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EFFECTS OF SEEDING TIME AND WEED CONTROL METHODS IN DIRECT SEEDED RICE (*ORYZA SATIVA* L.)

K. Mubeen, M. A. Nadeem*, A. Tanveer* and A. J. Jhala**

Department of Agronomy, University of Poonch, Rawalakot, Pakistan
*Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
**Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Keim Hall, Lincoln, NE 68583, USA
Corresponding Author E-mail: amit.jhala@unl.edu

ABSTRACT

Field experiments were conducted during the 2 year period from 2008 and 2009 to determine the effects of three seeding dates and seven weed control methods in DSR. The results suggested that seeding in the first week of July reduced weed density and biomass, increased kernel weight, leaf area index, and kernel yield compared to seeding rice in the first week of July. Amongst weed control methods, penoxsulam followed by hand-hoeing at 30 days after seeding (DAS) reduced weed density as low as ≤ 6 and ≤ 28 plants m^{-2} at 35 DAS and at harvest, respectively during both the years which was comparable with hand-hoeing at 15, 30 and 45 DAS. In addition, rice yield attributes including number of tillers, kernel weight, leaf area index, leaf area duration were higher, while kernel yield in this treatment was 70 and 61% higher compared to nontreated control during 2008 and 2009, respectively. A foliar spray of sorghum and sunflower water extract at 20 and 40 DAS and sorghum mulch at 6 t ha^{-1} were effective for weed control and secured kernel yield respectively, > 33% and 27% higher compared with the non-treated control. However, they were not as effective as penoxsulam, bispyribac-sodium, and/ or hand-hoeing treatments. The interaction effect of seeding time and weed control methods was significant for most of the variables. It is concluded that penoxsulam would be an additional chemical tool if integrated with hand-hoeing for weed control in DSR.

Nomenclature: Bispyribac-sodium; penoxsulam; Rice, *Oryza sativa* L.; sorghum, *Sorghum bicolor* (L) Moench.; sunflower, *Helianthus annus* L.

Key words: Hand hoeing, herbicide, mulch, seeding time, weed control, kernel yield.

INTRODUCTION

Rice (*Oryza sativa* L.), an important food and cash crop, is providing 35 to 60% of the dietary calories consumed by nearly 3 billion people (Fageria, 2003). Rice is the third largest crop in Pakistan after wheat (*Triticum aestivum* L.) and cotton (*Gossypium hirsutum* L.). In 2012, rice was grown on about 2311 thousand hectares with the production of about 5541 thousand tonnes in Pakistan (Anonymous, 2013). Rice can be established in field primarily through transplanting seedlings from nursery; however, transplanting is becoming increasingly difficult due to shortage of labors and scarcity of water (Tabbal *et al.*, 2000). Therefore, rice growers now a day are shifting towards direct seeding as it saves cost of raising, transportation, and transplanting of rice seedlings in many Asian countries including Pakistan (Farooq *et al.*, 2011). Direct seeded rice (DSR) has the potential of saving water through earlier establishment of plants and thus it facilitates early seeding of wheat in rice-wheat cropping systems (Ladha *et al.*, 2003).

There are few limiting factors associated with DSR that impair yields including crop-weed competition. Compared to transplanted rice, the yield losses in DSR is greater due to absence of flooding water at the early stage of the crop to suppress weed growth (Singh *et al*., 2007). Despite weed management, yield loss in lowland rice is usually in the range of 10 to 20%, could be higher if weeds are not controlled. It has been estimated that yield loss in rice could be as high as 60 to 74% due to weed infestations (Azmi, 2002). It has been estimated that yield loss in DSR was in the range of 17 to 24% when weeds were allowed to compete until 4 wk after seeding (Chauhan and Johnson, 2011). Therefore, there is a scope to increase yield by adopting integrated weed management approaches including tillage systems, competitive cultivars, use of crop residue as mulch, hand hoeing, and herbicides in DSR (Chauhan, 2012).

Seeding of rice at the optimum time is very important for obtaining high yield and good quality kernels (Chauhan, 2012). Delay in seeding increased yield losses of rice due to crop-weed competition and weather (Caton *et al.*, 1999). The decreasing trend in the grain yield due to delayed seeding might be associated with significantly lower number of panicles per m^2, less number of filled grains per panicle and low grain weight (Mishri and Kailash, 2005). Therefore, to improve the yield potential of DSR, optimum planting time needs to be precisely determined (Kathiresan and Manoharan, 2002).

