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Effects of different chemical herbicides and water application on the productivity and weed incidence of irrigated lowland rice (*Oryza sativa* L.)

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Abstract

Weed infestation causes great yield reduction in rice. However, application of herbicides under proper water management may control weeds and could increase the yield of irrigated lowland rice. This study aimed to determine the effects and appropriate water regimes and chemical herbicides; and assess the weed population and profitability ha^{-1} of using different chemical herbicides and water regimes in lowland rice production. The experiment was laid out in a nested design with complete block design in three replications. Different water regimes: M_1-continuous submergence at 5cm and M_2-Saturated condition as main plots and different herbicides as the sub plots T_0- Control (unweeded and no herbicide application), T_1- Butachlor, T_2- Propanil + Butachlor, T_3-Metsulpuron Methyl + Chlorimuron Ethyl, T_4- Butachlor + 2,4D, T_5- Cyhalofop butyl + Pyribenzoxim and T_6- Manual weeding at four weeks after transplanting. Results revealed that lowland rice under continuous submergence at 5cm significantly produced more number of productive tillers, 1,000 seed weight and resulted to the increased total grain yield (tha^{-1}). Application of chemical herbicides under different water regimes showed significant differences on the number of productive tillers, grain yield and harvest index. Moreover, rice plants treated with Butachlor + 2,4D (T_4) and Cyhalofop butyl + Pyribenzoxim (T_5) produced the highest grain yield of 7.78t ha^{-1} and 7.89t ha^{-1}, respectively. Lowest weed population of 3.50 was observed in plants applied Butachlor + 2,4D (T_4) while highest on Cyhalofop butyl + Pyribenzoxim (T_5). All chemical herbicide treatments had high weed control efficiency except Butachlor (T_1). Highest net income was observed in T_5 with a net income of PhP85,027.20 ha^{-1} that is equivalent to 46% higher than the control plants with a net income of PhP38,945.20 ha^{-1}.

Key words: submerged, saturated, herbicides, weeds and income

Introduction

Rice (*Oryza sativa* L.) is one of the important crop in Asian people. It is the staple food and considered as livelihood source of income for more than 100 million households in Asia and Africa (FAO 2004). In the Philippines, rice production is 7.16 million metric tons with the harvested area of 1,848 hectares during 2018 (PSA 2019). This production cannot meet our demand in the future with the increasing population and decreasing land area.

However, weed infestation causes great yield reduction in rice. According to Rao and Nagamani (2010), weeds can reduce the yield and quality of rice by competing for available resources, such as sunlight, water, nutrient, CO2 and spaces. Antralina et al (2011) reported that rice yield loss in System of Rice Intensification (SRI) which uses intermittent irrigation) was about 98.02%, while the yield loss in the conventional system was 74.03%.

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Many farmers do not realize that weed control is the most limiting factor in crop production. Traditionally, they depend on weed control practices including good land preparation, hand and mechanical weeding to remove weeds.

However, these methods comprise large amount of labor, time and money. Due to scarcity of labor at peak times of agricultural operations, different herbicide-based weed management technologies have been developed and utilized. Chemical weed control applied at pre-sowing, pre-emergence, early post-emergence and combinations of them are all against infestation (Barman et al 2016). Herbicidal weed management becomes a competitive and promising way to control weeds in transplanted rice. In rice production, the use of herbicides for controlling weeds has increased significantly because of increased labor wages, labor shortages and migration of labor to urban areas (Singh et al 2017; Mahajan et al 2014).

Aside from herbicide application, water management is also effective with the cheapest way of controlling weeds. According to Ismailia et al (2015), continuous flooding efficiently controls weed growth due to inability of weed seeds to germinate under anaerobic condition created by impounded water and suppression of already germinated weed seedlings. Moreover, weeds are significantly controlled by water depth. This study was conducted to determine the effects and appropriate water regimes and chemical herbicide; and assess the profitability ha^{-1} of using different chemical herbicides and water regimes in lowland rice production.

MATERIALS AND METHODS

The study was conducted in the experimental site of the Department of Agronomy, VSU, Visca, Baybay City, Leyte. An experimental area of 912m^2 was plowed and harrowed twice at weekly interval using hand tractor. After the last harrowing, the field was leveled and single dike was constructed to separate the main plots. Irrigation canals and drainage system were constructed to provide sufficient amount of water to the field.

