



Article

Exploiting Olive Mill Byproducts and Other Waste for Organic Weed Management

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Abstract: Weed management represents one of the most serious and costly challenges in organic crop production systems. Agricultural waste/byproducts might present phytotoxicity that can be exploited to control weeds. Two experiments were designed to study the effects of four concentrations of olive vegetation water (OVW) and a control water treatment (with no OVW) on cheeseweed (*Malva parviflora* L.) seed germination in petri dishes and pots. In a third experiment, two rates of four composts (crop residue mix (CR), olive pomace (OP), dairy/horse manure (DM), and an OP/DM mix) were mixed into a clay-loam soil at 0.10 or 0.20 L L⁻¹, to assess their effects on weed number and biomass, in addition to bell pepper (*Capsicum annuum* L.) growth. In the petri dish experiment, the three highest OVW concentrations completely prohibited germination during the five-week duration of the study. For the pot experiment, 25 mL application of OVW significantly delayed and reduced cheeseweed germination, with the reduction being proportional to the concentration of OVW. In the third experiment, composts reduced weed dry matter (composed mostly of purslane (*Portulaca oleracea* L.)), with the CR compost being the most effective, reducing total weed biomass by 67% compared to the control. CR10 and DM10 tended to increase bell pepper yields, although none of the plant parameters was significantly affected by the compost treatments.

Keywords: olive vegetation water; olive mill wastewater; olive pomace; manure compost; weeds; organic agriculture; germination; *Malva parviflora* L.; *Portulaca oleracea* L.

1. Introduction

Organic weed management has always suffered from a lack of tools. In addition, the existing tools are expensive and have limited effectiveness. Moreover, the ever-expanding weed resistance to herbicides has been adding to the challenges of weed control for conventional growers. A particular weed of interest is cheeseweed (*Malva parviflora* L.), which is becoming a problem in Mediterranean climates due to its tolerance to many herbicides [1]. In addition, it is capable of germinating at a wide range of temperatures (5–37 °C) and presents different dormancy attributes [2], making its control even harder. In the meantime, in olive- (*Olea europaea* L.) producing areas, olive oil processing activities result in large amounts of wastewater (aka olive vegetation water, OVW) and olive pomace (OP), which have polluting properties resulting from their content of organic compounds [3]. OVW contains high concentrations of lignins and tannins, which give it a characteristic dark color. In addition, this material is toxic to micro-organisms and plants due to its load of phenolic compounds, long-chain fatty acids, low pH, and salts [4,5]. This phytotoxicity has often been an issue restricting the feasibility of soil application of OVW to take advantage of its nutrient content for crop growth [6]. For example, a soil surface application of OVW in an olive orchard suppressed stomatal conductance and decreased soil mineral nitrogen, but increased soil micronutrients [7]. A 150 m³ ha⁻¹

soil application of OVW suppressed photosynthetic parameters, including the net carbon assimilation rate, in olive trees [8]. Plant germination seems to be one of the factors most sensitive to OVW. Germination of chickpeas (*Cicer arietinum* L.), durum wheat (*Triticum durum* Desf.), maize (*Zea mays* L.), and tomatoes (*Solanum lycopersicum* L.) was significantly reduced by OVW applications [9]. In tomatoes, OVW application rates of 80 m³ ha⁻¹ immediately decreased the relative germination rate to 20%, but this rate recovered to about 60% three days after the application [10]. Vegetable crops appear to be the most negatively affected by OVW soil application [11]. A lab bioassay indicated gradual germination inhibition of lettuce (*Lactuca sativa* L.) with increasing OVW rates resulting in 7.67%, 0.13%, and 0% germination rates at 80, 160, and 500 m³ ha⁻¹, respectively, compared to the untreated control germination rate of 87.6% [4]. This phytotoxicity might present an opportunity for weed management in organic and herbicide-resistance situations. Application of OVW suppressed the germination of certain weeds like redroot pigweed (*Amaranthus retroflexus* L.) by up to 90%, but was not so effective against other weeds [12]. Likewise, compared to the untreated control, the application of OVW at 10 L m⁻² reduced weed cover by 59%, 69%, 36%, 71%, and 76% for annual bluegrass (*Poa annua*, L.) shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), chickweed (*Stellaria media* (L.) Vill.), chamomile (*Matricaria chamomilla* L.), and henbit dead-nettle (*Lamium amplexicaule* L.), respectively [13]. A smaller dose of 5 L m⁻² was less effective at reducing weed pressure, and did not affect chickweed at all. OP at 3 and 10 L m⁻² was even more effective than the liquid waste treatments at reducing the weed cover of all those species [13]. Other studies have shown mixed results of sun-dried OP on weed germination, with some weeds like purslane and redroot pigweed being controlled, while others like puncturevine (*Tribulus terrestris* L.), purple nutsedge (*Cyperus rotundus* L.), and Johnsongrass (*Sorghum halepense* (L.) Pers.) were not affected by the treatment [14]. These studies show the potential of using olive mill byproducts and other agricultural waste composts in weed control, especially in organic crop production, where tools are limited and expensive. Still, our knowledge of the effects of this waste on weed pressure is very limited in terms of the weed species affected and doses needed. The objectives of this study were:

- to evaluate the effect of OVW application on cheeseweed germination, and
- to assess the weed suppression ability of different composts with or without OP.

