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Weed Dynamics in Maize (*Zea mays* L.) as Influenced by Pre and Post-emergence Herbicides under Temperate Conditions of Western Himalayan Region

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Authors' contributions

This work was carried out in collaboration among all authors. Author FuR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MIB, ZAD and SAH managed the analyses of the study. Authors SN, SB, SuN, SM and ZR managed the literature searches. Authors SI, BAL, AH and SK managed the editing and inserting the corrections of gallery proof. All authors read and approved the final manuscript.

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ABSTRACT

Field experiments were conducted in 2017-18 during main cropping seasons of the year 2017 and 2018 at Dryland *(Karewa)* Agriculture Research Station, SKUAST-K to determine the effect of different post and pre emergence herbicides application on weed dynamics in maize (*Zea mays* L.). The experiment was laid out in randomized block design with four replications and variety used was Bio-605. Five treatments Five treatments *viz,* Atrazine 50% WP @ 1.0 kg ha^{-1} as pre-emergence

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and Paraquat dichloride 24% SL @ 0.5 kg ha^{-1}, 2,4-D sodium salt 58% WSC @ 1.0 kg ha^{-1} as post-emergence herbicides (application at 2-3 leaf stage of weeds), hand weeding as standard check and weedy check as control were used. Effect of different herbicides on weed density was found significant. in plots managed with hand weeding, no weed was recorded. The Atrazine treated plots @ 1.0 kg *ai* ha^{-1} as pre-emergence had the weed population of 5.51, 5.4, 3.73, 5.12, 4.28 and 41.4m^{-2}, respectively in *Echinochloa spp., Eleusine indica, Digitaria sanguinalis, Amaranthus viridis, Sorghum halepense and Cyperus spp.* However, the maximum population of weeds was recorded in weedy check with 21.54 m^{-2}, 20.87 m^{-2}, 19.16 m^{-2}, 21.5 m^{-2}, 16.7 m^{-2} and 60.7 m^{-2}. No significant difference was observed between Paraquat dichloride 24% SL @ 0.5 kg *ai* ha^{-1} and 2,4- D Sodium salt 58% WSC @ 1.0 kg *ai* ha^{-1} except for *Cyperus spp.* with density of 51.37 m^{-2} and 43.04 m^{-2} respectively. The potential of the atrazine in controlling weeds thereby enhancing yield of maize was found in this study.

Keywords: Atrazine; paraquat dichloride; 2,4-D Sodium salt; Zea mays; yield.

1. INTRODUCTION

Maize is widely cultivated throughout the world and is produced each year than any other grain. It is cultivated on an area of 161.82 million hectares in the world with production of 844.36 million tonnes and productivity of 5.22 tonnes ha^{-1} [1]. Maize is the third most important food crop, after rice and wheat, in India. It is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions in India. Maize is of immense importance among India's cereal crops, covering more than 9.0 million hectares and contributing over 24.0 million tonnes annually to the nation's grain supply [2]. Hence it is considered as a promising option for diversifying agriculture for the North Indian states of the country, under which there is a plan to divert around 1.2 million hectares from water-guzzling paddy in the next five to seven years. The low productivity of maize in India, as compared to other maize growing countries of the world, can be attributed to several limiting factors, of which weeds have been one of the major factors responsible for reducing the yield by 27-60% depending upon the persistence of weed population in maize crop [3,4].

Weeds compete for all the resources, namely nutrients, water, sunlight, and space during the entire growth stages of maize. Their relative density also plays a significant role in reducing the yield of the crop. Being a more extensive row spaced crop coupled with frequent rains in the month of July and August in this region, weeds inflict yield losses up to 68.9% [5], by 27-60%, depending upon the growth and persistence of weed population in maize crop [3,6]. Maize is infested with a variety of weed flora including annual and perennial grasses, sedges and broadleaf weeds. The critical period of crop-weed competition started at 30 days after sowing and ended at 60 days after sowing of spring maize in North India [7]. Weeds emerging later or which escapes these herbicides, compete with the crop and inflict heavy losses in grain yield.

