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Mulching as an alternative technique for weed management in mandarin orchard tree rows

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Abstract – Moving towards sustainable agriculture implies exploring the interconnections between farming and the environment, and soil is a key component of sustainability. Mulching is one of the methods to protect and enhance the productivity of the soil. We studied here the effect of mulching applied to mandarin tree rows for weed control in two localities near Tortosa, Spain, to compare its performance with the present chemical weed control system using the herbicide glyphosate. Three mulches were tested in each citrus orchard: rice straw, almond husk and black geotextile. Five plots per treatment, that is, three mulches, glyphosate application and control, were arranged following a randomized block design. Each plot was five trees long and its width was the distance between the two drip-lines. Just before mulch installation, bags containing non-dormant seeds of *Amaranthus retroflexus* and *Diplotaxis erucoides* were buried at three depths, and were exhumed one year later. After exhumation, sets of 250 seeds were placed in incubators and cumulative germination was obtained. Moreover, the weed flora was monitored at the two localities on four dates over one year and its total cover was evaluated. Seeds of *A. retroflexus* and *D. erucoides* showed the highest germination below almond husk, 90.9% and 96.2%, respectively. In total 74 species were recorded covering the mandarin tree rows. Our results indicated that black geotextile and almond husk controlled the presence of weeds as well as or better than the applications of glyphosate at least during the first year after their introduction. No significant differences were found between the mean weed cover of black geotextile (0.88%), almond husk (4.04%) and herbicide plots (2.04%). Altogether, our results show that mulching is one weed control strategy in mandarin orchards that also provides other benefits in terms of sustainable agriculture, such as soil protection or avoiding herbicide pollution.

citrus / *Amaranthus* / *Diplotaxis* /seed germination / cover / almond husk / rice straw / black geotextile

1. INTRODUCTION

Conventional practices for weed management in Spanish citrus orchards usually include cultivation and annual application of residual herbicides in the inter-rows, as well as repeated use of glyphosate in the tree rows. Herbicides are considered excellent tools within a weed management strategy in many cropping systems; however, misuse of this technology can lead to problems such as residual carry-over, cropping restrictions, groundwater contamination and the development of genetically-based herbicide resistance (Booth et al., 2003). Particularly, in orchards, questions have been raised concerning the long-term environmental impacts of repeated tillage on soil erosion, and of pesticide applications on soil and water quality (Lipecki and Berbec, 1997; Castillo et al., 2003; Meli et al., 2003; Durán Zuazo et al., 2004).

Alternatively, Integrated Production systems, which have been successfully adopted in some of the main apple-growing regions of Europe (Sansavini, 1997), combine management methods commonly used in conventional farming with others developed for organic production systems, in an attempt to optimize both environmental quality and economic profit. The Spanish citrus Integrated Production regulation, published in June 2004, establishes that farmers should cover the inter-rows by allowing spontaneous vegetation growth or by leaving pruning residues on the ground, and recommends mulching, mowing or cultivation to control weeds in the tree row. Mowing is an important orchard management method; it is based on cutting the standing vegetation with a scythe or a mechanical device. Mulching is one of the advantageous practices you can use in agriculture; it consists of spreading on top of the soil a protective layer of a material that can either be organic or inorganic. Among the numerous benefits, mulch prevents weed growth.

Among the types of mulch that farmers can use are living mulches, black polyethylene and geotextile mulches, and dead organic mulches such as straw, bark and loose materials. Many studies have reported the advantages and limitations of each of them. Living mulch is defined as a mixed cropping system, in which one partner acts chiefly as a live soil cover for a considerable part of the life cycle of the main crop (Liedgens et al., 2004). These kinds of mulches are well suited to use in vineyards or fruit crops (Váradi et al., 1989; Ingels et al., 1994), but even in established orchards a living mulch growing along the planted row may depress crop growth (Domange, 1993; Marks, 1993). A ground cover that is actively growing in the summer takes up water; and this is a severe disadvantage in irrigated orchards, where water is limited and expensive (Ames and Kuepper, 2004).

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Black polyethylene mulches are used for weed control in a range of crops under the organic growing system (Bond and Grundy, 2001). For example, Bredell (1973) studied the effect of plastic mulching in a Valencia citrus orchard and concluded that tree yields and growth were positively stimulated, mainly due to soil moisture conservation. But these kinds of mulches do not provide the advantages of adding organic matter and nutrients to the soil and, if they are synthetic, they must eventually be removed.

Loose materials such as straw, bark and composted municipal green waste can provide effective weed control as organic mulches, but the thickness of the mulch layer needed to suppress weed emergence is likely to make transport costs prohibitive unless the material is produced on-farm (Merwin et al., 1995). Weed suppression by organic mulches can be due to the physical presence of the materials on the soil surface and/or the action of phytotoxic compounds generated by microbes (Ozores-Hampton et al., 2001). Because organic mulches decompose over time, they require periodic re-application in order to continue to suppress weeds; however, their decomposition could also provide benefits; for instance, by enhancing soil aggregation and water-holding capacity (Haynes, 1980).