2. Materials and Methods

This work consisted of three experiments conducted at the California Polytechnic State University, San Luis Obispo, CA, using OVW or composts. The OVW and OP were sourced from La Panza Ranch in Templeton, CA, which has a three-phase olive press. The OVW was kept in the refrigerator at 2 °C until use. The grape pomace consisted of seeds and skins of red-wine grapes, and was sourced from Cagliero Ranch in Paso Robles, CA. The composting process is described in Section 2.3.

2.1. Experiment 1: OVW Effects on Cheeseweed Germination in Petri Dishes

The effect of four dilutions of OVW and a control water treatment (with no OVW) on cheeseweed seed germination was studied in petri dishes (Figure 1). The experiment was laid out according to a completely randomized design with six replicates. Experimental units comprised 10 cheeseweed seeds that were disinfected in a 1% sodium hypochlorite solution and placed on towel paper in petri dishes. Each petri dish received 25 mL (corresponding to 3.13 L m⁻²) from one of the OVW dilutions presented in Table 1. pH values and electrical conductivity of the final treatments are also presented in Table 1.

Table 1. Composition, pH, and electrical conductivity of treatments used in Experiment 1.

Treatment	Description	PH	Electrical Conductivity (mS cm ⁻¹)
T1	No OVW + 100% tap water (Control)	7.4	0.66
T2	25% OVW + 75% tap water	5.1	3.39
T3	50% OVW + 50% tap water	5.0	5.48
T4	75% OVW + 25% tap water	4.9	6.65
T5	100% OVW (as is from press, no dilution)	4.9	7.23

**Figure 1.** Picture showing petri dishes after treatment applications. From left to right, top row presents treatments 1–3 and bottom row presents treatments 4 and 5.

All petri dishes were then incubated in a growth chamber at 25 °C day/18 °C night with a photoperiod of 16 h. Water was added thereafter in small amounts to keep the paper and seeds moist. Germination was observed daily, with a final germination count after five weeks of application. Any seed that had germinated a primary root of 2 mm or more was considered germinated.

2.2. Experiment 2: Effect of OVW on Cheeseweed Emergence in Soil-Filled Pots

In this experiment, PVC pots (10 cm top diameter and 12 cm deep) were filled with a clay-loam soil collected from the topsoil (0–15 cm) at the Cal Poly Organic Farm (35°18'15" N, 120°40'21" W) on 2 August 2018. The soil analysis is shown in Table 2. The soil had a natural, very high cheeseweed seed bank (>2500 weed m⁻²) from past weed pressure. The pots were placed in a greenhouse with natural lighting. The indoor maximum temperatures ranged between 30 °C and 35 °C and minimum temperatures between 18 °C and 22 °C. The pots were watered to 75% field capacity, then one application of 25 mL of treatments 1–5 mentioned in Experiment 1 was applied to each pot. This application rate corresponds to 3.13 L m⁻². To keep the soil moist, tap water was applied as needed to maintain the soil around 75% field capacity. The experiment was laid out according to a completely randomized design with five replicates. The number of cheeseweed seeds emerged in pots was recorded periodically, twice a week for two weeks.

2.3. Experiment 3: Effect of Composts on Weed Pressure in Bell Peppers

Two rates of four composts (crop residue mix (CR), olive pomace (OP), dairy/horse manure (DM), and OP/DM mix) were assessed to determine the effects on weed pressure. The CR was sourced from Engle and Gray (Santa Maria, CA, USA). It comprised a combination of vegetables, strawberry crowns, and grape pomace. The manure compost consisted of dairy and horse manures mixed with wood chips with a starting C/N ratio around 25. Composts were prepared aerobically in windrows during the winter and spring of 2018 at the Cal Poly composting unit according to the California Department of Food and Agriculture and organic certification guidelines. The composting process lasted for six months and composts were mechanically turned a minimum of five times. The composts were deemed mature when temperature stabilized and ammonia levels dropped below 4 mg g⁻¹ using a Solvita® (Solvita, Mt Vernon, ME, USA) compost kit. The OP/DM mix contained an

equal proportion of OP and DM. A full analysis of these composts is given in Table 3. Each of those composts was applied at 0.10 or 0.20 L L⁻¹ soil and thoroughly mixed with a clay loam soil (see Table 2 for soil properties before mixing) before filling in 10-L pots, to imitate mixing in the topsoil in the field. This arrangement resulted in nine treatments (Table 4).

Table 2. Chemical properties of the soil used in Experiments 2 and 3.

Soil PH	Organic Matter (g kg ⁻¹)	NO ₃ -N	Olsen P	K	Mg	Ca	S	Zn	Mn	Cu	Fe	B
		(mg kg ⁻¹)										
7.43	38	5.48	15.3	270	806	2576	23.9	2.33	16.2	6.30	60.7	0.85

Table 3. Chemical analysis of the composts used in Experiment 3.

