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INTERACTIVE EFFECTS OF ADJUVANT AND SALINE SPRAY WATERS ON HERBICIDE BIOEFFICACY, WEED INDICES, AND CROP TOLERANCE IN *RABI* MAIZE (*Zea mays* L.)

K. Bhavitha[1*], K. Suresh[2] and T. Ram Prakash[3]

[1*]*Department of Agronomy, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad - 500 030, Telangana (India)*
[2]*Water Technology Centre, C-NARE, Rajendranagar, Hyderabad - 500 030, Telangana (India)*
[3]*Regional Agricultural Research Station, Palem, Nagar Kurnool - 509 209, Telangana (India)*
*****e-mail: *kokkula.bhavitha@gmail.com*

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ABSTRACT

Post-emergence herbicides play a vital role in weed control in maize; however, their efficacy is often influenced by the quality of spray fluid. In semi-arid regions like Telangana (India), groundwater is mildly alkaline to alkaline with p^H in the range of 6.6 to 8.6. Due to the limited availability of quality water the farmers use ground waters for spraying herbicides. The dissolved salts, particularly calcium and magnesium ions, present in ground waters can antagonize active ingredients of herbicide, thereby reduce weed control efficiency. Therefore, a field study was undertaken to assess the efficacy of post-emergence herbicides when applied using different saline waters as spray fluids in maize (*Zea mays* L.) during *rabi* 2020-21 at College of Agriculture, Professor Jayashankar Telangana Agricultural University, Hyderabad (India). The experiment was laid out in a factorial randomized block design with different combinations of saline waters, herbicides, and adjuvant treatments. The results divulged that tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} with C_3S_1 saline water along with ammonium sulphate @ 2% as adjuvant (H_6W_1) resulted in lower weed index (10.3) and higher herbicide efficiency index (1.78) , crop resistance index (6.73, and 7.07 at 30, and 60 DAS) and yield (5006 kg ha^{-1}) of *rabi* maize compared to the other treatments of saline water without adjuvant next to tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + ammonium sulphate @ 2% at 21 DAS with distilled water (H_6W_3) indicating that ammonium sulphate as an effective adjuvant in negotiating the impact of hard water cations and improving the herbicide efficacy when saline water is used for spray.

Keywords: Ammonium sulphate, crop resistance index, herbicide efficiency index, saline waters, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is the world's leading crop widely cultivated as cereal grain (Rajeshwari *et al.*, 2025). In India, about 36.91 million t of maize was produced from an area of 10.78 million ha with an average productivity of 3422 kg ha^{-1} in 2024-25 (Anonymous, 2025). One of the major economic constraint leading to the low maize productivity is weed infestation which reduces maize yield upto 58-62% in winter and 67-79% in summer (Mukhtar *et al.*, 2007). Due to the costly inter-cultivation input and labour shortage, the use of herbicides is the most effective economic weed control method. To achieve a broad spectrum control of weeds in maize, tank mix applications of post-emergence herbicides such as tembotrione + atrazine, 2,4-D-dimethyl amine, and halosulfuron methyl + atrazine are recommended to provide long-season control until the critical period of crop-weed competition (Swetha *et al*., 2018; Mali *et al*., 2020). Herbicide dominates the crop protection market as a whole, and as per the conservative estimates it covers 44% of global crop protection industry (FICCI, 2013). The effectiveness of herbicides also influences the yield expression and net profit.

Water is a primary carrier solvent and critical component for herbicide applications. Herbicide efficiency is achieved only if spray carrier quality is maintained. Unlike pure water, groundwater quality varies with source, season, proximity to surface water, depth of exploitation, topography, aquifer, overburden characteristics and geology of the region. Herbicide performance has reportedly been inconsistent with variation of carrier water quality (Nalewaja *et al.*, 1991). Therefore, the availability of fresh water is a pressing concern not only in terms of its limited availability but also due to its deteriorating quality (Allocca *et al.*, 2018). In Telangana state of India, groundwater is mildly alkaline to alkaline with p^H 6.6 to 8.6 (Anonymous, 2017). The groundwater quality is monitored by several factors such as hardness, alkalinity and turbidity. Water quality is reduced by the presence of calcium and magnesium, bicarbonates, sulphates, chlorides and nitrates. The process of inactivation, breakdown or precipitation occurs when these ions interfere with chemicals, thereby reduce the efficiency of agro-chemicals. Glyphosate efficacy was reduced when applied with carrier water containing Ca^{+2}, Mg^{+2}, Zn^{+2} and Al^{+2} divalent metal cations (Abouziena *et al*., 2009). Mesotrione efficacy was reduced on giant ragweed, horseweed and palmer amaranth at carrier water hardness consisting of Ca^{+2} and Mg^{+2} > 200 mg L^{-1} (Pratap *et al.*, 2016). The impact of hard water cations can be mitigated by adding the appropriate adjuvant to the spray tank to aid in herbicide's mixing, application, or efficacy (Pratap *et al*., 2016). The most widely used adjuvant that lessens the antagonistic effect of hard water cations and increases the effectiveness of herbicides is ammonium sulphate (AMS), which is recommended in the majority of hard water areas (Hartzler, 2001). Therefore, a field study was conducted to evaluate the efficacy of post-emergence herbicides under different qualities of saline groundwater and adjuvants on weed control, crop growth and yield of *rabi* maize, with special emphasis on identifying the suitable spray water-adjuvant combinations under saline conditions, which remains less explored under semi-arid agro-ecosystems.

