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Nutrient availability and nutrient uptake as influenced by the post emergence application of herbicide mixtures

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Abstract

Field experiments were conducted to study the effect of herbicide mixtures *viz*., bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl on nutrient availability in soil, nutrient uptake by crop, nutrient removal by weeds and grain yield of direct seeded rice at Upanniyoor Padashekaram, Nemom block, Thiruvananthapuram, Kerala. Eleven weed control treatments along with weedy check were laid out in randomized block design with three replications. Results revealed that the lowest weed density, weed dry weight and nutrient uptake by weeds were observed in penoxsulam + cyhalofop butyl @ 135 g ha^{-1}. Compared to weedy check, herbicide treatments reduced the N removal by weeds to the tune of 89.04 to 99.22 per cent and 89.67 to 99.36 per cent respectively at 60 DAS during *Kharif* 2014 and *Rabi* 2014-15 seasons. Phosphorus removal by weeds has been reduced to the tune of 70.59 to 98.04 per cent and K removal has been reduced to the tune of 86.22 to 99.42 per cent respectively at 60 DAS during *Kharif* and *Rabi* seasons. Among the different doses of bispyribac sodium + metamifop, its higher dose (90 g ha^{-1}) was more effective in reducing the weed density and dry weight and nutrient depletion by weeds. Due to significant reduction in weed density and weed dry weight, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1}, bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1} and penoxsulam applied alone recorded higher availability of N, P and K in soil and uptake of these nutrients by the rice crop. The weed management practices enhanced the grain yield from 4285 to 8295 kg ha^{-1} during first crop season and from 4240 to 8889 kg ha^{-1} during second crop season with 48.34 and 52.30 per cent increase in yield respectively over weedy check. During *Kharif* 2014, penoxsulam + cyhalofop butyl at 130 g ha^{-1} recorded the highest grain yield which was statistically on par with penoxsulam + cyhalofop butyl at 135 g ha^{-1} and 125 g ha^{-1}. However, during *Rabi* 2014-15, penoxsulam + cyhalofop butyl at 135 g ha^{-1} recorded the highest grain yield which was significantly superior to all other treatments. Hence, post emergence application of penoxsulam + cyhalofop butyl @ 135 and 130 g ha^{-1} on 15 DAS can be recommended for the better control of weeds, nutrient availability and nutrient uptake by the crop and higher grain yield in wet direct seeded rice.

Keywords: Bispyribac sodium + metamifop, Grain yield, Nutrient availability, Nutrient uptake, Penoxsulam + cyhalofop butyl, Weed density, Weed dry weight

Introduction

Weeds are the major biological constraint in direct seeded rice. Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Raju and Reddy, 1992). Weeds compete with crop plant for growth factors *viz*., moisture, nutrients, space and light and if not properly controlled, weeds remove substantial quantity of nutrients and result in significant yield loss. Research evidences have shown that in the absence of effective weed control options, the yield loss is more in direct seeded rice than in transplanted rice. On an average, yield loss due to weed competition ranges from 15 to 20 per cent, but in severe cases it may exceed 50 per cent

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(Hasanuzzaman et al., 2009) or even complete crop failure (Jayadeva et al., 2011). Based on studies conducted at Rice Research Station, Moncompu, Raj et al. (2013b) reported that, season long weed competition in wet seeded rice caused 69.71 and 67.40 per cent reduction in grain yield during *Kharif* and *Rabi* season, respectively.

Weeds usually have faster growth, compete severely for nutrients and remove large amount of plant nutrients from the soil. Hence weeds not only increase the cost of cultivation but also deplete the resource base. According to Singh et al. (2002), weeds removed eight times more nutrients under direct seeded rice compared to puddled transplanted rice. Reduction in weed density and weed dry weight resulted in significant increase in the uptake of nutrients by crop (Payman and Singh, 2008). Nutrient removal by weeds and nutrient uptake by crops are inversely related (Ramachandiran et al., 2012).

