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Seed Germination and Seedling Emergence of Nalta Jute (*Corchorus olitorius*) and Redweed (*Melochia concatenata*): Important Broadleaf Weeds of the Tropics

Bhagirath S. Chauhan and David E. Johnson*

Nalta jute and redweed are widespread and significant broadleaf weed species of the tropics. Experiments were conducted to determine the effects of various environmental factors on seed germination and seedling emergence of these species. Light was not required for germination in either species. Germination was stimulated by seed scarification, suggesting that inhibition of germination in these species is mainly due to the hard seed coat. Scarified seeds of both species germinated over a wide range of alternating temperatures (25/15, 30/20, and 35/25 C). Both species were moderately tolerant of salt and osmotic stress, but nalta jute tolerated more stresses than redweed. Seedling emergence of nalta jute and redweed was greater than 87 and 93%, respectively, at soil depths of 0 to 2 cm but decreased as depth increased, with no emergence at 8 cm. Seedling emergence of both species was reduced by the addition of rice straw, though a high amount (4 to 6 t ha^{-1}) of straw was required to suppress emergence significantly. The information gained from this study could facilitate the development of effective weed control programs.
Nomenclature: Nalta jute, *Corchorus olitorius* L.; redweed, *Melochia concatenata* L.; rice, *Oryza sativa* L.
Key words: Burial depth, emergence, germination, scarification.

Nalta jute and redweed are important broadleaf weed species of rainfed crops in many tropical countries. (These weed species are not listed in the WSSA Composite List of Weeds [http://www.wssa.net/Weeds/ID/WeedNames/namesearch.php] but have been referred to as nalta jute and redweed by Buhler and Hoffman [1999].) Nalta jute, an herbaceous annual plant, belongs to family Tiliaceae. It is reported as a weed in 50 countries and in 28 crops, including upland rice, cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), sugarcane (*Saccharum officinarum* L.), wheat (*Triticum aestivum* L.), soybean [*Glycine max* (L.) Merr.], and vegetables (Holm et al. 1997). Nalta jute is a common weed of rice in India, Nepal, Sri Lanka, and the Philippines (Moody 1989). Juliano (1940) in the Philippines reported that seeds of the weed kept in moist sand germinated for several months after collection and seeds buried in soil were viable for 6.5 yr. Seedlings can emerge from up to a soil depth of 9 cm (Modiwala and Dubey 1976). Nalta jute varieties are grown as a vegetable in the Middle East, Egypt, Sudan, and Southeast Asia and perhaps some of these types have escaped to become weeds throughout the tropics (Holm et al. 1997). The potential of leaves for the supply of minerals, vitamins, and supplemental proteins makes them of critical importance to the health of people who are largely dependent upon cereals as dietary staples.

Redweed, an annual belonging to family Sterculiaceae, is native to the Asian tropics and is widely distributed in South and Southeast Asia (Holm et al. 1979). It occurs from sea level to 700 m and thrives in sunny or lightly shaded moist soils in crops, fallow fields, pastures, and water courses. Redweed is commonly associated with rainfed lowland and upland rice as well as other dryland crops in Asia and West Africa (Galinato et al. 1999; Johnson and Kent 2002). In direct-seeded rice crops, redweed has recently been reported to occur in 10 countries in dry-seeded rice and in four countries in wet-seeded rice (Rao et al. 2007).

Changes in cropping intensification and method of rice establishment have occurred in many Asian countries (Rao et al. 2007). Such changes in cropping practices, however, are likely to be associated with a shift in the weed floral composition. In a 5-yr experiment in West Africa, for example, Johnson and Kent (2002) recorded nalta jute in 25% of samples in upland fields in the first year, but in subsequent years it was succeeded by grasses.

Despite the widespread distribution of nalta jute and redweed in crops and regions of the world, very little is known of their seed biology. Several factors can affect seed germination, including temperature. In the United States, redweed seed germination ranged from 74 to 94% over constant temperatures ranging from 20 to 40 C (Eastin 1983). This may provide little guidance as to the response in nature, however, as constant temperature is not commonly encountered (Baskin et al. 2006). Fluctuations in temperature can influence seed germination differently from constant temperatures although such information is not available on nalta jute and redweed. Similarly, an ability to germinate under conditions of moisture stress or high salt content of soils may enable a weed to take advantage of conditions that limit growth of other species. Seed burial depth (buried by tillage or other means) also affects germination and emergence of several weed species (Benvenuti et al. 2001). Further, crop residues on the soil surface may suppress weed emergence (Chauhan and Johnson 2008a; Mohler and Calloway 1992; Teasdale et al. 1991) and may therefore be used as a component of integrated weed management systems.

