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# Growth Response of Itchgrass (*Rottboellia cochinchinensis*) to Water Stress

Bhagirath S. Chauhan*

Greenhouse studies were conducted to evaluate the growth response of itchgrass to water stress. Itchgrass plants produced the greatest aboveground biomass and seeds at 75% of field capacity and these parameters at 50 and 100% of field capacity were similar. With further increase in water stress, seed production was sharply reduced, but itchgrass was still able to produce an average of 63 and 9 seeds plant$^{-1}$ at 25 and 12.5% of field capacity, respectively. Itchgrass plants responded to increasing water stress with increased leaf weight ratio; it was 2.5 times greater at 12.5% of field capacity than at 100% of field capacity. In another study, compared with daily irrigation, intervals of 9 d between irrigations reduced aboveground biomass of itchgrass by 27% and 12-d intervals reduced aboveground biomass by 67%. Compared with the daily irrigation regime, itchgrass seed production was reduced by 61% at intervals of 12 d between irrigations; however, the weed plants produced a considerable number of seeds (153 seeds plant$^{-1}$) at the 12-d intervals. The ability of itchgrass to produce biomass and seeds under water stressed conditions necessitates strategies that minimize weed survival while maximizing irrigation efficiency for the crop at the same time.

**Nomenclature:** Itchgrass, *Rottboellia cochinchinensis* (Lour.) W. D. Clayton ROTCO; rice, *Oryza sativa* L. ORYSA.
**Key words:** Aboveground biomass; root biomass; seed production; soil moisture.

Itchgrass, a $C_4$ grass, is a problematic weed in rainfed environments and its populations can build up rapidly throughout the tropics (Holm et al. 1991). It has been reported as a major weed in several crops, including rice and corn (*Zea mays* L.). In addition, itchgrass also grows along roadsides. Infestation with itchgrass can reduce rice yields from 30 to 100%, depending on its density and time of emergence (Ampong-Nyarko and De Datta 1991; Holm et al. 1991). Farmers in Costa Rice spend 34% of total crop inputs on itchgrass control (Calvo et al. 1996). Hand weeding is very difficult in removing itchgrass from the fields because of the fiberglass-like hairs on its stems, which can penetrate the skin and cause severe irritation (Strahan et al. 2000). Itchgrass is a prolific seed producer and flowers throughout the year in the tropics (Holm et al. 1991). Itchgrass seeds may remain viable in the soil for more than 4 yr (Thomas and Allison 1975). In a recent study in the Philippines, itchgrass seedlings emerged from seeds buried at 8-cm depth and there was no difference in emergence between zero-till and conventional tillage systems (Bolfrey-Arku et al. 2011; Chauhan and Johnson 2009).

Water stress reduces rice yields on 23 million ha of rainfed area in South and Southeast Asia (Huke and Huke 1997). In years of drought, average loss in rice production can be more than one billion US dollars in Asia alone. Water shortage is becoming an increasing problem even in irrigated areas because of the growing demand in urban areas. By 2025, 22 million ha of irrigated dry-season rice may experience ‘‘economic water scarcity’’ (Tuong and Bouman 2003). In addition, rising fuel costs and limited water availability may decrease the capacity of farmers to irrigate their field frequently in irrigated areas, resulting in water stress for crops as well as weeds (Webster and Grey 2008). In rainfed areas, water stress can occur at any time during the rice-growing season because of sporadic rainfall events. In addition, weeds may reduce the available water to crops by competition, thereby causing water stress in crops (Patterson 1995).

Seeds of itchgrass can germinate under moderately water-stressed conditions (Bolfrey-Arku et al. 2011); however, there is limited published information on whether itchgrass is able to grow and produce seeds in water-stressed environments. Such information would help in developing integrated weed management options for drought-prone areas. The objective of this study was to determine the influence of water stress on the growth of itchgrass.

## Materials and Methods

Seeds of itchgrass were collected in January 2011 from rice fields in Los Baños, Philippines. Three to four seeds of itchgrass were placed on the soil surface in plastic pots (25 cm diameter and 25 cm height) and covered with an approximately 2-mm layer of soil. The soil (silt loam) used in this study was collected from upland fields, autoclaved, and passed through a 3-mm sieve. Immediately after sowing, the pots were irrigated to field capacity with a sprinkler system. The seedlings emerged after 3 to 4 d and were thinned to one plant per pot immediately after emergence.

