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Diversity of weed communities under different water regimes in bertam irrigated direct seeded rice field

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Abstract

Experiments were initiated at MARDI Bertam Rice Research Station in Penang in the dry season of 2004 and main season 2004/2005 to study the effect of different water regimes on diversity of weed species. Plots receiving continuous flooded treatment (T_1) and flooding up to panicle initiation (T_2) significantly suppressed weed population to approximately 18 – 58% and reduced weed biomass to 14 – 57% as compared to the highest values in continuous field capacity treatment (T_5) at all sampling dates (30, 60 and 90 DAS) in both planting seasons. Across water regime treatments the weed composition comprised of 11 weed species in the dry season and 10 weed species in the main season. Broadleaved weeds, especially *Monochoria vaginalis* and *Limnocharis flava* were the most dominant weeds in most water regime treatments. The SDR values of broadleaved weeds in the dry season were 48.7, 46.4, 44.2, 40.7 and 35.8% for T_2, T_1, T_3 (flooding for the first month), T_5 and T_4 (continuous saturation), respectively. In the main season, the SDR values for the broadleaved weeds increased to 79.5, 68.2, 62.4, 62.2, and 50.57% for T2, T1, T3, T4 and T5, respectively. *Fimbristylis miliacea* and *Cyperus iria* were dominant in the dry season with SDR values of more than 34% in all water regime treatments, but decreased to less than 23% in the main season. For grasses, comprising of mostly *Echinochloa crus-galli*, *Echinochloa colona* and *Leptochloa chinensis*, SDR values of more than 20% were recorded in T_4 and T_5 in the dry season, while in the main season SDR values of between 21 – 34% were observed in treatments T_1, T_3 and T_5.

Keywords: Water regimes; weed diversity, weed numbers; weed biomass; summed dominance ratio.
Abbreviations: DAS - days after sowing, SDR - summed dominance ratio, MOA - Ministry of Agriculture, MARDI - Malaysia Agricultural Research Development Institute.

Introduction

Rice is a staple food to feed more than 3 billion people and to provide 50-80% daily calorie intake (Khush, 2005). It is the third most important crop in Malaysia, grown mainly in eight granary areas in Peninsular Malaysia, covering an area of about 209,300 ha (MOA, 2007; Azmi and Mashhor, 1995). However, direct-seeded fields are exposed to aerobic conditions and in the dry season fields are not flooded during initial crop growth. These conditions are more conducive for weed growth (Moody and De Datta, 1982). Direct wet seeding (broadcasting of pre-germinated seeds on puddled soil) results in more weed growth than transplanting (Bhagat et al., 1996). Weed species respond differently to changing water regimes (Bhagat et al., 1999), and soil moisture status following planting is a major factor influencing weed flora composition (Drost and Moody, 1982; Anwar et al., 2010). In rice culture, water and weeds are often considered to be closely interlinked. Weed species respond differently to changing water regimes (Bhagat et al., 1999). For example, the dominance of grasses are favored by saturated and below saturated conditions, whereas (aquatic) broadleaves and sedges grow rapidly when soil is submerged with water (Bhagat *et al*., 1999). Under aerobic soil condition, weed diversity is much higher compared to saturated or flooded conditions (Anwar et al., 2010). In Malaysian rice farms in the Muda irrigation project, rapid changes in water management practices have caused major shifts in weed populations from annuals to perennials, from shallow emerging to deep emerging weeds and from less competitive to more competitive weeds (Noda, 1973; Bhagat et al., 1999). It is widely acknowledged that rice grown under submerged soil conditions competes better with weeds than in dryland conditions, and submergence of rice fields is an integral part of traditional weed control (Matsunaka, 1983). Submergence hinders weed germination and suppresses the population of most germinated weeds. Williams et al. (1990) compared the growth of several weeds in water seeded rice under shallow (5 cm), moderate (10 cm) and deep (20 cm) continuous flooding. In the absence of herbicides, 20 cm of standing water gave better weed control than other water depths. However, with herbicide, weed control improved at all water depths, but weeds were not fully controlled by the herbicide in shallow water. However, information on weed populations and distribution due to changes in water availability and management in Malaysian rice fields is limited. Moreover, the distribution can be variable depending on location and differences in microclimate. Location specific information on shifts in weed flora and changes in populations due to changing or variable water regimes can provide valuable indications on future weed problems and perhaps indispensable for evolving suitable weed control methods.

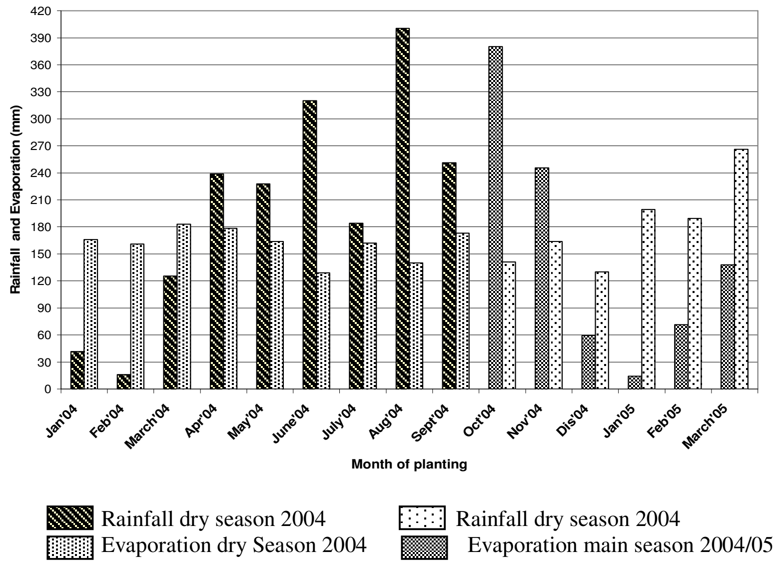

Fig 1. Rainfall and evaporation during the dry and main season (2004/2005)