A better understanding of seed germination biology of these species could contribute to the development of weed management technologies to help counter undesirable shifts in weed populations and could enable sustainable cropping intensification in rice-based systems and changes in crop management practices. The objectives of this study were therefore to determine the effect of various environmental factors on seed germination and seedling emergence of nalta jute and redweed.

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Materials and Methods

Seed Description and General Germination Tests. Seeds of nalta jute and redweed were collected in May 2007 from the periphery of several fields (over an area of approx. 5 km^2) around Los Baños (latitude 14°10′N, longitude 121°13′E), Philippines. Seeds collected from many randomly selected plants were bulked to obtain experimental samples. Seeds were cleaned manually and stored at room temperature (25 C) until used in the experiments. The 1,000-seed weight of nalta jute and redweed was 1.36 ± 0.02 and 2.78 ± 0.03 g, respectively.

The seeds used were scarified with concentrated sulfuric acid (H_2SO_4) for 60 min, unless otherwise specified. These seeds were washed in running tap water for 5 min before performing experiments with them. For germination studies, seeds were placed evenly in 9-cm-diam petri dishes containing two pieces of filter paper wetted with 5 ml of distilled water or a treatment solution, incubated in the light/dark (12 h/12 h) at 35/25 C unless otherwise stated. Germination was determined after 10 d, at which time seeds with an emerged radicle were considered to have germinated.

Effect of Scarification on Germination. Experiments were conducted to investigate whether seed germination in these species was inhibited by an impermeable seed coat. Seeds of both species were scarified with concentrated H_2SO_4 at different time intervals (0, 5, 10, 30, 60, 120, and 180 min). The seeds (25 seeds for each species) were then incubated as described above and germination determined.

Effect of Temperature and Light on Germination. To determine the effect of temperature and light on germination, 25 scarified seeds were incubated at different temperatures (35/25, 30/20, and 25/15 C alternating day/night temperatures) in both light/dark and dark regimes. These temperature regimes were selected to reflect the temperature variation occurring in the Philippines. In the dark treatment, the dishes were wrapped in a double layer of aluminum foil to prevent any accidental light penetration.

Effect of Salt and Osmotic Stress on Germination. To determine the effect of salinity on germination, 25 scarified seeds were incubated in sodium chloride (NaCl) solutions of 0, 25, 50, 100, 150, 200, and 250 mM. In a similar study, the effects of moisture stress on seed germination were assessed by incubating 25 scarified seeds in solutions with osmotic potentials of 0, −0.1, −0.2, −0.4, −0.6, −0.8, and −1.0 MPa, prepared by dissolving polyethylene glycol 8000 in distilled water, as described by Michel (1983). Germination was determined by incubating seeds as described above.

Effect of Seed Burial Depth on Seedling Emergence. The effect of seed burial depth in soil on seedling emergence was studied in a screenhouse by placing 50 seeds of each species in 15-cm-diam plastic pots. Seeds were placed on the soil surface or covered to depths of 0, 0.5, 1, 2, 4, 6, 8, and 10 cm with soil. Soil (clay, 36%; silt, 29%; and sand, 35%; pH 6.3; and organic carbon, 0.9%) used for this experiment was autoclaved and passed through a 0.3-cm sieve before conducting the experiment. Pots were watered as needed to maintain sufficient soil moisture. Seedlings were considered emerged when a cotyledon could be seen, and the experiment was terminated when no further emergence was recorded for a continuous 10-d interval. The ungerminated seeds were subjected to a simple pressure test with tweezers to determine whether the seeds were viable.

Effect of Rice Residue on Seedling Emergence and Dry Matter. Fifty seeds of each species were sown on the soil surface in plastic pots and finely chopped rice straw (variety IR64) was spread on the surface at rates equivalent to 0, 1, 2, 4, and 6 t ha^{-1}. The depth of residue in the treatments 1, 2, 4, and 6 t ha^{-1} corresponded to approximate depth of 0.34, 0.63, 1.34, and 1.80 cm, respectively. The soil used in this experiment was as described above. Emerged seedlings were counted at 3, 6, 9, 12, and 15 d after sowing and expressed as a percentage of the seeds sown. At the end of the experiment, emerged seedlings were harvested, placed in paper bags, and oven-dried at 70 C for 72 h to determine the biomass.