Atrazine is commonly used by the farmers for weed control in this crop worldwide. Being a pre-emergence herbicide, it is not effective against some of the weeds, both grass, and broadleaf weeds as well as the sedge *Cyperus rotundus*. Due to a shortage of labour, sometimes farmers skip the application of pre-emergent herbicides, they are left with no other alternative to control the weeds emerging during later stages. Atrazine as the pre-emergence application was the primary weapon to control weeds in maize, but for complex weed flora, it needs to be applied in herbicide mixtures [8,5]. Weed infestation is of supreme importance among biotic factors that are responsible for low grain yield of maize. Dominant weed species present in the experimental site were *Echinochloa spp., Eleusine indica, Digitaria sanguinalis, Amaranthus viridis, Sorghum halepense, Cyperus spp.* [9,10]. Worldwide maize production is hampered up to 40% by competition from weeds which are the most important pest group of this crop [11]. Generally weeds reduce crop yields by competing for light, nutrients, water and carbon dioxide as well as interfering with harvesting and increasing the cost involved in crop production. Overall, weeds impose the highest loss potential of 37%, which is higher than the loss potentials due to insect pests (18%), fungal and bacterial pathogens (16%) and viruses (2%) [12]. Weed species not controlled by atrazine is increasing in the maize-growing areas of India, especially, where the farmers are using atrazine year after year. So, it is imperative

to test the efficacy of post-emergence herbicides having a different mode of action than atrazine in maize.

Weeds have a more direct influence on human beings than any other pest in developing countries like India. Weeds not only cause severe crop losses but also compete with farmers and their families to spend a considerable amount of their time on weeding. More than 50% of labour is devoted to weeding, and is mainly done by the women and children in the farmer's family. Control of weeds in the fields of maize is, therefore, very essential for obtaining good crop-harvest. Weed control practices in maize resulted in 77 to 96.7% higher grain yield than the weedy check [13].

Different weed control methods have been used to manage the weeds but mechanical and chemical methods are more frequently used for the control of weeds. Mechanical methods including hand weeding are still useful but are more expensive, laborious and time-consuming. In the less developed countries, the situation still exists where the peak labor requirement is often for hand weeding [14]. Herbicides weed control is an important alternative to manual weeding because it is cheaper, faster and gives better weed control [12]. Weed control in maize with herbicides has been suggested by researches of [15,16,17]. However, continuous application of currently registered herbicides caused changing weed flora, poor controlling, and evolution of some herbicide resistant weed biotypes. This necessitates the introduction of some other new herbicide options with different modes of action. Therefore, this research work was carried out to evaluate the effect of herbicide (Atrazine; Paraquat dichloride; 2,4-D Sodium salt) on weeds and yield of maize under field condition at DARS, SKUAST-K, India.

2. MATERIALS AND METHODS

Field studies were conducted during *kharif* seasons of 2017 and 2018 at DARS, SKUAST-K. The physico-chemical properties of the soil in experimental field was silt clay in texture with sand, clay and silt percentage of 9.5% , 27.9% and 62.6% respectively. The bulk density of the field was 1.48 g cc^{-1}, moisture content 15.6% and medium water holding capacity with the value of 34.0%. As for as chemical properties of the experimental unit, the soil was having medium fertility status with pH: 7.2, electrical conductivity: 0.15 dS m^{-1}, organic carbon: 0.38%, available nitrogen: 480.2 kg ha^{-1} available phosphorus: 9.5 kg ha^{-1}, and available potash: 202.4 kg ha^{-1}. The crop was grown under *rainfed* conditions. The experimental site is situated in the temperate belt of J&K with the moderately hot summer and long cold winter.

The details of the climatic condition such as temperature, rainfall, relative humidity and sunshine hours day^{-1} pertaining to the period of experimentation (April to September) as observed and recorded from the meteorological observatory, Rambagh Srinagar is depicted below. The average minimum temperature ranged from 11.95^0C to 25.42^0C over two years (2017-18). The temperature range during the cropping season was more or less normal. The total rainfall received during the experiment season of April to September during 2017-18 was 315.4 mm. The maximum rainfall was 84.5 mm and 63.4 mm during April & June months in two years respectively. The monthly average relative humidity during the crop growing period of two years varied from 57.15% to 81.01%.

