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Mulches and Subirrigation Control Weeds in Container Production[1]

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Abstract

Weed control efficacy of organic mulches as well as a copper hydroxide-coated geotextile (fabric) disk was examined using *Rhaphiolepis indica* L. or *Callistemon citrinus* [(Curtis) Stapf] growing in containers. Rout (oxyfluorfen plus oryzalin) and corn gluten meal were included as herbicide treatments. In a second experiment, the effect of subirrigation versus surface irrigation and different depths of pine bark mulch on weed control was studied. In the mulch/herbicide studies, all of the mulch treatments, including the geotextile disk, provided broadleaf weed control, but not annual bluegrass control, similar to that of Rout. Broadleaf weeds were not controlled by corn gluten meal. Although though the number of grass seedlings was reduced 49% from that of the control, Rout reduced the number by 89%. In the mulch depth/irrigation study, mulching reduced weed weight by 92% over that of the control (no mulch and surface irrigated) 8 weeks after transplanting. Subirrigation reduced the number of weeds by at least 95% over that of the control.

Index words: mulches, weed control, geotextile, subirrigation.

Herbicides used in this study: Rout (oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenyoxy)-4-(trifluoromethyl) benzene) plus oryzalin (3,5-dinitro-N4,N4-dipropylsulfanilamide)) and corn gluten meal.

Species used in this study: India hawthorn (*Rhaphiolepis indica* L. ‘Snow White’ and ‘Pinky’) and Bottlebrush (*Callistemon citrinus* [(Curtis) Stapf]).

Significance to the Nursery Industry

Environmental issues due to herbicide use and runoff and the increasing cost of hand weeding challenge growers of container nursery stock. Where a herbicide is registered for a nursery species, generally 1 to 2 herbicide applications are made within 6 months of transplanting. Herbicides may be moved off-site by rainfall or sprinkler irrigation. Where no herbicide is available, growers must resort to hand removal of the weeds. Not only is this costly, it takes labor away from other duties. Other methods of weed control may be feasible for the nursery industry. For example, mulching is a commonly used method to control weeds in the landscape but largely underutilized in nurseries. Subirrigation is another practice used in landscapes and some cropping systems to reduce water loss by evaporation but can have the additional benefit of reduced weed growth. Our results show that weeds can be controlled in container-grown crops for at least 6 months when a 2.5–5.0 cm (1–2 in) layer of coarse organic mulch covers the potting mix surface. Broadleaf weed control can also be obtained using copper hydroxide treated geotextile disks. Subirrigation can be effective for controlling weeds but care must be taken to avoid overwetting the potting media. Rout herbicide provided long-term weed control but corn gluten meal did not provide an adequate level of weed control to be considered an effective herbicide alternative.

Introduction

Weed competition in container-grown plants can significantly reduce shoot dry weight of the desired plants (3). Herbicides have been developed which control weeds in container crops but environmental constraints and worker protection issues may limit their use in the future. Using no control measures other than hand weeding is often economically prohibitive as hand weeding costs ranging from $608 to $1,401 per hectare were reported in a survey of strategies to control weeds in container production nurseries (9).

As the primary weed control method, herbicides can be very useful and economical for controlling weeds in containers. However, alternative non-chemical systems of weed management may also provide satisfactory weed control. Hundreds of species of plants are grown for the ornamental market and often these nursery crops are too specialized to be considered for inclusion on herbicide labels. Production practices in container nurseries can be modified to incorporate non-chemical techniques as the first line of defense against weed seed establishment. These practices include the use of mulches and subirrigation.

Mulches have long been used in the landscape to exclude weeds; however, their potential for weed control has not yet been realized in container plant production. Additionally, subirrigation may also be a method of weed management if the potting mix surface stays dry and is therefore a less conducive substrate for weed seed germination and establishment.

Herbicides commonly used in container production include granular materials containing the active ingredients oxyfluorfen, oryzalin, pendimethalin, oxadiazon and others (7). During application, however, a high percentage of material may not fall into the container when broadcast over the containers (10, 15). This non-target loss could contribute to

[1]Received for publication March 16, 1999; in revised form August 9, 1999. This research was funded in part by grants from the University of California Statewide IPM Project and the California Association of Nurserymen.

