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EFFICACY OF HERBICIDES AND THEIR COMBINATION IN *CYPERUS*-DOMINATED *RABI* MAIZE (*ZEA MAYS* L.)

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ABSTRACT
A field experiment was conducted during winter (*rabi*) season of 2012-13 at the Research Farm, Tirhut College of Agriculture, R.A.U., Pusa, Bihar to determine the efficacy of halosulfuron methyl as POE in sole or in combination with different pre-emergence herbicides (atrazine and carfentrazone) on weed dynamics in maize in randomized block design with three replications and thirteen treatments. The results showed that the most effective treatment in controlling weed, reducing weed dry biomass and increasing maize grain yield was the weed-free treatment (97.71% reduction in weed biomass and 140.87% increase in grain yield) followed by carfentrazone 20 g a.i. ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g a.i. ha^{-1} at 30 DAS (88.22% reduction in weed biomass and 139.76% increase in grain yield) as compared to weedy check. Moreover, the sole application of halosulfuron methyl 135 g a.i. ha^{-1} at 30 DAS significantly controlled the *Cyperus* weeds (95.16% mortality) as against that of weed-free (98.83% mortality). This is an indication of the reliability and promise as well as the exhibition of the great potential of the halosulfuron in combination for the effective control of the *Cyperus* weeds and enhancing yield of maize.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in the world after rice and wheat. Being a wide space crop, it offers an opportunity to grow weeds in leftover spaces which come up along with the crop causing an intensive crop-weed competition resulting in poor crop yield. Weed control is of prime importance to save the wasteful losses of plant food nutrients, water, sunlight and finally the biological yield. The extent of losses caused by weeds depends on upon its density. The density of weed in maize crop has been found in the range of 28 to 100 per cent (Pandey *et al.*, 2001).

Nutsedge is described as one of the world's worst weed. Yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*) are troublesome perennial weeds. If nutsedge is left uncontrolled, they can significantly reduce stand establishment, yield and quality in maize, cotton and other field crops. Nutsedge can reduce yield substantially if allowed to compete with the crop during the first few weeks after planting, especially if the competition is great enough to cause moisture stress in crop seedlings. Purple nutsedge is capable of producing tubers three weeks after shoot emergence (Hauser, 1962) and a plant originating from one tuber can produce 99 tubers within three months (Rao, 1968). Purple nutsedge has been described as the world's worst weed due to its extensive distribution and ability to compete vigorously in all crops resulting in large losses of yield (Santos *et al.*, 1997). The research evidence suggests that the weedy environment beyond 30 days after sowing and up to 45 days after sowing was detrimental to maize crop and causes considerable yield losses (Prowal *et al.*, 2000). Herbicides have increasingly become a key component of weed management in India (Mallikarjun *et al.*, 2014) but there are no selective post-emergence (POE) herbicides and their combinations for proper controlling of sedges, grasses and broadleaf weeds in many of the crops. In maize crop, estimation of yield loss caused by weeds were reported to the tune of 77.7 per cent by grasses, 44.2 per cent by non-grassy and 38.4 per cent by sedges (Pandey and Ved, 2002) while Sen *et al*. (2000) reported that due to weed competition, yield losses occurred up to 15 to 75 per cent in maize crop.

Now, it is need of the hour to find out suitable weed control method to control the *Cyperus* weeds effectively. Hand hoeing is one of the best options which can control all weeds in maize field but *Cyperus* is perennial and develops as an underground mass or rhizome and tubers that make it difficult to control. Pre-emergence (PRE) use of atrazine and metribuzin were found effective to control most of the grassy and broadleaf weeds in the field of maize. Post-emergence (POE) application of 2,4-D is only herbicide which may control only broadleaf weeds. But sedges and some other weeds are not controlled by these herbicides. So, in order to control the population of *Cyperus* spp., there is a need to identify the new molecules of herbicides alone or in combination to achieve the effective control and also to obtain the optimum crop yields without damaging the crop plants. Hence, the present investigation was carried out with the objective to evaluate the efficacy of halosulfuron methyl as POE in sole application or in combination with different PRE-herbicides.