Nutrient/Salt/Characteristic	CR	OP	DM	OP/DM
Total N (g kg ⁻¹)	14	14	14	17
Ammonia (mg kg ⁻¹)	17	<10	13	21
Nitrate nitrogen (mg kg ⁻¹)	240	1.2	430	15
Organic N (g kg ⁻¹)	14	14	14	17
Phosphorus (P ₂ O ₅) (g kg ⁻¹)	8.9	1.2	13	9.1
Total phosphorus (g kg ⁻¹)	3.90	0.55	5.70	4.00
Potassium (K ₂ O) (g kg ⁻¹)	13	5.40	17	14
Total potassium (g kg ⁻¹)	11	4.50	14	12
Calcium (g kg ⁻¹)	24	4.00	25	18
Magnesium (g kg ⁻¹)	6.00	0.50	16.0	11.0
Sulfate (mg kg ⁻¹)	2500	34	1200	530
Copper (mg kg ⁻¹)	71	9.90	53	42
Zinc (mg kg ⁻¹)	190	12	210	130
Iron (mg kg ⁻¹)	11,000	1200	18,000	11,000
Manganese (mg kg ⁻¹)	300	18	500	300
Boron (mg kg ⁻¹)	22	14	21	27
Sodium (mg kg ⁻¹)	1600	97	3300	1900
Chloride (mg kg ⁻¹)	3700	190	2800	2200
pH value	8.1	5.47	8.4	8.71
Electrical conductivity (ds m ⁻¹)	4.40	1.10	3.60	2.60
Bulk Density (kg m ⁻³)	625	352	705	561
Carbonates (as CaCO ₃)	25	<0.1	32	15
Organic matter (g kg ⁻¹)	359	930	307	476
Organic carbon (g kg ⁻¹)	170	490	150	280
Ash (g kg ⁻¹)	641	70	693	524
C/N Ratio	12.1	35	10.7	16.5

Table 4. Compost and rate treatment combinations used in Experiment 3.

Treatment Mix	Treatment Name
Control with no compost	Control
Crop residue mix 0.10 L L ⁻¹	CR10
Crop residue mix 0.20 L L ⁻¹	CR20
OP 0.10 L L ⁻¹	OP10
OP 0.20 L L ⁻¹	OP20
Dairy manure 0.10 L L ⁻¹	DM10
Dairy manure 0.20 L L ⁻¹	DM20
OP and manure 0.10 L L ⁻¹	OP/DM10
OP and manure 0.20 L L ⁻¹	OP/DM20

Per the University of California Cooperative Extension recommendations, the equivalent of 200 kg N ha⁻¹ was added at soil mixing, using a chicken residue fertilizer (8:5:1 NPK) as a source. One day after soil mixing, bell pepper (*Capsicum annuum* L.) cv. 'Huntington' plugs were transplanted into the pots on 2 August 2018 and the pots were grown outside to imitate field growing conditions. Pots were laid out according to a completely randomized design with six replicates. The plants were watered 1–2 times a day to avoid any water stress. Data were collected during the third and fourth weeks after transplanting. The parameters monitored included plant height, number of leaves, fruit production and relative leaf chlorophyll concentration using SPAD-502 Plus (Konica Minolta, Tokyo, Japan). All these parameters were measured twice, on 13 and 23 August 2018. Fruits were harvested once they reached 6 cm or more in diameter. Only plants producing fruits exceeding this threshold were considered in the analysis. The last harvest was performed on 19 October 2018. SPAD absorbance readings were taken on the youngest mature leaf. For weeds, weed numbers were counted per species in each pot. Weeds were cut at the soil surface at four weeks after planting, chopped into 4–5 cm pieces and placed in an oven at 75 °C until constant weight was achieved to determine biomass production for each species.

2.4. Statistical Analyses

Weed seed germination data were log transformed before being subjected to statistical analysis. All data were analyzed according to a single-factor ANOVA using the IBM SPSS Statistics version 26.0 software package (IBM Corp., Armonk, NY, USA) [15]. When factor effects were significant, mean separation was performed using Tukey's honestly significant difference (HSD) test and differences were considered significant at the $P < 0.05$ level.

3. Results

3.1. Effect of OVW on Cheeseweed Germination in Petri Dishes

All OVW water treatments significantly ($P < 0.0001$) decreased cheeseweed germination in petri dishes (Figure 2). Treatments T3, T4, and T5 completely inhibited germination throughout the duration of the study, while treatment T2 (25% OVW) resulted in 3.33% germination rate at the end of the incubation period, compared to 16.7% in the T1 treatment (control with 0% OVW). Furthermore, the first seed germinated in the T2 treatment took nine days longer to germinated than the control (T1) treatment (data not shown), indicating an inhibitory or delaying effect of OVW on cheeseweed seed germination.

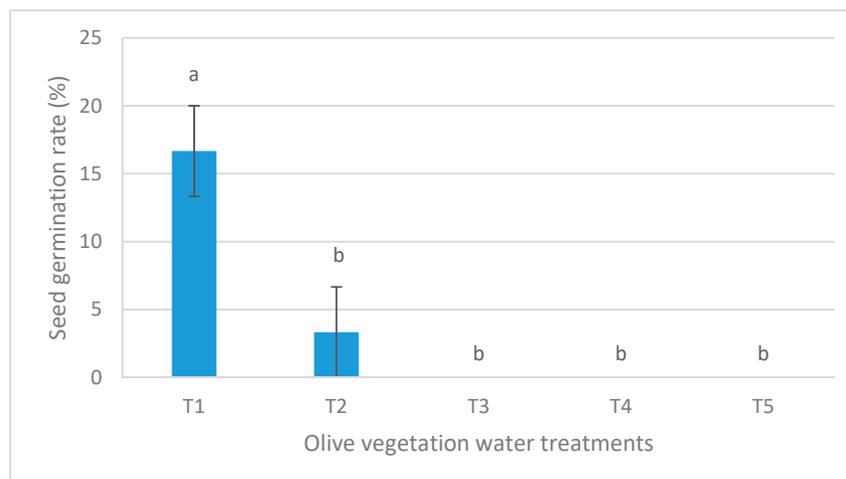


Figure 2. Cheeseweed germination in petri dishes that received 25 mL of OVW at five different strengths using dilutions with tap water (T1: 0% OVW, T2: 25% OVW, T3: 50% OVW, T4: 75% OVW,

T5: 100% OVW). Error bars represent \pm standard error. Bars sharing the same letter are not statistically different according to Tukey's HSD test (at $P < 0.05$).

