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Effectiveness of Herbicide to Control Rice Weeds in Diverse Saline Environments

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Abstract: To mitigate environmental pollution and food contamination caused by inappropriate and excessive herbicide usage, most potent herbicides should be screened to control rice weeds. A research trial was executed for assessing the comparative efficacy of different herbicides to control rice field weeds and to evaluate the toxicity on rice under normal (distilled water) as well as different salinity levels (4 and 8 dS m^{-1}). The study was designed to select the most potent herbicide and its appropriate dose for weed control of rice crop in coastal areas. Fourteen herbicidal treatments were included weed free crop, Pretilachlor (0.25, 0.50, 0.375 and 0.75 kg a.i. ha^{-1}), Propanil + Thiobencarb (0.6 + 1.2, 0.9 + 1.8, 1.2 + 2.4 and 1.8 + 3.6 kg a.i. ha^{-1}), Bensulfuron + MCPA (0.03 + 0.05, 0.045 + 0.075, 0.06 + 0.1 and 0.09 + 0.15 kg a.i. ha^{-1}) and weedy check (control). The results revealed that all tested herbicides in higher than recommended doses for non-saline rice fields were effective in controlling *Cyperus iria*, *Echinochloa colona* (salt-tolerant) and *Jussiaea linifolia* but showed in light injury in rice plants grown in non-saline soils. These higher doses of herbicides recorded severe crop injury under saline conditions indicating their differential efficacy from normal non-saline conditions. Treatments including Pretilachlor (0.375kg a.i. ha^{-1}), Propanil + Thiobencarb (0.9 + 1.8 kg ai/ha), Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}) and Pretilachlor (0.50 kg a.i. ha^{-1}) remained superior in terms of weed control and grain yield production under all salinitylevels at TanjungKarang, Malaysia. It is concluded that herbicides respond differently under saline conditions and optimization of their doses potentially prevent herbicidal injury in rice plants.

Keywords: herbicides effectiveness; rice weed control; saline environment

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population, particularly in Southeast Asia and Latin America [1,2]. It is the third most important crop in Malaysia, grown mainly in eight granaries in Peninsular Malaysia covering an area of about 205,548 ha [3]. Self-sufficiency of rice in Malaysia is about 70% and rising population along with decreasing land area are expected to boot rice import needs [4]. However, as the population of Malaysia is predicted to reach 66.4 million in 2056, it calls for more research and technological advancement to increase rice production to meet consumption within the nation [5].

Salinity is one of the most significant abiotic stresses influencing the metabolic activities and causing plant injures [6]. More than eight lack hectares of agricultural land have been estimated to be impaired by salinity worldwide [7].Rice production, especially in saline areas is becoming increasingly important because more rice areas are becoming saline due to the addition of anthropogenic contributions to global warming. Though salinity has not yet become a crucial problem in Malaysia, but it is predicted to affect productivity in 100,000 ha of rice growing areas that would be salt affected by the year 2056 [5]. Continuous intrusion of saline water will result in decreasing areas for rice production and lead to food shortages. Therefore, researchers and policy makers need to consider economic and efficient use of saline areas for rice production. Recently, saline water intrusion in coastal areas is expected to decrease rice production areas that lead to reduce total rice production and food shortages [5]. In order to ensure food and nutritional protection, extensive research is necessary to allow effective utilization of saline areas for rice production.

Globally, weeds are a serious pest of rice, which tend to decrease growth and rice yield especially if weeds invasion reaches beyond threshold levels at seedling stage. Weeds have emerged as one of the major constraints for rice production in saline areas. Weeds compete with rice for water, light, physical space, and nutrient thus reducing yields, while weed seeds contaminate harvested rice grains, and lowers grain quality and cash value of the crop [8]. Worldwide the annual rice yield loss due to weed infestation is about 15–21% and annual losses of 10 million metric ton of rice due to weed competition have been reported in China [9]. In fields without any weed control, the yield loss in rice due to weeds is estimated at 41–70%, and rice yield losses in Malaysia had been recorded to about 42% in uncontrolled fields infested with *Fimbristylis miliacea* [10]. The distribution and nature of the weeds of coastal area are expected to be different compared to flood plain areas. Therefore, introduction of salt tolerant rice varieties should also be followed by effective and appropriate weed control practices. The critical period of weed control is considered as a 'window' in the crop cycle to prevent unacceptable yield loss [11]. Herbicide-based weed management is becoming increasingly popular, but there is a great need to select appropriate herbicides and determine the effective minimum dose of the herbicides for controlling salt tolerant weeds in saline rice fields. Worldwide numerous reports have been published on salinity stress and weed management in rice [2]. In addition to salinity stress, the weed management of rice in coastal areas is one of the most potent challenges in all rice-producing countries such as Malaysia [12]. The composition weed species in saline areas is different from flood plain areas [13]. Salt tolerant weeds include *Cynodon dactylon, Eleusine coracana, Echinochloa crus-galli, Puccinellia ciliate, Cyperus iria* and *Echinochloa colona* [14]. Effective management of salt tolerant weeds is very critical for sustainable rice production in coastal areas. The chemical weed management is the most commonly used in Malaysia, and reliable method to control the weeds in the rice fields [15,16]. Herbicides may not be successful for the control of saline weeds by Malaysian farmers in coastal areas as per recommendation for the non-saline environment. Chemical weed control in saline environment can be different from the non-saline environment [17]. There is limited information on rice weed control under saline conditions reported so for which has necessitated conducting investigations to ensure food security under changing climate. It was hypothesized that different herbicides applied solely or in conjunction with each other might perform differently under saline environment. Therefore, the study was designed to select the most promising herbicides and their optimal doses to control rice field weeds in saline environments.