Statistical Analyses. All experiments were conducted in a randomized complete-block design. Treatments of each experiment were replicated three times, each experiment was conducted twice, and the data were combined for analysis as there were no interaction effects of treatment and experiment. In the laboratory experiments, each replication was arranged on a different shelf in the germination chamber and considered as a block for analyses. Data variance was visually inspected by plotting residuals to confirm homogeneity of variance before statistical analysis (GenStat 8.0 2005). Regression analysis was used where appropriate; otherwise, after analysis of variance, means were separated using standard error of mean.

Results and Discussion

Effect of Scarification on Germination. Seed germination of both species was stimulated by scarification of the seed coat. Germination increased with an increase in the duration of scarification with concentrated H_2SO_4 up to 60 min and declined after that (Figure 1). Seeds scarified for 60 min resulted in 93 and 97% germination compared with 3 and 23% for nonscarified seeds of nalta jute and redweed, respectively. Seeds scarified for 180 min had only 45% germination for nalta jute and 59% for redweed. The lower levels of germination after scarification beyond 60 min may have been due to embryo damage caused by greater penetration of H_2SO_4 (Upreti and Dhar 1997). In subsequent experiments therefore seeds were scarified for only 60 min.

Seeds may be scarified by sanding, brief immersion in boiling water, acid washes, or seed coat cracking. Seed scarification with emery cloth and seed coat cracking have been reported to be effective methods to increase germination in redweed (Eastin 1983) and nalta jute (Chavan and Trivedi 1962), respectively. In our study, the substantial increase in germination with scarification indicates that the hard seed coat is probably the primary mechanism of dormancy in nalta jute and redweed. The stimulation in germination with scarification could be due to increased imbibition or the release from physical restriction of the seed coat. Results suggest that seeds are unlikely to germinate in the field unless scarified and therefore seeds of these species may persist in the

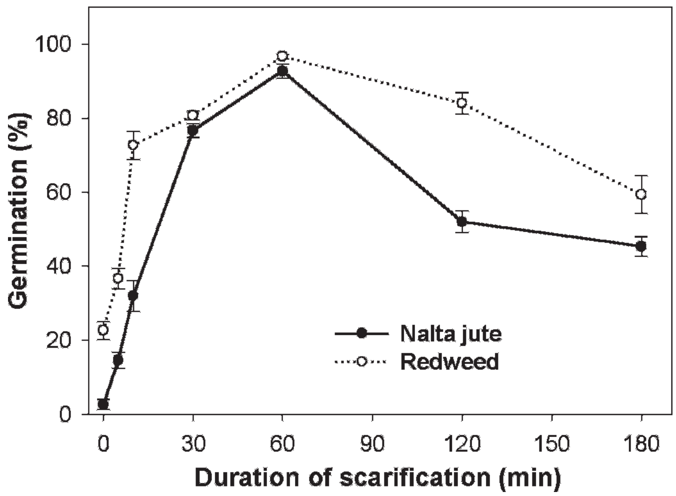

Figure 1. Effect of duration of scarification with concentrated H_2SO_4 on seed germination of nalta jute (solid line) and redweed (dotted line) after 10 d of incubation at 35/25 C alternating day/night temperatures. Vertical bars represent standard errors of the mean.

soil for a long time, causing a problem in future crops if scarification does not take place. Under natural conditions, scarification usually occurs due to extreme changes in temperature (which cause contraction and expansion of the seed coat), soil acids, bacterial action, passage through the digestive system of animals, abrasion by soil particles, and vegetation burning (e.g., Baskin et al. 1998; Galinato et al. 1999).

Effect of Temperature and Light on Germination. Germination of scarified seeds of nalta jute was not influenced by light conditions (data not shown), though it was influenced ($P = 0.04$) by the tested temperatures. Germination percentage was greater at 35/25 C (95 $\pm$ 1.3%) and 30/20 C (95 $\pm$ 1.4%) than at 25/15 C (91 $\pm$ 1.3%). Germination of redweed was not influenced by either the tested temperatures or light (data not shown). Mean germination across temperature and light conditions was 97%.