Two experiments, modified from earlier studies (Chauhan and Johnson 2010; Webster and Grey 2008), were conducted to determine the effects of water stress on the growth and seed production of itchgrass. In both experiments, water stress treatments were initiated 7 d after planting (DAP). The first experiment included five irrigation treatments: 12.5, 25, 50, 75, and 100% of soil field capacity. The field capacity (1.0 L water) of pots was determined in the manner described by Steadman et al. (2004). In this experiment, the volume of water was applied at 3-d intervals. The treatments in the second experiment were five durations of water stress: 1-, 3-, 6-, 9-, and 12-d intervals. In each treatment, 100% of field capacity of water was applied. The pots in both experiments were arranged in a greenhouse as a completely randomized block design with four replications. Both experiments were repeated once and each treatment was represented by a single pot within each experiment. Minimum and maximum temperatures recorded in the greenhouse were 22 and 42 C, respectively, and photosynthetically active photon density was 1310 mol $m^{-2}$ $s^{-1}$.

In both experiments, plant height and number of tillers and leaves per plant were determined at 7-d intervals until itchgrass maturity. At maturity (63 DAP), plants removed

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* Weed Scientist, Crop and Environmental Sciences Division, International Rice Research Institute, Los Baños, Philippines. Corresponding author’s E-mail: b.chauhan@irri.org

from the pots, and the roots were gently washed to remove soil particles. The plants were separated into different parts: roots, stems, and leaves. These plant parts were placed in separate paper bags and dried in an oven at 70 C for 72 h. In addition, seeds (viable) produced by each plant were counted. Tetrazolium chloride (2,3,5-triphenyltetrazolium chloride) was used to test viability of seeds. At harvest, leaf weight ratio was determined by dividing the amount of leaf biomass to total shoot biomass (g $g^{-1}$).

Data were subjected to ANOVA. Due to lack of treatment by experimental run interactions, the results of treatments are presented as means of the two experimental runs. Transformation did not improve homogeneity; therefore, ANOVA was performed on nontransformed values (GenStat 8.0 2005). Plant height, tiller number, and leaf number data were analyzed using a three-parameter sigmoid model and a two-parameter exponential growth model. The sigmoid model was

$$y = a \Big/ \left\{ 1 + e^{[-(x-d0)/b]} \right\} \quad [1]$$

where *a* is the maximum height or leaf number; *d0* is the time to reach 50% of the final height or leaf number, and *b* is the slope at time (DAP) *x*. The exponential growth model was

$$y = ae^{bx} \quad [2]$$

where *a* is the intercept and *b* is the slope at time (DAP) *x*. For biomass, seed production, and leaf weight ratio, treatment means were separated using LSD at the 5% level of significance.

## Results and Discussion

**Effect of Field Capacity on Itchgrass Growth.** Soil moisture content (field capacity) influenced plant height and development of tillers and leaves of itchgrass (Figure 1). Plant height at different field capacities increased in a sigmoid manner over the study period (Figure 1a; Table 1). The fitted sigmoidal model predicted a maximum height of 253 cm (*a*) at 100% of field capacity whereas this was 219 cm at 50% of field capacity. Compared with 100% of field capacity, itchgrass plant height was reduced by 49 and 63% at 25 and 12.5% of field capacity, respectively. At 50% or greater field capacity, the itchgrass plants kept growing and took greater than 34 d (*d0*) to reach 50% of the maximum height at their respective field capacity (Table 1). At 25 and 12.5% of field capacity, the plant took only 23 to 26 d to reach 50% of the maximum height. This response was not due to faster growth at 25 and 12.5% of field capacity, but to no increase in height (flat curve) at 35 DAP (Figure 1a). The slope (*b*) was greater at 50 to 100% of field capacity than at 25 and 12.5% of field capacity (Table 1).

