AGRIVITA
Journal of Agricultural Science
www.agrivita.ub.ac.id

Enhancing Rice Yield and Weed Management in Direct Seeded Rice Using Ammonium Sulfate as Adjuvant with Lower Dose of Early Postemergence Herbicides

Wajid Saeed[1], Saif Ullah[1], Abdul Khaliq[2], Fazal Munsif[1], Izhar Ali[1], Tahir Hussain Jandan[1], Anas Iqbal[1] and Pingwu Liu[1*]

[1] Key Laboratory of Crop Cultivation and Farming System, Guangxi University, Nanning, China
[2] Department of Agronomy, University of Agriculture Faisalabad, Pakistan

ARTICLE INFO

Keywords:
Adjuvants
Direct Seeded Rice (DSR)
Grain yield
Herbicides
Weeds control

Article History:
Received: October 21, 2019
Accepted: December 31, 2020

*) Corresponding author:
E-mail: gxulpw@gxu.edu.cn

ABSTRACT

A field experiment was conducted in 2016 to find out the sequential use of different herbicides with adjuvants (a substance which enhances pesticides efficiency) towards improved rice production and weed management in direct-seeded rice crop. The early postemergence herbicides (Kelion 50 WG, Ryzelan 240 SC, and Nominee 100 SC were applied at full or 75% of the full dose with and without adjuvants i.e. 2% solution of ammonium sulfate (AS) and alkyl ether sulfate (AES) at 14 days after sowing (DAS), followed by late post-emergence herbicides i.e. Puma super (7.5 EW) and Sunstar 60 WG at 28 DAS. Application of herbicides with and without adjuvant substantially suppressed weed with weed dry weight at 40 and 60 DAS and improved rice yield attributes over a weedy check. It was found that a combination of 75% of Nominee 100 SC along with adjuvant i.e. AS (2% v/v) resulted in higher biological yield (9.16 t/ha), harvest index (30.65%), more grains per panicle (98.13), 1000 grain weight (21.32 g) with improved seed yield (3.86 t/ha). Also, abortive kernel (5.33), chalky kernels (5.66), opaque kernels (5.00), normal kernel (70.66), water absorptive ratio (4.28), and kernel length (10.13).

INTRODUCTION

Rice (*Oryza sativa* L.) belongs to the family of cereal crops and ranked second in South Asia. It has global importance and covers 50% of the total cultivated area (Bahua & Gubali, 2020). Rice plantation is a common technique in rice-growing countries which is a conventional pulled method but requires more water while rice grown on beds saves 13-23% irrigation water with 14-25% yield losses due to weeds infestation (Gathala et al., 2011). On the other hand prerequisite population of the plant (250,000 plants per ha) is difficult to sustain under nursery (Khaliq & Matloob, 2011). Direct seeded rice (DSR) produces a 5.33% higher yield and 25-50% low water use compared to the conventional method (Liu et al., 2015). Moreover, a significant reduction in paddy yield is often recorded due to greater operating costs in transplanting rice (Javed, Afzal, & Mauro, 2021; Juraimi et al., 2013). DSR is considered the optimal choice for higher rice yield with a lower cost of production (Kumar & Ladha, 2011). It also matures 10 to 15 days earlier than transplanted rice which facilitates timely sowing of succeeding crops (Singh, Verma, & Singh, 2013). Likewise, Parthasarathi, Vanitha, Lakshamanakumar, & Kalaiyarasi (2012) concluded the conventional system is going to shift to the DSR system because of fewer evapotranspiration losses up to 44% even without sacrificing on yield and future needs (Kumar & Ladha, 2011; Phukan, Kalita, & Bora, 2021). However, weeds interference is a major hindrance in DSR adaptation by farmers (Khaliq, Riaz, & Matloob, 2011) which causes about 77% yield losses (Khaliq, Matloob, Mahmood, Abbas, & Bismillah Khan, 2012). similarly, Chauhan (2012) also found higher weeds infestation in DSR

ISSN: 0126-0537 Accredited First Grade by Ministry of Research, Technology and Higher Education of The Republic of Indonesia, Decree No: 30/E/KPT/2018

Cite this as: Saeed, W., Ullah, S., Khaliq, A., Munsif, F., Ali, I., Jandan, T. H., … Liu, P. (2021). Enhancing rice yield and weed management in direct seeded rice using ammonium sulfate as adjuvant with lower dose of early postemergence herbicides. *AGRIVITA Journal of Agricultural Science, 43(2)*, 310–324. https://doi.org/10.17503/agrivita.v43i2.2426

under field conditions compare to transplanting sowing.

Weeds are controlled effectively by different methods (Khaliq & Matloob, 2011) but chemical methods of weeds control are the most reliable in rice. Both pre and post-emergence herbicides are efficient under DSR for weed management if properly managed (Akbar, Ehsanullah, Jabran, & Ali, 2011). On the other hand, higher residual effects of herbicides cause serious environmental and health hazards (Ranagalage & Wathugala, 2015). Similarly, Duman, Urey, Temizgul, & Bozok (2010) also revealed that highly use of herbicide chemicals affects non-target organisms and causes soil, environmental and health hazards. Adjuvants enhance the efficiency of herbicides by improving their biological activities to control weeds (Zheng et al., 2012) which is economically viable as well as environmentally friendly (Khaliq, Riaz, & Matloob, 2011).

Adjuvants increase the herbicide's efficiency by improving biological properties and efficacy (Kucharski & Sadowski, 2009) and decrease the energy that is required for herbicide absorption through cell membrane barriers (Hilz & Vermeer, 2013). Besides, the adjuvant's application with herbicides increases herbicidal activity, stickiness, penetration and decreases surface tension. The use of Ammonium nitrate as an adjuvant increases the phytotoxicity of nicosulfuron (5-14%) by enhancing its penetration on cuticle surface of leaf (Asif, Tanveer, Safdar, Ali, & Ahmad, 2019). Ten up to twelve percent (10-12%) dose reduction using adjuvant (Urea) has the same treatment effects (Abdullahi, Ghosh, & Dawson, 2016). The application of Ammonium sulfate decreased hard water problems and increase the activity of herbicides on certain species of weeds (Moonmoon, 2015). A significant decrease in weed biomass was recorded when alkyl ether sulfate was used as an adjuvant with reduced herbicide (foramsulfuron + isoxadifen + iso-sulfuron methyl sodium) dose to restrict weeds in maize crop (Tahir et al., 2011). However, limited research work has been conducted on the combined application of herbicides and adjuvants to control weeds under DSR.

In light of previous actualities, this experiment was planned to investigate and compare the efficiency of two adjuvants with a reduced dose of early post-emergence herbicides for weed management, enhancing yield and biomass of direct-seeded rice (DSR) keeping in view the economics while using the adjuvants under reduced herbicide application.

MATERIALS AND METHODS

Description of Site and Crop Management

A field experiment was conducted at the agronomic research farm of the University of Agriculture Faisalabad in 2016. The soil of the experimental site was Haplic Yermosols in the FAO classification and the climate is arid due to high evapotranspiration and annual rainfall is about is 200 mm. The treatments were comprised of different early postemergence herbicides (Kelion 50 WG, Ryzelan 240 SC, and Nominee 100 SC were applied at their full doses (100%) and 75% of full dose with and without adjuvants i.e. 2% solution of ammonium sulfate and alkyl ether sulfate (AES) at 400 ml/ha. All the treatments were followed by late post-emergence herbicides (Puma super 7.5 EW) and Sunstar 60 WG were also applied 28 days after sowing with full and 75% of the full dose to the respective treatments. The experiment was laid out in RCBD and replicated thrice during summer 2016. The plot size was 3.0 m × 5.0 m with an R × R distance of 20 cm. The land was properly cultivated using a tractor twice followed by planking.