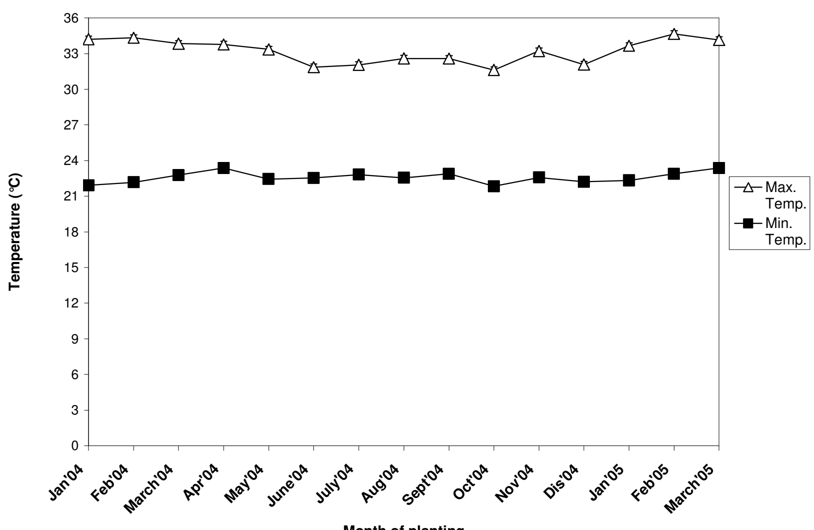

Fig 2. Maximum and minimum temperatures recorded during the field experiments

The present study was thus undertaken to investigate the population and status of dominant weeds under different water regimes in Bertam rice fields.

Materials and methods

Experimental site, soil and climate

The experiment was conducted during the dry season (2004) and main season (2004/2005) at MARDI Bertam Rice Research Station in Seberang Perai, Penang (5° 32' 47.64" N, 100° 27' 58.91" E). There were two crops of rice planting in Malaysia practiced by farmers; dry season and main season. The dry season is the planting season which precipitation is very rare, and days are typically hot and sunny throughout. In Malaysia, the dry season usually begins in April and ends in September. Meanwhile in the main season, which occurs from October to March, rain is common. Most of the rainfall occurs especially in the afternoon or evening. The soil series at the experimental site is classified as Sogomana Series (Sariam, 2004). The Sogomana Series is a fine, mixed, isohyperthermic palid *Tipik Tuajelkuts* (Paramananthan, 2000). The soil was a sandy clay loam with pH 4.49, organic carbon 0.52%, CEC ($cmol^+$)/kg 7.00, sand 51.50%, silt 12.00% and clay 36.50%. The experimental area is 1.5 m above sea level. Meteorological data recorded at a nearby weather station are presented in Figures 1 and 2. Significant rainfall occurred beginning April 2004 (in the middle of crop

Table 1. Effect of water regime treatments on number of major weed groups in unweeded plots. (no./ m^{-2}) (Bertam rice field; dry season 2004)

DAS	Weed groups	Water regime treatments				
		T_1	T_2	T_3	T_4	T_5
30	Broadleaved	34.25a	29.50a	25.25b	24.25b	34.57a
	Grass	15.07b	14.12b	9.82c	7.57c	15.57b
	sedge	25.50ab	17.00b	33.85a	42.17a	24.37b
60	Broadleaved	7.06a	11.81a	10.22a	3.92c	12.97b
	Grass	2.56b	2.62a	5.15b	6.87b	9.25c
	sedge	9.25a	12.50a	13.82a	13.97a	21.00a
90	Broadleaved	7.10a	11.60a	6.25b	8.83b	10.90a
	Grass	7.63a	4.40b	8.23a	3.75c	7.38b
	sedge	4.69b	3.43b	5.75b	11.50a	11.00a

Means within columns followed by the same letters are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated condition: T_3 = early flooding for the first month (30 DAS) followed by saturated condition: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

growth) and continued until ripening stage with August (end of dry season) reporting the highest amount of rainfall at 400 mm (Figure 1). In the main season, the highest amount of rainfall was recorded at the beginning of rice planting (September to November 2004) with an average of 250 – 380 mm, followed by less rainfall from the middle to the end of the season (15 – 140 mm). Meanwhile, there were no major differences in temperature ranges in all months of both the dry and main season, with a maximum temperature of 34.67 °C recorded in February 2005 (Figure 2).

