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Article

Weed Management in Direct Seeded Rice Grown under Varying Tillage Systems and Alternate Water Regimes

Gerenciamento de Plantas Daninhas em Arroz Semeado Direto Cultivado em Sistemas Variáveis de Plantio Direto e Regimes Alternativos de Água

RIAZ, A.[1,2]
KHALIQ, A.[2]
FIAZ, S.[1]
NOOR, M.A.[3,*]
NAWAZ, M.M.[3]
MAHBOOB, W.[4]
ULLAH, S.[5]

ABSTRACT - In direct seeded rice (DSR), flushes of weeds are encountered, and mostly subsequent herbicides need to apply to control weeds that appear later. A farmer friendly approach was hypothesized in present study to integrate the management strategies for water, soil and cost effective weed free rice production. Efficacy of various herbicides in weed control to improve the performance of aerobic rice grown under varying tillage and alternate water regimes was evaluated. Five weed management techniques (weedy check, weed-free, pendimethalin followed by manual weeding, pendimethalin + bispyribac sodium (BS) + bensulfuron (B) and pendimethalin + MCPA) were carried out within the alternate wetting and drying (AWD) regimes (15 and 20 cm depth) under two tillage systems (zero and conventional). All the herbicide treatments reduced the weed intensity as compared to weedy check, however minimum weed density and dry biomass was observed in pendimethalin at 40 and 60 days after sowing, respectively. Under conventional tillage, weed free plots showed maximum leaf area index, leaf area duration and crop growth rate. Maximum plant height, 1000-kernel weight and kernel per panicle along with less percentage of abortive, chalky and opaque kernels were recorded in pendimethalin followed by BS+B as compared to weedy check plots. Among the herbicides application, pendimethalin followed by BS+B gave highest benefit to cost ratio and net benefits under both AWD regimes. Overall, application of pendimethalin followed by BS+B is an efficient and economic approach to reduce weed infestation which results in improved yield of aerobic rice.

Keywords: aerobic rice, herbicides, irrigation management, benefit-cost ratio.

RESUMO - Em arroz semeado direto (DSR), são encontradas descargas de plantas daninhas, e a maioria dos herbicidas subsequentes precisam se aplicar para controlar as plantas daninhas que aparecem mais tarde. Uma abordagem amigável ao agricultor foi hipotetizada no presente estudo para integrar as estratégias de manejo de água, solo e produção de arroz sem ervas econômicas. Foi avaliada a eficácia de vários herbicidas no controle de plantas daninhas para melhorar o desempenho do arroz aeróbio cultivado em lavoura variável e regimes alternativos de água. Foram realizadas cinco técnicas de manejo de plantas daninhas (controle de plantas daninhas, sem plantas daninhas, pendimetalina, seguidas de remoção manual, pendimethalin + bispyribac sodium (BS) + bensulfuron (B) e pendimethalin + MCPA) nos regimes alternativos de molhagem e secagem (AWD) (15 E 20 cm de profundidade) sob dois sistemas de preparo do solo (zero e convencional). Todos os tratamentos de herbicidas reduziram a intensidade da planta daninha em comparação com a verificação de plantas daninhas, porém a

*** Corresponding author:**
<mehmood2017@gmail.com>.

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[1] China National Rice Research Institute, Hangzhou 310006, Zhejiang, China; [2] University of Agriculture, Faisalabad 38040, Pakistan; [3] Institute of Crop Science, Chinese Academy of Agricultural Sciences, Beijing 100081, China; [4] Plant Physiology Division, Nuclear Institute of Agriculture (NIA), Tandojam, 70050 Pakistan; [5] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China.

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densidade mínima de plantas daninhas e a biomassa seca foram observadas na pendimetalina aos 40 e 60 dias após a semeadura, respectivamente. Sob plantio convencional, as parcelas sem plantas apresentaram índice máximo de área foliar, duração da área foliar e taxa de crescimento da cultura. A altura máxima da planta, o peso do milho e a semente por panícula, juntamente com menos porcentagem de grãos abortivos, calcários e opacos, foram registrados em pendimetalina, seguido de BS + B, em comparação com parcelas de verificação de plantas daninhas. Entre a aplicação de herbicidas, a pendimetalina, seguida de BS + B, proporcionou maior benefício em relação custo e benefícios líquidos em ambos os regimes AWD. Em geral, a aplicação de pendimetalina seguida de BS + B é uma abordagem eficiente e econômica para reduzir a infestação de plantas daninhas, o que resulta em melhor produção de arroz aeróbio.

Palavras-chave: arroz aeróbico, herbicidas, gerenciamento de irrigação, relação custo-benefício.

INTRODUCTION

More than half of the world's population consumes rice (*Oryza sativa* L.) as staple food and this fact highlights the importance of rice in terms of food security and crop production (Langaro et al., 2016). Asia is a leading rice producer as well as consumer where more than 90% of the world's rice being grown and consumed.

In conventional tillage methods for puddled-soil rice production systems, an intensive cultivation of wet soil is required to create the puddled conditions, where 3-6 weeks old rice nursery seedlings are transplanted manually (Ashraf et al., 2014). These production techniques faced many challenges regarding resource use efficiencies, sustainability and economic viability. Such problems included high costs associated with manual transplanting and formation of hard pan through puddling which reduced soil permeability (Singh et al., 2005; Chauhan, 2012). Thus, water availability and water use efficiency is the most important factor for rice production, especially under climate change scenario. High costs associated with manual transplanting is another challenge.

Reduced water availability coupled with ever increasing demands for water use have prompted stakeholders to invest more in exploring improved rice production techniques (Ghosh et al., 2017). In some Asian rice growing countries, DSR is gaining popularity as an alternative approach among the farmers who respond to either reduced availability or increased costs of water and labor (Pandey and Velasco, 2002). In addition to low water requirement, drop-off labor demand and ease in farm operations resulted in conducive mechanizations which support DSR over transplanted rice. As far as weeds concerned, transplanted rice has a clear edge over DSR (Chauhan and Johnson, 2009; Chauhan, 2012). Hence, among various factors affecting rice growth like fertilizer management and sowing dates (Abid et al., 2015), weed invasion is one of the most severe problems in aerobic rice (Khaliq et al., 2012, Muhammad et al., 2016; Ullah et al., 2017) which caused reduction in grain yield up to 80% in DSR (Mahajan and Chauhan, 2015).