Seeds of rice cultivar Basmati-515 at the rate of 100 kg/ha were sown at 20 cm spaced rows with a single row hand drill machine. NPK at a rate of 100:65:60 kg/ha was applied during the experiment. The full dose of phosphorus and potassium along with a half dose of nitrogen was applied whereas the remaining nitrogen dose was applied in two equal splits with 1st and 2nd irrigation. First irrigation was applied before seed drill and the rest 4 irrigations were applied at field capacity. Individual and total weed density per m^2 and their biomass (g/m^2) were recorded at 40 and 60 days after sowing (DAS). The agronomic parameters i.e. plant height at maturity (cm), a total number of tillers per m^2, productive and unproductive tillers per m^2, panicle length (cm), branches per panicle, straw yield, grains per panicle, 1000 kernels weight (g), straw yield (t/ha), biological yield (t/ha) and harvest index (%) were recorded. The qualitative traits such as abortive kernels (%), chalkiness (%), normal kernels (%), opaque kernels (%), water absorption ratio, and kernel length-width ratio were also noted as per stander procedure. Different treatments combination of herbicides and adjuvants were applied to quantify the effect on yield and biomass of DSR. Full and half dose of Kelion 50 WG (orthosulfamuron), Ryzelan 240 SC (penoxsulam) and Nominee 100 SC (bispyribac sodium) at 14 DAS, followed by Puma super 7.5 EW (fenoxaprop *p*-ethyl) + Sunstar 60 WG (ethoxysulfuran ethyl) at 28 DAS with adjuvants ammonium sulfate and alkyle ether sulfate was applied as shown in Table 1.

Data Collection and Measurements

Weed Parameters

Weed density was recorded from two randomly selected quadrats (50 × 50 cm) in each plot. Individual weed counts were made after weed collection from each quadrate of every plot at 40 and 60 DAS. Average values of two quadrats were calculated and data were converted to m^2. Individual weeds pants were clipped and taken to the laboratory in kraft bags for further analysis. The weed sample was air-dried for 3-4 days and then at 70°C in an oven to a constant weight. The dry biomass of weed was measured by digital weighing balance and data values changed to g/m^2.

Growth Parameters

A leaf meter (Licor, Modle 3100) was used to measured leaf area. Also, the leaf area to land area ratio was calculated for the leaf area index (LAI). Two grams (2 g) leaves were taken from 10 randomly selected plants per m^2 to calculate leaf area then computed the average values. Leaf area duration (LAD) was calculated by leaf area index (at first and second harvest) divide by date of observation (at first and second LAI) (Kotula, Colmer, & Nakazono, 2014).

$$LAD = (LAI_1 + LAI_2) / (t_2 - t_1) / 2 \quad \text{...1)}$$

Where: LAD = Leaf Area Duration, LAI_1 = Leaf Area Index (at first harvest), LAI_2 = Leaf Area Index at (second harvest), t_1 = date of observation (first LAI), t_2 = date of observation (second LAI).

Data on crop growth rate was determined by total dry matter (first and second harvest) divide by date of observation at first and second TDM (total dry matter). Following formula (Kotula, Colmer, & Nakazono, 2014):

$$CGR = (W_2 - W_1) / (t_2 - t_1) \quad \text{...2)}$$

Where: CGR = Crop Growth Rate, W_1 = total dry matter (TDM) at first harvest, W_2 = total dry matter (TDM) at second harvest, t_1 = date of observation of first TDM, t_2 = date of observation of the second TDM.

Net assimilation rate was calculated by total dry matter divide by lead area duration.

$$NAR = TDM / LAD \quad \text{...3)}$$

Where: NAR = Net Assimilation Rate, TDM= Total Dry Matter, LAD = Leaf Area Duration.

Table 1. Different treatments combination of herbicides and adjuvant

Code	Treatment
T1	Weedy check
T2	Full dose of Kelion 50 WG (orthosulfamuron) at 75 g a.i./ha (14 DAS) followed by Puma super 7.5 EW (fenoxaprop *p*-ethyl) at 86.25 g a.i./ha + Sunstar 60 WG (ethoxysulfuran ethyl) at 30 g a.i./ha (28 DAS)
T3	Full dose of Ryzelan 240 SC (penoxsulam) at 0.15 g a.i./ha (14 DAS) followed by Puma super 7.5 EW at 86.25 g a.i./ha + Sunstar 60 WG at 30 g a.i./ha (28DAS)
T4	Full dose of Nominee 100 SC (bispyribac sodium) at 30 g a.i./ha (14 DAS) followed by Puma super 7.5 EW at 86.25 g a.i./ha + Sunstar 60 WG at 30 g a.i./ha (28DAS)
T5	Kelion 50 WG at 56.25 g a.i./ha (14 DAS) followed by Puma super at 64.68 g a.i./ha + Sunstar 60 WG at 22.5 g a.i./ha (28 DAS)
T6	Ryzelan 240 SC at 0.11 g a.i./ha (14 DAS) followed by puma super at 64.68g a.i./ha + Sunstar 60 WG 22.5 g a.i./ha (28 DAS)
T7	Nominee 100 SC at 22.5 g a.i./ha (14 DAS) followed by puma super at 64.68g a.i./ha + Sunstar 60 WG 22.5 g a.i./ha (28 DAS)
T8	T5 + Ammonium sulfate solution as adjuvant (2% v/v)
T9	T6 + Ammonium sulfate solution as adjuvant (2% v/v)
T10	T7 + Ammonium sulfate solution as adjuvant (2% v/v)
T11	T5 + Alkyl ether sulfate (bioenhancer) adjuvant at 400 ml/ha

Remarks: g a.i./ha = grams of active ingredient per hectare

Agronomic Parameters

A metering rod was used to measure the plant height from base to leaf tip of 10 randomly selected plants then calculated the average values. At crop maturity, an area of 1 m^2 in each plot was used to count the number of tillers then the average of tiller per m^2 was computed. The number of productive and non-productive tillers were counted from an area of 1 m^2 from three different locations of the plot and subtracted from the total tiller number of that unit area and then the average was calculated. Ten random panicles were manually collected from each plot for panicle length and grain count. Panicle length was measured by scale and grains were counted, then the average was taken. Similarly, the 1000 kernel weight of a random sample of grains from each experimental plot was recorded in grams using weighing balance and the average of three repeats was calculated. Biological yield from each plot was calculated after air-drying the harvested crop for almost a week and manual threshing against steel drum. The harvested paddy yield in kg per plot was converted into t/ha.

Paddy yield (t/ha) = (Plot yield / Plot size) × 10000

The ratio of grain to biological yield was to calculate harvest index.

Harvest index (%) = (Grain yield / Biological yield) × 100 ….4)

Statistical Analysis

Analysis of variance was performed by Fisher's analysis of variance technique (Steel & Torrie, 1986) using weeds density, dry weight, rice yield, and quality attributes. Furthermore, an honest significance difference (HSD) test was employed to compare the treatment mean differences ($P \leq 0.05$) (Washington, Karlaftis, Mannering, & Anastasopoulos, 2020).

RESULTS AND DISCUSSION

The Effect of Herbicides on Weed Growth with and Without Adjuvants

Weed flora of the experimental field contained different noxious weeds including, horse purslane (*Trianthema portulacastrum*), purple nutsedge *(Cyperus rotundus*) and crowfoot grass (*Dactyloctenium aegyptium*) species. Weed dynamics (density and dry biomass) varied significantly ($P \leq 0.05$) among different herbicide treatments in this study (Table 2). Significantly maximum weeds density of *T. portulacastrum* (132 and 160 per m^2), *C. rotundus* (108 and 138.68 per m^2), and *D. aegyptium* (92 and 114.68 per m^2) were recorded in weedy check plot at 40 and 60 days after sowing (DAS), respectively. Application of 2% ammonium sulfate (AS) as an adjuvant with 75% labeled dose of Nominee 100 SC (N) resulted in significantly ($P \leq 0.05$) highest suppression of *T. portulacastrum* (91 and 92%), *C. rotundus* (86 and 89%) and *D. aegyptium* (90 and 89.00%) at 40 and 60 DAS respectively than weedy check (Table 2). However, weed density remained statistically ($P \leq 0.05$) *at par* with all others treatments except 75% Kelion 100 SC (K) without adjuvant for *T. portulacastrum* and 100% Kelion 100 SC (K) for *D. aegyptium*.

