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Effect of Irrigation Threshold on Crop Performances in Wet Seeded Rice

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ABSTRACT

Decreasing availability and increasing costs of water and labour are driving researchers and farmers to find management strategies that increase input water productivity and reduce labour requirement in rice production. Wet seeding instead of transplanting greatly reduces the labour requirement for crop establishment, whereas use of alternate wetting and drying (AWD) instead of continuous flooding reduces irrigation input. However, the safe threshold for irrigating wet seeded rice (WSR), and how this varies with growth stage, has not been established. Therefore, a greenhouse experiment was conducted to determine the effects of different degrees of irrigation threshold during different crop growth stages on crop performance of WSR. This was done in greenhouse experiment in the 2011 wet season at the International Rice Research Institute, Los Baños, Philippines. In the experiments, water stresses were applied by withholding irrigation until soil water tension increased to 10, 20 or 40 kPa at 10 cm below the soil surface. Soil water tension was measured using 30 cm long gauge tensiometer installed with the center of the ceramic cup. The stresses were applied during three crop stages: 3-leaf (3L) to panicle initiation (PI), PI to flowering (FL), and FL to physiological maturity (PM). The experiment was also included a continuously flooded (CF) treatment. Stress during 3L to PI increased the time to PI (by 2 to 4 days) but reduced the duration of grain filling by 3 to 5 days, the larger values with 20 and 40 kPa thresholds. There was no effect of stress thresholds of 10 to 40 kPa during PI-FL on crop duration. Stress during grain filling reduced the duration of grain filling by 6 days for all thresholds. Stresses of 20 and 40 kPa during 3L to PI reduced green leaf and tiller density at PI, but this effect disappeared with the imposition of CF after PI. There were consistent trends for lower final biomass as the level of water deficit stress increased, and imposition of stresses of 20 and 40 kPa at any or all three stages significantly reduced biomass compared with CF. These results suggest that, for shortening the ripening period, water stress may be imposed as 10 to 20 kPa during FL to PM.

Key words: alternate wet and drying, wet seeded rice, irrigation threshold

INTRODUCTION

Lowland rice varieties are highly sensitive to soil drying, with yield generally declining once the soil starts to dry below saturation. Water stress may occur during any growth stage of the rice plant, and may follow a period when soils were flooded and anaerobic (Wade, 1999). At early stages, water stress may delay the phenological development of the rice plant (Inthapan and Fukai, 1988) and affect physiological processes like transpiration, photosynthesis, respiration and translocation of assimilates to the grain (Turner, 1986). Plant processes that depend on cell volume enhancement are particularly sensitive to water deficit. Leaf expansion and leaf gas exchange rates are two such sensitive processes. Thus, drought stress suppresses leaf expansion, tillering and midday photosynthesis (Kramer and Boyer, 1995), and reduces photosynthetic rates and leaf area due to early senescence (Nooden, 1988). Plant height is reduced by water stress during mid-tillering (Davatgar *et al*, 2009), and this might be due to inhibition of cell elongation and/or cell division.

Under rainfed conditions, drought during reproductive stage significantly reduced dry

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matter accumulation at flowering and maturity (Kumar *et al*, 2006). Drought stress at the reproductive stage significantly increased the dry matter partitioning from leaves and stems to grains. Such a lower partitioning to green leaves at maturity during reproductive stage drought was associated with a higher remobilization of assimilates to fill the grains. So, drought stress was negatively associated with grain yield and seemed to be governed by a lower plant water status due to delay in flowering. Thus the contribution of dry matter partitioning from stems and leaves to grain filling increased with the severity of drought stress, particularly in cultivars with an enhanced capacity for leaf senescence during grain filling, which acted to stabilize their grain yields under drought. The early senescence induced by a moderate water deficit during grain filling can enhance the remobilization of stored assimilates and accelerate grain filling of rice (Yang *et al*, 2001).

