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EFFICACY OF HERBICIDES, THEIR EFFECTS ON RICE YIELD UNDER SATURATED SOIL CONDITION

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Abstract

This study was carried out in containers which were placed outdoor to evaluate the efficacy of different herbicides with different mixtures on weed growth suppression in rice and their effects on rice grain yield under saturated soil water regime in two consecutive seasons (cropping season and off season) at the Universiti Putra Malaysia Farm, Serdang, Selangor, Malaysia during 2016 to 2017. Eight combinations of different herbicides, *viz.* T1, T2, T3, T4, T5, T6, T7 and T8 along with weed free and non-weeded treatments were used in the study following a RCBD. Weed composition in the experimental containers and their summed dominant ratio (SDR) at 60 days after planting were recorded from non-treated containers. Naturally grown eleven weed species mainly under the families of Poaceae, Cyperaceae and Pontederiaceae were found in the experimental containers. Based on the SDR values the dominant weed species were *Monochoria vaginalis, Echinochloa crus-galli,* and *Fimbristylis miliacea* in both the seasons. Results revealed that four herbicide treatments *viz.* Pretilachor fb Bentazon/MCPA (T1), Pretilachor+Pyribenzoxim fb Bentazon/MCPA (T2). Bispyribac-sodium fb Bentazon/MCPA (T2), Fenoxaprop+Ethoxysulfuron (T3), fb Bentazon/MCPA (T7) were superior in their effectiveness for weed control in both seasons and gave better rice grain yield with high economic return.

Introduction

Protecting rice yields from the damage by weeds is one of the important issues in agriculture since rice (*Oryza sativa* L.) which feeds more of 2/3rd population of the world. Rice plays a vital role in food security, stability of socio-economic culture within the nation of many countries (Omar *et al.* 2019, Shah *et al.* 2019, Firdaus *et al.* 2020, Vinci *et al.* 2023). In Malaysia, this crop is grown mainly in eight rice granary areas in Peninsular Malaysia as wetland rice areas (Firdaus *et al. 2020*) and weeds are one of the great problems here to harvest a good yield. Currently, self-sufficiency of rice in Malaysia is approximately 70% and the country still has been importing rice grains from other countries to fulfil the needs of the people. Therefore, there is a need for more technological advancement to improve rice production in order to meet the demand in Malaysia.

Weeds are the major biotic constraint to increased rice production worldwide. The importance of their effective control for harvesting better yields has been narrated by many researchers (Anwar *et al.* 2012, Juraimi *et al.* 2013). Recently, chemical weed control has been emphasized due to labor shortages and adverse effects of wet climates on mechanical control, leading to an increased use of herbicides for rice cultivation. A good water management in terms of depth, time, and duration of flooding is an important factor influencing effective weed control in rice. Juraimi *et al.* (2009) explained that the yield was reduced more by weeds under saturated conditions compared to flooded conditions, and thus creating great variation in the floristic composition of weeds.

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The effective weed control in different water regimes requires proper herbicide application in respect of timing and method of application (Anwar *et al.* 2012). Application of dissimilar herbicide in the second sequence of first application and mixing more than one compatible herbicide was proved as a better option for weed management elsewhere (Newman and Busi 2016). Poor weed control is usually occurred if the conditions are not met. Hence, strategic planning is needed for using herbicides such as herbicide rotation and appropriate selection of herbicide mixtures to sustain its efficacy to control weeds and its economic impacts on the farmers. Very less research has been done in Malaysia on the effects of herbicide rotation and mixing of compatible herbicides to have better effects in weed control. With these backgrounds, this study was designed to assess the effect of selected herbicides and their mixtures on weed control efficiency (WCE) in rice fields, their impacts on rice grain yields and the economic benefits for the farmers from the selected treatments especially under saturated water regime.

Materials and Methods

The experiment was furnished in containers (25 cm X 30 cm) placed outdoor. The soil analysis was conducted to determine the soil properties (Table 1). Equal amount of water was applied using water in measuring jar to make the containers at saturated conditions. The soil moisture was measured using tensiometer and maintained same moisture level. The experiment

Table 1. Chemical characteristics of soil in the experimental containers.