Although weed suppression is not the only reason for using mulches, it is the main goal in the case of integrated production. According to the "Guidelines for integrated production of citrus" of the International Organization for Biological and Integrated Control of Noxious Animals and Plants, trials involving mulches, especially loose materials from adjacent crops, are entirely appropriate in view of the modern approach to integrated plant protection in sustainable production systems. This work evaluated the performance for weed management of different types of mulch at two levels: (1) in the very short term, evaluating the weed cover developing in the course of one year, and (2) studying the seed germination behavior of two weed species exhumed one year after the application of the mulches.

2. MATERIALS AND METHODS

2.1. Field trials

The study was done in two mandarin (*Citrus reticulata*) orchards located in the northern area of the Spanish citrus production region: specifically, in the villages of Alcanar (0°29'E and 40°33'N) and Santa Bàrbara (0°30'E and 40°43'N). The long-term average yearly precipitation is 580.4 mm and the average monthly air temperature is 16.9 °C in the nearby city of Tortosa (MAPA, 1989). During the study, from March 2003 to March 2004, the accumulated rainfall was 758.9 mm, and the average monthly temperature was 18.7 °C in Tortosa according to data from the Spanish Meteorological Service.

The two surveyed orchards had drip fertirrigation systems; the amounts of applied fertilizers were 400–450 g N yr^{-1} $tree^{-1}$, 100–120 g P yr^{-1} $tree^{-1}$, 200–250 g K yr^{-1} $tree^{-1}$ and 25–30 g Mg yr^{-1} $tree^{-1}$. Each tree row was flanked by two drip-lines. Before mulch application, weed management included (i) chemical control of weeds by glyphosate spraying in the tree rows, 3–5 times a year at rates ranging from 270 g a.i. $ha^{-1}$to 720 g a.i. ha^{-1}, depending on the weed cover, and (ii) mowing of the natural inter-row vegetation. Both orchards, named Muller in Alcanar and El Virol in Sta Bàrbara, were planted in 1999. The chosen varieties were cv. 'Clementina arrufatina' in Muller and cv. 'Clementina nules' in El Virol, both on Carrizo citrange rootstock. The trees in Muller were spaced 2.5 m within rows in rows 6 m apart, yielding a density of 667 trees ha^{-1}, while in El Virol the spacing was 4 m within rows and 5 m between rows (500 trees ha^{-1}).

Three mulches were tested in each orchard: rice straw with a thickness of 20 cm, almond husk with a thickness of 20 cm, and black geotextile of woven polypropylene strips of 140 g m^{-2}. Periodic glyphosate applications, that is, the standard treatment applied before the onset of the experiment, and an unweeded control were the other two treatments tested (Fig. 1). The almond husks employed were loose materials from adjacent dryland crops, and the rice straw was from the rice crops of the Ebro Delta. Each elementary plot was composed of a rectangular surface five trees long and as wide as the distance between the two drip-lines of 2 m; the corresponding surfaces were 25 m^2 in Muller and 40 m^2 in El Virol. The five treatments were replicated 6 times at the two localities following a randomized block design. One glyphosate application was performed on the tree rows one week before mulch application, which took place on 11 March 2003 in Muller and on 12 March 2003 in El Virol.

2.2. Assessment of weed species richness, cover and floristic structure

The natural weed flora in the five treatments was inventoried in the two localities on four dates: 13/06/2003, 24/09/2003, 12/12/2003 and 10/03/2004. Species were determined according to Bolòs et al. (1993). Total weed cover was estimated visually by two trained persons and expressed as a percentage of the total surface. To minimize the edge effect, only the surface area between the trunks of the first and the fifth trees of each plot was assessed.

Weed species richness and total weed cover were subjected to analysis of variance followed by a least squares means multiple comparison. The Tukey-Kramer method was chosen for multiple comparison of the five levels of the main factor mulch, the two levels of the main factor locality, and the interaction between them. For these data, a pooled analysis of variance for measurements over time was used (Gomez and Gomez, 1984) considering three main factors: mulch, locality and time of observation (four levels). The General Linear Models procedure, which uses the method of least squares to fit general linear models, was used for analyses using the type III estimable function of parameters (SAS Institute Inc., 1999). Homogeneity of variances was tested. Natural logarithm transformation of percent weed cover was chosen as the best data transformation in order to homogenize variances.

Figure 1. Overview of the experiments in September 2003. Upper line: general view of Muller lawn (at left), and a control plot (at right). Lower line, from left to right, plots with almond husk mulch, with rice straw mulch, with black geotextile, and one recently treated with glyphosate.

