Efficacy of Bio-based Liquid Mulch on Weed Suppression and Water Conservation in Container Nursery Production[1]

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Abstract

To assess the effectiveness of bio-based liquid mulch at different application rates and binder loading types for weed suppression and evaporation reduction in container nursery production, a study was conducted outdoors in the summer of 2015 in Ontario, Canada. Three application rates [0.5 1.25, or 2.0 kg·m^{-2} (0.20 lb·ft^{-2})] and two binder loading types (AMP753 with 3.5% binder loading or AMP153 with 7% binder loading) of the liquid mulch were used in the trial. The evaporation rates (ER) from the container growing substrate were quantified daily for three 7-day cycles. All mulched treatments reduced total ERs starting from the second cycle compared to the no-mulch control, with the exception of the treatment binder loading type 3.5% with 0.5 kg·m^{-2} mulch. All mulched treatments had an equivalent effect at reducing weed numbers compared to the control. The 1.25 and 2.0 kg·m^{-2} rates were more effective for weed control than the low application rate (0.5 kg·m^{-2}) and there were no differences between binder loading types. No negative effects on overall plant health, flower or branch number, total aboveground biomass, leaf area, or plant growth index were observed on *Hydrangea paniculata* 'Jane' from the applied mulch. A major shortcoming with the product as tested was that it dried and shrunk within a couple of days of application. This caused a gap of approximately 10 to15 mm (0.39-0.59 inch) between the wall of the pots and the actual dried mulch. The 1.25 kg·m^{-2} rate of either binder loading type (3.5% or 7%) could be recommended if the shrinking issue of this mulch could be resolved.

Index words: Evaporation, witchgrass, Powell's amaranth, green foxtail, little lime hardy hydrangea.

Chemicals used in this study: Bio-based Liquid Mulch.

Species used in this study: witchgrass (*Panicum capillare* L.), Powell's amaranth (*Amaranthus powellii* S. Watson), green foxtail (*Setaria viridis* (L.) Beauv.), common groundsel (*Senecio vulgaris* L.), little lime hardyhydrangea (*Hydrangea paniculata* L. 'Jane').

Significance to the Horticulture Industry

Weeds control in a major issue either in horticultural crop production or in landscape maintenance. This research demonstrated that a newly-developed bio-based liquid mulch could be used to control weeds and conserve water if the shrinking issue could be resolved. The liquid mulch dried and shrunk within a couple of days of application. This caused a gap of approximately 10 to15 mm (0.39-0.59 inch) between the wall of the pots and the actual dried mulch.

Introduction

The Canadian nursery industry is an important component of the nation's economy and produces plants that benefit the environment. There is an increasing trend for producing nursery plants in containers; in 2013, sales from Canadian nursery production reached Canadian $673 million (Statistics Canada 2013). Weed and water management are important practices in container nursery production. Weeds compete with crops for nutrients, air, and water, while urbanization and global climate change will likely cause water availability to become limited in some areas (Mathers 2003, Zhu et al. 2005). Mulch can address both of these problems since application of mulch on a substrate surface can reduce, even eliminate, weeds and reduce the frequency of needed watering (Xie et al. 2006). Mulch is a material, other than soil, specifically established at the substrate-air interface to manage substrate and water by creating a favorable environment for plant growth (Case et al. 2005). The benefits of different mulches are dependent on the type, amount, and thickness of material (Tolk et al. 1999). Depending on the weed species, nurseries can spend between $500 and $4,000 per acre for manual removal of weeds (Mathers 2003). Weeds can also harbor insects, diseases, and rodents, which can damage nursery crops (Agriculture and Agri-Food Canada 2003). It is important that effective weed management practices are implemented in order to preserve the aesthetical and commercial value of nursery plants.

Mulches control weeds by inhibiting germination and suppressing weed growth (Case et al. 2005). Mulch application to landscape plantings is a common practice within the landscaping industry (Skroch et al. 1992). Skroch et al. (1992) found that, within a landscape setting, organic mulches (e.g., pine bark, hardwood bark) reduced total weed counts by 50% compared to bare soil plots. The study also found that complete weed control occurred when organic mulches were combined with solid polyethylene mulch. Billeaud and Zajicek (1989) found that pine bark nuggets significantly reduced weed counts compared to screened pine bark, hardwood, cypress, and the control. The study also concluded that mulch applied at depths of 15 cm (5.9 inch) controlled weeds better than when applied at shallower depths of 0 to 5 cm (2 inch), and that coarser mulches out-performed finer-textured material.

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The practice of mulching for weed control can also be applied to container production. Organic mulches like rice hulls, pine bark nuggets, shredded hardwood mulch, and cypress mulch have been known to significantly reduce weed counts when used in containers (Ahn and Chung 2000, Billeaud and Zajicek 1989). Hazelnut shells have also proven to be effective at controlling liverwort in container nurseries for up to 8 weeks (Svenson 1998). Inorganic mulching alternatives include weed discs made from geotextile fabric or foam, which can achieve an 85% reduction in stand of container weeds (Chong et al. 1989).