					Exchangable- Cation		
Soil pH	CEC	Soil OC	Total N	Available P	K	Ca	Mg
	$cmol_c$/kg	(%)	(%)	mg/kg		$cmol_c$/kg	
5.18	7	4.9	0.31	65.79	0.1	1.54	0.68

CEC= Cation exchange capacity, OC= Organic carbon.

was laid out in randomized complete block design (RBCD) with three replications in two consecutive seasons (2015-2016). The rice seedlings at 14 days age were transplanted in the containers which were maintained under saturated condition. The study consisted of ten weed control treatments (Table 2). The herbicide mixtures were prepared by mixing the appropriate number of different herbicides as per specified doses in a container. The knapsack sprayer with adjustable flat fan nozzle, delivering 450 l/ha with spray pressure of 220 kPa was used for herbicide application. More or less equal number of herbicides was applied to each container by controlling the appropriate dose and the area covered by the herbicide spray. The area covered by the containers were estimated excluding the gaps between the containers and then spraying was done uniformly. All the infesting weed species were collected from each container, their number was recorded, identified species-wise and the biomass was recorded after drying for 72 hrs at 70°C in the oven. The summed dominant ratio (SDR) of the weeds species that infested the containers was determined according to Janiya and Moody (1989). Weed control efficiency of each treatment was calculated based on weed dry weight data (Hasanuzzaman *et al.* 2008). The crop was harvested at full maturity and after harvest, the yield components *viz.* the number of panicles m^{-2}, number of grains per panicle, number of filled and unfilled grains per panicle and 1000-grain weight were recorded. The final grain yields were recorded at 12% moisture level after air-dried properly. The cost-efficiency of various treatments were determined by economic analysis using the current market price of herbicides, labours, sprayer, etc. and sales revenues of rice grain (Hussain *et al.* 2008). Statistical analysis was done using SAS v9.4 software (SAS Institute Inc., Cary, USA) following one-way analysis of variance (ANOVA) for determination of significant differences between the treatments. Fisher's protected least significant difference (LSD) at the 5% (0.05) level of probability was used to determine where the difference was occurred.

Table 2. Details of the herbicide treatments used in the experiment.

Label	Treatment	Rate of Application	Time of Application
T1	Pretilachor, fb Bentazon/MCPA	0.5 kg ai ha^{-1}fb. 0.6/0.1 kg ai ha^{-1}	6 DAT, followed by 23 DAT
T2	Pretilachor+Pyribenzoxim, fb Bentazon/MCPA	0.3+0.02 kg ai/litre/ha kg ai ha^{-1}fb 0.6/0.1 kg ai ha^{-1}	6 DAT, followed by 23 DAT
T3	Bispyribac-sodium, fb Bentazon/MCPA	0.03 kg ai ha^{-1} fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T4	Pyrazosulfuron, fb Bentazon/MCPA	0.012-0.02 kg ai ha^{-1} fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T5	Penoxsulam fb Bentazon/MCPA	0.5-liter product/ha fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T6	Thiobencarb+Propanil, fb Bentazon/MCPA	6-liter product/ha fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T7	Fenoxaprop+Ethoxysulfuron, fb Bentazon/MCPA	0.5-0.8-liter product/ha fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T8	Fenoxaprop, fb Bentazon/MCPA	0.7-0.8-liter product/ha fb 0.6/0.1 kg ai ha^{-1}	14 DAT, followed by 33 DAT
T9	Weed-free check (manual weeding)		14 DAT, followed by every 15 DAT until 85 DAT
T10	Weedy check (no weeding & no herbicides)		

Results and Discussion

Results showed that 11 weed species belonging to five families infested the rice containers (Table 3). Weed species from Cyperaceae and Poaceae together accounted for 27 to 45% of total weed vegetation. The values of SDR of the weed species from high to low dominance was in the order of *Monochoria vaginalis* (Burm. f.) Presl > *Echinochloa crus-galli* (L.) Beauv > *Cyperus iria* L. > *Fimbristylis milliacea* (L.) Vahl > *Leptochloa chinensis* (L.) Nees. The ranking of weed types in rice fields in Penang state as recorded by Juraimi *et al.* (2011) under saturated condition was in the order of sedges>broadleaf weeds > grasses which might be due to difference in edaphic and climatic conditions of the area. The differences in weed composition and dominance pattern are possibly attributed to variation in temperature, cropping pattern, rainfall conditions, management methods, and weed seed banks in the experimental plots (Juraimi *et al.* 2010, Golmohammadi *et al.* 2017).

The findings revealed that herbicide treatments exhibited significant effects on WCE (Table 4). The application of pretilachlor as a pre-emergence herbicide at 6 DAT recorded the highest WCE as compared to other treatments. It is because of the fact that the pre-emergence herbicide is able to reduce the weed germination at the earliest stage before it competes with the crop and efficiently control the weed in saturated condition. Additionally, Pretilachor, fb Bentazon/MCPA and Pretilachor+Pyribenzoxim, fb Bentazon/MCPA exhibited insignificant differences at all time intervals for both seasons in terms of WCE. Therefore, Pretilachor can be applied without pyribenzoxim in order to reduce the herbicide cost and usage without affecting the WCE. High WCE value was also observed for the treatment of Fenoxaprop (T7 and T8). Fenoxaprop, a grass selective herbicide (graminicide) is preferred by rice growers having grass weeds problem in their fields because of its high selectivity towards grasses, but at the same time

Table 3. Weed composition and Summed dominance ratio (SDR) of weed species at 60 DAT in the main season and off season.

