Effect of Mulching on Plant and Weed Growth, Substrate Water Content, and Temperature in Container-grown Giant Arborvitae

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Summary. This research evaluated the effectiveness of biodegradable mulches for weed control in container-grown 'Martin' giant arborvitae (*Thuja plicata*) and measured the effects of these mulches on evaporation and substrate temperature. The experiment was carried out in the 2008 and 2009 growing seasons. Four biodegradable mulching materials were tested and compared with a chemical control (oxadiazon) and a non-mulched/non-treated control. Two levels of overhead irrigation were evaluated: 1) daily irrigation to container capacity (well watered) and 2) daily irrigation to 30% of container capacity (water stressed). Two weed management regimes were used: 1) hand weeding three times during the growing season and 2) no weeding until the end of the growing season. Plants were potted in 3-L containers and arranged in a split–split plot design in an experimental nursery. Ornamental shoot dry weight was measured at the end of the growing season. Weed shoot dry weight per container was recorded after each hand weeding. Water content per pot (as a percentage of water-holding capacity) was measured by weighing containers every 2 hours during the day. Substrate temperature was measured in the warmest period of the day. Mulches limited weed growth to the same extent as the chemical control. In 2008, mulched plants resulted in a higher shoot dry weight than non-treated and non-mulched plants, while in the second year, no differences were observed. The black color of the 3-L containers was probably the main factor driving substrate temperature increase, indicating mulching materials did not affect substrate temperatures. In both experiments, container water content was unaffected by mulching materials. Results seem to demonstrate that transpiration is the main component of water loss from container-grown giant arborvitae plants.

Weed control is one of most costly operations in nursery production because weeds can decrease the value of the crops by reducing both growth and saleability. Weeds compete with containerized crops for water and nutrients because of the limited container volume (Berchielli-Robertson et al., 1990; Case et al., 2005; Roul and Lemay, 2000). Traditionally, weed control during nursery production has been managed through hand weeding and/or herbicides (Cochran et al., 2009; Gilliam et al., 1990; Hamill et al., 2004). However, the increase in labor cost has made hand weeding too expensive as the sole method of weed control (Everest et al., 1998). Moreover, this practice causes media removal from containers and a poor production quality (Chong, 2003; Mathers, 2003). Although herbicides may be an effective and cheap way to control weeds, some problems must be taken into account. Depending on container spacing, growth habit, methods, and frequency of chemical distribution, non-target herbicide loss can be as high as 86% (Gilliam et al., 1992) and can also lead to several types of environmental damage. Moreover, some herbicides (also in granular form) can cause damage to ornamental crops, a problem that may be especially serious when the label rate is not followed (Derr and Salihu, 1996; Moore et al., 1989). Economic losses in nursery production due to weed infestation have been estimated to reach as much as $17,000/ha (Chong, 2003).

There is a renewed interest among producers for sustainable techniques to control weeds in containerized plants. Organic or inorganic mulches can be used for this purpose. The effectiveness of several mulching materials was assessed in some experiments, and their ability to limit weed growth was reported (Altland and Lanthier, 2007; Amoroso et al., 2007, 2009; Chong, 2003; Samtani et al., 2007).

Several types of mulches have shown to be beneficial in reducing the water consumption of outdoor garden and landscape plants (Chalker-Scott, 2007; Ferrini et al., 2009), but the ability of the mulches to reduce the water requirements of plants in containers is largely unknown. Some researches studied evapotranspiration (ET) rates from mulched container substrates (primarily peat based) and found that water loss was reduced when the container surface is covered (Argo and Biernbaum, 1994; Lohr and Pearson-Mims, 2001). On the other hand, other studies showed that transpiration was the primary factor driving water loss (Altland and Lanthier, 2007; Medina et al., 2005). The ability of