Weeds in DSR can be controlled by several methods which can be used in various sets of conditions keeping in view the socio-economic condition of growers and several other factors. Historically, hand-weeding was the most important method for weed removal in rice in Pakistan (Alam, 1991); however, because of scarcity of agricultural workers, hand-weeding is not economical now (Farooq *et al.,* 2011). Hand hoeing (a physical method of weed control using hand hoes) is used as a method of weed control, specifically in DSR where line-planting is practiced. It has been reported that sorghum and sunflower extracts have allelopathic effects on certain weeds (Cheema *et al.,* 2010) and also on succeeding crops (Narwal *et al.,* 1999). Crop residues as mulch may selectively provide weed suppression through their physical presence on the soil surface (Erenstein, 2002) and can be a part of integrated weed management program (Chakraborty *et al.,* 2008).

Use of herbicides is an easy, effective and economically viable method for controlling different weed species in DSR (Chandra *et al.,* 1998). Several herbicides are registered and available commercially for weed control in rice and their application has increased rice yield by reducing crop-weed competition. Penoxsulam is usually used for POST control of grass, broadleaf and sedge weeds in rice; however, it also has soil residual activity. A previous study reported that penoxsulam was most effective on relatively small weeds, and higher penoxsulam rates (> 40 g ha^{-1}) were needed to control weeds larger than 5 to 8 cm (Williams and Burns, 2006). Bispyribac is a contact herbicide for POST control of grasses, broadleaf and sedge weeds in rice (Valent USA, 2003). It inhibits the acetolactate synthase (ALS) enzyme, which blocks branched-chain amino acid biosynthesis (Vencill, 2002). Bispyribac can be applied alone or in tank mixes with other herbicides for control of number of weed species in rice (O'Barr *et al.,* 2003).

Integrated weed management is the combination of multiple management tools to reduce weed populations to an acceptable level while preserving the quality of existing habitat, water, and other natural resources (Blackshaw *et al.,* 2005). Combinations of physical, cultural, and chemical management practices should be utilized for weed control in DSR. A combined use of hand-weeding and herbicides applied POST (2,4-D or propanil) provided excellent weed control compared to their use alone (Naklang, 1997). Research in DSR has been focused primarily on various aspects including effects of methods and time of land preparation on weed dynamics, use of herbicides for weed control (Rajendran and Kempuchetty, 1998; Pellerin *et al.,* 2004; Sinha *et al.,* 2005), effect of weather on the effectiveness of herbicides, and effect of combining herbicides and manual weed control (Singh *et al.,* 2005).

Thus, most research with DSR has been conducted using either physical weed removal methods or use of herbicides and information is limited for integrated effects of agronomic practices such as planting time and various weed control methods including herbicides, mulch, hand-hoeing, and use of plant extract. Therefore, the objectives of this study were to evaluate the best seeding time of DSR; to determine the best weed control method; and to evaluate the interaction effects of seeding time and weed control methods in DSR.

MATERIALS AND METHODS

Experimental Site. Field experiments were conducted for 2 yrs in 2008 and 2009 at the research farm of the Department of Agronomy, University of Agriculture, Faisalabad, Pakistan. The research site was located at 30.35° to 31.47' N latitude and 72.08° to 73.0' E longitude with an altitude of 150 m above sea level. The experimental soil was loam with pH 7.6, sand 36%, silt 45%, clay 17%, organic matter 1.0%, and total nitrogen 0.5%.

Experimental Treatments: Three seeding time of rice (1st and 3rd week of June, and 1st week of July) and seven weed management treatments were included in the experiment (Table 1). Weed management treatments included penoxsulam applied PRE at 15 g a.i ha^{-1} alone or followed by hand-hoeing at 30 days after sowing (DAS), bispyribac-sodium applied POST at 30 g a.i. ha^{-1} alone at 15 DAS or followed by hand-hoeing at 30 DAS, foliar spray of sorghum and sunflower water extract at 15 L ha^{-1} at 20 and 40 DAS, sorghum mulch at 6 t ha^{-1}, and hand hoeing at 15, 30 and 45 DAS, (Table 1). An untreated control was included for comparison. Sorghum and sunflower water extract was prepared as per the procedure in Cheema *et al.* (2003).