2. Materials and Methods

2.1. Experimental Design

The pot experiment was conducted at the glasshouse of University of Putra Malaysia, Malaysia (3°00′21.34″ N, 101°42′15.06″ E having an altitude of 37 m above the sea level, temperature (27 ± 2 °C) with 12 h light, humidity 68–77%, daily light cycle 3–35.5 µmolm^{-2}s^{-1}, with 12 h light, humidity 68–77%, daily light cycle 3–35.5 µmolm^{-2}s^{-1}, automated irrigation system and irrigation level 3–6 mm).

The experiment was arranged in a randomized complete block design (RCBD) with four replications. Treatments included three herbicides namely Pretilachlor (Sofit® Shandong Qiaochang Chemical Co. Ltd., Binzhou, China), Propanil + Thiobencarb (Satunil®, Biostadt India Limited, Mumbai, India), and Bensulfuron (Tekong®, Simonis B.V. Agrochemicals, Doetinchem, The Netherlands) + MCPA (AgChemAccess Ltd, Norfolk, UK) which were applied at different rates (125, 100, 75 and 50%, respectively of recommended dose) (Table 1) and three salinity levels (0, 4 and 8 dS m^{-1}). Detail of the herbicide treatments has been presented in Table 1.

Table 1. Herbicide treatments used in the study.

Code	Treatments	Increasing Rate of a.i. (kg ai/ha)	Application Time (DAT)
T_1	Weed free	-	Season-long
T_2	Pretilachlor	0.75	4
T_3	Pretilachlor	0.50	4
T_4	Pretilachlor	0.375	4
T_5	Pretilachlor	0.25	4
T_6	Propanil + Thiobencarb	1.8 + 3.6	10
T_7	Propanil + Thiobencarb	1.2 + 2.4	10
T_8	Propanil + Thiobencarb	0.9 + 1.8	10
T_9	Propanil + Thiobencarb	0.6 + 1.2	10
T_{10}	Bensulfuron + MCPA	0.09 + 0.15	7 + 40
T_{11}	Bensulfuron + MCPA	0.06 + 0.1	7 + 40
T_{12}	Bensulfuron + MCPA	0.045 + 0.075	7 + 40
T_{13}	Bensulfuron + MCPA	0.03 + 0.05	7 + 40
T_{14}	Weedy	-	Season-long

DAT = Days after transplanting.

Salt tolerant rice variety (MR232) was used as the test crop and herbicides were tested against three weeds (*Ehinochloa colona, Cyperus iria* and *Jussiaea linifolia*) in rice pots [18].

2.2. Crop Management and Observations

Soil collected from a rice field in Tanjung Karang, Malaysia (2°30′ N 112°30′ E) was used to fill the pots of the experiment.The soil was loamy clay in nature with sand, silt and clay contents of 18.3, 43.7 and 38% respectively. It was found to be acidic having 6.1 pH, 1.02% organic carbon and 1.56 dSm^{-1}EC. The soil contained total N (0.19%), available P (11.12 ppm), available K (122 ppm), Ca (620 ppm), Mg (290 ppm), S (7.63 ppm) and Zn (0.96 ppm).

Commercial salt (NaCl, Batch# 088K0089, SIGMA-ALDRICH Co., Saint Louis, MO, USA) was used in concentration of 2.54 and 5.08 gL^{-1} of distilled water for preparing salinity levels of 4 and 8 dSm^{-1}, respectively. The control treatment was supplied distilled water only. The reconfirmation of desired salinity levels was done by measuring EC with EC meter (model: Z 865/SCHOTT Instruments, Hattenbergstraße 10·55122 Mainz, Germany), and subsequently necessary adjustments were made. No significant difference among the replications of individual salinity treatments was observed measurement of EC with the EC meter.

Each pot (33 cm diameter × 23 cm depth) was filled with 10 kg soil which was thoroughly mixed with urea (4.5 g N pot^{-1}) (applied as basal dose 50% as well as rest of the portion as top dressing at 30 and 60 DAT), triple supper phosphate (6.0 g P_2O_5 pot^{-1}), muriate of potash (11.4 g K_2O pot^{-1}), and gypsum (1.5 g S pot^{-1}) were applied as basal dose during final pot preparation. Twenty-one days old three rice seedlings were transplanted into each pot considering one seedling as one hill. In each pot, 20 pre-soaked non-dormant weed seeds per species were sown on the same day of rice transplanting. All the weed seeds in all the pots were germinated, and these were sustained until spraying of herbicides. To impose salt stress, the salt treatments were applied during final pot preparation. The salt solutions were applied to transplanted rice into three splits with an aim to avoid osmotic shock. The EC of growth media was maintained as per treatments (4 and 8 dSm^{-1}) till the initiation of panicle. The agronomic management practices were carried out as per crop requirements [19]. For monitoring of EC of growth media in each pot, salt leachates were collected on daily basis. Necessary adjustments were made to maintain salinity of the specific treatments. The EC meter (Model: EC Tester, Spectrum Technologies Inc., 3600 Thayer Court, Aurora, IL 60504, USA) was used for the determination of leachates electrical conductivity throughout the trial period. The herbicides mixture was sprayed using hand sprayer (Model: Miaomanyoga Portable 800mL Chemical Sprayer, Mainland, China) having adjustable brass nozzle and the time has mentioned in Table 1. Weed population was recorded after 15 days of treatment application (Figure 1). There were no major changes in crop phenology due to salinity treatments because the chosen rice variety was salt-tolerant.

