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Influence of Weed Control Techniques on Weeds, Yield, and Economics of Dry Direct-seeded-Drip-irrigated Rice under Philippine Conditions

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The use of herbicides in combination with hand weeding has been shown to be effective against a variety of weeds in irrigated and rainfed wet direct-seeded rice in the Philippines. In the case of dry direct-seeded-drip-irrigated rice; however, these aspects are not known. A study was conducted to determine the influence of two weed control techniques on weeds, yield, and economics of dry direct-seeded-drip-irrigated rice under Philippine conditions. Four treatments – [T1] unweeded; [T2] application of pre-emergence herbicide using pretilachlor, followed by two times hand weeding; [T3] application of post-emergence herbicide using bispyribac-sodium, followed by two times hand weeding; and [T4] weed-free using the sequential application of pre- and post-emergence herbicides followed by six times hand weeding – were tested and arranged in RCBD with three repetitions. T1 has the highest weed density and biomass with lower grain yield (901.8 kg ha^{-1}) but no net income. T2 and T3 had lower weed biomass than T1 but could not be compared with T4, where no weed density and biomass were recorded at 15, 30, and 45 DAS (days after seeding) in both dry and wet seasons. Grain yields at T2 (3,794.4 kg ha^{-1}) were not significantly different from T3 (4,341.3 kg ha^{-1}) except when compared with T4 (5,7245 kg ha^{-1}). Net income in T2 was higher by PHP 20,575.1 over T1 and T3 by PHP 9,831.4 over T2. T4 had the highest grain yield among all treatments and achieved an advantage of PHP 45,272.1, 24,697.0, and 14,865.7 over T1, T2, and T3, respectively, in terms of net income. Herbicide application followed by hand weeding reduced weed growth and improved rice yield and net income. The combination of pre- and post-emergence herbicides followed by six times hand weeding was much more effective at suppressing weeds and achieving higher grain yield and net income.

Keywords: drill-seeding, drip irrigation, weed control efficiency, weed diversity

INTRODUCTION

Rice is the most important food and economic crop in Asia, producing 90% of global rice production (GRiSP 2013). In the Philippines, it has been ranked first among the staple foods and widely grown crops. In 2020, 35.2% of the country's 13.4 M ha agricultural areas were solely devoted to rice. In the same year, *palay* harvest was 19.3 M metric tons valued at PHP 318,711,000 (PSA 2021). The country's population is expected to grow in the coming decades, putting pressure on growing more rice. This situation is exacerbated by the decreasing supply and increasing costs of irrigation water, threatening food security. Therefore, the Philippine government is making more efforts to meet

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the growing demand of consumers and help farmers cope with the shortage of water for rice production. One of the strategies is to improve the productivity of rainfed-lowland areas that are often characterized by low yields due to a variety of abiotic stresses such as drought (Ohno *et al*. 2018). One of the promising methods in rice farming is to change the traditional transplanting method that requires submerged conditions, from soaking the soil to growing plants in partially or even fully aerobic rice field conditions (Bouman *et al*. 2007). This system known as aerobic rice production is a method of growing rice in well-drained, non-puddled, and non-saturated soil conditions. This is suitable for areas where water is scarce and barely managed, such as wheat or maize (Bouman 2008). The common farming method of crop establishment is dry direct-seeding.

Dry direct-seeding is a type of establishment wherein rice seeds are sown directly onto the puddled dry or moist soil either by manual broadcasting, row seeding, or drill seeding (Balasubramanian and Hill 2002). In the Philippines, this type of rice establishment is commonly practiced in areas with very limited water availability (*e.g.* rainfed lowland and upland areas) (Pandey and Velasco 2002). Dry direct-seeding is very susceptible to weed infestation because there is no flooding to suppress weeds in the initial flush, a lack of advantage in terms of seedling size that can compete with weeds, and uneven crop stands that provide space for weed growth. In fact, previous reports have shown that uncontrolled weed growths reduce the yield of dry direct-seeded rice by up to 72% (Singh *et al*. 2016). However, despite the threat, there are a number of weed management options that can be used to control weeds in dry direct-seeded rice – for example, proper tillage, planting of weed-competitive varieties, optimal spacing and seeding rates, crop residues, water management, manual weeding, and herbicide application (Donayre *et al*. 2018; Chauhan 2012).

Herbicide spraying and hand weeding are two of the most common weed management techniques used by farmers in the Philippines (Beltran *et al*. 2016; Donayre *et al*. 2014). Many farmers use hand weeding because of its immediate availability in implementation and suitability in small-scale rice fields. Similarly, farmers prefer herbicides because they are easy to use, require little effort, give immediate results, and are suitable for large-scale rice fields. Previous reports have shown that the combination of the two techniques has more influence on weed flora and rice yield. For example, pre-emergence or post-emergence followed by hand weeding lessens the numbers of different weed species and improved the yield of manually seeded rainfed rice (Donayre *et al*. 2021; Bhurer *et al*. 2013; Anwar *et al*. 2012). In dry-direct seeding, comparable yields to transplanted rice in irrigated areas can be achieved, when water and weeds can be controlled (Sharma *et al.* 2005).