Floristic data were analyzed by multivariate methods of classification in each locality. Firstly, the hypothesis of no differences between the floristic compositions of the five treatments tested was checked using a multi-response permutation procedure (MRPP: Zimmerman et al., 1985). Mulches were used as categorical variables. Secondly, floristic groups were obtained by cluster analysis. The Sørensen coefficient (Magurran, 1988) was used as a distance measure for species. Farthest neighbor was used as a similarity measure (van Torengen, 1987).

2.3. Seed germination of selected weed species

Seeds of two species, *Amaranthus retroflexus* and *Diplotaxis erucoides*, were collected in nearby mandarin orchards at the time of their natural dispersal, that is, in summer and spring of 2002, respectively. Both species are common throughout arable land in the area, including citrus orchards (Mas et al., 2007). After collection, the seeds were air-dried, cleaned and stored at room temperature until the experiment started. The weight of 1000 seeds was 0.487 g for *A. retroflexus*, and 0.181 g for *D. erucoides*. Groups of approximately 250 seeds, calculated by weight, were placed inside nylon mesh bags. Just before mulch installation, the bags were buried at 10 cm, 5 cm and 0 cm depths between two of the central trees of each elementary plot. Five replications per treatment were included.

After one year, on 15 March 2004 in El Virol and on 22 March 2004 in Muller, the seeds were exhumed and tested for germination. The seeds were rinsed for 5 minutes with 5% diluted sodium hypochlorite for surface sterilization (ISTA, 1985). Three replicates of 50 seeds from each bag were counted and placed in 9-cm diameter plastic Petri dishes. All the dishes were transferred to an incubator with a 35 °C 12 h/12 h dark/light treatment for *Amaranthus retroflexus* and a 25 °C 12 h/12 h treatment for *Diplotaxis erucoides*. These regimes are considered to be optimal for germination of non-dormant seeds of *A. retroflexus* (Baskin and Baskin, 1977) and *D. erucoides* (Pérez-García et al., 1995). Illumination was provided by white 3×8 W fluorescent tubes. Water was added as required. Seeds were considered to be germinated when the radicle was visible. The percentage of mouldy seeds and the percentage of empty episperms were also recorded.

The final germination percentage was subjected to analysis of variance followed by a Tukey-Kramer least squares means comparison test using the General Linear Models procedure (SAS Institute Inc., 1999) after arcsine transformation, considering Petri dishes as experimental units. For each species three main factors were considered: (1) locality, with two levels, (2) mulch, with five levels, and (3) depth, with three levels; the interaction between locality and treatment, and the interaction between treatment and depth were also included in the analysis of variance.

3. RESULTS AND DISCUSSION

To answer the aim of the present study concerning the performance for weed management of three types of mulch we present the results arranged in three groups: an evaluation of the weed species richness and the floristic structure, an annual monitoring to check the evolution of weed cover, and a survey of seed germinability of two weed species exhumed one year after the application of the mulches.

