DOI: https://doi.org/10.4038/ta.v167i2.72 *Tropical Agriculturist, Vol.167 (2), 2019*

Agronomic practices to enhance crop establishment, grain yield and weed suppression in flooded-direct seeded rice

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Abstract

The ability of rice to germinate and develop seedlings under water logged conditions is defined as anaerobic germination tolerance of rice (AG-tolerance) and can be combined with direct seeded rice (flooded-DSR) to suppress weeds and to increase crop stand in flood prone rice growing areas. However, success of flooded-DSR depends on agronomic practices that are being carried out. Therefore, two experiments were conducted at the Rice Research and Development Institute, Batalagoda, Sri Lanka to evaluate flood water heights at sowing and seeding rate on crop establishment, panicle density and grain yield and weed biomass in flooded-DSR. In experiment 1 (*Maha* 2014/15 and *Yala* 2015), two water levels (5 cm, saturated) and three seeding rates (60, 80, 100 kg/ha) were evaluated. The experiment 2 was conducted in *Maha* 2015/16 and *Maha* 2016/17 to evaluate three water levels (5 cm, 2.5 cm, saturated), and three different seeding rates (100, 125, 150 kg/ha). In all experiments, crop establishment reduced substantially in 5 cm flooding compared to saturated condition. When weeds were controlled, panicle density and grain yield increased in saturated condition compared to 5 cm flooding while under no weed control, 2.5 cm flooding gave the highest panicle density and grain yield with reduction of weed growth by 31-58% compared to saturated condition. Seeding rates ≤ 80 kg/ha reduced panicle density and grain yield under flooding. However, seeds sown ≥125 kg/ha rates had no effect to increase panicle density or grain yield. Therefore, adjusting flood water height at 2.5 cm at sowing and using 100 kg/ha seeding rate can optimize crop establishment, panicle density and grain yield with considerable reduction in grasses and sedges in flooded-DSR.

Key words: Anaerobic germination tolerance, Flooded-direct seeded rice, Seeding rate, Water height

Introduction

Direct Seeded Rice (DSR) represents more than 90% of the total rice cultivation in Sri Lanka due to low labor requirement and low cost of cultivation. However, the saturated moisture condition at sowing leads to high weed competition in DSR (Abeysekara *et al*., 2017). Use of herbicide to control weeds in DSR has increased during the last 5 decades. Nevertheless, improper application practices which leads to development of herbicide resistances is a widespread problem in Sri Lanka (Abeysekara *et al*., 2017). Therefore, alternative approaches to manage weeds in DSR using no or minimum amount of herbicides is important.

Rice is being adapted to submerged environments. Ability of some rice varieties to germinate and develop seedlings under water logged condition is known as Anaerobic Germination tolerance (AG-tolerance) of rice (Ella *et al*., 2011). The Quantitative Trait Loci (QTLs) responsible for AG-tolerance have been identified and cloned into some improved rice varieties (Angaji *et al*., 2010). Combination of AG-tolerance in rice with DSR can be defined as AG-tolerant DSR or flooded-DSR. The AG-tolerant ability of rice together with suitable agronomic practices can enhance crop establishment and weed suppression in DSR because of flooding during germination can effectively reduce the germination of most of the weeds including grasses and sedges (Ella *et al*., 2011; Sen *et al*., 2002). Most of the low-lying rice growing areas of the Wet zone of Sri Lanka are vulnerable to heavy rains and flooding during the monsoon seasons (Ranawake *et al*., 2014). Hence, flooded-DSR can be also practiced to achieve a high crop stand in paddy fields of flood prone areas.

Combination of genetic tolerance to AG with proper seed-handling strategies, seedbed management options and good agronomic practices are essential for efficient crop establishment and successful implementation of this technology (Ella *et al*., 2011) because QTLs for AG is only responsible for 18-34% phenotypic variability (Ismail *et al*., 2009). Adjusting water depth to about 5 cm coupled with healthy seeds of AG tolerant rice genotypes was identified as suitable to suppress the growth of most weeds without much reduction in seedling establishment (Ella *et al*., 2010). Manipulation of seeding density also decreases weed pressure because a high number of seedlings develop canopy rapidly and consequently suppresses weeds more effectively (Anwar *et al*., 2012). Zhao *et al*. (2007) reported that higher seeding rate of 500 seeds/m^2 reduced weed growth and increased crop yield compared to a lower seeding rate of 300 seeds m^2 under aerobic soil conditions.

