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# PERFORMANCE OF PRE- AND POST-EMERGENCE HERBICIDES IN STRIP TILLAGE NON-PUDDLED TRANSPLANTED *AMAN* RICE

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## Abstract

A study was conducted on transplanted *aman* rice (cv. BINA dhan-7) in strip-tilled non-puddled field with some commonly used rice herbicides (pre-emergence: pyrazosulfuron-ethyl and butachlor, early post-emergence: orthosulfamuron and late post-emergence: acetochlor + bensulfuron methyl, butachlor + propanil and 2,4-D amine) applied singly or in sequences during 2013 and 2014 at field laboratory, Bangladesh Agricultural University, Mymensingh to evaluate the effect of those herbicides on weeds as well as growth and yield of *aman* rice in strip-tilled non-puddled condition. The study showed that herbicides significantly reduced weed density by 75-94% in 2013 and 46-98% in 2014 compared to the weedy check. Sole application of pre- or early post-emergence herbicide provided less weed control than sequential application of pre-, early post- and late post-emergence herbicides or application of pre- and late post-emergence herbicides. A wide range of sequential application of herbicide treatments has identified in the study that provided control on weed density and biomass by 49-98% and 56-95%, respectively. Application of pyrazosulfuron-ethyl followed by orthosulfamuron and butachlor + propanil was the most effective combination in this new rice establishment condition that controlled all types of weeds successfully and provided maximum grain yield (5.42 t $ha^{-1}$ in 2013 and 6.18 t $ha^{-1}$ in 2014) with highest economic return (Tk. 55930 $ha^{-1}$ in 2013 and Tk. 69057 $ha^{-1}$ in 2014). The study suggests economically beneficial some combinations of currently used herbicides for strip-tlled non-puddled transplanted *aman* rice that may help farmers to choose and rotate in the same land yearwise for obtaining optimum yield.

Keywords: Chemical weed control, Herbicide rotation, Non-puddled transplanted rice, Strip tillage, Weed infestation.

## Introduction

Puddling of soil before transplanting rice (*Oryza sativa*) helps to suppress weeds during crop establishment but this practice is tedious, costly, time and energy-consuming (Gill *et al*., 2014). Moreover, puddling changes soil physical properties caused detriment to the succeeding non-rice crops in a rotation (Singh *et al.*, 2014 and Kumar *et al.*, 2012). On the other hand, non-puddled transplanting is an emerging option to overcome these problems (Haque *et al*.,

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2016 and Pandey *et al*., 2012) and also reduce cost of rice cultivation (Islam *et al*., 2014). Rice established by non-puddled transplanting gives similar or higher yield than that of puddled transplanted rice (Haque *et al*., 2016; Islam *et al*., 2014; Ladha *et al*., 2009), but grain yield may sharply decline if weed management is not done properly (Zahan *et al*., 2014; Ekeleme *et al*. 2007).

In conventional puddled transplanting systems, existing weeds are controlled by burying weed seeds into the saturated and submerged soil that results in less early post-emergence of weeds (Swanton *et al*., 2000; Chauhan *et al*., 2006). By contrast, pre-planting non-selective herbicides must be used to kill the existing weeds on the non-puddled field to achieve a similar low weed competition at crop establishment (Hartzler and Owen, 1997; Nalewaja, 2003). Depending on the density and type of weeds after rice transplantation, different effective herbicides need to be applied in this reduced tilled field because crop has to compete with huge weeds in this system for growing up as because of shifting in strip-tilled non-puddled condition from conventional puddled cultivation system (Zahan *et al*., 2014). This is the consequence of tillage that has a great influence on weed composition (Mishra and Singh, 2012) and moreover, minimum tillage usually alters species diversity (Murphy *et al*., 2006).

Traditionally weeds are managed by hand weeding. But, now-a-days, labour availability is decreasing with increasing wage, especially during the period of peak demand, is making manual weeding almost impossble for controlling weeds (Krishna *et al*., 2012). To overcome this situation, farmers are switching from manual weeding to herbicidal weed control (Hossain, 2015; Hasanuzzaman *et al*., 2008) as it is quick, effective and low cost weed control method (Kumar *et al*., 2008; Mahajan *et al*., 2002). Mazid (2001) reported that use of pre-emergence herbicides reduced the weeding cost by 38-46% compared with manual weeding in puddled transplanted rice, but thereafter only partial weed control can be achieved.

Available rice herbicides of our country are usually recommended for puddled transplanting system. The effectivity of those herbicides might have some divergence to control diversified weed species of strip-tilled non-puddled transplanted rice. Therefore, the present study was conducted to evaluate the effect of commonly used pre- and post-emergence rice herbicides on weeds and crop under strip tilled non-puddled transplanting condition.

## Materials and Methods

The study was conducted at the Agronomy Field Laboratory, Department of Agronomy, Bangladesh Agricultural University, Mymensingh ($24^0\ 75^/$ N latitude and $90^0\ 50^/$ E longitude in the south-west part of the old Brahmaputra plain). The experimental site was a medium-high land with sandy clay loam texture (50 % sand, 23 % silt, 27 % clay) and pH 7.2. The mean monthly maximum and minimum air temperatures were 29.5 and 23.1° C, and 29.6 and 23.4° C recorded during the growing seasons of 2013 and 2014, respectively. The highest air temperature was recorded in July (maximum 32.3º C and minimum 26.8º C in 2013 and maximum 32.5º C and minimum 26.7º C in 2014). Temperature declined gradually from July to November (29.6 to 23.1° C) during both years. The total rainfall received during the cropping period (June to November) was 1287 mm in 2013 and 1625 mm in 2014. Sufficient rain water was available in 2013 during transplantation and establishment of rice due to heavy rainfall in July (339 mm). In 2014, comperatively less rainfall (300 mm) was recorded in the month of July than 2013 but no additional irrigation was required at that period for rice transplantation and seedling establishment. The highest rainfall of 2014 was recorded in the month of August (568.6 mm).

