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Effect of Salinity on Growth of Barnyardgrass (*Echinochloa crus-galli*), Horse Purslane (*Trianthema portulacastrum*), Junglerice (*Echinochloa colona*), and Rice

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In Asia, a significant area under rice is affected by salinity. Salt stress can affect growth of crops as well as weeds. A study was conducted in a greenhouse to determine the effect of salinity (electrical conductivity [EC] of 1, 6, 12, 18, and 24 dS m^{-1}) on growth of barnyardgrass, horse purslane, junglerice, and rice. Growth variables were analyzed using regression analysis. The tested levels of EC influenced leaf production of barnyardgrass and junglerice but not that of horse purslane. As compared with the control treatment (EC of 1 dS m^{-1}), shoot biomass of barnyardgrass decreased by only 24% at 12 dS m^{-1}, whereas rice biomass declined by 59% at this level of EC. At EC of 24 dS m^{-1}, barnyardgrass still produced 4% of the biomass of the control treatment, whereas rice did not survive at this level of EC. Junglerice shoot biomass decreased by 73% at 18 dS m^{-1} EC compared with the control treatment, whereas rice shoot biomass declined by more than 86% at 18 dS m^{-1} EC. An EC of 10 dS m^{-1} was required to inhibit 50% shoot biomass of rice, whereas the EC to inhibit 50% shoot biomass of barnyardgrass and junglerice was 15 and 13 dS m^{-1}, respectively. Shoot biomass of horse purslane was not influenced by the tested levels of EC. At the highest EC (24 dS m^{-1}), at which rice did not survive, horse purslane shoot biomass was similar to that of the control treatment. In all weed species, data for root biomass showed trends similar to those of shoot biomass. The results of this study suggest that weeds were more tolerant to salt than rice, and horse purslane was the most tolerant species among the weeds.

Nomenclature: Junglerice, *Echinochloa colona* (L.) Link., ECHCO; barnyardgrass, *E. crus-galli* (L.) Beauv., ECHCG; horse purslane, *Trianthema portulacastrum* L., TRIPO; rice, *Oryza sativa* L., ORYSA.
Key words: Electrical conductivity; leaf production; root biomass; salt; shoot biomass.

Rice is a staple food for more than half of the world population. More than 90% of rice is grown and consumed in Asia. Because of less possibility of expansion in rice area in the future, there is a need to increase rice productivity in different environments, including unfavorable ecosystems. Salt-affected area is one of the unfavorable ecosystems, where salinity causes a significant reduction in crop yield. In Asia alone, about 21.5 million ha of rice area are affected by salt stress (Lafitte et al. 2006). Soils with greater than 4 dS m^{-1} are categorized as saline. Rice is a moderately salt-tolerant crop and high salinity reduces rice yields. Severe salt stress may result in complete failure of the rice crop.

In addition to salt stress, weed infestation also causes a yield reduction in rice. Many weeds, including barnyardgrass, horse purslane, and junglerice, are problematic species in rice, especially where rice is direct-seeded (Chauhan 2012). Barnyardgrass and junglerice (grass weeds) closely resemble rice at the seedling stage and they sometimes escape from hand-weeding. By the time these weed species can be easily recognized, crop yield losses may already be obvious (Holm et al. 1991). Barnyardgrass can reduce rice yield by more than 50% at a density of 9 plants m^{-2} (Maun and Barrett 1986). Under certain conditions (e.g., unfavorable weather conditions), herbicide application can be delayed and herbicides like bispyribac-sodium and penoxsulam + cyhalofop can be ineffective when they are applied after six-leaf stage (Chauhan and Abugho 2012). In rain-fed rice, junglerice seedlings were more abundant under zero-till systems than under conventional-tillage systems (Chauhan and Johnson 2009a). Horse purslane, a broadleaf weed, can flower within 30 d after emergence and can produce an average of 7,000 seeds $plant^{-1}$ (Galinato et al. 1999). Rice residue of 6 t ha^{-1} as mulch on the soil surface could not suppress emergence of this weed species (Lee et al. 2011). These studies demonstrate the problems of barnyardgrass, horse purslane, and junglerice in rice.