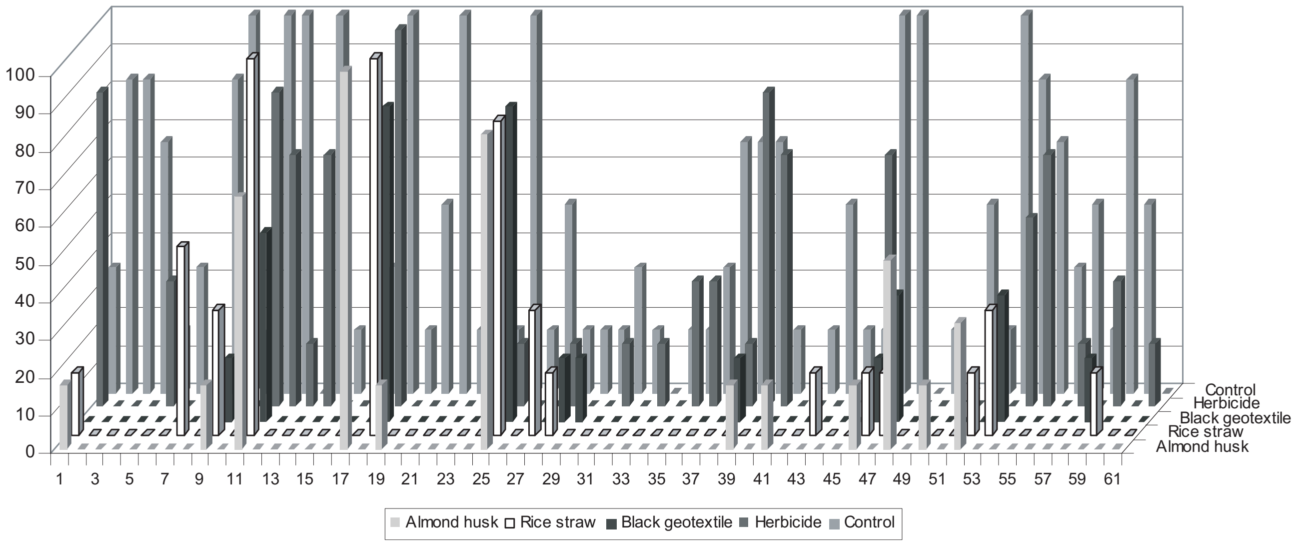

Figure 2. Percentage of the species frequency in each treatment in Muller. Species are: 1-*Allium roseum* L. 2-*Amaranthus blitoides* S. Watson. 3-*A. graecizans* L. 4-*A. retroflexus* L. 5-*Anagallis arvensis* L. 6-*Anacyclus valentinus* L. 7-*Asparagus acutifolius* L. 8-*Bromus rubens* L. 9-*Calendula arvensis* L. 10-*Capsella bursa-pastoris* (L.) Medik. 11-*Convolvulus arvensis* L. 12-*Conyza bonariensis* (L.) Cronquist. 13-*C. canadensis* (L.) Cronquist. 14-*C. sumatrensis* (Retz.) E. Walker. 15-*Coronopus didymus* (L.) Sm. 16-*Cynodon dactylon* (L.) Pers. 17-*Cynosurus echinatus* L. 18-*Cyperus rotundus* L. 19-*Digitaria sanguinalis* (L.) Scop. 20-*Diplotaxis erucoides* (L.) DC. 21-*Eragrostis barrelieri* Daveau. 22-*Erodium acaule* (L.) Bech. et Thell. in Bech. 23-*E. cicutarium* (L.) L'Hér. in Aiton. 24-*E. malacoides* (L.) L'Hér. 25-*Euphorbia prostrata* Aiton. 26-*E. serpens* Kunth in Humb., Bonpl. et Kunth. 27-*Fumaria officinalis* L. 28-*F. parviflora* Lam. 29-*Galium aparine* L. 30-*Geranium molle* L. 31-*G. rotundifolium* L. 32-*Heliotropium europaeum* L. 33-*Lamium amplexicaule* L. 34-*Lamarckia aurea* (L.) Moench. 35-*Lathyrus* sp. 36-*Lavatera* sp. 37-*Lolium rigidum* Gaudin. 38-*Medicago littoralis* Rhode ex Loisel. 39-*Medicago* sp. 40-*Muscari neglectum* Guss. ex Ten. 41-*Oryzopsis miliacea* (L.) Asch. et Graebn. 42-*Oxalis corniculata* L. 43-*Papaver rhoeas* L. 44-*Parietaria officinalis* L. 45-*Plantago lanceolata* L. 46-*Poa annua* L. 47-*Portulaca oleracea* L. 48-*Prunus dulcis* (Mill.) D. A. Webb. 49-*Rubia peregrina* L. 50-*Sedum album* L. 51-*Senecio vulgaris* L. 52-*Smilax aspera* L. 53-*Sonchus oleraceus* L. 54-*S. tenerrimus* L. 55-*Stellaria media.* 56-*Tragus racemosus* (L.) All. 57-*Tribulus terrestris* L. 58-*Veronica hederifolia* L. 59-*V. persica* Poiret in Lam. 60-*V. polita* Fr. 61-*Xanthium* sp.

3.1. Weed species richness and floristic structure

In the course of the study we identified 74 species, of which 61 were in Muller (Fig. 2) and 48 in El Virol (Fig. 3). The two localities shared 35 species. The percentage of the total site richness observed in the control treatments were 89% in Muller and 92% in El Virol. In Muller *Asparagus acutifolius*, *Conyza canadensis*, *Lamium amplexicaule*, *Oryzopsis miliacea*, *Prunus dulcis*, *Sedum album* and *Xanthium* sp. were observed only in the treated plots. *Anacyclus valentinus*, *Fumaria capreolata*, *Lolium rigidum* and *Prunus dulcis* appeared outside the control treatment plots in El Virol.

From the point of view of management, if we compare the species observed in the treated plots with those occurring in the control plots, the reduction in species richness was: (1) in Muller, 76%, 83%, 80% and 63% for the rice straw, almond husk, black geotextile and herbicide treatment, respectively; (2) in El Virol, 57%, 59%, 70% and 57%, respectively. For weed species richness, the main effect "mulch" and the interaction "mulch x locality" were significant at $P < 0.0001$ and $P = 0.0003$, respectively, while the main effect "locality" was not. It is noticeable that herbicide was the treatment with the least effective control in terms of presence of weed species (Tab. I).

Among the species that were able to grow on all three types of mulches in both localities, even taking advantage of splits in the case of geotextile, were *Convolvulus arvensis* and *Cyperus rotundus*. Both species are geophytes, and it seems that some rhizomes, as well as some stem tubers of *C. rotundus*, had sufficient food stores to form aerial shoots that could grow through the organic mulches and reach an illuminated environment. Also of interest is the finding of some perennial bird-dispersal species such as *Asparagus acutifolius*, *Rubia peregrina* and *Smilax aspera*, which are characteristic species of the Mediterranean evergreen forest (*Viburno-Quercetum ilicis* Rivas Mart. 1975).