MATERIALS AND METHODS

A field experiment was conducted at the Research Farm, Tirhut College of Agriculture, a campus of Rajendra Agricultural University, Pusa, Bihar (52.18 m altitude, 25.98º N and 85.60º E) on maize *var*. Shaktiman-3 during winter (*rabi*) season of 2012-13 under irrigated conditions. The soil was calcareous alluvial in nature, sandy loam in texture, alkaline in reaction (pH 8.1), low in available N (210.00 kg ha^{-1}) and available P (16.71 kg ha^{-1}), and medium in available K (121.50 kg ha^{-1}). The experimental design was randomized block design replicated thrice with 13 treatments (Table 1). The crop was sown in furrows at a depth of 3-4 cm on 10th November 2012 with a seed rate 20 kg ha^{-1} and spacing 75 cm × 20 cm. The crop was fertilized with 120 kg N, 75 kg P_2O_5 and 40 kg K_2O ha^{-1} through urea, DAP and muriate of potash, respectively. Half of N and full of P_2O_5 and K_2O was applied at the time of sowing and remaining N was top dressed at 30 DAS. Spraying of herbicides was done with the help of manually operated knapsack sprayer fitted with flat fan nozzle by using a spray volume of 500 liters ha^{-1}. The crop was grown with the standard package of practices for the region. Observation on weeds parameters was made at 60 DAS while the data on growth and yield parameters were recorded at harvest. The statistical analysis of data was done using SAS Windows Version 9.3.

Table 1: Treatment details

Treatments	
T_1	Halosulfuron methyl 52.5 g *a.i.* ha^{-1} at 30 DAS
T_2	Halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS
T_3	Halosulfuron methyl 82.5g *a.i.* ha^{-1} at 30 DAS
T_4	Halosulfuron methyl 135 g *a.i.* ha^{-1} at 30 DAS
T_5	2,4-D 900 g *a.i.* ha^{-1} at 30 DAS
T_6	Atrazine 500 g *a.i.* ha^{-1} at 1 DAS
T_7	Atrazine 250 g *a.i.* ha^{-1} at 30 DAS
T_8	Atrazine 500 g *a.i.* ha^{-1} at 1 DAS + Halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS
T_9	Atrazine 250 g *a.i.* ha^{-1} at 1 DAS + Halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS
T_{10}	Carfentrazone 20 g *a.i.* ha^{-1} at 30 DAS
T_{11}	Carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + Halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS
T_{12}	Weed-free check (HW at 30, 60 and 90 DAS)
T_{13}	Weedy check

RESULTS AND DISCUSSION

Effect on weeds

Cyperus rotundus among the sedges, *Cynodon dactylon* among the grasses and *Chenopodium album, Croton spp., Cannabis sativa, Parthenium hysterophorus* among the broad leaves (BLWs) were the main weed present in the field, though *Cyperus rotundus* (79.49%) was most pre-dominant weed followed by broad leaf and grassy weeds (13.34%).

Sedges

The data regarding sedge weeds (Table 2) revealed that weed density was significantly affected by all the treatments over weedy check and the lowest population (2.75 m^{-2}) was recorded under weed-free (98.83% reduction in sedge population). Among the herbicidal treatments, the maximum reduction in *C. rotundus* population was recorded under the application of halosulfuron methyl in all doses alone or with combination, which were found to be significantly higher than remaining treatments. Halosulfuron methyl 135.0 g ha^{-1} at 30 DAS provided the highest mortality of *C. rotundus*(95.16%) and was at par with carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (94.16%), atrazine 500 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (94.07%), atrazine 250 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (93.57%); and was followed by the lower doses of halosulfuron *i.*e. 82.5, 67.5and 52.5 g *a.i.* ha^{-1} (93.49, 93.32 and 93.16%, respectively). Similar results about that all weed control practices decreased the weed density over weedy check have been reported by Arnold *et al*. (2005) and James *et al*. (2006).

Grasses

All the weed control treatments significantly reduced the grassy weed population over weedy check (Table 2). The weed-free recorded the highest control of grassy weeds (89.81%) followed by halosulfuron methyl 135.0 g *a.i.* ha^{-1} at 30 DAS (31.48%); carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (29.63%) and the lower doses of halosulfuron methyl. Most of the herbicidal treatments recorded lesser population of grasses over weedy check but the differences among various herbicidal treatments were non-significant.

