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Biodegradable mulch controls weeds and increases water use efficiency in lettuce crops

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ABSTRACT

Vegetable cultivation requires high water use and weed control. Soil cover using recycled paper, can be an alternative to polyethylene film to reduce weed incidence, soil temperature and increase water use efficiency beyond reduces costs and environmental pollutions. The objective of this study was to evaluate the use of biodegradable mulch in weed management and water use efficiency (WUE) in lettuce crop. The treatments were composed of brown recycled paper (RP), black polyethylene film (PF) and soil without cover with weed removal (WR) and without weed removal (WW). RP and PF were efficient to control weeds. The soil temperature with RP was 8.2 and 2.1ºC lower than with PF and WR, respectively. The lettuce yield with RP was 14.5 and 28.3% higher than WR, and with PF, respectively. The water volume applied with RP was 26.5% lower, and WUE was 55.6% higher compared to WR. Soil cover with recycled paper controlled weeds, reduced soil temperature and water consumption and increased yield and water use efficiency in lettuce crop.

Keywords: *Lactuca sativa*, recycled paper, polyethylene film, thermal amplitude, applied water.

RESUMO

Mulch biodegradável controla plantas daninhas e aumenta a eficiência do uso de água na cultura da alface

O cultivo de hortaliças requer alto consumo de água e controle de plantas daninhas. A cobertura do solo com papel reciclado pode ser uma alternativa biodegradável ao filme de polietileno para reduzir a incidência de plantas daninhas, temperatura do solo e aumentar a eficiência do uso da água além de reduzir custos e poluição ambiental. O objetivo deste estudo foi avaliar o uso do mulch biodegradável no manejo de plantas daninhas e eficiência do uso da água (EUA) na cultura da alface. Os tratamentos foram papel reciclado marrom (RP), filme de polietileno preto (PF) e solo sem cobertura com remoção de plantas daninhas (WR) e sem remoção de plantas daninhas (WW). O RP e PF foram eficientes no controle das plantas daninhas. A temperatura do solo com RP foi 8,2 e 2,1ºC menor que PF e WR, respectivamente. A produtividade da alface com RP foi 14,5 e 28,3% superior ao WR e PF, respectivamente. O volume de água aplicado com RP foi 26,5% menor e EUA foi 55,6% maior em comparação a WR. A cobertura do solo com papel reciclado controlou a incidência de plantas daninhas, reduziu a temperatura do solo e o consumo de água e aumentou a produtividade e eficiência do uso da água na cultura da alface.

Palavras-chave: *Lactuca sativa*, papel reciclado, filme de polietileno, amplitude térmica, água aplicada.

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Lettuce is the most consumed leafy vegetable in Brazil (Silva *et al.*, 2017). This plant has a high transpiration rate and demands irrigation (Barbosa *et al.*, 2015). Weeds can reduce lettuce crop productivity (Odero & Wright, 2013) and are usually controlled by manual weeding, due to a lack of effective herbicides registered for this crop, and intensive soil rotation (Lati *et al.*, 2015).

Alternative methods for weed control and water use efficiency may include soil cover with inorganic and organic materials (Kader *et al.*, 2017a). The polyethylene film is the most used inorganic material to cover soil with high efficiency for weed control and reduced water use (Steinmetz *et al.*, 2016). However, the black polyethylene film increases soil temperature (Gu *et al.*, 2018), reduces plant crop and microorganism growth (Lamont, 2005; Schirmel *et al.*, 2018). The polyethylene film has high degradation resistance, which does not allow it to be incorporated into the soil, with its removal and elimination after the cultivation, being necessary increased costs and leading to environmental contamination (Kyrikou, 2007; Steinmetz *et al.*, 2016).