An exponential growth response was observed for itchgrass tiller number over the course of the study (Figure 1b). As estimated from the fitted model, itchgrass produced an average of 22 tillers $plant^{-1}$ at 100% of field capacity after 9 wk (Table 1). Compared with 100% of field capacity, tiller production by itchgrass was reduced by 82% at 12.5% of field capacity. Similar to the response of plant height, a sigmoidal response was observed for leaf number of itchgrass when grown at different field capacities over the study period (Figure 1c). Itchgrass plants produced a maximum number of leaves at 75% of field capacity (Table 1). The number of leaves produced by the itchgrass plants was lower at 100% of field capacity (34 leaves $plant^{-1}$) than at 75% (44 leaves $plant^{-1}$) and 50% (42 leaves $plant^{-1}$) of field capacity. The field capacity of 12.5% reduced leaf production by 56% compared with 100% of field capacity. Based on estimations from the sigmoidal model, 50% of maximum leaves were reached within 35 to 37 d (*d0*) at 50 to 100% of field capacity (Table 1). At 12.5% of field capacity, the itchgrass plant took an average of 15 d to reach 50% of maximum leaf production at this moisture content. This response was not due to early leaf production at 12.5% of field capacity but rather to lack of increase in leaf number at 35 DAP (Figure 1c).

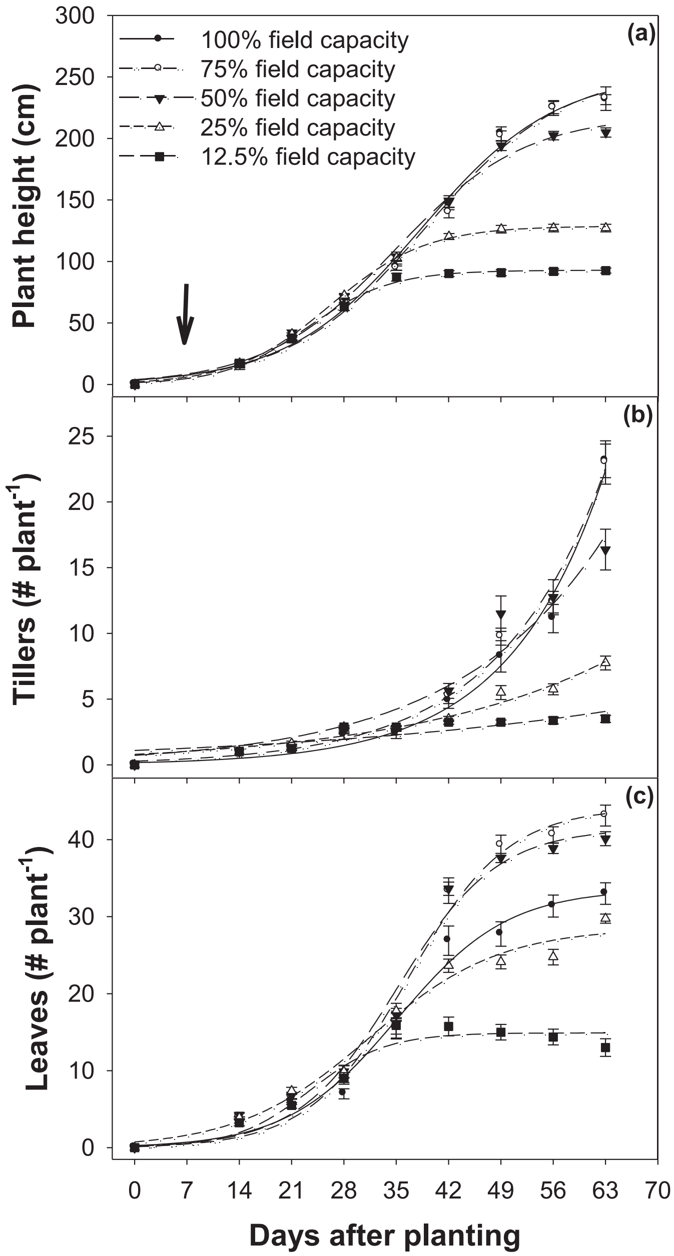


Figure 1. (a) Height, (b) tiller number, and (c) leaf number of itchgrass plants grown over 63 d after planting (DAP) at different field capacity regimes. The arrow denotes time (7 DAP) when water stress treatments were imposed and vertical bars represent standard error of means (n = 8).