The field experiment was set up in a randomized complete block design with split plot arrangement with planting time in main plots and weed management treatments in sub plots with four replications. The net plot size was 5 m × 2.6 m. To protect the crop from seed borne diseases, seeds were treated with thiophanate-methyl (Topsin-M fungicide) at 2 g kg^{-1}. The seeds were soaked in water for 24 h and kept under shade in a gunny bag for sprouting. The nitrogen at 140 kg ha^{-1}, phosphorus 80 kg ha^{-1}, and potash 60 kg ha^{-1} was applied in the form of urea, diammonium phosphate, and sulfate of potash, respectively. All of the P and K and 1/3rd of the N was incorporated into the soil at the time of seed bed preparation, while remaining N was top dressed in split dose at the time of booting and anthesis stage of the crop. The rice variety "Super Basmati" was planted in 20 cm rows using a single row hand driller at a seed rate of 75 kg ha^{-1}. Information is provided for dates of seeding and all other agronomic operations in 2008 and 2009 (Table 1). Herbicides were sprayed with a knapsack sprayer calibrated to apply 400 L ha^{-1} with flat fan nozzles. First irrigation was given to the crop 4-5 days after planting in such a way that emerging seedlings are not submerged and this practice was continued for 2 weeks, thereafter irrigation was given until harvest of the crop. The crop was harvested at physiological maturity then allowed to be sun dried in the field. After a week, the crop was threshed depending on moisture level.

Data Collection. The weed densities were assessed during the growing season within 0.5 m^2 quadrates (two quadrates per plot) at 35 days after seeding (DAS) and before harvest. Before harvesting rice, the weeds within a randomly selected 0.5 m^2 quadrates (two quadrates per plot) were cut at the stem base close to the soil surface, placed in paper bags, dried in an oven for 72 h at 60 °C and total weed biomass was recorded (Table 1). The data on crop injury were recorded at 15, 30 DAS and at harvest based on 0 to 100% scale where 0% being no injury and 100% being complete death of plant. Total number of tillers was counted within a randomly selected 0.5 m^2 quadrates (two quadrates per plot). Ten rice panicles were randomly selected from each plot to determine seeds per panicle and 1000 kernel weight. The crop was harvested manually and kernel yield was recorded. Harvest index was calculated as the ratio of kernel yield to total above ground biological yield and expressed in percent. Leaf area index was calculated as the ratio of leaf area to land area. Plants were harvested four times (see Table 1 for harvesting dates) from an area of 30 x 30 cm^2 and leaf area was measured using leaf area meter. Leaf area duration (LAD) was estimated by using the following formula:

$$LAD = (LAI_1 + LAI_2)(T_2 - T_1) / 2$$

Where,

LAD = Leaf are duration

LAI_1 = Leaf area index at first harvest

LAI_2 = Leaf area index at final harvest

T_1 = Date of observation of first leaf area index

T_2 = Date of observation of final leaf area index

Statistical Analysis: All data were subjected to ANOVA using statistical analysis software version 9.2 (SAS, 2009) to test for treatment effects and possible interactions. Normality, homogeneity of variance, and interactions of treatments and years were tested. Interactions among years were significant; therefore, data were presented separately for each year. Weed density data were collected for each species; however, the data were combined and a total weed density data were presented. The data of weed density and biomass were square root transformed, while that of herbicide injury were arc-sine transformed prior to analysis; however, non-transformed means are presented with mean separation based on transformed values. Where the ANOVA indicated that treatment effects were significant, means were separated at $P \leq 0.05$ and adjusted with Fisher's Protected Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Rice Injury. No significant rice injury was observed in any herbicide treatment in any year, which indicated that penoxsulam and bispyribac-sodium were safe for use in rice. In this study, bispyribac-sodium caused less than 10% foliar injury at 7 days after treatment (DAT) compared with the non treated control; however, by 21 DAT, the injury recovered and was equal to the non treated control (data not shown) with no effect on kernel yield. Willingham *et al.* (2008) reported similar injury on five rice cultivars at 7 DAT when bispyribac-sodium was applied POST at 30 g ha^{-1}. Scasta *et al.* (2004) revealed that bispyribac-sodium injured rice up to 30% when applied pre-flood, and injury increased with rate. Hand-hoeing was done as per the university recommended guideline, therefore no physical injury was observed on rice plants.