Additionally, mulches can conserve water and enhance plant growth by increasing the amount of water retained in the growing substrate for crops to use (Skroch et al. 1992). This can be accomplished by reducing substrate surface evaporation, which is the process of water moving up to the top layer of the growing substrate and into the air as a vapor (Zribi et al. 2015). Mulch does this by acting as a physical barrier to evaporation between the substrate surface and the atmosphere. It also shades the substrate, which reduces the substrate temperature (Mathers 2003). The rate and quantity of evaporation from a growing substrate surface is affected by many factors but the process is mainly controlled by energy and water availability. Lowering substrate evaporation rates can result in an increase in substrate moisture content and a decrease in the amount of irrigation water needed. With the anticipated reduction in water availability for the agricultural sector, the use of mulching materials can act to alleviate this concern (FAO 2011).

Zribi et al. (2015) studied five different mulching materials and found that the cumulative evaporation of initially water-saturated soil trays was highest in bare soils and lowest in the plastic mulching treatment. Pine bark, wheat straw, geotextile, and vine residue mulching treatments also had lower cumulative evaporation rates than bare soil during the first four days of the experiment. Yuan et al. (2009) found that gravel mulches reduced evaporation from the bare soil surface, especially when soil water contents were at high levels. The study also found that evaporation reduction rates under gravel mulches were negatively correlated with gravel sizes (effectiveness from least to most: bare soil, gravel size 4.5 cm, gravel size 2.5 cm, gravel size 0.5cm).

Though some synthetic mulches are proven effective at weed suppression and substrate moisture retention, there are environmental concerns surrounding their use because the materials are not biodegradable. Polyethylene plastic mulch is made of a non-renewable, petroleum-based material, and has an operational lifetime span of one growing season before it is disposed. Disposal practices include landfilling and incineration, which both have negative environmental impacts. Degradation of polyethylene mulch in landfills can result in the possible formation of environmentally harmful chemical products, such as aldehydes and ketones, while burning polyethylene mulch can release dioxins as an airborne pollutant (Hakkarainen and Albertsson 2004, Lemieux 1997, Levitan 2005). The use of biodegradable mulches could save resources and reduce pollution.

A new biodegradable liquid mulching material was recently made available by Advanced Micro Polymers Inc. (AMP, Milton, Ont., Canada). The base component of the liquid mulch material is made from corn, potato, wheat and cellulose. It is applied as a liquid over soil or growing substrate and dries to form a solid yet permeable layer. Various binder-loading types are designed for use in the greenhouse, nursery, landscaping, city park, and railway industries. Different application rates can be applied to produce different results. However, in the literature, no research has been conducted on the efficacy of this type of liquid mulch in controlling weeds and reducing growing substrate surface evaporation rates in a container nursery setting.

The objectives of this study were: 1) to determine the efficacy of liquid mulch for weed control and water conservation; 2) to determine which binder loading type and application rate are most effective for weed control and water conservation in container nurseries.

Materials and Methods

Substrate and plant speciess. Nursery #2 pots (22.9-cm (9.01 inch) diameter and 21.6-cm (8.5 inch) height) were filled with a common nursery potting substrate (Gro-Bark Ontario Ltd., Waterloo, Ont., Canada) containing 40% composted pine bark [$\leq$15/16 inch ($\leq$2.4 cm)], 35% aged bark-blend ($\leq$2.4 cm), 10% softwood [$\leq$1/2 inch (1.27cm)], and 15% compost ($\leq$1/2 inch). The substrate was incorporated with a controlled release fertilizer Polyon® 19N-2.6P-10.8K (Harrell's LLC, Lakeland, FL) at a rate of 4.16 kg·m^{-3} (7.01 lb.yrd^{-3}) 28 pots were filled with the fertilized substrate and then mulched to determine the efficacy of liquid mulch on water conservation without plants (*Trial one*). Another 28 pots were each filled with fertilized substrate, planted with a little lime hardy hydrangea (*Hydrangea paniculata* 'Jane'), and 20 seeds from each of the four weed species were sown on the substrate surface before liquid mulches were applied (*Trial two*). The four weed species were witchgrass (*Panicum capillare* L.), Powell's amaranth (*Amaranthus powellii* S. Watson), green foxtail [*Setaria viridis* (L.) Beauv.], and common groundsel (*Senecio vulgaris* L.) which were collected in Guelph, Ontario by researchers in the Department of Plant Agriculture, the University of Guelph. The growing substrate surface of each pot was divided into four quadrants, and 20 seeds of each species were placed in the respective quadrant.