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
0.5933	$lb/yard^3$	$kg \cdot m^{-3}$	1.6856
28.3495	oz	g	0.0353
33.9057	$oz/yard^2$	$g \cdot m^{-2}$	0.0295
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

mulches to reduce ground temperature in nursery field production is well known, but little information is available for its effect on substrate temperature when used in containerized crops (G. Amoroso, P. Frangi, R. Piatti, and A. Fini, unpublished data). Supraoptimal temperatures can affect many physiological and developmental processes leading to inhibited growth or plant decline (Fitter and Hay, 1987). Heat stress has been shown to be a major limiting factor for plant production and adaptability in containers (Appleton, 2001; Martin et al., 1989; Sibley et al., 1999). As reported by Johnson and Ingram (1984), root growth is negatively affected by substrate temperatures higher than 30 °C, with shoot necrosis, decline in photosynthetic rates and nutrient uptake, and increase in fine root and shoot mortality being commonly observed symptoms above this temperature (Fini et al., 2008; Graves, 1991, 1994; Hendrick and Pregitzer, 1993; Mathers, 2003). As reported by Miller (1986) and McMichael and Burke (1996), the optimal temperature for root growth in temperate plants is ≈25 °C.

The aim of this research was to evaluate the effectiveness of four biodegradable mulches in containerized crop and their effects on weed control, water consumption, and substrate temperature under different irrigation and weeding conditions.

Materials and methods

EXPT. 1. The experiment was conducted in an experimental nursery located at Fondazione Minoprio (Vertemate con Minoprio, Como, Italy) (lat. 45°44′ N, long. 9°04′ E, elevation 342 m). The experimental nursery consisted of a tunnel covered with a translucent film (Nowoflon ET6235-Z; Nowofol, Siegsdorf, Germany) to protect containers from precipitation.

For this experiment, 2-year-old giant arborvitae plants were used. Plants were potted up from 0.5-L containers purchased from a commercial nursery (Vivai Nord, Lurago d'Erba, Italy) into 3-L plastic containers in May 2008. Container substrate consisted of 80% (v/v) sphagnum peat and 20% (v/v) pumice, amended with 4 $kg \cdot m^{-3}$ of calcium carbonate. A 15N–3.5P–10K controlled-release fertilizer [8- to 9-month formulation at 20 °C (Ficote®; Scotts, Marysville, OH)] was incorporated at the rate of 4 $kg \cdot m^{-3}$ before potting.

Treatments for weed control in the experiment were 1) mulching with a disc made of natural fibers [coconut (*Cocos nucifera*), agave (*Agave* spp.), and jute (*Corchorus olitorius*)] mixed with natural latex [1100 $g \cdot m^{-2}$ (AW-Disk®; Engrow, Tiel, The Netherlands)]; 2) Type A mulching disc with the same composition as AW-Disk® but composed by a lower rate of natural fibers (800 $g \cdot m^{-2}$); 3) Type B mulching disc with the same weight as AW-Disk® but consisting of only coconut fiber (1100 $g \cdot m^{-2}$); 4) textile industry waste materials (TWM) mulching disc composed of 90% vegetal and 10% synthetic fibers [700 $g \cdot m^{-2}$ (Loraschi, Cellatica, Italy)]; 5) one application of 3.6 $kg \cdot ha^{-1}$ oxadiazon (Ronstar®; Bayer CropScience, Monheim am Rhein, Germany) in granular form immediately after potting; and 6) no mulch and no herbicide (control). All treatments were applied immediately after potting. The weed discs used in the experiment had a slit in the center so that they could be fitted around the stem of the plant. Two irrigation levels and two weed management methods were also carried out during the trial. Irrigation was carried out daily to maintain water content of the container at 100% [normal water (NW)] or 30% [reduced water (RW)] of the water-holding capacity. Method was calibrated as described by Sammons and Struve (2008). Two weeding management regimes were 1) regular hand weeding—removing also weed root system—(every 45 d; three events during the growing season) and 2) one hand weeding at the end of the growing season. This factor was introduced into the experiment to obtain information about the real necessity of carrying out hand weeding during the growing season in mulched plants.

Experiment was a split–split plot design where irrigation was the main plot and weed management was the subplot factor. The strategies for weed control were the sub-subplot factors and were evaluated in four blocks. There were 30 plants for each block arranged in six rows with a density of 11 plants/m², for a total of 480 plants.