Weed Density and Biomass. Common weed species infesting the experimental site during both the years were horse purslane (*Trianthema portulacastrum* L.), crowfootgrass [*Dactyloctenium aegyptium* (L.) Willd.], goosegrass (*Eleusine indica* L.), and sedges (*Cyperus* spp.). There was a significant treatment by year interaction, therefore, weed density and biomass data were presented separately for each year (Table 2). The results suggested that weed density was influenced by seeding time. For example, more weed density (51 to 59 plants m^{-2}) was recorded when rice was seeded late (3rd week of June or 1st week of July) compared to early seeding (1st week of June) at 35 DAS during 2008, while at harvest, the highest weed density was recorded when rice was seeded in the first week of July.

All weed management treatments were effective for reducing weed density compared to non treated control at 35 DAS and at harvest during 2008 (Table 2). Penoxsulam applied PRE followed by hand-hoeing at 30 DAS recorded the lowest weed density and it was comparable with hand-hoeing treatment at 35 DAS and also at harvest during 2008. This might be because penoxsulam has both residual and burn down activity, therefore it can control susceptible weeds emerged at the time of application or which germinate soon after application (Willingham *et al.,* 2008). Similar to this result, a weed control study in rice reported that application of penoxsulam provided 99 and 97% control of barnyardgrass [*Echinochloa crus-galli*] and broadleaf signalgrass (*Brachiaria platyphylla*) at 21 DAT (Ottis *et al.,* 2003). Bispyribac-sodium provided 80 and 85%

control of goose grass and crow foot grass, respectively at 10 DAS (data not shown); however, control reduced beyond 30 d. Williams (1999) reported that barnyard grass control was 98 to 100% with middle- to late-POST applications of bispyribac at 20 and 23 g ha^{-1}.

Similar results were usually observed during 2009 with more weed density in later seeding time compared with the early seeding. Penoxsulam or bispyribac-sodium applied alone was effective to reduce weed density compared with the non treated control, but it was more effective when followed by hand-hoeing. In California, late water grass [*Echinochloa phyllopogon* (Stapf) Koss] resistance to bispyribac-sodium has been reported in rice fields (Fischer *et al.,* 2000); therefore, prior to commercialization of bispyribac-sodium in Pakistan, a proactive management practice is required to avoid bispyribac-sodium resistant weeds. A foliar spray of sorghum and sunflower water extract and application of sorghum mulch resulted in weed density ≤ 30 and < 65 at 35 DAS and at harvest, respectively (Table 2) compared to non treated control that resulted in weed density 84 and 152 plants m^{-2} at 35 DAS and at harvest, respectively during 2009 (Table 2). This confirm the previous findings that suggested use of crop residues as mulch provided weed suppression through their physical presence (Singh *et al.,* 2007; Teosdale and Mohler, 2000).

Similar to 2008, the lowest weed density was recorded in penoxsulam followed by hand-hoeing treatment and it was comparable with hand-hoeing (three times) treatment at 35 DAS and at harvest during 2009. This was due to the fact that herbicides followed by hand weeding or hand-hoeing is much effective compared with application of herbicides alone in rice because of weed emergence later in the season that can be effectively controlled with physical methods without crop injury (Farooq, 2011). Weed biomass collected at the harvest was affected by time of seeding (Table 2). The lowest weed biomass was recorded in early seeding time compared to late seeding (1st week of July) with no difference between seeding time in 1st and 3rd week of June during 2008 and 2009. Among herbicide treatments, the highest weed biomass (193 and 147 g m^{-2} during 2008 and 2009, respectively) was recorded in bispyribac-sodium applied alone; in fact, it was comparable with non treated control in both the years. Penoxsulam applied alone reduced weed biomass compared with foliar spray of sorghum and sunflower extract and sorghum mulch; however, when penoxsulam was followed by hand-hoeing, a combination resulted in the lowest weed biomass (28 and 17 g m^{-2} during 2008 and 2009, respectively) that was comparable with hand hoeing at 15, 30 and 45 DAS (Table 2). Interaction effects of seeding time and weed management treatments were significant for weed density and biomass at 35 DAS and at harvest during 2008 and 2009 (Table 3).