DSR can be sown into a prepared seed bed or under zero-till (ZT) conditions which depends upon the production system. ZT has advantages over conventional tillage in terms of reduced costs, improved soil properties and conserved soil moisture (Chauhan, 2012). Tillage systems affect the vertical distribution of weed seeds and impact the composition of weed communities (Chauhan et al., 2006), the abundance of particular weed species and their relative time of emergence (Grundy et al., 2003). It has been reported that an increase in density of annual grass weeds and decrease in broad leaf weeds was noted in DSR under reduced tillage (Gill and Arshad, 1995; Tuong et al., 2005).

It is very important to improve water management in DSR to obtain optimum yield, as potential weed problem already posed a challenge to sustain yield in DSR as compared to conventional transplanted rice (Rao et al., 2007). Aerobic soil conditions and AWD in DSR are advantageous to the germination and growth of weeds (Mahajan and Chauhan, 2015). Studies about chemical weed control in DSR have highlighted some tricky situations and suggested that single application of pre or post-emergence herbicide may not completely eradicate the weeds: very short time window suitable for pre-emergence herbicide application (about 3 days) and farmer can miss this optimum time; it also requires proper moisture at time of application (Mahajan and Chauhan, 2015). Likewise, complexity in weed flora in DSR hinders the effective weed control through single herbicide (Majhi et al., 2009). Such studies have suggested sequential applications of pre and post-emergence herbicides.

Present study was conducted to optimize the crop production management in DSR, mainly focused on weed control which is key limitation in widespread adoption of DSR under varying water supply and tillage management. Specific objectives were i) to quantify the weed flora under different tillage system and water management in DSR, ii) to estimate the efficiency of some pre and post emergence herbicides alone or in combinations for weed control in DSR under different tillage and water regimes iii) to evaluate the agronomic and economic returns of DSR under these arrangements.

MATERIAL AND METHODS

Plant material and treatment application

The experiment was conducted at the research farm of Department of Agronomy, University of Agriculture Faisalabad, Pakistan. Soil type can be described as Aridisol-fine-silty, mixed, hyper thermic Ustalfic, Haplargid as per USDA classification, such soil type was categorized as Lyallpur soil series (Cheema and Khaliq, 2000). The physicochemical properties of that soil were pH 8.4, EC 0.43 dSm^{-1}, organic carbon 1%, total nitrogen 0.77% and available phosphate 120 ppm along with exchangeable Na 0.9 me 100 g^{-1} and K 104 ppm. Experimental area, considered as arid climate region due to high evapotranspiration having mean annual rainfall about 200 mm. The meteorological data (collected from AgroMet observatory, Department of Agronomy) during experiment are presented in Figure 1.

In the summer of 2014, experiment was laid out as randomized complete block design with three replicates under split-split plot arrangement. Tillage treatments i.e. zero tillage (ZT); and conventional tillage (CT) were kept in main plots, and AWD regimes i.e. 15 cm and 20 cm were assigned to sub-plots. Weed management treatments (WM) comprising, i) pendimethalin [455 CS] at 825 g ha^{-1} (immediately after sowing) followed by manual weeding (30 days after sowing [DAS]); ii) pendimethalin [455 CS] at 825 g ha^{-1} (immediately after sowing) followed by bispyribac sodium (BS) at 30 g ha^{-1} (12 DAS) + bensulfuron (B) [BS18% + B12%, 30 WP] at 375 g ha^{-1} (12 DAS); iii) pendimethalin [455 CS] at 825 g ha^{-1} (immediately after sowing) + MCPA [20 EC] at 450 g ha^{-1} (12 DAS); iv-v) plus two untreated controls with weed competition (weedy check) and weed-free were allotted to sub-sub plots. The plot size was 2.2 m x 8 m. CT included disc plough cultivation followed by ploughing thrice with a tractor-mounted cultivator and planked each time. In ZT treatment, tillage was performed in one operation by single row hand drill into undisturbed seed

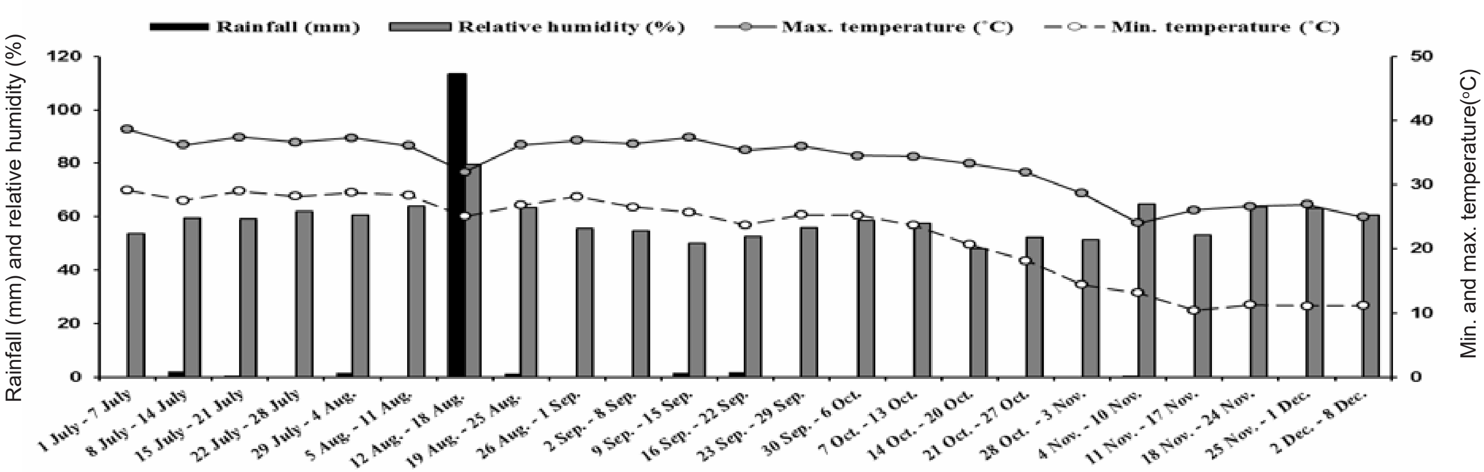


Figure 1 - Meteorological data on weekly average relative humidity (%), minimum and maximum temperature (°C), and weekly total rainfall (mm) during the course of present study (1st July – 8th December).