3.2. Effect of OVW on Weed Emergence in Soil-Filled Pots

The application of 25 mL OVW to soil with heavy cheeseweed seed bank decreased the cheeseweed emergence rate right after application (Figure 3). The suppression of cheeseweed emergence was proportional to the concentration of OVW. The differences between the control T1 treatment and all OVW treatments became significant on day 2 after application and remained so until day 7 after application, except on day 4 (Table 5). The suppression was proportional to the concentration of OVW, with this trend becoming clear after day 7. T5 had less than half the emergence rate observed in the T1 treatment throughout the study. Between days 5 and 6, T1 was not statistically different from T3, mainly due to the high variability. Between days 6 and 8, cheeseweed germination accelerated in all OVW treatments annulling the previous significant differences with the control treatment, except between T1 and T5. By day 8, all differences between treatments were not significant, and this trend remained until the end of the experiment. However, it is interesting to note that some of the weeds that germinated in treatments T2 and T3 had died after day 11.

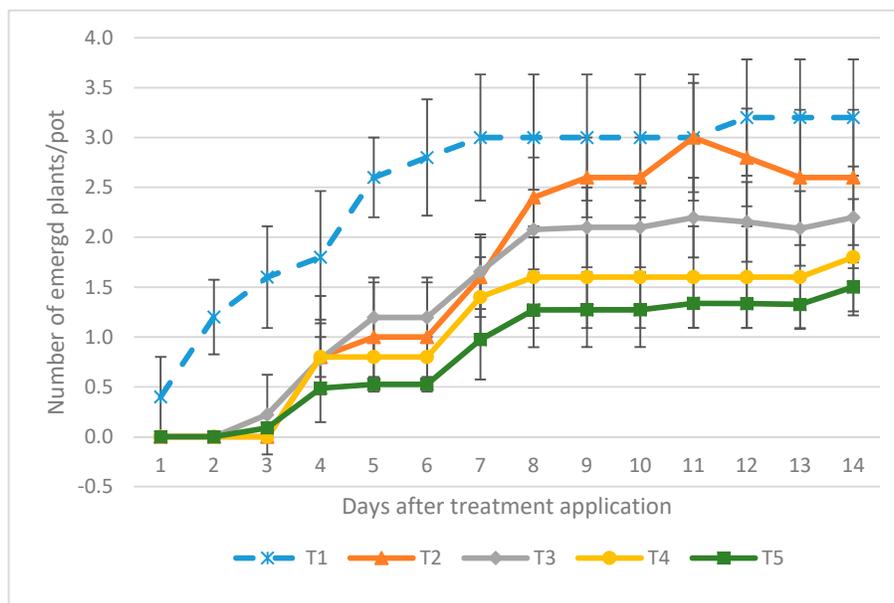


Figure 3. Number of cheeseweed plants emerging in pots that received 25 mL of OVW at five different strengths diluted with tap water (T1: 0% OVW, T2: 25% OVW, T3: 50% OVW, T4: 75% OVW, T5: 100% OVW). Error bars represent \pm standard error.

Table 5. P values for effect of 25 mL olive vegetation water application on cheeseweed emergence in soil-filled pots.

DAA ¹	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P	0.431	0.000	0.003	0.13	0.000	0.002	0.016	0.096	0.08	0.08	0.082	0.054	0.113	0.267

¹ DAA: Days after application.

3.3. Compost Pot Experiment

3.3.1. Weather information

The San Luis Obispo area enjoys Mediterranean weather with warm dry summers and mild wet winters. The weather parameters recorded during the experimental period are presented in Figure 4.

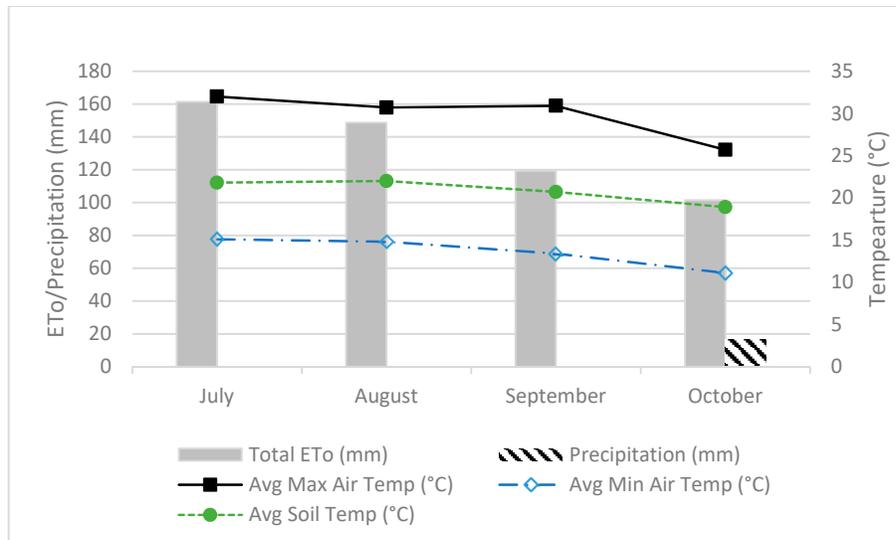


Figure 4. Weather data recorded during experimental period using a CIMIS station on site. ETo: Reference evapotranspiration.

