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Effect of Rice Hull Mulch on Nutrient Concentration of Fertilized Irrigation Water

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***Abstract*. Parboiled rice hulls (PBH) have been shown to be an effective mulch for weed control in container crops. As with other mulch products, there is concern that PBH mulch would interfere with nutrient delivery to the crop. The objective of this research was to determine the effect of PBH mulch on nutrient concentration of fertilized irrigation water as it passes through the mulch layer, and the subsequent effect on growth and nutrition of container-grown sunflower (*Helianthus annuus*). Parboiled rice hull mulch was placed in Buchner funnels at a depth of 0, 0.63, 1.25, or 2.50 cm. Irrigation was applied with a water-soluble fertilizer (20N–4.4P–16.6K) injected at a concentration of 100 mg·L^{-1} N. Filtrates were collected after passing through the PBH in the Buchner funnels and analyzed for nutrient concentration. In a separate study, sunflower in no. 3 containers were mulched with the same depths of PBH and irrigated with water fertilized similar to that in the funnel experiment. Parboiled rice hull mulch caused a temporary and slight decrease in NO_3^- and NH_4^+ concentration. Phosphate and K^+ concentrations generally increased with each irrigation event. Calcium and Mg exhibited an inverse relationship where the PBH mulch decreased Ca and increased Mg concentrations in the filtrates. Despite these measured differences in the chemical properties of water passing through the mulch layer, there were no measurable differences in sunflower growth or physical appearance, and only minor and inconsequential differences in plant nutrient status. Rice hull mulches are likely to have very minor effects on container crop nutrition with no adverse effect on plant growth over a 6 week production cycle as used in this experiment.**

Numerous mulch products have been evaluated for use in container crops. Pine bark nuggets have been shown to provide effective control of mulberry weed [*Fatoua villosa* (Thunb.) Nakai] (Penny and Neal, 2003), prostrate spurge (*Chamaesyce maculata* L.), eclipta (*Eclipta alba* L. Hassk) (Cochran et al., 2009), bittercress (*Cardamine* spp.), and oxalis (*Oxalis stricta* L.) (Richardson et al., 2008). In each of the aforementioned studies, weed control was shown to improve with increasing depth of pine bark mulch. Wilen et al. (1999) showed that composted greenwaste, pecan [*Carya illinoinensis* (Wangenh.) K. Koch] shells, and pine (*Pinus taeda* L.) bark at a depth of 2.5 cm provided excellent control of creeping woodsorrel (*Oxalis corniculata* L.), northern willow herb (*Epilobium ciliatum* Raf.), and common groundsel (*Senecio vulgaris* L.), but only moderate to poor control of annual bluegrass (*Poa annua* L.). Ferguson et al. (2008) showed that a 3.7 cm layer of wood chip mulches from southern redcedar [*Juniperus silicicola* (Small) E. Murray] and southern magnolia (*Magnolia grandiflora* L.) provided control of redroot pigweed (*Amaranthus retroflexus* L.) and large crabgrass [*Digitaria sanguinalis* (L.) Scop.].

Parboiled rice hulls have been shown to provide excellent control of flexuous bittercress (*Cardamine flexuosa* With.), liverwort (*Marchantia polymorpha* L.) (Altland and Krause, 2014), and creeping woodsorrel (*Oxalis corniculata* L.) (Altland et al., 2016a). Parboiled rice hulls prevent establishment of new weed seed by drying quickly following irrigation, resulting in insufficient moisture to support germination and establishment of new weeds. Parboiled rice hulls are less effective in preventing germination of weed seed preexisting on the substrate surface before mulch application. To prevent germination and establishment of preexisting weed seed, a sufficient mass must cover the substrate surface to physically impede germination (>500 g·m^{-2} or a depth of 1.25 cm) (Altland et al., 2016).