In the study, ten weed control treatments viz. $T_1$ = weedy check, $T_2$ = Weed-free check (four manual weedings done at 20, 35, 50 and 65 days after transplanting), $T_3$ = Pyrazosulfuron-ethyl fb (followed by) hand weeding (HW) at 25 days after transplanting (DAT), $T_4$ = Butachlor fb HW at 25 DAT, $T_5$ = Pyrazosulfuron-ethyl fb acetochlor + bensulfuron methyl, $T_6$ = Butachlor fb acetochlor + bensulfuron methyl, $T_7$ = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, $T_8$ = Butachlor fb orthosulfamuron fb butachlor + propanil, $T_9$ = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-Damine, $T_{10}$ = Butachlor fb orthosulfamuron fb 2,4-D amine during the first year and fifteen treatments viz. $T_1$ = weedy check, $T_2$ = Weed-free check, $T_3$ = Pyrazosulfuron-ethyl, $T_4$ = Butachlor, $T_5$ = Orthosufamuron, $T_6$ = Pyrazosulfuron-ethyl fb butachlor + propanil, $T_7$ = Butachlor fb butachlor + propanil, $T_8$ = Orthosulfamuron fb butachlor + propanil, $T_9$ = Pyrazosulfuron-ethyl fb 2,4-D amine, $T_{10}$ = Butachlor fb 2,4-D amine, $T_{11}$ = Orthosulfamuron fb 2,4-D amine, $T_{12}$= Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, $T_{13}$ = Butachlor fb orthosulfamuron fb butachlor + propanil, $T_{14}$ = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and $T_{15}$ = Butachlor fb orthosulfamuron fb 2,4-D amine during the second year were studied. The experiment was laid out in a randomized complete block design with three replications. In 2013, acetochlor + bensulfuron methyl (proprietary mixture) herbicide had phytotoxic effect on rice; therefore this herbicide was discarded in 2014. The chemical name, mode of action, time and dose of application of all tested herbicides are given in Table 1.

Before starting the experiment, the existing weeds of the field were initially killed by application of pre-planting non-selective herbicide, Roundup® (glyphosate 41 % SL- IPA salt) @ 75 mL/ 10 L water (2.25 L $ha^{-1}$) on 12 July 2013 and 10 July 2014. After one week, strip tillage was done in the field by Versatile Multi-Crop Planter (VMP) maintaining 20 cm line spacing (Haque *et al.*, 2016). The land was fertilized with phosphorus, potassium, sulphur and zinc @ 20, 35, 10 and 1.5 kg $ha^{-1}$ as triple super phosphate, muriate of potash, gypsum and $ZnSO_4$, respectively just before strip-tilled the field. Then, land was inundated to 3-5 cm depth of standing water for 48 hours. After two days, 25-day-old rice seedlings of cv. BINA dhan-7 were transplanted at 15 cm spacing between hills aparted from 20 cm strips allocating three seedlings per hill. Nitrogen was applied @ 70 kg N $ha^{-1}$ as urea into two installments, at 7 and 35 days after transplanting (DAT). Herbicides were applied by hand operated knapsack sprayer fitted with flat-fan nozzle at a spray volume of 300 L $ha^{-1}$.

**Table 1. Mode of action, time and rate of application of herbicides used in the experiment during 2013 and 2014**

| Herbicides | Time of application | Mode of action | Recommended dose |
|---|---|---|---|
| Pyrazosulfuron-ethyl | 3 DAT | Inhibitor of acetolactate synthase (ALS) | 150 g $ha^{-1}$ (100 g ai $kg^{-1}$) |
| Butachlor | 3 DAT | Inhibitor of microtubule assembly | 25 kg $ha^{1}$ (50 g ai $kg^{-1}$) |
| Orthosulfamuron | 13 DAT | Inhibitor of ALS | 150 g $ha^{-1}$ (500 g ai $kg^{-1}$) |
| Acetochlor + bensulfuron methyl* | 23 DAT | Inhibitor of cell division and ALS | 300 g $ac^{-1}$ (100 g ai $kg^{-1}$) |
| Butachlor + propanil* | 23 DAT | Inhibitor of very long-chain fatty acid synthesis and photosynthesis at photosystem II site A | 1 L $ha^{-1}$ (700 mL ai $L^{-1}$) |
| 2,4-D amine | 23 DAT | Synthetic auxin | 2.25 L $ha^{-1}$ (720 g ai $L^{-1}$) |

'DAT' means 'days after transplanting', 'ai' means 'active ingradient', * = Proprietary mixture