Plant materials, experimental treatments, design and crop husbandry

All crop management practices (land preparation, construction of plots, planting and maintenance applications) were carried out in the middle of May 2004, following methods outlined in MARDI's Rice Cultivation Manual (2002). A total of 40 plots were constructed to accommodate to all treatment combinations, which consisted of five irrigation regimes and two weeding regimes in four replications. Each plot measured 36 x 8.4 m and was separated by two 50 cm wide and 20 cm high bunds. All plots were kept under saturated condition before sowing. Pre-germinated MR220 rice seeds were broadcasted into each plot at a seeding rate of 200 kg ha^{-1} (5 kg $plot^{-1}$). Each water regime treatment was carried out at 7 DAS (day after sowing). The experimental plots were arranged in a split plot in Randomized Complete Block Design with four replicates. In each replicate, the main plots (84 x 36 m) comprised of weeded and unweeded plots, while subplots (8.4 x 36 m) consisted of water regime treatments. The double-layered bunds were constructed to prevent movement of irrigation water from one plot to another. A 1.0 m gap between plots was used for irrigation purposes. Two inlet and two outlet pipes were placed in each plot to control and maintain the water level in each water regime treatment. Five water regime treatments were tested in this study: T_1 = continuous flooding (10 cm water depth – recommended condition) until maturity, T_2 = early flooding (10 cm water depth) up to panicle initiation stage (55 DAS – day after sowing) followed by saturated condition until maturity, T_3 = early flooding (10 cm water depth) for the first month (30 DAS) followed by saturated condition until maturity, T4 = continuous saturated condition until maturity, T_5 = continuous field capacity condition throughout the experimental period. The days to grain maturity were indicated when the color of rice grains turned yellow and leaves started senescence (93 – 97 DAS) as indicated in MARDI's Rice Cultivation Manual (2002). For the saturated condition treatment (T_4), water was introduced into the soil until saturation (maintain the soil to muddy condition) to a maximum of 5 mm flooded condition. A reading of 0 kPa was used as an indicator of saturated soil condition. Meanwhile field capacity (T_5) condition ensures maximum amount of soil moisture or water content held in soil after the gravitational water has drained away and the rate of downward movement has materially decreased, which usually takes place within 2 – 3 days after a rain or irrigation in pervious soils of uniform structure and texture (Federer, 2002). To maintain the T_5 condition, tensiometers (Japan model Irrometers ®) were placed inside the plots (two tensiometers per plot) to determine water deficit. Irrigation to field capacity condition was done when soil water potential fell between -30 to -50 kPa as measured by the tensiometer. At 95 DAS, water from all flooded and saturated plots were drained out and maintained under field capacity condition until harvest.

Data collection

Weed biomass and number of weeds were assessed at 30, 60 and 90 DAS from all 40 experimental plots. Random samples were taken from within each plot using a 0.5 x 0.5 m quadrat (Kim and Moody, 1983). Sampling sites within each plot were pre-marked to minimize bias when locating the quadrats again in the same plot during the next sampling. Eight quadrat were sampled in each plot. Weed species collected from within each quadrat were identified, listed and counted. Collected weeds were washed, sorted by species, dried at 70 °C to constant weight and then weighed. For weed identification the nomenclature of Soerjani et al. (1987) was used. Data recorded included weed type and species, number of weeds, weed biomass and summed dominance ratio (SDR). The SDR of the weed species were computed using the following equations (Janiya and Moody, 1989; Bhagat et al., 1999):

$$\text{SDR} = \frac{\text{Relative density (RD)} + \text{relative dry weight (RDW)}}{2}$$

where,

$$\text{RD} = \frac{\text{Density of a given species}}{\text{Total density}} \times 100$$

$$\text{RDW} = \frac{\text{Dry weight of a given species}}{\text{Total dry weight}} \times 100$$

Table 2. Effect of water regime treatments on total weed numbers plants in unwedded plots at different sampling dates in the dry and main season (no/ m^{-2}). (Bertam rice field; 2004/2005)

Water regime treatments	Number of weed plants m^{-2}(dry season)			Number of weed plants m^{-2}(main season)		
	Day after sowing (DAS)					
	30	60	90	30	60	90
T_1	22.68b	6.29b	6.47c	10.55b	7.53c	3.65b
T_2	20.21b	8.98b	6.48c	11.81b	7.62c	3.90b
T_3	22.99b	9.73b	6.74c	14.46ab	7.86c	4.68b
T_4	27.16a	13.25a	8.03b	15.41ab	9.41b	6.56a
T_5	28.17a	14.40a	9.76a	21.00a	11.68a	6.13a

Means within columns followed by the same letters are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

Comparison of species affiliation and measurement of dominance among weed communities between treatments in each planting season were made using the "Sorenson's Index of Similarity" (S) (Goldsmith et al., 1986). Computation of the S values was as follows:

$$S = \frac{2J}{A + B} \times 100$$

where, S =Index of association between treatments A and B, J =Number of species common to both treatments A and B, A =Number of species present in treatment A, B =Number of species present in treatment B

Higher S values would indicate close similarity in species composition between treatments. Conversely, lower S values reflect divergence in species composition.

Statistical analysis

Data were analyzed using the ANOVA procedure in the SAS statistical software and means were tested using Tukey's studentized range test at 5% level of probability.