Herbicide based weed management is the smartest viable option for weed control in direct seeded rice due to labour scarcity at the critical time of weeding and high wage rate (Singh et al., 2006). Herbicide use in DSR systems becomes even more important as rice and weed seedlings emerge simultaneously and some weed seedlings (e.g., *Echinochloa* spp.) are morphologically similar to rice seedlings (Chauhan, 2012). Herbicides provide superior weed control and are more labour efficient than manual or mechanical methods of weed management (Chauhan et al., 2014). Though herbicides are considered to be effective and economical in controlling weeds in DSR, the continuous use of same herbicide or herbicides with similar mode of action will lead to the development of herbicide resistance and shift in weed flora either slowly or rapidly. One of the recent ways to overcome the shift in weed flora and to prevent the development or delay the development of herbicide resistance in weeds is the use of herbicide mixtures. Herbicide mixtures will help to prevent the resistance problem and shift in weed population, which is always a problem associated with the use of single herbicide (Wrubel and Gressel, 1994). With this background, the present experiment was undertaken to study the effect of two pre-mix herbicide mixtures, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl on weed growth, yield, nutrient availability in soil, nutrient uptake by crop and weed in direct seeded puddled rice.

Materials and Methods

Field experiment was conducted for two consecutive seasons during *Kharif* 2014 and *Rabi* 2014-15 in farmer's field at Upaniyooor padashekaram, of Kalliyoor panchayat in Nemom block, Thiruvananthapuram district. The experimental field was situated at 8º 26.762' N latitude and 77°0.136' E longitude and 29 m above mean sea level. The experiment was laid out in randomized block design with 12 treatments and three replications. The treatments comprised of four different doses of bispyribac sodium + metamifop at 60, 70, 80 and 90 g ha^{-1}, four different doses of penoxsulam + cyhalofop butyl at 120, 125, 130 and 135 g ha^{-1}, bispyribac sodium applied alone at 22.5 g ha^{-1}, penoxsulam at 25 g ha^{-1}, hand weeding twice at 20 and 40 DAS (days after sowing) and weedy check.

The soil of the experimental field was well drained sandy clay loam, acidic in reaction, high in organic carbon and medium in available N, P and K. The average annual rainfall received during the experimentation was 892 mm during *Kharif* 2014 and 210 mm during *Rabi* 2014-15. The mean maximum and minimum temperature recorded during *Kharif* and *Rabi* seasons were 30.1° C and 24° C and 30.8 ° and 22.6 º C respectively.

PTB 50 (Kanchana), a short duration variety of 100-105 days released from Regional Agricultural Station, Pattambi was used as the test crop. Pre-germinated seeds were broadcasted at 100 kg ha^{-1}. The crop was fertilized with 70:35:35 N: P: K kg ha^{-1}. One third N and K and half P were given at 15 and 35 DAS and remaining one third N and K at 55 days after sowing (DAS). Irrigation and plant protection measures were adopted as per Kerala Agricultural University Package of Practices Recommendations (KAU, 2011).

The herbicides were applied at 15 DAS as per treatment schedule. The spray volume used in the study was 500 L ha^{-1}. The herbicides were sprayed with hand operated knapsack sprayer fitted with a flat fan nozzle. In hand weeding treatment, manual weeding was done twice at 20 and 40 DAS.

Composite soil samples were collected from each treatment plot at harvest stage for the estimation of available N, P and K content of the soil. Soil samples were shade dried and sieved and kept in a polythene bag. Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by Dickman and Brays molybdenum blue method by spectrophotometer (Jackson, 1973) and available K was determined using neutral normal ammonium acetate and estimated using flame photometer (Jackson, 1973).

The data on weed density (60 DAS) were recorded with the help of a quadrate (0.5 m x 0.5 m) placed randomly at two representative sites in the sampling area. Weeds present inside the quadrate were uprooted and categorized into grasses, sedges and broad leaf weeds and total weed density was expressed in no. m^2. The uprooted weeds were sundried for one day and then oven dried at 60 ± 5º C until constant weight was attained and dry weight was recorded as g m^{-2}. Data on weed density, weed dry weight and nutrient uptake by weeds were subjected to square root transformations ($\sqrt{(x+0.5)}$ to normalize the distribution. For the determination of dry matter production (DMP) of crop, five hills were randomly selected from outside the net plot area of each treatment leaving two border rows at harvest stage. The samples were dried in a hot air oven at 60 ± 5º C to constant weight and DMP was expressed in kg ha^{-1}. The weed and plant samples were ground and sieved through 0.5 mm sieve. The required quantity of samples was weighed out accurately and was subjected to acid extraction and N, P and K content was determined. Total nitrogen content was estimated by modified microkjheldal method (Jackson, 1973), total phosphorus content by vanadomolybdate phosphoric yellow colour method (Jackson, 1973) and total potassium content was determined using flame photometer (Jackson, 1973). The N, P and K uptake of crop and weed was worked out by multiplying the nutrient content with DMP and expressed in kg ha^{-1}. The grain yield from each net plot area (4 m x 3 m) was dried to a moisture content of 14 per cent and expressed in kg ha^{-1}. Data generated were statistically analyzed using analysis of variance technique (ANOVA) and difference between the treatments means were compared at 5% probability level.

