaf	47 ± 2 (a)	54 ± 5 (a)
F	150***	102***

*, **, and *** indicate a significance level at p = 0.05, 0.01, and 0.001, respectively. In the columns, average values with the same letters are statistically equal to p = 0.05 (Tukey's).

Comparing the treatments in each soil indicate that pine bark is the material that retains the most moisture, and that the cereal straw and palm leaf waste show similar behavior between themselves.

Keeping in mind the aforementioned considerations on the water evaporation in this experiment, this process can be divided into 3 phases:

- Phase A. This corresponds to the first 16 days, where a clear linear relationship is observed in the moisture loss during this period in all cases, but one that is far more important in the control treatments. These conditions practically mean that after 14 days, a soil without mulch would require a water input.
- Phase B. Starting from day 17, which is considered a turning point, until approximately 5% of the water remained, a change in tendency can be seen in all treatments, more pronounced in the control soils.
- Phase C. Here, the moisture content reached very low levels, and that remaining was strongly retained in the soils, showing hardly any variation.

For the phases previously defined as A and B, a linear fit was performed for each treatment and the results are shown in **Table 5**. In it, the equation adjustment is indicated, expressed with the significant figures established from the standard errors of the distinct coefficients (in all cases, the t values have a significance level of $p > 0.001$). Likewise, the degree of correlation

Table 5. Results of the linear regression adjustments between the loss of water and time during phases A (days 1-16) and B (starting day 17 until each treatment reached 5% moisture)

		Phase A (days 1-16)			Phase B			
		Equation adjustment	R^2	p	Equation adjustment	R^2	p	Period (days)
Soil 1	Pine	y=-1.21x + 98.4	0.994	***	y=-1.49x + 109	0.985	***	17-71
	Straw	y=-1.61x + 98.6	0.997	***	y=-1.83x + 108	0.979	***	17-60
	Palm	y=-1.55x + 98.9	0.998	***	y=-1.62x + 104	0.972	***	17-66
	Control	y=-5.08x + 100	0.999	***	y=-0.86x + 33.0	0.993	***	17-33
Soil 2	Pine	y=-1.12x + 97.9	0.988	***	y=-1.22x + 104	0.990	***	17-85
	Straw	y=-1.47x + 97.9	0.993	***	y=-1.40x + 99.2	0.976	***	17-71
	Palm	y=-1.45x + 97.9	0.993	***	y=-1.43x + 100	0.976	***	17-71
	Control	y=-4.18x + 99.8	0.999	***	y=-1.02x + 48.2	0.995	***	17-43

*** indicates a significance level of $p < 0.001$ when applying the F statistic to the different linear regressions.

(R2), the significance level of the adjustments (p) derived from the F value, and the interval of days considered for the adjustments of Phase B are shown.

From the values of the slopes of the equations, the clear difference in the evolution of the water losses between the control soils and the losses in those treated with mulch is deduced during both phases. It can also be highlighted that the use of mulch translates into a fairly uniform loss of water during the testing time, enabling better management of soil water and avoiding situations of potential hydric stress in crops.

5. Conclusions

All three organic byproducts tested as mulching material on two soils presenting different textures were effective in reducing water loss from evaporation with respect to the bare soil, resulting in higher potential water availability for plants. Soils with mulch take between two and three times longer to lose the same quantity of water as the soils from the control treatments. During the first 16 days, a decrease in their initial water contents around 80% (soil 1) and 75% (soil 2) was quantified.

The data recorded in this experiment reflect an evolution of the very similar results for both types of soils, sandy and silty, which reinforces interest in the use of mulches for better management of water loss by evaporation.

Pine bark is clearly more effective at preventing the evaporation of water in soils than cereal straw and palm leaves, whose behavior is similar, on a statistically significant level.

In areas that produce plant waste, and in our case, waste generated from the trimming of abundant palm trees, the use of palm leaves, once shredded, is suitable as a material for soil mulch and presents certain advantages versus the other two wastes tested. As for pine bark, despite it being somewhat more effective than palm leaves, it has the disadvantage of costing more because of its demand in gardening and the transportation costs to haul it from its place of origin (forested areas).

Compared with cereal straw, shredded palm leaves are denser, so they may be affected less by wind erosion (loss of material) and be more effective upon the soil on which they are applied. The use of dry shredded palm leaves permits utilizing a local byproduct, which avoids dumping it in landfills (economic and environmental benefits) or burning it (an environmental benefit), enhancing its value, facilitating its incorporation into the soil as an organic matter, and promoting its use as mulch.

REFERENCES

• AENOR. 2001a. UNE 77308: Calidad del suelo. Determinación de la conductividad eléctrica específica.

• AENOR. 2001b. UNE 77315: Calidad del suelo. Extracción de oligoelementos con una disolución tampón de ADTP.

• AENOR. 2001c. UNE 77317: Calidad del suelo. Determinación del contenido en carbonato. Método volumétrico.

• AENOR. 2001d. UNE-EN 13038: Mejoradores del suelo y sustratos de cultivo. Determinación de la conductividad eléctrica.

• AENOR. 2001e. UNE-EN 13039: Mejoradores del suelo y sustratos de cultivo. Determinación del contenido en materia orgánica y de las cenizas.

• AENOR. 2008. UNE-EN 13040: Mejoradores del suelo y sustratos de cultivo. Preparación de las muestras para ensayos físicos y químicos. Determinación del contenido de materia seca, del contenido en humedad y de la densidad aparente compactada en el laboratorio.