The floristic composition of the mulches at the two localities was significantly different, as tested by the MRPP analysis ($P < 0.0001$). Cluster analysis detected six floristic groups in Muller (57 species), and seven floristic groups in El Virol (45 species) (Tab. II). Nevertheless, with regard to species frequencies (Figs. 2, 3), the floristic groups did not enable us to associate any type of mulching with a defined group of species at either locality.

3.2. Weed cover

The analysis of variance of weed cover (Tab. III) showed high significance ($P < 0.001$) for locality, mulch, time of

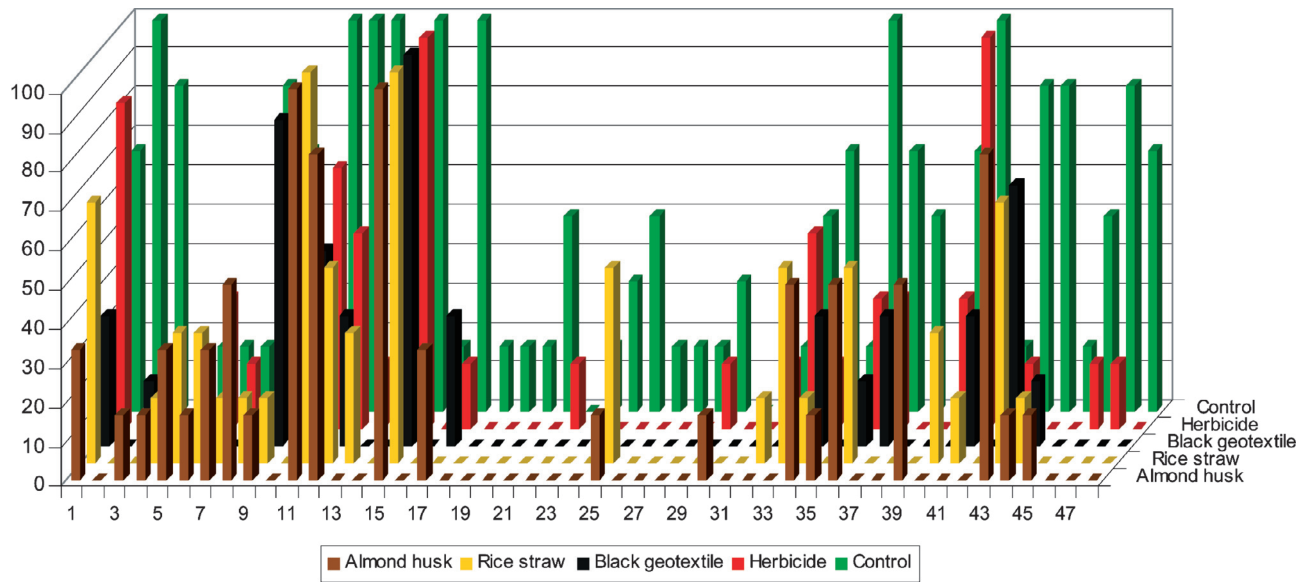

Figure 3. Percentage of the species frequency in each treatment in El Virol. Species are: 1-*Allium roseum* L. 2-*Amaranthus blitoides* S. Watson. 3-*A. retroflexus* L. 4-*Anacyclus valentinus* L. 5-*Araujia sericifera* Brot. 6-*Arum italicum* Mill. 7-*Asparagus acutifolius* L. 8-*Avena sterilis* L. 9-*Bromus catharticus* Vahl. 10-*Chenopodium album* L. 11-*Convolvulus arvensis* L. 12-*Conyza bonariensis* (L.) Cronquist. 13-*C. sumatrensis* (Retz.) E. Walker. 14-*Cynodon dactylon* (L.) Pers. 15-*Cyperus rotundus* L. 16-*Digitaria sanguinalis* (L.) Scop. 17-*Diplotaxis erucoides* (L.) DC. 18-*Echinochloa crus-galli* (L.) P. Beauv. 19-*Erodium malacoides* (L.) L'Hér. 20-*Euphorbia peplus* L. 21-*E. prostrata* Aiton. 22-*Fumaria capreolata* L. 23-*F. officinalis* L. 24-*F. parviflora* Lam. 25-*Galium aparine* L. 26-*Geranium. rotundifolium* L. 27-*Hordeum murinum* L. 28-*Lathyrus* sp.29-*Lavatera* sp.30-*Lolium rigidum* Gaudin. 31-*Medicago littoralis* Rhode ex Loisel. 32-*Mercurialis annua* L. 33-*Muscari neglectum* Guss. ex Ten. 34-*Oryzopsis miliacea* (L.) Asch. et Graebn. 35-*Oxalis corniculata* L. 36-*Parietaria officinalis* L. 37-*Poa annua* L. 38-*Portulaca oleracea* L. 39-*Prunus dulcis* (Mill.) D. A. Webb. 40-*Senecio vulgaris* L. 41-*Setaria verticillata* (L.) P. Beauv. 42-*Solanum nigrum* L. 43-*Sonchus oleraceus* L. 44-*S. tenerrimus* L. 45-*Sorghum halepense*(L.) Pers. 46-*Veronica hederifolia* L. 47-*V. persica* Poiret in Lam. 48-*V. polita* Fr.