Results and discussion

Effect of water regimes on number of weeds in both seasons

The effect of water regime treatments on the composition of major weed groups in the dry season 2004 is shown in Table 1. In general, all water treatments showed significantly higher suppression of grasses than broadleaved weeds and sedges at 30 and 60 DAS. At 30 DAS, broadleaved weeds were less affected compared to sedges and grasses in T_1, T_2 and T_5, while the number of sedges was highest in T_3 and T_4 at 60 DAS, followed by broadleaved weeds and grasses. The number of broadleaved weeds however was significantly reduced in T_4 and T_5 at this stage. Meanwhile, there was no clear trend observed at 90 DAS. Broadleaved weeds significantly dominated in treatment T_2, grasses dominated in T_1 and T_3 while sedges dominated in T_4 and T_5. In the main season, the weed numbers within some major groups declined significantly with time, especially from 30 to 60 DAS (Table 3). However, from 60 to 90 DAS, no definite decreasing trend was observed especially for grasses and sedges, where there was a minor decrease in some water regime treatments, and an increase in some treatments. Broadleaved weeds were observed to be significantly dominant, occurring in highest numbers in all water regime treatments at 30 and 60 DAS, while sedges and grasses were low in number, with no sedges recorded in T_1 at 30 DAS. At 90 DAS, no significant differences were recorded among the weed classes and numbers of weeds within all weed classes whereas almost similar. Previous reports have indicated that composition of rice weed communities is influenced by water management practices (Bhagat et al., 1996). Weed species respond differently to changing water regimes, and soil moisture status following planting is a major factor influencing weed composition (Janiya and Moody, 1982). Dominance of grasses such as *Echinochloa* species and *Leptochloa chinensis* (L.) is favoured by saturated and below saturation conditions (Bhagat et al., 1999), while increase in flooding depth and flooding duration encourages broadleaved weeds and sedges (Kent and Johnson, 2001). Grasses such as *Echinochloa crus-galli* grow at field capacity or saturation, whereas a high water table favors aquatic broadleaved weeds and sedges (Bhagat et al., 1996). However, in the present study no significant differences in weed species composition were observed. Broadleaved weeds were highly dominated in all the water regime treatments especially at 30 and 60 DAS in both planting seasons, followed by sedges, while the number of grasses was found to be significantly less in all water regime treatments in both planting seasons. However, excessive rainfall during the off season of 2004 (Figure 1) may have favored more sedges and broadleaved weeds to emerge. Most weeds under these two groups are categorized as semi-aquatic, aquatic or as weeds preferring wet/flooded habitats. The excess rain would have also restricted the growth of grasses, which are less prolific under flooded or submerged water conditions compared to sedges and broadleaved weeds (Itoh et al., 1996). The effect of water treatments on the number of weed plants m^{-2} in the dry season are presented in Table 2. In general, the water regime treatments had significant influence on the number of weed plants m^{-2} at all sampling dates. The number of weed plants m^{-2} also significantly decreased with time from 30 to 60 DAS and from 60 to 90 DAS. However, there was no significant interaction between water regime treatments and days after sowing (DAS). At 30 DAS, there was no significant difference between T_1, T_2 and T_3 as well as between T_4 and T_5. The results were significantly pronounced between the first group (T_1, T_2 and T_3) when compared to the second (T_4 and T_5). Treatment T_2 had the lowest weed population (20 plants m^{-2}), while the highest weed number was in T_5 (28 plants m^{-2}). Treatments T_1 and T_3 suppressed weeds to 23 plants m^{-2}, while T_4 suppressed weeds to 27 plants m^{-2}. At 60 DAS, a similar trend to 30 DAS was observed where T_1, T_2 and T_3 did not differ significantly from each other. All flooded regimes recorded significantly lower weed numbers m^{-2} as compared to T_4 and T_5. At this growth stage, T_1 had a much reduced weed number of only 6 plants m^{-2}, while T_5 again gave comparatively less weed suppression with 14 plants m^{-2}. T_2 and T_3 recorded 9 plants m^{-2} and 10 plants m^{-2} respectively, while T_4 recorded 13 plants m^{-2}. Meanwhile at 90 DAS, the number of weeds was significantly reduced

Table 3. Effect of water regime treatments on number of major weed groups in unweeded plots (no./ m^{-2}) (Bertam rice field; Main season 2004/2005).

DAS	Weed groups	Water regime treatments				
		T_1	T_2	T_3	T_4	T_5
30	Broadleaved	19.65a	21.37a	24.67a	24.02a	53.50a
	Grass	2.00b	1.15b	2.57b	5.50b	3.50b
	Sedge	0.0b	2.87b	1.12b	1.75b	6.00b
60	Broadleaved	14.58a	20.17a	19.25a	12.17a	13.32a
	Grass	4.00b	0.57b	6.33b	2.67c	6.25b
	Sedge	4.00b	2.12b	5.50b	7.37b	5.75b
90	Broadleaved	7.75a	4.75a	6.68b	7.43a	5.90a
	Grass	2.00b	6.13a	8.00a	4.13b	7.38a
	Sedge	1.23b	0.88b	5.00c	2.50c	5.13a

Means within columns followed by the same letters are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3= early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition

Table 4. Effect of water regime treatments on biomass of major weed groups in unweeded plots (g m^{-2}) (Bertam rice field; dry season 2004).

DAS	Weed gropus	Water regime treatments				
		T_1	T_2	T_3	T_4	T_5
30	Broadleaved	71.97a	44.88a	58.70a	45.64a	83.10a
	Grass	27.93b	21.72b	18.25b	15.41b	30.12b
	sedge	18.41c	13.22c	28.13b	25.15b	26.16b
60	Broadleaved	15.23a	26.18a	29.93a	12.36b	33.55a
	Grass	6.33b	7.41b	11.97b	19.26a	18.86b
	sedge	5.96b	11.97b	14.12b	12.35a	12.81c
90	Broadleaved	19.30a	25.11a	27.63a	13.99a	17.93a
	Grass	14.79b	14.92b	29.71a	10.58b	12.34b
	sedge	3.63c	3.34c	2.71b	5.90c	5.56c

At any sampling date, in a column, means followed by the same letter are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