Rice Yield Attributes. The results of rice yield attributes suggested that number of tillers were not affected by seeding time, but kernel weight and leaf area index increased when rice was planted in the first week of June compared to the first week of July with no difference between first and third week of June (Table 4). Leaf area duration was reduced with each late seeding time. Similar variation was recorded for the rice yield attributes among weed management treatments. The maximum number of tillers and 1000 kernel weight was in the treatment of penoxsulam followed by hand-hoeing and it was at par with the hand-hoeing treatment. The application of sorghum mulch resulted in a poor number of tillers (347 and 394 tillers m^{-2} during 2008 and 2009, respectively) compared to herbicide and hand-hoeing treatments, in fact that was comparable with non treated control (Table 4).

All weed management treatments resulted in higher leaf area index and leaf area duration compared to non treated control (Table 4). Leaf area index was highest in penoxsulam or bispyribac-sodium followed by hand-hoeing and hand-hoeing alone at 15, 30, and 45 DAS treatments during 2008 and 2009. The highest value for leaf area duration was in penoxsulam followed by hand-hoeing treatment and it was comparable with hand-hoeing alone at 15, 30, and 45 DAS (Table 4).

Rice Kernel Yield. Early seeding time (1st week of June) resulted 7.2 and 6.9% higher kernel yield compared to the seeding in the first week of July during 2008 and 2009, respectively (Table 5). The kernel yield improved with weed management treatments and there was a variation for kernel yield among weed control treatments. Compared to non treated control, all weed management treatments resulted in at least > 34% and > 27% higher kernel yields during 2008 and 2009, respectively. The highest kernel yield of 2670 and 2752 kg ha^{-1} was recorded when penoxsulam was followed by hand-hoeing in 2008 and 2009, respectively and it was statistically equal with hand hoeing at 15, 30 and 45 DAS (Table 5). A study by Bond *et al.* (2007) reported that rice grain yield was 6 to 9% higher following application of penoxsulam at 70 g ha^{-1} compared with the yield of the non treated control and yield following applications of penoxsulam at 35 g ha^{-1} or bispyribac-sodium at 28 g ha^{-1}. In this study, bispyribac-sodium followed by hand-hoeing has not provided any additional yield advantage over application of bispyribac-sodium alone. Application of sorghum mulch resulted 28 to 35% increase in kernel yield compared to the nontreated control. This may be due to the fact that mulches on the soil surface suppress weed emergence. Similar to our results, a study in India reported that application of mulch increased grain yield of dry-seeded rice by 17 to 22% (Singh *et al.,* 2007).

Due to increasing number of herbicide-resistant weeds, there have been considerable efforts in designing alternative weed management strategies. In this study, use of non-chemical methods such as sorghum mulch and spray of sorghum and sunflower extract was effective to reduce weed density and increased kernel yield compared with the non treated control. A recent study in Pakistan suggested that a mixture of sorghum and sunflower extract with penoxsulam at 7.5 g ha^{-1} reduced weed density and biomass same as recommended rate of penoxsulam (15 g ha^{-1}) in rice (Cheema *et al.,* 2010). Therefore, more research is required to combine penoxsulam, non-chemical methods followed by hand-hoeing for weed control in DSR.

This research showed that penoxsulam followed by hand-hoeing provided excellent weed control and secured highest kernel yield. It was also observed that penoxsulam or bispyribac-sodium had not any significant injury on rice, therefore they are safe to use in rice. In fact, in the United States, penoxsulam was granted a reduced risk pesticide status from the United States Environmental Protection Agency (USEPA) for use in rice due to its favorable human health risk profile and a favorable ecotoxicity profile compared with other ALS-inhibitors registered in rice (USEPA, 2004). Research is required to evaluate penoxsulam applied POST at various rates in combination with hand-hoeing for weed control in rice in Pakistan. Bispyribac-sodium was not as effective as penoxsulam in this study; however, more research is required to tank mix with other herbicides to improve weed control efficacy.

Table 1. Dates of agronomic operations conducted during the research experiment in 2008 and 2009.