Salinity can influence the germination and growth of weed species. Weed species differ in their response to increasing salt concentrations (Chauhan and Johnson 2010). Seed germination of junglerice, for example, was greater than 60% up to a concentration of 50 mM NaCl and some seeds still germinated at 150 mM NaCl (Chauhan and Johnson 2009b). Very limited information is available on the effect of salt stress on the growth of barnyardgrass, horse purslane, and junglerice. Under certain conditions, saline water is used as life-saving irrigation in rice, which may adversely affect the growth of rice. Therefore, studies are needed to evaluate the effect of different salinity levels on the growth of rice and weeds. Such studies may help determine these weeds' potential for invasion into saline areas. The main objective of this study was to determine the effect of salinity on the growth of barnyardgrass, horse purslane, junglerice, and rice.

Materials and Methods

Experiments were conducted in a greenhouse at the International Rice Research Institute, Los Baños, Philippines. Seeds of barnyardgrass, horse purslane, and junglerice were collected from several rice fields around Los Baños and stored at room temperature for at least 6 mo before the study began. Floats were fabricated from rectangular Styrofoam having 96 cells or holes (12 by 8 arrangements) with nylon net at the bottom. The floats were fit to rectangular plastic trays with 8-L capacity and 34- by 25- by 12-cm size. The trays were black in color as light penetration through light-colored trays promotes algae growth (Gregorio et al. 1997). Algae tend to

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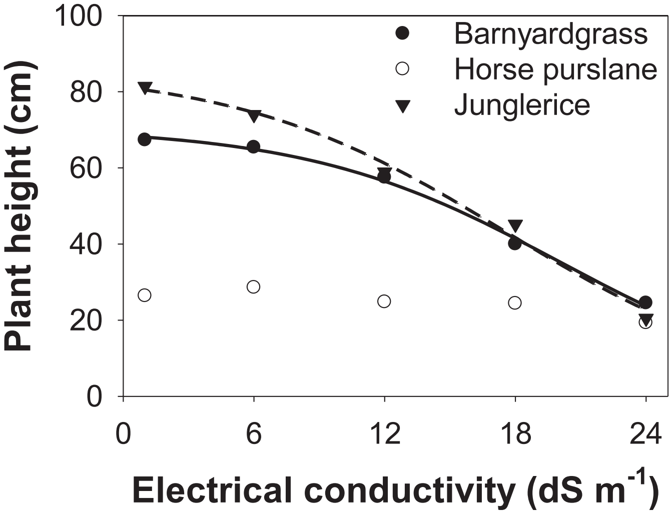

Figure 1. Plant height (cm) of different weed species at different electrical conductivity (dS m^{-1}). The lines represent a three-parameter sigmoid model $\left(y = a / \left\{1 + e^{[-(x - x_{50})/b]}\right\}\right)$ fitted to the plant height of different species.

increase pH particularly around midday. On each float, 40 cells were planted with individual weed species and 20 cells with rice (*cv.* 'FL478'). Cultivar FL478 has high seedling-stage salinity tolerance. Experiments with each weed species were conducted at different times. These floats were placed on trays filled with tap water for 3 d. After germination (3 d after sowing, DAS), the seedlings were thinned to retain only 40 seedlings of weeds and 20 seedlings of rice (one seedling per cell). At 4 DAS, nutrient solution (PETER's solution, The Scotts Company, 14111 Scottslawn Road, Marysville, Ohio) was introduced in all trays. This solution was prepared using tap water with an electrical conductivity (EC) of 1 dS m^{-1} and a pH of 5.5. The composition of the nutrient solution was 20% total nitrogen, 20% available phosphate, 20% available potash, and other nutrients (boron, copper, iron, magnesium, molybdenum, and zinc). The volume in every tray was 8 L and the solution volume was maintained at a constant level by adding water every day to compensate for evaporation and water absorbed by the plants.

Salt treatments began when 50% of the seedlings of barnyardgrass and junglerice reached 5-cm height (10 DAS). For horse purslane, salt treatments were introduced when 50% of the seedlings reached the four-leaf stage (11 DAS). NaCl was added to the nutrient solution to achieve EC of 6, 12, 18, and 24 dS m^{-1}. There was a control treatment (1 dS m^{-1}) in which nutrient solution was added but not NaCl. The pH of the solution in trays was monitored every 2 d and maintained at 5.5 using 1 N HCl or 1 N NaOH. At this pH (5.5), all the necessary nutrients were available to plants. EC levels were also measured over time; however, EC levels were not changed over time. The pH adjustment using HCl and NaOH did not change the EC of the solutions. Weed and rice plants were harvested 21 d after the introduction of salt treatments. The number of survived plants and leaves per plant was counted for each species. Shoot and root biomass was measured after drying samples at 70 C for 48 h. Plant height was measured only for weed species.