Plant shoot dry weight was measured at the end of the growing season on two plants per plot. The aboveground part was oven-dried (104 °C) until constant weight was reached to determine the dry weight. Weed shoot dry weight per pot was measured after hand weeding, while in non-weeded pots, the weight was measured only at the end of the trial. To quantify the water loss from pots (ET), eight containers per treatment, for each irrigation type and for each weeding management regime, were weighed every 2 h starting from the morning irrigation (0630 HR). These measurements were carried out on two sunny days (29 Aug. and 9 Sept.). Values obtained were expressed as average water content (percentage) in accordance with Sammons and Struve (2008).

Substrate temperature was recorded during the hottest time of the day (between 1430 and 1600 HR). The measurements were taken on 3 d with 30 °C maximum air temperature. Digital thermometers (Checktemp 1; Hanna Instruments, Woonsocket, RI) were used; the probe was always located in the same place in the pot (southwest, 5 cm to pot rim, 8 cm depth).

All data were processed with analysis of variance (ANOVA), or multivariate analysis of variance when two or three effects acted in combination, with the exception of container water content data, which were analyzed with repeated measures ANOVA. SPSS® (version 17.0; SPSS, Chicago, IL) was used. Means were separated by Duncan's multiple range test at $P \leq 0.05$ level of significance. Average water content (percentage) was transformed through the formula arcsin square root of x, where x is the percentage value divided by 100.

EXPT. 2. Experiment 1 was repeated in 2009 with the following changes. Three-year-old giant arborvitae plants were potted up from 0.75-L into 3-L plastic containers. Substrate temperature was recorded twice during the growing season, but the appearance of clouds during the second assessment (24 Aug.) invalidated the results; therefore, only the first assessment is reported. The container weight was recorded on 21 July and 13 Aug.

Results and discussion

ORNAMENTAL AND WEED PLANTS GROWTH. In the first experiment, the lowest giant arborvitae shoot dry weight was recorded in non-mulched non-treated control, and no differences were observed between mulching treatments and chemical control (Table 1). In the second experiment, neither mulching materials nor chemical control allowed a higher giant arborvitae growth in comparison with non-mulched non-treated control (Table 1). The larger liners used in the second year may explain the lower influence of weeds on the growth of giant arborvitae, as larger plants are less sensitive to weed competition than the smaller ones. At the end of the first experiment, weed biomass in non-mulched non-treated NW containers was greater than weed biomass in non-mulched non-treated RW containers, while no differences between other treatments were observed (Table 2). This result was probably due to higher weed growth in treatments with the highest water availability coupled with no chemical control and absence of mechanical barriers. In the second experiment, no differences in weed control between oxadiazon and mulching materials were detected, while the greater weed biomass in non-mulched non-treated containers did not significantly affect the growth of giant arborvitae (Table 1).

Biomass of the weeds was unaffected by the irrigation regime, while the use of irrigation at 100% of the water-holding capacity of the container allowed greater growth in giant arborvitae in both experiments (Table 1). In the first experiment, regular hand weeding during the growing season did not allow a significant weed biomass reduction, but led to greater growth in the giant arborvitae plants; while in the second experiment, regular hand weeding reduced the weed dry mass, but did not allow greater growth in giant arborvitae (Table 1). Most weeds found in the containers were dicotyledonous and, in decreasing frequency, were creeping wood sorrel (*Oxalis corniculata*), heath pearlwort (*Sagina subulata*), spotted ladysthumb (*Polygonum persicaria*), spotted spurge (*Euphorbia maculata*), petty spurge (*Euphorbia peplus*), common chickweed (*Stellaria media*), hairy bittercress (*Cardamine hirsuta*), shepherd's purse (*Capsella bursa-pastoris*), common sowthistle (*Sonchus oleraceus*), little hogweed (*Portulaca oleracea*), henbit deadnettle (*Lamium amplexicaule*), creeping cinquefoil (*Potentilla reptans*), eastern daisy fleabane (*Erigeron annuus*), mouse-ear chickweed (*Cerastium holosteoides*), and persian speedwell (*Veronica persica*). Among monocotyledons, bermudagrass (*Cynodon dactylon*) and hairy crabgrass (*Digitaria sanguinalis*) were observed.