3.3.2. Weed numbers

Composts did not have any significant effect ($P = 0.23$) on the total number of weeds per pot (Figure 5). The main weed observed was purslane, with lower numbers of redroot pigweed, lambs quarters (*Chenopodium album* L.), cheeseweed, and some grasses (mostly wall barley (*Hordeum murinum* L.)). Similar to total weeds, compost treatments did not significantly affect ($P = 0.293$) purslane numbers, although a suppressive trend was observed with all treatments, especially OP/DM10 (Figure 6). The control treatment had a total of 14 purslane weeds per pot, compared with 5.5–12.6 weeds per pot for the compost treatments.

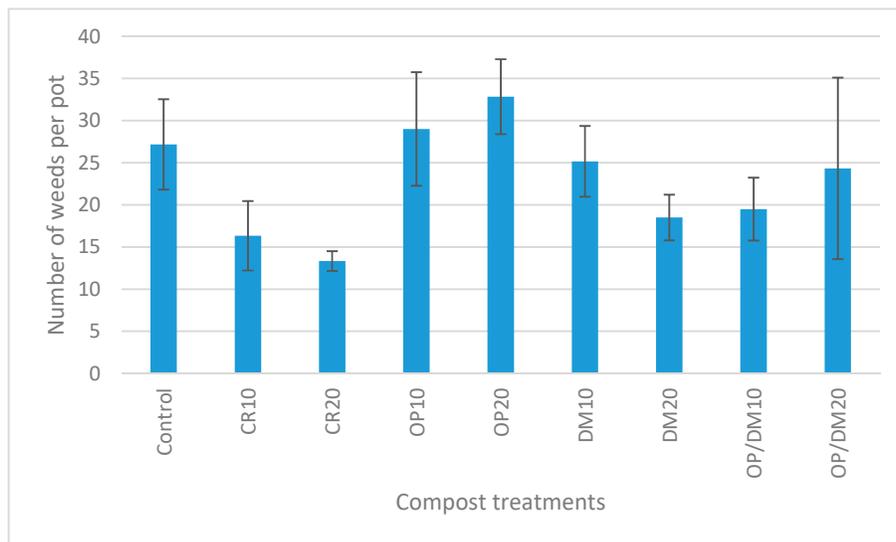


Figure 5. Number of weeds per pot as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.23$, $n = 6$).

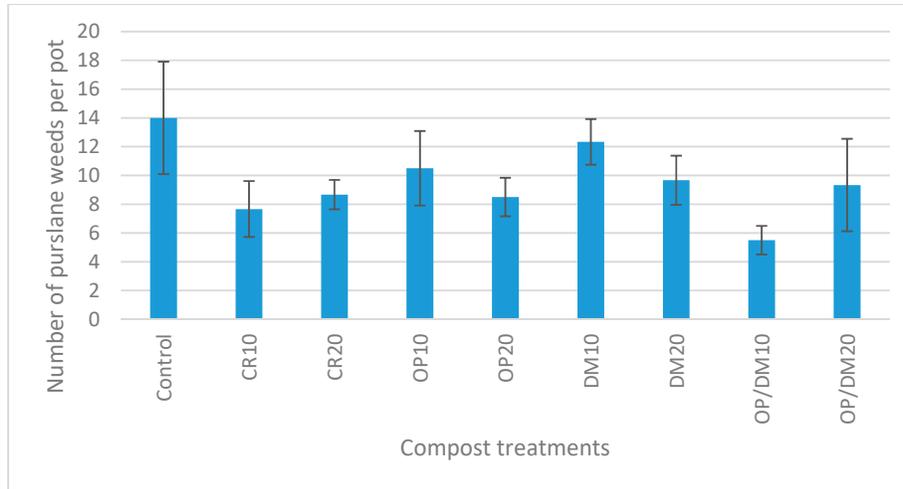


Figure 6. Number of purslane weeds per pot as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.293$, $n = 6$).

3.3.3. Weed dry matter production

More importantly than the number of weeds, total weed dry matter production was significantly ($P = 0.021$) reduced by several compost treatments (Figure 7). The best suppression was observed with the CR10 treatment, in which weed biomass was suppressed by 67% compared to the control. Given that purslane was the major weed observed, it was analyzed separately. Compost showed a significant ($P = 0.006$) suppressive effect on purslane dry matter production (Figure 8). The purslane dry matter production values in the compost treatments were 23.4% (OP20) to 48.5% (DM20) the values obtained in the control treatment.