Figure 1. A map of Leyte showing the location of the research site at Visayas State University (www.mapsofworld.com).

Experimental Design and Treatments

The experimental area was laid out in a nested design with complete block in three replications. Each plot measured 5m x 3m (15m2). Treatments were designated as follows: M_1- continuous submergence at 5cm and M_2-saturated condition as main plots and different herbicides as the sub plots T_0- Control (unweeded and no herbicide application), T_1- Butachlor, T_2- Propanil + Butachlor, T_3- Metsulpuron Methyl + Chlorimuron Ethyl, T_4- Butachlor + 2,4D, T_5- Cyhalofop butyl + Pyribenzoxim and T_6- Manual weeding at four weeks after transplanting.

Soil Chemical Properties

Ten (10) soil samples were randomly collected at 20cm deep in the experimental area. These were composited, air dried, pulverized and sieved using 2 mm wire mesh. The samples were analyzed at the Central Analytical Services Laboratory (CASL), Philrootcrops, Visayas State University, Visca, Baybay City, Leyte for its soil pH using Potentiometric method of 1:2.5 soil water ratio (Jackson 1974), % organic matter by modified Walkley and Black method (Nelson & Sommers 1982), total N (%) using kieldahl method (ISRIC 1995), available P by Modified Olsen method (Olsen & Sommer 1982), and exchangeable K by ammonium Acetate Extraction method (ISRIC 1995). For final soil analysis, samples were collected again from each treatment plot right after harvesting and compositing. These soil samples were analyzed for the same soil parameters mentioned above.

Cultural Management Practices

Wet seedbed was constructed at 1m x 6.5m. Rice seeds of NSIC Rc222 variety at 2.5kg were used. Complete fertilizer at the rate of two (2) tablespoon m^{-2} was applied on the seedbed a day before sowing. Fifteen-day-old seedlings were transplanted at the rate of 2 seedlings hill-1 at a distance of 20cm x 20cm between hills and rows. The fertilizer rate used was 120-60-60kg ha^{-1} N, P_2O_5 and K_2O as per regional recommendation. Golden apple snails (kuhol) and their egg masses were controlled by handpicking before and after transplanting. Rodents were controlled using zinc phosphide during panicle initiation and booting stage. Rice plants within the harvestable area were harvested when approximately 85% of the grains in each panicle were ripened as indicated by yellow color, firm matured and hard grains. All sample plants in the harvestable area excluding two border rows and one end plant in each row were cut at the base of the plants with the use of sharp sickle.

Herbicide Application

Table 1. Time of herbicide application

Herbicide	Time of Application
T_1-Butachlor	2 days before transplanting
T_2-Propanil + Butachlor	2 days before transplanting
T_3-Metsulpuron Methyl + Chlorimuron Ethyl	20 days after transplanting
T_4-Butachlor + 2,4D	2 days after transplanting
T_5-Cyhalofop-butyl + pyribenzoxim	20 days after transplanting

Water Application

Continuous Submergence at 5cm (M_1). The rice field was continuously submerged with 3cm water depth. Saturated Condition (M_2). The soil was kept saturated but not flooded. This was done by allowing the entry of water but immediately drained to prevent flooding.

Data Gathered and Analysis

For yield and yield components, the following parameters were gathered: number of productive tillers, number of filled grains panicle^{-1} percent (%) fertility, weight of 1000 grains (g) and grain yield (t ha^{-1})**.** For weed data, the following parameters were gathered: identification of prevalent weed species, weed population quadrat^{-1}, and weed control efficiency. Other parameters gathered were the following: harvest Index, soil chemical properties and profitability analysis. Data were analyzed using the Statistical Tool for Agricultural Research (STAR). Mean comparison was

Results and Discussion

Soil Chemical Properties

Table 2 presents the initial and final soil analysis of rice as influenced by herbicides and water applications. Results showed that the area had a pH of 5.35 with organic matter of 4.05%, total N of 0.26%, available P of 8.50mgkg-1 and exchangeable K of 0.43me 100g-1 soil (Table 2). The data indicated that the soil was strongly acidic with medium amount of organic matter, total nitrogen and exchangeable K but low available phosphorus (Landon 1991).