Table I. Comparison of the least square mean values of weed species richness within the levels of the significant ($P \leqslant 0.05$) effects "mulch" and "locality × mulch". In each column, means with different letters are significantly different at $P \leqslant 0.05$ (Tukey-Kramer test).

Mulch		Locality	Number of species	
Control	24.3 a	Muller	22.3	a
		El Virol	26.2	a
Herbicide	9.0 b	Muller	10.2	b
		El Virol	7.8	bcd
Rice straw	6.8 bc	Muller	5.5	cd
		El Virol	8.0	bcd
Almond husk	6.5 bc	Muller	4.5	cd
		El Virol	8.5	bc
Black geotextile	4.7 c	Muller	3.8	d
		El Virol	5.5	cd

observation and all interactions of these factors. The reduction of the weed cover due to all three types of mulch was effective (Tab. IV), because the mean values of weed cover were lower ($P < 0.05$) in the mulches than in the control at both localities. Furthermore, the mean weed cover value obtained for black geotextile was not significantly different from that of the herbicide treatment, therefore showing a good performance. Bredell (1973), using plastic sheets for weed control in citrus, found that *Echinochloa* spp. developed runners which penetrated through the plastic, resulting in a perfect stand of this weed. In our work, we did not observe any plants showing this emergence behavior under geotextile mulch.

Total weed cover in the almond husk mulch was not significantly different from that of herbicide treatment either. Almond husks can be a good alternative to the use of herbicides, because they are easy to transport and apply on the citrus rows. However, at present they are viewed as an alternative source of energy to fossil fuels (Demirbas, 2005) and in the study zone almond husks are not economical for mulching because they are used to heat glasshouses.

Total weed cover showed significant differences between localities (Tab. III), being higher in El Virol than in Muller (Tab. VI) for all five treatments. Differences in the abundance of natural weed vegetation (58.1% in El Virol vs. 19.9% in Muller in the control) could be attributable to a different history and weed management at the two localities. In fact, in El Virol the distance between trees was greater, hence the proportion of unshaded mulch surface was higher, which likely favored weed growth.

The similarity of the almond husk and herbicide total weed cover values obtained in Muller (1.3% and 1.1%, respectively) as opposed to El Virol (6.8% and 3.0%) explains the

Table II. Floristic groups of the two localities (Muller and El Virol) as obtained by cluster analysis.

Muller		El Virol	
I	*Digitaria sanguinalis* *Oryzopsis miliacea* *Sedum album*	I	*Anacyclus valentinus* *Prunus dulcis*
II	*Diplotaxis erucoides* *Erodium acaule* *E. cicutarium* *E. malacoides* *Plantago lanceolata* *Senecio vulgaris* *Tragus racemosus* *Tribulus terrestris*	II	*Arum italicum* *Cynodon dactylon* *Digitaria sanguinalis* *Echinochloa crus-galli* *Erodium malacoides* *Euphorbia peplus* *Fumaria parviflora* *Geranium rotundifolium* *Medicago littoralis*
III	*Euphorbia serpens* *Galium aparine* *Parietaria officinalis*	III	*Araujia sericifera* *Solanum nigrum*
IV	*Cynodon dactylon* *Cynosurus echinatus* *Geranium molle* *Heliotropium europaeum*	IV	*Asparagus acutifolius* *Chenopodium album* *Lathyrus* sp. *Lavatera* sp. *Muscari neglectum*
V	*Allium roseum* *Amaranthus blitoides* *A. graecizans* *A. retroflexus* *Anagallis arvensis* *Anacyclus valentinus* *Calendula arvensis* *Capsella bursa-pastoris* *Conyza canadensis* *Coronopus didymus* *Eragrostis barrelieri* *Fumaria officinalis* *Geranium rotundifolium* *Lamarckia aurea* *Lathyrus* sp. *Lavatera* sp. *Lolium rigidum* *Muscari neglectum* *Papaver rhoeas* *Portulaca oleracea* *Rubia peregrina* *Smilax aspera* *Sonchus oleraceus* *Veronica hederifolia* *V. polita*	V	*Amaranthus blitoides* *Euphorbia prostrata* *Fumaria officinalis* *Mercurialis annua* *Sonchus tenerrimus* *Veronica persica* *V. polita*
VI	*Bromus. rubens* *Convolvulus arvensis* *Conyza bonariensis* *C. sumatrensis* *Cyperus rotundus* *Euphorbia prostrata* *Fumaria parviflora* *Medicago littoralis* *Medicago* sp. *Oxalis corniculata* *Poa annua* *Sonchus tenerrimus* *Stellaria media* *Veronica persica*	VI	*Amaranthus retroflexus* *Conyza sumatrensis* *Galium aparine* *Oxalis corniculata* *Portulaca oleracea* *Senecio vulgaris* *Sorghum halepense* *Veronica hederifolia*
		VII	*Allium roseum* *Avena sterilis* *Bromus catharticus* *Convolvulus arvensis* *Conyza bonariensis* *Cyperus rotundus* *Diplotaxis erucoides* *Oryzopsis miliacea* *Parietaria officinalis* *Poa annua* *Setaria verticillata* *Sonchus oleraceus*