Weed density and biomass were taken from three randomly selected quadrats of 0.25 $m^2$ (50 cm x 50 cm) each at 20, 35 and 50 DAT (data at 20 and 50 DAT were not presented as these were less well correlated with grain yield) to evaluate the efficacy of herbicides. The weed density was counted in plants $m^{-2}$ and the weed dry matter was recorded in g $m^{-2}$ after oven drying the samples at 70 $^0$C for 72 hrs. Weed control efficiency (WCE) and weed control index (WCI) were calculated using the equations of Devasenpathy *et al.* (2008).

$$\text{WCE (\%)} = \frac{\text{WPc - WPt}}{\text{WPc}} \times 100$$

Where, $WP_c$ = Weed population (no. $m^{-2}$) in control (weedy) plot and $WP_t$ = Weed population (no. $m^{-2}$) in treated plot

$$\text{WCI (\%)} = \frac{\text{DMPc- DMPt}}{\text{DMPc}} \times 100$$

Where, $DMP_c$ = Weed dry matter production in control plot and $DMP_t$ = Weed dry matter production in treated plot

Plant height and yield attributing characters were recorded from five randomly selected hills before harvesting the whole plot. Grain and straw yields were recorded by harvesting the crop from the central area 6 $m^2$ (2 m × 3 m) area of the plot and grain yield was adjusted at 14% moisture level. Percent yield increase over control (YOC) was calculated by the following formula (Devasenpathy *et al*., 2008).

$$YOC\ (\%) = \frac{TY - WY}{WY} \times 100$$ Where, *TY* = Grain yield in weed control treatment and *WY* = Grain yield in weedy treatment

Economic analysis was carried out to determine the cost-effectiveness of different herbicide treatments following the procedure by Parvez *et al*. (2013). Four manual weeding operations were considered sufficient to keep the plots weed-free throughout the growing season. Labour required for one manual weeding and one herbicide spraying $ha^{-1}$ area were 25 and 2 person $day^{-1}$, respectively. The cost required for one labour was Taka 250 $day^{-1}$. Herbicide requirement was calculated by the amount of commercial product $ha^{-1}$ and the cost of each herbicide was calculated based on their local market price. The net return $ha^{-1}$ for each treatment was calculated by deducting the total cost (fixed cost + weed management cost) from the gross return.

Data were subjected to analysis of variance (ANOVA) and means were compared by Tukeys's Honest Significant Difference (HSD) test at $P<0.05$ using statistical package program 'Statistical Tool for Agricultural Research (STAR) nebula' developed by International Rice Research Institute (version 2.0.1, January 2014).

## Results and Discussion

### Distribution and density of weed species

Seven major weed species were identified in the strip tilled non-puddled transplanted rice field at 35 days after transplanting (DAT) during both years (Table 2). Among those weeds, two were grass (*Cynodon dactylon* and *Echinochloa colona*), three sedges (*Cyperus rotundus*, *Fimbristylis miliacea* and *Cyperus difformis*) and two broad leaf weeds (*Ludwigia decurrens* and *Cyanotis axillaris*). Besides those, some other weed species like *Leersia hexandra*, *Dactyloctenium aegyptium*, *Monochoria vaginalis*, *Commelina benghalensis* and *Cyperus iria* were present during 2013 at a very low density while those minor species were completely absent in 2014. Similar weed species composition in non-puddled field was also reported by Chhokar *et al*. (2014) and Timsina *et al*. (2010) but they conducted their study on direct seeded rice (DSR). However, the present study has identified some weed species in transplanted *aman* rice under strip-tilled non-puddled field condition that might be different in different location and soil type. Moreover, only continued for two consecutive years, it is too early to conclude weed species composition and diversity type under this reduced tillage system.

The study demonstrated that the highest densities of all the weed species were recorded from the weedy check while herbicide treatments significantly (P<0.001) reduced the densities of all the weed species during both the year (Table 2). Results also showed that densities of all weed species in 2014 were 30-75 % less in number compared to the preceeding year except *F. miliacea* that remained similar in number as it was in 2013 (Table 2).

Among grass weeds, relative to that high density of weedy plots, herbicide treated plots reduced *C. dactylon* by 66-87% in 2013 and 24-94% in 2014, whereas in case of *E. colona*, this reduction was by 45-100% in 2013 and 44-100% in 2014. Complete density reduction of *E. colona* in 2013 was provided by the treatment having pyrazosulfuron-ethyl as pre-emergence herbicide followed by acetochlor + bensulfuron methyl or followed by orthosulfamuron and butachlor + propanil / 2,4-D amine (Table 2). In 2014, pyrazosulfuron-ethyl followed by orthosulfamuron followed by butachlor + propanil and orthosulfamuron followed by butachlor + propanil treatments reduced the density of *E. colona* completely. But, none of the herbicide treatments gave complete density reduction of *C. dactylon* during both years, perhaps, due to the regenerating capability from the viable stolon and branched underneath rhizome of this perennial weed. However, the greatest density reduction of *C. dactylon* in 2013 was provided by butachlor followed by one hand weeding at 25 DAT and pyrazosulfuron-ethyl followed by orthosulfamuron and butachlor + propanil. In 2014, pyrazosulfuron-ethyl followed by orthosulfamuron and butachlor + propanil and orthosulfamuron followed by butachlor + propanil treatments offered the highest reduction. On the other hand, the lowest density reduction of *C. dactylon* was in pyrazosulfuron-ethyl followed by acetochlor + bensulfuron methyl treated plots during 2013 and in butachlor followed by 2,4-D amine during 2014.