In Sri Lanka, few studies have been conducted on AG-tolerance of rice (Herath *et al*., 2010; Illangakoon *et al*., 2016; Magneschi *et al*., 2008), and they were mainly focused on physiological aspects and screening of rice varieties for AG-tolerance. However, testing management practices suitable to AG-tolerance is also important in the field condition since the crop establishment, growth and yield of flooded-DSR are highly influenced by various environmental conditions and handling practices. Illangakoon *et al*., 2018 highlighted the importance of using higher seeding rates ≥100kg/ha and reducing flood water height at sowing <5 cm to enhance the performance of flooded-DSR using AG tolerant rice varieties. Therefore, this study was conducted to identify a suitable flood water height and a seeding rate to enhance crop establishment, panicle density, and grain yield while minimizing the weed growth under flooded-DSR.

Materials and methods

The study was conducted during *Maha* 2015/16 and *Maha* 2016/17 seasons in a split plot design with 3 replicates at the Rice Research and Development Institute (RRDI), Batalagoda. Three water levels, (i) 5 cm flood water at sowing for 7 days, (ii) 2.5 cm flood water at sowing for 7 days, and (iii) saturated soil moisture at sowing for 7 days were assigned as the main plots. Three seeding rates, 100 kg/ha (the recommended seeding rate for wet-DSR by the DOA, Sri Lanka), 125 kg/ha and 150 kg/ha were assigned as sub plots (18 m^2). The experiment was conducted using Bg 300 (a popular Sri Lankan rice variety having moderate AG-tolerance ability as identified by Illangakoon *et al*., 2016 under screen-house condition).

In both seasons, robust seeds (fully filled, un-damaged, no discoloration) were selected and germination test was performed to ensure >85% germination. Experimental field was ploughed twice, harrowed and leveled as recommended for the wet-DSR by the DOA, Sri Lanka. Bunds with 10 cm height were made around each plot and marked pegs were established in flooded plots to maintain the water level at specified water height. In each plot, outlets were prepared to remove excess water. In flooded treatments, plots were filled with irrigation water up to the specified water height before sowing while the other plots were kept under saturated soil moisture conditions. Pre-germinated seeds (soaked in water for 24h and incubated for 48h) were sown ensuring uniform seed density for each seeding rate. Water heights of the flooded plots were maintained by adding and removing irrigation water when necessary. After 7 days of sowing, both flooded and saturated plots were maintained under irrigated condition as in wet-DSR. Fertilizer application was done as recommended for irrigated rice in dry/intermediate zone (DOA, 2013). All other agronomic practices were done as recommended by the DOA, Sri Lanka. All the plots were kept un-weeded during the whole cropping season.

Crop establishment measured by seedling density at 3 Weeks After Sowing (WAS), weed density at 4 WAS, weed biomass at 6 WAS, panicle density and grain yield were recorded. The Weed Control Efficiency (WCE) and Weed Control Index (WCI) were also determined by using the formulae proposed by Mani *et al*. (1973). Experimental data were analyzed using SAS computer package (Version 9.1). All qualitative data (seedling, panicle and weed density) were analyzed using categorical data analysis while ANOVA was performed to analyze grain yield and weed biomass. Mean separation was done using LSD at $p=0.05$.

Results and discussion

Weather condition during the experimental period

Weather data of the RRDI experimental site during the study period are given in Table 1. Accordingly, *Maha* 2015/16 season was characterized with relatively high rainfall, low temperatures and sunshine compared to *Maha* 2016/17. The total rainfall received during *Maha* 2015/16 (1200 mm) was considerably higher than that received in *Maha* 2016/17 season (454 mm).

Crop establishment

Water level at sowing and seeding rate significantly influenced ($p<0.05$) rice crop establishment in both seasons while the interaction effect was only significant ($p<0.05$) in *Maha* 2015/16. Crop establishment under 2.5 cm and 5 cm flooding heights in *Maha* 2015/16 was considerably lower compared to those in *Maha* 2016/17 (Figure 1). The heavy rainfall and low sunshine received during the month of October 2015 (sowing period) compared to October 2016 (Table 1) might have reduced the seedling emergence in *Maha* 2015/16.