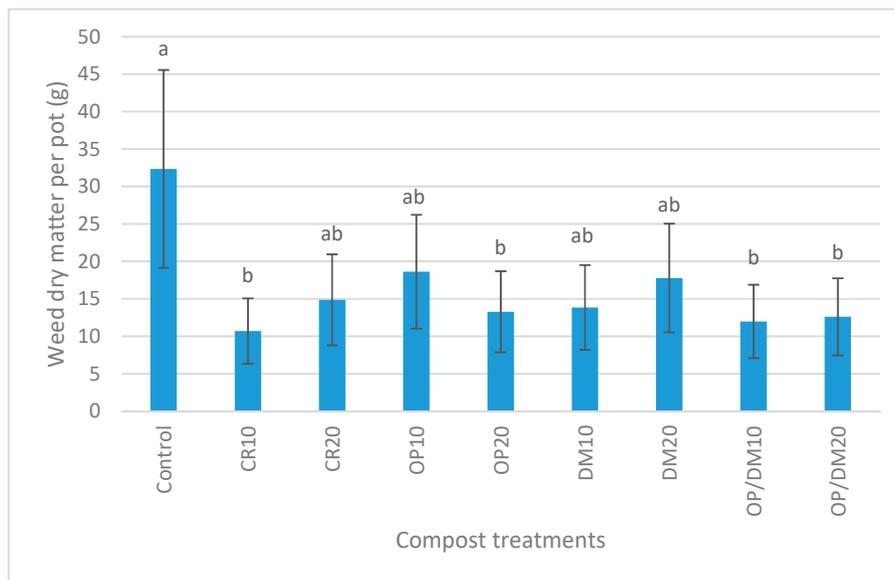


Figure 7. Total weed dry matter production as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.021$, $n = 6$). Bars sharing the same letter are not statistically different according to Tukey's HSD test (at $P < 0.05$).

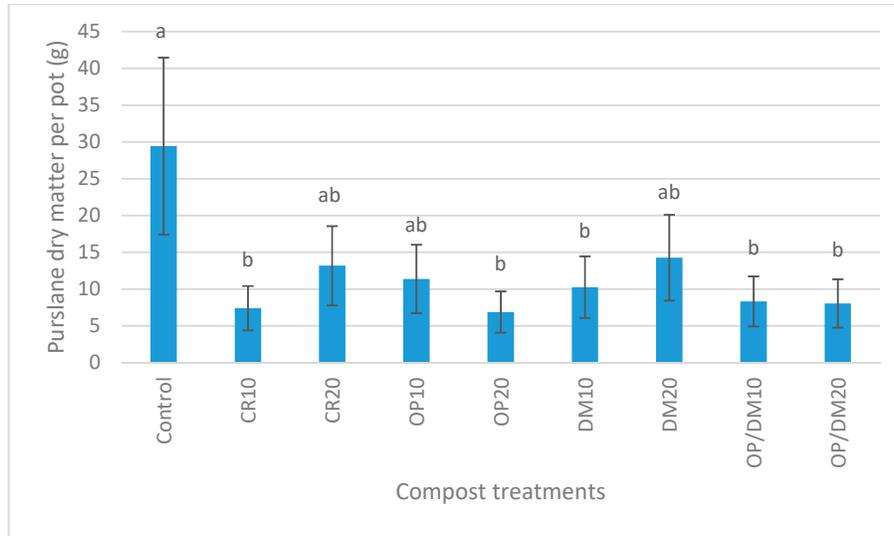


Figure 8. Purslane dry matter production per pot as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.006$, $n = 6$). Bars sharing the same letter are not statistically different according to Tukey's HSD test (at $P < 0.05$).

3.3.4. Bell pepper plant health and production

Composts did not have any significant effect on plant height or the number of leaves at the two dates of measurements (Table 6, Figure 9). Similarly, SPAD absorbance on both dates of measurements was not affected by the compost treatments. However, it is noteworthy to highlight that SPAD absorbance on 23 August tended to drop at the higher compost rate compared to the lower rate, especially for CR and DM (Figure 10). For these two materials, the SPAD absorbance at the higher dose was lower than the lower dose by 17% and 22%, respectively.

Fruit production was significantly affected by compost application (Table 6). However, Tukey's HSD test failed to detect any differences between means. Nevertheless, treatments CR10 and DM10 presented almost double the yields of the non-amended control treatment (Figure 11).

Table 6. *P* values for effect of two application rates of four composts on plant growth and health parameters.

Parameter	<i>P</i> -value
SPAD Absorbance 13 August	0.213
SPAD Absorbance 23 August	0.159
Plant height 13 August	0.405
Plant height 23 August	0.393
Number of leaves 13 August	0.127
Number of leaves 23 August	0.08
Cumulative fruit production	0.025

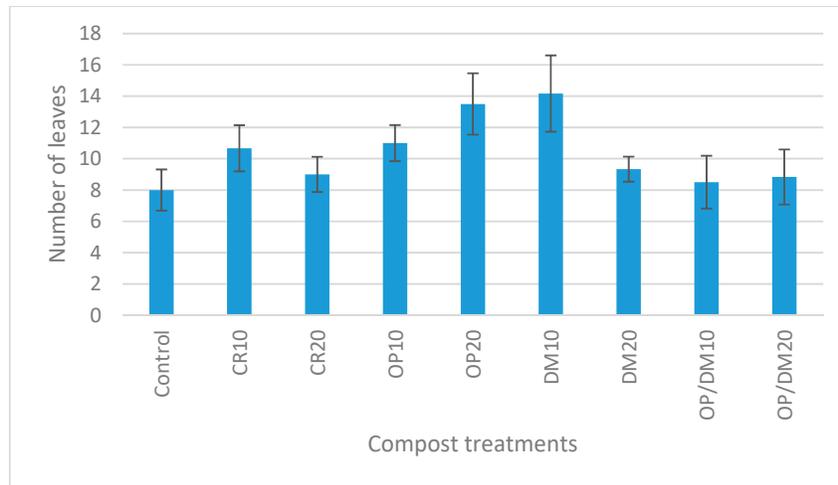


Figure 9. Number of leaves of bell pepper plants as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.08$, $n = 6$).

