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Efficiency of inorganic and organic mulching materials for soil evaporation control

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ABSTRACT

Soil evaporation is an important component of the water balance in irrigated agriculture. Mulching can be an effective technique to reduce soil evaporation but its efficiency depends on meteorological conditions and the characteristics of the different mulching materials. The objective of this work was to assess the effectiveness of inorganic (plastic) and organic (pine bark, vine pruning residues, geotextile, and wheat straw) mulching materials for soil evaporation control during the energy-limited and falling-rate evaporation stages. Soil evaporation rates (ER) were quantified through consecutive weighings of initially wet soils placed in trays in the laboratory and in microlysimeters in the field. ER depended on meteorological and experimental conditions, stage of evaporation and type of mulching material. In the falling-rate stage, ERs decreased linearly ($p < 0.001$) with decreases in GWC, and for long drying periods the ERs were low and similar among treatments, implying that soil mulching will be ineffective for soil evaporation control in low-frequency irrigation systems. In the energy-limited stage, all mulching materials decreased the ERs in relation to the bare soil, but the plastic, vine residues and pine bark materials had lower ERs than the rest of mulching materials. These materials will be therefore recommended for soil evaporation control in high-frequency irrigation systems where the soil surface remains wet most of the time.

1. Introduction

Soil evaporation is the process whereby liquid water is converted to water vapor and removed from the soil surface. Soil evaporation is determined solely by meteorologic conditions (i.e., solar radiation, air temperature, air humidity, and wind speed) when the amount of water available for evaporation at the soil surface is unlimited. During this “energy-limited stage”, soil evaporation is constant and occurs at its maximum rate limited only by meteorologic conditions. As the upper soil dries out, the decreasing hydraulic conductivity cannot be compensated by an increasing hydraulic gradient and water cannot be transported to the soil surface at the required rate to supply the potential demand. As a consequence, the evaporation rate is reduced in proportion to the water available at the soil surface (“falling-rate stage”) (Idso et al., 1974; Allen et al., 1998).

Soil evaporation is a very important component of the water balance in natural and cultivated systems. It is estimated that 50–70% of the annual precipitation returns to the atmosphere without any benefit to biomass production (Jalota and Prihar, 1990). The reduction of soil evaporation is essential to increase the water use efficiency of agricultural crops. The use of mulching materials is an efficient way to reduce the exchange of water vapor between the soil surface and the atmosphere. Consequently, the evaporation of water from a mulched soil decreases relative to a bare soil, and more water is available for beneficial crop transpiration (Sarkar et al., 2007; Hou et al., 2010).

The type, amount, or thickness of the mulching materials, and the atmospheric evaporative demand determine the rate of soil drying (Tolk et al., 1999). Mulching with impervious materials such as plastic films minimizes the evaporation of water from the soil surface, but prevents the entry of rainfall into the root zone of crops. In contrast, mulching with porous materials allows the entry of rainfall, but soil evaporation increases over that of impervious materials. Therefore, the benefits of the different types of mulching materials for water conservation are weather-dependent and rely on the balance between the water entering the soil from rainfall and irrigation, and the water leaving the soil by evaporation and transpiration.

Soil mulching is a well-established technique for increasing the profitability of crops, and the effectiveness of inorganic and organic mulches for soil evaporation control has been documented for

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numerous annual crops (Unger and Parker, 1976; Todd et al., 1991; Tolk et al., 1999; Ghosh et al., 2006; Awoodoyin et al., 2007). Particularly, in the last decade in China soil mulching with plastic film and different straw materials has been used to reduce soil evaporation, improve crop water use efficiency and minimize salt build-up in the root zone of crops (Huang et al., 2005; Deng et al., 2006; Xie et al., 2006; Dong et al., 2009 Yuan et al., 2009; Hou et al., 2010; Wang et al., 2014). However, most of these and other works were focused on the response of crops to soil mulching rather than on quantifying soil evaporation as affected by the different mulching materials.

Besides the benefits for water conservation, soil mulching is an efficient alternative to traditional methods of weed control because it prevents contamination of soil and groundwater by pesticides. Other advantages include protection against surface runoff and erosion, acceleration of crop maturity and, in general, an increase in the economic productivity of horticultural crops. The use of opaque materials such as black polyethylene films prevents light penetration, reduces the germination of weed seeds (Walsh et al., 1996) and provides a physical barrier to the emergence of weeds (Teasdale, 2003) and to gas exchange. Plastic films have been used widely as mulching materials and are used on a large scale in horticultural crops because in combination with high-frequency drip irrigation systems they substantially reduce the evaporation from the wetted surface and improve application irrigation efficiency. Soil mulching has shown positive effects on yield, fruit quality and earliness of harvest due to soil heating, an advantage of great interest in the marketing of early horticultural crops (Moreno and Moreno, 2008).

