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Weed management with pre- and post-emergence herbicides in maize under maize-greengram cropping system

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ABSTRACT

An experiment was conducted during the two consecutive years of winter, 2017-18, 2018-19 and summer, 2018 and 2019 at wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh, in a randomized block design with ten weed management treatments and three replications. The lowest weed density and biomass, highest weed control efficiency and maize growth parameters, yield attributes, kernel and straw yields were recorded with hand weeding (HW) twice at 15 and 30 days after seeding (DAS), which was statistically at par with atrazine 1.0 kg/ha as pre-emergence application (PE) followed by (*fb)* topramezone 30 g/ha or tembotrione 120 g/ha as post-emergence application (PoE) or one HW at 30 DAS. Higher greengram seed yield, haulm yield, and lower total weed density and biomass in succeeding greengram were noticed with HW twice at 15 and 30 DAS, which was comparable with atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS or topramezone 30 g/ha or tembotrione 120 g/ha or halosulfuron methyl 67.5 g/ha as PoE applied in maize. Based on this study it was concluded that atrazine 1.0 kg/ha as PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha as PoE can be used for the most effective weed management to increase the productivity in winter maize followed by summer greengram cropping system.

INTRODUCTION

Maize (*Zea mays* L.) is the third most economically important cereal crop after rice and wheat in India and is being used as food, feed and in the preparation of vast industrial products like starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, textiles, package and paper industries. Weed infestation is the major biotic stress responsible for the lower yield of maize in India (Rao *et al.* 2014, Rao and Chauhan 2015). Grain losses in maize varied between 28-100%, if weeds were not controlled during the critical stages of crop weed competition (Kumar *et al.* 2017) by competing for water, light, nutrients, space and other resources. Weeds also interfere with the harvesting process and ultimately increase the production cost. The critical period for weed control starts from four to six- leaf stage and may continue until ten leaf stage or flowering of maize (Gantoli *et al.* 2013). Hand weeding is most popular among the farmers for weed control but it is expensive, laborious and time-consuming. In India an acute shortage of labour occurs where the peak labour requirement is often for hand weeding. The application of herbicides for weed control is an important alternative to manual weeding because they are cheaper, faster and give better weed control. Usage of pre-emergence herbicides assumes greater importance in view of their effectiveness during initial stages. As the weeds interfere during aftercare operation and the harvesting of the crop, post-emergence or sequential use of herbicides may help in avoiding the problem of weeds at later stages. Some herbicides with residual effects may restrict the emergence and growth of succeeding crops in rotation. Hence, the present investigation was carried out to study the effect of sequential application of pre- and post-emergence herbicides on weeds and maize growth and yield and their residual effect in succeeding greengram.

MATERIALS AND METHODS

An experiment was conducted during two consecutive years of winter, 2017-18 and 2018-19 and summer, 2018 and 2019 at wetland farm of S.V. Agricultural College, Tirupati, which is geographically situated at 13.6°N latitude and 79.3°E longitude, at an altitude of 182.9 m above the mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh, India. The soil of the experimental site was sandy clay loam in texture, neutral in soil reaction, low in organic carbon (0.25%) and available nitrogen (174 kg/ha), medium in available phosphorus (20.5 kg/ha) and potassium (186 kg/ha). The experiment was conducted using a Randomized Block Design with ten treatments and was replicated thrice. Treatments include: atrazine 1.0 kg/ha pre-emergence application (PE) followed by (*fb)* one hand weeding (HW) at 30 days after seeding (DAS), atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha post-emergence application (PoE), atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, atrazine 1.0 kg/ ha PE *fb* 2,4-D amine salt 580 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of tembotrione 60 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of topramezone 15 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, hand weeding twice at 15 and 30 DAS and weedy check.

Maize hybrid '*DHM–117'* was sown at a spacing of 60 x 20 cm, on 19th November 2017 and 11th November 2018. After maize harvest, greengram variety '*IPM-02-14'* was sown in undisturbed layout of maize experimental plots as a succeeding crop after ploughing the maize field, at a spacing of 30 x 10 cm to study the residual effect of pre and post-emergence herbicides applied to maize on the weeds and greengram. Gross plot size of the experimental unit was 5.4 x 4. 6 m. Recommended doses of 240 kg N, 80 kg P and 80 kg K/ha for maize and 20 kg N and 50 kg of P/ ha for greengram was applied using urea, single super phosphate and muriate of potash to all the plots uniformly. The pre-emergence application of herbicide was done within 24 hours after sowing and post-emergence application of herbicide was done at 21 DAS of maize. Weeding was not done in greengram plots since the crop was raised to study the residual effect of herbicides applied to maize.