The use of drip irrigation on dry-direct seeded rice can help overcome the water shortage for irrigation during crop growth. Drip or trickle irrigation is a localized irrigation system that consists of dripping the water onto the soil and near plants at a very low rate from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers (Chapman 2019). It differs from surface irrigation and sprinkler irrigation, in that both systems involve wetting the entire soil surface. Using drip systems, drip irrigation has been shown to save up to 70% of water and increase fertilizer use efficiency by 30% (Chapman 2019; Shareef and Ma 2019). Drip irrigation has been shown to be very useful for growing rice in other countries (Bozkurt Colak 2021; Arbat *et al*. 2020; Sharda *et al.* 2016; Rajwade *et al*. 2018; Parthasarathi *et al*. 2018). In the Philippines, however, the potential of this type of irrigation has not been fully exploited, particularly for dry direct-seeded rice.

Knowledge of the impact of any weed control intervention on weed population dynamics is essential for predicting ecological changes in the field (Moody 1996), especially when new water management technique is introduced, such as drip irrigation. It is also essential to refine control techniques to avoid weed shifts and complexities in weed management strategies. The influence of combined effects of herbicide application and manual weeding on weed diversity and dominance, as well as on rice yield are known in wet direct-seeded rice grown under irrigated and rainfed-lowland conditions in the country (Donayre *et al*. 2021; Pascual *et al*. 2020). However, in the case of dry direct-seeded-drip-irrigated rice, these aspects are still unknown. Therefore, this study hypothesized that the application of a combination of herbicides and manual weeding interventions had a significant influence on weed flora, density, and biomass – as well as grain yield and economics of dry direct-seeded-drip-irrigated rice under Philippine conditions.

MATERIALS AND METHODS

Field Description

Field experiments were conducted at the experimental farm of Philippine Rice Research Institute (PhilRice) (15˚40'N, 120˚53 E), Science City of Muñoz, Nueva Ecija for the dry (December 2019–April 2020) and wet (June–October 2020) seasons. The soil texture in the area was sandy clay loam with 27.10% sand, 20.31% silt, and 52.52% clay. The area was previously used as a production plot for irrigated lowland rice in both wet and dry seasons. Weather conditions during the dry season had 21.8 mm total rainfall, 21.2 and 31.9 °C min and max temperatures, and 18.5 MJ/m^2 solar radiation; the wet season had 2042.6

mm total rainfall, 24.7 and 33.8 °C max temperature, and 17.3 MJ/m^2 solar radiation.

Experimental Treatments and Design

The experiment was arranged in a randomized complete block design with three replicates. Twelve (12) plots measuring 5 m x 6 m were prepared as the experimental units. The units were divided and assigned to four treatments: [T1] unweeded; [T2] application of pre-emergence herbicide using pretilachlor (300 g a.i. ha^{-1} applied 2–3 d after seeding), followed by two times hand weeding (25–30 and 40-45 d after seeding); [T3] application of post-emergence herbicide using bispyribac-sodium (26 g a.i. ha^{-1} applied 12–15 d after seeding), followed by two times hand weeding (25–30 and 40–45 d after seeding), and [T4] weed-free, a combination of T2 and T3 followed by six times hand weeding (25, 30, 35, 40, 45, and 50 d after seeding). All the herbicides were applied using a battery-operated 16-L capacity knapsack sprayer.

Crop Management

The whole experimental field area was prepared dry by plowing once, rotavating 2–3 times, and leveling once using a four-wheel tractor with an attached rotavator and leveler to achieve well-pulverized soil. After 2 wk, a drought-resistant inbred variety (NSIC Rc 222) was dry-seeded using a hand-tractor-drawn multipurpose-seeder at a 60 kg ha^{-1} seeding rate (Bautista *et al*. 2019). Compacted bunds and canals spaced at 0.5 m between plots as buffer zones were constructed to reduce seepage between plots during irrigation.

A drip irrigation system was installed after visible seedlings were observed to facilitate the layout of the drip lines spaced at 60 cm along the lateral line (Figure 1). The source of irrigation came from a 1000-L water tank placed on a three-meter platform. The tank had a floating valve inside that facilitates the automatic refill of water times the volume of water dropped to the 900-L meter mark. The main source of water came from a deep well-located 300 m away from the field experiment and connected to the water tank through a series of pipes. From the tank, PVC pipes as the mainline were connected to lateral lines to distribute water to the drip lines. The drip line consisted of equally spaced 30-cm-apart emitters and had a discharge rate of 1.65 L h^{-1}. In each block, one tensiometer was installed at 15 cm below the soil surface to facilitate the time of water introduction using the drip irrigation system. Drip irrigation was done whenever the tensiometer reading dropped to 30, 20, and 10 kPa at tillering, heading, and flowering stages, respectively (Belder *et al*. 2005; Bouman *et al*. 2007). The drip irrigation was stopped when the tensiometer reading dropped to a wet indicator (0–5 kPa) and the wetted perimeter between two adjacent drip lines overlapped.