Final soil analysis indicated that in continuous submergence at 5cm soil pH, OM, total N, available P and exchangeable K are still the same from the initial analysis except for T_0 in which the pH values had slightly decreased and in the saturated condition soil pH has also decreased, after harvest of the rice crop. This might be due to the utilization of nutrients by the crop. Organic matter, total N, available P, and exchangeable K are more or less the same relative to initial analysis.

Table 2. Soil test results before and after planting of rice under submerge and saturated water regimes

Treatment	**Soil pH**	**OM (%)**	**Total N (%)**	**Avail P ($Mg\ Kg^{-1}$)**	**Exch K ($Me\ 100g^{-1}$)**
Initial Soil Analysis	5.35	4.05	0.26	8.50	0.43
Final Soil Analysis					
Submerged at 5cm					
T_0- Control (unweeded and no herbicide application	4.90	4.45	0.21	8.07	0.32
T_1- Butachlor	5.00	4.45	0.21	8.07	0.32
T_2- Propanil + Butachlor	5.04	4.33	0.17	6.68	0.28
T_3- Metsulpuron Methyl + Chlorimuron Ethyl	5.04	4.32	0.25	6.19	0.16
T_4- Butachlor + 2,4D	5.16	4.17	0.25	7.26	0.22
T_5- Cyhalofop butyl + Pyribenzoxim	5.04	4.34	0.25	6.92	0.25
T_6-Manual weeding at 4 weeks after transplanting					
Saturated					
T_0- Control (unweeded and no herbicide application	4.81	4.51	0.28	9.21	0.34
T_1- Butachlor	4.66	4.69	0.25	7.17	0.44
T_2- Propanil + Butachlor	4.86	4.68	0.23	7.24	0.48
T_3- Metsulpuron Methyl + Chlorimuron Ethyl	4.79	4.72	0.27	8.32	0.25
T_4- Butachlor + 2,4D	4.73	4.66	0.25	9.92	0.19
T_5- Cyhalofop butyl + Pyribenzoxim	4.68	4.62	0.24	8.91	0.39
T_6-Manual weeding at 4 weeks after transplanting	4.65	4.47	0.26	5.95	0.16

Yield and Yield Components and Harvest Index

Yield and yield components as well as harvest index of lowland rice (NSICRc222) as influenced by the water regimes and chemical herbicides are presented in Table 3. Plants under continuous submergence at 5cm produced high number of productive tillers, weight of 1000 grains (g) and grain yield (t ha^{-1}) compared to those in saturated condition. It is because continuous submergence at 5cm helped control the weeds early which minimized the weed competition that resulted in high number of productive tillers, weight of 1000 grains (g) and grain yield (t ha^{-1}).

Table 3. Yield, yield components and harvest index of lowland rice (NSIC Rc222) as influenced by water regimes and chemical herbicides

Treatments	**Number of**		**Percent Fertility**	**Wt. of 1000 Grains (g)**	**Grain Yield (t ha^{-1})**	**Harvest Index (HI)**
	Productive Tillers	**Filled Grains**				
Water regimes						
Submerged at 5cm	13.11a	116.29b	61.23b	27.47a	7.54a	0.53
Saturated	10.90b	130.14a	75.30a	26.47b	5.82b	0.54
C.V. %	*1.01*	*1.31*	*1.41*	*1.40*	*13.44*	*2.74*
Chemical herbicides						
T_0	10.60b	124.22	67.80	27.20	5.11bc	0.52ab
T_1	10.72ab	128.48	72.05	26.70	6.08b	0.55ab
T_2	11.33ab	120.77	63.83	27.07	6.72b	0.50b
T_3	13.63a	113.63	67.42	25.97	6.39b	0.54ab
T_4	13.58a	124.03	66.40	27.18	7.78a	0.53ab
T_5	12.18ab	124.82	68.96	27.42	7.89a	0.54ab
T_6	12.00ab	126.55	71.40	27.27	6.78b	0.56a
C.V.%	*13.18*	*11.14*	*10.72*	*3.49*	*17.87*	*5.30*

Columns having the same letter(s) are not significantly different from each other at 5% level of significance