Organic materials such as plant residues (leaves, branches, crop residues, etc.) reduce weed incidence and soil temperature and increase soil moisture (Kader *et al.*, 2017a). Paper is a biodegradable material used to cover soil with effective temperature reduction (Zhang *et al.*, 2009; Haapala *et al.*, 2014), weed control (Moreno *et al.*, 2013; Haapala *et al.*, 2015) and soil moisture maintenance over longer periods (Kader *et al.*, 2017b), It reduces water consumption and increases its efficiency of use. Recycled paper consists of cellulosic and mineral calcium carbonate (Hubbe & Gill, 2016), is biodegradable and do not need to be removed from the field, being possible its incorporation into the soil, reducing costs (Haapala *et al.*, 2014). Moreover, its decomposition allows the release of calcium into the soil.

The objective was to evaluate the use of biodegradable mulch in weed management and water use efficiency in lettuce crop.

MATERIAL AND METHODS

The experiment was carried out in plastic greenhouse in the municipality of Viçosa, Minas Gerais, Brazil (20°45'28"S, 42°50'45"W, 645 m altitude) in summer 2017. The maximum and minimum temperatures were 30.10 and 18.65ºC with average 24.37ºC, and solar radiation 10.57 MJ m^{-2} day^{-1} day^{-1}. The relative humidity of 81.42% was recorded in the Irriplus E5000 weather station.

The soil in the experimental area was classified as clayey, presenting average organic matter content of 1.8 dag/kg. The average bulk density was 1.25 g cm^{-3} and the moisture for the field capacity and wilting point were 0.36 and 0.20 m^3 m^{-3}, respectively.

The lettuce cv. Vera seeds were sown in 200 cell polyethylene trays with commercial Plantimax® substrate. Lettuce plants were transplanted 18 days after being sown.

The experimental design was completely randomized with four treatments and five replications. The treatments consisted of soil covered with brown recycled paper (131 g m^{-2}) (RP) from Ponte Nova Papéis, Ponte Nova-MG, BR with black polyethylene film (22 µm) (PF) from Eletro Plastic, São Paulo-SP, BR, soil without cover with weed removal (WR) and soil without cover and without weed removal (WW). The dimensions of each experimental unit were 2.0 × 1.0 m with the plants spaced at 0.25 × 0.25 m.

Beds (10.0 × 1.0 m with 0.2 m height) were made after soil preparation consisting of one plowing and harrowing. Planting fertilization with 50 kg ha^{-1} N, 50 kg ha^{-1} P, 20 kg ha^{-1} K, was carried out with ammonium sulphate, simple superphosphate and potassium chloride, respectively, based on the soil analysis and recommendation (Ribeiro *et al.*, 1999). Fertilization with 100 kg ha^{-1} N, 0 kg ha^{-1} P, 40 kg ha^{-1} K, was carried out by fertigation at 10 and 20 days after transplanting (DAT) with ammonium sulfate and potassium chloride, respectively.

Dripping tapes with flow emitters of 1.60 L h^{-1}, spaced 0.20 cm on the tape, were laid longitudinally on the beds spaced 50 cm apart. Each drip tape irrigated two lettuce rows. Irrigation was carried out according to the soil water tension obtained by the tensiometer reading per treatment in all repetitions, installed at a depth of 10 cm, based on the water characteristic curve to maintain the soil field capacity.

Digital sensors, model DS18B20 (DFRobot, CN), with an accuracy of ±0.5°C, were installed 5 cm deep at the center of each experimental unit in all treatments and repetitions to monitor soil temperature during the crop cycle, every 15 min and stored in dataloggers constructed with a protoboard, Arduino Uno (DFRobot, CN).

The soil was covered with polyethylene film or recycled paper after fertilization and installation of the irrigation system. Circular holes of 3.0 cm diameter were opened in the polyethylene film and recycled paper to transplant the lettuce.

A 25 mm water blade was applied in all treatments after plant setting. Manual weeding was performed at 10 and 20 (DAT), in the treatment without cover with weed removal (WR).

Weed population density and dry matter were evaluated in a 0.5 × 0.5 m (0.25 m^2) square sample at 18 and 30 DAT. Weeds were collected at ground level, counted, separated by species and placed in forced air circulation, at 65°C, until constant mass was achieved to determine the dry matter.

The maximum, minimum, daily thermal amplitude and soil temperature variation throughout the day were measured during the lettuce crop cycle. Soil temperature was measured from 0 to 18 DAT, because after this period, the leaf shading of the crop reduces the soil temperature variation.