Weed type	Weed family	Main season	Off season
Grasses			
Echinochloa crus-galli (L.) Beauv	Poaceae	15.3 ± 0.3	11.9 ± 4.3
Leptochloa chinensis (L.) Nees	Poaceae	10.4 ± 1.2	16.5 ± 2.7
Echinochloa colona (L.) Link	Poaceae	5.2 ± 0.9	1.4 ± 0.8
Ischaemum rugosum Salisb	Poaceae	2.5 ± 0.7	2.2 ± 0.5
Oryza sativa complex (weedy rice)	Poaceae	3.5 ± 0.8	2.5 ± 0.7
Sedges			
Fimbristylis milliacea (L.) Vahl	Cyperaceae	10.7 ± 0.9	16.1 ± 2.2
Cyperus iria L.	Cyperaceae	13.1 ± 3.4	6.1± 0.5
Scirpus grossus L. f.	Cyperaceae	8.8 ± 2.2	10.6 ± 2.3
Broadleaf weeds			
Monochoria vaginalis (Burm.f.) Presl	Pontederiaceae	18.5 ± 4.5	21.2 ± 5.8
Ludwigia hyssopifolia (G. Don) Exell	Euphorbiaceae	3.9 ± 0.6	7.1 ± 2.4
Limnocharis flava (L.) Buchenan	Alismataceae	8.1 ± 1.6	4.4 ± 2.2

Table 4. Effects of herbicides application on weed control efficiency (%) in the rice cropping season and off season.

Herbicide treatments	Rice cropping season			Off season		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T1	92.33ab	96.00a	100.00a	100.00a	100.00a	100.00a
T2	91.33ab	94.33a	100.00a	89.00ab	98.33a	100.00a
T3	74.00abc	91.00a	93.33ab	67.00ab	79.33abc	82.33ab
T4	46.67c	49.00b	-27.33c	46.33c	57.00c	22.33c
T5	61.67bc	74.00ab	69.67ab	50.67b	60.33bc	-112.33c
T6	92.33ab	100.00a	90.67ab	72.67ab	85.00abc	89.00ab
T7	46.33c	58.33b	65.00ab	79.00ab	88.33ab	95.33ab
T8	49.67c	60.33b	60.67b	76.33ab	91.67a	84.33ab
T9	100.00a	100.00a	100.00a	100.00a	100.00a	100.00a
T10	0.0d	0.00c	0.00c	0.00c	0.00d	0.00c

In a column means followed by the same letter(s) donot differ significantly at 5% level by DMRT test. T1 = Pretilachor, followed by Bentazon/MCPA; T2 = Pretilachor+Pyribenzoxim, followed by Bentazon/MCPA; T3 = Bispyribac-sodium, followed Bentazon/MCPA; T4 = Pyrazosulfuron, followed by Bentazon/MCPA; T5 = Penoxsulam, followed by Bentazon/MCPA; T6 = Thiobencarb+Propanil, followed by Bentazon/MCPA;T7 = Fenoxaprop+Ethoxysulfuron, followed by Bentazon/MCPA; T8 = Fenoxaprop, followed by Bentazon/MCPA; T9= Weedy free check; T10= Weedy check

it produces low phytotoxicity to rice plants (Anwar *et al.* 2012). The Pyrazosulfuron, fb Bentazon/MCPA recorded the lowest WCE for both the seasons at 30 DAT indicating that the Pyrazosulfuron, followed by Bentazon/MCPA was not suitable in saturated condition, whereas this herbicide provided high WCE values in flooded rice fields (Pal *et al.* 2012). The Penoxsulam fb Bentazon/MCPA application in off season showed the lowest WCE value, indicating that this treatment failed to control weeds in saturated condition as well. Other remaining herbicide treatments exhibited an excellent weed control as they contained sedge/broadleaf herbicides and graminicide that were responsible for broad-spectrum weed control.