Experiments with each weed species were conducted in a completely randomized design with four replications. All experiments were repeated once over time. The data over the repeated experiments were combined for analysis as there was no significant interaction between treatments and experiments. Experiments with each weed species were conducted at

Table 1. Parameter estimates (*a*, maximum height [cm]; x_{50}, electrical conductivity [EC; dS m^{-1}] to inhibit 50% of the maximum height; and *b*, slope) of three-parameter sigmoid model fitted to the plant height of different species in Figure 1. Values in parentheses represent ±standard error of the mean.

	a	x_{50}		
Species	cm	dS m^{-1}	*b*	R^2
Barnyardgrass	70.6 (2.1)	20.0 (0.5)	−5.8 (0.6)	0.99
Horse purslane[a]				
Junglerice	86.0 (6.3)	17.6 (1.3)	−6.2 (1.2)	0.99

[a] Model did not fit.

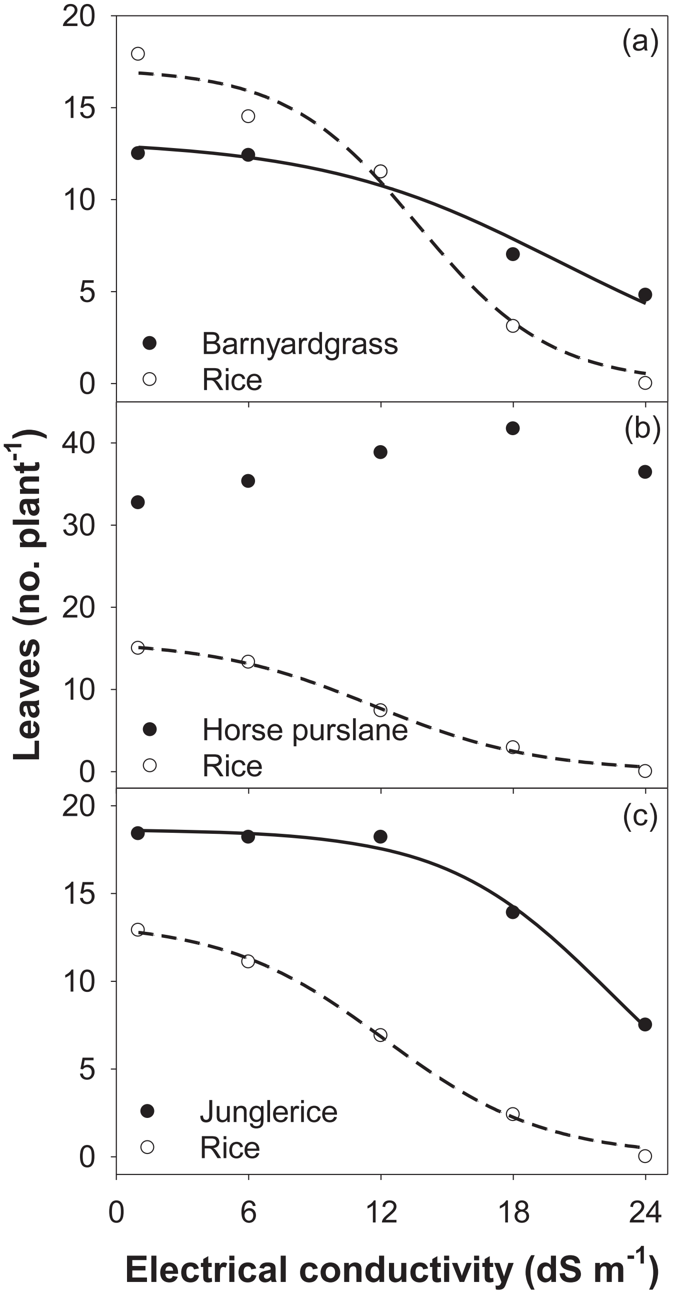

Figure 2. Number of leaves (no. plant^{-1}) of different weed species and rice at different electrical conductivity (dS m^{-1}). The lines represent a three-parameter sigmoid model $\left(y = a / \left\{1 + e^{[-(x - x_{50})/b]}\right\}\right)$ fitted to the number of leaves of different species.