A common concern about organic mulches is that they impose nitrogen (N) deficiency on crops they surround. After initial reports on the utility of PBH for weed control in container crops (Altland and Krause, 2014), a similar concern of N immobilization was voiced by nursery growers (J. Altland, personal observations, unpublished). In a review of mulch use in urban landscapes, Chalker-Scott (2007) explained that high carbon to nitrogen ratio (C:N) is incorrectly assumed by many practitioners to immobilize fertilizer N and thus deprive plants of sufficient nutrients. Chalker-Scott (2007) goes on to assert that mulches do not affect nutrition of landscape plants. There are numerous experiments in field soils that support this assertion and show mulches do not adversely affect nutrient uptake of field-grown crops (Broschat, 2007; Ram et al., 2003; Trinka and Pritts, 1992). However, this generalization about interactions between mulch and fertilizer in field crops might not be applicable to container crops. Altland and Lanthier (2007) reported that container-grown hydrangea [*Hydrangea macrophylla* (Thunb.) Ser. 'Fasan'] with controlled release fertilizer (CRF) placed below the mulch were larger and had higher foliar N concentration compared with those with CRF placed above the mulch. The implication was that N from CRF placed above the mulch was partially immobilized by the mulch layer. Likewise, Glenn et al. (2000) showed that recycled paper mulch reduced petunia (*Petunia floribunda* Hort. 'Midnight Madness' and *P. grandiflora* Hort. 'Ultra Blue') growth and leachate N when CRF was placed above the mulch layer. The objective of this research was to determine specifically how PBH mulch affects the nutrient concentration of irrigation water passing through the mulch layer, and subsequently how this affects substrate and plant nutrition.

Materials and Methods

Direct measurement of filtrates. Two-piece, PVC Buchner funnels (13.1 cm i.d., 6.6 cm tall, Fisher Scientific, Waltham, MA) were randomly assigned to receive PBH (Riceland Foods, Inc., Stuttgart, AK) at a depth of 0, 0.63, 1.25, or 2.50 cm. It was established that 2.5 cm depth of PBH weighed 44 g so that replicate funnels could be uniformly mulched by weighing 0, 11, 22, or 44 g of PBH for the 0, 0.63, 1.25, or 2.50 cm treatments, respectively. Funnels were placed on a greenhouse bench equipped with an overhead irrigation system and fixed pattern nozzles (Rain Bird 5H; Rain Bird Corp., Azusa, CA). Funnels received overhead irrigation consisting of city tap water injected (D14MZ2; Dosatron International Inc., Clearwater, FL) with a commercial complete fertilizer with micronutrients (Jack's 20N–4.4P–16.6K–0.15Mg–0.02B–0.01Cu–0.1Fe–0.05Mn–0.01Mo–0.05Zn; JR Peters, Inc., Allentown, PA) at a concentration of 100 mg·L^{-1} N. Each funnel was placed over a 400 mL glass jar (Fisher Scientific) so that the fertilized irrigation water passing through the mulch layer would collect in the jar beneath, and furthermore, only water passing through the funnel (and no other extraneous irrigation water) would enter into

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the jar. The irrigation system was run for 10 min per day, resulting in an application of ≈1.3 cm of water. About 30 min after irrigation ceased, the fertilized irrigation water that filtered through the mulch was collected from the jars beneath each funnel. Samples were filtered through GF/F binder-free borosilicate glass fiber filter paper (Whatman Ltd., Kent, UK) to remove particles greater than 0.7 μm. The filtrate was poured into 5 mL autosampler vials, capped, and analyzed using ion chromatography (ICS 1600 Ion Chromatography System; Dionex, Bannockburn, IL) for concentrations of nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{3-}), potassium (K), calcium (Ca), magnesium (Mg), and sulfate (SO_4^{2-}). There were six replications per mulch depth arranged on a single bench in a completely randomized design. Samples were collected daily for nine days, excluding weekends. This experiment was repeated.

Effect on plant growth. Sunflower (*Helianthus annuus* L. 'Sunbright') seeds (Ball Horticultural Co., West Chicago, IL) were sowed on 2 Aug. 2016 into 50-cell trays filled with a soilless substrate composed of 85 peatmoss : 15 perlite. On 23 Aug. 2016, when sunflowers were ≈8 cm tall, they were transplanted into 11.4 L containers (No.3; Nursery Supplies, Chambersburg, PA) filled with a 60 pine bark : 40 peatmoss substrate amended with 1.8 $kg{\cdot}m^{-3}$ dolomitic lime (ECOPHRST, National Lime and Stone Co., Findlay, OH). The substrate surface of each container was covered with 0, 0.63, 1.25, or 2.50 cm of PBH. It was established that a 2.50 cm layer of PBH weighed 132 g, thus PBH mulch layers of uniform depth were added to the containers by applying 0, 33, 66, or 132 g of PBH for 0, 0.63, 1.25, and 2.50 cm mulch treatments, respectively. Plants were grown in a glass-covered greenhouse in Wooster, OH, with natural photoperiod and heat and cool set-points at 24 and 27 °C, respectively. Containers were irrigated with the same water and fertilizer as in the previous study; however, it was applied through spray stakes (Yellow, 11.4 L per h, Netafim, Fresno, CA) rather than overhead nozzles to distribute the water over the substrate or mulch surface and avoid contact with foliage. Irrigation was run twice daily for 1 min each cycle, so that each plot received ≈1 cm of water per day.