Soil moisture content significantly influenced biomass of itchgrass plants (Figure 2). The weed produced the greatest biomass at 75% of field capacity and biomass was similar at 50 and 100% of field capacity. Itchgrass produced 17.5 g and

Table 1. Parameter estimates of a three-parameter sigmoidal model: $y = a / \{1 + e^{[-(x - d0) / b]}\}$ fitted to plant height and leaf number of itchgrass and parameter estimates of a two-parameter exponential growth model: $y = a e^{bx}$ fitted to tiller number of itchgrass when grown at different field capacity regimes.

| Field capacity | *a* | *d0* | *b* | $R^2$ | *a* | *d0* | *B* | $R^2$ | *a* | *b* | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plant height | | | | Leaves plant$^{-1}$ | | | | Tillers plant$^{-1}$ | | |
| % | | | | | | | | | | | |
| 100 | 253 (11)[a] | 38.3 (1.2) | 9.02 (0.85) | 0.99 | 33.6 (2.0) | 35.2 (1.6) | 7.39 (1.29) | 0.98 | 0.17 (0.05) | 0.08 (0.005) | 0.99 |
| 75 | 255 (12) | 38.9 (1.4) | 9.15 (0.94) | 0.99 | 44.2 (2.4) | 36.7 (1.4) | 6.63 (1.15) | 0.98 | 0.28 (0.07) | 0.07 (0.004) | 0.99 |
| 50 | 219 (8) | 34.8 (1.0) | 8.67 (0.79) | 0.99 | 41.5 (2.1) | 35.1 (1.4) | 6.66 (1.13) | 0.98 | 0.72 (0.25) | 0.05 (0.006) | 0.95 |
| 25 | 129 (1) | 26.1 (0.2) | 6.38 (0.21) | 0.99 | 28.5 (1.7) | 31.4 (1.8) | 8.71 (1.50) | 0.98 | 0.80 (0.16) | 0.04 (0.004) | 0.96 |
| 12.5 | 93 (1) | 23.1 (0.4) | 5.55 (0.40) | 0.99 | 14.9 (0.9) | 23.5 (1.8) | 5.04 (1.59) | 0.95 | 1.10 (0.32) | 0.02 (0.006) | 0.73 |

3.5 g aboveground and root biomass at 100% of field capacity, respectively (Figures 2a and b). Compared with 100% of field capacity, the aboveground biomass of itchgrass was reduced by 54 and 81% at 25 and 12.5% of field capacity, respectively (Figure 2a). The corresponding values for root biomass were 42 and 69%, respectively (Figure 2b). Itchgrass produced 560 and 460 viable seeds plant$^{-1}$ at 75 and 100% of field capacity (Figure 2c). Seed production was similar at 50 and 100% of field capacity. With further increase in water stress (25 and 12.5% of field capacity), seed production was sharply reduced, but itchgrass was still able to produce an average of 63 and 9 seeds plant$^{-1}$ at 25 and 12.5% of field capacity. This small amount of seeds per plant may be enough to cause heavy infestation in the next growing season. In a similar study, junglerice [*Echinochloa colona* (L.) Link] at 12.5% of field capacity produced 22% (1680 seeds plant$^{-1}$) of seeds relative to the plants at 100% of field capacity (Chauhan and Johnson 2010).

The plants grown at 100% of field capacity had lower leaf weight ratio than those grown at 25 or 12.5% of field capacity (Figure 2d). Leaf weight ratio at 12.5% of field capacity, for example, was 2.5 times greater than that at 100% of field capacity. The itchgrass plant responded with increased leaf weight ratio to the increase in water stress (or decrease in field capacity), suggesting that the weed plant under water stress conditions allocated more biomass to the leaf compared with the other shoot parts.

**Effect of Duration of Water Stress on Itchgrass Growth.** A sigmoidal response was observed for itchgrass plant height during the study period when grown at different durations of