Absence of a germination response to light in nalta jute and redweed indicates that seeds of these species are not photoblastic (i.e., germinating in response to light) and may therefore germinate even when buried or after canopy closure in most crops grown in the humid tropics. Late emerging seedlings after canopy closure, however, are likely to experience greater competition for light, water, and nutrients from the crop than the early cohorts and may, in consequence, result in less crop yield loss and weed seed production (O'Donovan et al. 1985; Uscanga-Mortera et al. 2007). Information on growth and fecundity of nalta jute and redweed as influenced by emergence time and competing crop is not available. Our study also suggests that either no-till or mulch systems will have no influence in terms of light exposure affecting germination. Species having a hard seed coat have been reported to have light-independent germination (e.g., Chauhan et al. 2006; Chauhan and Johnson 2008b). Temperature may also affect seed germination and in part govern seasonality and range expansion. Seeds of both species germinated (> 90%) over the range of temperatures tested and, therefore, depending on the status of scarification and moisture, the seeds of these species could germinate throughout the year at low altitudes in tropical countries.

Effect of Salt and Osmotic Stress on Germination. Germination of nalta jute exceeded 87% up to a concentration of 150 mM NaCl, and 17% of seeds germinated even at 250 mM NaCl (Figure 2). Similarly, redweed germination was greater than 91% up to a concentration of 150 mM, although germination was completely inhibited at 250 mM NaCl. As estimated from the model, the concentration resulting in 50% inhibition of maximum germination for nalta jute and redweed was 230 $\pm$ 2.3 and 198 $\pm$ 0.9 mM NaCl, respectively. These results indicate that, in saline conditions, a proportion of nalta jute and redweed seeds may germinate, which could be a key feature of these species enabling them to colonize saline areas. Salt stress is a major constraint to crop production worldwide; therefore, crop cultivation may be limited not only by salinity but also by weed competition. Soils with more than 100 mM NaCl (approximate electrical conductivity, 10 mmhos cm^{-1}) are known with high level of salt content and rice, a major cereal crop of the tropics, is considered a sensitive crop in these soils (Tanji and Kielen 2002). Flooded rice may suffer from salinity stress even at an electrical conductivity of 4 mmhos cm^{-1} (Sanchez 1976). Canola (*Brassica napus* L.) and rye (*Secale cereale* L.) have been reported as salt tolerant crops (Tanji and Kielen 2002).

In a similar way to the response to salinity, germination of redweed was affected to a greater degree by increasing water stress than was nalta jute. Germination of redweed was greater than 90% at osmotic potentials ranging from 0 to -0.4 MPa; 51% of seeds germinated at -0.6 MPa though germination was only 1% at -1.0 MPa osmotic potential (Figure 3). Conversely, germination of nalta jute was greater than 90% up to an osmotic potential of -0.6 MPa and 25% of seeds germinated even at -1.0 MPa. The osmotic potential required for 50% inhibition of maximum germination of redweed was -0.6 $\pm$ 0.02 MPa, whereas this was lower (-0.9 $\pm$ 0.01 MPa) for nalta jute. In contrast to these species, germination in small-flowered mallow (*Malva parviflora* L., also a hard-seeded species) was completely inhibited at an osmotic potential of -0.6 MPa (Chauhan et al. 2006). The ability of nalta jute and redweed to germinate under

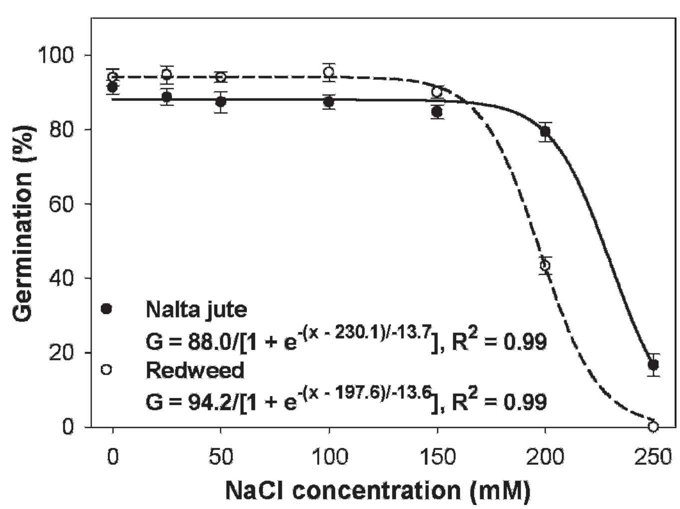

Figure 2. Effect of NaCl concentration on germination of scarified seeds of nalta jute (solid line) and redweed (dotted line) after 10 d of incubation in light/dark at 35/25 C alternating day/night temperatures. Vertical bars represent standard errors of the mean, and lines represent a three-parameter sigmoid model fitted to the data.