The weed population was counted with the help of 0.5 m^2 quadrat thrown randomly at two places in each plot and expressed as weed density (no./m^2). While recording weed density, weeds were harvested from each of the quadrat for estimating the weed biomass. Different weed species collected for assessing the density of weeds were dried separately in a hot air oven at 65ºC till constant dry weight was reached and expressed as weed biomass (g/m^2). Five randomly selected plants were tagged in each treatment, from each replication in the net plot area and used for making observations on yield attributes of maize and greengram. Due to large variation in values of weed density and biomass, the corresponding data was subjected to square root transformation $(\sqrt{x+0.5})$ and the corresponding transformed values were used for statistical analysis as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The predominant weed species in the experimental site were: *Brachiaria ramose* L., *Cynodon dactylon, Dactyloctenium aegyptium* (L.) Beauv, *Digitaria sanguinalis* (L.) Scop, amongst grasses, *Cyperus rotundus* L, a sedge and *Boerhavia erecta* L, *Borreria hispida* (L.) K. Schum, *Celosia argentea* L., *Cleome viscosa* L., *Clitoria ternatea* L., *Commelina benghalensis* L., *Corchorus aestuans* L., *Digera arvensis, Euphorbia hirta* L., *Phyllanthus niruri* L., *Trichodesma indicum* L. and *Tridax procumbens* L. amongst the broad-leaved weeds.

The HW twice at 15 and 30 DAS recorded significantly lower grass weed density and biomass which was closely followed by atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, without any significant difference among themselves. Sequential application of herbicides might have resulted in effective control of grass weed density and biomass and was equally effective to that of twice HW as also reported earlier by Puscal *et al.* (2018).

Sedge's density and biomass at 80 DAS of maize was significantly lower with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE which might be due to greater efficacy of halosulfuron-methyl in reducing the sedges than other PE or PoE herbicides. HW twice at 15 and 30 DAS, atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS were the next best treatments in reducing the sedges density and biomass without any significant difference among themselves.

Hand weeding twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS were equally effective in significantly lowering broad-leaved weed density and biomass. Broad-leaved weeds were not observed in the rest of the weed management treatments during the study due to greater efficacy of PE application of atrazine 1.0 kg/ ha in controlling the broad-leaved weeds in the initial stages of maize growth whereas and their management later stages of crop growth was done by

PoE herbicides or HW done at 30 DAS of resulting in absence of broad-leaved weeds in these treatments even at 80 DAS of maize.

The total weed density and biomass at 80 DAS was lower with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Lower total weed density and biomass might be attributed to effective control of weeds with two HW or due to initial flush of weeds management by PE application of atrazine whereas and prevention of the emergence and establishment of weeds at later stages of crop growth due to the PoE herbicides as reported by Dharam *et al.* (2018) and Sandeep *et al.* (2018).

At 80 DAS, **(Table 1)** higher weed control efficiency (WCE) was recorded with HW twice at 15 and 30 DAS, which was followed by atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Reduced weed density and biomass from the initial stages of crop growth with these treatments might have resulted in higher WCE as observed earlier by Mukherjee and Rai (2015).

Maize growth parameters, yield attributes and yield

The hand weeding twice at 15 and 30 DAS has resulted in taller maize plants with higher leaf area index, dry matter production, yield attributes, kernel and stover yield (**Table 2**). The application of atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, were equally effective in attaining higher growth, yield attributed and yield of maize without any statistically significant difference between these treatments. This could be mainly due to the reduced weed density and growth thus providing weed free environment during initial and later stages of crop growth, due to which all the growth resources were optimally utilized by the crop plants for better vegetative growth and reproductive potential that reflected as noticed with increased growth parameters, yield attributes and yield as reported by Mitra *et al.* (2018).