Legend: T_0-Control (Unweeded and no herbicide application), T_1- Butachlor, T_2- Propanil + Butachlor, T_3- Metsulpuron Methyl + Chlorimuron Ethyl, T_4- Butachlor + 2,4D, T_5- Cyhalofop butyl + Pyribenzoxim, T_6- Manual weeding at 4 weeks after transplanting

These results were similar with Mubeen (2014) that high number of productive tillers were observed when weed competition was minimal in which available resources needed for the growth and development of the crops were utilized efficiently. Mubeen (2014) added that when weeds competed with crop until harvest, it significantly reduced the number of productive tillers. Juraimi et al (2009) reported that higher 1000-grain weight was obtained under all the flooded condition compared to continuous field capacity. In addition, 1000-grain weight varied significantly with water management, where lower grain weight was observed under the field capacity condition as compared to flooded conditions (Sariam 2004). Moreover, high grain yield was obtained in continuous submergence at 5cm condition which significantly produced 7.54t ha^{-1} than those in saturated condition which only produced 5.82t ha^{-1}. Ahmed et al (2014) stated that the better water management, the higher grain yield. Sufficient amount of water is significant for growth and development of plants. It is a major constituent of tissues, reagent in chemical reactions, solvent and mode of translocation for metabolites and minerals within plants and essential for cell enlargement through increasing turgor pressure (Farooq et al 2006). Juraimi et al (2009) reported that continuous flooding favors rice growth and produces maximum rice yield. However, high weed competition was observed in saturated condition that resulted in lower number of productive tillers, weight of 1000 grains and yield, because weeds competed with the available resources such as water, nutrients, light CO2 and spaces. According to Mahajan et al (2014), weed competition caused significant reduction in grain yield of rice genotypes. Application of Metsulpuron Methyl + Chlorimuron Ethyl (T_3) and Butachlor + 2,4D (T_4) produced the highest number of productive tillers of 13.63 and 13.58, respectively. This implies that these herbicides were effective in controlling weeds infestation, reduced weed competition, thus produced higher number of productive tillers but was statistically comparable with T_1, T_2, T_5 and T_6. Kumawat et al (2018) reported that metsulfuron methyl + chlorimuron ethyl applied at 20 DAS also showed better suppression of weeds. Singh et al (2006) reported that pre-emergence application of butachlor along with 2, 4–D (1.5 + 0.5kg ha^{-1}) followed by one hand weeding were effective ways to minimize weed competition and enhance grain yield of rainfed lowland rice. Nasimulbari (2010) added that butachlor provided better weed control efficiency and contributed to better crop growth and grain yield compared to other treatments.

In terms of grain yield, application butachlor + 2,4D (T_4) and Cyhalofop-butyl + Pyribenzoxim (T_5) produced higher grain yield of 7.78t ha^{-1} and 7.89t ha^{-1}, respectively, and were both statistically comparable to T_1, T_2, T_3 and T_6. This indicates that the herbicide is proven effective in controlling weeds which helped produce high yield among the other herbicide-tested. This result is similar with Swapan and Mukherjee (2009), that application of butachlor + sequential application of 2, 4-D at 0.5kg ha^{-1} a.i on 40 DAS recorded highest grain yield of 4.36t ha^{-1}. In addition, application of butachlor at 1.5kg a.i. ha^{-1} as pre-emergence + 2, 4-D at 0.5kg ha^{-1} as post-emergence herbicide produced grain yield similar to hand weeding twice at 30 and 50 DAT (Singh et al 2004). Application of Metsulfuron methyl + Chlorimuron ethyl was effective against the control of broadleaves and sedges (Singh et al 2003). Singh et al (2007) added that Metsulpuron Methyl + Chlorimuron Ethyl at eight (8) g ha^{-1} a.i was found significantly superior in reducing the population of all types of weeds with higher weed control efficiency of 97.2% for broadleaves, 60.0% for sedges and 21.6% for grasses which were related to increase in yields.

Harvest index was significantly affected by different chemical herbicides. High harvest index was obtained in almost all treatment plants except plants applied with propanil + butachlor (T_2). Herbicide-treated plants were significantly comparable to untreated plants as control (T_0). High harvest index could have been attributed to high grain yield produced. Result of Kiasari et al (2018); Talla (2018); and Mirza (2008) showed that application of different chemical herbicides and manual weeding produce comparable harvest index in rice.