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surface or groundwater pollution. A plant-based product, corn gluten meal, reportedly has preemergent activity for controlling a broad spectrum of weeds in turfgrass (5). Corn gluten meal is a granular formulation that can be applied without adapting any currently used broadcast equipment. Since corn gluten meal is a byproduct of corn extracted during milling process to produce corn syrup, non-target losses of corn gluten meal may have less of an environmental impact than that of currently used synthetic products.

Organic mulch or geotextiles (landscape fabrics) are recommended to control weeds in landscape plantings (8) yet there is little information available on the use of mulches to control weeds in container crops (4). Benefits of mulches include reducing soil temperature fluctuations, reducing evaporation from the soil surface, and weed suppression (2, 4, 6, 14). However, weeds may grow in moist organic materials (1) such as bark mulches which may limit their use in reducing weed pressure. If bark mulch is used, Grantzau (11) recommended mulches with a coarse texture that would dry out quickly and render the surface unfavorable for weed seed germination.

In California and most of the southwestern United States where rainfall is infrequent most of the year, container plants are commonly watered by overhead irrigation, either by hand, impact sprinklers, drip, or microirrigation. With all of these methods the potting mix surface remains moist once wetted and creates an ideal surface for weed seed germination. With subirrigation this becomes less of a problem because the plants are watered from the bottom via capillary action. Therefore the media surface may remain drier and create less favorable conditions for weed seed germination.

In this paper we report the effect of three organic mulches, or fabric mulch in conjunction with herbicides on weed control and plant growth of container-grown woody plants. We also report the effect of subirrigation and mulch depth on weed control and plant growth.

Materials and Methods

The effect of four mulches and two herbicides on weed control and plant growth of *R. indica* cultivars was examined at both Davis (*R. indica* 'Pinky') and Irvine (*R. indica* 'Snow White'), CA, in 1996. The effect of mulch depth and method of irrigation on weed control in *R. indica* was also studied at Irvine. In 1997, the studies were repeated at Irvine only, using *C. citrinus*. All studies were conducted using a randomized complete block design with 10 replications. The choice of when weeds were harvested was based on weed development rather chronological time. Therefore, harvest dates are not consistent across years or locations. Since these studies were done in different years, locations, and used different plant species, we did not combine any of the tests. Analyses of variance were carried out after transformation of the data, if needed. Means were considered significantly different at $P < 0.05$. Mean separation was performed using Fishers Protected t-test. Where data were transformed, back-transformed data are presented. Where there was data missing for either the root or shoot dry weight, the total weight for an individual plant was not used in any analyses. As a result, the mean total dry weight reported in the tables is not always the sum of the means of the shoot and root dry weights.

Controlling weeds in containers with mulches and herbicides. R. indica 'Snow White' were transplanted from #1 containers into #5 containers in June 1996 in Irvine, CA. Potting media consisted of 49% compost, 28% redwood sawdust, 8% peatmoss, 14% sand, 1% perlite, and 1% starter fertilizer (1N–10P_2O_5–1K_2O). Immediately after transplanting, controlled-release fertilizer 17N–6P_2O_5–10 K_2O + minors (Sierra, Milpitas, CA) with a 6-month release time was applied as topdressing at a rate of 100 gm (0.2 lb) per pot.

The experiment used a factorial design with five levels of mulch and three levels of herbicide. Mulch treatments were no mulch, pine bark, composted greenwaste obtained from municipal collections, pecan shells, or copper hydroxide treated fabric disk. The choice of organic mulch was based on whether it was commonly available and had few fine or large pieces. Pine bark is widely used in landscaping; greenwaste is often diverted from landfills and composted; and pecan shells are a waste product from the pecan nut industry. Herbicide treatments were no herbicide, Rout (oxyfluorfen + oryzalin) (Scotts, Marysville, OH), or corn gluten meal.