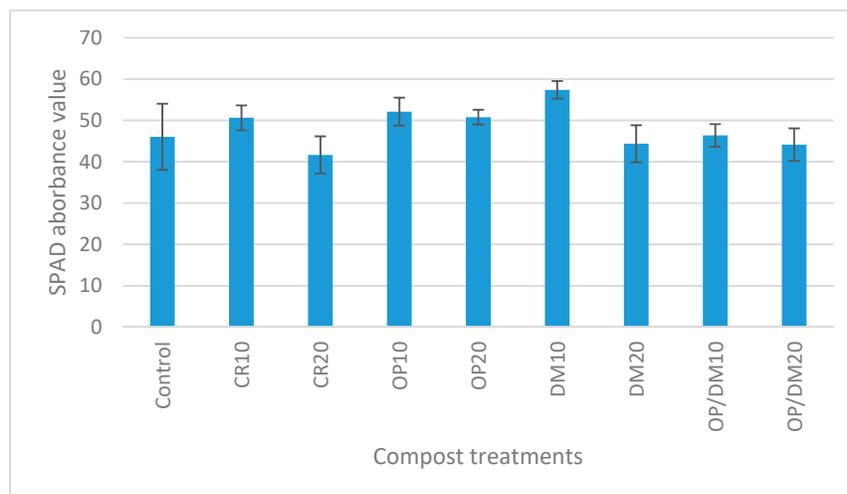


Figure 10. SPAD absorbance on 23 August 2018 as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.159$, $n = 6$).

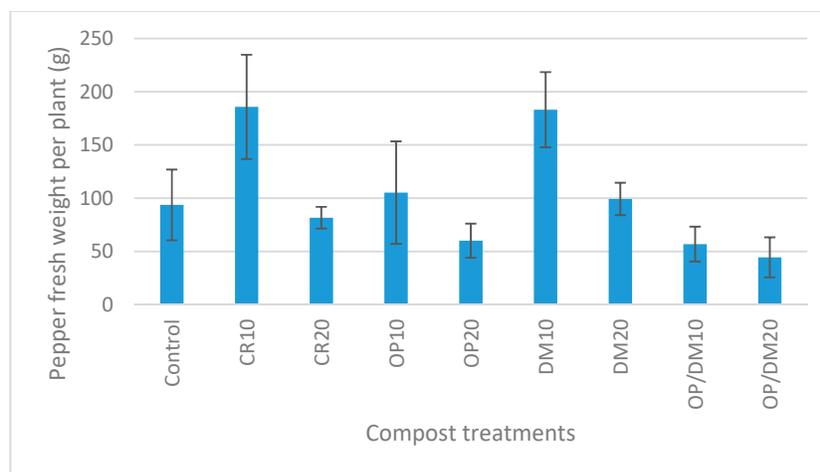


Figure 11. Fresh weight production of bell pepper fruits per plant as affected by different compost sources and rates. Error bars represent \pm standard error ($P = 0.025$, $n = 6$).

4. Discussion

OVW generally presented inhibitory or suppressive effects on weed seed germination, especially at full strength or higher concentrations (T5 and T4, respectively). OVW contains phytotoxic polyphenols such as catechol, 4-methylcatechol, tyrosol, hydroxytyrosol, and oleuropein [16] in addition to many amino acids [17] and flavonoids [5]. These materials present specific toxicity to crops. For example, in a study involving tomatoes and vegetable marrow (*Cucurbita pepo* L.) hydroxytyrosol was harmful only to tomatoes, while catechol and tyrosol were harmful only to vegetable marrow [16]. Fatty acids present in OVW such as cinnamic acid [17] result in xylem poles with a greater number of cells and a greater emission of lateral roots, leading to lower plant growth [18]. The combination of cinnamic acid and flavonoids leads to the premature formation of fibers by the phloem [18]. Other modes of action might be involved, as some short-chain fatty acids (e.g., capric and caprylic acids) act as desiccants against some weed species [19].

It is important to note that the maximum germination rate observed in the control treatment in the petri dish experiment was only 17%, indicating a high level of innate dormancy in cheeseweed seeds. This confirmed previous findings showing a 5% germination rate in fresh seeds increasing to 47% after a storage period of 13 months [20]. This dormancy presents a problem to weed control efforts and might need to be overcome for effective control to be achieved.

