Impact of Rice Hull Mulch Depth on Emergence of Multiple Weed Species at Varying Growth Stages in Nursery Containers

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Abstract

Rice hull mulch is widely used in container plant production due to its availability and effectiveness. This study evaluated whether common nursery weed species can survive or emerge through rice hull mulch when already established at the time of mulch application. Seeds of four weed species were sown to reach either the cotyledon to 1-leaf, 1–2 leaf, or 2–4 leaf growth stages using staggered seeding dates. Once seedlings reached the target stages, containers were thinned to five seedlings each and mulched with rice hulls at depths of 0, 0.6, 1.3, 2.5, or 5 cm (equivalent to 0, 0.25, 0.5, 1, or 2 in). Results showed that mulch depths of 1.3 cm and greater significantly suppressed emergence and growth of flexuous bittercress (*Cardamine flexuosa*), creeping woodsorrel (*Oxalis corniculata*), eclipta (*Eclipta prostrata*), and longstalked phyllanthus (*Phyllanthus tenellus*). These effects were observed at both early (1–2 leaf) and more developed (2–4 leaf) stages of these four species., The most effective suppression occurred at 2.5 and 5 cm depths, demonstrating the potential of rice hull mulch to serve as a sustainable weed management strategy, even if small weed seedlings are present at the time of application. All rice hull depths effectively prevented growth of liverwort (*Marchantia polymorpha*).

Species used in this study: eclipta (*Eclipta prostrata* L.), liverwort (*Marchantia polymorpha* L.), longstalked phyllanthus (*Phyllanthus tenellus* Roxb.), flexuous bittercress (*Cardamine flexuosa* With.), creeping woodsorrel (*Oxalis corniculata* L.).

Index words: container production. container nursery, mulch, non-chemical weed control, ornamental crops, weed management.

Significance to the Horticulture Industry

Weed control is a major cost and management concern in container nursery production. While preemergence herbicides are commonly used, options are limited, particularly for sensitive ornamental cultivars. In addition, more than 80% of broadcast-applied herbicide often misses the target containers, reducing efficacy and increasing waste. As a result, many growers have adopted parboiled rice hull mulch as a sustainable alternative. Rice hulls are lightweight, easy to apply, and hydrophobic, characteristics that make them ideal for use in container production. However, in nursery production there is often a 2–3-week gap between potting and mulch application, during which weed seedlings can become established. This study addressed a key industry question: Can rice hull mulch still suppress weeds if seedlings are already present at the time of application? The results demonstrated that mulch applied at depths of 1.3, 2.5, or 5 cm significantly reduced the growth of common container weeds, even when seedlings had already emerged. The greatest suppression occurred at depths of 2.5 and 5 cm, regardless of weed growth stage. Growers can apply rice hull mulch up to 2–3 weeks after potting and still achieve effective weed control, provided the mulch is applied at a minimum depth of 2.5 cm. These findings support the use of rice hulls as a cost-effective and sustainable weed management tool in container nursery production.

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Introduction

Weeds are a continual, year-round threat to nursery profitability, resulting in decreases in crop growth by up to 60% and reducing marketability (Berchielli-Robertson et al. 1990). Nursery growers may spend up to $11,000 per 0.4 ha (one acre) annually on weed management (Ingram et al. 2016, 2017). A large portion of this cost is allocated to herbicides, with container nursery growers in the southeastern U.S. typically applying 2 to 6 herbicide treatments per year (Stewart et al. 2017). While preemergence herbicides are effective, there are relatively few options available for use in ornamental plants, making herbicide rotation a challenge. Moreover, many branded/patented plants are more sensitive to over-the-top applications compared to older cultivars (Yin and Marble 2024). In terms of application, it has long been recognized that more than 80% of the herbicide applied may land off target, depending upon pot spacing, reducing efficiency and efficacy for weed control, at least within the container itself (Gilliam et al. 1992).