Weed Parameters

Data on weed species are presented in Tables 4 & 5. The major weed species observed in the experimental areas belongs to various weed species of grasses, sedges and broadleaves as shown in Table 4. Weeds have higher ability to absorb nutrients and moisture than many of our crop plants and accumulate them in their tissues in relatively large amount (Hasanuzzaman 2015). Moreover, absence of early weed competition improves crop growth and development which also improves the yield.

Table 4. Weed species observed during the entire growth of lowland rice as influence by water regimes and chemical herbicide

Weed Category	Common Name	Local Name	Scientific Name	Family	Life Cycle
Grasses	Jungle rice	Dukayang`	*Echinochloa colona* L.	Poaceae	Annual
	Ribbed murain grass	Bika-bika	*Ischaemum rugosum* S.	Poaceae	Annual
	Barnyard grass	Humay-humay	*Echinochloa crus-galli* L.	Poaceae	Annual
Broadleaf	Pickerel weed	Gabi-gabi	*Monochoria vaginalis*	Pontederiaceae	Annual, Perennial
	Goose weed	Mais-mais	*Sphenoclea zeylanica* G.	Sphenocleaceae	Annual
	Primrose willow	Kahoy-kahoy	*Ludwidia octovalvis*	Onagraceae	Annual, Perennial
Sedges	Tall fringe rush	Bungot-bongot	*Fimbristylis dichotoma L.*	Cyperaceae	Annual
	Flat sedge	-	*Cyperus compactus R.*	Cyperaceae	Perennial

Weed data of lowland rice (NSIC Rc222) as influenced by water regimes and chemical herbicide is presented in Table 5. Result showed that only weed population was significantly affected by water regimes. While, application of different chemical herbicide significantly affected the weed population and weed control efficiency. Escasinas (2009) stated that keeping the soil saturated but not flooded had more weed growth which led to higher crop-weed competition. Likewise, Itang (2014) reported that saturated plots had significantly higher weed population and consequently higher fresh and dry weight of weeds quadrat^{-1} compared to plots under continuous flooding.

Among weed control treatments, results showed that T_0- Control plots (unweeded and no herbicide application) statistically had the highest weed population. Application of Butachlor + 2,4D (T_4) had the lowest weed population comparable to Cyhalofop butyl + Pyribenzoxim (T_5). Singh et al (2016); Prakash et al (2013) reported that maximum reduction in weed density and dry weight of weeds were obtained with application of Butachlor 50% EC 4000g ha^{-1} and Butachlor 1500g ha^{-1} over weedy check (control). Datta (2017) added that application of 2, 4D at 80% EC had the lowest weed population of grasses, sedges and broadleaf. In weed control efficiency, the result revealed that all chemical herbicide treatments and manual weeding at four weeks after transplanting obtained high weed control efficiency except for Butachlor (T_1) and the control (T_0) that obtained a lowest weed control efficiency. Chauhan (2012) stated that the use of single herbicide could not provide effective weed control due to a diverse weed species in the field. Busi et al (2014); Owen and Powles, (2009) added that the use of herbicides with different modes of action is advisable to avoid herbicide resistance in weeds.

Table 5. Weed data of lowland rice (NSIC Rc222) as influenced by water regimes and chemical herbicides

Treatments	**Weed Population**	**Weed Control Efficiency (%)**
Water regimes		
Submerged at 5cm	7.29a	60.60
Saturated	14.71b	49.96
C.V. %	*17.71*	*12.85*
Chemical herbicides		
T_0- Control (Unweeded and no herbicide application)	27.83c	1.0c
T_1- Butachlor	9.33b	29.40b
T_2- Propanil + Butachlor	15.00b	52.48ab
T_3- Metsulpuron Methyl + Chlorimuron Ethyl	10.50b	56.42a
T_4- Butachlor + 2,4D	3.50a	68.92a
T_5- Cyhalofop butyl + Pyribenzoxim	6.00a	61.41a
T_6- Manual weeding at four (4) weeks after transplanting	4.83a	73.06a
C.V. %	*22.86*	*21.79*