MATERIALS AND METHODS

Experimental setup and treatments

The efficacy of post-emergence herbicides for the control of weeds in *rabi* maize using saline water as spray was studied in a field experiment at College of Agriculture, Rajendranagar, Hyderabad (India) during *rabi* season of 2020-2021. The experimental site lies in semi-arid area, and is situated at an altitude of 822 m masl in Southern Telangana zone with $17^0$19'21" N latitude and $78^0$24'36" E longitude as coordinates. The soil at the experimental site was sandy loam, slightly alkaline in reaction (7.84), medium in organic carbon (0.69%), low in available nitrogen (220.8 kg ha^{-1}) and phosphorus (9.38 kg ha^{-1}) and high in available potassium (351.18 kg ha^{-1}). The experiment was laid out in a factorial randomized block design with 20 treatments with each treatment replicated three times. The factor 1 comprised of 6 levels of herbicide and adjuvant (ammonium sulphate, AMS) combinations, namely H_1: post emergence application of tembotrione 34.4% SC 120 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1} without adjuvant as tank mix, H_2: post emergence of tembotrione 34.4% SC 120 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1} + AMS @ 2%, H_3: post emergence of 2,4-D-dimethyl amine 58% SL 0.5 kg ha^{-1} without adjuvant, H_4: post emergence of 2,4-D-dimethyl amine 58% SL 0.5 kg ha^{-1} + AMS @ 2% as adjuvant, H_5: post emergence of halosulfuron methyl 75% WDG 67.5 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1} without adjuvant; and H_6: post emergence of halosulfuron methyl 75% WDG 67.5 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1} + AMS @ 2% as adjuvant. The factor 2 involved 3 levels of quality of spray fluids, *i.e.*, W_1 (C_3S_1 class), W_2 (C_3S_2 class) and W_3 (distilled water) with two controls, C_1: unweeded control and C_2: weed free plot (hand weeding at 20 and 40 days after sowing (DAS)]. Maize cv. 'Deccan Hybrid Makka (DHM-117)' was used in this study. The seeds were hand dibbled in October 2020 at a plant spacing of 60 cm × 20 cm with 2 seeds hill^{-1} in gross plot size of 4.8 m x 4.2 m (net plot size, 3.6 m x 3.4 m). The crop was sown under irrigated conditions. Recommended fertilizer dose (180:60:60 kg ha^{-1} N, P and K) was applied in the form of urea, di-ammonium phosphate and muriate of potash, respectively. Plant protection measures were followed and applied at 15-20 days intervals based on infestation severity.

Saline water as spray fluids

Saline waters were prepared by dissolving different salts like sulphates and chlorides of calcium, magnesium, potassium and sodium in distilled water, and analyzed for pH, EC and SAR as per the standard methods (Dhyan Singh *et al*., 2005). The saline water of class C_3S_1 (EC, 0.75 to 2.25 dS m^{-1}; SAR, 0 to 10), C_3S_2 class (EC, 0.75 to 2.25 dS m^{-1}; SAR, 10 to 18); and distilled water (as control) were selected as spray fluids.

Herbicide sprays, and phytotoxicity & crop injury assessment

The herbicides intended for post-emergence use were sprayed on weeds on 21 DAS at 2-3 leaf stage of weeds, primarily using a knapsack sprayer fitted with a flat fan nozzle. Dosages were applied as tank mix along with different quality of spray fluids. Manual weeding was done in weed-free plots at 20 and 40 DAS. Visual observations on phytotoxicity of maize like yellowing, chlorosis, necrosis, epinasty, hyponasty, scorching and stunting due to application of combination of herbicides with varied quality of spray carriers were studied 3, 7 and 15 days after herbicide application. Crop injury was recorded as per the European Weed Research Council's recommendation (Singh and Rao, 1976).