Name of operation[a]	2008	2009
Seeding date in 1st week of June (S_1) aaw	02 June	05 June
Seeding date in 3rd week of June (S_2)	17 June	19 June
Seeding date in 1st week of July (S_3)	02 July	05 July
Penoxsulam (PRE) applied (after seeding)	03 June, 18 June, and 03 July, respectively for 3 seeding dates S_1, S_2, and S_3	06 June, 20 June, and 06 July, respectively for 3 seeding dates S_1, S_2, and S_3
Bispyribac-sodium (POST) applied at 15 DAS	17 June, 02 July, and 17 July, respectively for 3 seeding dates S_1, S_2, and S_3	20 June, 4 July and 20 July, respectively for 3 seeding dates S_1, S_2, and S_3
Hand-hoeing at 15, 30 and 45 DAS	S_1:17 June, 02 July and 17 July; S_2: 02 July, 17 July and 01 Aug.; and S_3:17 July, 02 Aug., and 17 Aug.	S_1: 20 June, 05 July and 20 July; S_2: 04 July, 19 July and 03 Aug.; S_3: 20 July, 05 Aug., and 20 Aug.
Foliar spray of sorghum and sunflower water extract at 20 and 40 DAS	S_1: 22 June and 12 July; S_2: 05 July and 25 July; S_3: 22 July and 11 Aug.	S_1: 25 June and 15 July; S_2: 07 July and 27 July; S_3: 25 July and 14 Aug.
Sorghum mulch applied (after seeding)	02 June, 17 June and 02 July, respectively for 3 seeding dates S_1, S_2, and S_3	05 June, 19 June and 05 July, respectively for 3 seeding dates S_1, S_2, and S_3
Penoxsulam (PRE) + hand-hoeing at 20 DAT	03 June + 22 June, 18 June + 05 July, and 03 July + 22 July, respectively for 3 seeding dates S_1, S_2, and S_3	S_1: 06 June + 25 June; S_2: 21 June + 08 July; and S_3: 06 July + 25 July
Bispyribac-sodium (POST) + hand-hoeing at 30 DAS)	17 June + 02 July, 02 July + 17 July, and 17 July + 02 Aug., respectively for 3 seeding dates S_1, S_2, and S_3	S_1: 20 June + 05 July; S_2: 4 July + 19 July and; S_3: 20 July+ 05 Aug.
Plants harvested for leaf area index	20 Aug., 5 Sep., 20 Oct., 5 Nov.	21 Aug., 6 Sep., 22 Oct., 7 Nov.
Weed density data recorded before harvest	22 Oct., 28 Oct., and 01 Nov., respectively for 3 seeding dates S_1, S_2, and S_3	23 Oct, 27 Oct, 02 Nov., respectively for 3 seeding dates S_1, S_2, and S_3
Weed biomass taken before harvest	25 Oct., 01 Nov. and 04 Nov., respectively for 3 seeding dates S_1, S_2, and S_3	26 Oct., 31 Oct. and 05 Nov., respectively for 3 seeding dates S_1, S_2, and S_3
Harvesting of rice	05 Nov. (for all seeding dates)	06 Nov. (for all seeding dates)
Threshing	08 Nov. (for all seeding dates)	09 Nov. (for all seeding dates)

[a] Abbreviations: DAS, days after seeding.

Table 2. Effects of seeding time and weed management treatments on total weed density at 35 DAS and at harvest in DSR in 2008 and 2009[a]

Treatment	Total weed density				Total weed biomass	
	2008[b,c]		2009[b,c]		2008[b,c]	2009[b,c]
	35 DAS	At harvest	35 DAS	At harvest	At harvest	At harvest
	------------------No. m^{-2}----------------				---------- g ---------	
Seeding time (ST)						
First week of June	36 [b]	92[b]	19 [b]	55[b]	93 [b]	61 [b]
Third week of June	51 [a]	92[b]	20 [b]	62[a]	94 [b]	65 [ab]
First week of July	59 [a]	98[a]	29 [a]	67[a]	110 [a]	73 [a]
Weed management treatments (WMT)						
Non treated Control	70 [a]	206[a]	84 [a]	152[a]	207 [a]	152 [a]
Penoxsulam at 15 g ai ha^{-1}	20 [c]	63[c]	35 [c]	31[c]	59 [d]	34 [c]
Bispyribac-sodium at 30 g ai ha^{-1}	46 [b]	105[b]	41 [b]	147[a]	193 [a]	147 [a]
Hand-hoeing at 15, 30, and 45 DAS	7 [d]	22[d]	7 [e]	12[d]	27 [f]	16 [d]
Foliar spray of sorghum and sunflower water extract (15 L ha^{-1}) at 20 and 40 DAS	45 [b]	100[b]	30[cd]	55[b]	97 [c]	65 [b]
Sorghum mulch at 6 t ha^{-1}	48 [b]	111[b]	22[d]	63[b]	114 [b]	64 [b]
Penoxsulam + hand-hoeing at 30 DAS	5 [d]	28[d]	6[e]	13[d]	28 [f]	17 [d]
Bispyribac-sodium at 30 g ai ha^{-1}+ hand-hoeing at 30 DAS	40 [b]	61[c]	30[cd]	32[c]	58 [e]	28 [c]
Interaction effects[d]						
ST X WMT	*	*	*	*	*	*