Results and Discussion

Effect on total weed density and dry weight

The total density and dry weight of weeds was significantly influenced by the weed control treatments (Table 1). Weedy check registered the total weed density and weed dry weight of 1236.7 m^{-2} and 1132.3 m^{-2} and 240.01 gm^{-2} and 227.40 m^{-2} respectively during *Kharif and Rabi* seasons, implying the severity of biological constraint offered by weeds in DSR and the importance of early weed management. The intense and uncontrolled wed growth adversely affected the crop growth and yield in weedy check. This is in conformity with the observations of Ganai et al. (2014) and Arya (2015). Penoxsulam + chalofop butyl @ 135 g ha^{-1} was found to be more effective in reducing the density and dry weight of weeds at 60 DAS during both the seasons. The result is in agreement with the findings of Abraham and Menon (2015) who reported that post emergence application of penoxsulam + cyhalfop butyl @ 135 g ha^{-1} resulted in very good control of all types of weeds in wet direct seeded rice. Among the different doses of bispyribac sodium + metamifop,

Table1. Effect of weed management practices on total weed density, dry weight and nutrient uptake by weeds (*Kharif* 2014 and *Rabi* 2014-15)

Treatments	Total density of weeds at 60 DAS, no. m^{-2}		Total weed dry weight at 60 DAS, g m^{-2}		Nutrient uptake by weeds at 60 DAS					
					N Uptake, kg ha^{-1}		P Uptake, kg ha^{-1}		K Uptake, kg ha^{-1}	
	Kharif season	*Rabi* season	*Kharif* season	*Rabi* season	*Kharif* season	*Rabi* season	*Kharif* season	*Rabi* season	*Kharif* season	*Rabi* season
Bispyribac sodium +	21.61	23.01	5.48	5.54	2.87	2.59	1.17	1.14	2.46	2.18
metamifop 60 g ha^{-1}	(469.0)	(530.0)	(29.63)	(30.33)	(7.72)	(6.28)	(0.86)	(0.79)	(5.62)	(4.27)
Bispyribac sodium +	14.23	16.54	3.47	4.27	2.07	2.09	0.90	1.01	1.70	2.10
metamifop 70 g ha^{-1}	(202.3)	(275.0)	(11.54)	(18.10)	(3.78)	(3.99)	(0.31)	(0.53)	(2.38)	(3.89)
Bispyribac sodium +	13.28	16.55	2.67	3.86	1.53	2.09	0.83	0.91	1.25	1.73
metamifop 80 g ha^{-1}	(176.7)	(280.0)	(6.61)	(14.55)	(1.85)	(3.89)	(0.19)	(0.33)	(1.07)	(2.49)
Bispyribac sodium +	10.77	271.7	2.18	3.44	1.28	1.81	0.78	0.92	1.20	1.30
metamifop 90 g ha^{-1}	(116.0)	(16.44)	(4.33)	(11.44)	(1.15)	(2.84)	(0.10)	(0.35)	(0.97)	(1.22)
Penoxsulam +	13.79	13.20	2.33	2.45	1.42	1.45	0.80	0.80	1.12	1.18
cyhalofop butyl 120 g ha^{-1}	(193.0)	(174.7)	(5.15)	(5.69)	(1.57)	(1.68)	(0.15)	(0.14)	(0.76)	(0.92)
Penoxsulam +	9.99	12.12	1.75	2.32	1.12	1.48	0.76	0.80	1.05	1.20
cyhalofop butyl 125 g ha^{-1}	(99.3)	(147.0)	(2.65)	(4.90)	(0.77)	(1.70)	(0.07)	(0.14)	(0.61)	(0.94)
Penoxsulam +	9.97	125.0	1.62	2.07	1.19	1.44	0.75	0.78	1.03	1.03
cyhalofop butyl 130 g ha^{-1}	(99.7)	(111.06)	(2.13)	(3.91)	(0.91)	(1.63)	(0.06)	(0.11)	(0.57)	(0.58)
Penoxsulam +	9.24	5.52	1.55	1.53	1.02	0.94	0.73	0.74	0.93	0.83
cyhalofop butyl 135 g ha^{-1}	(85.0)	(30.0)	(1.91)	(1.83)	(0.55)	(0.39)	(0.04)	(0.04)	(0.36)	(0.18)
Bispyribac sodium 25 g ha^{-1}	21.00	23.33	3.84	4.50	2.16	2.55	0.96	1.05	1.61	1.97
	(441.0)	(544.0)	(14.30)	(19.91)	(4.19)	(6.01)	(0.43)	(0.62)	(2.07)	(3.47)
Penoxsulam 22.5 g ha^{-1}	13.01	15.14	2.73	2.77	1.68	1.64	0.83	0.84	1.38	1.23
	(168.7)	(229.3)	(6.96)	(7.56)	(2.33)	(2.28)	(0.20)	(0.21)	(1.40)	(1.06)
Hand weeding, 20 and 40 DAS	14.97	17.44	3.36	3.33	1.80	1.85	0.90	(0.90)	1.55	1.36
	(227.7)	(304.0)	(10.81)	(11.07)	(2.76)	(3.01)	(0.31)	(0.32)	(1.89)	(1.39)
Weedy check	35.17	33.62	15.51	15.07	8.42	7.80	2.88	2.84	6.06	5.61
	(1236.7)	(1132.3)	(240.01)	(227.40)	(70.47)	(60.77)	(7.82)	(7.55)	(36.27)	(30.98)
SEm (±)	0.762	0.781	0.144	0.331	0.105	0.292	0.016	0.040	0.112	0.141
CD (0.05)	2.233	2.290	0.421	0.971	0.218	0.605	0.033	0.084	0.233	0.292