Table 2. MS value of growth, yield and quality parameters of direct seeded rice as affected by weeds control measures

Traits	MS values	Traits	MS values	Traits	MS values
Plant height	269.5**	1000-KW	11.93 **	Water absorptive ratio	0.095 *
Tillers per m^2	12447.8 **	Biological Yield	13.37 **	Kernel length	0.89 **
Productive tillers	16213.47 **	Paddy Yield	7.97 **	Panicle length	10.26 **
Nonproductive tillers	348.52 **	Abortive kernels	61.67**	Chalky kernels	33.71 **
Branches per panicle	2.32**	Opaque kernels	33.71 **	Grains per panicle	150.02 **
Normal kernel	28.50 **				

Remarks: * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level. MS: Mean square

The same trend as weed density was observed in dry matter biomass. The dry weight of all the weeds was affected significantly (*P* ≤ 0.05) at 20 and 40 days after sowing (DAS). Significant maximum dry weight was recorded in weedy check plot for all weeds at 40 and 60 DAS while minimum dry weight or highest suppression of *T. portulacastrum* (90 and 92%), *C. rotundus* (79 and 89%) and *D. aegyptium* (85 and 87%) were recorded in plots with 75% reduced dose of Nonimee 100 SC (N) along with 2% ammonium sulfate at 40 and 60 DAS, respectively (Table 3). However, weeds dry matter were statistically *at par* with all herbicide treatments except plots where 75% Kelion with and without adjuvant AES (60 DAS) for *T. portulacastrum*, 75% Kelion + AS (40 DAS) and 100% Kelion; 75% Kelion; 75% Ryzelan; 75% Kelion + AS; (60 DAS) for *C. rotundus,* 75% dose of Ryzelan; 75% Nominee; 75% Ryzelan + AS; 75% Kelion + AES (40 DAS); 100% Ryzelan and 75% Ryzelan; and Nominee, 75% Ryzelan + AS; 75% Kelion + AES for *D. aegyptium* (60 DAS) were applied and all weedy check plots (Table 3).

The highest value of weed dry mass (WDM) in controlled and unchecked plots resulted in high weeds dry matter (Table 3). These results are similar to Tahir et al. (2011) who concluded maximum values of dry weight in weedy check then herbicide treatments. Increased phototoxicity of herbicides due to the addition of adjuvants is responsible for decreased weed density and dry matter. These results are following the finding of Nurse, Hamill, Kells, & Sikkema (2008) who concluded that mixture of weedicides with adjuvants increase range and mode action of herbicides that is best to suppress and control the weeds such as adjuvants ammonium sulfate enhances the absorption activity of Glyphosate chemical. Further, the combined application of herbicide with adjuvants increases herbicide efficiency and retention and decreases surface tension through cuticle layer absorption (Zhang et al., 2013). Our findings of the study also line with Tanveer, Abbas, Safdar, & Ikram (2017) who concluded that 75% (MCPA + bromoxyinal + iodosulfuron-methyl sodium) with adjuvant ammonium sulfate reduced weeds density up to 25% and dry weight up to 56% of broadleaf weeds. Moreover, our data showed similarity with Donald (1985) who reported that herbicide chlorsulfuron with surfactant (0.2% v/v Tween 80) as adjuvant reduced dry mass of weeds up to 67.4% and also stop further growth of weeds. The combined application of bromoxynil + MCPA at a reduced rate with alkyl ether sulfate sodium salt showed 100% control of *Emex spinose* (Javaid, Tanveer, Ahmad, Yaseen, & Khaliq, 2012). Almost similar significant weed reduction was also observed when a mixture of adjuvants with different concentrations of herbicides was applied (Koger, Dodds, & Reynolds, 2007; VanGessel, Johnson, & Scott, 2016). Moreover, it is also reported that alkyl ether sulfate sodium salt enhanced tribenuron-methyl activity on *C. album* (Pannacci, Mathiassen, & Kudsk, 2010). Buehring, Talbert, & Baldwin (2006) also concluded that cyhalofop-butyl application had reduced barnyard grass weeds and enhanced the yield of rice. Akbar, Ehsanullah, Jabran, & Ali (2011) also concluded that reduced dose of herbicides (metsulfuron + 2.4-D) decreased dry weight 67.4% of weeds. Adjuvant 2% ammonium sulfate (AS) increases the efficiency of dicamba which controls parthenium weeds density in sorghum and enhances its yield by a 25% reduction of full dose herbicide has been reported (Asif, Tanveer, Safdar, Ali, & Ahmad, 2019).

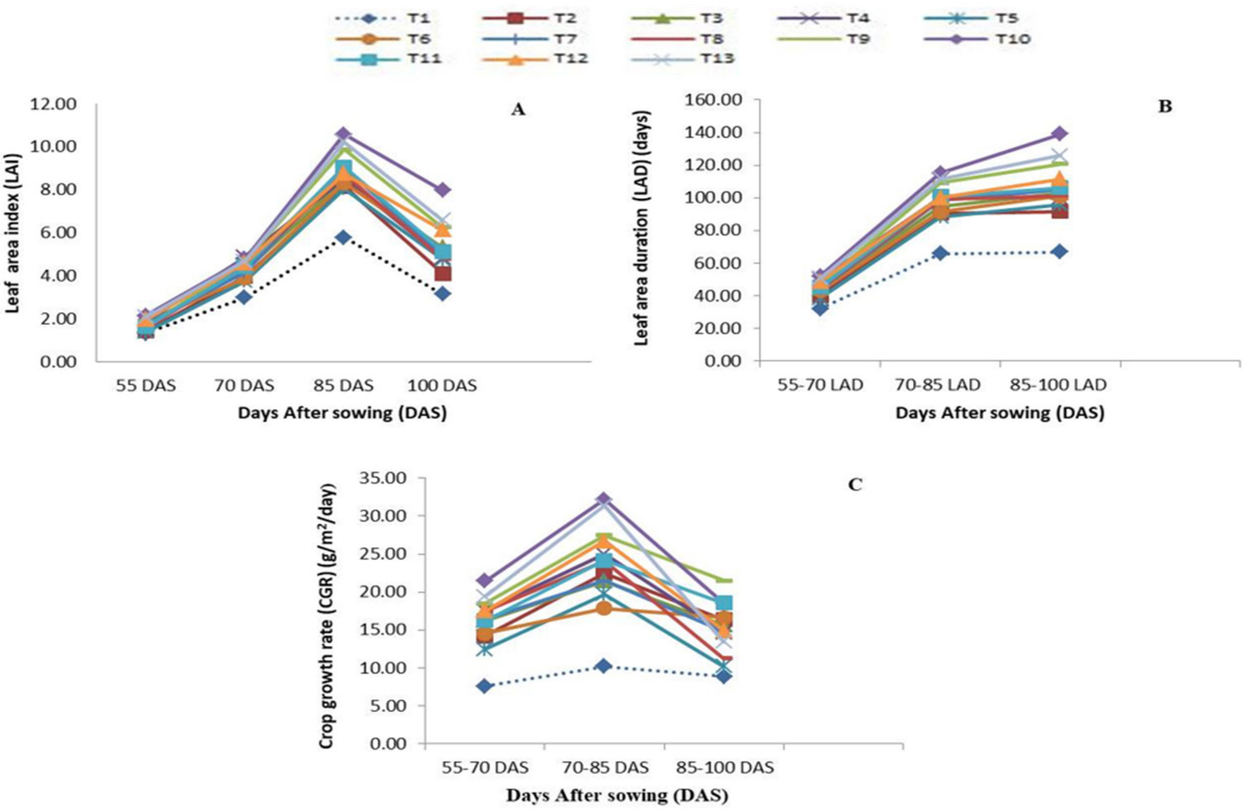
Table 3. Influence of different weed control treatments on weeds density and dry matter at 40 and 60 DAS in direct seeded rice