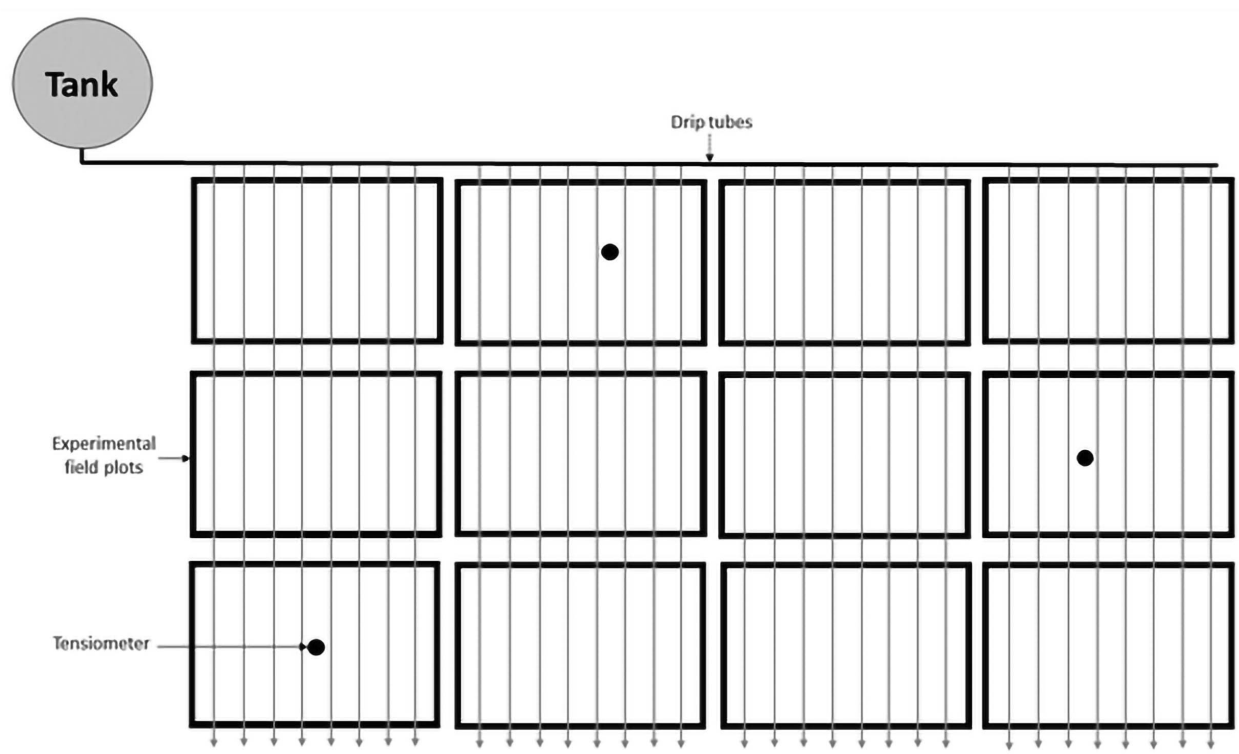

Figure 1. Field experimental plots installed with drip-irrigation system.

Each experimental plot received 857.13 g of complete fertilizer (14-14-14) at 15 DAS and 260.88 g of urea (46-0-0) at 30 and 45 DAS, respectively, to fulfill the PhilRice's 120-40-40 kg ha^{-1} NPK recommended rate for the dry season; 857.13 g of complete fertilizer (14-14-14) at 15 DAS, and 163.05 g of urea (46-0-0) at 30 and 45 DAS, respectively, to fulfill the 90-40-40 kg ha^{-1} NPK recommended rate for the wet season. The drip irrigation was followed immediately after fertilizer application for nutrient uptakes.

Data Collection and Calculation

Weed flora was determined by randomly taking three 0.5-m x 0.5-m quadrats in each plot at 15, 30, and 45 DAS. Weed species inside quadrats were collected, placed inside plastic bags, and brought into the Weed Science Laboratory of PhilRice for identification, counting, and weighing. Weed density was determined by counting the total number of each species per quadrant, whereas weed biomass was determined by drying biomasses of each weed species inside a drying oven for 72 h and weighing afterward over digital weighing balance (AND electronic balance FX-3000) (Moody 1987).

The yield of rice per plot was determined by harvesting the matured grains of rice within a 2-m x 2.5-m crop cut area. Cut panicles were placed inside nylon sacks and then oven-dried for 72 h. After drying, filled and unfilled grains were separated from branches and other dried parts of the plant. Moisture content and weight of filled grains from each plot were measured. Yields in each crop cut area (grams per 5 m^2) were then converted into kilograms per hectare after adjusting the grain moisture content at 14%. Weed control efficiency (WCE) of each treatment at 15, 30, and 45 DAS was computed based on the formula below. Weed control cost in each treatment was also computed based on the cost, volume sprayed, time, and the number of workdays spent for herbicide application and hand weeding.

$$\text{WCE} = \frac{\text{(Weed biomass in T1 – Weed biomass in T2, T3, and T4)}}{\text{Weed biomass in T1}} \times 100$$

Data Analysis

Data on weed density, weed biomass, WCE, and yield of rice were subjected to combined analysis of variance using the Statistical Tool for Agricultural Research (STAR 2013, IRRI). All heterogenous data were transformed using the square-root transformation method [$\sqrt{(x+0.5)}$]. Differences between means were compared by the least significant difference (LSD) at the 5% level of significance.