The phytotoxic effect of OVW observed on weeds in our study was more obvious in the petri dishes (Experiment 1) compared to the pot experiment (Experiment 2), as the latter delayed germination rather than inhibiting it. This is in agreement with observations from a similar petri dish experiment showing a complete inhibition of tomato and chicory (*Cichorium intybus* L.) seed germination when treated with full strength OVW [21]. The lower inhibitory effect in the soil compared to petri dishes can be attributed to the diluting effect of the soil and the irrigation water added afterwards to keep the soil moist in the pots. Furthermore, water application, albeit small, might have pushed OVW below the rootzone. Mekki et al. [22] have shown that polyphenols can leach down to 1.20 m in the soil. In addition, the soil and microbial processes might have accelerated the degradation of phenolic compounds in OVW. The phytotoxicity in our experiments lasted for a week or so before starting to fade away. A study in Tunisia showed that 20% concentrated OVW prohibited *Brassica cernua* (Thunb.) Matsum. (synonym of *Brassica juncea* (L.) Czern.) germination during a three-day assay, but with further diluted treatments achieved the same germination rate as the untreated control only three days after application [22]. Piotrowska et al. [10] noticed a 20% reduction in tomato germination at 40 m³ OVW ha⁻¹ compared to >80% reduction at 80 m³ ha⁻¹. On top of the dilution and rate level effects, OVW phytotoxicity in our study appeared to have decreased with time allowing more weed seeds to germinate. This confirmed findings by Piotrowska et al. [10], who showed a germination recovery after three days of application. The vanishing of the OVW effects on weed seed germination indicated that the rate used in our experiments could be increased to achieve higher and more permanent inhibitory effects.

Composts reduced weed growth, in terms of number and biomass. The C₄ plant purslane was the main weed present in the pots and was considerably controlled by composts, resulting in less than half the dry matter in the untreated control. This finding on purslane confirms previous results showing that sun-dried OP gradually reduced purslane numbers from 339 plants m⁻² in untreated control to 34.3, 24.8, and 11 plants m⁻² in 20, 30, and 40 t OP ha⁻¹ applications, respectively [14]. Although some studies showed no phytotoxic effect of composted OP, the presence of phytotoxicity in mature composted OP depends on the composting time [23] and the particle size of the pomace, with particles over 1 mm retaining some phytotoxicity and presenting a germination index around 50% [24]. Similarly, cress (*Lepidium sativum* L.) germination index was correlated to the length of the composting process of OP [23].

CR and DM composts sharply increased bell pepper fruit yields when applied at lower rates (10%), most likely due to the lower weed competition, as discussed above. This yield increase was not observed at higher compost application rates, as the composts might have resulted in immobilization of soil mineral nitrogen, therefore limiting plant nutrition and cancelling out any potential benefits from reduced weed competition. It is well established that low-nitrogen composts

might result in the immobilization of soil inorganic nitrogen for weeks or months. Paul and Beauchamp [25] have shown that soil inorganic nitrogen significantly dropped after addition of composted beef cattle manure and remained so until the end of their experiment after 12 weeks of incubation. Another observation that supports this hypothesis is the lower SPAD absorbance (Figure 10) we observed at higher compost rates, which might have resulted from lower soil mineral nitrogen. As for the OP and OP/DM treatments, the OP might have presented some residual phytotoxicity that did not allow bell pepper plants to fully benefit from the reduced weed competition, although no symptoms were detected in the plants. Several authors have shown that the composting process decreases the OP polyphenol content by one-half (composting for three months [26]) to two-thirds (composting for 22 weeks [23]), leaving the final polyphenol concentration below 10 mg g⁻¹. Total phenols in OP decreased by 93% after 12 months of composting [27].

The stronger negative effect of OP composts on weed germination compared to bell pepper transplant growth might imply a stronger effect of this material on seeds than on seedling roots. A possible mode of action might involve stimulating soil microorganism feeding/degradation of weed seeds. Another explanation for the lack of effect on plants could be the selectivity of OP phytotoxicity. Boz et al. [14] have shown suppressive effects on certain weeds (e.g., purslane), but no effect on crops (okra (*Abelmoschus esculentus* (L.) Moench), fava bean (*Vicia faba* L.), onions (*Allium cepa* L.)) or several other weeds (common lambs quarters, puncturevine, purple nutsedge, wild radish (*Raphanus raphanistrum* L.), and Johnsongrass). On some other weeds like yellow sweetclover (*Melilotus officinalis* (L.) Lam.), the effect was not consistent from year to year. The same authors showed only a partial control of black nightshade (*Solanum nigrum* L.), which is in the same family as peppers, indicating that peppers might be tolerant to this material. The selective phytotoxicity of hydroxytyrosol, catechol, and tyrosol [16] was discussed earlier in this section.

5. Conclusions

OVW represents a promising option for cheeseweed control, especially when applied before the crop is planted. This tool could be very useful in no-till situations or where mechanical cultivation is not an option. The direct application of OVW to cheeseweed seeds was more effective at reducing and delaying germination compared to soil application, although these phytotoxic effects decreased with time. Higher application rates or multiple applications will be needed to increase the effectiveness of this material at reducing weed seed germination and growth in soil. All composts at different rates reduced weed numbers and dry matter production compared to the untreated control. Composts did not negatively reduce bell pepper plant growth compared to the non-amended control, indicating that the benefits from compost applications will at least balance out any phytotoxic effects. The composts investigated in this study can be used to control purslane. More research is needed to determine the effects of these materials on other weeds. More application rates of OVW also need to be studied.

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