Table 2. Parameter estimates (*a*, maximum leaf number [no. plant^{-1}]; x_{50}, electrical conductyivity [EC; dS m^{-1}] to inhibit 50% of the maximum leaf number; and *b*, slope) of three-parameter sigmoid model fitted to the number of leaves of different species in Figure 2. Values in parentheses represent ±standard error of the mean.

	a	x_{50}		
Species	no. plant^{-1}	dS m^{-1}	*b*	R^2
Barnyardgrass	13.2 (1.1)	20.1 (1.6)	−5.5 (1.7)	0.97
Rice	17.1 (1.4)	13.7 (1.1)	−3.0 (0.9)	0.98
Horse purslane[a]				
Rice	15.9 (0.9)	11.7 (0.7)	−3.7 (0.5)	0.99
Junglerice	18.6 (0.4)	22.4 (0.4)	−3.8 (0.5)	0.99
Rice	13.4 (0.6)	12.2 (0.6)	−3.7 (0.5)	0.99

[a] Model did not fit.

different times and therefore rice data were presented separately with each weed species. Nontransformed values were used for analysis as transformation did not improve homogeneity of variance. Data were analyzed using regression analysis (SigmaPlot 10.0 statistical software, Systat Software, Inc., Point Richmond, CA). A three-parameter sigmoid model of the form

$$y = a \Big/ \left(1 + e^{[-\{x - x_{50}\}/b]}\right)$$

was fitted to the growth variables, where *y* is the estimated height, number of leaves, shoot biomass, or root biomass at time *x*; *a* is the maximum height, leaf number, shoot biomass, or root biomass; x_{50} is the EC to inhibit 50% of the final height, leaf number, shoot biomass, or root biomass; and *b* is the slope around x_{50}.

Results and Discussion

A sigmoid response was observed for barnyardgrass and junglerice height when grown at different EC levels (Figure 1; Table 1). Increasing EC reduced plant height of barnyardgrass and junglerice. As compared with the control treatment (1 dS m^{-1} EC), barnyardgrass and junglerice plant height decreased by 42 and 52%, respectively, at 18 dS m^{-1} EC. At an EC of 24 dS m^{-1}, these weed species attained a height of greater than 20 cm. The model could not fit to horse purslane height and this was flat across different EC levels (Figure 1; Table 1).

Salinity influenced leaf production of barnyardgrass and junglerice but not of horse purslane (Figure 2; Table 2). For the grassy weeds, leaf production was similar up to EC of 12 dS m^{-1}. However, the higher values of EC reduced leaf number in both weeds. Barnyardgrass produced eight and four leaves plant^{-1} at 18 and 24 dS m^{-1} EC, respectively. Rice, on the other hand, did not survive at 24 dS m^{-1} EC and increasing salinity reduced leaf production drastically. As compared with the control treatment, rice leaf production decreased by 36 and 83% at 12 and 18 dS m^{-1} EC, respectively. The sigmoid model could not fit to horse purslane leaf data. The leaf production of horse purslane ranged from 33 to 42 leaves plant^{-1} at the tested EC.

Shoot biomass of barnyardgrass and junglerice declined in a sigmoidal fashion with increasing EC (Figure 3; Table 3). Barnyardgrass shoot biomass was similar (0.45 to 0.46 g plant^{-1}) at 1 and 6 dS m^{-1} EC. As compared with the control treatment, shoot biomass of barnyardgrass declined by only 24% at 12 dS m^{-1}, whereas rice biomass decreased by 59% at this EC. At an EC of 24 dS m^{-1}, barnyardgrass still produced 4% biomass of the control treatment, whereas rice did not survive at this EC. As estimated from the fitted model, EC to inhibit 50% shoot biomass of barnyardgrass and rice was 15.4 and 10.0 dS m^{-1}, respectively (Figure 3). Junglerice shoot biomass was not influenced by salinity up to 6 dS m^{-1} EC but, after that, it decreased with increased EC (Figure 3; Table 3). The sigmoid model estimated that the EC to inhibit 50% shoot biomass of junglerice and rice was 12.8 and 10.0 dS m^{-1}, respectively (Table 3). Junglerice shoot biomass declined by 73% at 18 dS m^{-1} EC compared with the control treatment, whereas rice shoot biomass decreased by 86% at 18 dS m^{-1} EC. Rice did not produce any biomass at