With growing concerns over the environmental impact of chemical weed control, rising labor and chemical costs, and decreasing labor availability (Fulcher et al. 2023), many nurseries are increasingly focusing on sustainability in container-grown plants. As a result, more nurseries are turning to mulching as an alternative to preemergence herbicides. A comprehensive review of mulch materials used in container plant production and their associated benefits has recently been published (Khamare and Marble 2023). Some of the common mulch materials used consist of rice hulls, pine bark, wood chips, wood shavings, nuts (peanut, pecan shells), pine straw and other materials (Chalker-Scott 2007, Khamare and Marble 2023, Saha et al. 2018). Rice hull mulch is a popular mulch material used in container plant production due to its large-scale availability from rice-producing states that include California, Louisiana, Mississippi, Arkansas, and Texas in the United States (Snyder and Slaton 2001). Parboiled rice hulls are a waste product of the rice industry and are dry rice husks removed from rice grains. They are light weight, easy to ship and apply, and are hydrophobic (Altland et al. 2016), thus they make for an ideal mulch material in container grown ornamentals.

Research on rice hulls and organic mulch in general as a weed management strategy is not a novel concept. When applied at adequate depths, rice hull mulch has been shown to provide nearly 100% control of certain weed species, depending on the specific species targeted (Altland and Krause 2014). One manufacturer (Riceland Foods, Inc., Stuttgart, AK), recommends applying rice hull mulch at a depth of 3.8 to 5.0 cm (1.5 to 2 in) to achieve effective weed suppression in container-grown crops. Altland et al. (2016) reported that applying rice hull mulch at depths of 1.3 to 2.5 cm effectively reduced the emergence and growth of flexuous bittercress and creeping woodsorrel. Similar results were observed by Poudel and Witcher (2022), who found that rice hull mulch applied at depths of 1.3 and 2.5 cm reduced the germination of creeping woodsorrel by 46% and 90%, respectively, and significantly reduced shoot dry weight. Rice hull mulch has also shown to provide better control of Pennsylvania bittercress (*Cardamine pensylvanica* Muhl. ex Willd.) when compared to isoxaben or prodiamine applied at label rates (Yu and Marble 2022).

While there have been several studies focusing on the use of rice hull as a weed control tool, there is a need to address key questions from growers to optimize their use and provide growers with reliable, evidence-based recommendations. For instance, application practices vary, with some growers applying rice hulls at potting and others top-dressing after pots are placed in the production area. Many nursery weed species can germinate in as few as 4 to 7 days (Bachman and Whitwell 1994, Schwartz-Lazaro and Copes 2019), and if rice hull application is delayed due to labor shortages or weather, many small weed seedlings may be present in the pots at the time of application. A critical question is whether the application or reapplication of rice hulls after potting can suppress already emerged or emerging weed seedlings present in the container substrate. Therefore, the objective of this study was to determine whether common nursery weed species can survive or emerge through rice hull mulch when already present at the time of mulch application.

Materials and Methods

Experiment 1. Emergence of flexuous bittercress and creeping woodsorrel through rice hulls applied at four different depths. All experiments were conducted at the Mid-Florida Research and Education Center in Apopka, FL, USA. Square nursery containers [1.68 L (0.44 gal,13.30 cm height, 13.30 cm diameter] were filled with a substrate consisting of pine bark and sand mix (90:10 v:v) and fertilized with a controlled release fertilizer (CRF) (Osmocote® Plus micronutrients 21-4-8 N-P-K (8–9 mo), ICL Specialty Fertilizers, Dublin, OH, USA) at 4.7 $kg{\cdot}m^{-3}$. Each container was seeded with either flexuous bittercress or creeping woodsorrel seeds (approximately 20 seeds per pot) and allowed to reach a 1 to 2 leaf (1-2L) or a 2 to 4 leaf (2-4L) stage of growth. This was accomplished by using two different seeding dates spaced approximately 10 days apart. After weed seedlings reached the different stages of growth, containers were thinned to contain five seedlings of weed species in each container. Containers were then mulched with rice hulls at depths including 0, 0.6, 1.3, or 2.5 cm (0, 0.25, 0.5, or 1 in). The emergence of both weed species through the mulch was evaluated by taking weed counts at 4 and 8 weeks after mulching and dry weights at trial conclusion (10 week). All containers were maintained inside a shade house and received 0.7 cm of water using overhead irrigation. This experiment was initiated in September 2022 and repeated in November 2022.