Composted greenwaste, pine bark, and pecan mulches were applied at a depth of 2.5 cm (1 in). Particle size of composted greenwaste and pine bark mulch was approximately 0.31 to 5 cm (0.1 to 2 in) in length. Pecan shells were coarsely cracked and had a length of approximately 0.5–3 cm (0.2–1.2 in). Fabric disks, an inorganic mulch, with a diameter of 28 cm (11 in), manufactured of polypropylene and coated on the upper side with latex coating containing 6 gm/m^2 (2 oz/100 ft^2) copper hydroxide (Tex-R Geodisk, Texel, Henderson, NC), were placed on top of the fertilized media surface. Rout was applied in granular form at a rate of 10.8 gm/m^2 (2.2 lb/1000 ft^2) sprinkled over the mulched or bare container surface. Corn gluten meal was applied in the same manner at 98 gm/m^2 (20 lb/1000 ft^2) one week after transplanting.

A mixture of oxalis (*Oxalis corniculata*), northern willow herb (*Epilobium ciliatum*), and common groundsel (*Senecio vulgaris*) seeds was blended with fine sand and sprinkled over each container surface 10 days after transplanting. Irrigation was supplied by spitter emitters (Roberts Irrigation, San Marcos, CA) (2.5 liter (0.7gal)/min) to each individual pot and plants were watered every day for two weeks after transplanting and every other day thereafter. Watering times were adjusted as needed to maintain good plant growth.

The total number of weeds were counted two, three, and four weeks after transplanting. Weed coverage on a scale of 0 to 100% was visually rated on a monthly basis. Weeds were counted and removed and dry weight was determined for each weed species 8 and 24 weeks after transplanting. Because there was little weed growth after the first harvest, only the data from the 8 week weed harvest is presented.

Soil temperatures were compared by burying temperature dataloggers (Hobo datalogger, Onset Computer Corp., Pocasset, MA) 3 cm (approx. 1 in) below the potting mix surface in one unmulched container and one with the fabric mulch. Temperatures were recorded hourly for 61 days starting on July 23, 1996.

A similar experiment was conducted during 1996 at Davis, CA. *R. indica* 'Pinky' were transplanted from #1 containers into #5 containers in October 1996. Potting media consisted of 25% ground Canadian sphagnum, 25% coarse sand, 25% white pumice, and 25% redwood compost. Oyster shell, dolomite and single super phosphate were also mixed into the potting media at the rate of 3 lb/yd^3 (5.4 kg/m^3). Immediately after transplanting controlled release fertilizer (17N–6$P_2 0_5$–

$10K_2O$) + minors with a 6-month release time was applied as top dressing at a rate of 100 gm (0.2 lb) per pot.

The experiment was set up in the same manner as the Irvine study using the same mulch source, herbicides, and rates. Overseeded weeds in this study were annual bluegrass (*Poa annua)* and common groundsel. Irrigation was supplied by hand watering with a fine broadcast nozzle daily for the first two weeks after transplanting and as needed to maintain good plant growth thereafter. Plant height and canopy width, measured at the highest and widest points, were determined at time of transplanting.

Weeds were counted and removed 6 weeks after transplanting. Because there was little weed growth after the first harvest, only data from the initial weed harvest is presented. Common groundsel did not germinate well and data are not given. Plant height and canopy width were again measured 25 weeks after transplanting. The plants were then harvested, roots washed, and dried for 72 hr at 70C (165F) before weighing.

The study was repeated in 1997 in Irvine, CA, using *C. citrinus* as the nursery species. *C. citrinus* was transplanted from liners into #5 containers in March 1997 and topdressed with 115 gm (0.25 lb) per container Nutricote Total 18N–$6P_2O_5$–$8K_2O$ with 1-year release time (Plantco Inc., Brampton, Ontario, Canada) . The potting mix and irrigation were the same as in 1996. Corn gluten meal was not included as a treatment in 1997 but Rout was applied as above 13 days after transplanting. Weed seeds, as described for 1996, were applied 3 weeks after transplanting.

Controlling weeds in containers with different depths of mulches and method of irrigation. A separate study was conducted in 1996 and repeated in 1997 in Irvine, CA, to evaluate the effects of mulch depth and subirrigation on plant growth and weed control in containers.