In case of sedge weeds, treatments having pyrazosulfuron-ethyl gave 100% density reduction of *Cyperus rotundus*, *F. miliacea* and *C. difformis* during both the year, however exception was found in sole application of pyrazosulfuron-ethyl and pyrazosulfuron-ethyl followed 2,4-D amine as these treatments provided 57% and 90% density reduction, respectively during 2014. On the contrary, treatments with butachlor reduced the density of *C. rotundus* by 38-67% in 2013 and 52-100% in 2014; *F. miliacea* by 39-100% in 2013 and 50-80% in 2014; *C. difformis* by 76-100% in 2013 and 50-90% in 2014. Moreover, during 2014, only butachlor followed by butachlor + propanil provided complete reduction of *C. rotundus*. In case of *F. miliacea*, complete reduction was obtained from butachlor followed by orthosulfamuron fb butachlor + propanil and butachlor followed by orthosulfamuron fb 2,4-D amine treatments during both years (Table 2). In case of *C. difformis*, only butachlor followed by acetochlor + bensulfuron methyl gave complete density reduction during 2013 but none of the herbicide treatments of 2014 provided 100% reduction on the density of this species. In earlier studies, less effectivity of butachlor on sedges was also reported in DSR (Katherisan, 2001; Patra *et al*., 2006; Mahajan and Chauhan, 2008). Moreover, Olofintoye and Mabbayad (1980) conducted an experiment on weed control of upland rice and also found that butachlor was a less effective herbicide to control sedge under minimum tillage system compared to the conventional tillage practice.

**Table 2. Effect of herbicide treatments on absolute density (plants $m^{-2}$) and relative reduction in density (%, in parenthesis) of weed species in non-puddled transplanted rice at 35 days after transplanting during 2013[a] and 2014[b]**

| Treatment | *Cynodon dactylon* | *Echinochloa colona* | *Cyperus rotundus* | *Fimbristylis miliacea* | *Cyperus difformis* | *Ludwigia decurrens* | *Cyanotis axillaris* | Others |
|---|---|---|---|---|---|---|---|---|
| **2013** | | | | | | | | |
| $T_1$ | 60 (0) | 23 (0) | 32 (0) | 9 (0) | 34 (0) | 17 (0) | 29 (0) | 18 (0) |
| $T_3$ | 15 (75) | 1 (94) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 15 (47) | 5 (74) |
| $T_4$ | 8 (87) | 9 (63) | 11 (67) | 5 (49) | 8 (76) | 1 (92) | 15 (47) | 1 (96) |
| $T_5$ | 20 (67) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 11 (61) | 1 (96) |
| $T_6$ | 16 (73) | 13 (45) | 17 (48) | 6 (39) | 0 (100) | 3 (80) | 12 (58) | 0 (100) |
| $T_7$ | 10 (83) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 3 (91) | 0 (100) |
| $T_8$ | 14 (77) | 9 (60) | 20 (38) | 0 (100) | 5 (84) | 2 (86) | 4 (86) | 1 (96) |
| $T_9$ | 14 (77) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) |
| $T_{10}$ | 17 (72) | 3 (86) | 13 (60) | 0 (100) | 7 (79) | 0 (100) | 0 (100) | 0 (100) |
| $HSD_{0.05}$ | 4.59 | 2.59 | 2.99 | 1.54 | 2.54 | 2.62 | 3.71 | 2.05 |
| CV (%) | 13.76 | 22.92 | 16.94 | 40.60 | 24.13 | 57.51 | 21.75 | 69.40 |
| **2014** | | | | | | | | |
| $T_1$ | 40 (0) | 11 (0) | 8 (0) | 10 (0) | 9 (0) | 11 (0) | 15 (0) | - |
| $T_3$ | 17 (59) | 6 (45) | 0 (100) | 0 (100) | 4 (57) | 5 (58) | 6 (60) | - |
| $T_4$ | 22 (46) | 6 (45) | 4 (52) | 3 (73) | 4 (57) | 9 (15) | 9 (38) | - |
| $T_5$ | 5 (88) | 4 (65) | 0 (100) | 0 (100) | 4 (57) | 0 (100) | 0 (100) | - |
| $T_6$ | 5 (88) | 4 (65) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 2 (87) | - |
| $T_7$ | 6 (85) | 5 (53) | 0 (100) | 2 (80) | 3 (64) | 3 (70) | 5 (67) | - |
| $T_8$ | 2 (94) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | - |
| $T_9$ | 24 (40) | 5 (53) | 0 (100) | 0 (100) | 1 (90) | 0 (100) | 3 (78) | - |
| $T_{10}$ | 31 (24) | 6 (45) | 2 (76) | 5 (50) | 4 (57) | 0 (100) | 5 (67) | - |
| $T_{11}$ | 3 (93) | 3 (76) | 0 (100) | 0 (100) | 2 (75) | 0 (100) | 0 (100) | - |
| $T_{12}$ | 2 (94) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | - |
| $T_{13}$ | 3 (93) | 2 (82) | 2 (76) | 0 (100) | 1 (90) | 0 (100) | 3 (78) | |
| $T_{14}$ | 14 (65) | 2 (82) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | 0 (100) | |
| $T_{15}$ | 21 (49) | 3 (76) | 2 (76) | 0 (100) | 5 (50) | 0 (100) | 1 (96) | |
| $HSD_{0.05}$ | 4.90 | 2.65 | 2.58 | 1.94 | 2.74 | 2.23 | 3.21 | - |
| CV (%) | 20.10 | 34.94 | 103.71 | 73.18 | 54.09 | 52.14 | 46.70 | - |