Experiment 2. Emergence of eclipta, longstalked phyllanthus and liverwort through rice hulls applied at five different depths. A second experiment with eclipta or longstalked phyllanthus was conducted in June 2025 and repeated in July 2025. Following the same methods mentioned above, eclipta and longstalked phyllanthus were seeded in 1.69 L (0.44 gal) nursery containers using the potting substrate mentioned previously. The seedlings were allowed to reach a cotyledon to 1 leaf (C-1L) or a 2 to 4 leaf (2-4L) stage of growth. After weed seedlings reached the different stages of growth, containers were thinned to contain five seedlings of weed species in each container. Containers were then mulched with rice hulls at depths of 0, 0.6, 1.3, 2.5, or 5 cm (0, 0.25, 0.5, 1, or 2 in). The emergence of both weed species through the mulch was recorded by taking weed counts at 2, 4, and 8 weeks after mulching and dry weights at trial conclusion (10 weeks). All the containers were maintained inside a greenhouse and received 0.7 cm irrigation per day via overhead irrigation.

Experiment 3. Liverwort growth. A separate set of 1.68 L (0.44 gal) nursery containers were used to evaluate the effect of rice hull mulch application on liverwort growth. Before beginning the trial for liverwort, nursery containers were filled with a substrate mentioned previously. The surface of each square nursery container was covered with five to six pieces (2 cm each) of liverwort and placed in the previously described shade house. Containers were irrigated daily with 0.7 cm of water using overhead irrigation. They remained in the shade house until the liverwort fully colonized the surface, forming gemmae cups and obscuring the substrate. To initiate the experiment, a single piece approximately 5 cm (2 in) in size was placed on the substrate surface under the previously mentioned rice hull mulch treatments. This experiment was initiated in June 2025 and repeated in August 2025.

Liverwort surface coverage was measured at 16 WAP by carefully removing all rice hull mulch from the containers by hand and then taking digital photographs of each container in an indoor photo studio using a smartphone (iPhone 11 Plus; Apple, Cupertino, CA) positioned 0.91 m (3 ft) above the substrate surface. Images were cropped using Microsoft Paint (Microsoft Corp., Redmond, WA) to include only the visible substrate and liverwort. The resulting images were analyzed for percent liverwort coverage using the ImageJ software (U.S. National Institutes of Health, Bethesda, MD). Liverwort coverage was measured

Table 1. **Effect of rice hull depth on plant stand and shoot dry weight of flexuous bittercress (*Cardamine flexuosa*) at two growth stages[z].**

	Number per pot[y]		
Depth	**4WAP**	**8WAP**	**Shoot dry wt (g)[x]**
	1-2L stage		
0	8.9 a	7.6 a	3.2 a
0.6	7.4 a	6.4 a	2.3 b
1.3	4.3 b	4.1 b	1.8 b
2.5	0.2 c	0.4 c	0.3 c
	2-4 L stage		
0	10.5 a	8.4 a	2.2 a
0.6	7.4 ab	6.1 a	2.5 a
1.3	6.6 b	5.3 a	2.4 a
2.5	1.9 c	1.8 b	1.4 b

[z]Treatments consisted of pinebark/sand standard substrate with controlled release fertilizer (CRF) incorporated. flexuous bittercress was allowed to reach either 1-2 leaf stage (1-2L) or 2-4 leaf stage (2-4L) and thinned to contain 5 seedlings in each container. Containers were then mulched with rice hulls at depths of 0, 0.6, 1.3, or 2.5 cm. Means followed by the same letter within a column are not significantly different according to Tukey's HSD test $\alpha = 0.05$.

[y]Emergence of weed seedlings was evaluated by taking weed counts at 4 and 8 weeks after potting (WAP).

[x]Shoot dry weight was measured at the 8-week trial conclusion.