In the 1996 study, *R. indica* 'Snow White' were transplanted from #1 containers into #5 containers in June. Potting media and fertilizer were the same as that used in Irvine in 1996. The containers were overseeded with mixture of oxalis, northern willow herb, and common groundsel seeds, blended with fine sand and sprinkled over each container surface 10 days after transplanting. Data collection methods were the same as the 1996 Irvine mulch/herbicide study.

The experiment was set up as a factorial design with four depths of pine bark mulch, 0, 2.5, 5.0, or 7.5 cm (0, 1, 2, or 3 in), and two methods of irrigation, surface irrigation with spitter emitters or by subirrigation. To achieve randomization within each replication, subirrigated containers were placed in individual saucers and spitter emitters delivered water into each saucer. Plants were watered every day for two weeks after transplanting and every other day thereafter. Watering times were adjusted as needed to maintain good plant growth.

In 1997, *C. citrinus* was transplanted from liners into #5 containers in March and topdressed with 115 gm (0.25 lb) per container Nutricote Total 18N–$6P_2O_5$–$8K_2O$ with 1-year release time (Plantco Inc., Brampton, Ontario). This experiment was a randomized complete block design with treatments arranged in factorial combinations as described for 1996. Data collection methods were the same as the 1997 Irvine mulch/herbicide study.

In 1997 only, irrigation for both the surface and subirrigated treatments was regulated by fast response tensionmeters (Irrometer Co., Riverside, CA) which were placed 15 cm (6 in) deep into the growing medium. The tensionmeters were connected electronically to the irrigation controller and would only allow irrigation to occur if the soil moisture tension was 30 cbar or less. This was done to avoid standing water in saucers used for the subirrigated treatments.

Results and Discussion

Trends observed during the weekly or monthly weed counts were similar to those determined from the weed harvests; therefore only the harvest data are presented here.

Controlling weeds in containers with mulches and herbicide. In the 1996, Irvine, CA, study, weed counts 8 weeks after transplanting determined that all mulches controlled weeds equivalent to that of the commercial herbicide (Rout) and there was no significant difference between Rout alone and Rout plus mulch (Table 1). Corn gluten meal did not provide any weed control compared to the untreated check (Table 1). Differences among treatments were less distinct 6 months after transplanting; few weeds germinated after the first harvest probably due to shading by the *R. indica* plants and this interference may have confounded the weed suppression effects of the herbicide or mulch treatments during the latter part of the experiment.

R. indica shoot dry mass was influenced by the mulch treatments (Table 2) although root and total dry mass were not affected (data not shown). Shoot dry weight was less in the fabric disk treatments compared to pecan shell mulch but the fabric disk treatment was not significantly different from the pine bark or composted greenwaste treatments. We observed that despite growing in moist medium, some of the fabric-mulched plants appeared stressed during the latter part of this study and hypothesized that this stress may have been caused by increased soil temperature below the fabric. Hourly temperatures ranged from 5.0C (9.0F) cooler to 7.5C (13.5F) warmer under the fabric mulch than the unmulched treatment. The maximum temperatures reached were 44 and 42C (111 and 108F) for the fabric and the unmulched treatments, respectively, and the minimum temperature was 10C (50F) for both. On the average, the potting mix under the fabric mulch was 0.8C (1.4F) warmer than the unmulched treatment. High root zone temperature is detrimental to the growth of some woody plant species. Martin (13) reported that supraoptimal medium temperatures of 40C (104F) and above reduce plant growth and are a limiting factor in container production. Shoot growth may be limited by physiological changes in the roots which limit their ability to extract water (12)**.** Although not definitive, the higher medium temperature imparted by the fabric disk could have resulted in root damage. This could account for the observed symptoms of plant stress even though there was sufficient soil moisture for the plant to use.