Treatments	Weeds Density						Dry Mater					
	T. portulacastrum (per m^2)		*C. rotundus* (per m^2)		*D. aegyptium* Per (m^2)		*T. portulacastrum* (per m^2)		*C. rotundus* (per m^2)		*D. aegyptium* (per m^2)	
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60DAS
Weedy check	132 a	160 a	108 a	138.68 a	92 a	114.68a	112a	160a	58.24a	138.68a	105.32a	94.68a
100% Kelion 50 WG (K)	37.32 bc (-72)	53.32 bcd (-67)	28b (-74)	34.68 b (-75)	20 bc (-78)	26.68 b (-77)	23.88 bc (-79)	53.32bcd (-67)	20.68 bc (-64)	34.68b (-77)	16.16 f (-85)	26.68 cd (-72)
100% Ryzelan 240 SC (R)	29.32 bc (-78)	38.68 bcd (-76)	33.32 b (-69)	28 b (-80)	40 b (-56)	37.32b (-67)	24 bc (-78)	38.68 bcd (-76)	17.6 bc (-71)	28 bc (-80)	30 bc (-72)	37.32 bc (-61)
100% Nominee 100 SC (N)	17.32 c (-87)	30.68 cd (-81)	33.32 b (-79)	28 b (-82)	40 c (-86)	37.32 b (-81)	13.12 bc (-88)	30.68 cd (-81)	15.6 bc (-73)	25.32 bc (-82)	19.75 ef (-82)	21.32 cd (-77)
75% K	57.32 b (-57)	74.68 b (-53)	24 b (-78)	32 b (-77)	12 c (-87)	32 b (-72)	42 b (-62)	74.68 b (-53)	12.68 c (-78)	32 bc (-77)	20.92 ef (-80)	32.00 cd (-66)
75% R	40 bc (-70)	56 bcd (-65)	26.68 b (-75)	37.32 b (-73)	17.32 c (-81)	29.32b (-74)	20.68 bc (-81)	56 bcd (-65)	14 c (-76)	37.32 b (-73)	24.8 cde (-76)	29.32 bc (-69)
75% N	28 bc (-79)	29.2 cd (-27)	21.32 b (-80)	26.68 b (-81)	18.68 bc (-79)	22.68 b (-80)	17.96 bc (-84)	28 cd (-82)	12.92 c (-78)	26.68 b (-81)	34.28 b (-67)	22.68 bc (-76)
75% K + AS	29.32 bc (-78)	49.32 bcd (-69)	21.32 b (-80)	37.32 b (-73)	14.68 c (-84)	25.32 b (-78)	14.28 bc (-87)	49.32 bcd (-69)	24 b (-59)	37.4 b (-73)	21.6 def (-79)	25.32 cd (-73)
75% R + AS	25.28 c (-81)	37.32 bcd (-77)	24 b (-78)	33.32 b (-76)	24 bc (-73)	24 b (-62)	18.4 bc (-84)	37.32 bcd (-77)	15.04 bc (-74)	33.32 bc (-76)	29.6 bc (-72)	44 bc (-54)
75% N + AS	12 c (-91)	13.32 d (-92)	14.68 b (-86)	14.64 b (-89)	9.32 c (-90)	12 b (-89)	8.9c (-90)	13.32 d (-92)	11.72 c (-79)	14.68 c (-89)	15.88 f (-85)	12 d (-87)
75% K + AES	37.32 bc (-72)	60 bc (-63)	20 b (-81)	29.32 b (-79)	16 c (-83)	29.32 b (-74)	26.52 bc (-76)	60 bc (-63)	13.88 c (-76)	29.32 bc (-79)	27.72 bcd (-74)	29.32 bc (-69)
75% R + AES	41.24 bc (-68)	56 bcd (-65)	25.32 b (-77)	26.68 b (-81)	18.68 bc (-79)	26.64 b (-77)	25.72 bc (-75)	26.68 bcd (-66)	12.92 c (-76)	24 bc (-81)	20.12 cde (-76)	20 cd (-72)
75% N + AES	20 c (-85)	26.68 cd (-83)	17.32 b (-84)	24 b (-83)	10.68 c (-88)	20 b (-83)	32.52 bc (-77)	42.72 cd (-82)	8.96 c (-78)	19.8 bc (-80)	6.6 ef (-81)	36.73 cb (-79)
HSD (P ≤ 0.05)	7.93	10.68	6.3	8.67	5.48	9.12	8.13	10.68	2.24	4.95	1.65	9.18

Remarks: AS = Ammonium sulfate; AES = Alkyl ether sulfate; Different lower case letters represent a significant difference of different treatments at $P < 0.05$. DAS: Days after sowing

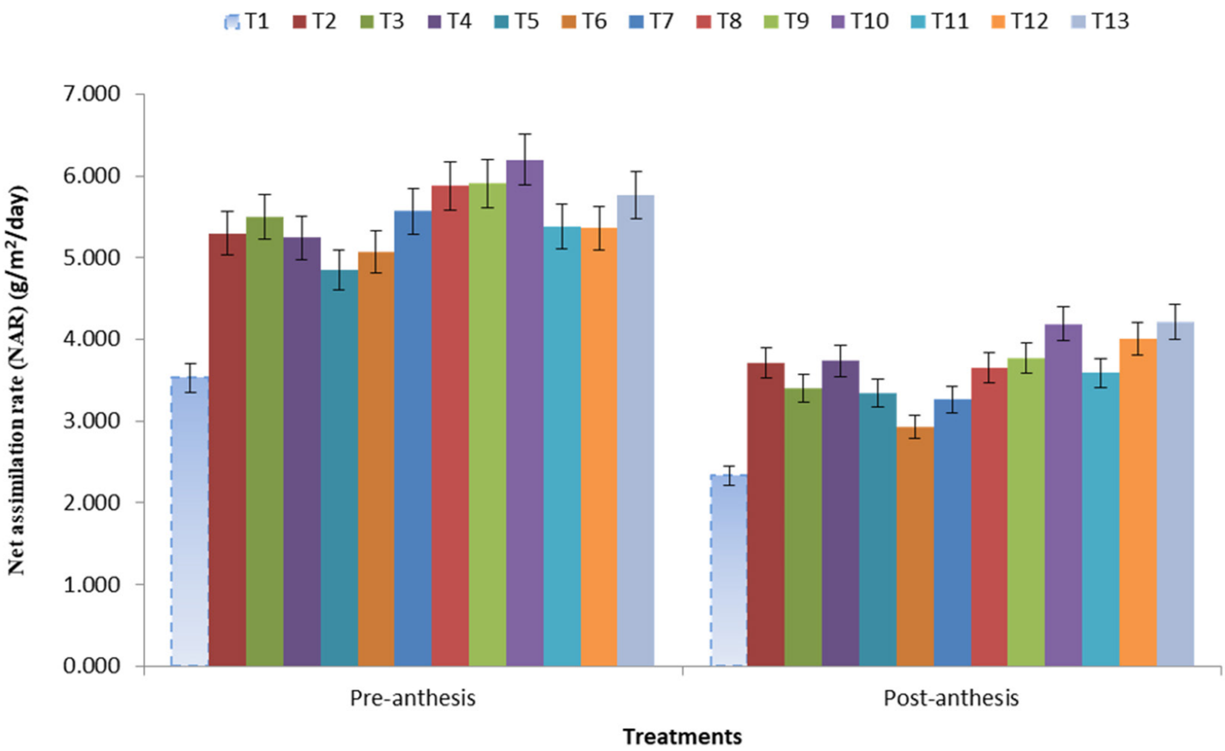
The Effect of Herbicides on Rice Growth and Development With and Without Adjuvants

Significant positive effects were observed of different weed control treatments on rice allometry. Various weed control treatments depicted a significant temporal increase in Leaf area index (LAI) ($P \leq 0.05$) (Fig. 1A) with a maximum value at 55 DAS which declined thereafter. However, a large leaf area was recorded in weeds free and tank mixture of 75% Nominee 100 SC with ammonium sulfate among all weed control treatments. Similar results were also observed for Leaf area duration (LAD) (Fig. 1B). First data of LAD and CGR was measured at 55-70 DAS while second and third LAD was measured at 70-85 DAS and 85-100 DAS, respectively. A progressive increase in LAD was observed up to the grand growth stage (85-100 DAS) and maximum values were recorded at 70-85 DAS under different experimental treatments. Insights into a pattern of crop growth rate (Fig. 1C) revealed a significantly improved rate of crop growth under various weed control treatments compared to the weedy check. The rate of crop growth achieved a plateau at 70-85 DAS because of efficient growth of crop and accumulation of dry matter in crop and showed sharp decline afterward. This decline in crop growth rate may be associated with phase transition into reproductive (heading) phase and end of vegetative growth phase (panicle initiation). Likewise, Net Assimilation Rate (NAR) of pre-anthesis was higher as compare to post-anthesis of the crop (Fig. 2) and maximum values in both cases (pre/post-anthesis) were noticed at 75% Nominee 100 SC along with ammonium sulfate while minimum values counted for weedy check plot.