• Altieri M. 1999. Agroecología: Bases científicas para una agricultura sustentable. Montevideo: Nordan-Comunidad.

• Bajgai Y, Kristiansen P, Hulugalle N, McHenry M. 2014. Effect of residue management and conventional and organic soil management systems on crop yields and weed biomass. Acta Hortic. 1018:227-234.

• Blakemore LC, Searle PL, Daly BK. 1987. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report No. 80. Lower Hutt, New Zealand: New Zealand Soil Bureau.

• Bremner JM, Mulvaney CS. 1982. Nitrogen total. In: Page AL, Miller RH, Keeney DR, editors. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Madison: ASA and SSSA. p. 595-624.

• Brouder SM, Gómez-Macpherson H. 2014. The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. Agric Ecosyst Environ. 187:11-12. DOI:10.1016/j.agee.2013.08.010.

• Cánovas A, Hilgers M, Jiménez R, Mendizábal M, Sánchez F. 1993. Tratado de agricultura ecológica. Almería: Instituto de Estudios Almerienses.

• Chalker-Scott L. 2007. Impact of Mulches on Landscape Plants and the Environment. A Review. J Environ Hortic. 25(4):239-249.

• Contreras F, García J, González-Benavente A, López J, Varó P. 2006. Estudio económico sobre alternativas al acolchado tradicional de polietileno en el cultivo de melón en la Región de Murcia. Murcia: Consejería de Agricultura, Agua y Medioambiente de la Región de Murcia.

• Daraz G, Din S, Ramzan M, Hanif M, Hameed M. 2014. Influence of Tillage and Mulching Practices on Soil Physical Properties under Semi-Arid Environment. J Environ Earth Sci. 4(9):120-124.

• Díez JA. 1982. Consideraciones sobre la utilización de la técnica extractiva para la evaluación de fósforo asimilable en suelos. Anal Edafol Agrobiol. 41:1345-1353.

• Dudrocq M. 1990. Guías de Agricultura y Ganadería: Sistemas de Irrigación. Barcelona: CEAC S.A.

• González S. 2014. Proper Mulching Techniques. Illinois: International Society of Arboriculture.

• Gee GW, Bauder JW. 1986. Particle-Size Analysis. In: Klute A, editor. Methods of Soil Analysis 1: Physical and Mineralogical Methods. 2nd ed. Madison: ASA and SSSA. p. 383-411.

• Haynes RJ. 1980. Influence of soil management practice on the orchard agro-ecosystem. Agro-Ecosystems 6(1):3-32.

• Jodaugiené D, Pupalienè R, Sinkevicienè A, Marcinke-vicienè A, Zebrauskaité K, Baltaduonyté M, Cepulienė R. 2010. The influence of organic mulches on soil biological properties. Zemdirbyste-Agriculture 97(2):33-40.

• Jordán A, Zavala L, Gil J. 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena 81:77-85. DOI: 10.1007/s11104-013-1889-4.

• Kuncheva GS. 2015. Comparative study of microbial activity and chemical properties of soil by implementing anti-erosion measure vertical mulching with organic residues. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 63(1):59-63.

• MAPA. 1986. Métodos oficiales de análisis. Tomo III. Madrid: Ed. MAPA.

• Moradi A, Teh Boon Sung C, Goh K, Husni Mohd Hanif A, Fauziah Ishak C. 2015. Effect of four soil and water conservation practices on soil physical processes in a non-terraced oil palm plantation. Soil Till Res. 145:62-71. DOI: 10.1016/j.still.2014.08.005.

• Nagaya L, Lal R. 2008. Mulching effects on selected soil physical properties. Soil Till Res. 98:106-111.

• Neilsen G, Hogue E, Forge T, Neilsen D. 2002. Surface application of mulches and biosolids affect orchard soil properties after 7 years. Can J Soil Sci. 83(1):131-137. DOI: 10.4141/S02-034.

• Nelson DV, Sommers LE. 1982. Total carbon, organic carbon, and organic matter. In: Page AL, editor. Methods of Soil Analysis. Part 2: Chemical and Biological Methods. Madison: ASA and SSSA. p. 539-579.

• Rees H, Chow T, Loro P, Lavoie J, Monteith J, Blaauw A. 2002. Hay mulching to reduce runoff and soil loss under intensive potato production in northwestern New Brunswick, Canada. Can J Soil Sci. 82(2):249-258. DOI 10.4141/S01-055.

• Tian G, Brussaard L. 1997. Mulching effect of plant residues of chemical contrasting compositions on soil organic matter content and cation exchange capacity. Commun Soil Sci Plant Anal. 28(17-18):1603-1611.

• Tosic I, Zarko I, Maksimovic I. 2014. The effect of plant mulching and covering on the lettuce yield and nitrate content (*Lactuca sativa*). Afr J Agri Res. 9(23):1774-1777. DOI:10.5897/AJAR2012.856.

• Zribi W, Aragüés R, Medina E, Faci J. 2015. Efficiency of inorganic and organic mulching materials for soil evaporation control. Soil Till Res. 148:40-45. DOI:10.1016/j.still.2014.12.003.

• Zribi W, Faci J, Aragüés R. 2011. Efectos del acolchado sobre la humedad, temperatura, estructura y salinidad de suelos agrícolas. ITEA 107(2):148-162.