Experimental design and liquid mulch application procedures. The experiment was a completely randomized design with 4 replications and a single pot per plot with one control (no mulch) and three application rates for each of the two binder loading types of liquid mulch (AMP753 with 3.5% binder loading and AMP153 with 7% binder loading). For both liquid mulch types (supplied by Advanced Micro Polymers Inc.), the application rates [kg·m^{-2} (1.84lb·yd^{-2})] substrate surface area) were low: 0.5, medium: 1.25, and high: 2.0 kg·m^{-2}. The liquid mulch was applied directly on top of the growing substrate surface by pouring. There were four replicates in each treatment.

The experiment was conducted outdoors at the Edmund C. Bovey Building of the University of Guelph, Guelph, Ont., Canada (lat. 43°31′38.3″N, long. 80°13′46.5″W) from July 2, 2015 to Sept. 7, 2015. The pots were placed on a tarp over a gravel surface.

Trial one: Effects of liquid mulch on water conservation. Cycle one: July 2 to 8, 2015. The pots were raised from the ground on a plastic grid to prevent water pooling from gravitational water or rainwater from getting into the pots from the bottom. Each pot was irrigated with well water to full saturation two hours before the liquid mulch application. Gravitational water was allowed to discharge through the holes at the bottom of the pots during this time so that growing substrate surface evaporation was the primary route for water loss. Treatments were randomly assigned and the liquid mulch was placed in direct contact with the surface of saturated growing substrate. The pots were weighed with an electronic scale (Mettler PM 16; Mettler-Toledo, Columbus, Ohio) immediately after the liquid mulch applications and daily thereafter at 1100 hr for the next six days. The experiment did not extend beyond seven days because the target of this experiment was to mimic a nursery setting, where irrigation occurs at least once a week during the growing season. All 28 pots were randomly rearranged daily to reduce any possible location effect.

The daily mean temperature was 12.3 to 24.3 C (54.14 to 75.74 F), with the highest temperature of 28 C on July 6 and the lowest temperature of 8 C on July 3 (Environment Canada, 2015). The daily mean relative humidity was 52.9% to 98.3%, with the highest relative humidity of 99% on July 3, 4, 5, and 6 and the lowest relative humidity of 38% on 3. The July wind speeds ranged from 4.33 to 9.92 km·h^{-1} (2.69 to 6.16 mile·h^{-1}), with the highest wind speed occurring on July 7. The pots were covered with a tarp when it rained on July 7.

Cycle two and three: Aug 5 to 11 and Sept 1 to 7, 2015, respectively. The same pots used in Cycle one without any modification or re-application of mulch were continuously used for cycle two and then cycle three. For measurements of water loss (due to evaporation), each pot was irrigated to full saturation and covered with a plastic tarp 24 h before the initial weighing. Gravitational water was allowed to drain through the holes at the bottom of the pots during this time so that growing substrate surface evaporation was the primary route for water loss. The pots were weighed with an electronic scale (Mettler PM 16) daily at 1100 hr for the next six days. All 28 pots were randomly rearranged daily to reduce any possible location effects. Evaporation water losses were measured during two cycles: the first (cycle two) was between Aug. 5and 11, 2015, and the second (cycle three) was between Sept. 1 and 7, 2015. During cycle one the mulch was wet and the water loss does not represent the water evaporated from the substrate only, therefore evaporation water losses were only measured in cycle two and three.

For cycle two, the daily mean temperature was 15.8 to 18.6 C, with the highest temperature of 22.9 C on Aug 7 and the lowest temperature of 7.8 C on Aug 6. (Environment Canada 2015). The daily mean relative humidity was 73% to 94%, with the highest relative humidity of 100% on Aug 6 and the lowest relative humidity of 46% on Aug 7. The wind speeds ranged from 4.0 to 11.8 km·h^{-1} (2.5-7.3 mile·h^{-1}) with the highest wind speed occurring on Aug. 11.

For cycle three, the daily mean temperature was 20.6 to 22.4 C, with the highest temperature of 29.6 C on Sept. 3 and the lowest temperature of 12.6 C on Sept. 1 (Environment Canada, 2015). The daily mean relative humidity was 75% to 86%, with the highest reached 100% on Sept.1, 2 and 6, and the lowest reached 46% on Sept. 4 The wind speeds ranged from 3.7 to 8.8 km·h^{-1}(2.3-5.5 mile·h^{-1}) with the highest wind speed occurring on Sept.7.

Trial two: Effects of liquid mulch on plant growth (hydrangea) and weed suppression. Treatments were randomly assigned to the 28 pots, and the liquid mulch was placed in direct contact with the growing substrate as described above. Pots were irrigated and rearranged after each watering event to reduce location effects.

Hydrangea Measurements. Hydrangea growth was measured monthly between July and September. The aboveground plant growth index was calculated as [(height x width$_1$ x width$_2$)/300], outlined by Ruter 1992). The branch and flower were counted at the beginning of the experiment and monthly thereafter. The experiment concluded on Sept. 2 2015 and final measurements for plant growth attributes, along with those mentioned previously, were made as follows: leaf area was measured for all plants using a leaf area meter (LI-3100 Area Meter; LI-COR Biosciences, Lincoln, Nebr.); fresh weights and dry weights of stems, leaves, and flowers (oven-dried at 60 to 70 C to a constant weight) were determined for aboveground biomass evaluation; and root percent coverage on the root ball surface was determined visually.