bed. Same tillage practices were performed in respective plots during preceding wheat crop. Alternate wetting and drying at the depth of 15 and 20 cm were maintained by perforated (holes of about 0.5 cm diameter and 2 cm apart) PVC tubes of varying lengths (25 cm and 30 cm long respectively) with diameter of 10 cm installed vertically in soil up to desired depth of 15 and 20 cm. Irrigation was applied to the field up to 5 cm depth, once the ponded water disappeared in the PVC tubes, afterwards weed management treatments (WM) were applied. The wetting and drying interval was maintained keeping in view the prevailing edaphic (e.g. soil type) and climatic (temperature) conditions. Rewetting (irrigation) was used to done, when the water level go beyond the treatments depth (15 and 20 cm) in the PVC tubes from field surface level (Figure 2). Whereas, rice field was kept irrigated at constant level of 5 cm above the soil surface throughout the flowering stage, to avoid any water stress. However, glyphosate (72 SL) was applied in ZT plots 20 days before sowing to eradicate already established weeds to make it comparable with CT where weeds were eradicated during cultivation.

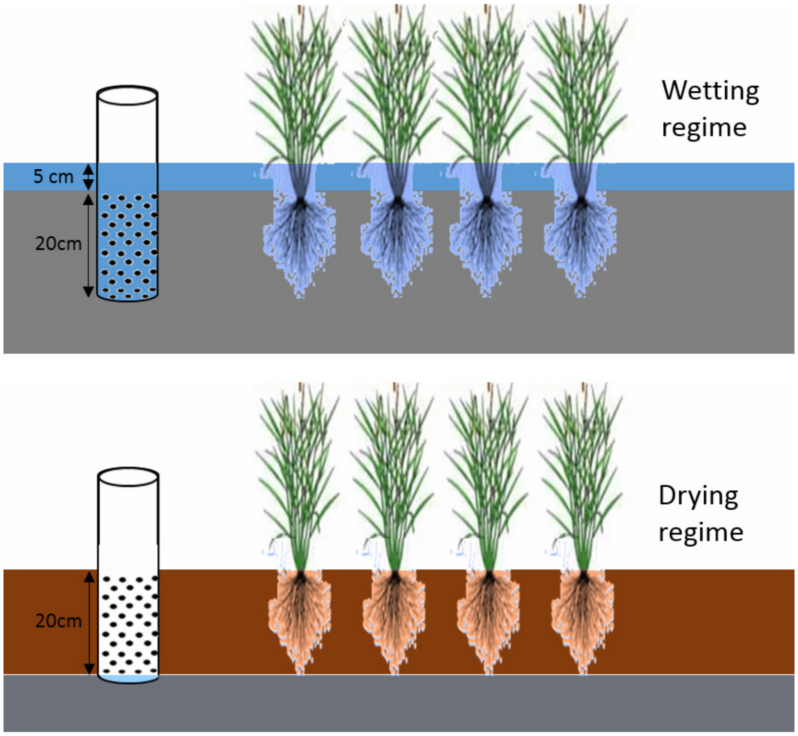


Figure 2 - Illustration of alternate drying and wetting regimes management for direct seeded rice.

Crop husbandry

Fine grain rice cultivar Basmati-515 was used as planting material and seeds were obtained from Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan. Fertilizer management included application of 114 kg N, 65 kg P_2O_5, and 50 kg K_2O per hectare in the form of urea (46% N), diammonium phosphate (18% N, 46% P_2O_5) and sulphate of potash (50% K_2O). Whole P, K and a split of N (38 kg) was incorporated in soil as basal doses at the time of sowing, while rest of N was applied in two equal splits at tillering (30 DAS) and panicle initiation (65 DAS) as top dressing. Other cultural practices including insect/pest control were followed as recommended across all treatments.

Measurements

Weed density and weed biomass were recorded at 30 and 60 DAS, using two randomly selected quadrats of 1 m x 1 m. Weeds within each quadrat were identified, counted, and clipped off above the soil surface. Individual weeds were grouped into weed type (grasses, broad-leaved and sedges) and oven dried at 70 °C for 72 h to determine biomass and used for further analyses.

For rice growth analysis, sampling was started when crop reached 60 DAS. Samples for growth analysis were collected from an area of 20 cm x 50 cm. Then this was separated into leaves and stems. For leave area measurement 5 g leaves sample was taken and leaf area was measured by leaf area meter (Licor, Model 3100). Remaining samples were sun dried for 24 hours then oven dried for 48 hours for the calculation of other growth parameters. Sampling was carried out with interval of 15 days.

Leaf area index was measured by using following formula described by Watson, (1947).

$$AI = \frac{Leaf\ area}{Land\ area}$$

while, leaf area duration (LAD), Crop growth rates (CGR) and net assimilation rate (NAR) were measured by following the standard methods proposed by Hunt (1978).

$$LAD = \left(LAI_1 + LAI_2\right) \left(t_2 - t_1\right)/2$$

$$CGR = \frac{W_2 / W_1}{t_2 / t_1}$$

$$NAR = \frac{TDM}{LAD}$$

Agronomic attributes were measured by selecting ten random rice plants from each plot and then average was computed. Paddy yield was measured after harvesting each plot (5 m x 1 m) and manual threshing. Grain yield was determined on the basis of 14% kernel moisture content. Kernel quality parameters were assessed by placing twenty kernels in front of light (Tungsten filament bulb) on working board. Afterwards, abortive, chalky, opaque and normal kernels were analyzed and expressed as percentage.

Gross income and total expenditures were calculated for each treatment. Total expenditures were calculated by adding the fixed cost of all the expenditures from sowing till harvesting and variable cost including market price of herbicides and labor charges. Cost benefit ratio was calculated by dividing gross income with total expenditures.

Statistical analysis

Data on weed density and weed biomass were square root [“(x þ 0.5)] to improve variance homogeneity. Statistix 8.1 statistical package (Analytical software, Statistix; Tallahassee, FL, USA, 1985-2003) was used to statistically analyze data for Fisher’s analysis of variance (Steel et al., 1997). Tukey’s test ($p \leq 0.05$) was used to compare the differences amongst the treatment means.

RESULTS AND DISCUSSION

Weeds adversely affected the growth and yield of rice under field conditions. Weed community of experimental site comprised the weeds horse purslane (*Trianthema parchulacastrum*), purple nutsedge (*Cyperus rotundus*), crowfoot grass (*Dactyloctenium aegyptium*), alligator weed (*Alternanthera philoxerides*), jungle rice (*Echinochloa colona*), and other minor weeds like bermuda grass (*Cynodon dactylon*), and rice flatsedge (*Cyperus iria*).