Rice physiological and morphological responses can be expressed as water stress by soil water tension, h (kPa). Wopereis *et al*, (1996) found a decline of relative transpiration (RT) of rice if the soil water tension dropped below -200 kPa (Wopereis *et al*, 1996).

The effect of water deficit stress at different crop stages has been the subject of many drought studies, primarily targeted at rainfed, lowland rice. These studies typically involved imposing high levels of water deficit stress by with holding irrigation for 2-3 weeks until the crop was stressed to the degree of complete leaf rolling (soil tension in excess of 500 kPa, Woopereis *et al*, 1996), or until there was significant leaf death, followed by well-watered conditions to maturity. These studies showed that periods of drought delayed phenological development, much more so (by up to about three weeks) when the stress was applied during the vegetative phase (e.g. Woopereis *et al*, 1996; Castillo *et al*, 2006; Davatgar *et al*, 2009). In these studies, applying stress during the reproductive stage (panicle initiation, booting, flowering) was more detrimental to grain yield than applying stress during the early vegetative stage, while applying the stress during mid-tillering was also detrimental. However, while it is generally agreed that the period during heading-anthesis is especially sensitive to drought stress, the review of Bouman and Tuong (2001) found no systematic trend for greater yield reduction when drought was imposed in certain development stages compared with other developmental stages. The results of De Datta *et al*, (1973a) showed that different cultivars had different responses to drought stress timing and intensity.

In irrigated rice culture, water saving technique is usually used to avoid stressing the crop to the degree that yield is reduced. Crop responses are found in many drought studies but the effect of low levels of water deficit stress on crop performances of wet seeded rice is lacking. Therefore the studies has been taken to understand the effect of threshold level on crop performances like tiller count, phenology and biomass.

MATERIALS AND METHODS

Rice was grown on a silty clay loam soil (28% sand, 34% silt, 39% clay) in 20 cm diameter, 25 cm high polyvinyl chloride pots in a greenhouse at the International Rice Research Institute (IRRI), Los Baños, Philippines (14°11′N, 121°15′E), from July to November 2011. Bulk soil was obtained from the IRRI experimental station, homogenized well with water and added to the pots to a depth of 20 cm. The soil was re-puddled using an electrical stirrer before wet seeding. The soil was slightly acidic, with medium levels of organic C, available P, exchangeable Ca and K, and total N (Table 1).

Table 1. Chemical properties of the soil used in the greenhouse experiment.

pH (1:5) in H_2O	Organic C (g. $100g^{-1}$)	Olsen P (mg. kg^{-1})	Exch. Ca (meq.$100g^{-1}$)	Exch. K (meq.$100g^{-1}$)	Total N (g. $100g^{-1}$)
6.0	1.56	39.3	15.3	0.90	0.17

The experiment was designed to evaluate the effects of different levels of water stress at different growth stages. There were three levels of water stress (10, 20 and 40 kPa soil water tension) applied at one of three growth stages: 3-leaf (3L) to panicle initiation (PI), PI to flowering (FL), and FL to physiological maturity (PM) (Table 2). In addition there was a control treatment which was continuously flooded (CF), and three treatments which had stresses of 10, 20 or 40 kPa during all the three stages. Thus, there were 13 water management treatments in a randomized complete block design.

Implementation of CF involved topping the pots up daily to a pond water depth of 2 to 3 cm. For the stress treatments, irrigation was applied whenever soil water tension increased to the threshold value (10, 20 or 40 kPa), with water added in two doses, topping up to a depth of 2 cm each time, to ensure that the soil was fully saturated to depth. Soil tension was measured using 30 cm long tensiometers installed in four replicateds pots of each treatment. The tensiometers were installed 4 cm to the side of the centre of the plant rows, and the middle of the ceramic cup was 10 cm below the soil surface. All pots of a given treatment were irrigated when the average of the 4 monitored pots reached the threshold value. All pots were kept continuously flooded at all stages other than during the stage when the 10, 20 or 40 kPa stresses were being applied.

Table 2. Water management treatments.