DAS - days after sowing, Values in parentheses are original values

its higher dose (90 g ha^{-1}) was found to be better than its lower doses and individual application of penoxsulam and bispyribac sodium. Raj et al. (2013a) reported that bispyribac sodium + metamifop @ 70 and 140 g ha^{-1} was more efficient than bispyribac sodium applied alone in reducing the dry weight of weeds. Results also pointed out that all the herbicide treatments except bispyribac sodium + metamifop @ 60 g ha^{-1} and bispyribac sodium applied alone @ 25 g ha^{-1} recorded lower density of weeds than hand weeding. Hand weeding failed to control the weeds effectively because of regeneration or escape of weeds (Singh, 2008).

Effect on nutrient uptake by weeds

Uptake of weeds was significantly influenced by the weed management treatments (Table 1). All the herbicide treatments and hand weeding treatment reduced the N, P and K uptake by weeds significantly, compared to weedy check during both the seasons. The loss of nutrients varied with intensity of weeds and its dry matter accumulation and percentage nutrient content. It has been observed that, among the three major plant nutrients, weeds removed large quantity of N than P and K (Table 1). The result is in agreement with the findings of Dayaram (2013) and Sasna (2014). Among the weed management treatments, penooxsulam + cyhalofop butyl @ 135, recorded the lowest uptake of nutrients by weeds which was followed by its lower doses (130 and 125 g ha^{-1}). The higher dose of bispyribac sodium + metamifop (90 g ha^{-1}) recorded lower N, P and K uptake by weeds among its other doses. Nutrient uptake by weeds was directly related to weed dry matter and inversely related to the rice grain yield. Reduction in nutrient uptake by weeds in direct seeded rice was also reported by Payman and Singh (2008) and Gowda et al. (2009). Compared to weedy check, herbicide treatments reduced the N removal by weeds to the tune of 89.04 to 99.22 per cent and 89.67 to 99.36 per cent respectively at 60 DAS during first and second crop seasons. Phosphorus removal by weeds was reduced to the tune of 70.59 to 98.04 per cent and K removal was reduced to the tune of 86.22 to 99.42 per cent respectively during *Kharif* and *Rabi* seasons. The results highlighted the necessity of weed control up to 60 DAS to avoid the excessive loss of nutrients through weeds in DSR. The highest uptake of nutrients by weeds in weedy check was due to high density of weeds (Table 1). Similar increase in nutrient uptake by increase in weed population was reported by Babar and Velayudham (2012) and Nath et al. (2014). Sharma et al. (2007) and Gowda et al. (2009) also reported that initial weed free period up to 40 to 45 DAS or longer resulted in lower weed dry weight and nutrient uptake by weeds and higher grain yield in DSR.