Weed control treatments had significantly reduced total weed density, whereas the tillage systems, alternate wetting and drying and their interaction with weed managements was non-significant (Table 1). Maximum weed density was observed in partially weedy check plot (control); however, rice plots treated with pendimethalin succeeded by BS+B treatment effectively reduced total weed density by 86% and 74% at 30 and 60 DAS respectively, as compared to control. Likewise,

Table 1 **-** Influence of tillage system, alternate wetting and drying and weed management on total weed density (m^2) at 30, 60 DAS in aerobic rice

Tillage systems (TS)	Total				Horse Purslane			
	Weed density 30 DAS (m^2)	Weed density 60 DAS (m^2)	Dry biomass 30 DAS ($g\ m^{-2}$)	Dry biomass 60 DAS ($g\ m^{-2}$)	Weed density 30 DAS (m^2)	Weed density 60 DAS (m^2)	Dry biomass 30 DAS ($g\ m^{-2}$)	Dry biomass 60 DAS ($g\ m^{-2}$)
Conventional	132.00	197.00	34.32	50.30	67.38 a	89.89 a	17.52 a	23.37 a
Zero tillage	128.42	193.42	33.39	51.21	62.00 b	84.5 b	16.12 b	21.97 b
HSD (p≤ 0.05)	NS	NS	NS	NS	4.07	4.07	1.05	1.06
Alternate wetting and drying regimes(AWD)								
15 cm	128.46	193.46	33.40	50.30	64.29	86.79	16.72	22.57
20 cm	131.96	196.96	34.31	51.21	65.08	87.58	16.92	22.77
HSD (p≤ 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management (WM)								
Weedy check	341.50 a	421.50 a	88.79 a	109.59 a	161.58 a	191.58 a	41.86 a	49.81a
Weed free	-	-	-	-	-	-	-	-
P ➡ MW	77.33 b	137.33 b	20.11 b	35.70 b	44.92 b	64.92 b	11.18 b	16.88 b
P ➡ BS+B	48.25 c	108.25 c	12.55 c	28.15 c	24.83 d	44.83 c	6.33 c	11.66 c
P ➡ MCPA	53.75 c	113.75 c	13.98 c	29.57 bc	27.42 c	47.42 c	6.85 c	12.33 c
HSD (p≤ 0.05)	6.85	6.88	2.09	6.88	2.42	6.88	0.69	0.74
Interactions								
TS x AWD	NS	NS	NS	NS	NS	NS	NS	NS
TS x WM	NS	NS	NS	NS	NS	NS	NS	NS
AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS
TS x AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS

NS = Non-significant, '➡' = Followed by; B = Bispyribac sodium, B = Benzo-sulfran, MH = Mannual hoeing, P = Pendimethalin, MW = manual weeding. * Means sharing same letter do not differ significantly from each other at Tukey5% probability level.

pendimethalin followed by BS+B also showed minimum weed dry biomass at 30 and 60 DAS by depicting highest reduction of 84% and 81% with respect of control (Table 1).

Application of pendimethalin in sequence with BS+B resulted in minimum total weed density. For tillage system, conventional tillage accounted 8% more horse purslane dry biomass than zero tillage. Maximum reduction in dry biomass of horse purslane (80% and 79%) against control at 30 and 60 DAS was observed when pendimethalin was followed by BS+B. Almost similar trend was recorded for Crowfoot grass and Purple nutsedge density (m^2) and dry biomass ($g\ m^{-2}$) at 30 DAS and 60 DAS presented in Table 2.

All growth attributes were significantly influenced by herbicide application and tillage systems (Figures 3, 4 and 5). LAI was progressively increased up to 90 DAS affected by tillage system and herbicides (Figure 3). In herbicides applications, maximum LAI was recorded when pendimethalin followed by BS+B under both zero tillage and conventional tillage respectively. Maximum LAD was observed in weed free treatment at zero tillage and conventional tillage which then followed by application of pendimethalin with addition to BS+B treatment (Figure 4). Results indicated that with the passage of time, crop growth rate increased and reached maximum after 75-85 DAS and then suddenly decreased on the onset of maturity (Figure 5). Among herbicides, pendimethalin followed by BS+B gave maximum CGR at 71-85 DAS. Figure 6 shows that pre and post anthesis NAR was higher in all treatments while it decreased in post anthesis stage. Weedy check plots showed reduced pre and post anthesis NAR under both tillage system. Seasonal NAR decreased in weedy check treatment (Table 3) while weed free and herbicide treatments improved seasonal NAR. Maximum NAR was recorded where pendimethalin followed by BS+B was applied 12 DAS.

Maximum plant height was recorded in weed free plots whereas it reduced to minimum in partial weedy check treatment. The improved plant height in weed free treatment is about 40%

Table 2 **-** Influence of tillage system, alternate wetting and drying and weed management on different weed densities (m^2) at 30, 60 DAS in aerobic rice

Tillage systems (TS)	Crowfoot grass				Purple nutsedge			
	Weed density 30 DAS (m^2)	Weed density 60 DAS (m^2)	Dry biomass 30 DAS (g m^{-2})	Dry biomass 60 DAS (g m^{-2})	Weed density 30 DAS (m^2)	Weed density 60 DAS (m^2)	Dry biomass 30 DAS (g m^{-2})	Dry biomass 60 DAS (g m^{-2})
Conventional	49.17	71.67 b	12.78 b	18.63 b	15.46	35.46	4.02	9.22
Zero tillage	53.88	76.38 a	14.01 a	19.86 a	12.54	32.54	3.26	8.46
HSD (p≤ 0.05)	NS	4.52	1.16	1.18	NS	NS	NS	NS
Alternate wetting and drying regimes (AWD)								
15 cm	50.88	73.38	13.23	19.08	13.29	33.29	3.46	8.66
20 cm	52.17	74.67	13.56	19.41	14.71	34.71	3.82	9.02
HSD (p≤ 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management (WM)								
Weedy check	151.25 a	181.25 a	39.33 a	47.13 a	28.67 a	48.67 a	7.45 a	12.65 a
Weed free	-	-	-	-	-	-	-	-
P ➡ MW	22.58 b	42.58 b	5.87 b	11.07 b	9.83 b	29.83 b	2.56 c	7.76 b
P ➡ BS+B	14.67 c	34.67 c	3.81 c	9.01 c	8.75 b	28.75 b	2.28 b	7.48 b
P ➡ MCPA	17.58 c	37.58 c	4.57 c	9.77 c	8.75 b	28.75 b	2.28 b	7.48 b
HSD (p≤ 0.05)	4.29	4.29	1.12	1.13	4.71	4.70	1.22	1.22
Interactions								
TS x AWD	NS	NS	NS	NS	NS	NS	NS	NS
TS x WM	NS	NS	NS	NS	NS	NS	NS	NS
AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS
TS x AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter do not differ significantly from each other at 5% probability level. **NS** = Non-significant, '➡' = Followed by; B = Bispyribac sodium, B = Benzo-sulfran, P = Pendimethalin, MH = Mannual hoeing, MW= manual weeding.