Total water volume applied was determined based on the daily and weekly consumption of the crop.

Twelve lettuce plants, from the two central rows, were harvested at ground level at 30 DAT and weighed on a digital scale. The fresh matter mass of the aerial part from ground level to the plant extremity (t ha^{-1}) and leaf number per plant from the basal leaves to the last open leaf, considering leaves larger than 5 cm were determined. The water use efficiency (USA, kg m^{-3}) was determined using the formula USA= Y/V, where Y is the yield (t ha^{-1}) and V the total water volume applied (m^3 ha^{-1}) (Green *et al.*, 2010).

The data were submitted to variance analysis and the means compared using Tukey's range test (α = 0.05) using the statistical program R (R Development Core Team, 2014).

RESULTS AND DISCUSSION

Weed density and dry matter accumulation were 98% lower with the polyethylene film and recycled paper at 18 and 30 DAT in relation to uncovered and WW treatments (Table 1). The reduction of weed density and dry matter accumulation in lettuce crop with the soil covered with polyethylene film and recycled paper occurred due to physical barrier formation, preventing light passage, inhibiting weed germination by physical pressure on emergence and/ or weed growth (Moreno *et al.*, 2013, Haapala *et al.*, 2014). In agreement with obtained result in this study, a reduction of 80% of weed density with soil cover with paper has been reported for lettuce in Quebec, Canada (Brault & Stewart, 2002), cucumber in Helsinki, Finland (Haapala *et al.*, 2015), tomato in Zaragoza, Spain (Anzalone *et al.*, 2010) and summer squash in Leingtanky, USA (Coolong, 2010). Recycled paper can be considered an efficient method to control weeds. The maximum soil temperature with the polyethylene film was 6.1ºC higher until the 18 DAT than in the treatment WR. The soil maximum temperature covered with

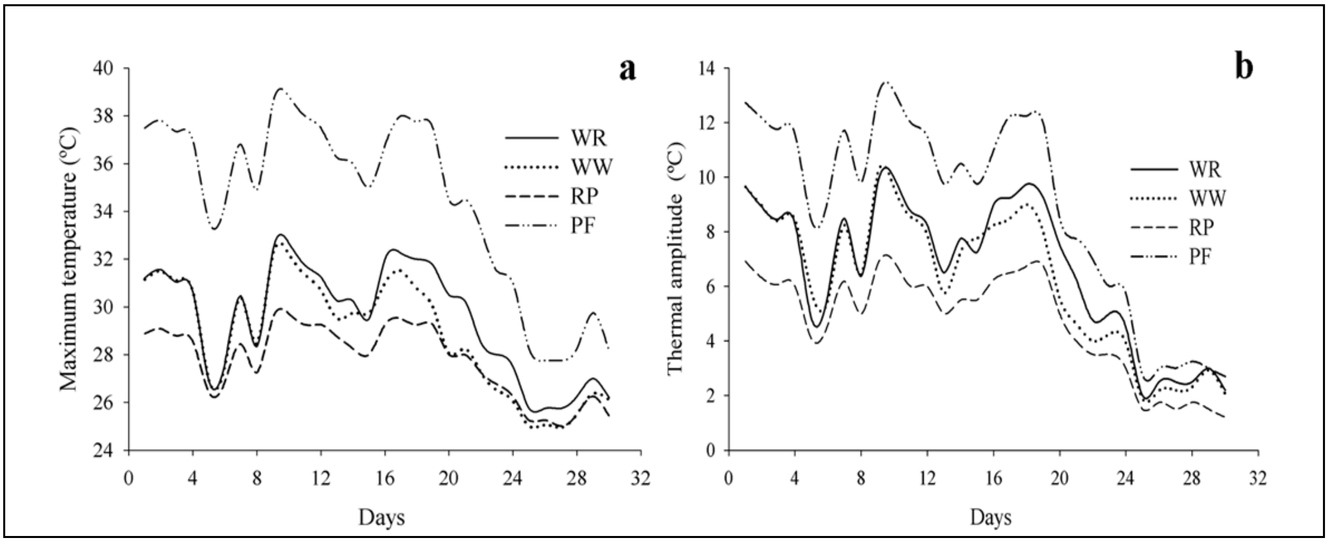

Figure 1. Maximum temperature (**a**) and thermal amplitude (**b**) of the soil during the lettuce cycle, in the treatments without soil cover with weed removal (WR), without soil cover and without weed removal (WW), covered with polyethylene film (PF) and recycled paper (RP). Viçosa, UFV, 2017.