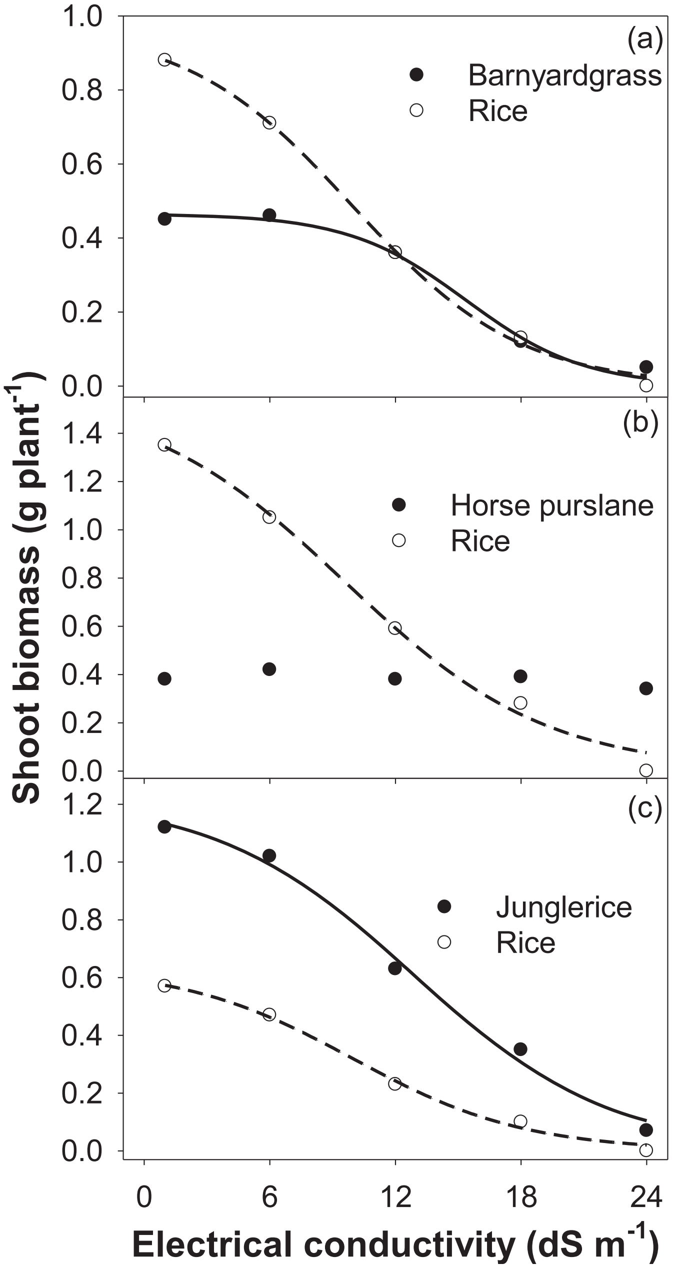

Figure 3. Shoot biomasss (g plant^{-1}) of different weed species and rice at different electrical conductivity (dS m^{-1}). The lines represent a three-parameter sigmoid model $\left(y = a/\{1+e^{[-(x-x_{50})/b]}\}\right)$ fitted to the shoot biomass of different species.

Table 3. Parameter estimates (a, maximum shoot biomass [g plant^{-1}]; x_{50}, electrical conductivity [EC; dS m^{-1}] to inhibit 50% of the maximum shoot biomass; and b, slope) of three-parameter sigmoid model fitted to the shoot biomass of different species in Figure 3. Values in parentheses represent ±standard error of the mean.

	a	x_{50}		
Species	g plant^{-1}	dS m^{-1}	b	R^2
Barnyardgrass	0.47 (0.02)	15.4 (0.5)	−2.8 (0.5)	0.99
Rice	0.97 (0.05)	10.0 (0.7)	−4.0 (0.4)	0.99
Horse purslane[a]				
Rice	1.57 (0.20)	9.6 (1.7)	−4.8 (1.0)	0.99
Junglerice	1.22 (0.10)	12.8 (1.2)	−4.7 (0.8)	0.99
Rice	0.64 (0.05)	10.0 (1.1)	−4.1 (0.7)	0.99

[a] Model did not fit.