Table 1. The influence of different weed management treatments on weed density and biomass of three categories of weeds in maize at 80 days after seeding (DAS)

Treatment	Weed density (no./m^2)								Weed biomass (g/m^2)								WCE (%)	
	Grasses		Sedges		BLW		Total		Grasses		Sedges		BLW		Total			
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	3.0 (8.3)	2.4 (4.67)	3.5 (11.6)	3.4 (10.7)	1.6 (1.7)	1.6 (2.3)	4.8 (21.7)	4.3 (17.7)	4.6 (20.4)	4.6 (20.6)	3.8 (13.4)	3.7 (12.6)	1.6 (1.7)	1.7 (1.8)	6.0 (35.5)	6.0 (35.1)	82.7	79.2
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha as PoE	2.9 (7.7)	2.3 (4.3)	3.5 (11.3)	3.4 (10.3)	1.0 (0.0)	1.0 (0.0)	4.5 (19.0)	3.9 (14.7)	4.6 (19.8)	4.5 (19.9)	3.8 (13.3)	3.67 (12.5)	1.0 (0.0)	1.0 (0.0)	5.8 (33.2)	5.7 (32.4)	83.8	80.6
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha as PoE	2.6 (6.0)	2.2 (4.0)	3.4 (11.0)	3.3 (9.7)	1.0 (0.0)	1.0 (0.0)	4.2 (17.0)	3.8 (13.7)	4.5 (19.5)	4.4 (18.3)	3.7 (13.2)	3.6 (12.3)	1.0 (0.0)	1.0 (0.0)	5.8 (32.7)	5.6 (30.6)	84.0	81.8
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	8.5 (72.0)	8.7 (75.7)	1.9 (3.0)	2.1 (3.3)	1.0 (0.0)	1.0 (0.0)	8.7 (75.0)	8.9 (79.0)	10.5 (108)	8.7 (74.4)	2.0 (3.3)	2.3 (4.3)	1.0 (0.0)	1.0 (0.0)	10.6 (112)	8.9 (78.7)	45.5	53.3
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha as PoE	7.6 (57.6)	7.7 (59.0)	7.0 (48.6)	7.7 (59.0)	1.0 (0.0)	1.0 (0.0)	10.3 (106)	10.9 (118)	9.2 (84.5)	7.7 (58.5)	5.7 (31.8)	5.8 (32.3)	1.0 (0.0)	1.0 (0.0)	10.8 (116)	9.6 (90.7)	43.3	45.8
Atrazine 1.0 kg/ha as PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	4.9 (23.6)	5.3 (26.7)	6.2 (37.3)	6.14 (36.7)	1.0 (0.0)	1.0 (0.0)	7.9 (61.0)	8.0 (63.3)	7.5 (54.9)	6.3 (38.5)	4.9 (23.2)	4.62 (20.3)	1.0 (0.0)	1.0 (0.0)	8.9 (78.2)	7.7 (58.8)	61.7	65.1
Atrazine 1.0 kg/ha PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	4.9 (23.3)	5.1 (25.3)	6.1 (36.0)	6.1 (36.0)	1.0 (0.0)	1.0 (0.0)	7.8 (59.3)	7.9 (61.3)	7.3 (52.5)	6.2 (37.4)	4.6 (20.4)	4.4 (18.5)	1.0 (0.0)	1.0 (0.0)	8.6 (72.9)	7.5 (55.9)	64.0	66.6
Atrazine 1.0 kg/ha PE *fb* halosulfuron- methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	7.8 (60.6)	8.1 (65.3)	3.4 (10.3)	3.2 (09.3)	1.0 (0.0)	1.0 (0.0)	8.5 (71.0)	8.7 (74. 7)	9.6 (92.2)	7.9 (61.5)	3.2 (9.1)	3.1 (8.6)	1.0 (0.0)	1.0 (0.0)	10.1 (101)	8.4 (70.1)	50.5	58.2
Hand weeding twice at 15 and 30 DAS	2.5 (5.3)	2.1 (3.7)	3.2 (9.3)	2.4 (07.6)	1.5 (1.3)	1.5 (2.0)	4.1 (16.0)	3.7 (13.3)	4.5 (19.4)	4.4 (18.2)	3.2 (9.07)	3.1 (8.5)	1.5 (1.3)	1.6 (1.7)	5.5 (29.8)	5.4 (28.3)	85.4	83.2
Weedy check	9.6 (93.0)	9.5 (89.3)	8.18 (64.3)	8.8 (76.3)	4.6 (20.3)	4.68 (20.3)	13.4 (177)	13.7 (186)	12.3 (149)	10.6 (111)	6.7 (43.9)	6.4 (40.0)	3.5 (11.4)	4.3 (17.5)	14.3 (205)	13.0 (169)	0.0	0.0
LSD (p= 0.05)	0.67	0.62	0.48	0.48	0.43	0.43	0.68	0.56	0.58	0.68	0.45	0.48	0.23	0.20	0.52	0.64	-	