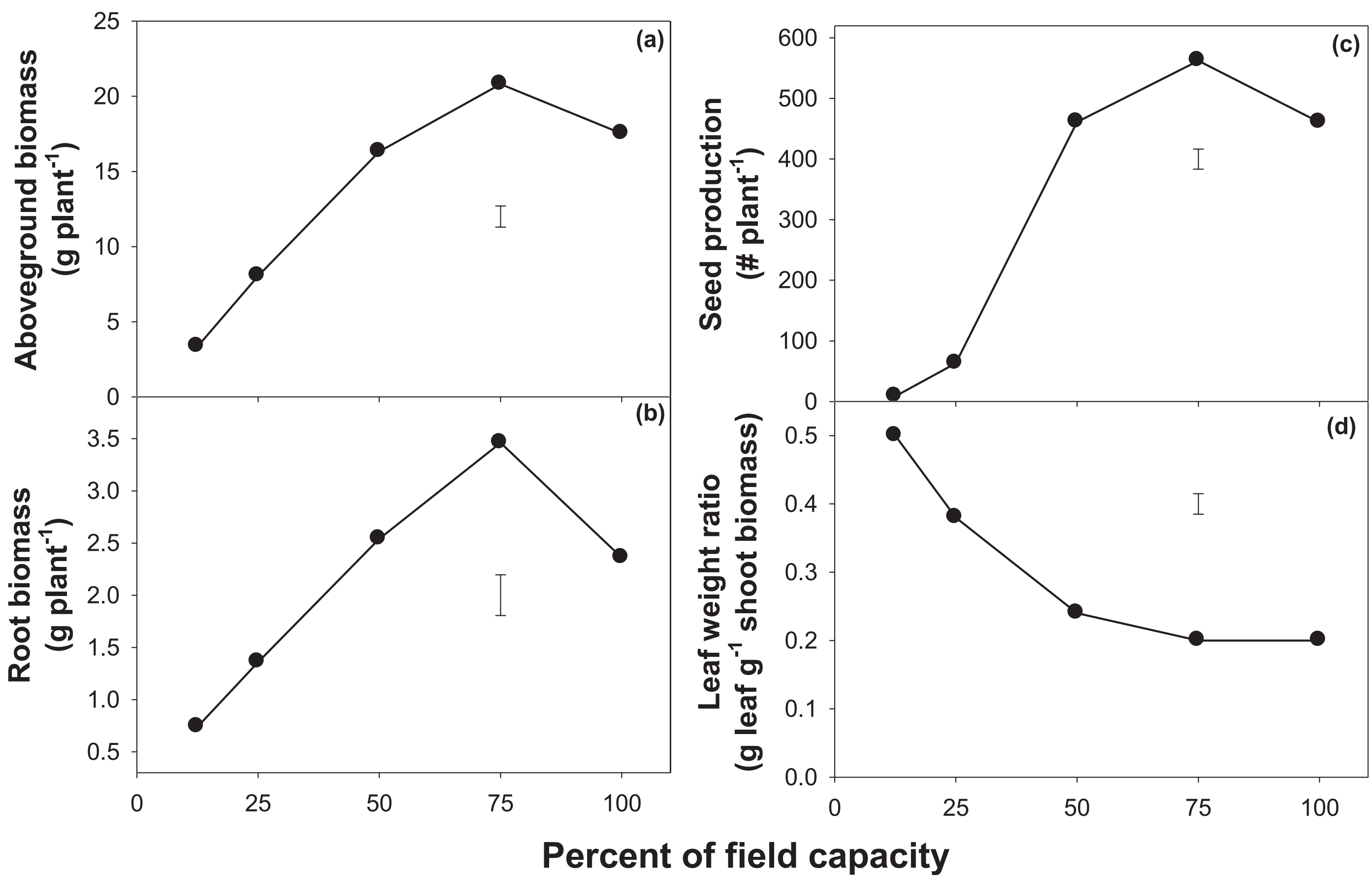


Figure 2. (a) Aboveground biomasss, (b) root biomass, (c) seed production, and (d) leaf weight ratio of itchgrass plants grown at different field capacity regimes. The vertical bar represents LSD at P = 0.05.