Weed Measurements. The numbers of weeds germinated were recorded monthly between July and September. At the end of the trial 9.5 weeks after study initiation, weeds number was recorded and total aboveground biomass was measured.

Data analysis. Data were subjected to a one-way analysis of variance (ANOVA) with differences (at $P <$ 0.05) among means determined by Tukey's multiple comparison test using SAS 9.4 (SAS Institute Inc., Cary, N.C.).

Results and Discussion

Water conservation. Water availability for evaporation in the mulch and substrate was higher in the mulched treatments than in the nontreated control in cycle one for the first 2 days during July 2 to 8 (data not shown) because mulch was applied onto the growing substrate surface in the liquid state and did not reach a completely solid state until after day two of the experiment (July 3). Based on the broad principles that energy and water availability influence growing substrate surface evaporation, increasing water availability in the mulched treatments (since the

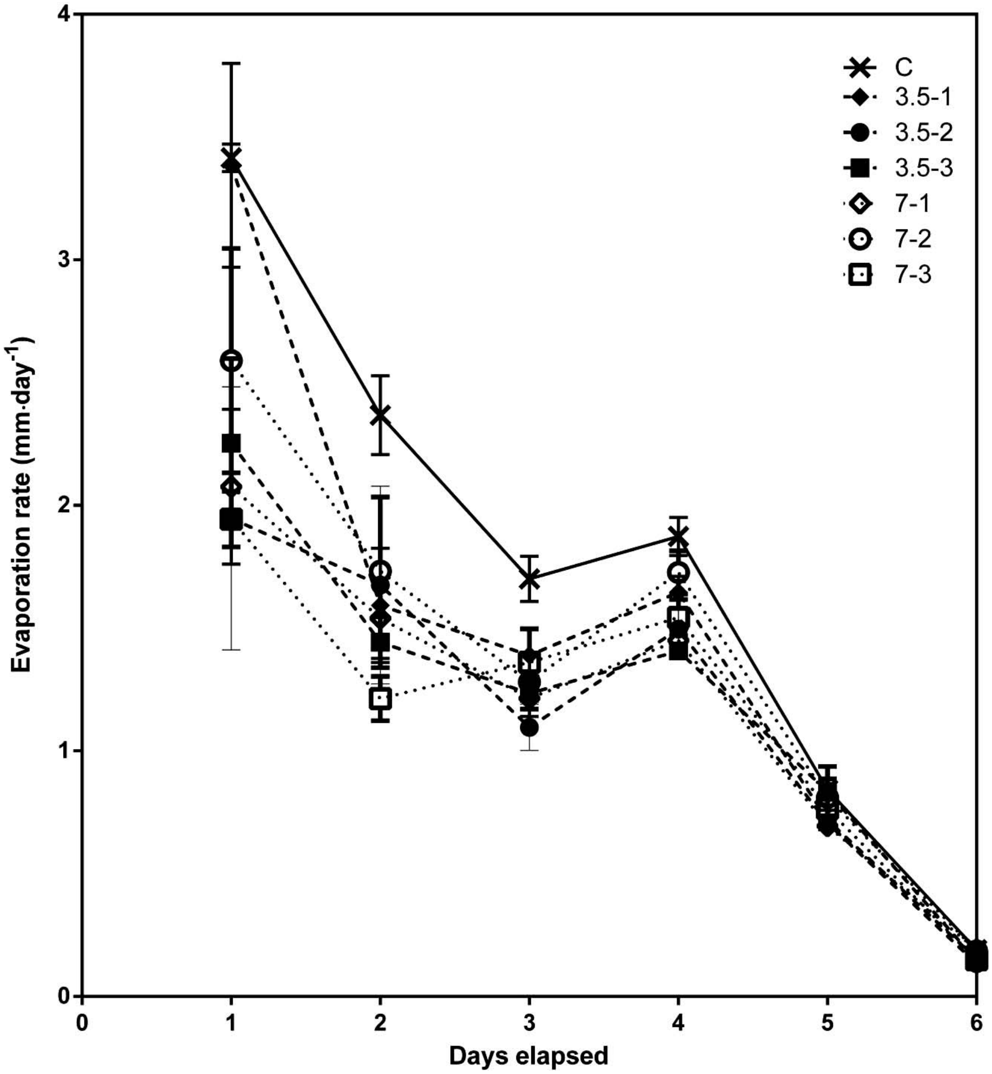

Fig. 1. Daily evaporation rates (mm·d^{-1}; 1.0 mm·d^{-1} = 0.04 inch·d^{-1}) of the initially water-saturated growing substrate measured in each treatment {Control (C), 3.5% low [3.5-1; 0.5 kg·m^{-2} mulch (1.0 kg·m^{-2} = 0.20 lb·ft^{-2})], 3.5% medium (3.5-2; 1.25 kg·m^{-2} mulch), 3.5% high (3.5-3; 2.0 kg·m^{-2} mulch), 7% low (7-1; 0.5 kg·m^{-2} mulch), 7% medium (7-2; 1.25 kg·m^{-2} mulch), 7% high (7-3; 2.0 kg·m^{-2} mulch)} from day one to six under natural conditions. Each point is the average of four replications (mean ± SE). Measurements were made from Aug. 5 to 11, 2015 (cycle two).