Evidently, a significant rice yield component (Table 5) and rice grain yields (Fig. 1) were observed in some weed control treatments in both the planting seasons. Regardless of planting season, the weed-free check recorded the highest rice yield (4.63 t/ha) whereas, the lowest was recorded in weedy check (2.5 t/ha). The treatments with successful weed control (high WCE values) obviously reduced the weed-crop competition and led to increase in the grain yields (Fig. 1). The herbicide treatments produced statistically similar grain yields to weed-free check, which was the consequence of higher WCE (Begum *et al.* 2008, Jaya Suria *et al.* 2011, Anwar *et al.* 2012). It can be mentioned here that the inter-specific competition between weed and crop reduced when the weeds were removed by proper herbicidal actions (Ashraf *et al.* 2018). Eventually, the crop plants utilized available resources more efficiently throughout the growth cycle and provided positive effects on crop yield (Gowda *et al.* 2009).

Table 5. Influence of herbicides application on yield components of rice in the main season and off season.

Herbicide treatments	Main Season 2015/2016				Off Season 2016			
	Panicle m^{-2}	Spikelet perpanicle^{-1}	Filled grains panicle^{-1}	1000-Grains weight (g)	Panicle m^{-2}	Spikelet perpanicle^{-1}	Filled grains panicle^{-1}	1000-Grains weight (g)
T1	430a	98ab	77abc	26.66ab	430ab	107abc	84ab	26.60abc
T2	412a	96ab	85abc	27.36a	425ab	106abc	79b	26.30c
T3	430a	100ab	82abc	26.50ab	430ab	103bc	81b	26.70abc
T4	453a	97ab	76bc	25.83b	440ab	102bc	83ab	26.66abc
T5	418a	97ab	78abc	25.90b	405b	97cd	84ab	27.53ab
T6	453a	106a	83abc	27.36a	450a	118a	93a	27.56a
T7	431a	100a	80abc	25.83ab	428ab	107abc	88ab	27.43ab
T8	468a	93ab	80abc	26.46ab	438ab	101bc	86ab	26.46c
T9	443a	101ab	86a	26.63ab	423ab	110ab	86ab	27.56a
T10	383a	74c	72c	25.80b	416ab	87d	64c	24.63d

In a column, values followed by the same letter(s) do not differ significantly at 5% level. T1 = Pretilachor, followed by Bentazon/MCPA; T2 = Pretilachor+Pyribenzoxim, followed by Bentazon/MCPA; T3 = Bispyribac-sodium, followed Bentazon/MCPA; T4 = Pyrazosulfuron, followed by Bentazon/MCPA; T5 = Penoxsulam, followed by Bentazon/MCPA; T6 = Thiobencarb+Propanil, followed by Bentazon/MCPA; T7 = Fenoxaprop+Ethoxysulfuron, followed by Bentazon/MCPA; T8 = Fenoxaprop, followed by Bentazon/MCPA; T9= Weedy free check; T10= Weedy check.

Among herbicide treatments, Pretilachor+Pyribenzoxim fb MCPA/Bentazon was found to be economic having the highest gross income and net benefits. Regardless of the herbicide prices, this herbicide selection appeared as the most economic due to its high WCE (> 90%) and low herbicide dosage. The Bispyribac-sodium, fb MCPA/Bentazon which produced a net benefit of RM 4,672/ha ranked as second most effective herbicide treatment with excellent weed control, WCE (> 80), and closely followed by Thiobencarb+Propanil, fb Bentazon/MCPA with the net benefit of RM 4,496/ha. The treatment of Thiobencarb+Propanil, fb Bentazon/MCPA with the cheapest herbicide price (RM 136/ha) was able to produce a high net benefit as well with high WCE (> 70%). These findings proved that herbicide efficacy along with herbicide price and application dose were important to determine the cost-effectiveness in rice farming. The weed-free