2.1 Treatment Details

The treatment for the experiment were hand weeding which was done manually, application of pre-emergence atrazine 50% WP @ 1.0 kg *a.i* ha^{-1}, post-emergence herbicide application of paraquat dichloride 24% SL @ 0.5 kg *a.i* ha^{-1}, 2,4-D- Sodium salt 58% WSC @ 1.0 kg *a.i* ha^{-1} and weedy check. The experiment was laid-out in a randomised block design with four replications.

2.2 Land Preparation

At optimum moisture condition, the land was first ploughed thoroughly cross wise for two times with tractor drawn harrow and final land preparation with mould board plough for obtaining good tilth followed by planking. After that, the clods and all stubbles of previous crops were removed from the land. After levelling, the field was laid out properly by making bund in each channel for irrigation as well as drainage.

2.3 Seed Treatment

The maize seed was treated with Captan 50 WP along with Imidachlorpid @ 2-4 g kg^{-1} seed.

Table 1. Meteorological data during the experimental period (Averaged over two years 2017-18)

Month	Total rainfall (mm)	Temperature (^{0}C)		Sunshine hours (mean day^{-1})	Relative humidity (%)	
		Min.	Max.		Min.	Max.
Apr-17-18	84.5	7.54	18.42	5.92	52.27	82.24
May-17-18	52.3	8.65	25.85	8.56	59.16	78.92
Jun-17-18	63.4	11.75	25.25	7.20	58.64	76.45
Jul-17-18	47.5	19.20	29.07	6.75	65.22	81.85
Aug-17-18	31.3	18.52	30.86	7.32	54.63	80.85
Sep-1718	24.2	11.32	26.34	7.62	53.72	82.35
Oct-17-18	12.2	6.70	22.17	6.72	56.45	84.45
Total / Average	315.4	11.95	25.42	7.15	57.15	81.01

Source: METEOROLOGICAL DEPARTMENT, Rambagh Srinagar

2.4 Sowing

Maize hybrid Bio-605 was sown with a seed rate 20 kg ha^{-1} on 20th of April, 2017 & 16th of April, 2018 with spacing 60 cm x 20 cm, seeding depth was 3-5 cm (approx).

2.5 Application of Manures & Fertilizers

Well decomposed organic manure was applied in the entire field area at the time of final land preparation. The fertilizers were applied @ 150:75:40:20 kg of N:P_2O_5:K_2O:Zn ha^{-1} respectively as recommended dose. The sources of fertilizers were urea for N; Single super phosphate (SSP) for P; Muriate of potash (MOP) for K and Zinc sulphate for Zn. During the land preparation, in maize crop ½ of total N and full dose of P_2O_5; K_2O; Zn were applied to the crop as basal application. The remaining ½ N was top dressed.

2.6 Selection of Site

The experiment was conducted on *karewa* land under *rainfed* ecology. The selected site had moderate weed infestation.

2.7 Method of Spraying of Herbicide

The herbicide atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} was applied at 3 days after sowing during both the years using Knapsack sprayer fitted with Flat fan Nozzle and water volume of 600 litres ha^{-1}. However in case of post emergence herbicides were directly applied towards the target weeds. At the time of herbicide application, the soil had sufficient moisture for good herbicidal activity.

2.8 Weed Population

Five places were selected at random and marked with pegs in each plot. Weed counts were recorded (species wise) using 1m×1m quadrant in the peg marked areas and computed to number of weeds per square meter**.** Observations on weed species from a composite sample (Collected from 5 different spots in the experimental area) were recorded. Weed population was recorded species wise at 45 days after application (DAA) during the experimental period.

2.9 Weed dry Matter Production

During both the years weed biomass was harvested from each quadrate. The harvested weeds were placed into paper bags separately and drying in oven at a 60^{0}C temperature for 24 hours till constant weight was achieved and subsequently the dry weight was measured and converted in to g m^{-2}.

2.10 Weed Control Efficiency

The weed control efficiency (WCE) was calculated based on weed dry weight recorded at 45 DAA using the following formula.

$$WCE\ (\%) = \frac{DMC - DMT}{DMC} \times 100$$

Where, DMC =Dry matter of weeds in control plot and
DMT = Dry matter of weeds in treated plot

2.11 Plant Height

Plant height was measured in centimetres (cm) from eight randomly selected (pre tagged) plants at the middle four rows, from the ground level to the apex of each plant at dough stage of the plant.