substrates of both mulched and not mulched pots were saturated at the beginning of the treatment, it is assumed there was more water at the mulched substrate surface due to the wetness of the liquid mulch) would therefore increase their rate of evaporation (Shaw et al. 2005). This was consistent with the results from cycle one, where the bare substrate (control) had lower ($P < 0.05$) daily evaporation rates than any of the six liquid-mulched treatments after day one (data not shown). This principle was also illustrated in a study conducted by Shaw *et al.* (2005), who measured the effects of various mulching materials on substrate evaporation and found that mulches with the highest water holding capacity lost the most water in a landscape setting.

However, once the liquid mulch reached a solid state after the initial application, it remained solid even after subsequent exposure to water. This shift in the mulch's water content and physical state influenced its effectiveness at reducing growing substrate evaporation in the following two cycles. Measurements conducted between Aug. 5 and 11, 2015 (cycle two) showed that both liquid mulch types [AMP753 with 3.5% binder loading (3.5) and AMP153 with 7% binder loading (7)] significantly reduced water loss via evaporation by the end of the experiment compared to the control with no mulch, except 3.5-1 (low rate; $P < 0.05$; Fig. 1 and 2). The daily evaporation rates were higher from day one to four then gradually decreased in all the treatments, which may be due to there being less water in the substrate for evaporation in the later days (Fig. 2). There were no differences amongst the mulch types and application rates, except that the highest application rate of AMP153 with 7% binder loading (7-3) lost the least amount of water up to day four. However, this advantage diminished towards the end of the measurement cycle in terms of accumulated water loss (Fig. 1). Substrate in 7-3 had 45% less evaporation compared to the control on day two, with the difference dropping to 33% on day six. A similar trend was observed during the measurements