[a]*$T_1$ = Weedy check; $T_3$ = Pyrazosulfuron-ethyl followed by (fb) hand weeding(HW) at 25DAT; $T_4$ = Butachlor fb HW at 25 DAT; $T_5$ = Pyrazosulfuron-ethyl fb acetochlor + bensulfuron methyl; $T_6$ = Butachlor fb acetochlor + bensulfuron methyl; $T_7$ = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil; $T_8$ = Butachlor fb orthosulfamuron fb butachlor + propanil; $T_9$ = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and $T_{10}$ = Butachlor fb orthosulfamuron fb 2,4-D amine.*

[b]*$T_1$ = Weedy check; $T_3$ = Pyrazosulfuron ethyl; $T_4$ = Butachlor; $T_5$ = Orthosulfamuron; $T_6$ = Pyrazosulfuron ethyl fb butachlor + propanil; $T_7$ =Butachlor fb butachlor + propanil; $T_8$ =Orthosulfamuron fb butachlor + propanil; $T_9$ = Pyrazosulfuron ethyl fb 2,4-D amine; $T_{10}$ = Butachlor fb 2,4-D amine; $T_{11}$ = Orthosulfamuron fb 2,4-D amine; $T_{12}$ = Pyrazosulfuron ethyl fb orthosulfamuron fb butachlor + propanil; $T_{13}$ = Butachlor fb orthosulfamuron fb butachlor + propanil; $T_{14}$ = Pyrazosulfuron ethyl fb orthosulfamuron fb 2,4-D and $T_{15}$ = Butachlor fb orthosulfamuron fb 2,4-D amine.*

In case of broadleaf weeds, pyrazosulfuron-ethyl having all treatments provided full control of *Ludwigia decurrens* in both years (Table 2). Moreover, butachlor followed by orthosulfamuron followed by 2,4-D amine also ensured complete control of this species during both the year whereas butachlor followed by orthosulfamuron followed by butachlor + propanil was also offered full control of this broadleaf weed in 2014. In case of *Cyanotis axillaris*, pyrazosulfuron-ethyl followed by (fb) orthosulfamuron fb 2,4-D amine and butachlor fb orthosulfamuron fb butachlor + propanil gave complete control in 2013. During 2014, orthosulfamuron, orthosulfamuron fb butachlor + propanil, orthosulfamuron fb 2,4-D amine, pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil and pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine fully controlled this species. Previous study also found sequential herbicide treatments including post-emergence herbicide were effective for broadleaf weed control (Chauhan *et al*., 2015). But, the study showed less *C. axillaris* control efficiency of acetochlor + bensulfuron methyl compared to other post-emergence herbicides that is consistent with the previous study of Ahmed and Chauhan (2014) where this herbicide was also less effective on broadleaf weed in DSR.

In case of other minor weed species, herbicide treatments reduced their densities by 74-100% compared to weedy check in 2013 and this species were totally absent in 2014.

**Total weed density and biomass**

Weedy check had the highest weed densities (222 and 105 plants $m^{-2}$ in 2013 and 2014, respectively) and biomass (36.8 and 23.8 g $m^{-2}$ in 2013 and 2014, respectively). This result clearly indicated that the weed density and biomass in 2014 were remarkably lower than the preceeding year by 53-55% (Table 3). This might be related to the practice of strip tilled non-puddled transplanting in rice followed by strip tillage plus residue retention in the succeeding crops (wheat and mungbean) of the rotation. Mishra and Singh (2012) also reported the decrease of weed biomass by three-fold in the second year compared to the first year in DSR under zero tillage system.

Herbicide treatments had significant effect on reduction of weed density and biomass during both years and this reduction was 70-94% during 2013 and 46-98% during 2014 in case of weed density whereas in case of weed biomass, the reduction was recorded 56-94% in 2013 and 43-95% in 2014 compared to the weedy check (Table 3). Treatments with pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil offered the highest weed control effiency (WCE) and weed control index (WCI) during both the year (Table 3). Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine was also ensured higher WCE and WCI compared to other treatments in both years. Chauhan (2012) reported that use of single herbicide could not provide effective weed control due to the presence of the complex mixture of the weed species in the field. With sequential application of herbicides different weed species can control effectively, but use of herbicides with different modes of action is advisable to avoid herbicide resistence development in weeds (Busi *et al*., 2014; Owen and Powles, 2009). On the contrary, the lowest WCE and WCI were obtained from butachlor fb acetochlor + bensulfuron methyl in 2013 and in 2014, from sole application of butachlor. This lower weed controlling efficiency of butachlor might be related to the less control of *Echinochloa colona* and *Cyperus rotundus* at 35 DAT (Table 2). Moreover, acetochlor + bensulfuron methyl had poor control on on broadleaf weeds. Similar result was also by Halder *et al*. (2005) that pyrazosulfuron-ethyl @ 15g a.i $ha^{-1}$ reduced weed density and biomass more than butachlor @ 750g a.i $ha^{-1}$ while both herbicides were applied at 4 days after transplanting of rice, however the study was conducted in puddled field condition.