Treatment	Irrigation thresholdduring each crop stage[a] (kPa)		
	3L to PI	PI to FL	FL to PM
CF-CF-CF	CF	CF	CF
10-CF-CF	10	CF	CF
20-CF-CF	20	CF	CF
40-CF-CF	40	CF	CF
CF-10-CF	CF	10	CF
CF-20-CF	CF	20	CF
CF-40-CF	CF	40	CF
CF-CF-10	CF	CF	10
CF-CF-20	CF	CF	20
CF-CF-40	CF	CF	40
10-10-10	10	10	10
20-20-20	20	20	20
40-40-40	40	40	40

[a]3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded.

After the final puddling, the soil was allowed to settle for 1 day. A solution of 27 ml of fertilizer containing muriate of potash, diammonium phosphate and zinc sulphate was poured onto the soil surface 24 h before seeding, giving a basal fertilizer application rate of 40 kg K_2O ha^{-1}, 41 kg P_2O_5 ha^{-1}, 30 kg N ha^{-1} and 5 kg Zn ha^{-1}. Urea was top-dressed at maximum tillering, PI and heading at 50, 50 and 30 kg N ha^{-1}, respectively, and muriate of potash (40 kg ha^{-1}) was also applied at PI. The top dressing was done immediately prior to irrigation.

The rice variety NSIC Rc222 was pre-germinated by soaking the seeds for 24 h, draining, then incubating for 24 h prior to sowing. NSICRc222 was selected for its high yield potential under non-continuously flooded conditions. The seeds were placed on the saturated soil surface on 20 July 2011. Twelve pre-germinated seeds were sown in a single 20 cm long row along the diameter of each pot. The plants were thinned to 8 plants per pot after establishment. The pots were kept weed free by hand weeding as needed. Insects were well-controlled by applying insecticides as needed against whorl maggot, leaf and plant hoppers, stemborer, and rice bugs.

Soil water tension was measured at approximately 8 am every morning. The volume of water added to each pot was measured at each irrigation using a measuring cylinder.

The number of plants with the first leaf expanded was counted daily to determine the date of 50% emergence. The date of PI in each water stress treatment was determined by dissecting the main stem of plants in the border pots. PI was determined as the date when the panicle was visible to the naked eye (~1 mm panicle) in three out of four plants. The date of 50% anthesis for each treatment was determined as the date when anthesis had commenced in half the panicles in all pots of that treatment. The date of physiological maturity (PM) of each treatment was determined as the date when all grains in the panicles had changed to a golden colour.

Tiller density (no pot^{-1}), leaf area (cm^2 pot^{-1}) and above ground biomass (g pot^{-1}) were determined from destructive sampling of all plants in four replicates at four stages (3L, PI, FL, PM). All data were analyzed by analysis of variance (ANOVA) using GenStat V.14.1. The interaction between water stress treatment and growth stage was also analyzed using a factorial design with three levels of water stress (10, 20 and 40 kPa) and three stages of stress application (3L-PI, PI-FL, FL-PM). The comparison of treatment means was made by the least significant difference (LSD) at the 5% level of probability (p=0.05).

RESULTS AND DISCUSSIONS

As the irrigation threshold increased, the degree and duration of soil drying increased significantly during 3L-PI and FL-PM (Table 3). For example, during FL-PM, the CF-CF-10 treatment experienced 7.5 d in which soil tension exceeded 10 kPa, and on 4.5 and 3 of those days soil tension exceeded 20 and 40 kPa, respectively. During the same stage, the treatment with a 20 kPa irrigation threshold experienced 11 d with soil water tension greater than 10 kPa, and on 6.5 and 3 of those days tension exceeded 20 and 40 kPa, respectively. Similarly, the treatment with a 40 kPa irrigation threshold experienced 13 d with soil water tension greater than 10 kPa, of which 9.5 and 5.5 d had tensions greater than 20 and 40 kPa, respectively. The reason for exceeding the designed threshold for sometimes was because the decision to irrigate was based on soil tension at 8 O'clock each morning, and between then 8 am on the next morning, the soil tension had sometimes increased beyond the threshold, more often in the 10 kPa treatments. Over the whole season (3L-PM), the frequency and degree of soil drying in 40-40-40 was far greater than in any other treatment, followed by 20-20-20 and treatments with 40 kPa thresholds during 3L-PI or FL-PM (Table 4).