2.12 Number of Cobs Plant^{-1}

The number of productive cobs was counted in each sample plants. Eight randomly selected tagged plants from the four central rows were used for counting productive.

2.13 Ear/cob Diameter

The diameter was measured in centimetres (cm) from eight randomly taken ears at midpoint of cob using calliper and the averages were recorded.

2.14 Test Weight

Thousand kernels were counted from each plot and their weight (g) was recorded and adjusted to 12.5% moisture content.

2.15 Grain Yield

The grain yields of maize were recorded plot wise and further converted to quintals per hectare (q ha^{1}) after proper drying at 16% and threshing.

2.16 Statistical Analysis

Population density and dry matter production of weeds data was subjected to square root transformation $\sqrt{X + 0.5}$ in order to have normally distributed data. Mean separation was conducted for significant treatment means using least significance differences at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Weed Density/ Population

The weed flora infesting the maize field were *Echinochloa colona*, *Portulaca oleraceaes, Cynodon dactylon, Digitaria sanguinalis, Eleusine indica, Xanthium, strumarium, Cyperus spp., Amaranthus viridis, Sorghum halepense, Chenopodium album, Polygonum spp,.* The average weed population of grasses was more in comparison to broad-leaved weed species, while weedy check recorded more number of sedges as compared to grasses and broad-leaved weeds. The weed count showed that herbicide atrazine 50% WP @ 1.0 kg ha^{-1} was significantly premium to control broad-leaved weeds and grasses as against other herbicides (Table 2). The results indicate the highest weed density in weedy check plots compared to other treatments. However, the lowest population was observed in the hand weeded plot. The results are in conformity with [18] who found that highest weed density in weedy check.

3.2 Weed Dry Matter Production

The weed dry matter (Table 3) showed that atrazine 50% WP at 1.5 kg ha^{-1}dose was able to control broad-leaved and grasses weeds very effectively. Better efficacy was obtained by the herbicide as against control plot which showed the maximum weed dry matter of the grassy and broad-leaved weeds. The highest weed dry weight m^{-2} for all the weed species was observed in the control and the lowest was observed in the hand weeded plot. Among the herbicidal treatments, the weed dry matter significantly decreased with the application of atrazine compared to other treatments. Herbicides significantly reduced the weed intensity at all the stages of crop growth, hence dry matter production of weeds was low in treated plots. The results were in accordance with [18] who reported that herbicides reduced the weed infestation and control weeds well in the maize crop in comparison to the control plots.

3.3 Weed Control Efficiency (WCE)

At all the stages of crop growth during both the years, the highest weed control efficiency for the entire weed species were observed in the hand weeded plot. Among the herbicidal treatments, significantly paramount results were recorded with application of atrazine @ 1.0 kg ha^{-1} (Table 4). Since the herbicidal application reduced the weed dry mass as compared to the control this resulted in increased weed control efficiency. The results are in conformity with those of [19] who recorded similar findings in maize.

3.4 Maize Grain Yield

All the treatments resulted in significant increase in maize yield compared to weedy check. Among the herbicidal treatments, atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} as pre-emergence herbicide recorded significantly higher grain as well as stover yield but at par with paraquat dichloride 24% SL @ 0.5 kg. ha^{-1} in respect to stover yield of maize. Treatments paraquat dichloride 24% SL @ 0.5 kg. ha^{-1} and 2,4- D Sodium salt 58% WSC @ 1.0 kg a.i. ha^{-1} as post-emergence were statistically at par. Increase in maize yield may be attributed to effective control of weeds and

Table 2. Major weeds in maize and their density at 45 DAA (m^{-2}) pooled over two years