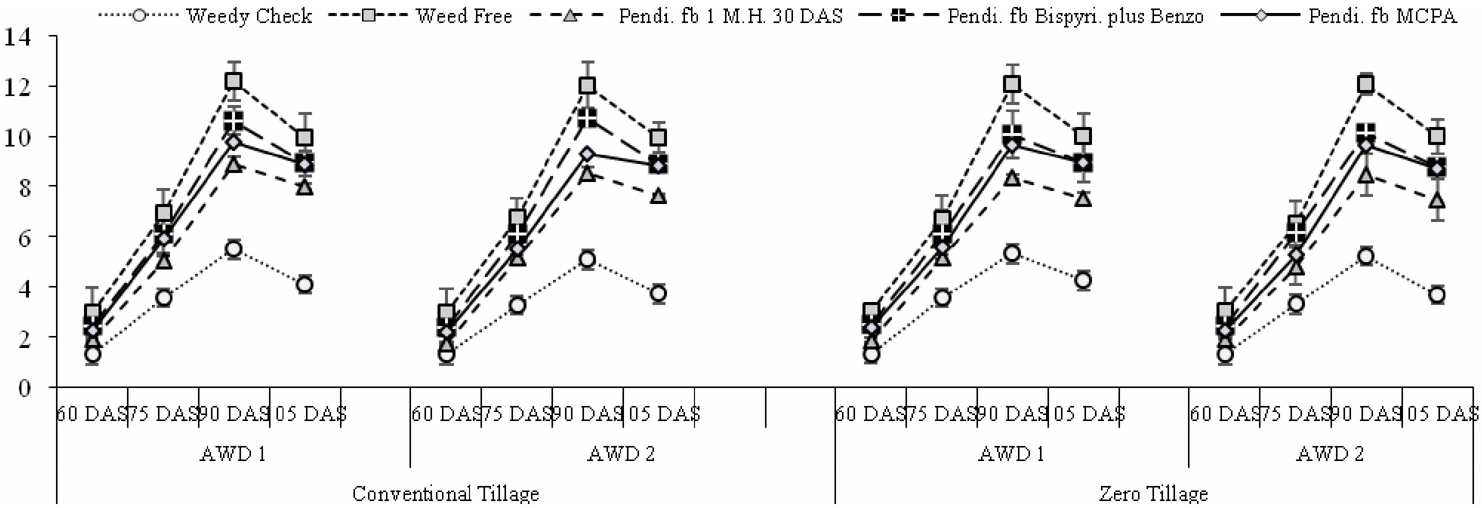
Table 3 **-** Influence of weed management treatments on seasonal net assimilation rate (g m^{-2} day^{-1}) in aerobic rice grown under varying tillage system and alternate wetting and drying (AWD) regimes

Weed management	Tillage system			
	Convention tillage		Zero tillage	
	AWD_1	AWD_2	AWD_1	AWD_2
Weed check	2.95 ± 0.30	2.90 ± 0.26	3.00 ± 0.16	2.92 ± 0.26
Weed free	4.16 ± 0.13	4.11 ± 016	4.17 ± 0.09	4.17 ± 0.12
Pendi. fb MH	4.17 ± 0.24	4.12 ± 1.28	4.21 ± 0.12	4.21 ± 0.17
Pendi, fb Bispyri, + Benzo.	4.25 ± 0.14	4.20 ± 0.14	4.31 ± 0.07	4.26 ± 0.09
Pendi, fb MCPA	4.18 ± 0.20	4.18 ± 0.21	4.28 ± 0.15	4.28 ± 0.14

Vertical bars above mean denote the standard error of three replicates. Bispyri. = Bispyribac sodium, fb = followed by, Benzo = Benzo-sulfran, MH. = Mannual hoeing, Pendi. = Pendimethaline.

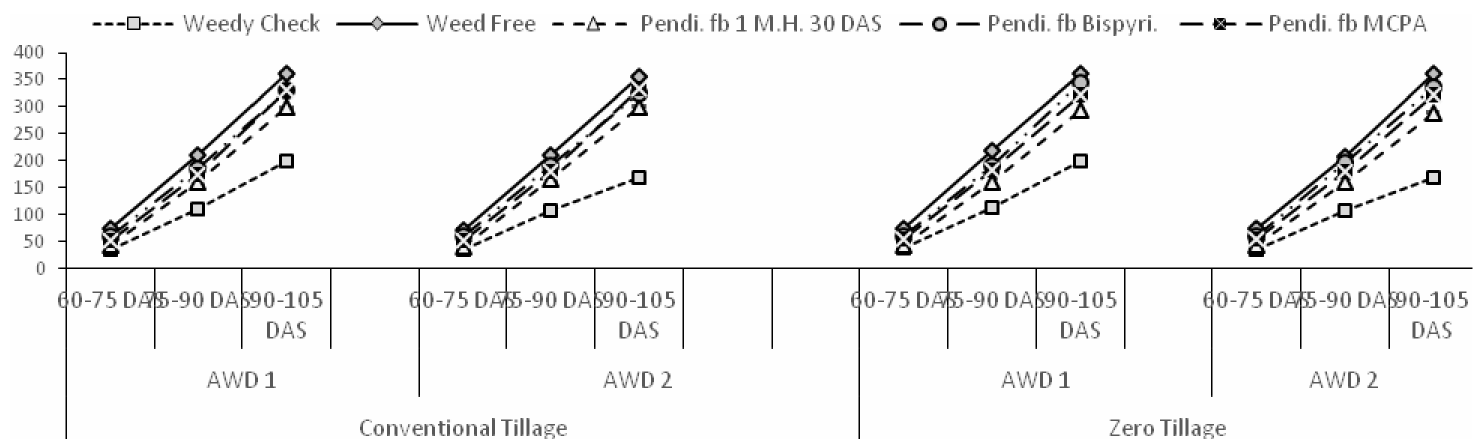
than partial weedy check. However, in the herbicides applied treatment maximum plant height was recorded where pendimethalin (0 DAS) was followed by BS+B (12 DAS) (Table 4). Similarly, among the herbicide treatments, pendimethalin followed by BS+B treatment gave maximum values for number of tillers, productive and non-productive tillers, panicle length, branches per panicle and kernels per panicle (Table 4). Among the herbicide applications, maximum 1000 kernels weight was recorded for the treatment pendimethalin followed by BS+B and improved 20% kernel weight over weedy check (Table 4).