Remarks: T1 = Control; T2 = Kelion 50 WG followed by Puma super 7.5 EW + Sunstar 60 WG; T3 = Ryzelan 240 SC followed by Puma super 7.5 EW + Sunstar 60 WG; T4 = Nominee 100 SC WG followed by Puma super 7.5 EW + Sunstar 60 WG; T5 = Reduced dose (75%) of each herbicide as in T2; T6 = Reduced dose 75% of respective herbicide in T3; T7 = reduced dose 75% of respective herbicide in T4; T8 = T5 + ammonium sulfate solution as adjuvant; T9 = T6 + ammonium sulfate solution as adjuvant; T10 = T7 + ammonium sulfate solution as adjuvant; T11 = T5 + alkyl ether sulfate (bioenhancer) as adjuvant; T12 = T6 + alkyl ether sulfate (bioenhancer) as adjuvant; T13 = T7 + alkyl ether sulfate (bioenhancer) as adjuvant

Fig. 1. Influence of different weed control treatments (A) on Leaf Area Index (LAI) in aerobic rice (B) on Leaf Area Duration (LAD) in aerobic rice (C) on Crop Growth Rate (CGR) in aerobic rice



Remarks: T1 = Control; T2 = Kelion 50 WG followed by Puma super 7.5 EW + Sunstar 60 WG; T3 = Ryzelan 240 SC followed by Puma super 7.5 EW + Sunstar 60 WG; T4 = Nominee 100 SC WG followed by Puma super 7.5 EW + Sunstar 60 WG; T5 = Reduced dose 75% of each herbicide as in T2; T6 = Reduced dose 75% of respective herbicide in T3; T7 = reduced dose 75% of respective herbicide in T4; T8 = T5 + ammonium sulfate solution as adjuvant; T9 = T6 + ammonium sulfate solution as adjuvant; T10 = T7 + ammonium sulfate solution as adjuvant; T11 = T5 + alkyl ether sulfate (bioenhancer) as adjuvant; T12 = T6 + alkyl ether sulfate (bioenhancer) as adjuvant; T13 = T7 + alkyl ether sulfate (bioenhancer) as adjuvant

Fig. 2. Influence of different weed control treatments on Net Assimilation Rate (NAR) in aerobic rice

Weedy check plot had shown a reduction in LAI, LAD, CGR, NAR growth parameters due to intensive growth of weeds and higher growth competition between crop plants. Later on, dense and early canopy closure might suppress weed growth. Prompt growth and high biomass accumulation by rice plants are presumably due the improved resource procurement and utilization. Higher leaf area index and duration in early growth season manage to capture more radiation that might have contributed to higher dry matter accumulation in experimental treatments. Enhancement in rice growth parameters under various weed control treatments is in support of the results of Anwar et al. (2011) and photosynthetic activity of crops which responded positively in weeds suppression. The vigorous growth of crops which caused a reduction of competition for resources between crop and weeds meant crop plants were able to better out-compete the weeds (Leishman, Thomson, & Cooke, 2010). LAI showed the photosynthetic activity of crops which responded positively in weeds suppression. CGR and NAR are used as indicators of dry matter accumulation and grain yield in many cereal crops (Hodgson et al., 2011), and an increase in those traits responded positively to a reduction in weed pressure.

The Effect of Herbicides on Rice Yield Components With and Without Adjuvants

Data regarding rice yield and its component (Table 4) showed a positive effect of weeds control treatments. Significantly maximum plant height (91.10 cm) was recorded with 75% Nominee 100 SC along with ammonium sulfate which is statistically ($P \leq 0.05$) *at par* with all other treatments except weedy check and 75% Kelion 50 WG. Significantly minimum plant height (54.06 cm) was recorded in the weedy check plot. This minimum plant height in weedy check has been due to more weed density and dry weight (Table 3) which compete and deprive the crop plants of nutrients and moisture. Plant height was affected because of high weeds infestation and with the application of weed control practices the plant height increased due to more availability of resources in the absence or scarcity of the weed plants. These results are supported by Khan, Marwat, Hassan, & Khan (2002) who reported lower plant height in weedy check plot.

The number of tillers was affected significantly by different weed control practices. The number of tiller varied from 141.33 per m^2) to highest value (404.33 per m^2). Significantly maximum number of tillers (404.33 per m^2) were counted in a plot where 75% Nominee 100 SC + ammonium sulfate was applied that was statistically ($P \leq 0.05$) *at par* with rest all treatments except weedy check and 100% Kelion 50 WG. Differences among different weed control practices also affect productive and unproductive tillers. The high value of productive tillers (347.67) was recorded in 75% Nominee 100 SC with ammonium sulfate while maximum numbers of unproductive tillers (94.00) were recorded in weedy check plot which is statically ($P \leq 0.05$) similar with 75% Ryzelan 240 SC (alone) and 75% Kelion 50 WG with adjuvant alkyle ether sulfate (AES) and because of high weeds in weedy check plot. Weedy check plot showed a minimum value of panicle length (cm) while maximum values (21.43 cm) were recorded in 75% Nominee 100 SC with ammonium sulfate. Similarly, the number of branches per panicle kept significant difference among different treatments that fewer branches per panicle were recorded in weedy check plot while maximum values (9.30) recorded with 75% Nominee 100 SC along with ammonium sulfate which is statistically ($P \leq 0.05$) similar with rest treatments except weedy check plot and 100% dose Ryzelan 240 SC. These results lined with Chhokar, Sharma, & Chander (2011) who reported that 25% reduced dose of romoxynil + MCPA+ iodosulfuron-methyl sodium with AES at 400 ml/ha as adjuvant reduced weeds density and dry matter in wheat and also increase tillers, spike length, 1000 grain and yield of the crop.

Weeds control practices are affected the grains per panicle significantly. Maximum grains per panicle was recorded when 75% reduced dose of nominee 100 SC was used along with ammonium sulfate as adjuvant and was statistically ($P \leq 0.05$) similar 75% Kelion 50 WG with alkyle ether sulfate, 75% Kelion 50 WG and Ryzelan 240 SC with ammonium sulfate and 100% dose of Kelion 50 WG. 1000 kernel weight (KW) was also affected significantly ($P \leq 0.05$) by weeds control treatments. Maximum kernel weight (21.32 g) was recorded with 75% Nominee 100 SC along with ammonium sulfate adjuvant that was statistically ($P \leq 0.05$) *at par* with all other weeds control treatments except weedy check and 75% reduced dose of Ryzelan 240 SC and Nominee 100 SC. While minimum 1000-KW (13.24) in weedy check plot was also statistically ($P \leq 0.05$) similar with full and 75% reduced dose of Nominee 100 SC, 75% reduced dose of Ryzelan 240 SC alone and with alkyle ether sulfate. The maximum number of weeds exerted greater weed-crop competition, which is responsible for reduced plant growth and height, resulted in lower grain in weedy check compared to other treatments (Table 4). These observations supported the results of minimum grain weight in weedy check treatment compared to the test reported by Tahir et al. (2011).

Biological yield (BY), Paddy yield (PY), and Harvest Index (HI) were also influenced significantly ($P \leq 0.05$) under different weed control treatments. Maximum BY, PY and HI were recorded with 75% N + AS that were statistically ($P \leq 0.05$) similar with all other weeds control treatments except weedy check and 75% reduced dose of Kelion and Ryzelan. These results are close to Tanveer, Abbas, Safdar, & Ikram (2017) who concluded a 75% reduced dose of herbicides (MCPA + bromoxynil + iodosulfuron-methyl sodium) with adjuvants (alkyl ether sulfate) gave the significant results with 10.46-56.1% increase in yield of wheat over control. These results were similar to Hammami, Aliverdi, & Parsa (2014) who concluded that the application of propanil with surfactant and methylated seed oil as adjuvant gave significant results to control barnyard grass and higher yield of rice.