Treatments	Dosage (kg *a.i.* ha^{-1})	*Echinochloa spp.*	*Eleusine indica*	*Digitaria sanguinalis*	*Amaranthus viridis*	*Sorghum halepense*	*Cyperus spp.*
Hand weeding	-	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Atrazine 50 % WP	1.0	5.5 (9.0)	5.4 (8.3)	3.7 (4.8)	5.1(11.4)	4.2 (7.2)	4.5(41.4)
Paraquat dichloride 24 % SL	0.5	6.4 (8.8)	5.4 (6.1)	4.1 (11.3)	5.2 (9.7)	4.7(12.1)	6.3(44.4)
2,4- D Sodium salt 58% WSC	1.0	4.5(12.4)	4.1(9.0)	4.1(9.4)	3.8(4.2)	3.5(13.1)	5.1(49.0)
Weedy check	-	7.6(21.5)	9.4(20.8)	8.1(19.1)	8.6(21.5)	10.2(16.7)	5.5(43.9)
CD at 5%	-	0.98	0.89	0.81	0.72	0.68	0.98

Numbers within the parenthesis are original means

Table 3. Major weeds in maize and their dry matter (g m^{-2}) at 45 DAA pooled over two years

Treatments	Dosage (kg *a.i.* ha^{-1})	*Echinochloa spp.*	*Eleusine indica*	*Digitaria sanguinalis*	*Amaranthus viridis*	*Sorghum halepense*	*Cyperus spp.*
Hand weeding	-	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Atrazine 50% WP	1.0	3.6 (13.2)	4.4(17.1)	4.3(20.3)	3.6(15.5)	4.3(17.1)	5.7(36.6)
Paraquat dichloride 24% SL	0.5	3.8(11.5)	3.04(9.6)	2.8(7.4)	3.7(9.5)	2.8(6.4)	7.9(36.6)
2,4- D Sodium salt 58% WSC	1.0	4.2(12.3)	6.1(9.5)	3.3(8.3)	3.8(6.2)	5.3(8.2)	10(48.5)
Weedy check	-	5.2(19.5)	5.3(20.3)	5.9(21.4)	4.7(21.0)	4.6(19.2)	11.8(36.3)
CD at 5%	-	0.38	0.26	0.32	0.28	0.38	0.67

Numbers within the parenthesis are original means

Table 4. Weed control efficiency (%) at 45 DAA pooled over two years

Treatments	Dosage (kg *a.i.* ha^{-1})	*Echinochloa spp.*	*Eleusine indica*	*Digitaria sanguinalis*	*Amaranthus viridis*	*Sorghum halepense*	*Cyperus spp.*
Hand weeding	-	100.0	100.0	100.0	100.0	100.0	100.0
Atrazine 50% WP	1.0	83.10	82.20	83.16	79.58	75.52	2.84
Paraquat dichloride 24% SL	0.5	46.98	59.42	61.35	50.55	68.12	1.65
2,4- D Sodium salt 58% WSC	1.0	38.95	43.75	34.83	27.45	46.20	3.85
Weedy check	-	0	0	0	0	0	0
CD at 5%	-	0.28	0.16	0.18	0.15	0.14	2.17

Table 5. Grain and straw yield (q ha^{-1}) of maize as influenced by application of herbicides (pooled over two years)

Treatments	Dosage (kg *a.i.* ha^{-1})	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	% increase in Maize grain yield over control
Hand weeding	-	66.70	134.30	42.82
Atrazine 50 % WP	1.0	54.41	106.05	16.50
Paraquat dichloride 24 % SL	0.5	50.37	92.55	7.85
2,4- D Sodium salt 58% WSC	1.0	48.08	86.56	2.95
Weedy check	-	46.70	81.7	-
CD at 5%	-	3.54	14.68	-

marked improvement in crop growth and yield attributes [20]. The lowest yield (both grain and stover yield) was obtained in the control plot and highest in the hand weeded plot (Table 5). Higher yield in these treatments may be attributed to effective control of weeds during the early stages of crop growth and helped in better development of infrastructure of the plant. Due to less competition for the nutrients, radiation and water from weeds facilitated for the better growth and development of the crop. Improved grain yield with the application of herbicides in maize was also reported by [21,22,8].

4. CONCLUSION

It is concluded from the two years of experiment that atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} was found very effective in reducing the biomass of all categories of weeds and in improving the yield of maize crop as compared to Paraquat dichloride 24 % SL @ 0.5 kg *a.i.* ha^{-1} and 2,4- D Sodium salt 58% WSC @ 1.0 kg *a.i.* ha^{-1}.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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