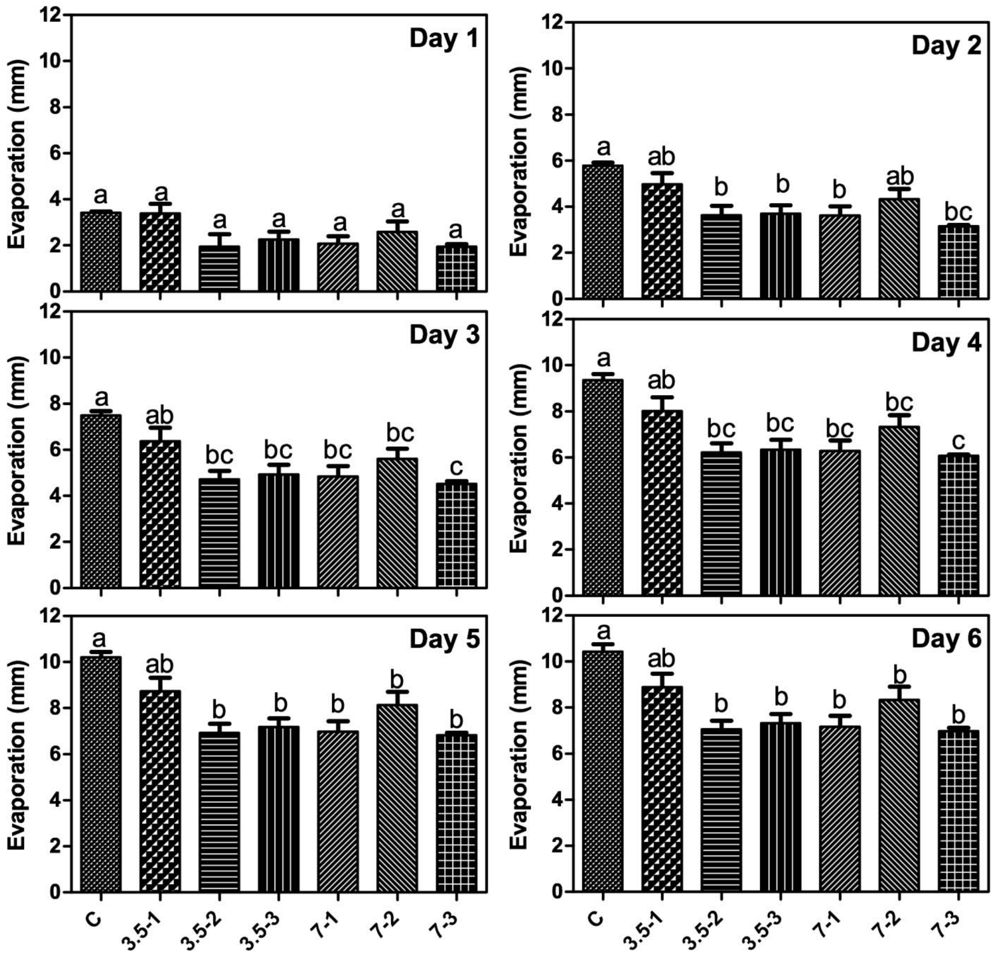

Fig. 2. Cumulative evaporation (mm; 1.0 mm = 0.04 inches) of the initially water-saturated growing substrate on different elapsed days in each treatment {Control (C), 3.5% low [3.5-1; 0.5 kg·m^{-2} mulch (1.0 g·m^{-2} = 0.20 lb·ft^{-2})], 3.5% medium (3.5-2; 1.25 kg·m^{-2} mulch), 3.5% high (3.5-3; 2.0 kg·m^{-2} mulch), 7% low (7-1; 0.5 kg·m^{-2} mulch), 7% medium (7-2; 1.25 kg·m^{-2} mulch), 7% high (7-3; 2.0 kg·m^{-2} mulch)}. Data (means ± SE, n = 4) bearing the same letter are not significantly different at the 5% level. Measurements were made from Aug. 5 to 11, 2015 (cycle two).

conducted between Sept. 1, and 7, 2015 (cycle 3; data not shown). Studies conducted on the efficacy of mulching materials with low water holding capacities, such as sand and gravel, also show a reduction in substrate surface evaporation rates, compared to a bare soil control (Modaihsh et al. 1985, Xie et al. 2006, Yuan et al. 2009). In relation to actual container nursery production systems, the liquid mulch would remain in a solid state for the remainder of the growing season after initial mulch application as observed in this trial, and therefore reduce the irrigation demand by reducing water loss through evaporation.

Weed suppression. All mulched treatments had an equivalent effect at reducing the number of weeds compared to the bare substrate control (Table 1). Weed

Table 1. Total weed number and fresh weight (grams[z]) in containers as affected by mulch binding type and application rate eight weeks from seeding.

Binder loading	Application rate type	Number of weeds per container[y]	Weed fresh weight (g) per container
Control	No mulch	9.0 ± 1.78 a[x]	27.1 ± 7.80 a
3.5%	0.5 kg·m^{-2}[w]	2.8 ± 1.25 b	32.4 ± 14.59 a
	1.25 kg·m^{-2}	0.8 ± 0.48 b	9.2 ± 5.44 a
	2.0 kg·m^{-2}	0.3 ± 0.25 b	0.5 ± 0.45 b
7%	0.5 kg·m^{-2}	3.5 ± 0.50 b	24.0 ± 9.21 a
	1.25 kg·m^{-2}	0.8 ± 0.48 b	2.6 ± 2.01 b
	2.0 kg·m^{-2}	0.3 ± 0.33 b	3.2 ± 3.16 b

[z]1.0 g = 0.04 oz

[y]Data are means ± SE (n = 4).

[x]Within each column, values followed by the same letter are not significantly different ($P > 0.05$).

[w]1.0 kg·m^{-2} = 0.20 lb·ft^{-2}

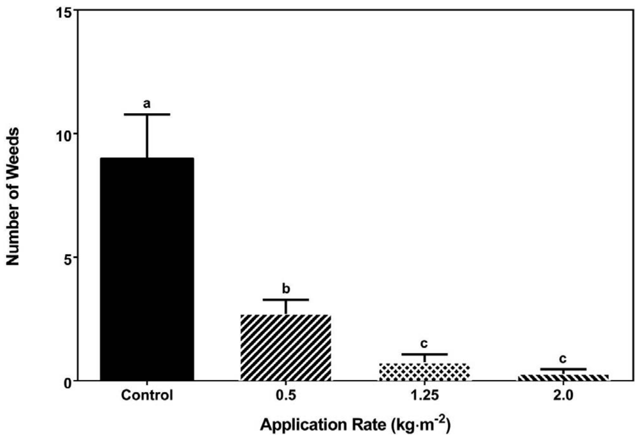

Fig. 3. Total weed count of the three weed species (green foxtail, Powell's amaranth, and witchgrass) for the control and for the three application rates {low [0.5 kg·m^{-2} mulch (1.0 kg·m^{-2} = 0.20 lb·ft^{-2})], medium (1.25 kg·m^{-2} mulch), and high (2.0 kg·m^{-2} mulch)} at the end of the experiment, averaged over binder loading types (3.5% and 7%) . Bars [means ± SE, n = 4 (control) and n = 8 (application rates)] bearing the same letter are not significantly different at the 5% level. Measurements were made on Sept. 2, 2015.