RESULTS

Common Weeds

Eighteen (18) weed species grew and infested the dry direct-seeded and drip-irrigated rice during the entire conduct of the experiment (Tables 1 and 2). Of these, five belonged to the group of grasses [*Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link, *Eleusine indica* (L.) Gaertn., *Ischaemum rugosum* Salisb., and *Leptochloa chinensis* (L.) Nees], three to sedges [*Cyperus difformis* L., *C. iria* L., and *Fimbristylis miliacea* (L.) Vahl.], and 10 to broadleaves [*Aeschynomene indica* L., *Alternanthera sessilis* (L.) DC., *Cleome rutidosperma* DC., *Corchorus olitorius* L., *Ipomoea triloba* L., *Ludwigia hyssopifolia* (G. Don) Exell, *Macroptilium lathyroides* (L.) Urb., *Melochia concatenata* L., *Phyllanthus debilis* Klein ex Willd., and *Physalis angulata* L.].

Weed Density, Biomass, and Control Efficiency

The effect of season and treatment was significant on weed density and biomass (Table 1). Thus, all data on weed density and biomass in the dry season are presented separately from the data in the wet season. T1 plots had the highest weed density among treatments at 15, 30, and 45 DAS during the dry season (Table 2). These values were significantly comparable to weed densities in T3 plots, particularly at 15 and 30 DAS. T2 plots, on the other hand, had lesser weed densities at 15 and 30 DAS. The values, however, were not significantly different from T3 plots at a 5% level of significance. T3 plots had the least weed densities than T1 and T2 at 45 DAS.

Table 1. Summary of *P*-values for the effects of season and treatments on weed density and biomass in dry direct-seeded-drip-irrigated rice.

	Weed density			Wet biomass		
	15[a]	30	45	15	30	45
Season (S)	0.0251*	0.1134ns	0.0378*	0.0000**	0.0026**	0.0022**
Treatment (T)	0.0000**	0.0000**	0.0000**	0.0000**	0.0001**	0.0000**
S x T	0.0143*	0.0038**	0.0001**	0.0000**	0.0008**	0.0000**

[a] Days after seeding; *$P < 0.05$, **$P < 0.005$, ns – not significant at 5% level of significance

Table 2. Influence of selected weed control techniques on weed density of dry direct-seeded and drip-irrigated rice.

Treatment	Weed density m^{-2}					
	Dry season			Wet season		
	15[a]	30	45	15	30	45
T1	357 a	577 a	648 a	1459 a	1679 a	959 a
T2	59 bc	251 b	557 a	80 c	137 b	74 c
T3	218 ab	324 ab	388 b	824 b	309 b	171 b
T4	0 c	0 c	0 c	0 c	0 c	0 d

[a]Days after seeding; T1 – unweeded, T2 – pre-emergence herbicide applied at 2–3 DAS followed by two times hand weeding (25–30 and 40–45 DAS), T3 – post-emergence herbicide applied at 12–15 DAS followed by two times hand weeding (25–30 and 40–45 DAS), and T4 – weed-free, a combination of T2 and T3 followed by six times hand weeding (25, 30, 35, 40, 45, and 50 DAS); means having common letters are not significantly different by LSD at 5% level of significance

T1 plots also had higher weed density in the wet season but with a much higher value compared that in the dry season. T2 and T3 plots had lower weed densities compared to T1 plots. But T3 plots had higher weed densities than T2 at 15, 30, and 45 DAS. Despite that, weed densities between T3 and T2 were not significantly different. Weed-free (T4) plots had zero weed densities at 15, 30, and 45 DAS both in dry and wet seasons.

T1 plots had the highest weed biomasses at 15, 30, and 45 DAS in both seasons (Table 3). T2 and T3 plots significantly had lower weed biomasses compared to T1 plots. T2 plots had lower but comparable weed biomasses to T3 at 15 DAS in both seasons. In reverse, T3 had lower weed biomasses than T2 at 30 and 45 DAS in the dry season, whereas it was only at 30 DAS in the wet season. Weed biomasses in T3 plots were significantly different to T2 plots at 45 DAS in the dry season but not in the wet season. T4 plots had no weed biomasses at 15, 30, and 45 DAS both in dry and wet seasons, respectively.

Results on WCE in the dry season were presented separately from those in the wet season because of the significant interaction effect of season and treatment. WCE of different treatments varied across seasons and time of sampling (Table 4). In general, the WCE was higher in the wet season than in the dry season. In both seasons, T1 had the lowest WCE; T4 had the highest.

Table 3. Influence of selected weed control techniques on weed biomass of dry direct-seeded and drip-irrigated rice.