One-third of the plants in each treatment was randomly selected and harvested each at 2, 4, and 6 weeks after potting (WAP). At harvest, foliar relative chlorophyll content was determined with a chlorophyll meter (Minolta-502 SPAD meter; Spectrum Technologies, Inc., Plainfield, IL) by taking a measurement on five recently matured leaves per plant and recording the mean for each experimental unit. Recently matured foliage was harvested for foliar nutrient analyses (Mills and Jones, 1996), rinsed with deionized water, then oven dried at 55 °C for 3 d. Samples were ground in a mill (Tecator Cyclotec AB, Hogenas, Sweden) through a 0.5 mm screen. Foliar nitrogen (N) was determined by measuring ≈2.5 mg of dry tissue into tin capsules (Costech Analytical, Valencia, CA) and analyzing with a CHNS/O Perkin Elmer Elementar Analyzer (PerkinElmer, Waltham, MA). Other macronutrients and micronutrients were determined by first processing samples with microwave digestion (MARS 6; CEM Corp., Matthews, NC), then injection in an optical emission spectrometer (iCAP 6300 Duo). The elemental content of PBH was also determined by subjecting five unused samples to the same preparation and analyses as the sunflower tissue samples.

Immediately after leaf tissue harvests, shoot dry weight (SDW) was determined by removing the aboveground portion of the plant, oven drying at 55 °C for 3 d, and weighing. Substrates were analyzed for pH, electrical conductivity (EC), and water extractable nutrients using a modified saturated media extraction procedure (Warncke, 1986). Substrate from the center of the root ball was transferred to a 400 mL glass jar. Reverse osmosis (RO) water was added to the point of saturation. The substrate slurry was allowed to come to equilibrium for 24 h. Afterward, the liquid phase of the slurry was extracted by pouring over a PVC Buchner funnel (13.1 cm i.d., 6.6 cm tall, Thermo Fisher Scientific) fitted with a fiberglass filter paper (G6, Thermo Fisher Scientific). The Buchner funnels were attached to an erlenmeyer flask and placed under vacuum to facilitate extraction of the water from the substrate and through the filter paper. Solution pH was determined with a pH/ion analyzer (MA 235; Metler Toledo, Columbus, OH) and EC with a conductivity meter (Fisher 06-662-61, Thermo Fisher Scientific). Samples were subsequently filtered through GF/F binder-free borosilicate glass fiber filter paper (Whatman Ltd.) to remove particles greater than 0.7 μm. The filtrate was poured into 5 mL autosampler vials, capped, and analyzed using ion chromatography (ICS 1600) for concentrations of NO_3^-, NH_4^+, PO_4^{3-}, K, Ca, Mg, and SO_4^{2-}. Micronutrient