Effect on soil nutrient status

Weed management treatments significantly influenced the available soil nutrient status at harvest stage (Table 2). During both the seasons, weedy check recorded the lowest available nutrient status. This might be due to severe competition exerted by the weeds throughout the crop growth and increased nutrient removal by weeds (Table 1). Weeds usually have faster growth and competitive advantage in absorbing more nutrients from the soil than the crop. Compared to weedy check, all the herbicide treatments recorded higher available soil nutrient status. Application of herbicides effectively controlled the weeds and reduced nutrient removal by weeds (Kumar et al., 2010) and thus increased the nutrient availability in soil. The enhanced availability of nutrients in soil also might have contributed to higher grain yield in herbicide treatments. The present study also indicated the need for effective control of weeds at the critical stages of crop growth to prevent the excessive removal of nutrients, which would have otherwise been utilized by the crop plants for growth and development, contributing to final yield.

The availability of N, P and K did not follow the similar trend. Critical appraisal of N, P and K availability at harvest stage revealed that, among the herbicide treatments, penoxsulam + cyhalofop butyl at 135,130 and 125 g ha^{-1}, bispyribac sodium + metamifop at 90, 80 and 70 g ha^{-1} and penoxsulam applied alone @ 22.5 g ha^{-1} were more effective in maintaining a high level of available N, P and K content in the soil. This clearly showed the efficacy of herbicides in controlling the major weeds and reducing the competition for the applied nutrients thereby making them available for crop growth. Enhanced nutrient availability due to the control of weeds was reported earlier by Yadav (2006), Dayaram (2013) and Sasna (2014).

Effect on nutrient uptake by crop

Nutrient uptake by crop is a function of nutrient content in dry matter and the dry matter production. Nutrient content is related to the photosynthetic activity of leaves, because the essential nutrients *viz*., N, P and K are directly and indirectly involved in photosynthesis and respiration. A linear relationship exists between nutrient absorbed by the plant and the grain yield or economic produce (Ramamoorthy et al., 1967).

Weed management treatments significantly influenced the N uptake by crop at harvest stage. During *Kharif* season, at harvest stage, penoxsulam + cyhalofop butyl at 125 g ha^{-1} recorded the highest N uptake and during *Rabi* season, its higher dose (135 g ha^{-1}) recorded the highest uptake. This was due to high nitrogen content and DMP registered in these treatments (Table 3). Increased availability of N (Table 2) in these treatments resulted in better uptake of N. Since, nutrient uptake is partly a function of dry matter production and concentration of nutrients in the plant, increased N content and

Table 2. Effect of herbicide mixtures on nutrient availability and uptake in direct seeded rice at harvest stage (*Kharif* 2014 and *Rabi*, 2014-15)