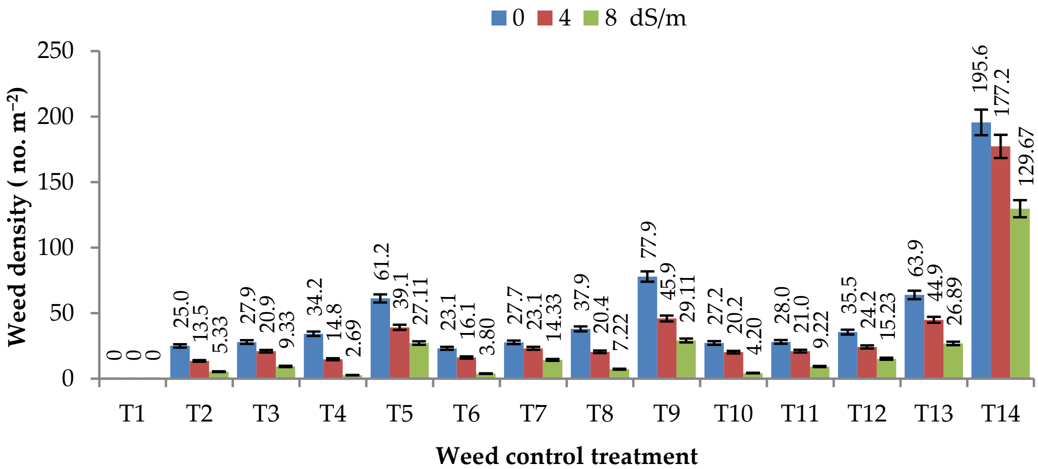

Figure 1. Weed population (number per meter square) after 15 days of treatments application (T_1—Hand weeding (weed free),T_2—Pretilachlor (0.75 kg a.i. ha^{-1}), T_3—Pretilachlor (0.50 kg a.i. ha^{-1}), T_4—Pretilachlor (0.375 kg a.i. ha^{-1}), T_5—Pretilachlor (0.25 kg a.i. ha^{-1}), T_6—Propanil + Thiobencarb (1.8+ 3.6 kg a.i. ha^{-1}), T_7—Propanil + Thiobencarb (1.2 + 2.4 kg a.i. ha^{-1}), T_8—Propanil + Thiobencarb (0.9 + 1.8 kg a.i. ha^{-1}), T_9—Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}), T_{10}—Bensulfuron + MCPA (0.09 + 0.15 kg a.i. ha^{-1}), T_{11}—Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}), T_{12}—Bensulfuron + MCPA (0.045 + 0.075 kg a.i. ha^{-1}), T_{13}—Bensulfuron + MCPA (0.03 + 0.05 kg a.i. ha^{-1}) and T_{14}—Weedy check).

Recommended rate for rice

(a) Pretilachlor: 0.50 kg a.i. ha^{-1} (2.4 L product/ha),
(b) Propanil + Thiobencarb: 1.2 kg a.i. ha^{-1-1}+ 2.4 kg a.i. ha^{-1} (6 L product/ha),
(c) Bensulfuron: 0.06 kg a.i. ha^{-1} (2.5 L product/ha) and
(d) MCPA:recommended rate 0.1 kg a.i. ha^{-1} (1.6 L product/ha).

Weed control data rating and plant phytotoxicity were visually evaluated after herbicide application at early tillering stage of rice. The visual rating scale of 1–5 [20] was used in this study (Table 2).

Table 2. Effect of treatments on weed control and crop toxicity at 10 days after application.

Treatments	Rate (kg a.i. ha^{-1})	Weed Control Rating (Based on Weed Consistent)			Crop Toxicity Rating		
		Salinity Levels (dS m^{-1})					
		0	4	8	0	4	8
Weed free	-	0	0	0	1	1	1
Pretilachlor	0.75	1	1	1	1	2	2
Pretilachlor	0.50	1	1	1	1	1	2
Pretilachlor	0.375	1	1	1	1	1	1
Pretilachlor	0.25	2	3	3	1	1	1
Propanil + Thiobencarb	1.8 +3.6	1	1	1	2	4	5
Propanil + Thiobencarb	1.2 +2.4	1	3	3	1	2	2
Propanil + Thiobencarb	0.9 +1.8	1	1	1	1	1	2
Propanil + Thiobencarb	0.6 +1.2	1	1	1	1	1	1
Bensulfuron + MCPA	0.09 + 0.15	1	1	1	3	4	5
Bensulfuron + MCPA	0.06 + 0.10	1	1	1	1	2	2
Bensulfuron + MCPA	0.045 + 0.075	1	1	1	1	1	1
Bensulfuron + MCPA	0.03 + 0.05	2	3	3	1	1	1
Weedy	-	5	5	5	1	1	1

Note: Satisfactory weed control + plant with light injury = 1, Good weed control plus light injury = 2. Fair/moderately weed control+ phytotoxic = 3, Poor weed control + severely phytotoxic = 4, andVery poor weed control or no weed control+100% kill of the crop plants = 5.

Plant height: Plant height (cm) of the rice plants were measured from the ground level to the tip of the longest leaf by using measuring scale.

Tillers: The total numbers of tiller $hill^{-1}$, productive tiller $hill^{-1}$ was counted at maturity of the rice plants at 90 days after transplanting (DAT).