[a] Abbreviations: DAS, days after seeding; DSR, direct seeded rice.
[b] The data were arc-sine transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.
[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P \leq 0.05$.
[d] Interaction effects denoted by an asterisk (*) is significant at $P \leq 0.05$.

Table 3. Interaction effects of seeding time and weed management treatments on total weed density and biomass at harvest in DSR in 2008 and 2009[a]

Treatment	Total weed density at harvest						Total weed biomass at harvest (g)					
	2008[b,c]			2009[b,c]			2008[b,c]			2009[b,c]		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
	---------------------No. m^{-2}---------------------------						----------------------- g -----------------------------					
Non treated Control	200[ab]	196[b]	221[a]	140[b]	152[ab]	164[a]	198[b]	201[b]	224[a]	143[b]	148[ab]	164[a]
Penoxsulam at 15 g ai ha^{-1}	35[e]	33[e]	59[d]	16[e]	19[de]	40[d]	50[ef]	59[ef]	69[e]	29[de]	34[de]	39[d]
Bispyribac-sodium at 30 g ai ha^{-1}	189[b]	187[b]	204[ab]	138[b]	151[ab]	154[ab]	182[b]	188b	208[ab]	139[b]	142[b]	160[ab]
Hand-hoeing at 15, 30, and 45 DAS	21[e]	22[e]	22[e]	10[e]	13[e]	14[e]	27[f]	28[f]	28[f]	13[e]	17[e]	18[e]
Foliar spray of sorghum and sunflower water extract (15 L ha^{-1}) at 20 and 40 DAS	99[c]	99[c]	102[c]	50[cd]	54[cd]	59[c]	92[d]	98[cd]	100[cd]	56[cd]	68[c]	69[c]
Sorghum mulch at 6 t ha^{-1}	110[c]	112[c]	111[c]	57[c]	64[c]	70[c]	108[c]	119[c]	115[c]	63[c]	60[c]	68c
Penoxsulam + hand-hoeing at 30 DAS	27[e]	28[e]	29[e]	14[e]	17[e]	17[e]	35[f]	42[f]	48[ef]	22[de]	27[de]	33[de]
Bispyribac-sodium at 30 g ai ha^{-1} + hand-hoeing at 30 DAS	60[d]	60[d]	63[d]	28[de]	30[de]	37[d]	50[ef]	60[ef]	64[ef]	21[de]	25[de]	36[de]

[a] Abbreviations: DAS, days after seeding; DSR, direct seeded rice; S_1, seeding time in first week of June; S_2, third week of June; S_3, first week of July.
[b] The data were arc-sine transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.
[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P \leq 0.05$.

Table 4. Effects of seeding time and weed management treatments on number of rice tillers, kernel weight, leaf area index, and leaf area duration in 2008 and 2009