**Height of rice plant**

Plant height of transplanted *aman* rice was significantly affected by herbicides during both years (Table 4). Results demonstrated that the highest plant height in 2013 was recorded from butachlor fb hand weeding at 25 DAT (108.5 cm), and in 2014, the highest height was obtained from orthosulfamuron (111.7 cm) whereas weed-free plots had plant height of 104.5 cm in 2013 and 108.7 cm in 2014. The lowest plant height of 2013 was in butachlor fb acetochlor + bensulfuron methyl which was closely followed by pyrazosulfuron-ethyl fb acetochlor + bensulfuron methyl. During 2014, the lowest plant height was recorded from weedy plots.

**Number of panicles $m^{-2}$ and filled grains $panicle^{-1}$**

Number of panicles $m^{-2}$ and number of filled grains $panicle^{-1}$ of strip-tilled non-puddled transplanted rice were significantly affected by herbicide treatments during 2013 and 2014 (Table 4). In 2013, the highest numbers of panicles $m^{-2}$ and filled grains $panicle^{-1}$ were counted from weed-free plots and identical results were also obtained from pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil treated plots. Butachlor fb orthosulfamuron fb butachlor + propanil also provided similar number of panicles $m^{-2}$ and pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine gave similar number of filled grains $panicle^{-1}$ with weed-free control. This might be happened for ensuring better weed control by those treatment that leads to reduced crop-weed competition and facilitated the uptake of more nutrients resulted healthier rice plants with more tillers and panicles (Ahmed and Chauhan, 2014; Awan *et al*., 2014).

**Table 3. Effect of herbicide treatments on weed density and biomass and their weed control efficiency (WCE) and weed control index (WCI) in strip-tilled non-puddled transplanted rice field at 35 days after during 2013 and 2014**

| Treatments | Weed density (no. $m^{-2}$) | WCE (%) | Weed biomass (g $m^{-2}$) | WCI (%) |
|---|---|---|---|---|
| | | **2013** | | |
| Weedy check | 222 | - | 36.8 | - |
| Pyrazosulfuron-ethyl fb HW at 25 DAT | 36 | 84 | 4.6 | 88 |
| Butachlor fb HW at 25 DAT | 56 | 75 | 5.2 | 86 |
| Pyrazosulfuron-ethyl fb aceto + bensul | 32 | 85 | 10.5 | 72 |
| Butachlor fb aceto + bensul | 66 | 70 | 16.6 | 56 |
| Pyrazosulfuron-ethyl fb orthosul fb buta + prop | 13 | 94 | 2.2 | 94 |
| Butachlor fb orthosul fb buta + prop | 56 | 75 | 6.3 | 83 |
| Pyrazosulfuron-ethyl fb orthosul fb 2,4-D | 14 | 94 | 2.5 | 93 |
| Butachlor fb orthosul fb 2,4-D | 40 | 82 | 6.6 | 82 |
| $HSD_{0.05}$ | 6.95 | | 1.42 | |
| CV (%) | 7.79 | | 9.90 | |
| | | **2014** | | |
| Weedy check | 105 | - | 23.8 | - |
| Pyrazosulfuron-ethyl | 37 | 65 | 10.1 | 58 |
| Butachlor | 57 | 46 | 13.6 | 43 |
| Orthosul | 13 | 88 | 7.0 | 71 |
| Pyrazosulfuron-ethyl fb buta + prop | 11 | 90 | 4.2 | 82 |
| Butachlor fb buta + prop | 25 | 76 | 6.1 | 74 |
| Orthosul fb buta + prop | 2 | 98 | 1.9 | 92 |
| Pyrazosulfuron-ethyl fb 2,4-D | 33 | 68 | 6.4 | 73 |
| Butachlor fb 2,4-D | 54 | 49 | 8.1 | 66 |
| Orthosul fb 2,4-D | 8 | 92 | 5.0 | 79 |
| Pyrazosulfuron-ethyl fb orthosul fb buta + prop | 2 | 98 | 1.2 | 95 |
| Butachlor fb orthosul fb buta + prop | 11 | 90 | 3.6 | 85 |
| Pyrazosulfuron-ethyl fb orthosul fb 2,4-D | 16 | 85 | 3.3 | 86 |
| Butachlor fb orthosul fb 2,4-D | 31 | 71 | 4.9 | 79 |
| $HSD_{0.05}$ | 8.26 | | 2.29 | |
| CV (%) | 9.48 | | 10.75 | |

'fb' = 'followed by', 'aceto + bensul' = 'acetochlor + bensulfuron methyl', 'orthosul' = 'orthosulfamuron', 'buta + prop' = 'butachlor + propanil', '2,4-D' = '2,4-D amine', 'CV' = co-efficient of variance

## Rice grain and straw yield

Grain and straw yield of T. *aman* rice was significantly influenced by the application of different weed control treatments (Table 5). In both years, the lowest grain and straw yields were in weedy control whereas weed-free control produced the highest grain and straw yield in 2013, and in 2014, the highest yields were recorded from pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil. Moreover, this treatment and butachlor fb orthosulfamuron fb butachlor + propanil also provided similar higher grain yield as weed-free control in 2013. During 2014, pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine, butachlor fb orthosulfamuron fb butachlor + propanil and orthosulfamuron fb butachlor + propanil produced similar grain and straw yield with weed-free control. The increase in yield with herbicides owed the significant reduction in density and dry matter of weeds which were unable to compete with the crop plants for different growth factors which consequently resulted in the better expression of yield components and thus gave higher yield of rice. Awan *et al*. (2015) and Zahan *et al*. (2014) reported that sequential application of pre-emergence, early post- and late-post-emergence herbicides effectively controlled weeds during the whole crop growth stage and therefore higher yield was achieved.