Table 2. **Effect of rice hull depth on seed emergence and shoot dry weight of creeping woodsorrel (*Oxalis corniculata*) at two growth stages[z].**

	Number per pot[y]		
Depth[w]	**4WAP[y]**	**8WAP**	**Shoot dry wt[x]**
	1-2L stage		
0	7.8 b	7.7 b	2.6 a
0.6	11.2 a	10.1 a	2.8 a
1.3	2.9 c	2.5 c	1.1 b
2.5	0 c	0.2 d	0.1 c
	2-4L stage		
0	8.4 a	8.3a	2.3 a
0.6	8.6 a	7.5 ab	2.6 a
1.3	8.1 a	6.4 b	2.6 a
2.5	0.1 b	0.8 c	0.6 b

[z]Treatments consisted of pinebark/sand standard substrate with controlled release fertilizer (CRF) incorporated. creeping woodsorrel were allowed to reach either 1-2 leaf stage (1-2L) or 2-4 leaf stage (2-4L) stage and thinned to contain 5 seedlings in each container. Containers were then mulched with rice hulls at depths of 0, 0.6, 1.3, 2.5 cm. Means followed by the same letter within a column are not significantly different according to Tukey's HSD test $\alpha = 0.05$.

[y]Emergence of weed seedlings was evaluated by taking weed counts at 4 and 8 weeks after potting (WAP).

[x]Shoot dry weight was measured at the 8-week trail conclusion.

using the color threshold tool, with the color threshold parameters (hue, saturation, and brightness) adjusted to separate liverwort from the substrate.

Statistics. All trials used a completely randomized design with eight single plant replications for each treatment and repeated in time with the same methodology. Data were subjected to analysis of variance (ANOVA) using a statistical software package (JMP Pro version 14; SAS Institute, Cary, NC). Before final analysis, all data were inspected to ensure the assumptions of the ANOVA were met. Data were pooled over experimental runs because there was no treatment × experimental run interactions. Previous research in both nursery and landscape environments clearly demonstrates that weed control increases as mulch depth increases. As it is more important from a production standpoint to determine differences and make comparisons between individual mulch depths from a weed control standpoint, a multiple comparison test was performed in lieu of a regression analysis despite the treatment structure of 4 or 5 increasing rice hull depths. Post hoc means comparisons were performed when ANOVA indicated a significant treatment effect using Tukey's honestly significant difference test, with differences considered significant at $P \leq 0.05$.

Results and Discussion

Experiment 1. Emergence of flexuous bittercress and creeping woodsorrel through rice hulls applied at four different depths. At the 1–2L stage, flexuous bittercress emergence at a mulch depth of 0.6 cm was not significantly different from the non-mulched control (0 cm) at either 4 or 8 weeks after potting (WAP) (Table 1). However, emergence at the 1-2L stage declined substantially at a depth of 1.3 cm. At 2.5 cm, flexuous bittercress emergence was reduced by 97% and 95% at 4 and 8 WAP respectively. Shoot dry weight data showed that flexuous bittercress emergence was significantly reduced at depths of 0.6 cm or greater, with a 90% reduction being observed at the 2.5 cm depth.

At the 2−4L growth stage, similar trends were observed for flexuous bittercress, with no significant difference in weed counts between the 0.6 cm mulch depth and the non-mulched control at either 4 or 8 WAP. Mulch depths of 1.3 cm and 2.5 cm reduced weed counts by 37% and 82%, respectively at 4 WAP. However, by 8 WAP, a significant reduction in emergence was observed only at the 2.5 cm depth, which resulted in a 78% decrease compared to the non-mulched control. Regarding biomass, mulch depths of 0.6 cm and 1.3 cm had no significant effect on flexuous bittercress shoot dry weight, whereas the 2.5 cm depth resulted in a 36% reduction relative to the non-mulched treatment.

In the case of creeping woodsorrel, emergence at the 1-2L stage was actually higher in containers with a mulch depth of 0.6 cm compared with the non-chemical control at both 4 and 8 WAP (Table 2), but reductions of 60% were observed at the 1.3 cm depth. At a mulch depth of 2.5 cm, creeping woodsorrel counts were reduced by 99% at both 4 and 8 WAP. Shoot dry weight data showed reductions of creeping woodsorrel biomass of 57% and 96% at mulch depths of 1.3 cm and 2.5 cm, but there was no difference in creeping woodsorrel shoot mass at a depth of 0.6 cm.