under T_1 and T_2, which had the lowest number of weeds with 6 plants m^{-2}. T_3, which was not significantly different from T_1 and T_2, had a low weed number of 7 plants m^{-2}, while T_4 produced 8 plants m^{-2}. Plots treated with T_5 again encouraged weed emergence and contained the highest weed infestation (10 plants m^{-2}) compared to other water regime treatments. Differences in water regimes applied into soil significantly affected the number of weeds emerging in the main season (Table 3). The number of weeds was reduced from 30 to 60 DAS and from 60 to 90 DAS, although there was no significant interaction between water regime treatments and days after sowing. At 30 DAS, there was no significant difference observed between the treatments T_1, T_2, T_3 or T_4 and T_3, T_4 or T_5. Significant differences were only found between T_1 and T_2 as compared to T_5. Submerging rice plots with treatment T_1 significantly decreased the number of weeds to 11 plants m^{-2} compared to T_5 (21 plants m^{-2}). T_2, T_3 and T_4, which were not statistically significant from T_1, suppressed the weed population to 12, 14 and 15 plants m^{-2}, respectively. At 60 DAS, all flooded regimes (T_1, T_2 and T_3) had significantly less weed numbers compared to both dry regimes (T_4 and T_5). T_1 (7 plants m^{-2}) recorded the lowest number of weeds, while the highest number was in T_5 (12 plants m^{-2}). T_2 and T_3 had 8 plants m^{-2}, while T_4 produced 9 weed plants m^{-2}. Meanwhile at 90 DAS, T_1 successfully suppressed weed populations to 4 plants m^{-2}, while T_2 and T_3, which were not statistically significant from T_1, recorded 4 and 5 weed plants m^{-2} respectively. T_4 (7 plants m^{-2}) and T_5 (6 plants m^{-2}), which were not significantly different from each other, produced higher number of weeds compared to T_1. Weed suppression through surface water ponding has been reported earlier (Baltazar and De Datta, 1992; Bhagat et al., 1999). Continuous flooding and alternate flooding showed better results on weed suppression compared to continuous saturation (Bhagat et al., 1999; Juraimi et al., 2009). Studies have shown that excessive water serves as a means of weed reduction (Moody, 1978). The application of any flooded condition suppresses many weeds (Bhan, 1981), while reduced water condition to field capacity encouraged weed growth (Smith and Fox, 1973). Bhagat et al. (1996) reported that weed density was about 70% higher under reduced water conditions than under submergence. In our study, the number of weeds at 90 DAS was relatively less than at 30 and 60 DAS in both seasons. This is because at the early stage most rice field weeds begin rapid growth along with the rice plants. Thus weed plants m^{-2} at 30 DAS recorded higher number of plants compared to 60 and 90 DAS. At 60 DAS, weeds especially grasses achieved heading or maturation stage and begin to cover the rice canopy at between 45 to 75 DAS. The number of weeds was reduced with increasing competition among weeds and rice plants. After 75 DAS, most weeds begin to wilt and die (Tsuru, 1991). Hence, at 90 DAS lower numbers of weeds were recorded compared to 30 and 60 DAS. Meanwhile, the absence of weeds in weeded plots at all DAS in both seasons indicated the effectiveness of weed control treatments (herbicides application + hand weeding) in all water regime treatments. Kim (1980) and Bhagat et al. (1999) have reported similar findings in their studies elsewhere. All results discussed above reveal that under flooded conditions (either continuous or alternate flooding), the degree of weed suppression was high, while saturated and field capacity

Table 5. Effect of water regime treatments on weed biomass in unweeded plots at different sampling dates in the dry and main season. (g m^{-2}) (Bertam rice field (Bertam rice filed; 2004).

Water regime treatments	Dry weight of weed plants (g m^{-2}) (dry season)			Dry weight of weed plants (g m^{-2}) (main season)		
	Day after sowing (DAS)					
	30	60	90	30	60	90
T_1	23.19c	9.18d	10.02d	10.55b	7.53c	3.65b
T_2	26.61c	14.44c	12.57c	11.81b	7.62c	3.90b
T_3	32.52b	18.68b	14.45b	14.46ab	7.86c	4.68b
T_4	32.49b	18.41b	20.16a	15.41ab	9.41b	6.56a
T_5	46.46a	21.75a	21.94a	21.00a	11.68a	6.13a

Means within columns followed by the same letters are not significantly different at 5% level by Tukey's Test. DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition

Table 6. Effect of water regime treatments on summed dominance ratio of major weed groups in unweeded plots at 60 DAS (%) (Bertam rice field; dry and main season, 2004/2005)

Water regime treatments	Dry season			Main season		
	Broadleaved	Grass	Sedge	Broadleaved	Grass	Sedge
T_1	46.38	18.28	35.34	68.16	20.89	10.95
T_2	48.66	12.55	34.23	79.54	5.35	15.11
T_3	44.22	19.51	36.28	62.40	25.64	11.96
T_4	35.77	21.97	42.25	62.16	15.17	22.68
T_5	40.33	25.16	34.11	50.57	33.96	15.46

DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

conditions encouraged weed growth. Thus if soils are to be maintained at saturation or field capacity level to save irrigation water, herbicides have to be used to achieve weed control. Tabbal et al. (1992) and Bhagat et al. (1999) have also obtained similar results in terms of water saving while maintaining soil under saturated condition.