Effect of water stress treatment on crop performance

Phenology. There were small effects of water stress on phenology. The duration of 3L- PI ranged from 42-46 d, PI-FL from 26-28 d and FL-PM from 38-45 d. The CF treatment reached PI first, 55 d after sowing (DAS) (Table 5). PI was delayed by 2 d with irrigation at 10 kPa and by 4 d with irrigations at 20 and 40 kPa. This effect was carried through to a slight delay in anthesis (by 1 d with 10 kPa from 3L-PI and by 3 d with 20 and 40 kPa). There was little effect of water stress between PI and FL on the duration of PI to FL, with a delay of 1 d in the most extreme (40 kPa) treatment. There was no effect of water stress during PI-FL on the date of maturity, however stresses of 10, 20, and 40 kPa at 3L-PI reduced the grain filling period by 3, 5 and 5 d, respectively, and as a result these treatments matured 2 d

Table 3. Water deficit indices (the number of days soil water tension exceeded the specified value) of the water stress treatments during each growth stage.

Treatment	Number of days the value of soil tension (kPa) was exceeded							
	3L – PI				PI – FL			
	<10	≥10	≥20	≥40	<10	≥10	≥20	≥40
10	36.5	7.5	0.5	0.0	23.0	4.0	2.0	1.5
20	38.0	8.0	4.0	1.0	22.8	4.3	2.8	1.0
40	32.0	14.0	9.5	5.5	24.0	4.0	3.0	1.3
10-10-10	38.8	5.3	1.5	0.5	23.5	2.5	2.3	1.5
20-20-20	40.8	5.3	2.5	1.0	22.0	4.0	3.3	2.0
40-40-40	34.0	12.0	7.5	3.8	19.8	6.3	4.5	3.3
$LSD_{0.05}$	3.05	3.05	2.6	1.62	ns	ns	ns	ns

	FL-PM			
	<10	≥10	≥20	≥40
10	31.5	7.5	4.5	3.0
20	28.0	11.0	6.5	3.0
40	26.0	13.0	9.5	5.5
10-10-10	36.3	3.8	2.8	1.5
20-20-20	33.3	4.8	3.3	2.3
40-40-40	29.5	8.5	6.3	4.8
$LSD_{0.05}$	3.9	3.9	3.9	2.7

3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded. Irrigation threshold applied during 3L-PI, PI-FL or FL-PM; data are for the threshold applied during that stage.

Table 4. Water deficit indices (the number of days soil water tension exceeded the specified value) of the water stress treatments during each growth stage.

Treatment	Number of days the value of soil tension (kPa) was exceeded during 3L-PM			
	3L-PM			
	<10	≥10	≥20	≥40
10-CF-CF	104.5	7.5	0.5	0.0
20-CF-CF	104.0	8.0	4.0	1.0
40-CF-CF	98.0	14.0	9.5	5.5
CF-10-CF	110.0	4.0	2.0	1.5
CF-20-CF	109.8	4.3	2.8	1.0
CF-40-CF	110.0	4.0	3.0	1.3
CF-CF-10	100.5	7.5	4.5	3.0
CF-CF-20	97.0	11.0	6.5	3.0
CF-CF-40	95.0	13.0	9.5	5.5
10-10-10	98.5	11.5	6.5	3.5
20-20-20	96.0	14.0	9.0	5.3
40-40-40	83.3	26.8	18.3	11.8
$LSD_{0.05}$	3.5	3.5	3.2	2.2

3L=3 leaf stage, PM=physiological maturity, CF=continuously flooded. Irrigation threshold applied during 3L-PM, data are for the threshold applied during that stage.

earlier than the CF treatment. Stresses of 10, 20 and 40 kPa during FL-PM reduced the grain filling period and time to maturity by 6 d. Applying the stresses at all three stages delayed flowering by 1 to 3 d, and advanced PM by 4 days at all stress levels. As a result, the grain filling period was reduced from 45 d in the CF control to 40 d with a 10 kPa threshold from 3L-PM, and to 38 d with 20 or 40 kPa thresholds.