Table 4. Influence of different weed control treatments on the yield parameters of direct seeded rice

Treatments	Plant height (cm)	Tillers (per m²)	Productive tillers (per m²)	Unproductive tillers (per m²)	Panicle length (cm)	Branches per panicle	Grains per panicle	1000-KW (g)	BY (t/ha)	PY (t/ha)	HI (%)
Weedy check	54.06 c	141.33 c	47.33 c	94.00 a	14.07c	6.57 c	73.86 e	13.24 c	2.60 d	0.43 c	11.93 c
100% Kelion 50 WG (K)	86.93 ab	333.67 b	268.33 b	65.33 cd	17.97abc	8.90 a	92.23ab	17.75 ab	8.03abc	3.01 ab	27.31 ab
100% Ryzelan 240 SC (R)	85.13 ab	378.67 ab	320.00 ab	58.67 d	18.12abc	6.97 bc	84.00 b-e	18.42 ab	7.97abc	2.98 ab	27.21 ab
100% Nominee 100 SC (N)	89.40 a	374.67 ab	308.67 ab	66.00 cd	17.16abc	9.00 a	83.53 be	17.18abc	8.44abc	3.09 ab	27.24 ab
75% K	77.50 b	344.67 ab	272.33 b	72.33 bcd	15.62 bc	9.07 a	79.80 b-e	18.83 ab	6.98 c	2.51 b	26.24 b
75% R	89.06 a	379.33 ab	291.67ab	87.67 ab	16.53 bc	7.57abc	77.66 c-e	15.66 bc	7.27 c	2.56 b	25.88 b
75% N	89.23 a	362.67 ab	295.00 ab	67.67 bcd	17.37abc	7.60abc	81.33bcde	16.65 bc	7.33 bc	2.91 ab	28.25 ab
75% K + AS	83.96 ab	375.67 ab	307.33 ab	68.33 bcd	15.47 bc	8.97 a	86.67 a-e	18.49 ab	81 1abc	3.16 ab	28.02 ab
75% R + AS	83.6 ab	368.33 ab	298.67ab	69.67 bcd	18.30abc	8.27abc	90.63 a-c	20.09 ab	7.98 abc	3.24 ab	28.88 ab
75% N + AS	91.10 a	404.33 a	347.67 a	56.67 d	21.43 a	9.30 a	98.13 a	21.32 a	9.16 a	3.86 a	30.65 a
75% K + AES	83.63 ab	369.33 ab	286.00 b	83.33 abc	18.21abc	8.97 a	88.5 a-d	17.99 ab	8.21 abc	2.97 ab	26.51 b
75% R + AES	83.7 ab	386.67 ab	315.33 ab	71.33 bcd	17.00 bc	8.57ab	75.93 de	17.09 abc	7.87 abc	2.97 ab	27.31 ab
75% N + AES	85.73 ab	378.33 ab	309.00 ab	69.33 bcd	19.27 ab	8.70ab	78.67 b-e	18.54 ab	9.01 ab	3.30 ab	28.26 ab
HSD (P≤0.05)	9.94	63.45	59.04	20.69	4.42	1.8	14.05	4.491	1.705	2.64	3.65

Remarks: AS = Ammonium sulfate; AES = Alkyl ether sulfate ; BY = Biological yield; PY = Paddy yield; HI = Harvest Index; Different lower case letters represent a significant difference of different treatments within differents yield parameters at $P < 0.05$

Table 5. Influence of different weed control treatments on qualitative parameters of direct seeded rice

Treatments	Abortive kernels	Chalky kernels	Opaque kernels	Normal kernel	Water absorptive (%)	Kernel length
Weedy check	18.33 a	19.00 a	18.00 a	30.67 c	3.62 b	8.33 d
100% Kelion 50 WG (K)	10.33 ab	9.33 b	9.67 bc	59.66 ab	3.85 ab	9.37 abc
100% Ryzelan 240 SC (R)	7.00 b	9.66 b	10.66 bc	56.33 b	4.01 ab	9.42 abc
100% Nominee 100 SC (N)	9.33 b	11 b	8.67 bc	60.66 ab	4.05 ab	9.72 ab
75% K	12.34 ab	9.33 b	11.67 b	55.33 b	3.80 ab	8.79 cd
75% R	10.33 ab	11.00 b	13.83 ab	61.66 ab	4.01 ab	8.92 bcd
75% N	12.33 ab	7.33 b	12.67ab	56.66 b	3.80 ab	8.98 bcd
75% K + AS	8.66 b	6.33 b	13.66 bc	60.23 ab	4.04 ab	9.42 abc
75% R + AS	13.00 ab	10.33 b	10.33 bc	61.32 ab	3.99 ab	9.57 abc
75% N + AS	5.33 b	5.66 b	5.00 c	70.66 a	4.28 a	10.13 a
75% K + AES	13.66 ab	9.00 b	9.33 bc	58.67 ab	3.69 ab	9.90 a
75% R + AES	9.00 b	12.00 ab	12.00 b	60.67 ab	4.13 ab	9.37 abc
75% N + AES	8.33 b	9.33 b	11.67 b	67.33 ab	4.01 ab	10.04 a
HSD ($P \leq 0.05$)	8.66	7.01	5.87	13.96	0.64	0.89

Remarks: AS = Ammonium sulfate; AES = Alkyl ether sulfate; Different lower case letters represent a significant difference of different treatments within differents quality parameters at $P < 0.05$

The application of carfentrazone + sulfosulfuron with adjuvant (surfactant) at 45 g a.i./ha shown a significant increase in yield and yield components of the wheat crop without any phytotoxic hazards (Akbar, Ehsanullah, Jabran, & Ali, 2011). It is reported by Safdar et al. (2020) that in a mixture tank, reduce the dose of halosulfuron with alkyle ether sulfate as adjuvant resulted in reducing weed density and dry weight and increasing pod yield of okra. It also reduces the labeled dose of halosulfuron up to 25% without compromising on okra yield. Alkyl ether sulfate was reported as a responsible adjuvant as it can help in diminishing herbicide dose up to 75% of the prescribed dose without impairing its effectiveness and brought about higher grain yield (Tanveer, Abbas, Safdar, & Ikram, 2017). Javaid & Tanveer (2013) concluded that wheat grain yield was increased with herbicides along with alkyl ether sulfate sodium salt as an adjuvant when compared with the recommended dose of herbicide. Pacanoski (2017) also concluded that cyhalofop-butyl application had reduced barnyard grass weeds and enhanced yield of rice.

The Effect of Herbicides on Kernel Quality Attributes With and Without Adjuvants

Kernel quality traits were improved significantly ($P \leq 0.05$) under weed control treatments (Table 5). Uncontrolled weed spread (weed control plots) enhanced abortive (18.33), chalky (19.00), opaque (18.00) and normal kernels (30.67) as well as for water absorptive ratio (3.62) and its length (8.33). However, a contrary trend for these traits was recorded under weed control. A tank mixture of 75% dose of Kelion 100 SC along with ammonium sulfate as adjuvant recorded best ($P \leq 0.05$) results of abortive (5.33), chalky (5.66), opaque (5.00) and normal kernels (70.66) as well as for water absorptive ratio (4.28) and kernel length (10.13) over weedy control. All the results were statistically ($P \leq 0.05$) *at par* with 75% Nominee 100 SC+ ammonium sulfate except treated plots with 75% Kelion 50 WG, Ryzelan 240 SC, Nominee 100 SC without and with Alkyle ether sulfate for the opaque kernel, 100% dose of Ryzelan 240 SC, and 75% Kelion 50 WG and Nominee 100 SC for the normal kernel, 75% Kelion 50 WG, Ryzelan 240 SC, Nominee 100 SC for kernel length and weedy check plots as shown in (Table 5). In this study, improved kernel length indicated greater photo-assimilate production and its translocation and partitioned into the sink.

Improved kernel traits indicated great source capacity to produce photo-assimilates. Akbar, Ehsanullah, Jabran, & Ali (2011) concluded that suppression of weeds enhances grain quality and also determines market values. Similarly, Irshad, Cheema, & Farooq (2008) reported that less weeds-crop competition facilitates carbohydrates to panicles translocation. According to Farooq et al. (2011), weeds free environment improved the kernel quality, panicles per unit area, and yield of rice. Akbar, Ehsanullah, Jabran, & Ali (2011) also reported that different weeds control method (hoeing, mechanical and chemical) improved seed quality and had given 60.47% increment of a normal kernel and improved 7-19% yield in direct-seeded rice. Chauhan (2012) and Mahajan, Gill, & Singh (2010) revealed that optimum seed rate in DSR improvement of grain quality like its protein and amylose contents reflects a reduction of weeds pressure. In crux, early postemergence application of Nominee 100 SC + alkyle ether sulfate mixture secure quality and quantity of produce.