Effect of water regime treatments on weed growth in both seasons

In the dry season, the variable water regime treatments influenced the growth of weeds in all weed classes (Table 4). In general, broadleaved weeds were less suppressed, while the biomass of grasses and sedges were significantly reduced under all water regime treatments at all recorded sampling dates. The trend in decreasing biomass of weeds was generally consistent for all weed species and sampling dates. The weed biomass decreased from 30 to 60 DAS as the population of weeds declined. However, from 60 to 90 DAS the biomass of broadleaved weeds increased in T_1 and T_4, while the biomass of grasses increased in T_2, T_3 and T_5. Water regime treatments did not significantly reduce the growth of broadleaved weeds, while the growth of grasses and sedges were highly suppressed under all water regime treatments at 30 DAS. A similar trend was also observed at 60 DAS, where broadleaved weeds again dominated in most of the water regime treatments, except T_4 where grasses was found to produce significantly higher biomass than broadleaved weeds and sedges. At 90 DAS, broadleaved weeds again dominated in all five water regime treatments, while the biomass of sedges was significantly suppressed. In the dry season all water regime treatments showed high significant effects on weed biomass (Table 5). The growth of weeds also declined as the population decreased from 30 to 90 DAS. However, there were no significant interaction effects between water regime treatments and days after sowing. At 30 DAS, differences in water regime treatments significantly affected weed biomass. T_1 effectively reduced weed growth to a biomass of 23.19 g m^{-2}, followed by T_2, which produced 26.61 g m^{-2}. T_4 and T_3 which produced biomass of 32.49 g m^{-2} and 32.52 g m^{-2}, respectively did not differ significantly. Meanwhile, T_5 significantly enhanced weed growth with the highest weed biomass of 46.46 g m^{-2}, which was two fold higher than in T_1. A similar trend was observed at 60 DAS where all water regime treatments significantly suppressed weed biomass, except for T_5 . Treatments T_3 (18.68 g m^{-2}) and T_4 (18.41 g m^{-2}) showed no significant differences. T_1 effectively suppressed weed growth to a minimum of 9.18 g m^{-2}, followed by T_2 (14.44 g m^{-2}). T_5 was the least effective in suppressing weed growth, and had the highest weed biomass (21.75 g m^{-2}). Significant differences were also observed among water regime treatments at 90 DAS. T_1 produced a weed biomass of 10.02 g m^{-2}, significantly the lowest weed biomass compared to other water regime treatments. Alternate flooding regimes of T_2 and T_3 also showed high suppression in weed growth, with biomass production of 12.47 and 14.45 g m^{-2}, respectively. T_4, had less influence on weed suppression than all other flooding regimes, and produced 20.16 g m^{-2} weed biomass, while T_5 significantly enhanced weed growth to produce the highest biomass (21.94 g m^{-2}). In main season, the growth response of different classes of weeds to various water regime treatments showed a dissimilar pattern compared to the previous dry season (Table 5). Broadleaved weeds had significantly higher biomass compared to grasses and sedges at 30 and 60 DAS in all the water regime treatments, except in T_5 at 60 DAS, where the biomass of broadleaved weeds was not significantly different from grasses. However, at 90 DAS broadleaved weeds produced the highest biomass only in T_1 and T_4, whereas in T_3 and T_5 grasses indicated the highest production. The growth of sedges was significantly reduced in all water regime treatments at all DAS.

Table 7. Effect of water regime treatments on summed dominance ratio of weed species in unweeded plots at 60 DAS in the dry season (%) (Bertam rice field; 2004).

Weed Species	Water Regime Treatments				
	T_1	T_2	T_3	T_4	T_5
Limnocharis flava (L.) Buchenau	17.61	28.02	5.42	15.66	11.07
Ludwigia hyssopifolia (G. Don) Exell	2.98	0.27	4.71	4.27	8.52
Monochoria vaginalis (Burm. f.) Presl.	33.51	42.72	32.95	4.62	26.28
Sagittaria guyanensis H. B. K.	1.34	4.61	-	-	-
Echinochloa colona (L.) Link	5.83	0.49	5.33	1.33	5.86
Echinochloa crus-galli (L.) P. Beauv.	12.01	-	6.11	-	9.75
Leptochloa chinensis (L.) Nees.	3.65	9.35	8.89	25.65	12.17
Panicum repens L.	0.48	-	-	-	-
Cyperus iria L.	1.51	-	14.02	22.12	1.78
Cyperus haspan L.	-	-	2.41	0.25	-
Fimbristylis miliacea (L.) Vahl.	21.07	14.55	20.16	26.10	24.56

DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

Nevertheless, in contrast to the results on number of weeds (Table 4), there was no consistent decreasing trend in biomass from 30 to 60 DAS or from 60 to 90 DAS for all three weed groups. In main season, the results showed that water regime treatments significantly influenced weed biomass (Table 5). There was also a consistent decrease from 30 to 90 DAS in all water regime treatments. At 30 DAS, increase in duration of flooding suppressed the biomass of weed species significantly. The biomass of weeds showed a general increase from T_1 to T_5. The biomass of weeds was reduced to the lowest under T_1 (10.55 g m^{-2}), followed by T_2 (11.81 g m^{-2}) and T_3 (14.46 g m^{-2}). The biomass of weed species under T_2 and T_3 were not statistically significant. Under T_4, the weed biomass increased to 15.41 g m^{-2}, while the highest weed biomass was recorded under T_5 (21.00 g m^{-2}), which was significantly higher than with the other four aforementioned water regime treatments. Meanwhile, there was no definite trend found at 60 DAS. The effect of different water regime treatments on weed growth was less visible at this stage as compared to 30 DAS. T_2 (7.62 g m^{-2}) significantly suppressed weed growth to the lowest level, while T_3 (7.86 g m^{-2}), T_4 (9.41 g m^{-2}) and T_5 (11.68 g m^{-2}), which was not statistically significant with each other produced higher weed biomass than T_2. T_1 did not differ significantly from T_2, T_3, T_4. T_5 produced a weed biomass of 5.32 g m^{-2}. A trend similar to 60 DAS was observed at 90 DAS, where the effect of different water regime treatments on weed biomass was not consistent. T_1 (3.65 g m^{-2}) significantly restricted weed growth to the lowest biomass compared to other water regime treatments. T_4 enhanced weed growth to a high of 6.56 g m^{-2}, while T_5 (7.24 g m^{-2}) recorded the highest weed biomass. However, the biomass of weeds in T_4 and T_5 were not significantly different. Variability in water conditions significantly affects the growth of different rice weed communities (Bhagat et al., 1996). Studies have revealed that different weed species grow differently with different water management practices (Kim, 1980; Piggin et al., 1998). Bhagat et al. (1999) reported that broadleaved weeds produced higher weed biomass than sedges and grasses in flooding regimes, while in saturated condition the opposite result was obtained. However, in the present study there were no definite differences in growth among the water regime treatments, broadleaved weeds were significantly dominated in all five water regime treatments. A high number of weeds probably contributed to the higher weed biomass for broadleaved weeds and a lower biomass for grasses and sedges. The results were similar with the results obtained by Bhagat et al. (1999) in the wet season. Studies have shown that weed growth suppression can be achieved through water control (Bhagat et al., 1999, Rao et al., 2007). Weed dry weights are generally higher under saturated conditions than under submerged conditions (Anwar et al., 2010; Bhagat et al., 1996). Tabbal et al., (1992, 2002) reported that maintaining continuous shallow submergence, especially during vegetative growth, effectively suppressed weed growth. Poor water management often contributes to increase in biomass of weed species (Navarez et al., 1979; Bouman et al., 2007; Bhagat et al., 1999). Williams et al. (1990) had also indicated that flooded conditions (similar to T_1, T_2 and T_3) suppressed weed growth, while reduced water conditions (T_4 and T_5) enhanced weed growth. In deep water, weeds were generally smaller and in some cases, they appeared weak, whereas those in reduced water conditions were larger, vigorous and more competitive (Williams et al., 1990).