Once creeping woodsorrel reached the 2-4L stage, there were no reductions in creeping woodsorrel emergence at 4 WAP at the 0.6 or 1.3 cm mulch depth in relation to the non-mulched control group (Table 2), but the 2.5 cm depth reduced emergence by approximately 22%. At 8 WAP, mulch depths of 1.3 and 2.5 cm resulted in decreased creeping woodsorrel counts, with a 90% reduction observed at the 2.5 cm depth. Furthermore, mulch depths of 0.6 cm and 1.3 cm had no significant effect on shoot dry weight, but a depth of 2.5 cm reduced shoot dry weight by 73%.

Table 3. **Effect of rice hull depth on seed emergence and shoot dry weight of eclipta (*Eclipta prostrata*) at two growth stages[z].**

	Number per pot[y]				
Depth[w]	2WAP[x]	4WAP	6WAP	8WAP	Shoot dry wt[x]
			C-1L stage		
0.0	4.9 a[z]	4.8 a	5.0 a	5.0 a	24.3 a
0.6	2.8 b	2.6 b	4.1 b	3.2 b	22.7 a
1.3	0 c	0.0 c	1.0 c	0.2 c	9.9 b
2.5	0 c	0.0c	0.1 cd	0.0 c	3.5 bc
5.0	0 c	0.0 c	0.0 d	0.0 c	0.0 c
			2-4L stage		
0.0	5.0 a	5.0 a	5.0 a	5.0 a	25.4 a
0.6	3.6 b	3.3 b	3.2 b	3.5 b	24.7 a
1.3	0.9 c	1.4 c	1.1 c	1.4 c	16.6 b
2.5	0.4 cd	0.5 d	0.4 cd	0.2 d	7.1 c
5.0	0.0 d	0.0 d	0.0 d	0.0 d	0 c

[z]Treatments consisted of pinebark/sand standard substrate with controlled release fertilizer (CRF) incorporated. Weed species consisting of either eclipta were allowed to reach cotyledon to 1 leaf (C-1L) stage or 2-4 leaf (2-4L) stage and thinned to contain 5 seedlings in each container. Containers were then mulched with rice hulls at depths of 0, 0.6,1.3, 2.5, and 5 cm. Means followed by the same letter within a column are not significantly different according to Tukey's HSD test $\alpha = 0.05$.

[y]Emergence of weed seedlings was evaluated by taking weed counts at 2, 4, 6 and 8 weeks after potting (WAP).

[x]Shoot dry weight was measured at the 8-week trail conclusion.

Table 4. **Effect of rice hull depth on seed emergence and shoot dry weight of longstalked phyllanthus (*Phyllanthus tenellus*) at two growth stages[z].**

	Number per pot[y]				
Depth[w]	2WAP[x]	4WAP	6WAP	8WAP	Shoot dry wt[x]
			C-1L stage		
0.0	4.9 a[z]	4.8 a	5.0 a	5.0 a	24.7 a
0.6	4.4 a	3.3 b	4.5 a	4.2 a	21.2 a
1.3	1.8 b	1.2 c	2.2 b	2.1 b	10.2 b
2.5	0.5 c	0.5 c	0.7 c	0.5 c	5.5 bc
5.0	0.1 c	0.3 c	0.3 c	0.2 c	2.8 c
			2-4L stage		
0.0	5.0 a	5.0 a	5.0 a	5.0 a	26.7 a
0.6	4.4 a	4.5 a	4.1 a	4.2 b	31.7 a
1.3	1.8 b	2.4 b	2.6 b	2.4 c	25.8 a
2.5	0.5 c	0.6 c	0.7 c	0.4 d	18.3 b
5.0	0.0 c	0.0 c	0.0 c	0.1 d	9.9 c

[z]Treatments consisted of pinebark/sand standard substrate with controlled release fertilizer (CRF) incorporated. Weed species consisting of longstalked phyllanthus were allowed to reach cotyledon to 1 leaf (C-1L) stage or 2-4 leaf (2-4L) stage and thinned to contain 5 seedlings in each container. Containers were then mulched with rice hulls at depths of 0, 0.6,1.3, 2.5, and 5 cm. Means followed by the same letter within a column are not significantly different according to Tukey's HSD test $\alpha = 0.05$.