Treatment	Weed biomass (g m^{-2})					
	Dry season			Wet season		
	15[a]	30	45	15	30	45
T1	2.0 a	37.1 a	107.3 a	44.6 a	1209.3 a	478.3 a
T2	0.4 b	6.8 a	82.1 a	1.5 c	92.0 b	60.6 b
T3	1.5 a	2.9 a	27.0 b	23.0 b	65.6 bc	65.7 b
T4	0 b	0 a	0 c	0 c	0 c	0 c

[a]Days after seeding; T1 – unweeded, T2 – pre-emergence herbicide applied at 2–3 DAS followed by two times hand weeding (25–30 and 40–45 DAS), T3 – post-emergence herbicide applied at 12–15 DAS followed by two times hand weeding (25–30 and 40–45 DAS), and T4 – weed-free, a combination of T2 and T3 followed by six times hand weeding (25, 30, 35, 40, 45, and 50 DAS); means having common letters are not significantly different by LSD at 5% level of significance

Table 4. Weed control efficiency of different treatments.

Treatment	Dry season			Wet season		
	15[a]	30	45	15	30	45
T1	0 c	0 c	0 c	0 d	0 c	0 c
T2	37.9 b	51.9 b	12.3 c	79.0 b	68.1 b	64.8 b
T3	11.8 c	67.3 b	48.9 b	27.9 c	73.1 b	63.7 b
T4	100 a	100 a	100 a	100 a	100 a	100 a

[a]Days after seeding; T1 – unweeded, T2 – pre-emergence herbicide applied at 2–3 DAS followed by two times hand weeding (25–30 and 40–45 DAS), T3 – post-emergence herbicide applied at 12–15 DAS followed by two times hand weeding (25–30 and 40–45 DAS), and T4 – weed-free, a combination of T2 and T3 followed by six times hand weeding (25, 30, 35, 40, 45, and 50 DAS); means having common letters are not significantly different by LSD at 5% level of significance

In the dry season, T2 had significantly higher WCE compared to T3 at 15 DAS, comparable to T3 at 30 DAS, and significantly lower than T3 at 45 DAS. In reverse, T3 had significantly higher WCE at 30 and 45 DAS. In the wet season, T2 still had higher WCE at 15 DAS and comparable to T3 at 30 and 45 DAS.

Grain Yield, Weed Control Cost, and Net Income

Grain yields and economics of dry direct-seeded-drip-irrigated rice in dry and wet seasons were pooled because the effects of season and treatment were not significant (*P* = 0.2188). T1 had the lowest grain yield (901.8 kg ha^{-1}) among treatments, as shown in Figure 2. T2, having a lesser grain yield (3,794.4 kg ha^{-1}), did not significantly differ from T3 (4,341.3 kg ha^{-1}). T2 and T3 significantly differed from T1 except when compared to T4, which had the highest grain yield (5724.5 kg ha^{-1}) among all treatments. From T1, grain yields in T2, T3, and T4 were increased by 4.2, 4.8, and 6.3 times, respectively.

T1 had the lowest weed control cost, total production cost, and gross income but did not gain any net income compared to the other treatments (Table 5). T2 was higher by PHP 6,642.2 and 11,492.6 over T1 in terms of weed control and total production cost. Similarly, it was higher by PHP 48,504.2 and 20,575.1 over T1 in terms of gross income and net income, respectively. Although T3 had higher total weed control and production costs, it gained by PHP 10,612.3 and 9,831.4 over the T2 when it comes to gross and net income, respectively. On the other hand, T4 had higher gross and net income over the other treatments despite having higher weed control and production costs. It gained an advantage of PHP 81,160.1, 32,655.9, and