Leaf area. Green leaf area increased approximately 10-fold between the 3L stage and PI (Table 6). At PI, leaf area with irrigations at 20 and 40 kPa during 3L-PI was significantly lower than with irrigation at 10 kPa. At FL, there was a consistent trend for about 25% lower leaf area for all tension-based treatments during either or both growth stages compared to the CF treatment, but there were no significant differences. There were relatively small changes in leaf area between PI and FL, but leaf area at maturity was much reduced in all treatments. The reduction was least in the treatments stressed during FL-PM only. At PM, leaf area in the later treatments had significantly higher (approximately double) than the treatments stressed only at 3L-PI or PI-FL. There were no trends and no significant differences in leaf area between the different levels of water stress within each growth stage. However, when the same stress was applied throughout 3L-PM, there was a trend for increasing leaf area at maturity with increasing stress, and leaf area of the 40 kPa treatments was significantly higher than that of the 10 kPa treatment.

The results of the 2-factor analysis showed that there was no significant interaction between degree of water stress and stage during which it was applied on leaf area (Table 7). Increasing the irrigation threshold from 10 to 20 or 40 kPa during 3L-PI significantly reduced leaf area at PI, but there were no significant effects of degree of stress on leaf area at FL or PM. Deferring the application of the stress to FL-PM resulted in a much higher leaf area at maturity than applying it at earlier stages.

Table 5. Time (DAS) of key development stages as affected by water stress treatment during different growth stages.

Treatment	3L	PI	FL	PM
CF-CF-CF	13	55	82	127
10-CF-CF		57	83	125
20-CF-CF		59	85	125
40-CF-CF		59	85	125
CF-10-CF			82	127
CF-20-CF			82	127
CF-40-CF			83	127
CF-CF-10				121
CF-CF-20				121
CF-CF-40				121
10-10-10		57	83	123
20-20-20		59	85	123
40-40-40		59	85	123

3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded

Table 6. Green leaf area as affected by water stress treatment during different growth stages in comparison with continuous flooding.

Treatment	Leaf area (cm^2. pot^{-1})			
	3L	PI	FL	PM
CF-CF-CF	38	4145	4466	573
10-CF-CF		4418	3327	655
20-CF-CF		3047	3507	749
40-CF-CF		3606	3368	726
CF-10-CF			3114	577
CF-20-CF			3388	545
CF-40-CF			3093	552
CF-CF-10				1194
CF-CF-20				1140
CF-CF-40				1418
10-10-10			3172	716
20-20-20			2847	964
40-40-40			2817	1090
$LSD_{0.05}$		591	ns	313

Data were analyzed by RCBD, 3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded.

Table 7. Green leaf area as affected by water stress treatment during different growth stages.

Treatment	Leaf area (cm^2. pot^{-1})		
	PI	FL	PM
Water stress (W, kPa)			
10	4418	3221	809
20	3047	3448	811
40	3606	3230	898
$LSD_{0.05}$	593	ns	ns
Crop stage (S)			
3L-PI	3690	3401	710
PI-FL		3198	558
FL-PM			1251
$LSD_{0.05}$	n/a	ns	183
S×W			
$LSD_{0.05}$	n/a	ns	ns

Data were analyzed by factorial without the CF-CF-CF, 10-10-10, 20-20-20 or 40-40-40 treatments. PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded. n/a = not applicable.