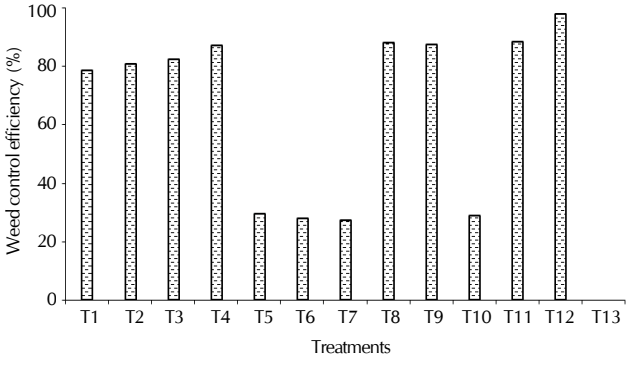

Figure 1: Weed control efficiency (%) as affected by different weed control treatments

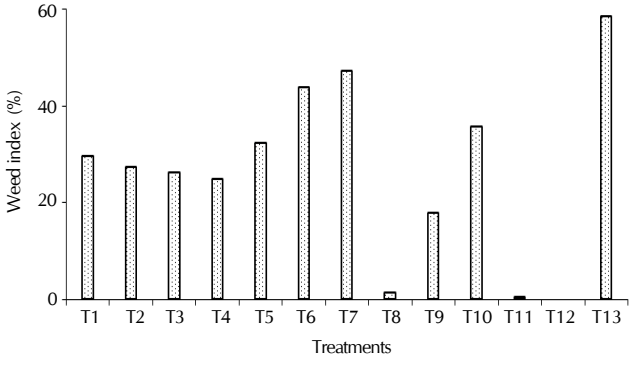

Figure 2: Weed index (%) as affected by different weed control treatments

Table 2: Mortality of weeds in *Rabi* maize as affected by different weed control treatments

Treatments	Weed density at 60 DAS						Weed Dry Biomass at 60 DAS
	Sedges	Mortality %	Grasses	Mortality %	BLWs	Mortality %	(g m^{-2})
T_1	20.50	93.16	20.50	24.07	21.00	58.21	79.30
T_2	20.00	93.32	20.25	25.00	17.25	65.67	71.80
T_3	19.50	93.49	19.75	26.85	13.75	72.64	65.50
T_4	14.50	95.16	18.50	31.48	10.25	79.60	48.00
T_5	239.00	20.20	20.75	23.15	5.75	88.56	261.50
T_6	236.75	20.95	20.75	23.15	8.25	83.58	267.80
T_7	240.00	19.87	21.50	20.37	9.00	82.09	270.30
T_8	17.75	94.07	20.25	25.00	6.5	87.06	44.80
T_9	19.25	93.57	20.75	23.15	7.75	84.58	46.50
T_{10}	237.25	20.78	21.75	19.44	9.75	80.60	264.30
T_{11}	17.50	94.16	19.00	29.63	8.75	82.59	43.80
T_{12}	3.50	98.83	2.75	89.81	2.25	95.52	8.50
T_{13}	299.50	0.00	27.00	0.00	50.25	0.00	371.8
SEm ±	15.17	-	2.23	-	2.66	-	18.60
LSD (P = 0.05)	44.27	-	6.51	-	7.77	-	54.29

Table 3: Growth and yield parameters of *Rabi* maize as affected by different weed control treatments

Treatments	Plant height at harvest (cm)	Grain yield (t ha^{-1})	% Increase over Check
T_1	165.60	5.66	69.58
T_2	166.30	5.85	75.15
T_3	166.60	5.93	77.57
T_4	167.20	6.05	81.05
T_5	164.10	5.44	62.99
T_6	161.90	4.53	35.51
T_7	161.60	4.25	27.16
T_8	174.20	7.93	137.40
T_9	167.70	6.61	98.02
T_{10}	162.60	5.17	54.67
T_{11}	179.00	8.01	139.76
T_{12}	179.30	8.05	140.87
T_{13}	139.90	3.34	0.00
SEm ±	4.10	0.24	-
LSD (P = 0.05)	11.81	0.69	-

Table 4: Phytotoxicity effect of herbicides on *Rabi* maize plants

Treatments	Mean observations recorded after 1, 3, 7 and15 days of application					
	Vein clearing	Necrosis	Wilting	Epinasty	Hyponasty	Stunting
T_1	0	0	0	0	0	0
T_2	0	0	0	0	0	0
T_3	0	0	0	0	0	0
T_4	0	0	0	0	0	0
T_5	0	0	0	0	0	0
T_6	0	0	0	0	0	0
T_7	0	0	0	0	0	0
T_8	0	0	0	0	0	0
T_9	0	0	0	0	0	0
T_{10}	0	0	0	0	0	0
T_{11}	0	0	0	0	0	0
T_{12}	0	0	0	0	0	0
T_{13}	0	0	0	0	0	0