Weed management treatments significantly influenced biological yield of aerobic rice (Table 5). However, tillage systems, AWD regimes and their interactive effect with weed



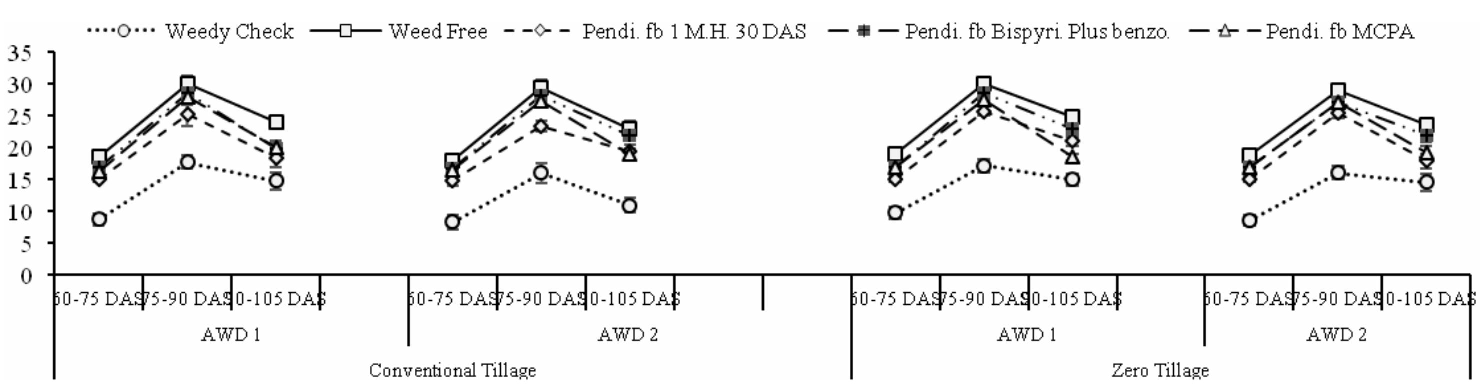
Vertical bars above mean denote the standard error of three replicates; * Bispyri. = Bispyribac sodium, fb = followed by, Benzo = Benzo-sulfran, MH. = Mannual hoeing, Pendi. = Pendimethalin.

Figure 3 **-** Influence of weed management treatments on leaf area index in aerobic rice grown under varying tillage system and alternate wetting and drying regimes.



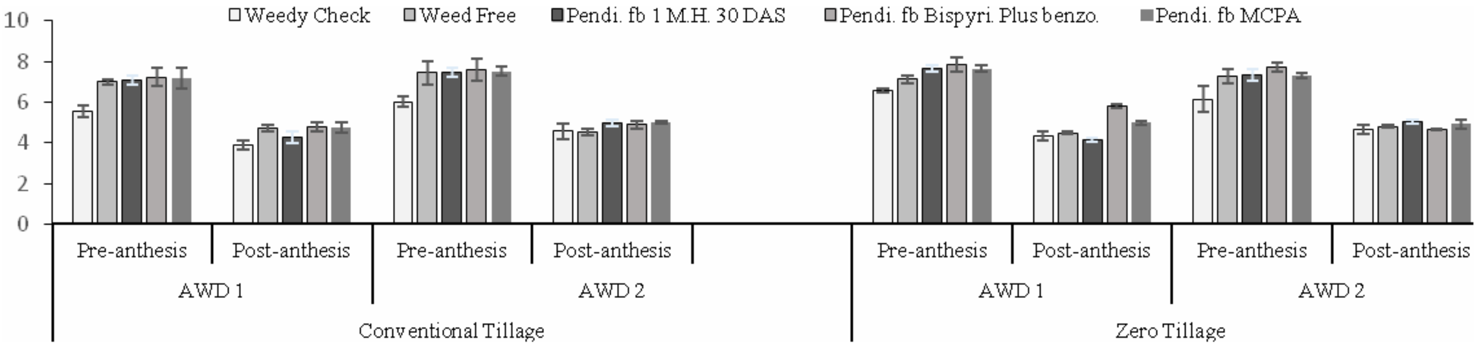
Vertical bars above mean denote the standard error of three replicates.*Bispyri. = Bispyribac sodium, fb = followed by, Benzo = Benzo-sulfran, MH. = Manual hoeing, Pendi. = Pendimethalin.

Figure 4 **-** Influence of weed management treatments on leaf area duration (days) in aerobic rice grown under varying tillage system and alternate wetting and drying regimes.



Vertical bars above mean denote the standard error of three replicates.*Bispyri. = Bispyribac sodium, fb = followed by, Benzo = Benzo-sulfran, MH. = Manual hoeing, Pendi. = Pendimethalin.

Figure 5 **-** Influence of weed management treatments on crop growth rate (g m^{-2} d^{-1}) in aerobic rice grown under varying tillage system and alternate wetting and drying regimes.



Vertical bars above mean denote the standard error of three replicates.*Bispyri. = Bispyribac sodium, fb = followed by, Benzo = Benzo-sulfran, MH. = Mannual hoeing, Pendi. = Pendimethalin.

Figure 6 - Influence of weed management treatments on net assimilation rate (g m^{-2} day^{-1}) in aerobic rice grown under varying tillagesystem and alternate wetting and drying regimes.