Table 1. Effect of weed control strategies (WCSs) (four types of biodegradable mulching discs, chemical control, and non-mulched non-treated control), irrigation regime (IR) (normal irrigation and reduced water), and hand weeding (HW) on shoot dry weight of 3-L (0.8 gal) container-grown giant arborvitae and weeds at the end of the 2008 and 2009 experiments.

	Expt. 1 (2008)		Expt. 2 (2009)	
	Shoot dry wt		Shoot dry wt	
	Giant arborvitae (g)[z]	Weeds (g/pot)	Giant arborvitae (g)	Weeds (g/pot)
WCS[y]				
AW-Disk®	66.4 a[x]	2.5 c	160.4 a	1.3 b
Type A disc	68.1 a	1.2 c	149.4 a	1.3 b
Type B disc	67.9 a	2.0 c	158.2 a	0.5 b
TWM disc	66.0 a	2.3 c	144.5 a	0.7 b
Oxadiazon	66.0 a	6.3 b	161.1 a	1.2 b
NT–NM control	58.4 b	17.5 a	143.9 a	4.0 a
IR[w]				
Normal water	71.0 a	2.7 a	166.2 a	1.5 a
Reduced water	59.9 b	1.7 a	139.6 b	1.5 a
HW				
No	63.5 b	3.0 a	148.9 a	2.3 a
Yes[v]	67.4 a	1.5 a	156.9 a	0.7 b
Probability				
WCS	*	**	NS	***
IR	***	NS	***	NS
HW	*	NS	NS	***
IR × WCS	NS	*	NS	NS
WCS × HW	NS	NS	NS	NS
HW × IR	NS	NS	NS	NS
HW × IR × WCS	NS	NS	NS	NS

[z]1 g = 0.0353 oz.
[y]AW-Disk®, natural fibers mixed with natural latex [1100 g·m^{-2} (Engrow, Tiel, The Netherlands)]; Type A disc, natural fibers mixed with natural latex [800 g·m^{-2} (Engrow)]; Type B disc, only coconut fiber without natural latex [1100 g·m^{-2} (Engrow)]; TWM disc, textile industry waste materials [700 g·m^{-2} (Loraschi, Cellatica, Italy)]; oxadiazon (Ronstar; Bayer CropScience, Monheim am Rhein, Germany) was applied in granular form at the rate of 3.6 kg·ha^{-1} (3.21 lb/acre); NT–NM control, non-treated non-mulched control; 1 g·m^{-2} = 0.0295 oz/yard^2.
[x]Means for each main factor and within each column followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.
[w]Normal water, daily irrigation up to 100% of container capacity; reduced water, daily irrigation up to 30% of container capacity.
[v]The weed biomass reported was obtained as sum of the three HW events carried out during each experiment.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Substrate temperature. In both experiments, mulching materials did not reduce the substrate temperature compared with non-mulched controls (data not shown). In 3-L containers, the substrate covering the surface was not able to reduce the warming of potting medium during the hottest period of the day. The black color of the containers was probably the main factor causing the increase in substrate temperature, as pointed out by Cervelli and Giampietro (2004). They reported that the maximum substrate temperature of the south-facing side of the black pots exceeded 40 °C in some summer days (Sanremo, Italy), while in polystyrene-protected pots, the maximum temperature was decreased by almost 30%. In each assessment carried out during the two experiments, an interaction between weeding management and irrigation regime was observed (data not shown); despite this, in each measurement, the substrate temperature of NW containers was always lower than that recorded in RW containers (Table 3). This can be explained by the higher moisture content of NW containers; the high specific heat of water limited the substrate temperature increase. Additionally, the lower substrate temperature could explain the greater plant growth in the NW regime due to reduced temperature stress during the

Table 2. Effect of weed control strategies (four types of biodegradable mulching discs, chemical control, and non-mulched non-treated control) and irrigation regime (IR; normal irrigation and reduced water) on shoot dry weight of weeds grown in 3-L (0.8 gal) container-grown giant arborvitae.