At the Davis, CA, location there were insufficient numbers of broadleaf weeds to compare broadleaf weed control. Herbicide and mulch both affected the total number of grass seedlings, although the interaction was not significant. The most effective herbicide treatment was Rout (Table 3). Corn gluten meal reduced the number of grasses from that of the non-herbicide treatment by 51% but the reduction was not adequate for commercial weed control. All mulches reduced the number of grass plants from that of the unmulched treatments (Table 4). There was an increase in dry weight of *P.*

Table 1. **Weed number and dry weight in containers amended with different mulches and herbicides 8 weeks after transplanting in 1996 and 28 weeks after transplanting in 1997 (Irvine, CA)[z].**

		1996		1997	
Herbicide	**Mulch**	**Number of weeds per container**	**Weed dry wt (gm)**	**Number of weeds per container**	**Weed dry wt (gm)**
None	None	9.7a[y]	0.45b	16.7a	6.23a
Corn gluten meal	None	10.1a	1.54a	—	—
Rout	None	0.1b	0.02c	3.9b	1.11b
None	Pine	0.2b	0.08c	1.8bc	0.41bc
Corn gluten meal	Pine	0.1b	0.06c	—	—
Rout	Pine	0.1b	0.00c	0.0c	0.00c
None	Composted greenwaste	0.2b	0.00c	0.6c	0.38bc
Corn gluten meal	Composted greenwaste	0.3b	0.04c	—	—
Rout	Composted greenwaste	0.0b	0.00c	0.0c	0.02c
None	Pecan	0.4b	0.01c	0.0c	0.09c
Corn gluten meal	Pecan	0.2b	0.05c	—	—
Rout	Pecan	0.2b	0.15bc	0.1c	0.03c
None	Fabric	0.5b	0.11c	0.0c	0.03c
Corn gluten meal	Fabric	0.2b	0.04c	—	—
Rout	Fabric	0.1b	0.00c	0.0c	0.00c
ANOVA					
Mulch		***[x]	***	***	***
Herbicide		***	**	*	***
Mulch × herbicide		***	***	*	**

[z]There were no significant differences among treatments 24 or 12 weeks after transplanting in 1996 and 1997, respectively.
[y]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.
[x]***, **, * indicate a significant F-value at $P < 0.001$, 0.01, and 0.05, respectively.

annua when composted greenwaste was used as mulch, perhaps due to texture of the material. The composted greenwaste may have been coarse enough for the grass seedling to emerge through gaps and establish in the containers. Also, seedlings grew around the edges of the fabric mulch, which would be unacceptable for control. Based on *P. annua* dry weight, pecan shells proved the most effective mulch for controlling grass seedlings. It is likely that the combination of small pecan shell chips, which more completely covered the container surface, and larger chips that dried out quickly, created an unsuitable site for grass seedling establishment and growth (18).

R. indica shoot and root dry mass or growth difference from beginning to the end of the study was unaffected by the herbicide treatment (data not shown). Mulches had no effect on the shoot dry mass (Table 2), but mulched plants did have an increase in total root dry weight. Root dry mass was smaller in pots without an organic mulch or where fabric was used over soil. There may have been a more uniform moisture regime in the mulched pots compared to unmulched or it is possible that moisture moved along the inside of the container and outside the fabric, thus not uniformly wetting the potting media at each irrigation. Higher soil media temperature may have also reduced plant growth. Growth differences of the plants were least without a mulch or fabric cover on the soil. Plant growth was less in the composted greenwaste treated plants than in the plants treated with the pecan shell mulch for some unexplained reason. However, there were no significant differences among composted greenwaste, pine bark, or the fabric disk treatments (Table 2).

In Irvine in 1997, all mulches were equivalent in reducing weed numbers and dry mass at both harvests and mulched treatments resulted in significantly fewer weeds with less dry weight than the unmulched control (Table 5). The addition of Rout to any other treatment did not improve weed control except when Rout was combined with the unmulched treat-

Table 2. **Shoot and root dry mass and growth difference of shoots of *R. indica* grown for 24 weeks in Irvine or 25 weeks in Davis in 1996 with different mulch amendments. Means are averaged over herbicide treatments.**

	Irvine		Davis		
Mulch	**Shoot dry wt (gm)**	**Root dry wt (gm)**	**Shoot dry wt (gm)**	**Root dry wt (gm)**	**Growth difference**
None	169a[z]	73	39.1	10.2b	351.7c
Pine	160ab	64	41.7	13.8a	425.1ab
Composted greenwaste	159ab	62	38.2	13.2a	411.5b
Pecan	171a	65	40.0	13.8a	470.7a
Fabric	151b	63	36.6	11.2b	421.3ab
		NS	NS		