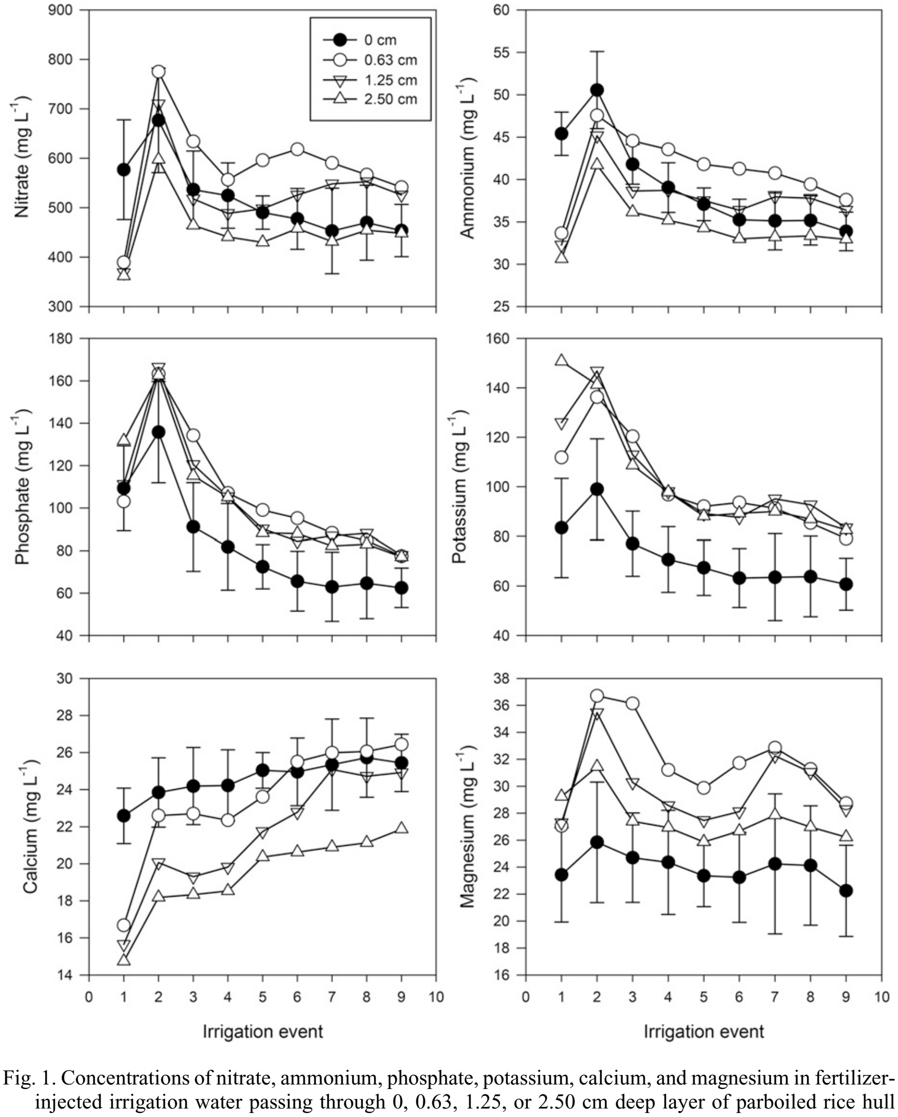

Fig. 1. Concentrations of nitrate, ammonium, phosphate, potassium, calcium, and magnesium in fertilizer-injected irrigation water passing through 0, 0.63, 1.25, or 2.50 cm deep layer of parboiled rice hull mulch. The irrigation water was injected with a water-soluble fertilizer (20N–4.4P–16.6K) at 100 $mg{\cdot}L^{-1}$ N (Expt. 1). Bars around the nonmulched control means represent the minimum significant difference from the Dunnett's *t* test.

(Fe, Mn, Cu, B, Mo, and Zn) concentrations were determined with optical emission spectrometry (iCAP 6300 Duo View ICP-OES Spectrometer; Thermo Fisher Scientific). Six replications per mulch treatment were harvested each at 2, 4, and 6 WAP. Plants were arranged on a single greenhouse bench in a completely randomized design.

Data from both experiments were subjected to analysis of variance (ANOVA) using statistical software (SAS v9.3; SAS Institute, Cary, NC). Regression analysis was used to determine the significance of linear or quadratic responses to mulch depth. Means were separated with Dunnett's least significant difference test (Figs. 1 and 2) and Fisher's protected least significant difference test (Tables 1 and 2).

Results and Discussion

Direct measurement of filtrates. Repeated measures analysis showed a significant time by mulch depth interaction for each of the six nutrients analyzed in Expt. 1 ($P < 0.0075$) and Expt. 2 ($P < 0.0302$) (data not shown). Nitrate concentrations were lower in filtrates from all mulched funnels compared with the nonmulched control after the first irrigation event in Expt. 1 (Fig. 1). Funnels with 2.50 cm PBH had filtrate NO_3^- concentrations lower than the nonmulched control at the fourth and fifth irrigation events, but similar concentrations on all other dates. On the second and subsequent irrigation events, funnels with 0.63 and 1.25 cm mulch had similar or greater NO_3^- concentrations than the nonmulched control. Nitrate concentrations fluctuated less over time in Expt. 2 (Fig. 2). In Expt. 2, NO_3^- concentrations from funnels with 2.50 cm PBH were less than nonmulched controls on the sixth irrigation event only. Otherwise, NO_3^- concentrations from all mulched funnels were similar or greater than nonmulched controls throughout the experiment.

Ammonium concentration in filtrates from mulched funnels was lower than the nonmulched control at the first irrigation event in Expt. 1 (Fig. 1). Funnels with 0.63, 1.25, and 2.50 cm PBH mulch had similar or higher NH_4^+ concentrations than the nonmulched control by the second, fourth, and sixth irrigation event, respectively. In Expt. 2, NH_4^+ concentrations from mulched funnels were lower than the nonmulched control through the third irrigation event. All treatments were similar with respect to NH_4^+ concentration on the fourth irrigation event. From the fifth irrigation event and to the end of the experiment, NH_4^+ concentrations in funnels mulched with 2.50 cm PBH were lower than nonmulched controls.