However, some practical problems may arise in soil mulching. Plastic films may rip and deteriorate with time in open meteorological conditions and must be reinstalled. Also the remains of plastic materials have to be properly removed from the field at the end of the crop growing cycle to avoid soil contamination, although the introduction of photo- and biodegradable plastic materials has greatly reduced this problem. Organic mulches have to be renewed periodically to maintain their effects because they decompose with time (Haynes, 1980). In general, soil mulching implies a high economic cost factor since the materials are not often available within the farm and have to be purchased elsewhere, transported to the site and installed on the plots. These aspects have restricted the use of mulching in most cases to high-value commercial crops (McCraw and Motes, 2009).

Many mulching experiments measuring its effectiveness in reducing soil evaporation were conducted in cropped soils and therefore their results are affected by the difficulties to separate soil evaporation from crop transpiration. The objective of the present work was to determine the evaporation losses from uncropped soils subject to different types of inorganic (plastic) and organic (pine bark, vine pruning residues, geotextile, and wheat straw) soil mulching materials with the aim to assess their efficiency for soil evaporation control.

2. Materials and methods

Soil evaporation was measured or estimated with different inorganic and organic mulching materials in laboratory (experiment 1) and field (experiments 2) conditions. In experiment 1, the top layer (0–10 cm) of a clayey soil located in the experimental farm of the Agrifood Research and Technology Center of Aragon (CITA) was used. The soil of experiment 2, located in the AFFRUCAS (Association of fruit growers of the County of Caspe) farm, has an average depth of 1.5 m and is classified as calcic haploxerept, fine loamy, mixed, thermic (Soil Survey Staff, 2006).

The field capacity (FC) and permanent wilting point (PWP) determinations were performed in the CITA laboratory with a pressure plate apparatus at pressures of 33 and 1500 kPa, respectively, according to Klute (1986). Disturbed soil samples were taken at several locations in each experiment with a 50 mm diameter auger. The particle size composition and the values of FC and PWP of the soils used in the two experiments are presented in Table 1 (means of three replications).

2.1. Experiment 1 (soil trays)

Soil evaporation from a saturated soil placed in plastic trays closed at the bottom and covered with different mulching materials was measured by weighing periodically the trays with a 0.1 g precision balance. The trays were located in a room maintained at constant air temperature (28 °C) and air relative humidity (60%). The trays (29 cm length, 19 cm width, and 5 cm height) were filled with 1000 g of air-dry soil. Based on a measured saturation percentage of the soil of 56 g per 100 g, the required amount of water was evenly added to each tray to bring it to saturation. The gravimetric values of FC and PWP of the soil were 27.5 g per 100 g and 18.7 g per 100 g, respectively (Table 1). Thereafter, the mulching materials were placed over the saturated soil in direct contact with it. The trays were weighed the first day of the trial just after the installation of the mulching materials over the saturated soil. The weight was measured three days after the beginning of the experiment and daily thereafter at 09:00 am. The positions of the eighteen trays on the bedplate were changed randomly every day.

Besides the control or bare soil, the following mulching materials were examined: black polyethylene (PE) film of 0.1 mm thickness with a specific weight of 0.09 g cm^{-3} (plastic); natural fibers of jute geotextile (*Corchorpsus caularis)* with a thickness of 5.5 mm and a specific weight of 0.10 g cm^{-3} (Ponpun Viscosa Yute-6.5 of 650 g m^{-2}; Bontrech Co., Zaragoza, Spain) (geotextile); wheat chopped straw with 5 cm thickness and a specific weight of 0.08 g cm^{-3} (wheat straw); vine pruning residue with 5 cm thickness and a specific weight of 0.09 g cm^{-3} (vine residues); pine bark (chunks of 3 cm average diameter) with a thickness of 5 cm and a specific weight of 0.17 g cm^{-3} (pine bark).

The statistical design was at random with three replications per treatment.

2.2. Experiment 2 (microlysimeters)

Soil evaporation was measured by weighing periodically 36 microlysimeters (ML) installed in a nectarine orchard located in the AFRUCCAS experimental farm (county of Caspe, Zaragoza, Spain, 41° 18′ 57″ N, 0° 4′ 57″ E, 157 m elevation above sea level). Gravimetric values of FC and PWP of the soil layer 0–20 cm were 26.0 g per 100 g and 11.0 g per 100 g, respectively (Table 1). The climate was characterized using the daily data gathered in an

Table 1
Soil texture and gravimetric water contents at field capacity (FC) and permanent wilting point (PWP) of the 0–10 cm soil depth in experiment 1 (soil trays) and 0–20 cm soil depth in experiment 2 (microlysimeters).

	Sand (%)	Silt (%)	Clay (%)	FC (g per 100 g)	PWP (g per 100 g)
Experiment 1	33	28	39	27.5	18.7
Experiment 2	25	50	25	26.0	11.0