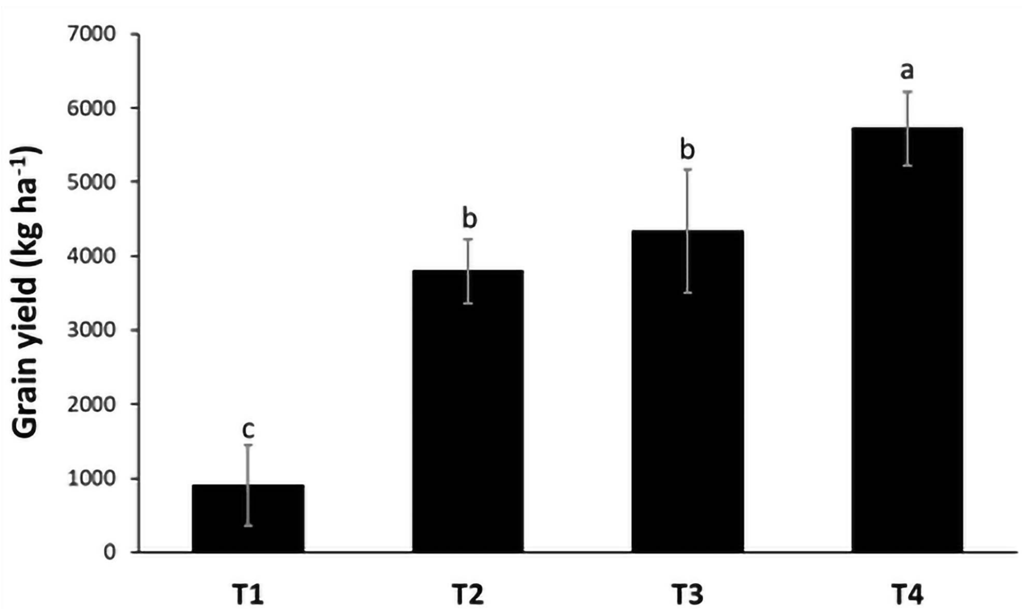

Figure 2. Influence of weed control techniques on grain yield of dry direct-seeded-drip-irrigated rice. Bars having common letter are not significantly different by LSD at 5% level of significance; vertical lines are ± SE of the means.

Table 5. Influence of selected weed control techniques on weed control cost, production cost, gross income, and net income of dry direct-seeded and drip-irrigated rice.

Treatments	Herbicide application cost (PHP ha^{-1})	Hand weeding cost (PHP ha^{-1})	Total weed control cost (PHP ha^{-1})	Total production cost (PHP ha^{-1})	Gross income (PHP ha^{-1})	Net income (PHP ha^{-1})
T1	0	0	0	32.917.9	16,481.3	0
T2	1,150	5,492.2	6,642.2	34,743.6	64,985.5	20,575.1
T3	1,735	5,208.4	6,943.4	44,410.5	75,597.8	30,406.4
T4	2,885	8,450.5	11,335.5	45,772.8	97,641.4	45,272.1

T1 – unweeded, T2 – pre-emergence herbicide applied at 2–3 DAS followed by two times hand weeding (25–30 and 40–45 DAS), T3 – post-emergence herbicide applied at 12–15 DAS followed by two times hand weeding (25–30 and 40–45 DAS), and T4 – weed-free, a combination of T2 and T3 followed by six times hand weeding (25, 30, 35, 40, 45, and 50 DAS).

22,043.7 over the T1, T2, and T3, respectively, in terms of gross income; the gains were PHP 45,272.1, 24,697.0, and 14,865.7 over the same order of treatments in terms of net income.

DISCUSSION

The combined effects of herbicide and manual weeding interventions influenced the weed diversity and grain yield of wet direct-seeded rice grown under irrigated and rainfed-lowland conditions. The influence of these two weed control techniques on dry direct-seeded and drip-irrigated rice, however, is not yet known in the country. In this study, numerous weed species grew with dry direct-seeded and drip-irrigated rice, suggesting that this type of crop establishment is also prone to severe infestation by different weed species. In India, Ramesh and Rathika (2020) and Palani *et al*. (2020) reported that weed species such as *E. colona*, *L. chinensis*, *C. dactylon*, *C. olitorius*, *Cleome viscosa*, *C. difformis, Eclipta alba*, *Euphorbia prostrata*, *Trianthema portulacastrum*, *Amaranthus viridis*, *Acalifa indica*, *Panicum repens*, and *Cyperus rotundus* were observed under different weed management techniques for drip-irrigated aerobic rice.

Unweeded plots resulted in severe weed infestation and a reduction in the yield of dry direct-seeded and drip-irrigated rice, suggesting that failure to implement weed control will definitely end in numerous weed growths and yield loss by as much as 99%. Ramesh and Rathika (2020) also reported that unweeded drip-irrigated aerobic rice had 4–13 times weed density, 3–6 times weed weights, and 54–64% reduced yield over rice plants applied with either herbicide, plastic mulch, or hand weeding. Palani *et al*. (2020), on the other hand, reported that unweeded drip-irrigated aerobic rice had 2–5 times weed density, 2–8 times weed weights, and 23–47% reduced yield over rice plants that were applied with combinations of herbicides. Singh *et al*. (2016) also reported that unweeded plots of dry direct-seeded rice resulted in 89 and 75% yield loss in two sites in Karnal, India. Anwar *et al*. (2012), on the other hand, reported a 72% yield loss on dry direct-seeded rice.

A single application of either pre-emergence or post-emergence herbicide followed by hand weeding influenced the weed dynamics in this study. In the works of Donayre *et al*. (2021), they also found that the two techniques influenced the weed diversity, abundance, and dominance in wet direct-seeded rice under rainfed conditions. Although the combination of the techniques lessens the weed densities and growths, cluster analysis showed that plots applied with pre-emergence herbicide (pretilachlor) followed by hand weeding were mainly dominated by *Paspalum distichum*, whereas post-emergence (bispyribac-sodium) herbicide with hand weeding was dominated by *Leptochloa chinensis*.