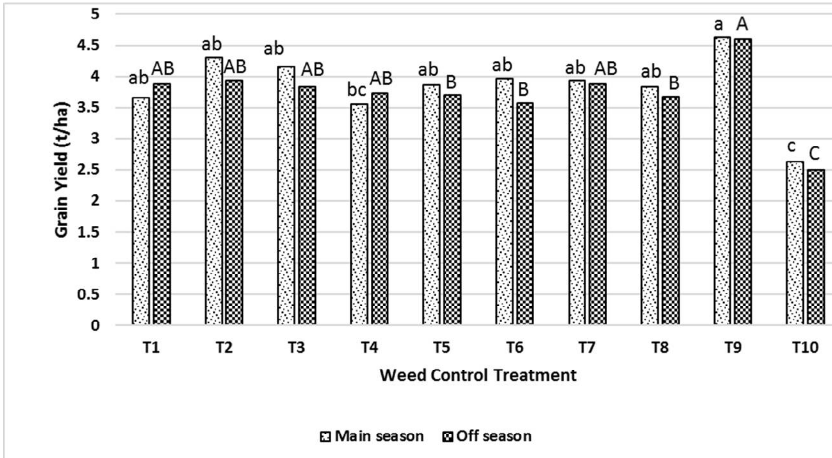

Fig. 1. Effect of herbicides application on rice grain yield. The lower-case letters compared the yields within main season, whereas the upper-case letters compared the yield within off season. Different letters suggest a significant difference between compared groups at α = 0.05 by LSD test. T1 = Pretilachor, followed by Bentazon/MCPA; T2 = Pretilachor+Pyribenzoxim, followed by Bentazon/MCPA; T3 = Bispyribac-sodium, followed Bentazon/MCPA; T4 = Pyrazosulfuron, followed by Bentazon/MCPA; T5 = Penoxsulam, followed by Bentazon/MCPA; T6 = Thiobencarb+Propanil, followed by Bentazon/MCPA; T7 = Fenoxaprop+Ethoxysulfuron, followed by Bentazon/MCPA; T8 = Fenoxaprop, followed by Bentazon/MCPA; T9= Weedy free check; T10= Weedy check.

Table 6. Cost effectiveness of various herbicide treatments (averaged over seasons).

Herbicide treatments	Herbicides cost (RM/ha)	Labour cost for spraying /weeding (RM/ha)	Total cost (RM/ha)	Gross income (RM/ha)	Net benefit (RM/ha)
T1	180.00	120.00	300.00	4,392.00	4,092.00
T2	178.00	120.00	298.00	5,160.00	4,862.00
T3	200.00	120.00	320.00	4,992.00	4,672.00
T4	233.00	120.00	353.00	4,272.00	3,919.00
T5	153.00	120.00	273.00	4,632.00	4,359.00
T6	136.00	120.00	256.00	4,752.00	4,496.00
T7	304.00	120.00	424.00	4,716.00	4,292.00
T8	174.00	120.00	294.00	4,596.00	4,302.00
T9	0.00	3,150.00	3,150.00	5,556.00	2,406.00
T10	0.00	0.00	0.00	3,156.00	3,156.00

T1 = Pretilachor, followed by Bentazon/MCPA; T2 = Pretilachor+Pyribenzoxim, followed by Bentazon/MCPA; T3 = Bispyribac-sodium, followed Bentazon/MCPA; T4 = Pyrazosulfuron, followed by Bentazon/MCPA; T5 = Penoxsulam, followed by Bentazon/MCPA; T6 = Thiobencarb+Propanil, followed by Bentazon/MCPA; T7 = Fenoxaprop+Ethoxysulfuron, followed by Bentazon/MCPA; T8 = Fenoxaprop, followed by Bentazon/MCPA; T9= Weedy free check; T10= Weedy check RM: Ringgit Malaysia. Market price of herbicide commercial products: Pretilachor (Sofit) = RM135/ha, Pretilachor+Pyribenzoxim (Solito) = RM 98/ha, Bispyribac-sodium (Nominee) = RM 120/ha, Pyrazosulfuron (Basmin) = RM153/ha, Penoxsulam (Rainbow) = RM 73/ha, Thiobencarb+Propanil (Satunil) = RM 55/ha, Fenoxaprop+Ethoxysulfuron (Tiller-G)= RM 130/ha, Fenoxaprop (Rumpas M)= RM94/ha, Bentazon/MCPA (Basagran) = RM 83/ha. Manual weeding cost: 15 laborers/ha for 7 weeding at RM30/laborer/day, herbicide application cost: 1 laborer/ha/round at RM30/laborer/day; market price of paddy: RM 1,200.00 t/ha, gross income= paddy yield (t/ha) x market price (RM t/ha) and net benefit = gross income – total cost.

check showed an excellent weed control with WCE (100%), however this method is not cost effective and not practical for managing a huge rice field due to higher laborour cost (RM 3150/ha), whilst the herbicide treatments were highly effective against broad spectrum of weeds and cost effective as well (Table 6). This finding is in agreement with the findings of Juraimi *et al.* (2010), who observed that good weed control can be achieved using the combination of herbicide treatments in minimal water condition. Therefore, it may be concluded that the application of herbicides has economic impacts to produce significantly higher net benefit as compared to manual weeding (Islam *et al.* 2000, Hussain *et al.* 2008). The herbicide rotation with different modes of action might aid to resist the evolved herbicide resistance. Thus, the herbicides that have been suggested in this study may perhaps be recommended in other research area, or even different countries that have a similar climatic condition and weed community. The different patterns of weed control depending on the climate, weed flora, water regimes showed that the management of weed in rice fields have to be used in rotation for the sustainability in weed management.

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