recycled paper was 8.2 and 2.1ºC lower than with polyethylene film and either WW, respectively (Figure 1a). The soil thermal amplitude with polyethylene film and recycled paper over time was 11.2 and 5.9ºC, respectively, up to 18 DAT (Figure 1b).

The reduction of soil temperature with recycled paper is due to the lower solar radiation absorption (Hapaala *et al.*, 2014, 2015; Kader *et al.*, 2017a), unlike the polyethylene film that absorbs more solar radiation, emits thermal radiation and increases soil temperature (Xiukang *et al.*, 2015; Moreno *et al.*, 2016; Gu *et al.*, 2018). Lower thermal amplitude is attributed to the physical characteristics of the paper that reduces soil maximum temperature and increases minimum temperature (Moreno *et al.*, 2008). The soil temperature reduction is due to lower energy absorption; so, the recycled paper shows the efficiency of this material to reduce the soil temperature.

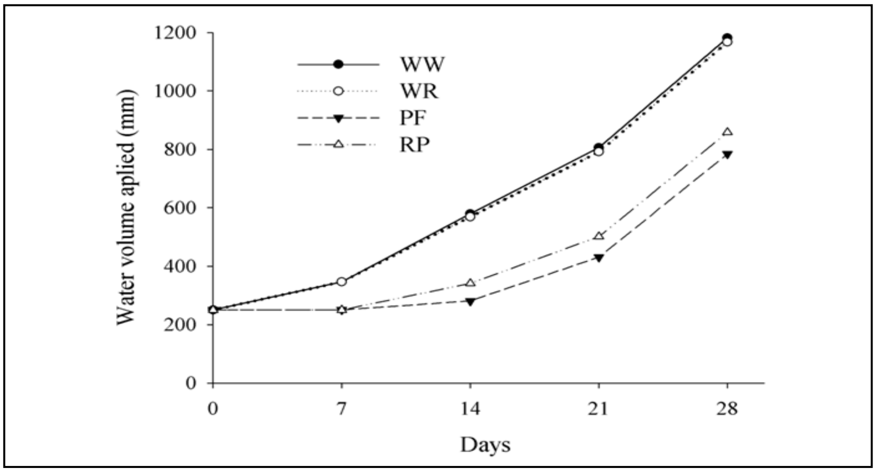

Figure 2. Water volume applied during the lettuce cycle, in the treatments soil without cover with weed removal (WR) and soil without cover and without weed removal (WW), covered with polyethylene film (PF) and recycled paper (RP). Viçosa, UFV, 2017.

The lettuce yield was higher in the soil covered with recycled paper (47.7 t ha^{-1}), followed by the treatments WR (41.7 t ha^{-1}) and polyethylene film (37.2 t ha^{-1}). Production was lower in the treatment without cover and WW (23.92 t ha^{-1}). The lettuce leaf number was highest in the treatments with recycled paper, polyethylene film and the treatment WR and lowest with WW. The lettuce plant height was higher with the recycled paper and WW and similar in the other treatments (Table 2). The highest lettuce yield obtained in the soil covered with recycled paper is due to the soil temperature reduction, which is important because high temperature decreases growth and increases roots thickness, contributing to lower water and nutrient absorption (He *et al.*, 2009). Additionally, higher soil temperature increases the root respiration rate (Klock *et al.*, 1997) decreasing CO_2 assimilation, stomatal conductance and relative leaf water content (He *et al.*, 2001). The lower plant yield observed in the uncovered treatment and WW was due to higher weed infestation competing with lettuce for water, light and nutrients, and decreasing leaf area and number of leaves (Ngouajio *et al.*, 2003).