Table 1. Rainfall, temperature and sunshine of the experimental site, RRDI, Batalagoda during *Maha* 2015/16 and *Maha* 2016/17

Season	Month	Rainfall (mm)	Temperature (°C)		Sunshine (h)
			Maximum	Minimum	
Maha 2015/16	September	95.1	31.3	23.9	6.1
	October	303.2	31.3	23.7	5.6
	November	385.3	30.5	22.2	4.7
	December	304.0	30.2	22.8	5.3
	January	0.0	30.4	21.5	8.9
	February	112.0	30.9	21.1	8.0
Maha 2016/17	September	0.7	31.9	24.5	7.2
	October	139.0	32.0	23.1	7.4
	November	233.4	30.3	22.5	4.8
	December	65.0	30.4	21.7	8.0
	January	3.2	30.7	21.4	8.1
	February	12.3	31.8	21.5	7.8

Source: RRDI, Batalagoda

Flooding reduced the crop establishment by 19% and 28% (average of *Maha* and *Yala* seasons) at 2.5 cm and 5 cm, respectively compared to the crop establishment of saturated water level (Figure 1). These results agreed with Chamara *et al*. (2018) where they reported that the seedlings emergence of rice at 2 cm of flooding was 28% lower than that under saturated condition while this reduction reached up to 37% when flooding depth increased to 5 cm. Ella *et al*. (2010) also stated that seedling survival can decrease about 5% and 18% when flood water depth was increased from 2-4 cm to 5-7 and 8-10 cm, respectively in field conditions. Seedling emergence can decrease considerably under water even in AG-tolerant genotypes due to limited O_2 and light transmission (Ella *et al*., 2010), and the low seedling density recorded at 5 cm flooding height could also be due to those reasons.

The crop establishment increased with increasing seeding rate (Figure 1). However, in *Maha* 2015/16, seedling densities were the same when 125 and 150 kg/ha of seeds were sown at 5 cm and 2.5 cm flooding heights. The seedling density recorded at 100 kg/ha of seeding rate in saturated water level (300 m^2) was not achieved by using 125 or 150 kg/ha of seeding rates either in 5 or 2.5 cm flooding heights in the same season. However, in *Maha* 2016/17, when seeds were sown at 150 kg/ha rate in 5 cm flooding or under all seeding rates in 2.5 cm of flooding, seedling densities recorded were >300/m^2. Thus, a satisfactory crop establishment under flooded-DSR can be achieved by maintaining flood water height at 2.5 cm and sowing seeds at 100 kg/ha (the minimum possible seeding rate).

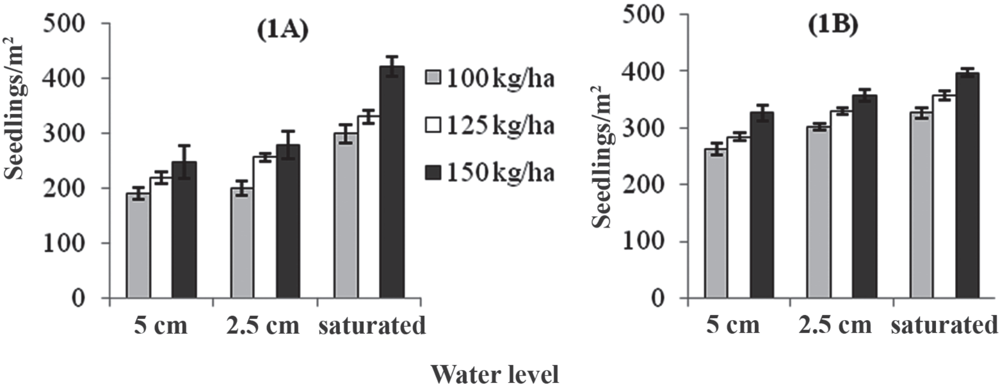

Figure 1. Seedling densities at different water levels and seeding rates at sowing (1A) *Maha* 2015/16 and (1B) *Maha* 2016/17. Vertical lines indicate the standard error of the means

Panicle density

All factors significantly influenced ($p<0.05$) on panicle density in both seasons. The panicle densities recorded under saturated water levels were lower than those at 5 cm and 2.5 cm flooding heights in both seasons (Figure 2). This could be due to high weed pressure experienced throughout the cropping season under saturated condition compared to flooded condition. The highest panicle densities were recorded at 2.5 cm of flooding height, due to high seedling emergence compared to 5 cm of flooding and lower weed competition compared to saturated condition. On average, panicle density recorded at 2.5 cm flooding was about 21% higher than that of the saturated condition.

None of the seeding rates produced panicle density >300/m^2 in *Maha* 2015/16 while panicle densities recorded in all seeding rates in *Maha* 2016/17 were higher than those recorded in *Maha* 2015/16 (Figure 2). This could be attributed to high seedling densities recorded in *Maha* 2016/17. All the seeding rates in 2.5 cm flooding and 125 and 150 kg/ha seeding rates in 5 cm of flooding produced panicle density >300/m^2 in *Maha* 2016/17. In DSR, 300-350/m^2 of panicle numbers is considered to be the optimum for a maximum productivity (Shaobing *et al*., 2008). These results indicate that the reduction of water height <5 cm is the most important management option to obtain optimum panicle density under flooded-DSR. Based on the results of the two seasons, sowing of 100 kg/ha of seeds in 2.5 cm of flood water height can be recommended for flooded-DSR to optimize the panicle density. However, 5 cm of flooding at sowing with 100 kg/ha seeding rate is also possible to practice only if environmental conditions are favorable during the time of sowing.