[y]Emergence of weed seedlings was evaluated by taking weed counts at 2, 4, 6 and 8 weeks after potting (WAP).

[x]Shoot dry weight was measured at the 8-week trial conclusion.

Experiment 2. Emergence of eclipta, longstalked phyllanthus and liverwort through rice hulls applied at five different depths. At the C–1L growth stage, eclipta emergence was reduced by all four mulch depths, with no emergence observed at the 5 cm depth across all sampling intervals (2, 4, 6, or 8 weeks after WAP) (Table 3). Even a mulch depth as shallow as 0.6 cm resulted in a 36% reduction in emergence at 8 WAP. However, shoot dry weight at the 0.6 cm depth was comparable to the non-mulched control, while mulch depths of 1.3 cm and 2.5 cm reduced shoot dry weight by 50% and 86%, respectively.

Similar trends were observed at the 2–4L growth stage (Table 3). Eclipta emergence was reduced at all four mulch depths, with complete suppression at 5 cm across all sampling intervals. Emergence decreased progressively with increasing mulch depth, with reductions of 30%, 72%, 96%, and 100% at 0.6, 1.3, 2.5, and 5 cm, respectively. At this stage, shoot dry weight was not reduced at the 0.6 cm depth, but was reduced by 35% and 72% at 1.3 cm and 2.5 cm, respectively.

Longstalked phyllanthus emergence at the C-1L stage was not reduced at the 0.6 cm depth, but depths of 1.3 cm and greater significantly decreased emergence, with the lowest emergence observed at the 5 cm depth (Table 3). Similar to results observed with eclipta, shoot dry weight of longstalked phyllanthus was not reduced by the 0.6 cm mulch depth but reductions were observed as mulch depth increased, resulting in a. 58%, 77%, and 88% reduction at 1.3, 2.5, and 5 cm depth, respectively.

At the 2-4L stage, the 0.6 cm mulch depth had minimal to no effect on longstalked phyllanthus emergence (Table 4). Reductions were observed, however, at depths of 1.3 cm or greater, with close to a 100% reduction being achieved at the 5 cm depth. In contrast, shoot dry weight data showed that the 2.5 and 5 cm depths were the only rice hull levels which had a meaningful impact on longstalked phyllanthus biomass reduction.

Numerous reports are available examining the ability of mulch to suppress weed emergence from seed. Eclipta, creeping woodsorrel, longstalked phyllanthus, and flexuous bittercress typically exhibit light-dependent (photoblastic) germination. In a controlled growth chamber study, creeping woodsorrel seeds germinated only under light and failed to germinate in complete darkness, highlighting their strong photoblastic nature (Holt 1987). Similarly, eclipta seeds required light for germination, with no emergence observed in darkness; however, even low light intensities (6% of full sunlight) were sufficient to trigger germination (Altom and Murray 1996). In other work, Bartley et al. (2017) demonstrated that increasing mulch depth significantly suppressed weed emergence from seed, with depths of 5 and 10 cm reduced fresh weight of eclipta, longstalked phyllanthus, and spotted spurge (*Euphorbia maculata* L.) by 99.5% and 100%, respectively. The effectiveness of rice hull mulch in suppressing flexuous bittercress, creeping woodsorrel, longstalked phyllanthus and eclipta in this study is likely attributable to both light exclusion and the creation of a physical barrier limiting emergence through the rice hulls (Chalker-Scott 2007, Khamare and Marble 2023). Rice hulls at depths greater than 1 cm (0.4 inch) have been shown to reduce photosynthetically active radiation to 1 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ or less (Altland et al. 2016). While the weed species evaluated here had already germinated and light emittance was not measured, depths of 1.3 cm or higher likely greatly reduced PAR beneath the mulch layer and disrupted seedling development. Additionally, the creation of a physical barrier also likely contributed as has been shown in previous studies