24 dS m^{-1} EC, whereas junglerice still produced 9% of the biomass of its control treatment. In contrast to the grassy weeds, shoot biomass of horse purslane was not influenced by the tested levels of EC. The response of horse purslane shoot biomass to the tested levels of EC was flat and therefore the sigmoid model could not fit to the data. At the highest EC, at which rice did not survive, horse purslane biomass was similar to that of its control treatment. These results suggest that horse purslane was the most tolerant species among the weeds. Barnyardgrass and junglerice data are in agreement with previous studies in which increasing salinity reduced biomass and height of weed seedlings (Israelsen et al. 2011; Yang et al. 2009).

A sigmoidal response was observed for the root biomass of only barnyardgrass and junglerice with increasing EC levels but the response of horse purslane height was flat to the tested EC levels (Figure 4; Table 4). Root biomass of barnyardgrass and junglerice declined with increase in EC. Compared with the control treatment, 12 dS m^{-1} EC reduced root biomass of barnyardgrass by only 24%, whereas root biomass of rice declined by 60% at this EC. EC to inhibit 50% root biomass of barnyardgrass was 15.4 dS m^{-1}, whereas this level of EC for rice was 10.4 dS m^{-1}. Barnyardgrass and junglerice produced root biomass even at 24 dS m^{-1} EC, whereas rice did not produce any biomass at this EC. Similar to the results observed for shoot biomass, root biomass of horse purslane was not influenced by EC up to 24 dS m^{-1} (Figure 4; Table 4). Horse purslane root biomass was 0.040 to 0.045 g plant^{-1} at different EC. In all weed species, data for root biomass showed trends similar to those of shoot biomass. Therefore, the root-to-shoot biomass ratios did not vary significantly with increasing EC (data not shown). In a previous study, however, increasing salinity increased the root-to-shoot biomass ratio in smooth brome (*Bromus inermis* Leyss.) (Yang et al. 2009). The authors suggested that salinity caused plants to allocate more biomass to roots, which enabled plants to increase water uptake.

The results of our study demonstrate that the three weed species are more salt-tolerant than rice. Rice growth decreased more with increasing EC than weed growth. Weeds survived at the highest EC (24 dS m^{-1}), whereas rice did not survive at this EC. Reductions in survival and growth of rice seedlings due to salt stress are the main causes of biomass and yield reduction in salt-affected areas (Nakhoda et al. 2012). In field conditions, an EC of only 6 dS m^{-1} decreased the grain yield of many rice varieties by 50% (Maas and Hoffman 1977). In our study, the growth response to salt was specific to weed species. Barnyardgrass and junglerice responded similarly to salinity, whereas the response of horse purslane was different. The growth of horse purslane was not influenced by the tested levels of salinity. The plants that are tolerant of and adapted to saline conditions are called halophytes (Israelsen et al. 2011). Such plants may have different salt-tolerance mechanisms, such as salt exclusion and uptake and compartmentalization of salts (Israelsen et al. 2011; Munns and Tester 2008).