significance of the locality × mulch interaction (Tab. III). Furthermore, the significance of the factor "time of observation" was probably due to the fact that more than 75% of the species found in the two localities are annuals with a seasonal life cycle.

All three types of mulching persisted and covered the soil throughout the year of the experiment. However, most of the rice straw was blown away by the strong winds that are common in the Ebro Valley.

3.3. Seed germination of selected weed species

In general, there were no methodological problems with the bags that contained the seeds of *Amaranthus retroflexus* at the time of exhumation, in either location or in any treatment. The three main effects considered as sources of variation were significant ($P < 0.01$, Tab. V), as well as the mulch × depth interaction. Seeds exhumed from almond husk showed a higher mean germination than those exhumed from the herbicide and rice straw treatments (Tab. VI). The mulch × depth interaction was significant because seeds buried below almond husk did not follow the general behavior with regard to depth, since the highest germination was observed at 5 cm.

Data from this research do not provide information about the viability of the treated seeds, but the seeds that failed to germinate did not show a broken coat or a squashed embryo. Considering the information provided by studies on the viability and dormancy of this species (i.e. Egley, 1990; Omami et al., 1999; Uremis and Uygur, 2005) it could be that, during the burial period, the proportion of *A. retroflexus* seeds that acquired dormancy below almond husk was lower than in the other treatments tested. Omami et al. (1999), in a 12-month study period, found that the reduction in germination of *A. retroflexus* became greater as depth of burial increased. These authors concluded that seeds may have increasingly acquired dormancy because of inhibitory factors, such as darkness or the lack of edaphic conditions suitable for germination. Seed decay should also be considered, as Ozores-Hampton et al. (2001) indicated that weed suppression by organic mulches can be due to the action of phytotoxic compounds. Nevertheless, this eventuality may have little importance in this case, because Urrestarazu et al. (2005) conclude that almond husk seems to be an acceptable growing media as a rockwool substitute for soilless vegetable production.

Table III. Analysis of variance on percent weed cover considering the main effects "locality", "mulch" and "time of observation". Data values were transformed (ln + 1) before analysis.

Source of variation	Degree of Freedom	Mean Square	*F*-value	*P*
Locality	1	26.38	48.21	<0.0001
Mulch	4	53.59	97.89	<0.0001
Interaction Locality-Mulch	4	3.78	6.90	0.0002
Error (a)	50	0.55		
Time of observation	3	1.34	6.61	0.0003
Interaction Time of observation-Locality	3	5.04	24.70	<0.0001
Interaction Time of observation-Mulch	12	0.77	3.76	<.0001
Interaction Time of observation-Locality-Mulch	12	1.11	5.41	<.0001
Residual	148*	0.20		

* There were two missing values.

Table IV. Total weed cover (%) for the effects "locality" "mulch" and "locality × mulch". Within each source of variance means with different letters are significantly different at $P \leqslant 0.05$ (Tukey-Kramer test), based on transformed (ln + 1) data.

Source			Total cover	n
Locality		El Virol	16.04 a	119
		Muller	5.21 b	119
Mulch		Control	37.22 a	46
		Rice straw	10.05 b	48
		Almond husk	4.04 c	48
		Herbicide	2.04 cd	48
		Black geotextile	0.88 d	48
Interaction Locality-Mulch	Control	El Virol	55.98 a	23
		Muller	18.46 b	23
	Rice straw	El Virol	15.13 bc	24
		Muller	4.98 d	24
	Almond husk	El Virol	6.83 cd	24
		Muller	1.25 e	24
	Herbicide	El Virol	3.00 de	24
		Muller	1.08 e	24
	Black geotextile	El Virol	0.92 e	24
		Muller	0.83 e	24

Table V. Analysis of the effects "locality", "mulch" and "depth" on the percentage of germination of exhumed *Amaranthus retroflexus* and *Diplotaxis erucoides* seeds, obtained after 30 days of incubation. Data were arcsine-transformed before analysis.