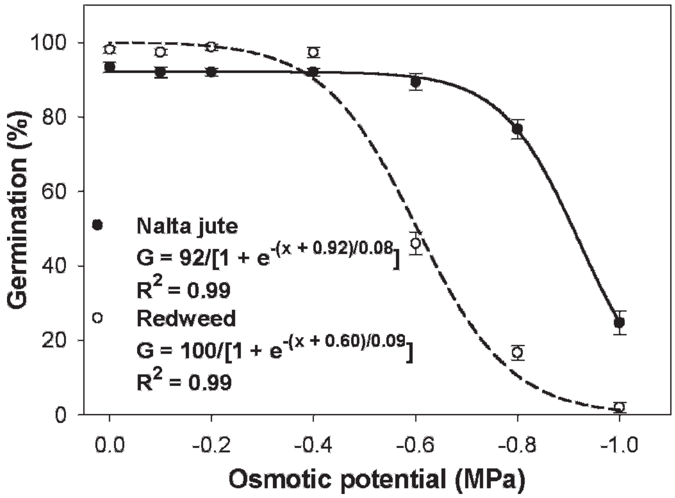

Figure 3. Effect of osmotic potential on germination of scarified seeds of nalta jute (solid line) and redweed (dotted line) after 10 d of incubation in light/dark at 35/25 C alternating day/night temperatures. Vertical bars represent standard errors of the mean, and lines represent a three-parameter sigmoid model fitted to the data.

moderate water-stress conditions could enable them to gain advantage as weeds due to earlier seedling emergence under water-stress conditions.

Effect of Seed Burial Depth on Seedling Emergence. In both species, a sigmoid response for seedling emergence was obtained with increasing seed burial depth (Figure 4). Seedlings emerged from all burial depths ranging from 0 to 6 cm. Emergence of nalta jute and redweed was greater than 87 and 93%, respectively, at depths of 0 to 2 cm but this decreased progressively as depth increased, and no emergence was recorded at a depth of 8 cm. Soil depth for 50% inhibition of maximum seedling emergence of nalta jute and redweed was 5.4 ± 0.07 and 5.1 ± 0.05 cm, respectively.

Decreased seedling emergence due to increased burial depth has been reported in several weed species (Benvenuti et al. 2001; Boyd and Van Acker 2003). Larger seeds with greater carbohydrate reserves can emerge from greater depths of burial (Baskin and Baskin 1998). On the other hand, small-seeded species such as nalta jute and redweed may have insufficient energy reserves to support hypocotyl elongation from deeper depths. Previous studies also suggest that decreased germination may be due to raised CO_2 derived from soil biological activity and slower gas diffusion, which is inversely correlated with burial depth (Benvenuti and Macchia 1995). Decreasing thermal fluctuation with increasing burial depth has also been suggested to reduce emergence of weeds from greater depths (Roberts and Totterdell 1981).

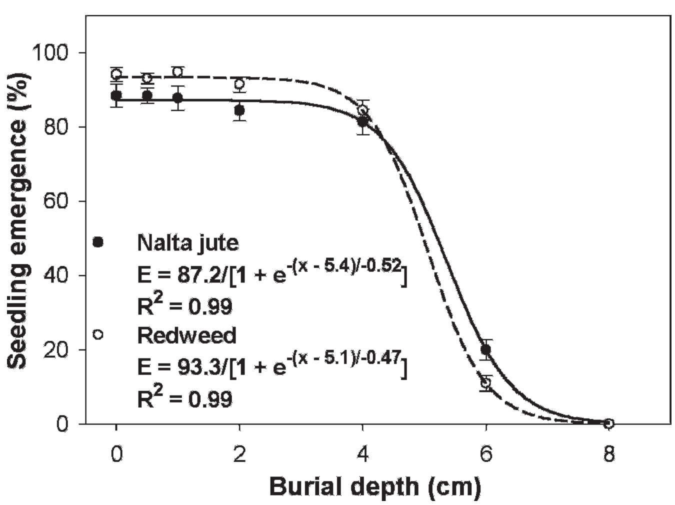

Figure 4. Effect of burial depth on seedling emergence of scarified seeds of nalta jute (solid line) and redweed (dotted line). Vertical bars represent standard errors of the mean, and lines represent a three-parameter sigmoid model fitted to the data.