## Economic analysis

Partial economic analysis results revealed that the lowest gross income and net benefit were calculated from the weedy check in both years. Results also showed that weed-free treatment had the highest gross income in 2013 but the highest net return was calculated from pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil. The reason might be the high weed management cost involment of weed-free plots that reduced the amount of net return compared to the pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil treatment. In 2013, except pyrazosulfuron-ethyl fb acetochlor + bensulfuron methyl and butachlor fb acetochlor + bensulfuron methyl, all other herbicide treatments had higher economic return by 5.6-43.1% over weed-free treatment (Table 5). In 2014, the highest gross income and net return were also calculated from pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil. Treatments that also had higher net benefit over weed-free control treatment in 2014 were pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine > butachlor fb orthosulfamuron fb butachlor + propanil > orthosulfamuron fb butachlor + propanil > pyrazosulfuron-ethyl fb butachlor + propanil > butachlor fb orthosulfamuron fb 2,4-D amine > orthosulfamuron fb 2,4-D amine. This findings are in support with several previos researches that also reported high weeding cost made weed-free treatment economically non-profitable (Parvez *et al*., 2013).

**Table 4. Effect of herbicide treatments on plant height, number of panicles $m^{-2}$ and filled grains $panicle^{-1}$ of transplanted *aman* rice in non-npuddled soil during 2013 and 2014**

| Treatments | Plant height (cm) | Panicles $m^{-2}$ (No.) | Filled grains $panicle^{-1}$ (No.) |
|---|---|---|---|
| | | **2013** | |
| Weedy check | 103.9 | 339 | 58.0 |
| Weed-free check | 104.5 | 429 | 74.7 |
| Pyrazosulfuron-ethyl fb HW at 25 DAT | 105.7 | 371 | 72.1 |
| Butachlor fb HW at 25 DAT | 108.5 | 358 | 68.1 |
| Pyrazosulfuron-ethyl fb aceto + bensul | 95.9 | 401 | 59.6 |
| Butachlor fb aceto + bensul | 95.3 | 340 | 52.2 |
| Pyrazosulfuron-ethyl fb orthosul fb buta + prop | 104.5 | 412 | 73.2 |
| Butachlor fb orthosul fb buta + prop | 104.1 | 409 | 70.3 |
| Pyrazosulfuron-ethyl fb orthosul fb 2,4-D amine | 103.1 | 352 | 74.4 |
| Butachlor fb orthosul fb 2,4-D amine | 102.0 | 350 | 73.0 |
| $HSD_{0.05}$ | 1.76 | 31.63 | 2.62 |
| CV (%) | 1.12 | 4.90 | 2.26 |
| | | **2014** | |
| Weedy check | 107.0 | 316 | 50.2 |
| Weed-free check | 108.7 | 409 | 92.3 |
| Pyrazosulfuron-ethyl | 110.3 | 352 | 71.2 |
| Butachlor | 110.6 | 334 | 63.9 |
| Orthosul | 111.7 | 342 | 65.0 |
| Pyrazosulfuron-ethyl fb buta + prop | 108.9 | 386 | 79.5 |
| Butachlor fb buta + prop | 109.1 | 374 | 67.8 |
| Orthosul fb buta + prop | 109.3 | 370 | 76.5 |
| Pyrazosulfuron-ethyl fb 2,4-D amine | 108.7 | 353 | 62.2 |
| Butachlor fb 2,4-D amine | 108.3 | 348 | 60.2 |
| Orthosul fb 2,4-D amine | 107.2 | 348 | 66.2 |
| Pyrazosulfuron-ethyl fb orthosul fb buta + prop | 109.2 | 425 | 94.8 |
| Butachlor fb orthosul fb buta + prop | 107.2 | 385 | 81.6 |
| Pyrazosulfuron-ethyl fb orthosul fb 2,4-D amine | 107.8 | 391 | 85.2 |
| Butachlor fb orthosul fb 2,4-D amine | 109.1 | 368 | 75.8 |
| $HSD_{0.05}$ | 2.85 | 41.75 | 11.11 |
| CV (%) | 7.89 | 3.76 | 5.04 |

‘fb’ = ‘followed by’, ‘aceto + bensul’ = ‘acetochlor + bensulfuron methyl’, ‘orthosul’ = ‘orthosulfamuron’, ‘buta + prop’ = ‘butachlor + propanil’, ‘2,4-D’ = ‘2,4-D amine’, CV = co-efficient of variance