IR[z]	Weed control strategies[y]	Weed shoot dry wt (g/pot)[x]
Normal water	AW-Disk®	2.3 b[w]
	Type A disc	0.6 b
	Type B disc	1.7 b
	TWM disc	1.9 b
	Oxadiazon	1.7 b
	NT–NM control	7.9 a
Reduced water	AW-Disk®	2.8 b
	Type A disc	3.7 b
	Type B disc	0.6 b
	TWM disc	0.1 b
	Oxadiazon	0.7 b
	NT–NM control	2.5 b

[z]Normal water, daily irrigation up to 100% of container capacity; reduced water, daily irrigation up to 30% of container capacity.
[y]AW-Disk®, natural fibers mixed with natural latex [1100 g·m^{-2} (Engrow, Tiel, The Netherlands)]; Type A disc, natural fibers mixed with natural latex [800 g·m^{-2} (Engrow)]; Type B disc, only coconut fiber without natural latex [1100 g·m^{-2} (Engrow)]; TWM disc, textile industry waste materials [700 g·m^{-2} (Loraschi, Cellatica, Italy)]; oxadiazon (Ronstar; Bayer CropScience, Monheim am Rhein, Germany) was applied in granular form at the rate of 3.6 kg·ha^{-1} (3.21 lb/acre); NT–NM control, non-treated non-mulched control; 1 g·m^{-2} = 0.0295 oz/yard^2.
[x]1 g = 0.0353 oz.
[w]Means followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

Table 3. Effect of irrigation regime (IR; normal irrigation and reduced water) and hand weeding (HW) on substrate temperature during the hottest time of the day (1430–1600 HR) in 3-L (0.8 gal) container-grown giant arborvitae.

		Substrate temp (°C)[y]			
IR[z]	HW	18 Aug. 2008	28 Aug. 2008	9 Sept. 2008	13 July 2009
Normal water	No	25.0 c[x]	25.6 d	24.4 c	28.5 c
	Yes[w]	27.7 b	26.3 c	25.3 b	28.7 c
Reduced water	No	29.5 a	31.8 a	29.3 a	30.7 a
	Yes	29.3 a	30.9 b	29.1 a	29.6 b

[z]Normal water, daily irrigation up to 100% of container capacity; reduced water, daily irrigation up to 30% of container capacity.
[y]$(1.8 \times °C) + 32 = °F$.
[x]Means within each column followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.
[w]HW was carried out for three times during each experiment.

hottest summer periods. As reported in previous research (McMichael and Burke, 1996; Miller, 1986), temperatures higher than 25 °C could affect root vitality and plant development. No interactions between weed control strategies and weeding management or irrigation regimes were found (data not shown).

CONTAINER WATER CONTENT. In both experiments, container water content was unaffected by mulching methods (the assessments gave similar results; therefore, only one assessment is reported in Table 4). This was probably due to the higher effect of transpiration on water consumption in comparison with evaporation in a 3-L container. This result is similar to what was observed by Altland and Lanthier (2007) and by Medina et al. (2005). As expected, the NW containers showed a greater water consumption than the RW containers. This result can be explained by both greater plant growth and higher water availability for the NW plants. Weeding did not affect container water consumption probably because giant arborvitae transpiration was greater than weed transpiration.