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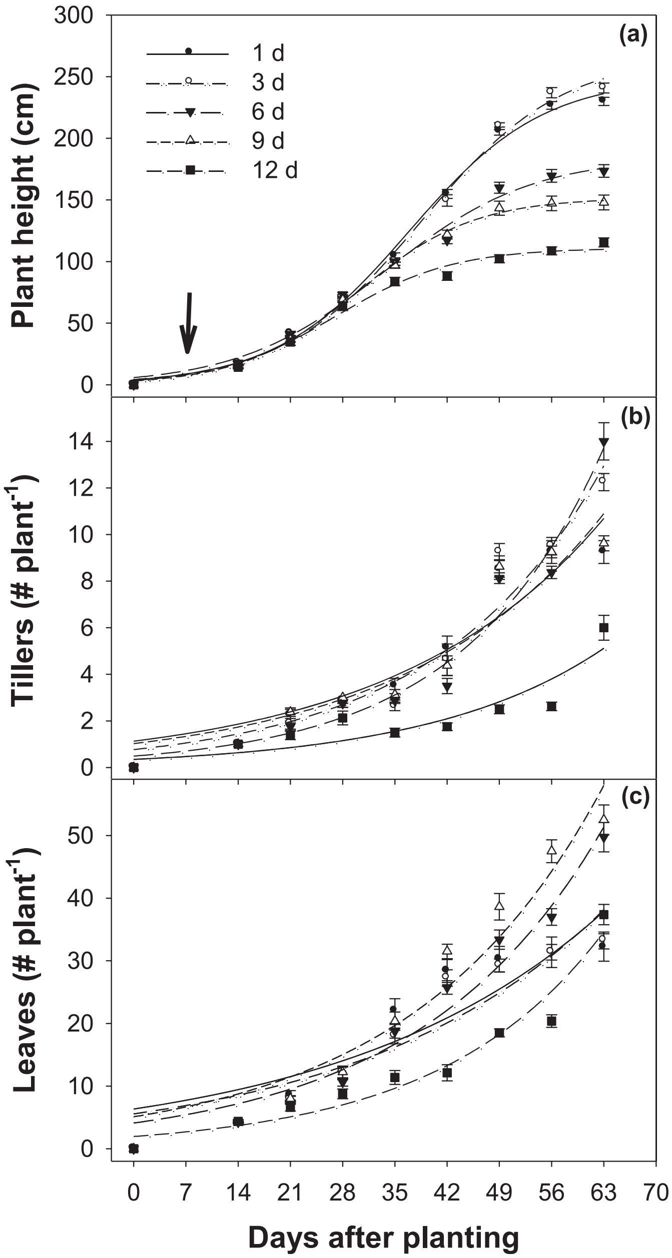


Figure 3. (a) Height, (b) tiller number, and (c) leaf number of itchgrass plants grown over 63 d after planting (DAP) at different durations (d) of water stress. The arrow denotes time (7 DAP) when water stress treatments were imposed and vertical bars represent standard error of means (n = 8).

water stress (Figure 3a). Plant height was similar between the 1-d (249 cm) and 3-d (267cm) intervals of water stress (Table 2). Intervals of 9 d and 12 d between irrigations reduced plant height by 39 and 55%, respectively, relative to daily irrigation (1 d). Itchgrass plants took 37 d (*d0*) to reach 50% of their maximum height when irrigated every day. At 9 to 12-d duration of water stress, the weed plants took 27 to 30 d to reach 50% of the maximum height.

Tillers produced by itchgrass were more or less similar when irrigation was at intervals of 1 to 9 d (Figure 3b; Table 2). Itchgrass produced five tillers plant$^{-1}$ when the interval between irrigation was 12 d. Leaf production by itchgrass showed an exponential response when grown at different water stress durations during the study period (Figure 3c). The weed produced an average of 38 leaves plant$^{-1}$ when irrigated everyday or at 3-d interval. Interestingly, intervals of 6 d and 9 d between irrigations increased leaf number per plant relative to the 1- or 3-d intervals. Itchgrass produced 35 leaves plant$^{-1}$ when irrigation was given at the 12-d interval.

The aboveground and belowground (root) biomass of itchgrass decreased with increasing duration of water stress (Figure 4a and b). The aboveground biomass of itchgrass was similar between 1-d and 3-d intervals of water stress (Figure 4a). Compared with the daily irrigation, intervals of 9 d between irrigations reduced aboveground biomass by 27% and the 12-d interval reduced aboveground biomass by 67%. The root biomass of itchgrass was similar between irrigation intervals of 1 d and 6 d (2.3 to 2.9 g plant$^{-1}$) (Figure 4b). Intervals of 12 d between irrigations reduced root biomass of itchgrass by 71% relative to daily irrigation. Itchgrass produced a similar amount of viable seeds (383 to 404 seeds plant$^{-1}$) at 1 to 6 d intervals of irrigation (Figure 4c). Compared with the daily irrigation regime, itchgrass seed production was reduced by 61% at intervals of 12 d between irrigations. However, the weed plant produced considerable amount of seeds (153 seeds plants$^{-1}$) at the 12-d interval. The leaf weight ratio value was 0.22 when the plants were irrigated daily and it was two times greater than this value when plants were irrigated at 12-d intervals. The increased leaf weight ratio with duration of water stress suggests that itchgrass allocated more biomass to the leaf as compared with the stem at high levels of water stress.