Broadleaf weeds

A perusal of the data regarding BLWs revealed that the weed density was significantly reduced by all the treatments over weedy check (Table 2). Weed-free check recorded lowest BLWs population (2.25 m^{-2}) with mortality percentage of 95.52% over weedy check. Among the herbicidal treatments, 2,4-D 900 g *a.i.* ha^{-1} at 30 DAS provided highest mortality of BLWs (88.56%) and was at par with atrazine 500 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (87.06%); atrazine 250 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (84.58%); atrazine 500 g *a.i.* ha^{-1} at 1 DAS (83.58%); carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (82.59%); atrazine 250 g *a.i.* ha^{-1} at 30 DAS (82.09%); and halosulfuron

methyl 135.0 g *a.i.* ha^{-1} at 30 DAS (79.60%). This result is supported by the findings of Rehman *et al*. (1998) who reported the largest reduction in weed population (sedges and broad leaf weeds) when halosulfuron was applied as POE along with atrazine as PRE in the field of maize crop.

Weed dry biomass and weed control efficiency

The results from Table 2 and Figure 1 revealed that all the weed control treatments recorded significantly lower weed dry biomass than the weedy check. The weed-free treatment recorded highest percentage of reduction in weed biomass (97.71%) over weedy check and was at par with carfentrazone 20 g *a.i.* ha^{-1}at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1}at 30 DAS (88.22%), atrazine 500 g *a.i.* ha^{-1}at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (87.95%), atrazine 250 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (87.49%) and halosulfuron methyl 135 g *a.i.* ha^{-1} at 30 DAS (87.09%) and was followed by lower doses of halosulfuron (82.5, 67.5 and 52.5 g *a.i.* ha^{-1}) when applied at 30 DAS. Halosulfuron methyl is systemic in nature and comes under sulfonylurea herbicides group. It severally damages the foliage of *Cyperus* and reduces its population and ground cover. The recently released sulfonylurea herbicide, halosulfuron, has shown good activity against purple nutsedge following soil and/or foliar applications (Suzuki *et al*., 1991; Vencill *et al*., 1995).

Weed index

The result from Figure 2 revealed that lowest weed index was noticed with the weed-free treatment. Among the herbicidal treatments, carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS recorded the lowest weed index (0.50%) followed by atrazine 500 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (1.49%) and both the treatments were superior over other PRE- and POE-herbicidal treatments when applied either alone or in combination.

Phytotoxicity observations

Application of the various kinds of herbicide *viz*. pre-emergence and post-emergence herbicides did not show any kind of phytotoxicity symptoms like leaf epinasty and hyponasty, stunting, vein clearing, wilting and necrosis on the maize plants throughout the observation period (Table 4). This result showed that there was no phytotoxic effect of any of the herbicides when they are applied as alone or in combination.

Growth and yield parameters

Plant height

Plant height reflects the efficiency of the plant for photosynthetic radiation interception and vegetative growth character of crop plants in response to various applied inputs. Data obtained on plant height at harvest (Table 3) showed that all the treatments recorded significantly taller plants than the weedy check. Weed-free treatment recorded maximum plant height (179.30 cm), however, was statistically similar to carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (179.00 cm), atrazine 500 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (174.20 cm) and atrazine 250 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (167.70 cm); and was followed by halosulfuron methyl 135 g *a.i.* ha^{-1} at 30 DAS (167.20 cm). Variation in plant height of maize in all weed control treatments could be attributed to varying effect of weed competition duration for available resources offered by different weed densities in different weed control practices. This result is in line with Kumar *et al*. (2016), who stated maximum plant height was in weed control plots, which might be due to lower weed infestation for longer period of time.

Grain yield

Grain yield is a function of the cumulative behaviour among various yield determining components namely the number of cobs per plants, cob length, number of grains per cob and 1000-grain weight which showed variations by prevailing growing conditions and various crop management practices. The significantly maximum grain yield of 8.05 t ha^{-1} with weed-free treatment (148.87% increase in yield over check); and was statistically at par with carfentrazone 20 g *a.i.* ha^{-1} at 28 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (8.01 t ha^{-1} and 139.76% increase in yield), atrazine 500 g *a.i.* ha^{-1} at 1 DAS + halosulfuron methyl 67.5 g *a.i.* ha^{-1} at 30 DAS (7.93 t ha^{-1} and 137.40% increase in yield). The statistically minimum grain yield was obtained in weedy check plots (3.34 t ha^{-1}) as compared to all other treatments during the investigation (Table 3). The lowest grain yield was recorded in weedy check could be attributed to maximum weed density which suppressed the growth and development of maize plants by competing for moisture, light and nutrients. The efficiency of various chemicals and other weed control practices in enhancing grain yield had also been observed by Stefanovic *et al*. (2004); and Singh and Paikra (2014).

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