The target N concentration in the irrigation water was 100 mg·L^{-1} N (60% NO_3^--N and 40% NH_4^+-N). This concentration and proportion of N forms should have resulted in 265 mg·L^{-1} NO_3^- and 51 mg·L^{-1} NH_4^+. Nitrate levels were generally higher and NH_4^+ levels were lower than expected in nonmulched controls for both experiments. Only the deepest mulch layer of 2.50 cm sporadically reduced NO_3^- or NH_4^+ concentrations. Gachukia and Evans (2008) reported slightly increasing NO_3^- and decreasing NH_4^+ concentrations in leachates from substrates with increasing PBH percentages immediately after mixing peat and PBH substrate blends.

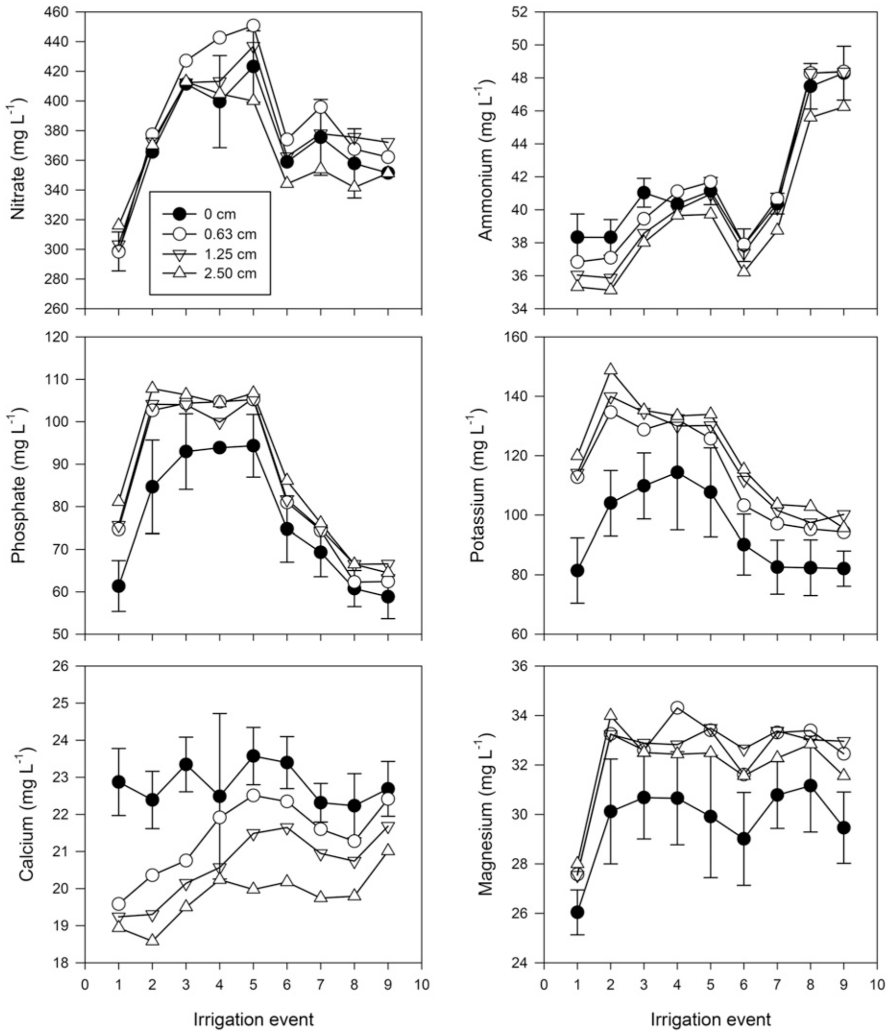

Fig. 2. Concentrations of nitrate, ammonium, phosphate, potassium, calcium, and magnesium in fertilizer-injected irrigation water passing through 0, 0.63, 1.25, or 2.50 cm deep layer of parboiled rice hull mulch. The irrigation water was injected with a water-soluble fertilizer (20N–4.4P–16.6K) at 100 mg·L^{-1} N (Expt. 1). Bars around the nonmulched control means represent the minimum significant difference from the Dunnett's *t* test.