Data in parentheses are original values, which were transformed to $\sqrt{x + 0.5}$ and analysed statistically; PE= Pre-emergence application; PoE: Post-emergence application; *fb*: followed by; HW: Hand weeding

Table 2. The effect of different weed management treatments on growth, yield attributes and yield of maize

Treatment	Plant height (cm)		Leaf area index		Dry matter production (t/ha)		Cob length (cm)		Cob girth (cm)		No. of kernels/cob		Kernel yield (t/ha)		Stover yield (t/ha)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	203	203	1.90	1.85	15.13	13.40	20.37	20.21	17.64	17.03	461	462	8.16	7.40	10.62	9.99
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha as PoE	205	206	1.91	1.87	15.20	13.40	20.73	20.24	17.80	17.40	469	469	8.25	7.42	10.72	10.01
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha as PoE	206	207	1.93	1.89	15.38	13.57	21.07	20.85	17.97	17.53	478	470	8.39	7.52	10.74	10.15
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	164	154	1.47	1.53	11.63	10.06	16.11	16.35	13.86	12.20	377	386	5.12	4.57	7.61	6.90
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha as PoE	163	151	1.46	1.48	11.05	9.89	16.07	16.27	13.43	12.03	375	383	4.84	4.48	7.57	6.88
Atrazine 1.0 kg/ha PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	180	177	1.68	1.68	13.63	11.35	18.15	18.27	15.63	14.30	411	415	6.73	5.79	9.01	8.25
Atrazine 1.0 kg/ha as PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	184	179	1.70	1.69	13.91	11.54	18.43	18.29	15.80	14.47	412	422	6.94	5.92	9.10	8.15
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	143	132	1.25	1.32	9.25	8.17	14.10	14.26	11.32	10.27	331	347	3.62	3.12	5.39	5.46
Hand weeding twice at 15 and 30 DAS	209	210	1.96	1.92	15702	13.82	21.30	20.96	18.30	17.60	489	471	8.52	7.65	10.86	10.30
Weedy check	123	114	0.96	0.88	8043	6.85	12.07	11.30	9.48	8.70	281	286	2.28	2.02	3.94	3.93
LSD (p=0.05)	5	14	0.06	0.13	927	1.19	1.25	1.89	1.61	1.47	29	27	0.57	0.54	1.11	1.02

*PE= Pre-emergence application; PoE: Post-emergence application; *fb*= followed by; HW= Hand weeding

Phytotoxicity on succeeding greengram

Phytotoxicity was not observed on succeeding greengram crop at 10[th] and 15[th] day after sowing due to various pre and post emergence herbicides applied in maize. Similar results of post emergence application of tembotrione in maize with no residual phytotoxicity on succeeding wheat and mustard crop was reported by Dharam *et al.* (2018).

Weed density and biomass in succeeding greengram

At 20 DAS of greengram lower grasses weed density and biomass **(Table 3)** was recorded with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE and atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE. The density and biomass of sedges were lower with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, which was at par with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, which indicated that recommended dose or half of the recommended dose of halosulfuron-methyl is effective in controlling the sedges in maize-greengram cropping system, whereas the broad-leaved weed density and biomass were lower with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, which was comparable with atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, HW twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Weedy check recorded significantly highest density and biomass of grasses, sedges and broad-leaved weeds in the succeeding greengram.

The total weed density and biomass in greengram at 20 DAS **(Table 3)** due to the residual effect of weed management practices imposed in preceding maize, was lower with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE , which was in parity with hand weeding twice at 15 and 30 DAS, atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS and atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, without significant differences amongst them due to better control of weeds under these treatments in maize that might have resulted in the lower weed seedbank in the soil, which in turn reduced the density and dry weight of weeds in succeeding greengram as also reported by Verma *et al.* (2009).