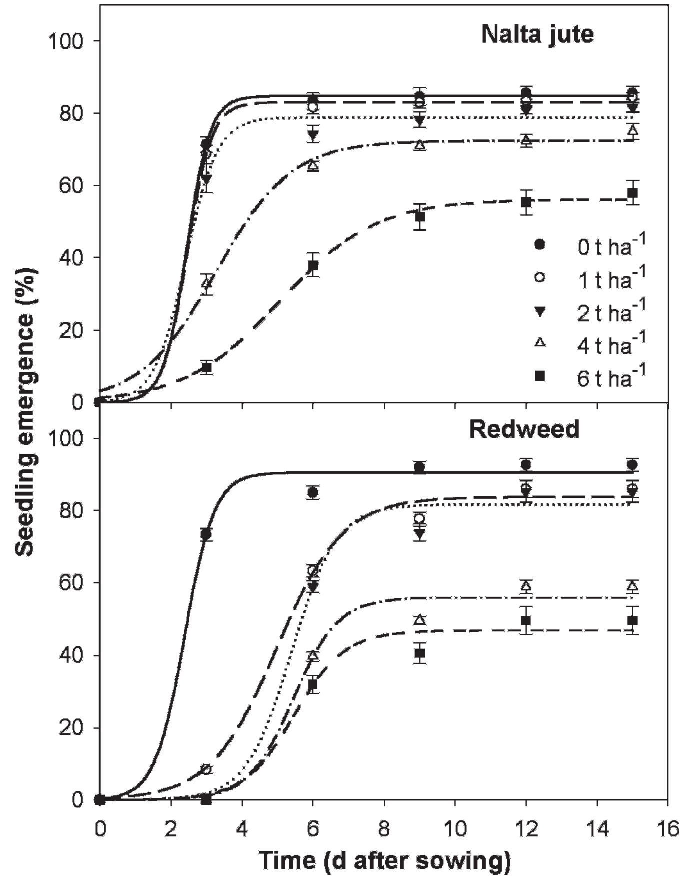

Figure 5. Effect of residue amounts on seedling emergence pattern of nalta jute and redweed. Vertical bars represent standard errors of the mean, and lines represent a three-parameter sigmoid model fitted to the data.

The results of this study suggest that cultivation practices that achieve shallow burial of seeds may promote greater seedling emergence of nalta jute and redweed. On the other hand, deep-tillage operations that bury the seeds below the maximum zone of emergence (i.e., 8 cm) would suppress emergence providing subsequent tillage is shallow to avoid the possibility of bringing back the seeds toward the soil surface.

Effect of Rice Residue on Seedling Emergence and Dry Matter. Seedling emergence of both species was reduced by the addition of rice residue to the soil surface, though a large amount of residue was required to suppress emergence significantly. Emergence of both species declined by less than 10% when residue was applied up to 2 t ha^{-1} compared with when no residue was applied (Figure 5; Table 1). Emergence

Table 1. Parameter estimates of a three-parameter sigmoid model fitted to the seedling emergence in Figure 5.

	Parameter estimates[a]							
	Nalta jute				Redweed			
Residue amount	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
t ha^{-1}	%		d		%		d	
0	84.8	0.33	2.45	0.99	90.6	0.42	2.39	0.99
1	83.1	0.34	2.47	0.99	83.8	0.93	4.98	0.99
2	78.8	0.44	2.42	0.99	81.7	0.64	5.40	0.99
4	72.4	1.07	3.27	0.99	56.0	0.63	5.45	0.99
6	56.2	1.35	5.08	0.99	46.9	0.71	5.48	0.98

[a] E_{max}, maximum seedling emergence (%); T_{50}, time to reach 50% of maximum seedling emergence (d); E_{rate}, slope.