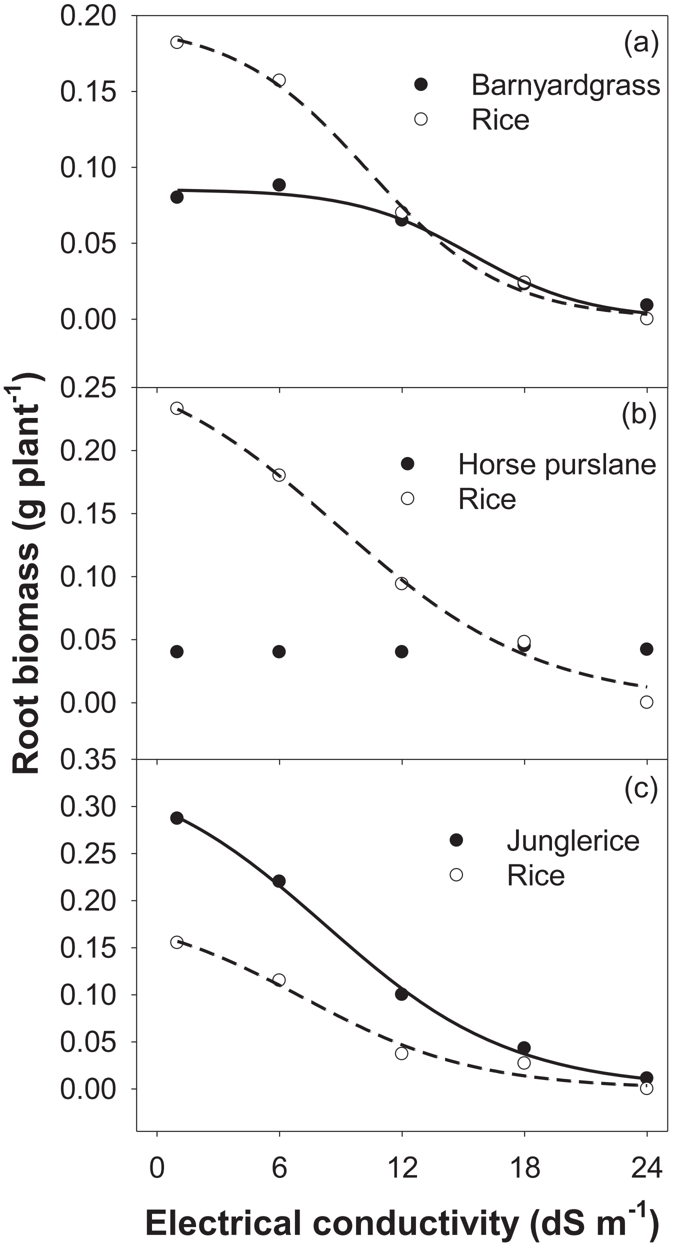

Figure 4. Root biomasss (g plant^{-1}) of different weed species and rice at different electrical conductivity (dS m^{-1}). The lines represent a three-parameter sigmoid model $\left(y=a/\left\{1+e^{[-(x-x_{50})/b]}\right\}\right)$ fitted to the root biomass of different species.

Our results clearly show that barnyardgrass, horse purslane, and junglerice will have a distinct advantage over the rice crop, which may be stressed in salt-affected areas. The tolerance of soil salinity in these weed species may allow them to establish in areas where competition from other plant species is limited.

Table 4. Parameter estimates (a, maximum root biomass [g plant^{-1}]; x_{50}, EC [dS m^{-1}] to inhibit 50% of the maximum root biomass; and b, slope) of three-parameter sigmoid model fitted to the root biomass of different species in Figure 4. Values in parentheses represent ±standard error of the mean.

	a	x_{50}		
Species	g plant^{-1}	dS m^{-1}	b	R^2
Barnyardgrass	0.09 (0.01)	15.4 (1.0)	−2.9 (0.8)	0.98
Rice	0.20 (0.01)	10.4 (0.7)	−3.3 (0.5)	0.99
Horse purslane[a]				
Rice	0.28 (0.04)	8.8 (2.0)	−4.9 (1.1)	0.99
Junglerice	0.35 (0.03)	8.2 (0.9)	−4.6 (0.5)	0.99
Rice	0.19 (0.05)	7.2 (3.0)	−4.2 (1.5)	0.98

[a] Model did not fit.

Seed fecundity is an important component of a weed species to ensure its persistence in the next growing season. Different weed management strategies should target the weed seed bank in the soil and minimize the size of the seed bank (Chauhan 2012; Chauhan et al. 2012). In a crop, it is important to control weeds at the early stages of crop growth and save resources for the crop.

There is a need to improve salt tolerance in rice cultivars to increase rice yields in salt-affected areas. In such areas, weed management can be improved by incorporating weed-competitive traits in salt-tolerant rice cultivars. However, such research for saline areas is limited on the weed component because the main breeding focus is on improving crop cultivars tolerant of salt stress. Herbicides are an important component of weed control in direct-seeded rice systems. There is a need to see the performance of PRE herbicides in salt-affected areas because PRE herbicides (soil active) may interact differently with saline soils.

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