On the other hand, the sequential application of pre- and post-emergence herbicides followed by hand weeding (weed-free treatment) resulted in excellent weed control and a higher yield of dry direct-seeded and drip-irrigated rice. In Malaysia, Anwar *et al*. (2013) also reported that sequential application of pre-emergence herbicide (pretilachlor at 0.5 kg a.i. ha^{-1}, 1 DAS) and post-emergence herbicide (propanil/thiobencarb at 1.2/2.4 kg a.i. ha^{-1}, 10 DAS) followed by hand weeding (30 DAS) gave better weed control and yield of dry direct-seeded aerobic rice compared to a single application of either pre- (pretilachlor) or post-emergence (bispyribac-sodium) herbicides followed by one hand weeding, respectively. Similarly, Singh *et al*. (2008) in India reported that the application pre-(pretilachlor at 0.5 kg a.i ha^{-1}, 3 DAS) and post-emergence (chlorimuron + metsulfuron at 0.004 kg a.i. ha^{-1}, 21 DAS) herbicides followed by one hand weeding effectively controlled all the weeds and gave the highest yield of direct-seeded aerobic rice. In a separate study, Singh *et al*. (2016) reported that sequential application of pre- and post-emergence herbicides but without hand weeding also gave better weed control and yield of dry direct-seeded rice compared to either application of pre- or post-emergence herbicide alone. In Taraori site, the sequential application of pre-emergence and post-emergence herbicides (pendimethalin + bispyribac-sodium + azimsulfuron, pendimethalin + bispyribac-sodium, pendimethalin + azimsulfuron, oxadiargyl + azimsulfuron, butachlor + bispyribac-sodium, and oxadiargyl + bispyribac-sodium) gave 92, 88, 87, 85, and 80% WCE at 45 DAS. Oxadiargyl and bispyribac-sodium applied alone only resulted in 45 and 60% WCE. In the Madhuban site, the sequential applications of the same herbicides gave 85, 68, 83, 82, 62, and 68% WCE; oxadiargyl and bispyribac-sodium were applied alone by 52 and 63%. Across locations, the sequential applications provided significantly higher net returns and benefit-cost ratios. In Nepal, Bhurer *et al*. (2013) also reported that the application of pre-emergence (pendimethalin) and post-emergence (2,4-D) herbicides followed by one-hand weeding gave better weed control and yield of dry direct-seeded rice.

CONCLUSION

The application of either pre-emergence herbicide or post-emergence herbicide followed each by two hand weeding lessened weed growths and improved rice yield, as well as the net income. The combination of pre- and post-emergence herbicides followed by six times hand weeding was much more effective in suppressing the weeds and further improving the yield and net income of dry direct-seeded-drip irrigated rice. The results of this study are useful in developing comprehensive and sustainable weed management for dry direct-seeded-drip irrigated rice in the country. To expand weed control options for dry direct-seeded-drip irrigated rice, further research is needed by [a] evaluating the different rice varieties that have weed-competitive characteristics, as well as tolerance to drought, and [b] evaluating other combinations of pre- and post-emergence herbicides with hand weeding. Further research is also recommended to determine the possible outcomes of using the herbicides found effective in this study, particularly in relation to weed shifts and residue retentions in the soil.

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CONFLICT OF INTERESTS

The authors declared no conflict of interests.

REFERENCES

ANWAR MP, JURAIMI AS, PUTEH A, MAN A, RAHMAN MM. 2012. Efficacy, phytotoxicity, and economics of different herbicides in aerobic rice. Acta Agriculturae Scandinavica, Section B – Soil and Plant Science 62(7): 604–615.

ANWAR MP, JURAIMI AS, MOHAMED MTM, UDDIN MK, SAMEDANI B, PUTEH A, MAN A. 2013. Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. The Scientific World Journal 2013: 916408.

ARBAT G, CUFÍ S, DURAN-ROS D. 2020. Modeling approaches for determining dripline depth and irrigation frequency of subsurface drip irrigated rice on different soil textures. Journal of Water 12: 1724.

BALASUBRAMANIAN V, HILL J. 2002. Direct seeding of rice in Asia: emerging issues and strategic research for the 21st century. In: Direct seeding: research issues and opportunities. Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B eds. Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities. Bangkok, Thailand. p. 15–39.

BAUTISTA EG, GAGELONIA EC, ABON JE, CORALES AM, BUENO CS, BANAYO NP, LUGTO RV, SURALTA RR, KATO Y. 2019. Development of hand tractor-mounted seed drill for rice-based cropping systems in the Philippines. Plant Production Science 22(1): 54–57.

BELDER P, SPIERTZ JHJ, BOUMAN BAM, LU G, TUONG TP. 2005. Nitrogen economy and water productivity of lowland rice under water-saving irrigation. Field Crops Research 93: 169–185.

BELTRAN JC, BORDEY FH, LAUNIO CC, LITONJUA AC, MANALILI RG, MATAIA AB, RELADO RZ, MOYA PF. 2016. Pesticide use and practices. In: Competitiveness of Philippine Rice in Asia. Bordey FH, Moya PF, Beltran JC, Dawe DC eds. Philippine Rice Research Institute, Maligaya, Science City of Muñoz, Nueva Ecija, Philippines. p. 75–86.

BHURER KP, YADAV DN, LADHA JK, THAPA RB, PANDEY K. 2013. Effect of integrated weed management practices on performance of dry direct-seeded rice (*Oryza sativa* L.). Agronomy Journal of Nepal 3: 53–63.