Chlorophyll: ChlSPAD values were measured by using a chlorophyll meter (ChlSPAD-502, Minolta Camera Co., Osaka, Japan) from fully expanded young leaves at 60 days after transplanting and 90 days after transplanting.

Gain yield: The crop was harvested when 90% of grains attained golden yellow color, while the grain yields were recorded after post-harvest processing. The grain yield adjustment was done based on grain moisture of 12%.

Weed dry matter: Weed dry matter was recorded at 60 DAT after drying in an oven at 80 °C for 72 h, and it converted from g pot^{-1} to gm^{-2}.The weed control efficiency (WCE) was calculated based on weed dry matter using the following equation [21].

$$\text{Weed control efficiency (WCE)} = \frac{\text{DWC} - \text{DWT}}{\text{DWC}} \times 100 \quad (1)$$

where, DWC = Weeds dry weight in weedy check plots (Weedy average check plots), DWT = Weeds dry weight in herbicidal treated plots.

2.3. Statistical Analysis

Analysis of Variance (ANOVA) procedure was used to perform statistical analyses of recorded all experimental data while significant differences among treatment means were determined using Least Significant Difference (LSD) test at the probability level of 5% with the help of statistical software package of "SAS version 9.0".

3. Results and Discussion

3.1. Crop Phenology

The phonology of rice crops throughout the entire lifetime was good enough to maintain plant growth, because the selected variety was salt-tolerant.

3.2. Visual Weed Control Rating and Crop Injury

Results presented that most of the herbicidal treatments controlled weeds (Table 2). The Pretilachlor (0.25 kg a.i. ha^{-1}), Bensulfuron + MCPA (0.03 + 0.05 kg a.i. ha^{-1}), and Propanil + Thiobencarb (1.2 + 2.4 kg a.i. ha^{-1}) showed fair control of all selected weeds under saline conditions. The results suggest that weeds can be effectively managed with minimal levels of herbicides in the fields affected by salt. Pretilachlorine (0.375 kg a.i. ha^{-1}), Propanil (0.9 + 1.8 kg a.i. ha^{-1}) and Bensulfuron + MCPA (0.045 + 0.075 kg a.i. ha^{-1}) are clearly appropriate for successful control of weeds under the saline conditions. Crop toxicity increased with increased herbicide concentrations and increased salinity (Table 2). For Pretilachlor, a higher herbicidal dose caused slight injury under saline condition, but recommended (0.5 kg a.i. ha^{-1}) and lower than recommended doses did not show any injury to rice plants. The higher dose of Propanil + Thiobencarb was a mild injury in non-saline conditions, and significant phytotoxicity and complete killing ofrice plant were observed at 4 and 8 dS m^{-1} salinity levels.In case of Bensulfuron + MCPA, plants showed severe phytotoxicity as well and ultimately the plants were died under saline conditions but no phytotoxic effects were found under non-saline conditions with those herbicidal treatments. The recommended and lower thanrecommendedrates ofall herbicides did not lead to rice damage symptoms under non-salinesoil, and the recommended rate presented light injure during salinity conditions.Anwar et al. [16] also noticed light injure like leaf chlorosis along with growth stunting of rice with herbicides like Pretilachlor + Sefener (0.5 + 0.6 kg ai ha^{-1}) and Bentazon + MCPA (0.1 + 0.6 kg ai ha^{-1}) at 7 to 14 days after application. The result of the present findings corroborated with the findings of Yew et al. [22], who inferred that low doses of herbicides performed better under saline conditions.

3.3. Weed Population, Dry Matter and Control Efficiency

The population and dry matter of weeds along with weed control efficiency (WCE) were significantly declined by different herbicide treatments (Figures 1 and 2 and Table 3). The highest number of weed density (195 m^{-2}) and also weed dry matter (16.30 g m^{-2}) was found in the weedy check under non-saline conditions. While the lowest number of weeds (2.70 m^{-2}) and dry matter (0.19 gm^{-2}) were observed for Pretilachlor (0.375 kg a.i. ha^{-1}) at 8 dS m^{-1}. Among the herbicidal treatments, the maximum weed population (78.0 m^{-2}) and weed dry matter (6.33 g m^{-2}) was found in pots treated by Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}) followed by Pretilachlor (0.25 kg a.i. ha^{-1}) and Bensulfuron + MCPA (0.03 + 0.05 kg a.i. ha^{-1}). While the least number of weeds (23.0 m^{-2}) and dry matter (1.93 g m^{-2}) was obtained in pots treated by Propanil +Thiobencarb (1.8 + 3.6 kg a.i. ha^{-1}) followed by Pretilachlor (0.375 kg a.i. ha^{-1}). At 4 dS m^{-1}, the highest number of weeds (46.0 m^{-2}) and weed dry matter (3.53 g m^{-2}) was in pots treated by Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}) followed by Bensulfuron + MCPA (0.03 + 0.05 kg a.i. ha^{-1}) treatment while the lowest number of weeds (13.5m^{-2}) and weed dry matter (1.04 gm^2) was in pots treated by Pretilachlor (Sofit®) followed by Pretilachlor0.75 kg a.i. ha^{-1}.Similar trend was also observed for salinity level of 8 dS m^{-1}.