Source		Degree of Freedom	Mean Squares	*F*-value	*P*
Locality	*A. retroflexus*	1	2.746	12.11	0.0006
	D. erucoides	1	0.798	7.51	0.0069
Mulch	*A. retroflexus*	4	0.964	4.25	0.0023
	D. erucoides	4	0.519	4.88	0.0010
Depth	*A. retroflexus*	2	1.287	5.67	0.0038
	D. erucoides	1	0.157	1.48	0.2264
Interaction Locality-Mulch	*A. retroflexus*	4	0.490	2.16	0.0732
	D. erucoides	4	0.249	2.35	0.0575
Interaction Mulch-Depth	*A. retroflexus*	8	1.029	4.54	< 0.0001
	D. erucoides	4	0.197	1.85	0.1220
Error	*A. retroflexus*	344	0.227		
	D. erucoides	141	0.106		

With respect to the seeds of *Diplotaxis erucoides*, a lower proportion of seeds failed to germinate below all three mulches than in the control. However, even considering that the main factor "mulch" was highly significant (Tab. V), the results of the mean comparison test (Tab. VI) were not as conclusive as those for *A. retroflexus*.

The percentage of germination of *D. erucoides* seeds located at 0 cm was not considered because of lack of data. The reasons for this were: (i) in the control plots the seeds germinated (and the plants flowered in some cases) inside the bags, (ii) in the almond husk plots the bags were perforated and many seeds were lost, and (iii) in the rice straw, black geotextile and herbicide treatments the seeds were found to be mouldy or showed fatal germination. From all these problems it could be concluded that below two of the three mulches most of the seeds germinated and the plants died. Thus, rice straw and black geotextile would control the fraction of the *D. erucoides* seed population that come into contact with the mulch layer (0 cm). An increase in seedling mortality when using plastic sheets was observed in Spanish citrus orchards (Delgado, 1995), but we could not find any information about the behavior of rice straw as mulch in orchards to compare with our results. Moreover, on the basis of our one-year experience, rice straw appears to be the least stable mulching system over time, because it blows away easily in the wind and loses volume (thickness) in a few weeks.

4. CONCLUSION

Considering weed species richness and cover, all three mulches tested had better performance than the control treatment. Mean species richness was significantly lower in mulches than in control plots; it ranged from 4.7 to 6.8 in

Table VI. Mean percent germination of exhumed *Amaranthus retroflexus* and *Diplotaxis erucoides* seeds after 30 days of incubation. For each species and effect, means with different letters are significantly different at $P \leqslant 0.05$ (Tukey-Kramer test based on arcsine-transformed data).

Effect			*A. retroflexus*	n	*D. erucoides*	n
Locality	El Virol		85.0 a	182	93.0 a	68
	Muller		76.6 b	182	85.1 b	88
Mulch	Almond husk		90.9 a	59	96.2 a	34
	Black geotextile		83.7 ab	78	86.6 a	32
	Control		83.8 ab	75	81.1 b	27
	Herbicide		74.4 b	76	87.3 ab	28
	Rice straw		73.4 b	76	89.6 a	35
Depth	0 cm		88.2 a	114	-	-
	5 cm		82.7 ab	129	-	-
	10 cm		71.8 b	121	-	-
Interaction Mulch-Depth	0 cm	Almond husk	96.9 a	20	-	-
		Black geotextile	91.2 a	26	-	-
		Control	71.9 ab	18	-	-
		Herbicide	90.3 a	23	-	-
		Rice straw	87.9 a	27	-	-
	5 cm	Almond husk	80.8 ab	22	-	-
		Black geotextile	86.9 a	26	-	-
		Control	84.4 a	30	-	-
		Herbicide	83.3 ac	26	-	-
		Rice straw	77.1 ab	25	-	-
	10 cm	Almond husk	96.9 a	17	-	-
		Black geotextile	73.1 ab	26	-	-
		Control	91.2 a	27	-	-
		Herbicide	52.1 b	27	-	-
		Rice straw	53.1bc	24	-	-

mulches and reached 24.3 in the control treatment. In turn, the mean percent weed cover attained in control plots was 37.22%, while in mulches it ranged between 0.88% and 10.05%. It is noticeable that neither black geotextile (0.88%) nor almond husk (4.04%) presented significant differences in mean percent weed cover as compared with the herbicide treatment (2.04%). The only mulch that presented problems of field persistence was rice straw, which blew away in the strong winds that are usual in the Ebro Valley. Seeds of *D. erucoides* exhumed after one year of burial under black geotextile and rice straw showed the highest mortality, attributable to germination and seedling death plus the effect of mould. In contrast, below almond husk the seeds of both *D. erucoides* and *A. retroflexus* presented the highest germination, 96.2% and 90.9%, respectively. Our work makes clear that black geotextile and almond husk as new organic mulch are successful alternatives to glyphosate applications for managing weeds in the citrus rows, at least during the first year. This being so, to evaluate new different types of mulch for weed management it is important to know weeds' ability to cover soil, but other mulch effects on the soil seed bank should be considered in future studies, since to a larger extent weeds can be a consequence of management decisions.

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