Phosphate concentration in filtrates from funnels mulched 2.50 cm was higher than the nonmulched controls on the first irrigation event, whereas all other mulched funnels were similar to the nonmulched control (Fig. 1). By the second irrigation and throughout the experiment, all mulched funnels had higher PO_4^{3-} concentrations than the nonmulched control. A similar trend occurred in Expt. 2. All mulched funnels had higher PO_4^{3-} concentrations than the nonmulched control through the first five irrigation events. Thereafter, only funnels with 2.50 cm PBH had a consistently higher PO_4^{3-} concentration than the nonmulched control. Elevated PO_4^{3-} concentrations in mulched funnels were expected. Parboiled rice hulls contained 0.06% P on a dry weight basis (Table 1), of which 83% was water-soluble and released from the PBH within 4 d (Altland et al., 2016b). Likewise, Evans et al. (2011) reported water-extractable P concentrations from 60 to 130 mg·L^{-1} over the course of 56 d from parboiled PBH of varying particle size.

Table 1. Nutrient content of parboiled rice hulls used for mulch, on a dry weight basis (mean and SD, $n = 5$).

	(%)
N	0.31 ± 0.06
P	0.06 ± 0.01
K	0.17 ± 0.01
Ca	0.07 ± 0.01
Mg	0.05 ± 0.00

Potassium concentration of filtrates was lower in the nonmulched control than all mulched funnels throughout both experiments, with the exception of irrigation 4 in Expt. 2 (Figs. 1 and 2). Similar to PO_4^{3-}, high K^+ concentrations in the filtrates from mulched funnels were expected because of contributions from PBH. The K^+ concentration of PBH used in this experiment was

0.17% of dry mass (Table 1), of which 88% was water soluble in the first 5 d (Altland et al., 2016).

Calcium concentration in filtrates was higher in the nonmulched control than all other mulched funnels on the first irrigation event (Fig. 1). Funnels with 0.63 and 1.25 cm PBH were similar to the nonmulched control by irrigation 2 and 7, respectively. Calcium concentration from funnels with 2.5 cm PBH remained lower than the nonmulched control throughout the experiment. A similar trend occurred in Expt. 2, with respect to Ca^{2+} concentration being suppressed in mulched funnels (Fig. 2). Funnels with 0.63 cm PBH were eventually similar to nonmulched controls at irrigation 4 and 7, whereas those with 1.25 and 2.50 cm PBH remained lower than the nonmulched control throughout the study.

Magnesium was lower in filtrates of the nonmulched control compared with filtrates from mulched funnels (Figs. 1 and 2). Throughout Expt. 1 and 2, the nonmulched control had a similar Mg^{2+} concentration to funnels with 2.50 cm PBH (with a few sporadic exceptions), whereas those with 0.63 or 1.25 cm generally had higher Mg^{2+} concentrations than the nonmulched control. The effect of mulch depth on Ca^{2+} and Mg^{2+} concentrations seems to be inversely related. Calcium is more tightly bound to cation exchange sites than Mg^{2+} because of its greater atomic radius. It is possible that as Ca^{2+} from the fertilizer solution was retained by the PBH mulch, it displaced Mg^{2+} ions, thus the net effect was reduced Ca^{2+} and increased Mg^{2+} in filtrates passing through the PBH mulch.

Effect on plant growth. Sunflower foliar SPAD readings increased from week 1 to week 6 ($P < 0.0001$), but were unaffected by treatment within any give date ($P > 0.1487$) nor the interaction between time and treatment ($P = 0.4389$). Sunflower height was similar across treatments at each of the three harvest dates ($P > 0.2118$). Likewise, sunflower shoot dry weights were also similar at each harvest date across treatments ($P > 0.4339$). Rice hull mulch depth had no effect on plant growth or appearance (SPAD foliar chlorophyll). By the conclusion of the experiment, plant height averaged 118 cm and flower buds were just beginning to form.

Substrate pH was affected by mulch treatment at 2 and 4 WAP, but not 6 WAP (Table 1). At 2 WAP, substrates with 2.50 cm mulch had the highest pH, whereas at 4 WAP nonmulched containers had the highest pH. The difference between the highest and lowest pH within each date was at most 0.5 pH units. Dole and Wilkins (1999) recommend pH to be 6.0–6.5, and warn that pH below 5.5 can result in Mg or Fe toxicity. Substrate pH was below 5.5 in all treatments for at least one of the harvest dates, yet no signs of nutrient toxicity were observed.

Substrate EC levels were affected by treatment at 2 and 6 WAP, but not 4 WAP (Table 1). In both cases the nonmulched control treatment had slightly higher EC than containers with 1.25 cm mulch. At 6 WAP, the nonmulched controls were also higher than containers with 0.63 cm mulch. Such minor differences do not likely reflect important nutritional differences in the substrates.