CONCLUSION

It is concluded from the current study that application of 75% labeled dose of Nominee 100 SC, Ryzelan 240 SC, or Kelion 50 WG at 14 DAS followed by Puma super 7.5 EW + Sunstar 60 WG at 28 DAS along with adjuvant ammonium sulfate solution (2% of the total volume of spray) at 40 and 60 DAS had suppressed the growth of noxious weeds in direct-seeded rice (DSR) which ultimately enhanced crop growth, yield, and qualitative indicators. It is pertinent to mention that the lower dosage of herbicides is also an environment-friendly approach for weed control and enhancing the quantitative as well as the qualitative value of the crop.

REFERENCES

Abdullahi, S., Ghosh, G., & Dawson, J. (2016). Effect of different weed control methods on growth and yield of maize (*Zea mays* L.) under rainfed condition in Allahabad. *IOSR Journal of Agriculture and Veterinary Science*, *9*(4), 44–47. Retrieved from http://www.iosrjournals.org/iosr-javs/papers/vol9-issue4/Version-2/J0904024447.pdf

Akbar, N., Ehsanullah, Jabran, K., & Ali, M. A. (2011). Weed management improves yield and quality of direct seeded rice. *Australian Journal of Crop Science*, *5*(6), 688–694. Retrieved from http://www.cropj.com/ali_5_6_2011_688_694.pdf

Anwar, P., Juraimi, A. S., Puteh, A., Selamat, A., Man, A., & Hakim, A. (2011). Seeding method and rate influence on weed suppression in aerobic rice. *African Journal of Biotechnology*, *10*(68), 15259–15271. Retrieved from https://www.ajol.info/index.php/ajb/article/view/97342

Asif, M., Tanveer, A., Safdar, M. E., Ali, A., & Ahmad, S. (2019). Effect of dicamba and adjuvant combination on parthenium control, fodder yield and yield components of forage sorghum (*Sorghum bicolor*). *Planta Daninha*, *37*, e019189215. https://doi.org/10.1590/s0100-83582019370100036

Bahua, M. I., & Gubali, H. (2020). Direct seed planting system and giving liquid organic fertilizer as a new method to increase rice yield and growth (*Oryza sativa* L.). *AGRIVITA, Journal of Agricultural Science*, *42*(1), 68–77. https://doi.org/10.17503/agrivita.v42i1.2324

Buehring, N. W., Talbert, R. E., & Baldwin, F. L. (2006). Rice (*Oryza sativa*) response and annual grass control with graminicides. *Weed Technology*, *20*(3), 738–744. Retrieved from https://www.jstor.org/stable/4495747

Chauhan, B. S. (2012). Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology*, *26*(1), 1–13. https://doi.org/10.1614/WT-D-11-00105.1

Chhokar, R. S., Sharma, R. K., & Chander, S. (2011). Optimizing the surfactant dose for sulfosulfuron and ready mix combination of sulfosulfuron and carfentrazone against weeds in wheat. *Indian Journal of Weed Science*, *43*(3&4), 153–162. Retrieved from http://www.isws.org.in/IJWSn/File/2011_43_Issue-3&4_153-162.pdf

Donald, W. W. (1985). Chlorsulfuron (Glean) for control of shoot growth and root buds of Canada thistle. *Farm Research*, *42*(4), 20–22. Retrieved from https://library.ndsu.edu/ir/handle/10365/8807

Duman, F., Urey, E., Temizgul, R., & Bozok, F. (2010). Biological responses of a non-target aquatic plant (*Nasturtium officinale*) to the herbicide, tribenuron-methyl. *Weed Biology and Management*, *10*(2), 81–90. https://doi.org/10.1111/j.1445-6664.2010.00372.x

Farooq, M., Siddique, K. H. M., Rehman, H., Aziz, T., Lee, D. J., & Wahid, A. (2011). Rice direct seeding: Experiences, challenges and opportunities. *Soil and Tillage Research*, *111*(2), 87–98. https://doi.org/10.1016/j.still.2010.10.008

Gathala, M. K., Ladha, J. K., Kumar, V., Saharawat, Y. S., Kumar, V., Sharma, P. K., … Pathak, H.

(2011). Tillage and crop establishment affects sustainability of South Asian rice–wheat system. *Agronomy Journal*, *103*(4), 961–971. https://doi.org/10.2134/agronj2010.0394

Hammami, H., Aliverdi, A., & Parsa, M. (2014). Effectiveness of clodinafop-propargyl, haloxyfop-p-methyl and difenzoquat-methyl-sulfate plus Adigor® and Propel™ adjuvants in controlling *Avena ludoviciana* Durieu. *Journal of Agricultural Science and Technology*, *16*(2), 291–299. Retrieved from https://www.sid.ir/en/journal/ViewPaper.aspx?id=374058

Hilz, E., & Vermeer, A. W. P. (2013). Spray drift review: The extent to which a formulation can contribute to spray drift reduction. *Crop Protection*, *44*, 75–83. https://doi.org/10.1016/j.cropro.2012.10.020

Hodgson, J. G., Montserrat-Martí, G., Charles, M., Jones, G., Wilson, P., Shipley, B., … Royo Pla, F. (2011). Is leaf dry matter content a better predictor of soil fertility than specific leaf area? *Annals of Botany*, *108*(7), 1337–1345. https://doi.org/10.1093/aob/mcr225

Irshad, A., Cheema, Z. A., & Farooq, M. (2008). Influence of nitrogen on the interference of barnyard grass (*Echinochloa crus-galli*) with fine grain aromatic rice. *Archives of Agronomy and Soil Science*, *54*(5), 493–505. https://doi.org/10.1080/03650340802294311

Javaid, M. M., & Tanveer, A. (2013). Optimization of application efficacy for POST herbicides with adjuvants on three-cornered jack (*Emex australis* Steinheil) in wheat. *Weed Technology*, *27*(3), 437–444. https://doi.org/10.1614/WT-D-11-00130.1

Javaid, M. M., Tanveer, A., Ahmad, R., Yaseen, M., & Khaliq, A. (2012). Optimizing activity of herbicides at reduced rate on *Emex spinosa* campd. with adjuvants. *Planta Daninha*, *30*(2), 425–435. https://doi.org/10.1590/S0100-83582012000200023

Javed, T., Afzal, I., & Mauro, R. P. (2021). Seed coating in direct seeded rice: An innovative and sustainable approach to enhance grain yield and weed management under submerged conditions. *Sustainability*, *13*(4), 2190. https://doi.org/10.3390/su13042190

Juraimi, A. S., Uddin, M. K., Anwar, M. P., Mohamed, M. T. M., Ismail, M. R., & Man, A. (2013). Sustainable weed management in direct seeded rice culture: A review. *Australian Journal of Crop Science*, *7*(7), 989–1002. Retrieved from https://www.cropj.com/uddin_7_7_2013_989_1002.pdf

Khaliq, A., & Matloob, A. (2011). Weed-crop competition period in three fine rice cultivars under direct-seeded rice culture. *Pakistan Journal of Weed Science Research*, *17*(3), 229–243. Retrieved from https://wssp.org.pk/weed/ojs/index.php/pjwsr/article/view/354

Khaliq, A., Matloob, A., Mahmood, S., Abbas, R. N., & Bismillah Khan, M. (2012). Seeding density and herbicide tank mixtures furnish better weed control and improve growth, yield and quality of direct seeded fine rice. *International Journal of Agriculture and Biology*, *14*(4), 499–508. Retrieved from http://www.fspublishers.org/published_papers/76200_..pdf

Khaliq, A., Riaz, Y., & Matloob, A. (2011). Bio-economic assessment of chemical and non-chemical weed management strategies in dry seeded fine rice (*Oryza sativa* L.). *Journal of Plant Breeding and Crop Science*, *3*(12), 302–310. Retrieved from https://academicjournals.org/journal/JPBCS/article-full-text-pdf/593E6249531