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

Table 3. **Number and shoot dry mass of *P. annua* in containers amended with different mulches and herbicides six weeks after transplanting in 1996 (Davis, CA). Means are averaged over mulch treatments.**

	P. annua	
Treatment	**dry mass (gm)**	**number/container**
None	18.5a[z]	128.6a
Corn gluten meal	10.9b	66.2b
Rout	0.7c	14.1c

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

Table 4. **Number and dry mass of *P. annua* in containers amended with different mulches 6 weeks after transplanting in 1996 (Davis, CA). Means are averaged over herbicide treatments.**

	P. annua	
Mulch	**dry mass (gm)**	**number/container**
None	107.3b[z]	23.1a
Pine	66.6c	7.7b
Composted greenwaste	128.6a	10.5b
Pecan shells	10.8e	7.8b
Fabric[y]	35.0d	1.3c

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

[y]*P. annua* emerged around the outer edge of the fabric disk.

Table 5. **Number and dry weight of weeds in containers amended with different mulches 12 weeks after transplanting in 1997 (Irvine, CA). Means are averaged over herbicide treatments.**

Mulch	**Number of weeds per container**	**Weed dry wt (gm)**
None	3.4a[z]	5.67a
Pine	0.1b	0.26b
Composted greenwaste	0.4b	0.84b
Pecan	0.1b	0.20b
Fabric	0.2b	0.41b

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

Table 6. ***C. citrinus* shoot and root dry weight after growing for 28 weeks in containers amended with different mulches (Irvine, CA). Means are averaged over herbicide treatments.**

Mulch	**Shoot dry wt (gm)**	**Root dry wt (gm)**	**Total dry wt[y] (gm)**
None	139d[z]	24b	161c
Pine	240a	44a	266a
Composted greenwaste	209b	43a	253a
Pecan	237a	43a	281a
Fabric	177c	31b	211b

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

[y]The total weight may not always be the numerical sum of the root and shoot weight due to missing data. See text for explanation.

ment. This improvement was only significant at the second weed harvest, 28 weeks after transplanting (Table 1).

Root and shoot dry mass were 62% and 79% greater, respectively, when *C. citrinus* was grown under the organic mulches compared to unmulched plants (Table 6). Shoot and root dry mass of plants grown with the fabric mulch was less than those grown under organic mulch.

Controlling weeds in containers with different depths of mulches and method of irrigation. Subirrigation and/or mulching at any tested depth (2.5, 5, or 7.5 cm) in 1996 reduced weed weight and number from that of the unmulched, surface-irrigated control. Surface irrigated, unmulched containers averaged 14.9 weeds per container and the mean total dry weight of the weeds was 1.02 gm. In comparison, all of the other mulch/irrigation combinations averaged 0.3 plants or less per container with an average dry weight of 0.2 gm per container. The potting mix surface in the subirrigated containers, in general, remained dry, therefore, weed seeds did not have a suitable substrate for germination and growth. Although growth of *R. indica*, as determined by dry weight, was not affected by any of the mulch depths (data not shown) root, shoot, and total plant weight were adversely affected by subirrigation (Table 7). Despite adjusting irrigation times and frequency, the potting mix was often waterlogged in approximately the bottom half of the containers that were subirrigated. Much of the root growth was consequently along the wall of the container and in the upper half of the potting mix. Undoubtedly, this compromised plant growth in the subirrigated treatments.

To address the waterlogging problem encountered in the subirrigated treatments in 1996, tensiometers were used to regulate water to the containers in the 1997 study. This improved the growing conditions, as the subirrigated plants were not continually subjected to overwatering. Results for weed control in 1997 were similar to those in the previous year. Weed number and dry weight were reduced from that of the unmulched, surface-irrigated control (2.1 weeds per container and 2.36 gm) by using any other mulch/irrigation combination. These treatments had 0.1 or fewer weeds per container with mean weight of 0.2 gm or less per container (data not shown).