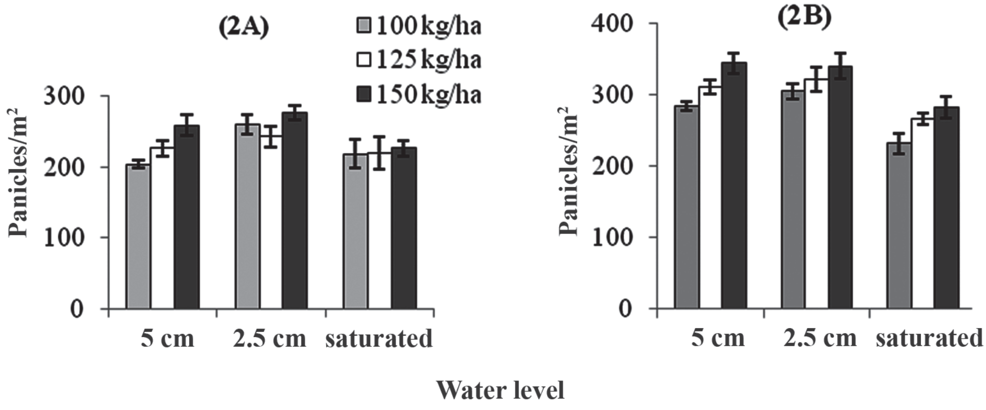

Figure 2. Panicle densities under flooded and saturated conditions at different seeding rates. (2A) *Maha* 2015/16 and (2B) *Maha* 2016/17. Vertical lines indicate the standard error of the means

Grain yield

Grain yield varied only with water level (p<0.05), but the seeding rate or the interaction showed no influence on that of both *Maha* 2015/16 and 2016/17 seasons. In *Maha* 2016/17, a relatively high grain yield was recorded compared to *Maha* 2015/16, and this could be due to high panicle densities produced in *Maha* 2016/17 season (Table 2). Among the three flooding heights evaluated, the lowest grain yield was recorded under saturated water level. The grain yields recorded at 5 cm and 2.5 cm of water heights did not vary, and the average yield reduction in saturated water level due to weed competition was about 38% compared to those under flooding. High weed competition can result low tiller and panicle densities leading to poor yield under saturated condition. Considering these results, maintaining water height up to 2.5 cm at sowing with 100 kg/ha of seeding rate can be recommended to optimize the yield under flooded-DSR.

Table 2. Grain yield (*mean±se*) under different water levels in *Maha* 2015/16 and *Maha* 2016/17

Water level	Grain yield (mt/ha)	
	***Maha* 2015/16**	***Maha* 2016/17**
5 cm	4.27 ± 0.06^{a} *	5.44 ± 0.11^{a}
2.5 cm	4.24 ± 0.06^{a}	5.84 ± 0.10^{a}
Saturated	3.10 ± 0.10^{b}	4.09 ± 0.11^{b}
CV %	16.5	13.5

** means followed by the same superscript letter within a column are not significantly different at p=0.05*

Weed biomass

Weed biomass was greatly determined by water level ($p<0.001$) in both trials. Broad leaf weeds were the most abundant at 5 cm and 2.5 cm water heights while the grasses were the most abundant at saturated condition (Table 3). Results of this study was also in agreement with Bhagat *et al*. (1996) who reported that broad leaves produced high biomass than grasses and sedges in flooding regimes, while in saturated condition, the results were opposite. The weed biomass at 5 cm water level was 42% and 62% less than that of the saturated condition, respectively in *Maha* 2015/16 and 2016/17 seasons. This reduction was 31% and 58% under 2.5 cm flooding, respectively in the same seasons. Ella *et al*., (2010) reported that shallow water heights tend to increase weed growth while a water height of 5 cm coupled with healthy seeds of AG-tolerant genotypes can probably suppress the growth of most weeds without much reduction in seedling establishment. Most of the weed seeds including grasses and sedges cannot germinate and complete their life cycles because of low oxygen availability due to the anaerobic condition created in flooding. Further, water acts as a pre-emergent herbicide in controlling weeds (Juraimi *et al*., 2012; Leeper, 2010). However, flooding during germination does not have any effect on control of aquatic weeds (Ella *et al*., 2010).