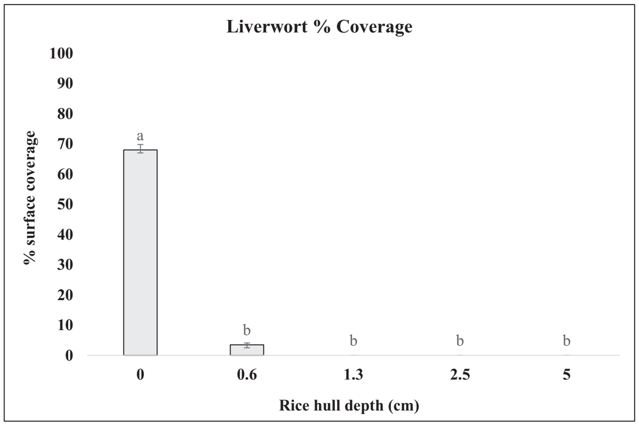

Fig. 1. Effect of four different rice hull depths on liverwort (*Marchantia polymorpha*) coverage. Containers containing liverwort were mulched with rice hulls at depths of 0, 0.6, 1.3, 2.5 and 5 cm. Error bars represent standard errors.

(Teasdale and Mohler 2000), but more focused experiments are needed to more fully understand these dynamics.

Experiment 3. Liverwort growth. Growth of liverwort was negligible across all treatments following rice hull mulch application (Fig. 1). At a mulch depth of 0.6 cm, liverwort coverage was reduced to just 6% compared to the non-mulched control (100%). No liverwort growth was observed at mulch depths of 1.3, 2.5, or 5 cm. These results are consistent with findings from a previous study using stratified substrates and rice hull mulch, which reported a 90–99% reduction in liverwort establishment (Khamare et al. 2023). Similar results were also reported by Altland and Krause (2014) with a nearly 100% control of flexuous bittercress and liverwort with either a 1.3 or 2.5 cm depth of rice hulls.

Liverwort, a bryophyte, thrives in environments with high humidity, excessive moisture, and low ultraviolet light levels (Newby et al. 2007, Svenson 1998). Additionally, research has shown that light serves as a strong stimulus for thallus development and rhizoid proliferation in liverwort (Nishihama et al. 2015). The thallus is a flat, green, photosynthetic structure and is the primary organ responsible for photosynthesis, nutrient storage, growth, and regeneration (Ligrone and Duckett 1994). Rhizoids, by contrast, function mainly in anchorage and water distribution along the underside of the thallus, helping maintain the humid microenvironment essential for liverwort survival (Cao et al. 2014). While liverwort explants can initiate regeneration in complete darkness if sucrose is provided, these regenerants remain underdeveloped and fail to form laterally expanded thalli without light exposure, particularly to white light containing red (R) and far-red (FR) wavelengths (Nishihama et al. 2015, Pashkovskiy et al. 2023). Rice hull mulch dramatically reduces photosynthetically active radiation (PAR). Even a shallow 0.3 cm layer reduces PAR by 97%, and depths of 0.6 cm or more block over 99% (Altland et al. 2016). Although rice hulls allow relatively more transmission of red and far-red light than blue and green, this transmission still declines steeply at $\geq$0.6 cm mulch depth. This explains the effectiveness of rice hulls as a liverwort suppressant, not merely by shading or drying the surface, but by disrupting the processes by which liverworts use light signals to regulate their growth, development, and differentiation.

The results demonstrated that rice hull mulch applied at depths of 1.3, 2.5, and 5 cm significantly suppressed the growth of flexuous bittercress, creeping woodsorrel, eclipta, phyllanthus, and liverwort. These mulch depths were effective at both early C-1L, 1-2L and more established (2–4 leaf) weed growth stages. The greatest weed control was observed at mulch depths of 2.5 and 5 cm when compared to non-mulched controls, which is similar to previous findings examining rice hull efficacy on weed growth via seed reproduction (Altland et al. 2016, Altland and Krause 2014, Khamare et al. 2023).

These findings indicate that rice hull mulch can be effectively applied 2–3 weeks after potting, if a minimum depth of 2.5 cm is maintained. This study provides valuable insights into the practical use of rice hull mulch as a sustainable and effective strategy for weed suppression in container plant production. Additional research is underway to further optimize the use of rice hull mulch by evaluating its interaction with topdressed controlled-release fertilizers, quantifying nutrient release, and assessing its effectiveness when combined with herbicide treatments. Furthermore, a long-term study is being conducted to examine the degradation of rice hulls under typical nursery conditions.

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