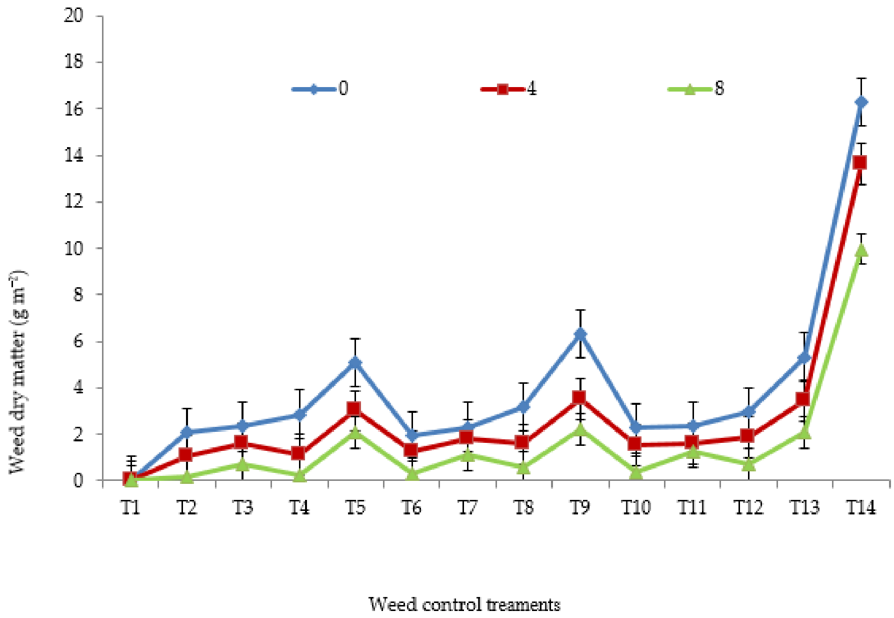

Figure 2. Effect of weed control treatments on cumulative weed dry matter at 90 DAT (T_1—Hand weeding (weed free), T_2—Pretilachlor (0.75 kg a.i. ha^{-1}), T_3—Pretilachlor (0.50 kg a.i. ha^{-1}), T_4—Pretilachlor (0.375 kg a.i. ha^{-1}), T_5—Pretilachlor (0.25 kg a.i. ha^{-1}), T_6—Propanil + Thiobencarb (1.8+ 3.6 kg a.i. ha^{-1}), T_7—Propanil + Thiobencarb (1.2 + 2.4 kg a.i. ha^{-1}), T_8—Propanil + Thiobencarb (0.9 + 1.8 kg a.i. ha^{-1}), T_9—Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}), T_{10}—Bensulfuron + MCPA (0.09 + 0.15 kg a.i. ha^{-1}), T_{11}—Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}), T_{12}—Bensulfuron + MCPA (0.045 + 0.075 kg a.i. ha^{-1}), T_{13}—Bensulfuron + MCPA (0.03 + 0.05 kg a.i. ha^{-1}) and T_{14}—Weedy check).

Table 3. Effect of treatments on weed control efficiency (%) under different salinity regimes.

Treatments (kg a.i. ha^{-1})	Salinity Levels (dS m^{-1})		
	0	**4**	**8**
Weed free (hand weeding)	100 a	100 a	100 a
Pretilachlor (0.75)	82.60 bc	87.46 b	93.48 abc
Pretilachlor (0.50)	81.12 bc	83.59 b	88.18 cde
Pretilachlor (0.375)	77.89 bc	87.44 b	93.31 abc
Pretilachlor (0.25	60.75 d	70.67 c	75.12 f
Propanil + Thiobencarb (1.8 + 3.6)	83.56 b	86.29 b	97.05 ab
Propanil + Thiobencarb (1.2 + 2.4)	81.22 bc	82.35 b	84.33 de
Propanil + Thiobencarb (0.9 kg + 1.8)	76.00 c	83.84 b	89.81 cd
Propanil + Thiobencarb (0.6 + 1.2)	56.57 d	69.49 c	72.93 f
Bensulfuron + MCPA (0.09 + 0.15)	81.46 bc	83.97 b	91.77 bc
Bensulfuron + MCPA (0.06 + 0.1)	77.23 bc	84.72 b	88.27 cde
Bensulfuron + MCPA (0.045 + 0.075)	81.06 bc	83.53 b	82.18 e
Bensulfuron + MCPA (0.03 + 0.05)	62.38 d	70.05 c	73.90 f
Weedy check	0.0	0.0	0.0

Means within same columns having similar lettering are non-significant (LSD, $p \leq 0.05$).

At control salinity level, the highest WCE (83.56%) was observed for Propanil + Thiobencarb (1.8 + 3.6 kg a.i. ha^{-1}) (Table 3). However, similar WCE was also observed in pots treated by Pretilachlor @ 0.75 kg a.i. ha^{-1}, Bensulfuron + MCPA (0.09 + 0.15 kg a.i. ha^{-1}), Pretilachlor @ 0.05 kg a.i. ha^{-1}and Bensulfuron + MCPA (0.045 + 0.075 kg a.i. ha^{-1}). The minimum WCE (60.75%) was recorded for Pretilachlor (0.25 kg a.i. ha^{-1}), while other herbicidal treatments remained at par to each other under optimal conditions. At 4 dS m^{-1}, the highest value (87.46%) of WCE was obtained for Pretilachlor (0.75 kg a.i. ha^{-1}) but other treatments gave non-significant differences. The lowest WCE (69.49%) was given by Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}).The treatments which showed lower efficiency in controlling weeds might be due to less killing effects or more emergences of new weeds (individuals) at later stages.

Our findings revealed that the effectiveness of weed controls was considerably better if herbicides were applied more than prescribed, but they showed a high level of phytotoxicityfor rice causing death ofrice plants particularly in severe salt conditions. Therefore, higher dose cannot be acceptable under saline condition. The above results are in agreement with those findings of [21,23–25].