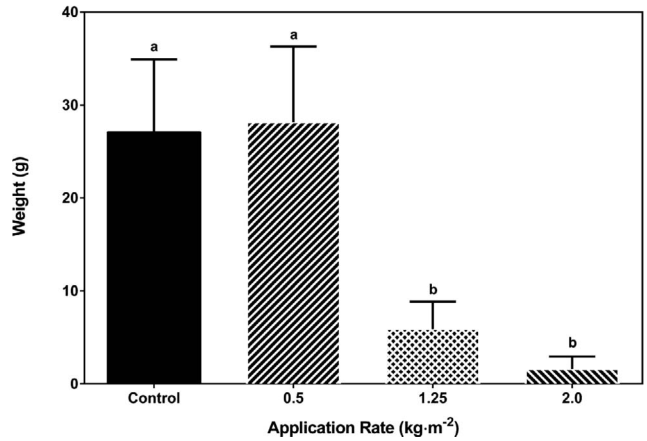

Fig. 4. Total weed biomass (g; 1.0 g = 0.04 oz) of the three weed species (green foxtail, Powell's amaranth and witchgrass) for the control and for the three application rates {low [0.5 kg·m^{-2} mulch (1.0 g·m^{-2} = 0.20 lb·ft^{-2})], medium (1.25 kg·m^{-2} mulch), and high (2.0 kg·m^{-2} mulch)} at the end of the experiment. Both binder loading types (3.5% and 7%) were included. Bars [means ± SE, n = 4 (control) and n=8 (application rates)] bearing the same letter are not significantly different at the 5% level. Measurements were made on Sept. 2, 2015.

count was reduced by at least 61% in all mulched treatments compared to the control, with treatment 3.5-3 reducing the total weed count by 97.2%. Based on the total aboveground fresh weights of all weed species, 3.5-3 and 7-2 were the most effective mulches for controlling weed growth. The medium and high application rates (1.25 and 2.0 kg·m^{-2}, respectively) were more effective at controlling the total weed count and total weed biomass than the low application rate (0.5 kg·m^{-2}; Fig. 3 and 4).There were no differences in weed count or weed biomass between binder loading types (3.5% and 7%). Common groundsel was not included in the above weeds growth attributes because it did not grow during the trial.

Based on our experience with the liquid mulch, it can be easily applied by any equipment which can pour liquid on a surface. In this case, it's the surface of the growing substrate. When applying, the liquid mulch can naturally flow and evenly distribute on the growing substrate surface without touching the leaves of the ornamental plant in the pot. Installing liquid mulch at the beginning of the growing season can reduce labor costs because liquid mulch can reduce weed count by 61.1% to 97.2%. A medium application rate of 1.25 kg·m^{-2} is sufficient to control weeds, as there was no difference between the medium and high application rates (1.25 kg·m^{-2} and 2.0 kg·m^{-2}) in terms of weed control efficacy ($P > 0.05$).

Another benefit of the product is that liquid mulch may improve fertilizer retention if top dressing fertilizer is applied before applying the mulch. The dry mulch film that binds with the top layer of the substrate may help conserve the fertilizer by acting as a barrier to inclement weather and may prevent fertilizer loss if containers are knocked over throughout the growing season. However, this speculation needs to be tested through actual trials.

Within container nursery production, weed seeds are not purposely placed beneath the liquid mulch and most of the substrate supply companies have quality control procedure to reduce and eliminate weed seeds exist in their product, thus, not that many seeds are underneath the mulch in a real life setting as observed in many commercial nursery operations in Ontario and other parts of North America. Under actual container nursery production circumstances, weed seeds will most likely fall on to the surface of the liquid mulch during the growing season, when the liquid mulch has already hardened into its solid form. Seeds need a certain level of moisture to germinate, and since the dried, solid mulch does not provide optimal growing conditions, it is suspected that the weed seeds will be unable to germinate while on the mulch surface.

A major disadvantage with the product was that it dried and shrunk within a couple of days of application. This caused a gap of approximately 10 to15 mm (0.39-0.59 inch) between the wall of the pots and the actual dried mulch, allowing weeds to germinate within the gap. The weeds that grew in these gaps were not included in our study because our objective was to determine if the liquid mulch was effective for weed control. Though the actual liquid mulch was able to reduce the number and growth of weeds in the containers, the shrinking problem will need to be resolved before it can be recommended to the growers.

Appleton and Derr (1990) studied the use of geotextile disks for container weed control and encountered a similar problem. Weed growth occurred around the outside edges of the disk because it did not properly fit the container. The study concluded that the success of geotextile disks for weed control was dependent on an extremely tight fit around the container edge and liner.

Hydrangea plant growth. The liquid mulch had no negative (e.g., toxic) effect on overall hydrangea growth based on data recorded between July 2 and September 7 (data not shown). No differences were observed for flower or branch number, total aboveground biomass (both fresh and dry biomasses), leaf area, or plant growth index among the treatments, including the bare substrate control ($P > 0.05$).