Itchgrass growth and seed production was lower at 100% of field capacity than at 75% of field capacity. These results suggest that the optimal moisture for itchgrass growth was 75% of field capacity. In field situations, the rice crop may suffer from water stress at 75% of field capacity and itchgrass may grow vigorously and compete strongly with rice. In such situations (rainfed or upland conditions), it is important to

Table 2. Parameter estimates of a three-parameter sigmoid model—$y = a / \{1 + e^{[-(x - d0) / b]}\}$ fitted to plant height of itchgrass and parameter estimates of a two-parameter exponential growth model—$y = a e^{bx}$ fitted to leaf and tiller number of itchgrass when grown under different durations of water stress.

| Duration of water stress | A | d0 | b | $R^2$ | A | B | $R^2$ | a | b | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Plant height | | | | Leaves plant$^{-1}$ | | | Tillers plant$^{-1}$ | | |
| D | | | | | | | | | | |
| 1 | 249 (9)[a] | 36.9 (1.0) | 8.99 (0.73) | 0.99 | 6.3 (2.1) | 0.03 (0.006) | 0.83 | 1.13 (0.35) | 0.04 (0.006) | 0.91 |
| 3 | 267 (13) | 38.7 (1.4) | 9.37 (0.93) | 0.99 | 5.6 (1.7) | 0.03 (0.006) | 0.88 | 0.77 (0.24) | 0.05 (0.006) | 0.95 |
| 6 | 185 (9) | 33.7 (1.6) | 9.84 (1.19) | 0.99 | 4.1 (0.9) | 0.04 (0.004) | 0.97 | 0.49 (0.15) | 0.05 (0.005) | 0.97 |
| 9 | 152 (3) | 30.1 (0.5) | 7.78 (0.44) | 0.99 | 5.1 (1.3) | 0.04 (0.005) | 0.95 | 1.03 (0.33) | 0.04 (0.006) | 0.91 |
| 12 | 111 (4) | 27.0 (1.2) | 7.87 (1.06) | 0.99 | 2.0 (0.5) | 0.05 (0.005) | 0.95 | 0.35 (0.18) | 0.04 (0.009) | 0.83 |

[a] Values in parentheses are standard error of mean.



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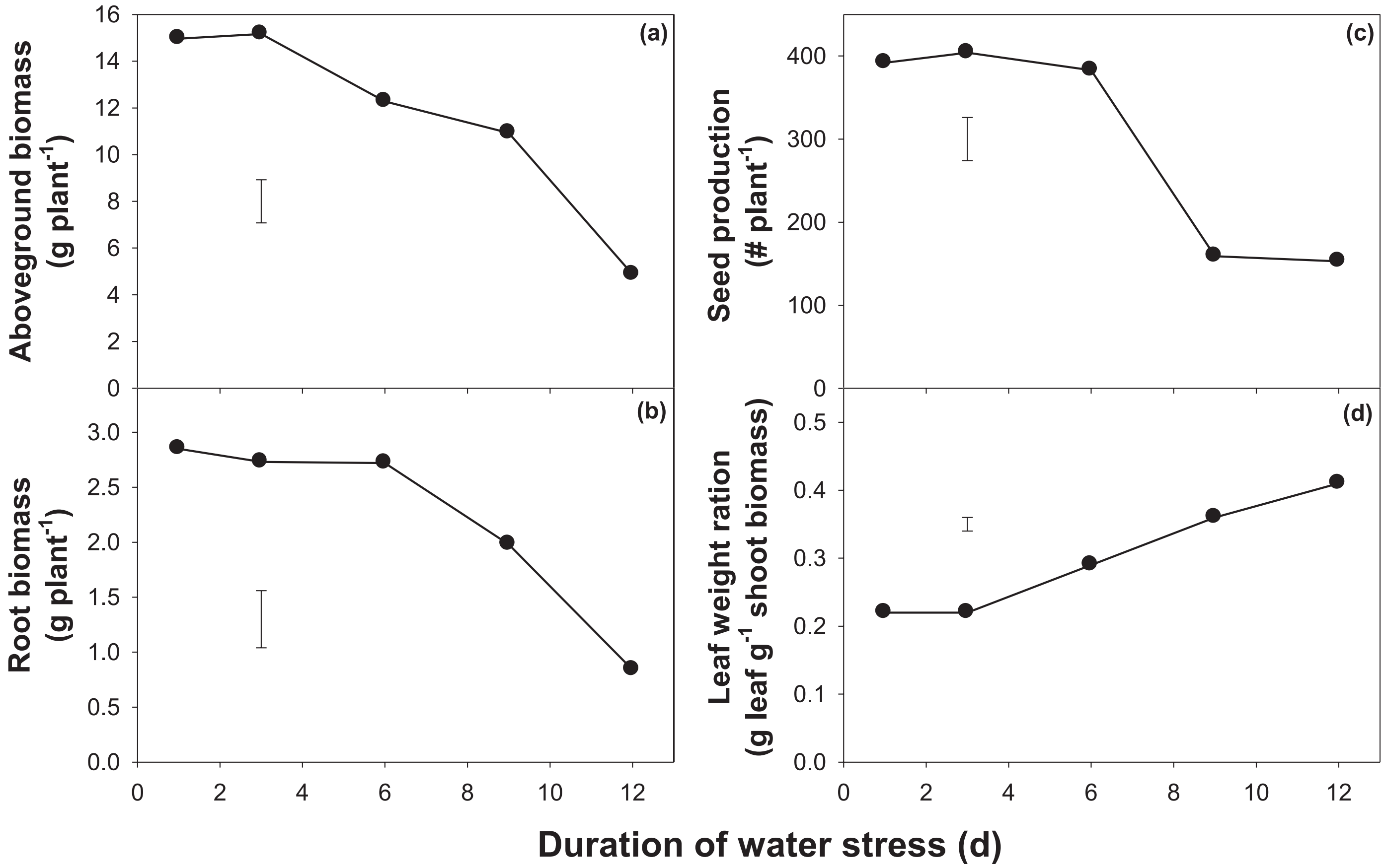