Columns having the same letter(s) are not significantly different from each other at 5% level of significance

Profitability Analysis

Results of profitability analysis of lowland rice (NSIC Rc222) as influenced by water regimes and chemical herbicides is presented in Table 6. Highest net income of PhP85,027.20 ha^{-1} and PhP83,525.20 ha^{-1}was obtained with application of Cyhalofop-butyl + pyribenzoxim (T_5) and Butachlor + 2,4D (T_4) due to higher grain yield. This is followed by the application of Propanil Butachlor (T_2) with a net income of PhP65,425.20 ha^{-1}. Manual weeding at four weeks after transplanting (T_6) had a net income of only PhP62,835.20 ha^{-1}. On the other hand, plants in T_0- Control (unweeded and no herbicide application) had lowest net income of PhP38,945.20 ha^{-1}. This was attributed to lower grain yield. Meanwhile, continuous submergence at 5cm water regime obtained a higher net income of PhP78,542.49^{-1}. This was due to high total grain yield obtained than the saturated condition which only had a net income of PhP 50,202.49^{-1}.

Table 6. Profitability analysis of lowland rice (NSIC Rc222) as influenced by water regimes and chemical herbicides

Treatments	Grain Yield (tha^{-1})	Gross Income (Php ha^{-1})	Production Cost (Php ha^{-1})	Net Income (Php ha^{-1})
Water regimes				
Submerged at 5cm	7.54	128,180.00	49,637.51	78,542.49
Saturated	5.82	98,940.00	48,737.51	50,202.49
Chemical herbicides				
T_0- Control (unweeded and no herbicide application)	5.11	86,870.00	47,924.80	38,945.20
T_1- Butachlor	6.08	103,360.00	48,905.80	54,454.20
T_2- Propanil Butachlor	6.72	114,240.00	48,814.80	65,425.20
T_3- Metsulpuron Methyl + Chlorimuron Ethyl	6.39	108,630.00	48,404.80	60,225.20
T_4- Butachlor + 2,4D	7.78	132,260.00	48,734.80	83,525.20
T_5- Cyhalofop butyl + pyribenzoxim	7.89	134,130.00	49,102.80	85,027.20
T_6- Manual weeding at four (4) weeks after transplanting	6.78	115,260.00	52,424.80	62,835.20

Calculation of gross income is based on the current price of dried palay at PhP17kg^{-1}

Conclusion

Rice plants grown in continuous submergence at 5cm significantly increased the productive tillers, weight 1000 grains (g), and grain yield (t ha^{-1}). On the other hand, those under saturated conditions significantly produced a greater number of filled grains and high percent fertility. Moreover, application of different chemical herbicides significantly increased the number of productive tillers, grain yield (t ha^{-1}) and harvest index when the rice plants were planted under continuous submergence at 5cm. Rice plants applied with Butachlor + 2, 4D (T_4) and Cyhalofop butyl + Pyribenzoxim (T_5) under continuous submergence at 5cm obtained the highest grain yield but statistically comparable to T_1, T_2, T_3 and T_6. Lowest weed population occurred under continuous submergence at 5cm. Likewise, unweeded and no herbicide application as control plot (T_0) obtained the highest weed population. Among the chemically treated plants, Butachlor + 2,4D (T_4) had the lowest weed population comparable to Cyhalofop butyl + Pyribenzoxim (T_5). All chemical herbicide treatments had high weed control efficiency except Butachlor (T_1). Application of Butachlor + 2,4D (T_4) and Cyhalofop butyl + Pyribenzoxim (T_5) obtained a favorably higher net income of PhP83,525.20^{-1} and PhP85,027.20^{-1} respectively, while T_0-Control (unweeded and no herbicide application) had the lowest net income due to lower grain yield.

Recommendations

Application of Butachlor + 2,4D (T_4) and Cyhalofop butyl + Pyribenzoxim (T_5) under continuous submergence at 5cm is recommended for optimum rice production. It is recommended that a similar study will be conducted on a different season to verify further the results of this study and monitor the amount of water use in the two water regime treatments to verify the amount of water saved in growing rice.

Conflict of Interest

The authors declare that there are no conflict of interest.

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