of nalta jute decreased by 15 and 34% with residues of 4 and 6 t ha^{-1}, respectively, whereas redweed emergence decreased by 38 and 48% at these levels. The time taken for 50% of maximum seedling emergence (T_{50}) increased with larger quantities of residue (Table 1). Crop residue had a more pronounced effect on weed seedling dry matter than seedling emergence. Dry matter of emerged seedlings decreased linearly with increased amounts of residue (Figure 6). Residue of 4 and 6 t ha^{-1} reduced the dry matter of redweed seedlings by 42 and 63%, respectively, compared with the control (no residue), whereas nalta jute dry matter declined by only 34 and 52% with these quantities of residue.

It is unclear why there was a difference in seedling emergence between seeds buried at shallow depths in soil (up to 2 cm; Figure 4) and seeds placed under a mulch cover of 6 t ha^{-1} (equivalent to 1.8 cm; Figure 5). The widely grown rice variety (IR64) used in our study is not reported for its allelopathic effects and it is unlikely that allelochemicals were responsible for reduced emergence in the residue experiment. It is speculated that increased incidence of pests and diseases in the presence of straw-mulch may be one possibility for low emergence. Further research is needed to better understand the effects of surface mulch and seed burial depth on seedling emergence and their growth.

Emergence of many weeds has been reported to be reduced with the addition of crop residue (Mohler and Calloway 1992); however, greater quantities of residue than those normally found in fields may be required to cause a substantial reduction in weed densities. A constraint to increasing the quantities of straw may be that in some areas straw is used for cattle. Further research is needed in field conditions to determine the amount of residue required to effectively suppress weeds. In some countries, such as India, because of concern about the depletion of soil organic matter and environmental pollution due to the burning of crop residues, retention of residues is proposed. Direct seeding of rice into anchored or loose residue of up to 7 to 8 t ha^{-1} has been reported (Gupta et al. 2006), which could be beneficial to suppress these weed species. It is important, however, to balance the quantities of residue required to suppress weeds with those that will not hinder crop establishment.

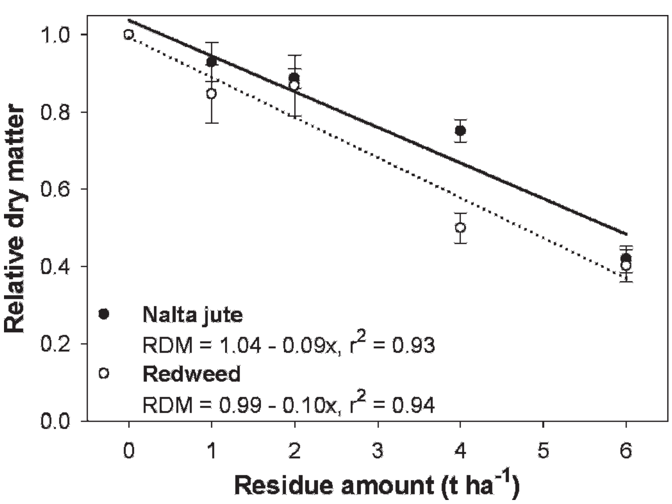

Figure 6. Effect of residue amounts on relative dry matter of nalta jute (solid line) and redweed (dotted line) seedlings. Vertical bars represent standard errors of the mean, and lines represent a linear model fitted to the data.

In conclusion, seed germination of nalta jute and redweed was stimulated by scarification, which indicates that the hard seed coat is probably the primary reason for inhibition of germination in these species. Germination was not influenced by light conditions for either species. This suggests that no-till systems will make no difference from the point of view of light exposure. Seedling emergence was optimal at shallow burial depths, indicating that farming practices such as reduced tillage might promote greater seedling emergence of nalta jute and redweed, and tillage to bury their seeds below 6 cm would be appropriate. Alternatively, there is the possibility of integrating the use of crop residue (as a mulch) together with other weed management options to improve management of these weed species. Seeds germinated at a range of alternating temperatures (25/15, 30/20, and 35/25 C), suggesting that these species could emerge throughout the year at low altitudes in tropical countries. Although seeds used in this study were collected from a large area (5 km^2), germination may vary among seeds collected from different sites. Inferences drawn from the results of this study should therefore be limited to the weed population sampled.

Acknowledgments

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