Among the weeds present in DSR in Sri Lanka, grasses are the most troublesome species responsible for grain yield reduction (Abeysekara *et al*., 2017). This was evidenced by *Monochoria veginalis* (Burm.f.) C. Presl, which is an aquatic weed being the most abundant weed species recorded under flooded condition representing more than 95% of the biomass of broad leaves. Results of the present study highlight the importance of flooding during sowing as an alternative strategy to control grasses found in DSR. Further, the cost for weed control in wet-DSR in Sri Lanka is around 3200 Rs/ha (SEPC, 2018), and this amount can be saved if flooded-DSR is practiced since water is freely available for farmers in Sri Lanka.

In both the seasons, seeding rate had an effect on weed biomass only at saturated moisture level ($p<0.05$) but not at the flooding ($p<0.05$). Since flooding itself reduced the weeds, increasing seeding rate under flooded-DSR does not have any effect to weed suppression. Chauhan and Yadev (2013) also reported that, there was no effect of seeding rates ranging from 15 to 125 kg/ha on the grain yield of rice grown in weed-free conditions. In contrast, higher seeding rates reduced the weed density under saturated condition because high seeding densities cover the ground fast compared to low seeding rates.

Table 3. Weed biomass (mean±standard error) of different weed categories under 2.5 and 5 cm flooding and saturated conditions in *Maha* 2015/16 and 2016/17

Weed category	Weed biomass (g/m²)					
	***Maha* 2015/16**			***Maha* 2016/17**		
	5 cm	**2.5 cm**	**Saturated**	**5 cm**	**2.5 cm**	**Saturated**
Broad leaves	$44.9±2.8^{a}$ *	$48.6±2.2^{a}$	$11.4±1.0^{b}$	$123.0±1.83^{a}$	$145.5±3.4^{a}$	$43.8±1.09^{b}$
Grasses	$2.7±0.6^{b}$	$8.7±0.8^{b}$	$66.8±2.1^{a}$	$10.0±4.3^{b}$	$2.3±0.2^{b}$	$302.8±13.9^{a}$
Sedges	$0.2±0.04^{c}$	$0.0±0.0^{c}$	$4.6±0.4^{c}$	$0.33±0.06^{c}$	$0.0±0.0^{c}$	$2.8±0.08^{c}$
Total	47.8	57.3	82.8	133.3	147.8	349.4
CV %	27.8	14.9	17.3	6.7	12.3	20.8

** means followed by the same superscript letter within a column are not significantly different at p=0.05*

Weed Control Efficiency (WCE) and Weed Control Index (WCI)

Both WCE and WCI were slightly varying between the seasons (Table 4). This variation could be due to the variation in environmental conditions which influence the number of weeds present and the dry matter production. The WCE at 5 cm of flood water height varied between 59.1% and 61.5%. In 2.5 cm of flood water, WCE was around 48.0%. WCI followed the same pattern and ranged between 72.1% and 76.5% at 5cm cm water heights and 49.0% and 58.0% at 2.5 cm water height. Compared to water height of 2.5 cm, the WCE and WCI at 5 cm of water height were about 25% and 39% high, respectively. Ismaila *et al*. (2015) reported that 25-45% of WCE and 44-64% WCI can be achieved by maintaining 5 cm of water height in transplanted rice. Therefore, 5 cm would be better in concerning weed control efficiency. However, manipulating the water level to have a high crop stand together with simultaneous weed suppression is important in flooded-DSR.

Table 4. Weed control efficiency and Weed control index under different water levels

Water level	WCE (%)		WCI (%)	
	***Maha* 2015/16**	***Maha* 2016/17**	***Maha* 2015/16**	***Maha* 2016/17**
5 cm	59.1	61.5	76.5	72.1
2.5 cm	47.7	48.8	48.7	58.0

Conclusion

Flooding at sowing minimizes the weed pressure in DSR. Flooding with 5 cm water reduces grass weed emergence substantially, but also lower the crop establishment and grain yield simultaneously. However, 2.5 cm of flooding has the ability to produce a satisfactory crop stand and weed suppression without much reduction in grain yield in flooded-DSR. Seeds sown at ≥ 125 kg/ha rates have no effect in increasing panicle density or grain yield under flooding. Therefore, adjusting flood water height to 2.5 cm at sowing and use of 100 kg/ha seeding rate can optimize the crop establishment, panicle density and grain yield while minimizing grasses and sedges. However, adapting a suitable control measure is essential if aquatic weeds are abundantly present in the field.

Acknowledgment

Authors wish to acknowledge IPSDRA and Closing Rice Yield GAP (CORIGAP) project at IRRI for providing financial support to conduct this study.

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