Treatment	Number of tillers[a,b,c]		1000 kernel weight[a,b,c]		Leaf area index[a,b,c]		Leaf area duration[a,b,c]	
	2008	2009	2008	2009	2008	2009	2008	2009
	-----No. m^{-2}-----		--------g------					
Seeding time(ST)								
First week of June	392.8 [a]	444.4 [a]	16.5 [a]	17.1 [a]	2.29[a]	2.39[a]	119.38[a]	123.36[a]
Third week of June	390.0 [a]	434.8 [a]	16.4 [a]	16.8 [a]	2.25[ab]	2.33[ab]	117.28[b]	121.05[b]
First week of July	370.6 [a]	408.7 [a]	14.8 [b]	15.9 [b]	2.18[b]	2.24[b]	114.18[c]	117.18[c]
Weed management treatments (WMT)								
Non treated Control	336.8 [e]	383.9 [f]	13.0 [e]	14.3[e]	1.91[d]	1.98[d]	101.90[e]	105.26[g]
Penoxsulam at 15 g ai ha^{-1}	389.2 [c]	425.2 [d]	16.1 [c]	16.6[c]	2.27[b]	2.38[b]	118.75[c]	122.70[cd]
Bispyribac-sodium at 30 g ai ha^{-1}	386.2 [c]	427.6 [cd]	15.9 [c]	16.6[cd]	2.24[bc]	2.32[bc]	117.38[c]	121.21[d]
Hand-hoeing at 15, 30, and 45 DAS	442.9 [a]	489.9 [a]	17.7 [a]	18.5[a]	2.44[a]	2.52[a]	126.91[a]	130.52[a]
Foliar spray of sorghum and sunflower water extract (15 L ha^{-1}) at 20 and 40 DAS	358.9 [d]	402.1 [e]	15.6 [d]	16.3[d]	2.16[bc]	2.25[c]	113.63[d]	117.73[e]
Sorghum mulch at 6 t ha^{-1}	347.4[de]	394.5[ef]	15.4 d	16.1[d]	2.11[c]	2.18[c]	111.08[d]	114.44[f]
Penoxsulam + hand-hoeing at 30 DAS	422.8 a	474.2 a	17.6 a	18.2[a]	2.38[ab]	2.46[ab]	126.3[a]	130.2[a]
Bispyribac-sodium at 30 g ai ha^{-1}+ hand-hoeing at 30 DAS	402.5[bc]	443.1[c]	16.6[b]	17.2[b]	2.34[ab]	2.42[ab]	122.03[b]	124.70[c]

[a] Abbreviations: DAS, days after seeding.
[b] The data were arc-sine transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.
[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P \leq 0.05$.

Table 5. Effects of seeding time and weed management treatments on rice kernel yield, percent increase in kernel yield, and harvest index in 2008 and 2009

Treatment	Kernel yield (kg ha^{-1})		Increase in kernel yield		Harvest index	
	2008[a,b,c]	2009 [a,b,c]	2008 [a,b,c]	2009 [a,b,c]	2008 [a,b,c]	2009[a,b,c]
	------kg ha^{-1}-------		--------%--------		---------%--------	
Seeding time (ST)						
First week of June	2390[a]	2480[a]	7.2	6.9	19.8[a]	20.7[a]
Third week of June	2304[ab]	2400[ab]	3.4	3.5	19.2[ab]	20.0[ab]
First week of July	2229[b]	2320[b]	-	-	18.5[b]	19.0[b]
Weed management treatments (WMT)						
Non treated Control	1573[e]	1704[e]	-	-	16.2[e]	17.2[e]
Penoxsulam at 15 g ai ha^{-1}	2400[bc]	2475[c]	52.7	45.4	19.6[c]	20.4[bc]
Bispyribac-sodium at 30 g ai ha^{-1}	2323[c]	2395[c]	47.8	40.7	19.1[c]	19.7[c]
Hand-hoeing at 15, 30, and 45 DAS	2791[a]	2921[a]	77.4	71.5	22.1[a]	22.5[a]
Foliar spray of sorghum and sunflower water extract (15 L ha^{-1}) at 20 and 40 DAS	2209[cd]	2279[cd]	40.5	33.8	18.0[d]	18.2[d]
Sorghum mulch at 6 t ha^{-1}	2084 [d]	2179 [d]	34.6	28.0	17.3[d]	18.0 [de]
Penoxsulam + hand-hoeing at 30 DAS	2670[a]	2752[ab]	69.7	61.5	21.6[a]	21.7[ab]
Bispyribac-sodium at 30 g ai ha^{-1}+ hand-hoeing at 30 DAS	2458[bc]	2590[bc]	56.4	52.2	20.4[bc]	21.0[b]
Interaction effects[d]						
ST X WMT	*	*	-	-	*	*

[a] Abbreviations: DAS, days after seeding.
[b] The data were arc-sine transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.
[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P \leq 0.05$.
[d] Interaction effects denoted by an asterisk (*) is significant at $P \leq 0.05$.

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