Treatments	N availability, kg ha^{-1}		N uptake, kg ha^{-1}		P availability, kg ha^{-1}		P uptake, kg ha^{-1}		K availability, kg ha^{-1}		K uptake, kg ha^{-1}	
	Kharif 2014	*Rabi 2014-15*	*Kharif 2014*	*Rabi 2014-15*	*Kharif 2014*	*Rabi 2014-15*	*Kharif 2014*	*Rabi* 2014-15	*Kharif 2014*	*Rabi* 2014-15	*Kharif 2014*	*Rabi* 2014-15
Bispyribac sodium + metamifop 60 g ha^{-1}	238.34	221.61	203.98	199.80	17.32	19.04	15.89	16.38	189.54	191.75	150.00	156.91
Bispyribac sodium + metamifop 70 g ha^{-1}	282.24	234.16	236.06	222.94	19.75	27.56	17.95	24.08	206.19	215.06	156.65	153.47
Bispyribac sodium + metamifop 80 g ha^{-1}	269.70	238.34	241.09	239.05	18.37	19.54	17.59	18.55	195.47	208.55	157.61	174.35
Bispyribac sodium + metamifop 90 g ha^{-1}	269.70	242.52	232.48	243.97	18.80	22.07	18.11	16.60	198.02	233.86	157.14	164.38
Penoxsulam + cyhalofop butyl 120 g ha^{-1}	244.61	250.88	231.98	235.07	21.87	34.30	17.48	24.19	196.90	197.34	152.63	169.32
Penoxsulam + cyhalofop butyl 125 g ha^{-1}	288.51	255.10	248.34	246.53	22.68	24.60	18.73	23.96	202.83	218.18	158.05	171.27
Penoxsulam + cyhalofop butyl 130 g ha^{-1}	282.24	259.24	242.92	249.53	23.01	23.19	19.10	18.97	219.56	215.72	163.24	169.51
Penoxsulam + cyhalofop butyl 135 g ha^{-1}	271.79	271.79	233.19	254.11	20.83	25.87	19.09	25.40	218.74	260.96	162.55	166.05
Bispyribac sodium 25 g ha^{-1}	269.70	221.61	208.95	205.81	17.16	18.55	16.18	17.78	184.02	195.67	157.02	144.77
Penoxsulam 22.5 g ha^{-1}	305.17	234.15	234.81	228.53	18.06	28.11	17.73	26.26	223.03	212.28	156.47	146.59
Hand weeding 20 and 40 DAS	280.15	255.06	235.91	224.63	18.77	23.57	18.52	23.44	190.40	195.22	152.64	151.11
Weedy check	227.86	200.70	152.07	138.60	15.34	15.67	12.03	13.08	165.87	173.94	104.94	121.11
SEm (±)	5.262	7.995	2.886	5.677	0.779	1.986	0.800	1.459	2.899	3.357	2.851	7.512
CD (0.05)	22.985	23.450	8.463	16.651	2.283	5.824	2.347	4.281	8.504	9.846	8.361	22.031

dry matter accumulation in the plant parts increased the N uptake. The lowest N uptake by weedy check at all stages of crop growth might be due to severe competition for growth factors. This result is in agreement with the findings of Nath et al. (2014).

Similarly, P uptake by the crop was also significantly influenced by the weed management treatments during both the seasons. Better control of weeds resulted by the application of herbicides and manual weeding in the weed management treatments, minimized the crop weed competition and enhanced the P availability and uptake. Similar observations were also made by Babar and Velayutham (2012) and Kumar et al. (2010). P uptake by crop at harvest stage revealed that, penoxsulam + cyhalofop butyl @130 g ha^{-1} and penoxsulam applied alone @ 22.5 g ha^{-1} recorded the highest P uptake during *Kharif* and *Rabi* seasons, respectively (Table 2). The increased P availability (Table 2) in these treatments might have resulted in greater P content and crop uptake. Mali et al. (2015) reported that, the P uptake by crop largely depends on dry matter accumulation and concentration of P in the plant parts at cellular level and availability of P in the soil.

Similar to N and P uptake by crop, K uptake was also significantly influenced by the weed management treatments. All the weed management treatments registered higher uptake of K by the crop than weedy check (Table 2). This was due to the enhanced availability of soil K and better expression of growth attributes by the crop, resulting from the better control of weeds. Similar findings have also been reported by several researchers (Ramamoorthy et al., 1998; Payman and Singh, 2008; Gowda et al., 2009). At harvest stage, penoxsulam + cyhalofop butyl at 130 g ha^{-1} and bispyribac sodium + metamifop at 80 g ha^{-1} recorded the highest uptake during *Kharif* and *Rabi* seasons, respectively. The highest uptake of K in these treatments is a direct reflection of high K content as well as high dry matter accumulation in the crop (Table 3).