Water-extractable NO$_3^-$ concentrations decreased linearly with increasing mulch depth at 2 WAP (Table 2). There were no differences in substrate NO$_3^-$ concentration at 4 WAP. By 6 WAP, there was a quadratic response to increasing PBH depth, and the nonmulched controls had greater water-extractable NO$_3^-$ concentrations than all other substrates. Water-extractable NH$_4^+$ levels were low or undetectable throughout

Table 2. Substrate pH, electrical conductivity (EC), and concentration of nitrate, phosphate, potassium, calcium, and magnesium in the saturated media extract of substrates covered with 0, 0.63, 1.25, or 2.50 cm of parboiled rice hull mulch. Substrates were from destructively harvested containers at 2, 4, and 6 weeks after potting [week after potting (WAP)].

				Nitrate	Phosphate	Potassium	Calcium	Magnesium
WAP	Rice hull depth (cm)	pH	EC (mS·cm^{-1})	(mg·L^{-1})				
2	0	5.4	0.42	84.3	14.4	15.9	13.5	11.9
	0.63	5.2	0.39	92.9	17.2	17.1	14.5	12.3
	1.25	5.5	0.25	37.6	11.1	13.3	10.9	9.1
	2.50	5.7	0.33	35.2	11.6	14.3	12.1	10.1
Trend[z]		L*	Q*	L*	L*	NS	NS	NS
LSD$_{0.05}$[y]		0.3	0.11	50.7	4.5	NS	NS	NS
4	0	5.9	0.38	9.6	11.0	17.7	15.1	13.1
	0.63	5.4	0.27	7.8	10.7	15.9	14.2	11.5
	1.25	5.6	0.40	37.6	14.2	17.0	15.4	12.3
	2.50	5.7	0.34	10.7	13.0	14.3	14.1	11.7
		Q*	NS	NS	NS	NS	NS	NS
LSD$_{0.05}$		0.3	NS	NS	NS	NS	NS	NS
6	0	5.6	0.45	84.1	16.4	13.0	20.0	16.7
	0.63	5.3	0.32	20.2	11.2	10.4	18.2	14.5
	1.25	5.4	0.25	9.4	9.7	9.3	14.6	10.9
	2.50	5.3	0.36	32.5	16.8	8.6	14.3	10.8
		NS	Q**	Q*	Q**	NS	L**	L**
LSD$_{0.05}$		NS	0.11	51.8	5.4	NS	3.4	3.6

[z] L and Q represent significant linear or quadratic trends with respect to rice hull mulch depth, with *, **, or *** indicating a level of significance at 0.05, 0.01, or 0.001, respectively. NS indicates no significance.

[y] Least significant difference (LSD) value for means within a leaching event.

Table 3. Foliar nutrient concentrations in sunflower (*Helianthus annuus* 'Sunbright') grown in no.3 containers covered with 0, 0.63, 1.25, or 2.50 cm of parboiled rice hull mulch. Leaves were harvested six weeks after potting.

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Rice hull depth (cm)	(%)						(mg·kg^{-1})				
0	5.65	1.16	3.63	2.55	0.84	0.83	102.0	16.7	148.7	285.5	115.7
0.63	5.34	1.02	3.28	2.81	0.86	0.92	114.8	16.5	142.1	336.6	104.9
1.25	5.46	1.03	3.31	2.27	0.69	0.80	88.3	18.8	134.5	250.6	100.0
2.50	5.23	0.93	3.02	2.25	0.63	0.81	100.0	16.6	130.4	245.0	94.7
Trend[z]	NS	L**	L***	NS	L**	NS	NS	NS	NS	L*	L*
LSD$_{0.05}$[y]	NS	0.12	0.29	NS	0.18	NS	15.9	NS	NS	61.9	NS

[z] L and Q represent significant linear or quadratic trends with respect to rice hull mulch depth, with *, **, or *** indicating a level of significance at 0.05, 0.01, or 0.001, respectively. NS indicates no significance.

[y] Least significant difference (LSD) value for means within a leaching event.

the experiment, despite the fertilizer solution containing 40% NH_4^+-N. Niemiera and Wright (1987a) reported rapid nitrification in containers between 20 and 30 °C, where application of 100 $mg \cdot L^{-1}$ NH_4^+ resulted in leachates with only 2–4 $mg \cdot L^{-1}$ NH_4^+ in just 6 d. Furthermore, based on NO_3^- accumulation rates in pine bark substrates, it has been projected that a 40 $mg \cdot L^{-1}$ NH_4^+ solution could be completely oxidized in 20 h (Niemiera and Wright, 1987b). Despite differences in water-extractable NO_3^- levels, foliar N in sunflower plants was similar in all treatments throughout the experiment (Table 3; data for 6 WAP only presented). Foliar N levels were within the recommended range of 5% to 6% (Whipker et al., 1998).