3.4. Plant Height of Rice

Herbicide treatments affected considerably rice plant height at various levels of salinity (Table 4). At 45 DAT, the tallest plants (63.9 cm) were recorded by Pretilachlor (0.375 kg a.i. ha^{-1}), and Propanil + Thiobencarb (0.6 + 1.2 kg a.i. ha^{-1}) followed by Pretilachlor (0.25 kg a.i. ha^{-1}), and weed-free treatment under non-saline conditions. The shortest plants (40.7 cm) were found in weedy checked was followed by pots treated with Propanil + Thiobencarb (1.8 + 3.6 kg a.i. ha^{-1}), and Pretilachlor (0.75 kg a.i. ha^{-1}) under 8 dS m^{-1} salinity level.At 90 DAT, the tallest plants (112.2 cm) were recorded for Pretilachlor (0.375 kg a.i. ha^{-1}), and this was comparable to the weed-free and Pretilachlor (0.25 kg a.i. ha^{-1}) treatments under non-saline conditions. The shortest plants (76.2 cm) were found in the weedy control treatment followed by Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}) at 8 dS m^{-1} salinity level. Other treatments produced intermediate plant height. The shortest plants (40.7) were found in weedy checked was followed by pots treated with Propanil + Thiobencarb (1.8 + 3.6 kg a.i. ha^{-1}), and Pretilachlor (0.75 kg a.i. ha^{-1}) under 8 dS m^{-1} salinity level. At the highest salinity level, plants treated with Bensulfuron + MCPA (0.09 + 0.15 kg a.i. ha^{-1}) were died completely. Ronstar 25EC at 1.25 L ha^{-1} + IR5878 50 WP at 120 g ha^{-1} produced the tallest plants [21], while the shortest plants were found in weedy checks which are similar to the present results. Higher doses of Golteer 5G @12.35 kg ha^{-1} adversely influenced the plant height in rice [26].

Table 4. Effect of weed control treatments on rice plant height (cm) under different salinity regimes.

Treatments (kg a.i. ha^{-1})	Salinity Levels (dS m^{-1})					
	45 DAT			At Harvest		
	0	4	8	0	4	8
Weed free (hand weeding)	63.2 ab	61.8 a	57.0 a	111.6 a	104.5 ab	91.6 cd
Pretilachlor (0.75)	59.1 cd	53.4 b	45.8 d	102.1 cd	98.5 de	87.4 e
Pretilachlor (0.50)	61.4 abc	59.5 a	55.8 b	106.9 ab	103.6 ab	93.0 bc
Pretilachlor (0.375)	63.9 a	62.3 a	59.6 a	112.2 a	106.8 a	93.3 bc
Pretilachlor (0.25)	63.5 ab	62.5 a	58.8 a	110.3 a	100.0 bcd	89.9 d
Propanil + Thiobencarb (1.8 + 3.6)	53.9 e	52.5 b	45.6 d	96.8 d	0.0	0.0
Propanil + Thiobencarb (1.2 + 2.4)	62.6 abc	61.4 a	59.7 a	105.3 bc	101.2 bc	97.3 a
Propanil + Thiobencarb (0.9 kg + 1.8)	62.9 a	63.0 a	60.6 a	104.9 bc	100.3 bcd	92.3 cd
Propanil + Thiobencarb (0.6 + 1.2)	63.9 a	63.6 a	58.1 a	106.5 ab	102.6 bc	96.8 a
Bensulfuron + MCPA (0.09 + 0.15)	49.7 f	42.1 c	0.0	95.0 d	0.0	0.0
Bensulfuron + MCPA (0.06 + 0.1)	60.3 bcd	51.8 b	49.9 c	105.3 bc	100.2 bcd	93.4 bc
Bensulfuron + MCPA (0.045 + 0.075)	59.3 cd	56.6 ab	53.7 b	102.4 cd	93.8 ef	87.5 de
Bensulfuron + MCPA (0.03 + 0.05)	60.0 bcd	55.5 ab	51.6 bc	107.0 ab	95.1 def	90.4 cd
Weedy check	45.3 g	39.0 d	40.7 e	90.0 e	86.9 g	76.2 f

Means within same columns having similar lettering are non-significant (LSD, $p \leq 0.05$).

3.5. Tillering Ability of Rice

There was significant effect of herbicide treatments on the production of productive and total tillers hill^{-1} of rice (Table 5). The treatments of Pretilachlor(0.375 (kg a.i. ha^{-1})), Propanil + Thiobencarb(0.9 + 1.8 (kg a.i. ha^{-1}), weed-free, and Bensulfuron + MCPA (0.06 + 0.1 (kg a.i. ha^{-1}) generated the highest number of productive and total tillers hill^{-1} followed by the treatments of Propanil + Thiobencarb(1.2 + 2.4 (kg a.i. ha^{-1}), Propanil + Thiobencarb(0.6 + 1.2 (kg a.i. ha^{-1}), Pretilachlor(0.50 (kg a.i. ha^{-1}), and Pretilachlor (0.25 (kg a.i. ha^{-1}) under non-saline conditions. The lowest number of tillers were noticed under weedy check which was identically followed by Bensulfuron + MCPA (0.09 + 0.15 (kg a.i. ha^{-1}), and Propanil + Thiobencarb (1.8 + 3.6 (kg a.i. ha^{-1}). Under saline conditions, the highest numbers of tillers were found in weed free condition, identically followed by all other treatments except weedy check, Bensulfuron + MCPA (0.09 + 0.15 (kg a.i. ha^{-1}) and Propanil + Thiobencarb (1.8 + 3.6 (kg a.i. ha^{-1}). The lowest number of productive and total tillers hill^{-1} was found in weedy check which was followed by the treatment of pretilachlor (0.75 (kg a.i. ha^{-1})under salinity level of 8 dS m^{-1}. No tiller was produced under this saline conditions due to severe phytotoxicity of herbicides such as Bensulfuron + MCPA (0.09 + 0.15 (kg a.i. ha^{-1})and Propanil + Thiobencarb (1.8 + 3.6 (kg a.i. ha^{-1}). On the other hand, the weedy check produced less number of tillers due to severe competition from *C. iria*, *E. colona* and *J. linifolia*. The Bensulfuron + MCPA (0.045 + 0.075 (kg a.i. ha^{-1})and Bensulfuron + MCPA (0.03 + 0.05 (kg a.i. ha^{-1}) produced the lowest number of productive and total tillers compared to other treatments. Similar results have been reported by Awan et al. [27]. The results are also in harmony with those of [24,28,29].