Tiller production and mortality

At the 3-leaf stage, tillering had not commenced and there were 8 plants. pot^{-1}. By PI there was an average of 3.4 to 5 tillers. plant^{-1}, depending on treatment. There was considerable tiller mortality between PI and FL, at around 40-50% in all treatments except for the treatment, which received 40 kPa during 3L-PI which had a lower tiller mortality (30%). At all stages from PI to maturity there was a consistent trend for lower tiller density in treatments that had been stressed during the 3L-PI stage, with significantly lower tiller count in the 20 and 40 kPa treatments at PI and FL than in the CF treatment (Table 8). This was a result of lower tiller production during 3L-PI in the 20 and 40 kPa treatments, and of higher tiller mortality between PI and FL in the treatment stressed at 10 kPa between 3L and PI. There was no effect of water stress during PI-FL alone on tiller count at FL. As a result, the number of tillers at FL in treatments with water stress during 3L-PI was significantly lower than that of respective treatments stressed during PI-FL alone. There was no effect of stress during FL-PM alone on tiller count. At PM there were no significant treatment effects on tiller count, and no consistent trends other than lower tiller density with application of 20 and 40 kPa stresses during all three stages.

The factorial analysis showed no significant interaction between water stress treatment and the stage at which it was applied on tiller count (Table 9). At PI, tiller count decreased significantly as the stress increased from 10 to 20 to 40 kPa. However, there was no significant effect of increasing water stress on tiller count at FL or PM. Applying the stresses at 3L-PI resulted in significantly lower tiller density at FL than applying the stresses from PI-FL, but there was no effect of application stage of the stresses on tiller density at PM.

Table 8. Tiller count as affected by water stress during different growth stages in comparison with continuous flooding.

Treatment	Tiller count (no. pot^{-1})			
	3L	PI	FL	PM
CF-CF-CF	8.0	37.8	24.0	23.5
10-CF-CF		39.5	20.5	17.8
20-CF-CF		32.0	18.0	19.3
40-CF-CF		26.8	18.8	19.8
CF-10-CF			26.0	20.8
CF-20-CF			25.5	22.8
CF-40-CF			24.5	19.5
CF-CF-10				21.5
CF-CF-20				21.0
CF-CF-40				22.5
10-10-10			20.3	19.3
20-20-20			16.3	17.3
40-40-40			16.5	16.8
$LSD_{0.05}$		5.0	4.3	ns

The experiment was designed following RCBD. 3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded n/a = not applicable.

Table 9. Tiller count as affected by water stress treatment during different growth stages.

Treatment	Tiller count (no. pot^{-1})		
	PI	FL	PM
Water stress (W, kPa)			
10	40	23	20
20	32	22	21
40	27	22	21
$LSD_{0.05}$	4	ns	ns
Crop stage (S)			
3L-PI	33	19	19
PI-FL		25	21
FL-PM			22
$LSD_{0.05}$	n/a[B]	3	ns
S×W			
$LSD_{0.05}$	n/a[B]	ns	ns

Data were analyzed following factorial design without the CF-CF-CF, 10-10-10, 20-20-20 or 40-40-40 treatments. PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded. n/a = not applicable.

Biomass

At all stages there was a trend for decreasing total biomass with increasing water stress during the 3L-PI stage, with significantly lower biomass of the 40 kPa treatment compared with CF at FL, and of the 20 and 40 kPa treatments at PM (Table 10). There was no significant effect of stress from PI-FL on biomass at FL, but at PM all treatments had significantly lower biomass than CF. Applying the stresses during FL-PM resulted in significantly lower final biomass with stresses of 20 and 40 kPa compared with CF. At PM, biomass of treatments irrigated at 20 or 40 kPa at any or all growth stages (except 20 kPa during FL-PM only) was significantly lower than biomass of the CF treatment. The treatments exposed to 20 and 40 kPa from 3L-FL had significantly lower biomass than the CF-CF treatment at FL, and stresses of 20 and 40 kPa from 3L-PM had significantly lower biomass than CF and 10-10-10 from 3L-PM at PM. There was a consistent trend for lower biomass at FL and PM when stresses of 20 and 40 kPa were applied at all stages compared to a single stage, however, the differences were never significant.