Conclusions

According to previous research (Amoroso et al., 2007, 2009; Chong, 2003), mulching materials can be successfully used as an alternative to chemical weed control. The mulching materials tested provided a similar weed control. No mulching treatment reduced water consumption when compared with non-mulched controls. These results agree with previous research (Altland and Lanthier, 2007; Medina et al., 2005), which indicates transpiration as the main factor of water loss from the soil–plant system in container-grown plants. Moreover, no mulching materials were found to reduce the pot temperature. According to Cervelli and Giampietro (2004), the black color of the containers was probably the primary component driving substrate temperature increase in a 3-L container, while the mulch covering was not sufficient to shield the substrate from sunlight effects. Hand weeding can be avoided when mulching materials are used, since the weed growth in mulched containers did not affect plant growth and substrate water content. RW affected plant growth in comparison with NW. This could be explained not only by the lower amount of water available for RW plants but also by supra optimal temperatures of the root zone recorded in RW containers in comparison with NW containers. The effect of weeding on weed biomass and giant arborvitae growth was different in the two experiments, which could confirm how weed control becomes less important with increasing size and age of the crop plants.

Nowadays, the cost of container mulches is the main constraint in their use in nursery production; nonetheless, the current decrease in the use of chemical products could result in a rise in non-chemical alternatives used for weed control and, as a consequence, in a reduction of the mulch production cost. As reported by Amoroso et al. (2007), chemical weed control is the cheapest way to control weeds in 3-L containers ($0.05/pot per application), but this value does not take into account chemical externalities, such as environmental damage and the inefficient application and distribution that can result in up to 86% of product loss (Gilliam et al., 1992). Overall cost per 18-cm-diameter mulching disc (including installation) is ≈$0.27/pot for both AW-Disk® and TWM disc. In any case, the long duration of these materials allows their cost to be spread over 2 years. Cost for manual removal of weeds per container ranges between $0.15/pot and $0.53/pot per growing season, depending on the growing rate of the species.

Table 4. Effect of weed control strategies (WCS) (four types of biodegradable mulching discs, chemical control, and non-mulched non-treated control), irrigation regime (IR) (normal irrigation and reduced water), and hand weeding (HW) on container water content (percentage) in 3-L (0.8 gal) container-grown giant arborvitae on 9 Sept. 2008.

	Container water content (%)				
	0830 HR	1030 HR	1230 HR	1430 HR	1630 HR
WCS[z]					
AW-Disk®	58.5	55.0	50.3	46.4	44.0
Type A disc	64.5	60.8	56.0	52.2	49.8
Type B disc	63.5	59.8	55.2	51.4	49.1
TWM disc	60.8	57.1	52.4	48.7	46.3
Oxadiazon	52.9	49.3	44.8	41.0	38.5
NT–NM control	55.2	51.5	46.9	43.0	40.4
IR[y]					
Normal water	93.2	90.6	85.0	80.0	76.6
Reduced water	25.2	20.6	16.9	14.2	12.8
HW					
No	59.5	55.4	51.2	46.5	45.3
Yes[x]	59.0	55.8	50.7	46.5	44.1
Probability					
Time[w]	***				
Time × WCS	NS				
Time × IR	***				
Time × HW	NS				

[z]AW-Disk, natural fibers mixed with natural latex [1100 g·m^{-2} (Engrow, Tiel, The Netherlands)]; Type A disc, natural fibers mixed with natural latex [800 g·m^{-2} (Engrow)]; Type B disc, only coconut fiber without natural latex [1100 g·m^{-2} (Engrow)]; TWM disc, textile industry waste materials [700 g·m^{-2} (Loraschi, Cellatica, Italy)]; oxadiazon (Ronstar; Bayer CropScience, Monheim am Rhein, Germany) was applied in granular form at the rate of 3.6 kg·ha^{-1} (3.21 lb/acre); NT–NM control, non-treated non-mulched control; 1 g·m^{-2} = 0.0295 oz/yard^2.
[y]Normal water, daily irrigation up to 100% of container capacity; reduced water, daily irrigation up to 30% of container capacity.
[x]HW was carried out for three times during each experiment.
[w]Time factor, measurements carried out on the same samples for five times during the day (assessments every 2 h). Estimates of sphericity (ϵ) < 0.75 (Greenhouse and Geisser's correction used); Mauchly's test sphericity significance = ***.
NS, ***Nonsignificant or significant at $P \leq 0.001$, respectively.

The results of this experiment may be a useful tool for ornamental plant growers, improving the knowledge of the effect of mulching on plant growth, substrate temperature, and water content in containerized plant production.

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