Compared to the control (bare substrate), all mulched treatments, except for 3.5-1, were effective at weed control and were able to reduce evaporation rates, during the trial except the first few days after the application of the mulch, without causing phytotoxicity or any negative effect on hydrangea plant growth. There were no differences in weed count, weed biomass, or evaporation rates between binder loading types (3.5% and 7%). There were no differences between application rates in reducing evaporation rates but the medium and high application rates (1.25 and 2.0 $kg \cdot m^{-2}$, respectively) were more effective at reducing the total weed count than the low application rate (0.5 $kg \cdot m^{-2}$). Therefore, a medium application rate (1.25 $kg \cdot m^{-2}$) of either binder loading type can be recommended for container nursery production after the shrinkage issue is solved, as it is the most cost-efficient and effective treatment for weed and growing substrate evaporation control.

Literature Cited

Agriculture and Agri-Food Canada. 2003. Canadian nursery crop profile. McTavish Resource & Management Consultants Ltd., British Columbia. <http://publications.gc.ca/collections/collection_2009/agr/A118-10-27-2003E.pdf>. Accessed October 10, 2017.

Ahn, J.K. and I.M. Chung. 2000. Allelopathic potential of rice hulls on germination and seedling growth of barnyard grass. Agron. J. 92:1162–1167.

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

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.

Case, L.T., H.M. Mathers, and A.F. Senesac. 2005. A review of weed control practices in container nurseries. HortTechnology 15:535–545.

Chong, C., B. Hamersma, and D. Ponzo. 1989. In search of the ultimate weed control disc. Hort. Rev. (Ontario) 7:8–11.

Environment Canada. 2015. Daily data report for July and August 2015. <http://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=49568&timeframe=2&StartYear=1840&EndYear=2017&Day=9&Year=2015&Month=7#>. Accessed October 10, 2017.

Hakkarainen, M. and A. Albertsson. 2004. Environmental degradation of polyethylene, p. 177–199. *In*: A. Albertsson (ed.). Long term properties of polyolefins. Springer-Verlag Berlin Heidelberg.

Lemieux, P. M. 1997. Evaluation of emissions from the open burning of household waste in barrels. U.S. Environ. Protection Agency Report 600/R-97-134a; Washington, DC; p 70.

Levitan, L. 2005. Reducing dioxin emissions by recycling agricultural plastics: Creating a viable alternative to open burning. Pages? *In:* Great Lakes Regional Pollution Prevention Roundtable, New York.

Mathers, H. 2003. Novel methods of weed control in containers. HortTechnology 13:28–34.

Modaihsh, A.S., R. Horton, and D. Kirkham. 1985. Soil water evaporation suppression by sand mulches. Soil Sci. 139:357–361.

Ruter, J.M. 1992. Influence of source, rate, and method of applicating [sic] controlled release fertilizer on nutrient release and growth of 'Savannah' holly. Fert. Res. 32:101–106.

Shaw, D.A., D.R. Pittenger, and M. McMaster. 2005. Water retention and evaporative properties of landscape mulches. Proc. Annu Irr. Show. Irr. Assn. 26:134–144.

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.

Statistics Canada. 2013. Greenhouse, sod and nursery industries. <http://www.statcan.gc.ca/daily-quotidien/140424/dq140424b-eng.htm>. Accessed October 10, 2017.

Svenson, S.E. 1998. Suppression of liverwort growth in containers using irrigation, mulches, fertilizers, and herbicides. Sou. Nur. Assoc. Res. Conf. Proc. 43:396–402.

The Food and Agriculture Organization of the United Nations. 2011. The state of the world's land and water resources for food and agriculture: Managing systems at risk. Earthscan. <http://www.fao.org/docrep/017/i1688e/i1688e.pdf>. Accessed October 10, 2017.

Tolk, J.A., T.A. Howell, and S.R. Evett. 1999. Effect of mulch, irrigation, and soil type on water use and yield of maize. Soil Tillage Res. 50:137–147.

Xie, Z., Y. Wang, W. Jiang, and X. Wei. 2006. Evaporation and evapotranspiration in a watermelon field mulched with gravel of different sizes in northwest China. Agric. Water Mgt. 81:173–184.

Yuan, C., T. Lei, L. Mao, H. Liu, and Y. Wu. 2009. Soil surface evaporation processes under mulches of different sized gravel. Catena 78:117–121.

Zhu, H., C.R. Krause, R.H. Zondage, R.D. Brazee, R.C. Derksen, M.E. Redings, and N.R. Fausey. 2005. A new system to monitor water and nutrient use in pot-in-pot nursery production systems. J. Environ. Hort. 23:47–53.

Zribi, W., R. Aragüés, E. Medina, and J.M. Faci. 2015. Efficiency of inorganic and organic mulching materials for soil evaporation control. Soil Tillage Res. 148:40–45.