There were no significant interactions between the degree of water stress and the stage at which it was applied on biomass (Table 11). There were no significant differences between stresses of 10, 20 and 40 kPa on biomass at PI or FL, but at PM biomass of the 20 and 40 kPa treatments was significantly lower than biomass of the 10 kPa treatment. There was no effect of application time of the stresses on biomass at FL or PM.

Table 10. Biomass production as affected by water stress imposed at different growth stages compared to continuous flooding.

Treatment	Biomass (g pot^{-1})			
	3L	PI	FL	PM
CF-CF-CF	0.1	30.0	57.4	93.0
10-CF-CF		29.0	53.3	83.6
20-CF-CF		21.0	52.9	72.5
40-CF-CF		23.3	40.3	67.1
CF-10-CF			51.6	77.1
CF-20-CF			55.5	70.4
CF-40-CF			45.5	69.0
CF-CF-10				95.9
CF-CF-20				78.7
CF-CF-40				67.4
10-10-10			45.4	87.6
20-20-20			36.2	67.4
40-40-40			38.5	59.4
$LSD_{0.05}$	11	ns	13.2	16.7

The experiment was designed following RCBD. 3L=3 leaf stage, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded.

Table 11. Biomass production as affected by irrigation treatment at different growth stages.

Treatment	Biomass (g pot^{-1})		
	PI	FL	PM
Water stress (W, kPa)			
10	27.0	52.3	85.5
20	21.3	51.3	73.9
40	24.2	47.2	67.8
$LSD_{0.05}$	Ns	ns	9.8
Crop stage (S)			
3L-PI		48.5	74.4
PI-FL		52.1	72.2
FL-PM			80.7
$LSD_{0.05}$	n/a	ns	ns
S×W			
$LSD_{0.05}$	n/a	ns	ns

Data were analyzed following factorial design without the CF-CF-CF, 10-10-10, 20-20-20 or 40-40-40 treatments.
3L=3 leaf, PI=panicle initiation, FL=flowering, PM=physiological maturity, CF=continuously flooded. n/a = not applicable.

CONCLUSIONS

There were small effects of water stress on phenology. The duration of 3L-PI ranged from 42-46 d, PI-FL from 26-28 d and FL-PM from 38-45 d. Green leaf area increased approximately 10-fold between the 3L stage and PI. At PI, leaf area with irrigation at 20 and 40 kPa during 3L-PI was significantly lower than with irrigation at 10 kPa. At FL, there were no significant differences of leaf area between the water stress treatments. At PM, leaf area in the later treatments had significantly higher (approximately double) leaf area than the treatments stressed only at 3L-PI or PI-FL.

At the 3-leaf stage, tillering had not commenced and there were eight plants pot^{-1}. By PI there was an average of 3.4 to 5 tillers. plant^{-1}, depending on treatment. There was considerable tiller mortality between PI and FL, at around 40-50% in all treatments except for the treatment which received 40 kPa during 3L-PI which had a lower tiller mortality (30%). The factorial analysis showed no significant interaction between water stress treatment and the stage at which it was applied on tiller count. At all stages there was a trend for decreasing total biomass with increasing water stress during the 3L-PI stage. There was no significant effect of stress from PI-FL on biomass at FL, but at PM all treatments had significantly lower biomass than CF. There were no significant interactions between the degree of water stress and the stage at which it was applied on biomass. There were no significant differences between stresses of 10, 20 and 40 kPa on biomass at PI or FL, but at PM biomass of the 20 and 40 kPa treatments was significantly lower than biomass of the 10 kPa treatment.

RECOMMENDATIONS

The degree of soil drying and the number of drying events are important determinants of crop response to soil drying, and this needs to be considered in setting the irrigation threshold for safe AWD.

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