**Table 5. Effect of herbicides on grain and straw yield and their cost effectiveness in strip-tilled non-puddled transplanted *aman* rice in 2013 and 2014**

| Treatments | Grain yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) | Weed management cost (Tk. $ha^{-1}$) | Total cost (Tk. $ha^{-1}$) | Gross income (Tk. $ha^{-1}$) | Net benefit (Tk. $ha^{-1}$) |
|---|---|---|---|---|---|---|
| | | | **2013** | | | |
| Weedy check | 3.10 | 4.84 | 0 | 42125 | 59960 | 17835 |
| Weed-free check | 5.51 | 6.54 | 25000 | 67125 | 103225 | 36100 |
| Pyrazo fb HW | 4.76 | 5.98 | 7140 | 49265 | 89890 | 40625 |
| Buta fb HW | 4.68 | 5.99 | 8300 | 50425 | 88545 | 38120 |
| Pyrazo fb aceto + bensul | 3.83 | 5.32 | 2146 | 44271 | 73090 | 28819 |
| Buta fb aceto + bensul | 3.44 | 5.23 | 3306 | 45431 | 66325 | 20894 |
| Pyrazo fb orthosul fb buta + prop | 5.42 | 6.17 | 3850 | 45975 | 101905 | 55930 |
| Buta fb orthosul fb buta + prop | 5.02 | 5.79 | 5010 | 47135 | 94025 | 46890 |
| Pyrazo fb orthosul fb 2,4-D | 5.25 | 6.03 | 4515 | 46640 | 98295 | 51655 |
| Buta fb orthosul fb 2,4-D | 4.98 | 5.80 | 5675 | 47800 | 93360 | 45560 |
| $HSD_{0.05}$ | 0.31 | 0.24 | - | - | - | - |
| CV (%) | 3.88 | 2.46 | - | - | - | - |
| | | | | **2014** | | |
| Weedy check | 2.69 | 4.24 | 0 | 42125 | 52147 | 10022 |
| Weed-free check | 5.99 | 6.36 | 25000 | 67125 | 111427 | 44302 |
| Pyrazo | 3.58 | 5.11 | 890 | 43015 | 68463 | 25448 |
| Buta | 3.20 | 4.69 | 2050 | 44175 | 61430 | 17255 |
| Orthosul | 3.75 | 5.44 | 1550 | 43675 | 71910 | 28235 |
| Pyrazo fb buta + prop | 5.30 | 5.68 | 2300 | 44425 | 98563 | 54138 |
| Buta fb buta + prop | 4.42 | 5.14 | 3460 | 45585 | 82912 | 37327 |
| Orthosul fb buta + prop | 5.67 | 6.04 | 2960 | 45085 | 105393 | 60308 |
| Pyrazo fb 2,4-D | 4.68 | 5.42 | 2965 | 45090 | 87752 | 42662 |
| Buta fb 2,4-D | 4.12 | 5.26 | 4125 | 46250 | 77935 | 31685 |
| Orthosul fb 2,4-D | 4.84 | 5.44 | 3625 | 45750 | 90445 | 44695 |
| Pyrazo fb orthosul fb buta + prop | 6.18 | 6.61 | 3850 | 45975 | 115032 | 69057 |
| Buta fb orthosul fb buta + prop | 5.82 | 6.23 | 5010 | 47135 | 108228 | 61093 |
| Pyrazo fb orthosul fb 2,4-D | 6.01 | 6.46 | 4515 | 46640 | 111865 | 65225 |
| Buta fb orthosul fb 2,4-D | 4.95 | 5.82 | 5675 | 47800 | 92937 | 45137 |
| $HSD_{0.05}$ | 0.51 | 0.49 | - | - | - | - |
| CV (%) | 3.53 | 2.86 | - | - | - | - |

- Details of the fixed cost calculation have not been shown.

[‘fb’ = followed by, ‘Pyrazo’ = pyrazosulfuron-ethyl, ‘buta’ = butachlor, ‘orthosul’ = orthosulfamuron, ‘aceto + bensul’ = acetochlor + bensulfuron methyl, ‘buta + prop’ = butachlor + propanil and ‘2,4-D’ = 2,4-D amine]

Market price of commercial herbicides: pendimethalin = Tk. 2525 $ha^{-1}$, pyrazosulfuron-ethyl = Tk. 390 $ha^{-1}$, butachlor = Tk. 1550 $ha^{-1}$, pretilachlor = Tk. 790 $ha^{-1}$, orthosulfamuron = Tk. 1050 $ha^{-1}$, acetochlor+ bensulfuron methyl = Tk. 756 $ha^{-1}$, butachlor+ propanil = Tk. 910 $ha^{-1}$ and 2,4-D amine = Tk. 1575 $ha^{-1}$.

Manual weeding cost: 100 labours $ha^{-1}$ for 4 weeding (season-long weed free) @ Tk. 250 $labour^{-1}$ $day^{-1}$, Herbicide application cost: 2 labours $ha^{-1}$ $round^{-1}$ @ Tk. 250 $labour^{-1}$ $day^{-1}$, Market price of grain: Tk. 17,000 $ton^{-1}$, Market price of straw: Tk. 1500 $ton^{-1}$, Gross income = {grain yield (t $ha^{-1}$) × market price (Tk. $ton^{-1}$)} + {straw yield (t $ha^{-1}$) × market price (Tk. $ton^{-1}$)} , Net benefit = Gross income – Total cost.

## Conclusion

Sole application of pre-emergence herbicide was not effective for controlling weeds in strip-tilled non-puddled transplanted rice. Sequential application of pyrazosulfuron-ethyl with orthosulfamuron followed by butachlor + propanil was the best under reduced tillage system that offered high grain yield with highest economic return. Pyrazosulfuron-ethyl followed by orthosulfamuron followed by 2,4-D amine, butachlor followed by orthosulfamuron and butachlor + propanil or 2,4-D amine were also performed better in respect of weed control and economic benefit. But, use of pyrazosulfuron-ethyl followed by butachlor + propanil/2,4-D amine or orthosulfamuron fb butachlor + propanil also could be effective and economically viable in strip tillage non-puddled transplanted rice.

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