Table 4 - Influence of tillage system, alternate wetting and drying and weed management on yield contributing attributes in aerobic rice

Tillage systems (TS)	Plant height (cm)	Tillers (m^2)	Productive tillers (m^2)	Non-productive tillers (m^2)	Panicle length (cm)	Branches per panicle	Kernels per panicle	1000 kernels weight (g)
Conventional	93.09	305	269	36	25.37	9.40	74.96	16.94
Zero tillage	94.37	306	270	36	25.69	9.47	74.46	17.05
HSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
Alternate wetting and drying regimes(AWD)								
15 cm	93.66	306	270	36	25.53	9.43	74.88	17.02
20 cm	93.81	304	269	35	25.54	9.44	74.54	16.97
HSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management (WM)								
Weedy check	76.02 d	190	163 d	27 c	23.14 c	8.21 c	62.90 c	14.58 c
Weed free	105.80 a	354 a	308 a	46 a	27.56 a	9.97 a	80.13 a	18.18 a
P ➡ MW	89.31 c	323 c	288 d	35 b	24.97 b	9.58 b	75.83 b	17.31 b
P ➡ BS+B	99.27 b	331 b	295 b	36 b	25.96 b	9.76 b	76.85 b	17.50 b
P ➡ MCPA	98.26 b	327 bc	292 c	35 b	26.02 b	9.66 b	76.60 b	17.41 b
HSD ($p \leq 0.05$)	5.21	4.76	1.79	1.20	1.31	0.21	1.03	0.33
Interactions								
TS x AWD	NS	NS	NS	NS	NS	NS	NS	NS
TS x WM	NS	NS	NS	NS	NS	NS	NS	NS
AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS
TS x AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter do not differ significantly from each other at 5% probability level. **NS** = Non-significant, '➡' = Followed by; B = Bispyribac sodium, B = Benzo-sulfran, MH = Mannual hoeing, P = Pendimethalin, MW= manual weeding.

management were non-significant in this regard. Weed free plots recorded maximum biological yield (aboveground biomass) and was improve 96% over the weedy check. Among the herbicide application maximum biological yield was recorded where pendimethalin was followed by BS+B and improved 69% biological yield over weedy check. Similarly, this treatment also improved kernel and straw yield over other herbicides. Maximum harvest index was recorded where pendimethalin was applied followed by manual weeding (Table 5).

Similar trend of treatment significance was found for quality attributes as for growth and yield. Maximum normal kernels were counted in weed free treatment and among herbicides, pendimethalin followed by BS+B treated plots recorded higher percentage of normal kernels.

Table 5 **-** Influence of tillage system, alternate wetting and drying and weed management on agronomic and quality traits in aerobic rice

Tillage systems (TS)	Aboveground dry biomass (t ha^{-1})	kernel yield (t ha^{-1})	straw yield (t ha^{-1})	Harvest index (%)	Normal kernels (%)	Abortive kernels (%)	Chalky kernels (%)	Opaque kernels (%)
Conventional	12.20	3.20	9.00	25.66	63.23	11.67	12.80	12.53
Zero tillage	12.43	3.25	9.22	25.61	63.85	11.30	12.27	11.70
HSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
Alternate wetting and drying regimes(AWD)								
15 cm	12.35	3.20	9.15	25.38	63.40	11.30	12.80	11.83
20 cm	12.28	3.21	9.07	25.89	63.67	11.67	12.27	12.40
HSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management (WM)								
Weedy check	7.77 d	1.35 c	6.42 d	17.61 e	45.33 b	19.00 a	16.08 a	16.17 a
Weed free	15.27 a	3.89 a	11.38 a	25.52 d	72.25 a	8.58 c	9.75 d	9.33 d
P ➡ MW	12.41 c	3.53 b	8.88 c	28.85 a	63.08 c	11.33 b	13.83 b	13.42 b
P ➡ BS+B	13.18 b	3.65 b	9.53 b	28.49 b	68.58 b	9.17 c	11.42 c	10.75 c
P ➡ MCPA	12.95 bc	3.59 b	9.35 bc	27.71 c	68.52 b	9.33 c	11.58 c	10.92 c
HSD ($p \leq 0.05$)	0.60	0.30	0.61	0.30	2.09	1.73	1.73	1.19
Interactions								
TS x AWD	NS	NS	NS	NS	NS	NS	NS	NS
TS x WM	NS	NS	NS	NS	NS	NS	NS	NS
AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS
TS x AWD x WM	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter do not differ significantly from each other at 5% probability level. **NS =** Non-significant, '➡' = Followed by; B = Bispyribac sodium, B = Benzo-sulfran, MH = Mannual hoeing, P = Pendimethalin, MW= manual weeding.

Same treatment was found effective in reduced percentage of abortive kernels (Table 5). Minimum chalky kernels were counted in weed free treatment and among herbicides, pendimethalin followed by BS+B recorded minimum chalky and opaque kernels (Table 5).

In the present study, cost of production of rice was calculated on the basis of fixed and variable cost for area of one hectare. Maximum variable cost was recorded for weed free rice plots under both the irrigation and tillage managements. Whereas, all the herbicide treatments under both irrigation and tillage managements ranged in 38.56-57.96 USD for variable costs, with cheapest treatment of pendimethalin followed by MCPA (Table 6). Among herbicides maximum variable costs were observed for pendimethalin followed by BS+B treatment, which is due to extra expenditure of pre- and post-emergence herbicides combination. Maximum net field benefits were achieved in case of weed free plots for both the tillage systems under two water regimes. While, maximum benefit to cost ratio (BCR) of 1.96 was found for pendimethalin followed by BS+B treatment. This was due to more gross income of this treatment than others (Table 6). The gross income of partial weedy check treatment was less than total cost of production.