Figure 4. (a) Aboveground biomasss, (b) root biomass, (c) seed production, and (d) leaf weight ratio of itchgrass plants grown under different durations (d) of water stress. The vertical bar represents LSD at P = 0.05.

control itchgrass in the early stages of crop growth and save soil moisture for the crops. Any plant escaping after herbicide application should be removed from the field to prevent seed production.

In a previous study, rice grew best at 120 to 160% of field capacity, whereas itchgrass grew best at 85 to 90% of field capacity (Zimdahl et al. 1987). In another study, with sufficient moisture, rice was more competitive than itchgrass, but with water stress, itchgrass was more competitive than rice (Janiya and Moody 1991). In limited water supply, weeds may have higher leaf water potential than rice, suggesting that a limited amount of water in soil would benefit weeds more than rice (Moody and Janiya 1987). In an earlier study, hand weeding increased rice yield when soil moisture was adequate, but when moisture was limited, weeding did not improve rice yield (Janiya and Moody 1984). These results suggest that, even with effective weed control, high rice yields may not be obtained without adequate moisture.

Seed production is the most important trait for a weed species to ensure its persistence over a long period of time. Itchgrass seed production was reduced with increased water stress, both in terms of duration of water stress as well as field capacity. However, even a few weed seeds can cause infestation in the succeeding crops (Chauhan and Johnson 2010). The ability of the weed to produce seeds at all soil moisture conditions would help itchgrass to survive in an unpredictable environment. Different weed management strategies, such as the use of stale seedbed practice, encouraging weed seed predation, and pulling of weed seedlings escaped from herbicide application or hand weeding, should be used to target the weed seed bank in the soil and to minimize the size of the seed bank as low as possible.

In water-stressed conditions, the POST herbicides may be less effective due to less herbicide absorption. In an earlier study, the doses of different herbicides to effectively control Bengal dayflower (*Commelina benghalensis* L.) increased up to 250 times at 25% of field capacity relative to the application of the same herbicides at 100% of field capacity (Steptoe et al. 2006). In water-stressed conditions, weed plants often develop thicker leaf cuticles, which interfere with herbicide entry into the leaf (Patterson 1995). POST herbicides provide effective control of weeds when applied to actively growing plants and therefore, the timing of herbicide application is very critical in water-stressed conditions.

Future research should focus on understanding the effects of water stress on rice-weed competition and on herbicide efficacy in rice weeds. The information gained from such studies would help in developing weed management strategies in future for areas where water shortage is expected.

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