Effect on grain yield

Grain yield was significantly influenced by the weed management treatments during both the seasons (Table 3). Grain yield is the final product of growth and development, which is controlled by the dry matter production during the grain formation and grain filling stages. Herbicide mixtures tested in this study significantly enhanced the grain yield as compared to weedy check during both the seasons (Table 3). Phuong et al. (2005) reported that any reduction in weed pressure can be expected to promote yield, as it reduces the competition for resources. The weed management practices enhanced the grain yield from 4285 to 8295 kg ha^{-1} during *Kharif* season and from 4240 to 8889 kg ha^{-1} during *Rabi* season. Season long weed competition caused 40.33 to 48.34 per cent reduction in yield during *Kharif* season and the magnitude of yield reduction in *Rabi* season ranged from 42.59 to 52.30 per cent. Penoxsulam + cyhalofop butyl 130 g ha^{-1} recorded the highest grain yield but it was statistically on par with its lower doses (130 and 125 g ha^{-1}) during *Kharif* season. The higher dose of bispyribac sodium + metamifop at 90 g ha^{-1} was statistically on par with penoxsulam + cyhalofop butyl at 125 and 135 g ha^{-1}. However, during *Rabi* season, penoxsulam + cyhalofop butyl at 135 g ha^{-1} recorded significantly higher grain yield compared to other treatments. Among the different doses of bispyribac sodium + metamifop tested, its higher doses, (80 and 90 g ha^{-1}) recorded better yield than its lower doses. The increased grain yield recorded in these treatments might be due to the better expression of growth and yield attributes resulting from the better control of weeds and enhanced uptake of nutrients (Tables 1 and 2). Higher availability and uptake of nutrients at critical stages of crop growth ultimately led to higher grain yield. Yadav and Singh (1997) pointed out that higher uptake of nutrients resulted in higher grain yield. Ramachandra et al. (2015) reported that application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} at 15 days after transplanting (DAT) recorded higher grain yield (6640 kg ha^{-1}) than hand weeding (6266 kg ha^{-1}) in transplanted rice. The superiority of tank mix applications of herbicides in increasing the grain yield over individual application of herbicides has also been demonstrated earlier by Kumavat et al. (1998). Weedy check recorded significantly lower grain yield during both the seasons might be due to greater depletion of nutrients by weeds at the critical stages of crop

Table 3. Effect of herbicide mixtures on dry matter production and grain yield in direct seeded rice (*Kharif* 2014 and *Rabi* 2014-15)

Treatments	Dry matter production at harvest, kg ha^{-1}		Grain Yield, kg ha^{-1}	
	Kharif, 2014	*Rabi*, 2014-15	*Kharif*, 2014	*Rabi*, 2014-15
Bispyribac sodium + metamifop 60 g ha^{-1}	14730	14248	7441	7385
Bispyribac sodium + metamifop 70 g ha^{-1}	14931	14871	7643	8273
Bispyribac sodium + metamifop 80 g ha^{-1}	15028	15198	7620	8373
Bispyribac sodium + metamifop 90 g ha^{-1}	15104	15220	7659	8442
Penoxsulam + cyhalofop butyl 120 g ha^{-1}	15189	15234	7441	8273
Penoxsulam + cyhalofop butyl 125 g ha^{-1}	15246	15313	8017	8473
Penoxsulam + cyhalofop butyl 130 g ha^{-1}	15702	15657	8295	8547
Penoxsulam + cyhalofop butyl 135 g ha^{-1}	15281	16029	8037	8889
Bispyribac sodium 25 g ha^{-1}	14152	14482	7181	7724
Penoxsulam 22.5 g ha^{-1}	15187	15121	7629	7997
Hand weeding 20 and 40 DAS	15426	14546	7698	8171
Weedy check	12685	10467	4285	4240
SEm (±)	164.80	200.08	133.1	115.7
CD (0.05)	483.38	587.67	390.2	339.3

growth resulting in poor expression of yield attributes. This result is in conformity with the findings of Mohan et al. (2010), Raj et al. (2013a), Mallikarjun et al. (2014) and Jacob et al. (2014).

It is evident from the results that among the treatments, penoxsulam + cyhalofop butyl @ 135g ha^{-1} exhibited better efficacy in weed control, reduction in nutrient depletion by weeds and recorded higher grain yield. Among the different doses of bispyribac sodium + metamifop, its higher dose (90 g ha^{-1}) recorded lower total weed density and weed dry matter and lower uptake of nutrient by weeds. Effective control of weeds by the application of herbicides resulting in better availability of nutrients and nutrient uptake by crop. However, availability N, P and K in the soil and their utilization by the crop were found to be more in penoxsulam + cyhalofop butyl at 135,130 and 125 g ha^{-1} than bispyribac sodium + metamifop at 90, 80 and 70 g ha^{-1} and recorded comparatively higher grain yield. Hence, post emergence application of penoxsulam + cyhalofop butyl at 135 and 130 g ha^{-1} on 15 DAS can be recommended for the broad-spectrum control of weeds, better availability and uptake of nutrients by crop and higher grain yield in direct seeded puddled rice.

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