Khan, M. A., Marwat, K. B., Hassan, G., & Khan, N. (2002). Impact of weed management on maize (*Zea mays* L.) planted at night. *Pakistan Journal of Weed Science Research*, *8*(1–2), 57–62. Retrieved from https://wssp.org.pk/weed/ojs/index.php/pjwsr/article/view/82

Koger, C. H., Dodds, D. M., & Reynolds, D. B. (2007). Effect of adjuvants and urea ammonium nitrate on bispyribac efficacy, absorption, and translocation in barnyardgrass (*Echinochloa crus-galli*). I. Efficacy, rainfastness, and soil moisture. *Weed Science*, *55*(5), 399–405. https://doi.org/10.1614/WS-06-146.1

Kotula, L., Colmer, T. D., & Nakazono, M. (2014). Effects of organic acids on the formation of the barrier to radial oxygen loss in roots of *Hordeum marinum*. *Functional Plant Biology*, *41*(2), 187–202. https://doi.org/10.1071/FP13178

Kucharski, M., & Sadowski, J. (2009). Influence of adjuvants on behavior of phenmedipham in plant and soil. *Polish Journal of Agronomy*, *1*, 32–36. Retrieved from https://iung.pl/PJA/wydane/1/PJAI6.pdf

Kumar, V., & Ladha, J. K. (2011). Direct seeding of rice: Recent developments and future research needs. In D. L. Sparks (Ed.), *Advances in Agronomy* (1st ed., Vol. 111, pp. 297–413). San Diego, USA: Academic Press. https://doi.org/10.1016/B978-0-12-387689-8.00001-1

Leishman, M. R., Thomson, V. P., & Cooke, J. (2010). Native and exotic invasive plants have fundamentally similar carbon capture strategies. *Journal of Ecology*, *98*(1), 28–42. https://doi.org/10.1111/j.1365-2745.2009.01608.x

Liu, H., Hussain, S., Zheng, M., Peng, S., Huang, J., Cui, K., & Nie, L. (2015). Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agronomy for Sustainable Development*, *35*(1), 285-294. https://doi.org/10.1007/s13593-014-0239-0

Mahajan, G., Gill, M. S., & Singh, K. (2010). Optimizing seed rate to suppress weeds and to increase yield in aerobic direct-seeded rice in Northwestern Indo-Gangetic plains. *Journal of New Seeds*, *11*(3), 225–238. https://doi.org/10.1080/1522886X.2010.496109

Moonmoon, J. F. (2015). *Evaluation of herbicidal efficacy and residual activity on transplanted aromatic boro rice*. Sher-e-Bangla Agricultural University. Retrieved from http://www.saulibrary.edu.bd/daatj/public/index.php/thesis/thesis_individual/4768

Nurse, R. E., Hamill, A. S., Kells, J. J., & Sikkema, P. H. (2008). Annual weed control may be improved when AMS is added to below-label glyphosate doses in glyphosate-tolerant maize (*Zea mays* L.). *Crop Protection*, *27*(3–5), 452–458. https://doi.org/10.1016/j.cropro.2007.07.015

Pacanoski, Z. (2017). Different post herbicide programs for control of Echinochloa crus-galli in direct wet-seeded rice. In *International Scientific Conference on IT, Tourism, Economics, Management and Agriculture (ITEMA) 2017, Budapest, Hungary* (pp. 898–906). Belgrade, Serbia: Association of Economists and Managers of the Balkans. Retrieved from https://scholar.google.com/scholar_lookup?title=Different+post+herbicide+programs+for+control+of+Echinochloa+crus-galli+in+direct+wet-seeded+rice&author=Pacanoski%2C+Zvonko+%28+Ss.+Cyril+and+Methodius+University%2C+Skopje+%28Former+Yugoslav+Republic+of+Macedonia%29.+Faculty+for+Agricultural+Sciences+and+Food%29&publication_year=2017

Pannacci, E., Mathiassen, S. K., & Kudsk, P. E. R. (2010). Effect of adjuvants on the rainfastness and performance of tribenuron-methyl on broadleaved weeds. *Weed Biology and Management*, *10*(2), 126–131. https://doi.org/10.1111/j.1445-6664.2010.00376.x

Parthasarathi, T., Vanitha, K., Lakshamanakumar, P., & Kalaiyarasi, D. (2012). Aerobic rice-mitigating water stress for the future climate change. *International Journal of Agronomy and Plant Production*, *3*(7), 241–254. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20123384638

Phukan, J., Kalita, S., & Bora, P. (2021). Weed management in direct seeded rice: A review. *Journal of Pharmacognosy and Phytochemistry*, *10*(2), 742-748. Retrieved from https://www.phytojournal.com/archives/?year=2021&vol=10&issue=2&ArticleId=13883

Ranagalage, A. S., & Wathugala, D. L. (2015). Allelopathic potential of improved rice (*Oryza sativa* L.) varieties against *Echinochloa crus-galli* L. *Allelopathy Journal*, *36*(1), 37–48. Retrieved from https://www.allelopathyjournal.com/archives/?Year=2015&Vol=36&Issue=1&Month=7

Safdar, M. E., Mumtaz, Q., Asif, M., Nadeem, M. A., Ali, A., Nadeem, M., & Hayyat, M. S. (2020). Use of adjuvant and allelopathic plant extract to minimize the herbicide dose for controlling parthenium (*Parthenium hysterophorus* L.) in okra (*Abelmoschus esculentus*). *Journal of Pure and Applied Agriculture*, *5*(2), 79–90. Retrieved from https://jpaa.aiou.edu.pk/wp-content/uploads/2020/07/JPAA_2020_5_2_79-90.pdf

Singh, R. K., Verma, S. K., & Singh, R. P. (2013). Bioefficacy of carfentrazone-ethyl + sulfosulfuron in wheat. *Indian Journal of Weed Science*, *45*(4), 243–246. Retrieved from http://isws.org.in/IJWSn/File/2013_45_Issue-4_243-246.pdf

Steel, R. G. D., & Torrie, J. H. (1986). *Principles and procedures of statistics: A biometrical approach* (2nd ed.). New York, USA: McGraw-Hill. Retrieved from https://books.google.co.id/books?id=-gA-tQEACAAJ

Tahir, M., Nadeem, M. A., Tanveer, A., Ayub, M., Hussain, A., Naeem, M., & Javeed, H. M. R. (2011). The effect of urea as adjuvant on herbicide effectiveness, yield and weeds of maize with full and reduced doses of herbicide. *Pakistan Journal of Life and Social Sciences*, *9*(1), 45–51. Retrieved from http://pjlss.edu.pk/pdf_files/2011_1/10.pdf

Tanveer, A., Abbas, N., Safdar, M. E., & Ikram, R. M. (2017). Alkyl ether sulfate improves efficacy of herbicides against common goosefoot and field bindweed in wheat. *Planta Daninha*, *35*, e017164307. https://doi.org/10.1590/s0100-83582017350100084

VanGessel, M. J., Johnson, Q. R., & Scott, B. A. (2016). Evaluating postemergence herbicides, safener, and tolerant hybrids for corn response. *Weed Technology*, *30*(4), 869–877. https://doi.org/10.1614/WT-D-16-00011.1

Washington, S., Karlaftis, M. G., Mannering, F., & Anastasopoulos, P. (2020). *Statistical and econometric methods for transportation data analysis* (3rd ed.). CRC Press. Retrieved from https://books.google.co.id/books?id=_TT3DwAAQBAJ

Zhang, J., Zheng, L., Jäck, O., Yan, D., Zhang, Z., Gerhards, R., & Ni, H. (2013). Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (*Zea mays* L.) fields in North China Plain. *Crop Protection*, *52*, 26–32. https://doi.org/10.1016/j.cropro.2013.05.001

Zheng, J., Li, R., Zhu, J., Zhang, J., He, J., Li, S., & Jiang, J. (2012). Degradation of the chloroacetamide herbicide butachlor by *Catellibacterium caeni* sp. nov DCA-1T. *International Biodeterioration & Biodegradation*, *73*, 16–22. https://doi.org/10.1016/j.ibiod.2012.06.003