BOUMAN BAM. 2008. Developing a system of temperate and tropical aerobic rice in Asia (STAR). Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food.

BOUMAN BAM, HUMPHREYS E, TUONG TP, BARKER R. 2007. Rice and water. Advances in Agronomy 92: 187–237.

BOZKURT COLAK Y. 2021. Comparison of aerobic rice cultivation using drip systems with conventional flooding. The Journal of Agriculture Science 159: 544–556.

CHAPMAN L. 2019. Irrigation: Systems, Technology, and Impacts. Syrawood Publishing House, USA. 192p.

CHAUHAN BS. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technology 26(1): 1–13.

DONAYRE DKM, TAYSON CE, CIOCON IMG. 2021. Effects of different weed management strategies in wet direct-seeded rice under rainfed conditions. Rice-based Biosystems Journal 8: 1–9.

DONAYRE DKM, ENDINO CA, SEVILLE CU, CIOCON IMG. 2014. Major weeds and farmers' weed management practices in rainfed rice fields of Negros, Philippines. Asia Life Sciences 23(1): 137–148.

DONAYRE DKM, MARTIN EC, SANTIAGO SE, LEE JT. 2018. Weeds in Irrigated and Rainfed Lowland Rice fields in the Philippines. 2nd Ed. Maligaya, Science City of Muñoz, Nueva Ecija, Philippines: Philippine Rice Research Institute. 196p.

[GRiSP] Global Rice Science Partnership. 2013. Rice Almanac, 4th Edition. International Rice Research Institute, Los Baños, Philippines. 283p.

MOODY K. 1987. Weeds: generating populations, field sampling, and data analysis. In: Crop Loss Assessment in Rice. International Rice Research Institute, College, Laguna, Philippines. p. 75–86.

MOODY K. 1996. Weed community dynamics in rice fields. In: Herbicides in Asian Rice: Transitions in Weed Management. Naylor R ed. Institute for International Studies, Stanford University, Palo Alto, CA; International Rice Research Institute, Philippines. p. 27–36.

OHNO H, BANAYO NP, BUENO C, KASHIWAGI JI, NAKASHIMA T, IWAMA K, CORALES A, GARCIA R, KATO Y. 2018. On-farm assessment of a new early-maturing drought-tolerant rice cultivar for dry direct seeding in rainfed lowlands. Field Crops Research 219: 222–228.

PALANI R, RAMESH T, RATHIKA S, BALASUBRAMANIAM P. 2020. Evaluation of weed management techniques in drip irrigated aerobic rice. International Journal of Current Microbiology and Applied Sciences *9*(12): 2463–2471.

PANDEY S, VELASCO L. 2002. Economics of direct seeding in Asia: patterns of adoption and research priorities. In: Direct Seeding: Research Issues and Opportunities. Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B eds. Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities. Bangkok, Thailand. p. 3–14.

PARTHASARATHI T, VANITHA K, MOHANDASS S, VERED E. 2018. Evaluation of drip irrigation system for water productivity and yield of rice. Agronomy Journal 110: 1–12.

PASCUAL KS, MARTIN EC, ARIOLA CP. 2020. Effects of water and weed management on the weed density, grain yield, and water productivity of wet-seeded rice. Philippine Journal of Science 149 (1): 121–131.

[PSA] Philippine Statistics Authority. 2021. 2021 Selected Statistics on Agriculture. Quezon City, Metro Manila, Philippines. Retrieved on 05 Apr 2022 from https://psa.gov.ph/sites/default/files/SSA2021_signed.pdf

RAJWADE AY, SWAIN DK, TIWARI KN, BHADORIA PBS. 2018. Grain yield, water productivity, and soil nitrogen dynamics in drip irrigated rice under varying nitrogen rates. Agronomy Journal 110: 868–878.

RAMESH T, RATHIKA S. 2020. Effect of weed management techniques on drip irrigated aerobic rice. Plant Archives 20(2): 4462–4466.

SHARDA R, MAHAJAN G, SIAG M, SINGH A, CHAUHAN BS. 2016. Performance of drip-irrigated dry-seeded rice (*Oryza sativa* L.) in South Asia. Paddy Water Environ. DOI10.1007/s10333-016-0531-5

SHAREEF TAE, MA Z. 2019. Essentials of drip irrigation system for saving water and nutrients to plant roots: as a guide for growers. Journal of Water Resource and Protection 11: 1129–1145.

SHARMA SK, PANDEY DK, GNAGWAR KS, TOMAR OK. 2005. Effect of crop establishment methods on performance of rice cultivar and their effect on succeeding wheat. Indian Journal of Agronomy 50: 253–255.

SINGH V, JAT ML, GANIE ZA, CHAUHAN BS, GUPTA RK. 2016. Herbicide options for effective weed management in dry direct seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains Crop Protection 81: 168–176.

SINGH S, LADHAB JK, GUPTAA K, BHUSHANA L, RAO AN. 2008. Weed management in aerobic rice systems under varying establishment methods. Crop Protection 27: 660–671.