Table 5. Effect of weed control treatments on number of tillers hill^{-1} under different salinity regimes.

Treatments (kg a.i. ha^{-1})	Salinity Levels (dS m^{-1})					
	Total Tillers			Productive Tillers		
	0	4	8	0	4	8
Weed free (hand weeding)	10.12 a	9.73 a	7.31 a	7.37 a	6.63 a	5.47 a
Pretilachlor (0.75)	8.73 b	7.94 b	5.51 b	6.15 b	5.17 b	3.69 c
Pretilachlor (0.50)	9.89 a	9.39 a	7.03 a	6.63 a	6.37 a	4.82 ab
Pretilachlor (0.375)	10.18 a	9.93 a	7.11 a	7.53 a	7.12 a	5.57 a
Pretilachlor (0.25)	9.98 a	9.51 a	7.00 a	6.63 ab	6.33 a	4.52 b
Propanil + Thiobencarb (1.8 + 3.6)	8.93 ab	0.0	0.0	6.04 b	0.0	0.0
Propanil + Thiobencarb (1.2 + 2.4)	9.99 a	9.76 a	6.97 a	6.71 ab	6.48 a	5.02 a
Propanil + Thiobencarb (0.9 kg + 1.8)	10.15 a	9.41 a	6.67 ab	7.18 a	6.67 a	5.15 a
Propanil + Thiobencarb (0.6 + 1.2)	9.95 a	9.35 a	7.04 a	7.02 a	6.57 a	4.57 b
Bensulfuron + MCPA (0.09 + 0.15)	8.23 b	0.0 c	0.0	5.58 b	0.0	0.0
Bensulfuron + MCPA (0.06 + 0.1)	10.02 a	9.73 a	7.31 a	7.35 a	6.73 a	5.47 a
Bensulfuron + MCPA (0.045 + 0.075)	8.53 b	8.04 b	5.71 b	6.30 b	5.24 b	3.84 c
Bensulfuron + MCPA (0.03 + 0.05)	9.89 a	9.49 a	6.93 a	6.33 b	6.47 a	4.72 ab
Weedy check	6.73 c	6.01 c	5.13 c	5.55 c	4.01 c	3.19 d

Means within same columns having similar lettering are non-significant (LSD, $p \leq 0.05$).

3.6. ChlSPAD Values

The leaf ChlSPAD values of rice under various levels of salinity were significantly influenced by the herbicidal treatments (Table 6). At 45 DAT, the highest ChlSPAD value ((37.1)) was observed in the weed-free treatment followed by Pretilachlor (0.375 kg a.i. ha^{-1}) under non-saline conditions, while the lowest ChlSPAD values (26.5) was found in Pretilachlor (0.75 kg a.i. ha^{-1}) followed by Propanil + Thiobencarb (1.2 + 2.4 kg a.i. ha^{-1}) (29.5) at the 8 dS m^{-1} salinity level. However, the differences among the treatments were statistically insignificant except in lethal dose. There were indications that the chlorophyll content was increased at 90 DAT which suggested that low chlorophyll content at 45 DAT might be due to the effect of herbicide which gradually recovered at maturity. At the maturity stage (90 DAT), higher ChlSPAD values was observed in the treatment of pretilachlor (0.375 kg a.i. ha^{-1}) in comparison with control (weed free) treatment under non-saline conditions, while the non-significant least ChlSPAD value(33.3) were recorded in the weedy treatment which was similar with all other herbicide treatments under saline conditions. Weeds generally compete with rice for water, light, physical space and nutrients. The rice plants under weedy conditions resulted in reduced growth and photosynthesis capacity. Reduction in chlorophyll content also results in lower photosynthesis capacity. These findings are in corroboration with those of [20,30], who observed less chlorophyll content under weedy environments and rice plants treated with various herbicides.

Table 6. Effect of weed control treatments on SPAD values of rice under different salinity regimes.