There was a significant mulch depth × irrigation method interaction for *C. citrinus* shoot and total dry mass. When plants were subirrigated, there was no effect on plant growth due to mulch depth but when surface irrigated, shoot and total weights of *C. citrinus* grown under 5 cm (2 in) deep mulch were less than that of the 2.5 cm (1 in) deep mulch but comparable to the unmulched and 7.5 cm (3 in) deep mulch, surface irrigated treatments (Table 8). A possible explanation for this is that because subirrigation necessarily relies on capillary action to move water up through the potting medium, the potting mix was more uniformly wetted resulting in better plant growth. However, we cannot explain why there was a decrease in plant weight over in the 5 cm (2 in) deep mulch as compared to the 2.5 (1 in) or 7.5 (3 in) deep mulch in the surface irrigated treatments. Overall, shoot and total weights were greater when the plants were mulched or subirrigated without mulch compared to the unmulched surface-irrigated treatment. There was not a significant interaction between mulch depth and irrigation method for root dry mass but root dry mass was significantly greater for subirrigated (19.1 gm) versus surface-irrigated plants (12.0

Table 7. **Plant growth of *R. indica* growing in containers for 24 weeks and surface or subirrigated. Means are averaged over mulch depth treatments.**

Irrigation	Shoot dry wt (gm)	Root dry wt (gm)	Total dry wt (gm)	Height (cm)	Caliper (mm)
Surface	171a[z]	70a	241a	26.7a	17.5a
Sub	139b	55b	194b	24.5b	16.4b

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

gm). Root dry mass was also significantly greater when plants were mulched 2.5 cm (1 in) deep (18.6 gm) versus no mulch (12.8 gm), 5 cm (2 in) (15.6 gm), or 7.5 cm (3 in) (15.5 gm) deep mulches. The root weight under the deeper mulches was not significantly different from the unmulched treatment.

Overall, organic mulches offer an alternative to herbicides for mid to long-term weed control in container nurseries. Our results demonstrate effective weed exclusion for 24 to 28 weeks. Pellett and Heleba (14) reported similar results in field grown nursery crops where weeds were reduced from 281/m^2 in the unmulched plots to 5 weeds/m^2 in the plots covered with a 5 cm (2 in) layer of bark mulch after 133 days. Subirrigation may also be a potential cultural tool that would also help alleviate weed problems. However, each method has its drawbacks. Mulches must be replenished periodically to maintain weed control. Otherwise, they become a good substrate for weed growth as they break down into smaller particles (4). In our experiment, a mulch depth of 2.5 cm (1 in) was sufficient for weed control over the 24 or 28 week period. There is also the issue of how to automate application of the mulch during the canning process. Weed control as the primary motive for adopting subirrigation is unlikely. However, a grower would probably be able to reduce his or her herbicide or other weed control efforts if this technology is used correctly.

Plant growth was enhanced for *C. citrinus* in containers with organic mulch. Plant growth of *R. indica* was greater at one test location but was not significantly different from the unmulched treatment at the other location. Nevertheless, there was no detrimental effect on plant growth from the use of organic mulches and there was the benefit of long-term weed control. Although the fabric disk provided good weed control when it completely covered the container surface, further work is needed to determine if their use contributes to plant stress or root injury when plants are grown under warm conditions. Organic mulches are reported to reduce maximum temperatures by 2.3 to 3.3C (4.1 to 5.9F) and increase minimum temperatures under the mulch by 1.1 to 2.2C (2.0 to 4.0F) (17). Another factor for improved growth when using organic mulches may have been reduced evapotranspiration of mulched plants (16) or reduced fluctuation of soil moisture. In our experiment, mulch depths up to 7.5 cm (3 in) did not limit plant growth. However, Billeaud and Zajicel (4) reported new growth of *Ligustrum japonicum* was reduced in plants grown under 10 or 15 cm (4 or 6 in) mulch.

Literature Cited

1. Appleton, B. and J. Derr. 1990. Use of geotextile disks for container weed control. HortScience 25:666–668.

2. Appleton, B.L., J.F. Derr, and B.B. Ross. 1990. The effect of various landscape weed control measures on soil moisture and temperature, and tree root growth. J. Arboriculture 16:264–268.