The total water volume applied was higher at 30 days in the treatments without cover WW and WR, 1,182 and 1,167 m^3 ha^{-1}, respectively (Figure 2). This application was 33.4 and 26.5% lower with the polyethylene film and recycled paper mulching, respectively, than in the treatment without cover and WR. The water use efficiency was higher with recycled paper (55.5 kg m^{-3}), followed by polyethylene film

Table 1. Density and dry matter of weeds (mean ± standard error) in lettuce cultivation at 18 and 30 days after transplanting, in treatments without soil cover with weed removal (WR), without soil cover and without weed removal (WW), covered with polyethylene film (PF) and recycled paper (RP). Viçosa, UFV, 2017.

Treataments	Density (plants m^{-2})		Dry matter of weeds (g m^{-2})	
	18 days	30 days	18 days	30 days
WW	338.4 ± 65.8 a	325.6 7 ± 70.6 a	103.9 ± 20.2 a	205.0 ± 41.5a
WR	-	85.8 ± 4.83 b	-	9.1 ± 0.7 b
PF	0.8 ± 0.3 b	1.9 ± 0.6 c	0.2 ± 0.1b	2.9 ± 0.9 c
RP	2.2 ± 0.7 b	2.9 ± 0.3 c	0.2 ± 0.1 b	0.9 ± 0.5 c
CV (%)	22.15	11.00	20.13	14.00

*Means followed by the same letter per column do not differ by the Tukey test (P≤0.05). -data not evaluated due to weeding in the plots. CV= coefficient of variation.

Table 2. Yield, number of leaves per plant (Lea), plant height (H) and water use efficiency (WUE) in the lettuce culture (mean ± standard error) in treatments (Trat) without soil cover with weed removal (WR), without soil cover and without weed removal (WW), covered with polyethylene film (PF) and recycled paper (RP). Viçosa, UFV, 2017.

Trat	Yield (t ha^{-1})	Lea ($planta^{-1}$)	H (cm)	WUE (kg m^{-3})
WW	23.9 ± 2.4 d	13.1 ± 0.2 b	28.3 ± 0.4 ab	23.0 ± 2.0 d
WR	41.6 ± 0.9 b	17.0 ± 0.2 a	24.8 ±0.2 bc	35.7 ± 0.9 c
PF	37.2 ± 0.2 c	17.5 ± 0.8 a	24.0 ± 0.4 c	47.4 ± 0.2 b
RP	47.7 ± 0.4 a	18.0 ± 0.7 a	26.7 ± 0.8 a	55.5 ± 0.5 a
CV (%)	7.52	7.30	4.37	6.10

*Means followed by the same letter per column did not differ by the Tukey test (P≤0.05) CV= coefficient of variation.

mulching (47.4 kg m^{-3}) and the other treatments. This efficiency was 56 and 33% higher using recycled paper and the polyethylene film mulching, respectively, than in the soil without cover and WR (35.7 kg m^{-3}).

The higher water volume applied in the uncovered treatments was due to a higher water evaporation rate from the soil and the highest weed density (Kader *et al.*, 2017b; Sharma & Bhardwaj, 2017). The reduction in water volume applied on plants is due to the physical barrier imposed by polyethylene film and recycled paper that reduces the soil water losses by evaporation (Haapala *et al.*, 2014; Zhao *et al.*, 2014), and thus keeping the soil moisture for a longer period (Chakraborty *et al.*, 2008). The lower water use with the polyethylene film can be attributed to maintaining soil moisture for longer time, due to its lower porosity, which decreases soil water loss (Haapala *et al.*, 2014). The greater efficiency of water use with recycled paper compared to polyethylene film is due to the higher yield of lettuce obtained, related to the volume of applied water and in addition to the reduction in maximum temperature and thermal amplitude that contributed to this increase.

Soil cover with recycled paper controls weeds, reduces soil temperature and water consumption and increases the yield and water use efficiency in lettuce crop.

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