The results from present study indicated that heavy weed infestation (both in terms of density and dry biomass) in aerobic rice grown under different tillage system and alternate wetting and drying regimes can be tackled by the use of sequential application of herbicides. It was observed that conventional tillage favored broad-leaved weeds such as horse purslane, while zero tillage plots had more growth of grasses (especially crowfoot grass) on their credit, and such differences between the two tillage systems were more pronounced at early stages of weed competition. Contrarily, the broad-leaved weeds were the dominant weed type under conventional tillage and grassy weeds were dominant in zero tillage in present study (Table 1). Singh et al. (2005) reported that *C. rotundus* were dominant weeds of drill sown rice under zero tillage. However, under season-long weed competition, the density and biomass of grassy weeds was considerably higher under both the tillage systems. Application of herbicides in direct seeded rice considerably restrict the density of broad leaved weeds (Ramírez and Plaza, 2015). Recently, Singh et al. (2016) reported a

Table 6 **-** Benefit to cost ratio (USD)* for the weed management in direct seeded rice under different tillage and watering regimes

Tillage system	Alternate wetting and drying	Weed management	Variable	Fixed cost	Total cost	Gross income	Net field benefit	Net returns	Benefit cost ratio
			(USD ha^{-1}) (1)						
Conventional Tillage	AWD_1	Weed check	31.84	834.68	866.52	602.80	572.95	-253.67	0.70
		Weed free	121.40	834.68	956.08	1654.67	1535.27	708.65	1.73
		Pendi. fb MH	57.46	834.68	892.14	1503.68	1448.21	621.58	1.69
		Pendi. fbbispyr.+benzo.	38.80	834.68	873.48	1551.43	1514.61	687.99	1.78
		Pendi. fb MCPA	38.56	834.68	873.24	1538.37	1501.81	675.18	1.76
	AWD_2	Weed check	32.34	834.68	867.02	604.97	575.12	-252.00	0.70
		Weed free	121.89	834.68	956.57	1656.7	1537.30	710.18	1.73
		Pendi. fb MH	57.96	834.68	892.64	1498.65	1443.18	616.06	1.68
		Pendi. fbbispyr.+benzo.	39.30	834.68	873.98	1559.88	1523.07	695.95	1.78
		Pendi. fb. MCPA	39.05	834.68	873.73	1521.69	1485.12	658.00	1.74
Zero tillage	AWD_1	Weed check	31.84	834.68	866.52	66.60	633.74	-163.13	0.77
		Weed free	121.40	834.68	956.08	1842.00	1722.61	925.73	1.93
		Pendi. fb MH	57.46	834.68	892.14	1672.26	1616.79	819.92	1.87
		Pendi. fbbispyr.+benzo.	38.80	834.68	873.48	1712.51	1675.69	878.82	1.96
		Pendi. fb. MCPA	38.56	834.68	873.24	1698.88	1662.32	865.45	1.95
	AWD_2	Weed check	32.34	834.68	867.02	647.66	617.81	-179.56	0.75
		Weed free	121.89	834.68	956.57	1889.05	1769.65	972.28	1.97
		Pendi. fb MH	57.96	834.68	892.64	1652.20	1596.73	799.36	1.85
		Pendi. fb bispyr.+benzo.	39.30	834.68	873.98	1714.40	1677.58	880.21	1.96
		Pendi. fb. MCPA	39.05	834.68	873.73	1686.20	1649.63	852.26	1.93

(1) USD = 100.503 PKR, during the crop growth period.

significant decrease (67-86%) in weed dry biomass with maximum rice grain yield when sequential herbicide application done with pendimethalin followed by bispyribac-sodium + azimsulfuron in DSR. Likewise, superior weed suppression can be attributed to efficient control of all three weeds types, i.e. grasses, broad-leaved and sedges. In present investigation, all the herbicides have efficiently controlled narrow leave weeds in terms of density and dry biomass; however, herbicide type, its application timing and soil conditions greatly affect the weed emergence and growth (Abbas et al., 2015). Pre-emergence herbicides are reported to suppress equally the density of grasses, broadleaf weeds and sedges (Singh et al., 2016). It can be concluded that sequential use of herbicides in both zero and conventional tillage can effectively control a wide range of recalcitrant weed flora in aerobic rice. Because sequential application of pre- and post-emergence herbicides widens the spectrum of weed control (Walia et al., 2008), which gives better suppression to the weeds density at early growth stages of rice.

In DSR system, early management of weed is crucial to avoid the rice-weed competition for nutrients and water resources at earlier seedlings stage, as weeds appear simultaneously in this growing system. Season long competition between weed and rice crop in partial weedy check treatment restricts the availability of nutrient, moisture, light and other factors to growing plants which results in reduced LAI, LAD and crop growth rate (Awan et al., 2015). Irshad and Cheema (2005) revealed that NAR decreased with the increase of weed-crop competition period in transplanted rice. However, in present investigation, herbicides application had effectively terminated the weed-crop competition and provided better condition to crop plant for assimilation of more photosynthates through high NAR.

In direct seeded rice, plant height, total tillers and productive tillers reduced in competition with weeds with varying level of AWD under both tillage systems. Previous studies suggested that season long competition between weeds and rice decreased plant height (Mann et al., 2007), total tillers and productive tillers (Ashraf et al., 2014) in DSR. These increments might be due to availability of favorable conditions for plant growth, resulted from herbicides application through elimination of weeds. Improved yield attributes were observed in herbicides treated plots as a result of weed free environment produced in response to herbicides, resulting in relatively higher kernel yield. Findings from recent report of Singh et al. (2016) also observed similar enhanced yield attributes of DSR. Our study also revealed that hand weeding and herbicides application not only increased the yield, but also improved quality of aerobic rice as well.

Both weed free treatments and herbicides application eradicated weeds and provided crop with more favorable conditions for growth i.e. improved nutrient and moisture availability (Walia, 2006). These favorable conditions results in more fertilization and produced less sterile spikelet as well as uniform distribution of photo assimilates throughout the panicle, producing more normal kernels and less abortive, chalky, opaque kernels (Farooq et al., 2011). In partial weedy check more competition was noted between weeds and rice restricting the availability of resources to rice which caused a decrease in LAI, by effecting photosynthetic capacity and ultimately ended with poor kernel quality (Ghosh et al., 2017). Mixed application of two herbicides may also be the reason of better weed control, as mixture of both the herbicides allow their molecules functioning on wide weed spectrum as compared to sole herbicide with its narrow weed control activity on limited weed spectrum. Although, the variable costs for herbicides mixture posed maximum values in this study, but maximum benefit to cost ratio has ranked the treatment pendimethalin + BS + B as highest in terms of economic benefits.

In conclusion, application of pendimethalin followed by BS+B (12 DAS) is an efficient approach to increase aerobic rice yield. This treatment has sufficiently minimized the weed density as well as weed dry biomass especially, as weed dry biomass is the realistic information during the evaluation of any weed management practices, as compared to density. Similarly, significant improvements in aerobic rice growth attributes and agronomic traits had eventually resulted in higher rice yields. However greater net benefits and economic feasibility for this herbicide treatment was noticed in alternate wetting and drying at 15 cm depth under zero tillage.

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