Greengram growth parameters, yield attributes and yield

The growth parameters, yield attributes and yield of succeeding greengram differed significantly due to different weed management practices

Table 3. The weed density and biomass at 20 days after seeding (DAS) of greengram as influenced by weed management treatments applied in preceding maize

Treatment	Weed density (no./m^2)								Weed biomass (g/m^2)							
	Grasses		Sedges		BLW		Total		Grasses		Sedges		BLW		Total	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS	7.7 (57.7)	5.8 (33.0)	6.6 (43.3)	5.5 (29.0)	2.1 (3.3)	2.1 (3.3)	10.3 (104)	8.1 (65.3)	4.2 (16.5)	3.9 (14.1)	4.5 (18.9)	4.4 (18.2)	1.8 (2.4)	1.8 (2.4)	6.0 (35.1)	6.2 (37.9)
Atrazine 1.0 kg/ha as PE *fb* tembotrione 120 g/ha as PoE	8.2 (66.0)	6.0 (34.7)	6.5 (42.0)	5.2 (26.3)	1.7 (2.0)	1.8 (2.3)	10.5 (110)	8.0 (63.3)	4.5 (19.2)	4.2 (16.3)	4.3 (17.8)	4.2 (17.1)	1.7 (2.0)	1.72 (2.0)	6.0 (35.4)	6.3 (39.0)
Atrazine 1.0 kg/ha as PE *fb* topramezone 30 g/ha as PoE	8.1 (65.0)	5.9 (33. 7)	6.2 (38.0)	5.1 (25.3)	1.6 (1.7)	1.7 (2.0)	10.3 (104)	7.9 (61.0)	4.4 (18.7)	4.1 (16.2)	4.1 (16.1)	4.1 (16.1)	1.5 (1.4)	1.5 (1.4)	5.9 (33.6)	6.1 (36.2)
Atrazine 1.0 kg/ha as PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	9.9 (98.0)	9.4 (87.0)	2.9 (7.7)	3.4 (10.7)	3.1 (8.3)	3.2 (9.3)	10.7 (114)	10.4 (107)	5.8 (32.8)	5.5 (28.9)	2.5 (5.3)	2.5 (5.3)	3.1 (8.6)	3.1 (8.6)	6.6 (42.9)	6.9 (46.7)
Atrazine 1.0 kg/ha as PE *fb* 2,4-D amine salt 580 g/ha as PoE	9.9 (97.3)	9.3 (85.0)	7.6 (57.3)	6.6 (42.3)	3.1 (8.7)	3.3 (9.7)	12.8 (163)	11.7 (137)	5.8 (33.1)	5.5 (30.1)	5.3 (26.8)	5.4 (28.6)	3.2 (9.2)	3.1 (8.9)	8.3 (67.7)	8.3 (68.7)
Atrazine 1.0 kg/ha as PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	9.9 (96.7)	9.2 (83.7)	7.6 (57.0)	6.4 (40.0)	2.9 (7.3)	3.1 (8.7)	12.7 (161)	11.5 (132)	5.8 (32.2)	5.4 (27.9)	5.2 (26.3)	5.3 (26.9)	3.1 (8.6)	3.1 (8.6)	8.0 (63.5)	8.2 (67.1)
Atrazine 1.0 kg/ha as PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	9.6 (91.3)	9.2 (83.3)	7.6 (56.3)	6.3 (38.3)	2.8 (7.0)	3.0 (8.0)	12.5 (154)	11.4 (129)	5.6 (30.4)	5.2 (26.4)	5.1 (25.2)	5.2 (26.5)	2.9 (7.3)	2.9 (7.3)	7.8 (60.2)	7.9 (62.9)
Atrazine 1.0 kg/ha as PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	10.1 (102)	9.4 (87.3)	3.0 (08.3)	3.7 (13.0)	3.1 (9.0)	3.3 (10.0)	10.9 (119)	10.5 (110)	6.1 (35.9)	5.61 (30.5)	2.8 (6.7)	2.8 (6.7)	3.1 (8.9)	3.2 (9.1)	6.9 (46.2)	7.3 (52.1)
Hand weeding twice at 15 and 30 DAS	7.4 (54.7)	5.7 (31.3)	6.6 (42.7)	5.4 (28.3)	1.9 (3.0)	1.9 (3.0)	10.0 (100)	7.9 (62.7)	3.9 (14.7)	3.8 (13.4)	4.4 (18.6)	4.3 (17.3)	1.8 (2.4)	1.8 (2.3)	5.8 (33.2)	6.0 (35.7)
Weedy check	12.1 (147)	10.6 (112)	10.3 (104)	9.5 (90.0)	5.0 (24.3)	5.2 (25.7)	16.6 (276)	15.1 (228)	6.9 (47.3)	6.3 (39.3)	6.5 (41.8)	6.5 (41.8)	4.1 (15.9)	4.1 (15.9)	9.9 (97.1)	10.3 (105)
LSD (p= 0.05)	1.27	0.82	0.50	0.63	0.48	0.47	1.07	0.77	0.58	0.48	0.49	0.52	0.37	0.33	0.54	0.49