Treatments (kg a.i. ha^{-1})	45 DAT			90 DAT		
	Salinity Levels (dS m^{-1})					
	0	4	8	0	4	8
Weed free (hand weeding)	37.1 a	36.6 a	35.3 a	40.2 ab	38.8 a	36.1 a
Pretilachlor (0.75)	28.2 cd	27.8 b	26.5 c	36.7 b	36.4 ab	33.9 ab
Pretilachlor (0.50)	33.3 a–d	32.5 ab	31.7 abc	39.4 ab	37.9 a	34.8 a
Pretilachlor (0.375)	35.0 ab	34.5 a	33.8 ab	41.0 a	38.1 a	35.6 a
Pretilachlor (0.25)	33.8 abc	33.1 ab	32.3 abc	39.7 ab	38.2 a	34.9 a
Propanil + Thiobencarb (1.8 + 3.6)	28.3 cd	0.0	0.0	38.4 ab	0.0	0.0
Propanil + Thiobencarb (1.2 + 2.4)	31.7 bcd	30.9 ab	29.5 bc	39.1 ab	36.5 ab	33.8 ab
Propanil + Thiobencarb (0.9 kg + 1.8)	34.7 ab	34.1 a	32.4 abc	40.1 ab	37.6 a	34.0 ab
Propanil + Thiobencarb (0.6 + 1.2)	33.1 a–d	33.2 ab	31.9 abc	39.0 ab	38.4 a	35.8 a
Bensulfuron + MCPA (0.09 + 0.15 kg ai/ha)	27.9 d	0.0	0.0	36.3 b	0.0 b	0.0
Bensulfuron + MCPA (0.06 + 0.1)	35.0 ab	33.5 ab	32.6 abc	39.6 ab	36.7 ab	35.3 a
Bensulfuron + MCPA (0.045 + 0.075)	33.7 a–d	33.1 ab	32.2 abc	38.8 ab	36.8 ab	34.2 ab
Bensulfuron + MCPA (0.03 + 0.05)	32.1 a–d	31.4 ab	30.6 abc	37.5 ab	35.6 b	32.4 b
Weedy check	25.7 e	23.8 c	22.0 d	34.8 c	31.1 c	27.3 c

Means within same columns having similar lettering are non-significant (LSD, $p \leq 0.05$).

3.7. Grain Yield

Significant differences due to various herbicide treatments were examined for grain yield under various saline conditions (Table 7).The greatest grain yield (13.82 g hill^{-1}) was found in weed-free treatments that was comparable to Pretilachlor (0.375 kg a.i. ha^{-1}) (13.14 g hill^{-1}), while the lowest grain yield (3.05 g hill^{-1}) was noted in the weedy treatment under non-saline conditions. A similar trend was also observed for salinity levels of 4 and 8 dS m^{-1}. Treatments of Propanil + Thiobencarb (1.8 kg + 3.6 a.i. ha^{-1}) and Bensulfuron + MCPA (0.09 + 0.15 kg a.i. ha^{-1}) did not produce grain yields under saline conditions as the rice plants were completely died due to the combinedphytotoxic effects of herbicides and salinity stress. The results indicated that Pretilachlor (0.375 kg a.i. ha^{-1}), Propanil + Thiobencarb (0.9 + 1.8 kg a.i. ha^{-1}) and Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}) were superior in terms of yielding higher grain yield compared to other herbicidal treatments. Lower grain yield is attributed to decreased yield components, higher sterility percentage and higher weed biomass (data not presented here). The results are in harmony with the findings of many others [16,26,29] who also found that different herbicides affected yield components of rice which resulted in varying grain yields.

Table 7. Effect of weed control treatments on the grain yield (g hill^{-1}) of rice under different salinity regimes.

Treatments (kg a.i. ha^{-1})	Salinity Levels (dS m^{-1})		
	0	4	8
Weed free (hand weeding)	13.82 a	11.84 a	7.38 a
Pretilachlor (0.75)	9.09 cde	6.38 c	3.35 c
Pretilachlor (0.50)	11.54 a–e	9.82 ab	6.47 ab
Pretilachlor (0.375)	13.14 a	10.34 ab	7.29 a
Pretilachlor (0.25)	10.56 b–e	8.12 b	5.61 bc
Propanil + Thiobencarb (1.8 + 3.6)	8.44 de	0.0	0.0
Propanil + Thiobencarb (1.2 + 2.4	10.89 a–e	9.71 ab	5.37 bc
Propanil + Thiobencarb (0.9 kg + 1.8)	12.92 abc	9.98 ab	6.34 ab
Propanil + Thiobencarb (0.6 + 1.2)	11.85 a–d	9.93 ab	5.25 bc
Bensulfuron + MCPA (0.09 + 0.15)	7.65 e	0.0	0.0
Bensulfuron + MCPA (0.06 + 0.1)	12.85 abc	10.16 ab	6.78 ab
Bensulfuron + MCPA (0.045 + 0.075)	9.91 cde	8.55 b	6.34 ab
Bensulfuron + MCPA (0.03 + 0.05)	9.66 cde	8.33 b	5.09 b
Weedy check	3.05 f	2.14 d	0.97 d

Means within same columns having similar lettering are non-significant (LSD, $p \leq 0.05$).

4. Conclusions

Herbicides at recommended doses for non-saline conditions are not appropriate to rice crop under saline environment due to differential physiological responses of the crop and weeds although the weeds are controlled properly. Even lower doses of herbicides under saline condition can control weeds effectively since the weeds growth is discouraged by salinity, and the rice crop grows healthy. To mitigate environmental pollution and possible food contamination through inappropriate herbicides usages, the application of potent herbicide with its appropriate doses is essential for better outcomes in rice production and environmental protection. Pretilachlor (0.375 kg a.i. ha^{-1}), Propanil + Thiobencarb (0.9 +1.8 kg a.i. ha^{-1}), Bensulfuron + MCPA (0.06 + 0.1 kg a.i. ha^{-1}) and pretilachlor (0.50 kg a.i. ha^{-1}) performed better and seems promising herbicidal treatments in saline condition of Tanjun Kerang area of Malaysia. However, the rice farmers should conduct more trials to have recommendation for general adoption.

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