Effect of water regime treatments on weed flora and community dominance in both seasons

The effect of weed interfere at 60 DAS would have a significantly higher impact on rice production as compared to 30 and 90 DAS. Bhagat et al. (1999) had also stated that the period from 45 – 60 DAS is the stage when maximum weed pressure against the rice crop is observed. Rice yields drastically declined to its lowest production when allowed to compete with weed plants up to 50 DAS (Zimdhal, 1993), between 49 – 63 DAS (De Datta, 1980), or between 56 – 72 DAS (Mahfuza, 2006). Eleven weed species were recorded in the dry season (Table 8), while ten weed species were observed from the same plots in the main season (Table 10). The SDR of weed species was greatly affected by water regimes in both planting seasons. In the dry season, the weed flora composition in T_1 plots was mostly dominated by broadleaved weeds with an SDR value of 46.38% (Table 6), comprising namely of *L. flava, M. vaginalis, S. guyanensis* and *L. hyssopifolia* (Table 7). Sedges, mostly *F. miliacea* and *C. iria* showed some moderate endurance to continuous flooded (35.34%), while grasses mainly *L. chinensis, E. crus-galli, P. repens* and *E. colona* were the least tolerant with only 18.28% SDR value. With plots experiencing flooding until 55 DAS followed by saturation (T_2), weed flora composition was also dominated by broadleaved weeds, mainly with *L. flava, M. vaginalis, S. guyanensis* and *L. hyssopifolia* with highest SDR value of 48.66%, followed by sedges (34.23%) consisting mainly *F. miliacea*, while emergence of grasses, mostly *L. chinensis* and *E. colona*,

Table 8. Effect of water regime treatments on summed dominance ratio (%) of weed species in unweeded plots at 60 DAS in the main season (%) (Bertram rice field; 2004/2005).

Weed species	Treatment				
	T_1	T_2	T_3	T_4	T_5
Limnocharis flava (L.) Buchenau	15.96	20.12	4.45	15.88	8.27
Ludwigia hyssopifolia (G. Don) Exell	3.22	4.76	10.43	15.95	10.90
Monochoria vaginalis (Burm. f.) Presl.	54.52	58.69	49.53	34.76	34.38
Echinochloa colona (L.) Link.	3.26	-	12.18	2.16	2.26
Echinochloa crus-galli (L.) P. Beauv.	15.10	2.39	7.56	10.32	23.48
Echinochloa spp.	-	2.32	-	-	-
Leptochloa chinensis (L.) Nees.	3.81	1.02	7.26	4.51	9.69
Cyperus iria L.	-	8.90		-	-
Fimbristylis globulosa (Retz.) Kunth.	4.13	-	1.61	15.20	6.90
Fimbristylis miliacea (L.) Vahl.	-	1.80	7.00	1.22	4.12

DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

were greatly reduced to 12.55%. In plots experiencing flooding until 30 DAS followed by saturation (T_3), the results were similar to T_1 and T_2, where broadleaved weeds, mainly *L. flava, M. vaginalis* and *L. hyssopifolia*, had the highest dominance with SDR of 44.22%, followed by sedges, mostly *F. miliacea, C. iria* and *C. haspan* (36.28%), while grasses, mainly *L. chinensis, E. colona* and *E. crus-galli*, were least dominated in T3 plots with SDR value of 19.51%. Under continuous saturation (T_4), sedges comprising of *F. miliacea, C. iria* and *C. haspan* dominated with the highest SDR value (42.25%). Broadleaved weeds consisting of *L. flava, M. vaginalis* and *L. hyssopifolia* ranked second with SDR value of 35.77%, while grasses, mainly *L. chinensis* and *E. colona*, were highly suppressed with the lowest SDR value (21.97%). Meanwhile, under continuous field capacity (T_5), broadleaved weeds predominantly *L. flava, M. vaginalis* and *L. hyssopifolia* showed the highest SDR value (40.73%), followed by sedges mainly *F. miliacea* and *C. iria* (34.11%), whereas the lowest SDR value of 25.16% was observed for grasses, mostly *L. chinensis, E. crus-galli* and *E. colona*. In the main season broadleaved weeds, predominantly *L. flava, M. vaginalis* and *L. hyssopifolia*, dominated all T_1 plots with more than half the coverage (SDR of 68.16%) (Table 6). Grasses, mainly *L. chinensis, E. crus-galli* and *E. colona* (Table 8), also dominated some plots (20.89%) while sedges, comprising of *F. miliacea* and a new found species *F. globulosa*, which was not found in dry season, had the least dominance with SDR value of only 10.95% (Tables 12). In plots receiving the T_2, broadleaved weeds were mainly *L. flava, M. vaginalis* and *L. hyssopifolia* which recorded the highest SDR value (79.54%), followed by sedges *F. miliacea* and *C. iria* (15.11%). Meanwhile, grasses consisting of *L. chinensis, E. crus-galli* and an unidentified *Echinochloa* spp. had the lowest SDR value (5.35%). In plots exposed to the T_3 regime, broadleaved weeds predominantly *M. vaginalis, L. flava* and *L. hyssopifolia* again dominated the composition with the highest SDR value of 62.40%. Grasses, mainly *L. chinensis, E. crus-galli* and *E. colona* were second in dominance (25.64%), while sedges, mostly *F. miliacea* and *F. globulosa* had the lowest SDR (11.96%). Meanwhile in T4 plots, broadleaved weeds, predominantly *L. flava, M. vaginalis* and *L. hyssopifolia*, were again the most dominant with SDR value of 63.16%, followed by sedges (22.68%), mainly *F. globulosa* and *F. miliacea*, while the emergence of grasses were significantly reduced under this water regime treatment with a low SDR value of 15.17%. The highest SDR value in T_5 plots was obtained with broadleaved weeds (50.57%), mainly *L. flava, M. vaginalis* and *L. hyssopifolia*. Grasses were moderately dominant (33.96%), while sedges, mostly *F. miliacea* and *F. globulosa*, had a low SDR value of 15.46%. Dominance of different weed species under different water regimes have been reported earlier (Bhagat et al., 1996; 1999). The composition of rice weed communities is strongly influenced by water management practices (Bhagat et al., 1996). However in the present study, we found that sedges and broadleaved weeds were highly dominant in all water regime treatments, while the grasses were significantly restricted. Excess rainfall during the dry season and continuous rainfall at the early stage of rice growth in the main season (Figure 1). is believed to have favored sedges and broadleaved weeds to emerge rapidly, whilst at the same time, the excess rain restricted the growth of grasses. *Ludwigia hyssopifolia* (G. Don) Excel, which was not dominant in the dry season, was found to be nearly dominant in most water regime treatments in the main season (Table 5). Three species; *Sagittaria guyanensis* H. B. K., *Cyperus haspan* L. and *Panicum repens* L. which were present in the dry season, disappeared from the plots in the main season. However new species, *Fimbristylis globulosa* (Retz.) Kunth. and a unidentified *Echinochloa* spp. which were not recorded in the dry season were found to emerge in the main season. Such shifts in weed species due to changes in water management have been previously recorded (Noda, 1973; De Datta, 1988; Bhagat et al., 1999).

Coefficient of similarity

Tables 9 and 10 indicate the coefficient of similarity between different water regime treatments in the dry and main season. High values of Sorenson's Index of Similarity of between 66.67 to 100% indicate the close similarity in weed species among all water regime treatments in both seasons. In the dry season, a 100% similarity in weed species was observed between T_3 with T_4, T_3 with T_5 and between T_4 with T_5, indicating that weed species infesting plots T_3, T_4 and T_5 were identical to each other (Table 10). The coefficient of similarity between T_1 with T_3, T_1 with T4 and T_1 with T_5 recorded a similar value of 93.33%, while a similarity index of 75% was observed between T_2 with T_3, T_2 with T_4 and T_2 as compared to T_5. Meanwhile T_1 and T_2 recorded the lowest similarity index of 66.67%, indicating there was some variability in weed species infesting these plots. Similar results were obtained in the main season (Table 10). The highest value was recorded between T_3 with T_4 and T_3 with T_5 and between T_4 and T_5 (100%), while the lowest value of 66.67% similarity was observed between T_1 and T_2. These results reveal that differences in water regime treatments did not significantly affect variability in weed species, except for

Table 9. Sorenson's Index of Similarity in weed species among water regime treatments in unweeded plots at 60 DAS in the dry season (%).

Water regime treatments	T_1	T_2	T_3	T_4	T_5
T_1	-	66.67	93.33	93.33	93.33
T2	66.67	-	75	75	75
T3	93.33	75	-	100	100
T4	93.33	75	100	-	100
T5	93.33	75	100	100	-

DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

Table 10. Sorenson's Index of Similarity (%) in weed species among water regime treatments in unweeded plots at 60 DAS in the main season (%)

Water Regime Treatments	T_1	T_2	T_3	T_4	T_5
T_1	-	66.67	93.33	93.33	93.33
T2	66.67	-	75	75	75
T_3	93.33	75	-	100	100
T_4	93.33	75	100	-	100
T_5	93.33	75	100	100	-

DAS = Day after sowing: T_1 = continuous flooded condition: T_2 = early flooding up to panicle initiation stage (55 DAS) followed by saturated: T_3 = early flooding for the first month (30 DAS) followed by saturated: T_4 = continuous saturated condition: T_5 = continuous field capacity condition.

T_1 and T_2. Bhagat et al. (1999) also observed similar responses in similarity index in their study elsewhere among weed species under three different water regimes in rice fields.

Conclusion

Variability in water regimes affected the weed species population and growth. Under unweeded condition, continuous flooding throughout the season (T_1) and flooding until panicle initiation [55 DAS] followed by saturation (T_2) resulted in effective suppression of weeds. A greater weedy condition was generally associated with continuous saturation (T_4) and continuous field capacity (T_5) treatments. Herbicides application and hand weeding gave a significantly higher degree of weed suppression under all water regime treatments over the un-weeded plots. In terms of community dominance across water regimes, broadleaved weeds predominantly *M. vaginalis* and *L. flava* were the most dominant weeds in most of the water regime treatments in un-weeded plots. Those two weed species were highly dominant in T_1, T_2 and T_5 in the dry season and completely outnumbered other weeds under all water regime treatments in the main season, the dominance of sedges, namely *Fimbristylis miliacea*, and grasses *Leptochloa chinensis* were high in T_4 and T_5 in the dry season. Monitoring the distribution of these weed species in response to water management and selection of appropriate control measures is important for effective weed management.

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