Data in parentheses are original values, which were transformed to $\sqrt{x + 0.5}$ and analysed statistically; PE: Pre-emergence application; PoE: Post-emergence application; *fb*: followed by; HW: Hand weeding

Table 4. Influence of different weed management treatments applied in maize on yield attributes and yield of succeeding greengram

Treatment	Germination (%)		Plant height (cm)		Dry matter production (kg/ha)		No. of pods/ plant		No. of seeds/ pod		Seed index (g)		Seed yield (kg/ha)		Haulm yield (kg/ha)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	89.0	90.3	50.0	50.3	2135	2082	12.93	12.30	9.87	9.26	43.3	42.6	663	637	1026	1020
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	89.6	91.7	48.6	47.3	2123	2077	12.57	12.23	9.70	9.22	41.9	41.8	637	623	1010	1014
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	91.1	90.7	49.0	49.0	2130	2079	12.63	12.27	9.80	9.23	42.6	42.2	641	628	1023	1017
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE	92.6	89.4	47.4	46.9	2120	2032	12.53	12.16	9.53	9.20	41.5	41.5	633	621	1007	1013
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha PoE	89.9	90.1	40.7	38.6	1908	1868	10.83	9.80	8.27	7.93	38.1	37.5	534	531	875	847
Atrazine 1.0 kg/ha PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha PoE	89.8	91.6	40.9	39.1	1910	1871	10.87	10.13	8.30	8.04	38.5	37.8	546	536	890	880
Atrazine 1.0 kg/ha PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha PoE	89.9	90.4	41.4	40.2	1912	1872	10.93	10.17	8.37	8.05	39.1	38.4	551	541	814	863
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE	88.0	89.5	39.4	37.0	1901	1860	10.73	9.53	8.20	7.91	37.5	36.9	518	525	872	832
Hand weeding twice at 15 and 30 DAS	89.6	89.8	51.1	51.1	2177	2089	12.97	12.47	9.97	9.30	43.8	43.2	679	660	1033	1032
Weedy check	90.8	90.2	32.6	31.9	1654	1655	8.83	8.23	6.80	6.88	33.3	33.6	391	446	761	726
LSD (p=0.05)	NS	NS	1.32	4.9	71.8	153	0.357	1.12	0.33	0.90	1.23	2.81	18.7	56	85	24.3

*PE= Pre-emergence application; PoE: Post-emergence application; *fb*=followed by; HW: Hand weeding implemented in maize **(Table 4)**. The higher growth parameters, yield attributes, seed and haulm yield of greengram was recorded with hand weeding twice at 15 and 30 DAS, which was closely followed by application of atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, in the order of descent, without significant disparity among them **(Table 4)**. This might be due to higher WCE in the respective treatments in both maize and greengram, which might have lead to lower weed density and biomass in the succeeding greengram that in turn favored greengram to accumulate higher dry matter, enhanced synthesis and translocation of assimilates to developing pods and seeds that may lead to higher yields of succeeding greengram.

The present study has revealed that atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha PoE were the most effective weed management treatments that effectively managed weeds and increased the productivity of winter maize and succeeding summer greengram. These treatments may be used for effective management of weeds in maize at times of labor shortage, and without any residual effect on succeeding greengram

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