3. Berchielli-Robertson, D.L., C.H. Gilliam, and D.C. Fare. 1990. Competitive effects of weeds on the growth of container-grown plants. HortScience 25:77–79.

4. Billeaud, L.A. and J.M. Zajicek. 1989. Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum*. J. Environ. Hort. 7:155–157.

5. Bingaman, B.R. and N.E. Christians. 1995. Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. HortScience 30:1256–1259.

6. Borland, J. 1990. Mulch, examining the facts and fallacies behind the uses and benefits of mulch. Amer. Nurseryman 172:132.

7. Derr, J.F., J.C.Neal, L.J. Kuhns, R.J.Smeda, L.A. Weston, E. Elmore, C.A.Wilen, J. Ahrens, A. Senesac, and T. Mervosh. 1998. Weed management in landscape and nursery plantings. pp. 42–59 *In*: M.E. McGiffen Jr. (Ed.). Weed Management in Horticultural Crops. ASHS Press, Alexandria, VA.

8. Dreistadt, S.H., J.K. Clark, and M.L. Flint. 1994. Pests of Landscape Trees and Shrubs: An Integrated Pest Management Guide. Division of Agriculture and Natural Resources. University of California. Publication 3359.

9. Gilliam, C.H., W.J. Foster, J.L. Adrain, and R.L. Shumack. 1990. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hort. 8:133–135.

Table 8. **Shoot and total dry mass of *C. citrinus* after growing for 28 weeks in containers amended with different mulch depths and irrigated with surface or subirrigation.**

Irrigation	Mulch depth (cm)	Shoot dry mass (gm)	Root dry mass (gm)	Total dry mass[y] (gm)
Surface	0	51.7c[z]	7.1	56.6c
Sub	0	83.5ab	17.3	100.9ab
Surface	2.5	91.7a	16.6	108.3a
Sub	2.5	84.2ab	20.9	105.7ab
Surface	5.0	71.4bc	11.0	82.5bc
Sub	5.0	79.4ab	20.1	99.4ab
Surface	7.5	86.5ab	12.3	97.5ab
Sub	7.5	86.2ab	18.4	104.7ab
			NS	

[z]Means followed by the different letters within a column are significantly different at $P < 0.05$ by Fisher's Protected t-test.

[y]The total weight may not always be the numerical sum of the root and shoot weight due to missing data. See text for explanation.

10. Gilliam, C.H., D.C. Fare, and A. Beasley. 1992. Nontarget herbicide losses from application of granular Ronstar to container nurseries. J. Environ. Hort. 10:175–176.

11. Grantzau, E. 1987. Bark mulch ideal for weed control in cut-flower perennials. Zierpflanzenbau 27:805–806.

12. Graves, W.R., R.J. Joly, and M.N. Dana. 1991. Water use and growth of honey locust and tree-of-heaven at high root-zone temperature. HortScience 26:1309–1312.

13. Martin, C.H. 1990. Modeling temperature patterns in a container medium and acclimatization of three tree species to supraoptimal root-zone temperatures. Ph.D. Dissertation. Univ. of Florida, Gainesville.

14. Pellett, N.E. and D.A. Heleba. 1995. Chopped newspaper for weed control in nursery crops. J. Environ. Hort. 13:77–81.

15. Porter, W.C. and R.L. Parish. 1993. Nontarget losses of granular herbicide applied to container-grown landscape plants. J. Environ. Hort. 11:143–146.

16. Robinson, D.W. 1988. Mulches and herbicides in ornamental plantings. HortScience 23:547–552.

17. Skroch, W.A., M.A. Powell, T.E. Bilderback, and P.H. Henry. 1992. Mulches: durability, aesthetic value, weed control, and temperature. J. Environ. Hort. 10:43–45.

18. Smeda, R. and L. Weston. 1995. Weed management systems for horticultural crops. Pages 553–601 *In*: A.E. Smith, (Ed.) Handbook of Weed Management Systems. Marcel Dekker, Inc. New York.