Water-extractable PO_4^{3-} from substrates followed a similar trend to NO_3^- across the three harvest dates. Phosphate decreased with increasing PBH depth at 2 WAP, whereas there were no differences at 4 WAP. At 6 WAP, PO_4^{3-} concentration decreased and then increased quadratically as PBH depth increased. The nonmulched control and those with 2.50 cm PBH had similar substrate PO_4^{3-} concentrations, whereas those with 1.25 cm PBH had a lower PO_4^{3-} concentration. Results from the filtrate experiment suggest that PBH are a source of PO_4^{3-} and thus should increase water-extractable PO_4^{3-} in the substrate (Figs. 1 and 2). The net increase in PO_4^{3-} from PBH in the filtrate experiments generally ranged from 10 to 20 $mg \cdot L^{-1}$, whereas the target PO_4^{3-} concentration supplied in the irrigation stream was 66 $mg \cdot L^{-1}$ (based on N application rates). Thus the increase in PO_4^{3-} from the PBH was relatively small compared with the actual application rate of PO_4^{3-}, and did not manifest as large increases in substrate available PO_4^{3-} concentrations when sunflowers were grown in PBH-mulched substrates. Foliar P decreased linearly with increasing PBH depth (Table 3), although in all treatments it was well above recommended tissue levels of 0.7% to 0.8% (Whipker et al., 1998).

Water extractable K concentration was similar across treatments at each harvest date (Table 2). Although the difference in K between mulched and nonmulched funnels was more pronounced in the filtrate experiments (Figs. 1 and 2), the lack of treatment effects in water-extractable K concentrations from the substrate in the sunflower study likely follows the same logic as provided for PO_4^{3-}. Foliar K concentration was similar at 2 and 4 WAP (data not shown); however, it decreased with increasing PBH mulch depth at 6 WAP (Table 3). Foliar K concentration at 6 WAP was lower than recommended (5.4% to 6.3%, Whipker et al., 1998) in all treatments. A general purpose fertilizer was used in this experiment with macro-element ratio of 20N–4.4P–16.6K. Whipker et al. (1998) suggest a high-K fertilizer regime with macro-element ratios of 20N–2.5P–25K. Higher P and lower K supplied in this experiment resulted in higher than recommended foliar P concentrations and lower than recommended foliar K concentration.

Water-extractable Ca was similar across PBH depths at 2 and 4 WAP, but decreased linearly with increasing PBH depth at 6 WAP (Table 2). This trend follows what might be expected considering the depressed Ca concentration observed in funnel filtrates at PBH mulch depth increased (Figs. 1 and 2). Foliar Ca concentrations were similar regardless of mulch depth throughout the experiment. Subtle differences in filtrate or substrate Ca concentrations were not enough to affect foliar Ca levels.

Water-extractable Mg followed a trend similar to Ca, in that substrate concentrations decreased linearly with increasing mulch depth at 6 WAP only (Table 3). This is the opposite of what would be expected considering the additional Mg released from PBH in the filtrate experiments (Figs. 1 and 2). As with other nutrients previously discussed, the difference in Mg concentration between mulched and nonmulched funnels in the filtrate experiment was relatively small compared with the Mg concentration applied via the irrigation stream. Foliar Mg also decreased linearly with increasing mulch depth, although all treatments had foliar Mg within or slightly above recommended concentrations (Whipker et al., 1998).

The objective of this research was to determine how PBH mulch affects the fertilizer nutrient concentration of irrigation water passing through the mulch layer, and its subsequent effect on plants. We measured subtle changes in the fertilized irrigation water immediately after it passed through the mulch layer. Parboiled rice hull mulch caused a temporary and slight decrease in NO_3^- and NH_4^+ concentration. Phosphate and K concentrations generally increased with each irrigation event due to the relatively high concentrations of those elements in PBH. Calcium and Mg exhibited an inverse relationship where the PBH mulch decreased Ca and increased Mg concentrations in the filtrates. Despite these measured differences, there were relatively few and minor differences in the nutrient concentration of the substrate. Furthermore, there were no measurable differences in sunflower growth or physical appearance (SPAD foliar chlorophyll), and only minor and inconsequential differences in plant nutrient status (and only at 6 WAP). In summary, although we were able to measure small changes in fertilized irrigation water because of the presence of PBH mulch, these changes had no meaningful effect on the growth or development of container-grown sunflower plants. Rice hull mulches are not likely to affect the nutrition of container-grown plants.

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