Weed density and dry weight

Weed density and weed dry weight were recorded at 30, and 60 DAS using 1.0 m × 1.0 m quadrat and were analyzed after square root transformation (Gomez and Gomez, 1984). Weed density was recorded treatment-wise by counting the number of grassy weeds, sedges and broad leaved weeds present in the quadrat. Weed index (WI) was evaluated using the formula given by Gill and Kumar (1969).

$$\mathrm{WI}\ (\%) = \frac{\text{Maize yield from weed free plot} - \text{Maize yield from herbicide treated plot}}{\text{Maize yield from weed free plot}} \times 100$$

Crop resistance index and herbicide efficiency index

Crop resistance index which indicates the relationship between a proportionate increase in crop biomass and a proportionate decrease in weed biomass in treated plots was estimated as per the formulae given by Mishra and Misra (1997).

$$\mathrm{CRI} = \frac{\text{Dry matter production of crop in treated plot}}{\text{Dry matter production of crop in control plot}} \times \frac{\text{Dry weight of weeds in control plot}}{\text{Dry weight of weeds in treated plot}}$$

The herbicide efficiency index which indicates the potential of herbicides for killing weeds and their phytotoxicity on the crop was calculated as per the formula of Krishnamurthy *et al*. (1995).

$$\mathrm{HEI} = \frac{(Y_T - Y_C)/Y_T}{W_T/W_C}$$

Wherein, Y_T = Yield of treated plot; Y_C = Yield of control (unweeded) plot; W_C = Weed dry weight in control (unweeded) plot; W_T = Weed dry weight in treated plot

Crop harvest

The crop was harvested on 3rd March, 2021 and threshed. Clean grains were weighed, and yield plot^{-1} noted. The stalk yield for each plot was measured after sun-drying, and reported in kg ha^{-1}.

Statistical analysis

The statistical significance of data was analyzed by two-way analysis of variance at 5% level of significance using 'F' test (Gomez and Gomez, 1984). The critical differences (CD) was worked out to test the significance. Correlation analysis was performed to assess the degree and direction of association between weed dry weight and maize yield. Data was subjected to statistical analysis using Pearson's appropriate probability levels (p = 0.05 and p = 0.01).

RESULTS AND DISCUSSION

Weed species

The prominent weed species associated with the experimental field were *Cynodon dactylon* L., *Digitaria sanguinalis* L., *Dactyloctenium aegyptium* L., *Echinocloa spp* L., *Eleusine indica* L. (grasses), *Euphorbia hirta* L., *Parthenium hysterophorus* L., *Commelina benghalensis* L., *Celosia argentia* L., *Trianthema portulacastrum* L., *Cleome viscosa* L., *Digera arvensis* L. (broadleaved weeds) and *Cyperus rotundus* L., among sedges.

Weed density (No. m^{-2})

Weed density recorded at 30 DAS (Table 1 & 2) and 60 DAS (Table 3 & 4) during *rabi* season of 2020-21 revealed that herbicides + adjuvant and quality of spray fluids and their interaction effects significantly influenced the grass, sedge and total weed density. Tank mix application of tembotrione @ 120 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% as adjuvant at 21 DAS with distilled water recorded lowest density of grasses (9.33 and 14.67 m^{-2} at 30 and 60 DAS, respectively) followed by (*fb)* tank mix application of tembotrione @ 120 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} at 21 DAS with distilled water. Broadleaved weeds density at 30 and 60 DAS revealed that different herbicides + adjuvant and quality of spray fluid have a significant influence but their interaction effects were non-significant. With regard to herbicides + adjuvant treatments, significantly lowest density (8.44 and 14.33 m^{-2} at 30 and 60 DAS) was recorded with tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @

Table 1: Effect of post-emergence herbicides and spray fluid quality on weed density (No. m^{-2}) of grasses & sedges in *rabi* maize at 30 DAS

Herbicides + adjuvant	Grasses				Sedges			
	Quality of spray fluid				Quality of spray fluid			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
H_1	4.92 (23.33)	5.38 (28.00)	3.78 (13.33)	4.69 (21.56)	6.26 (38.67)	6.79 (45.33)	5.37 (28.00)	6.14 (37.33)
H_2	4.28 (17.33)	4.35 (18.00)	3.21 (9.33)	3.95 (14.89)	5.73 (32.00)	5.84 (33.33)	5.23 (26.67)	5.60 (30.67)
H_3	7.89 (61.33)	7.92 (62.00)	7.63 (57.33)	7.81 (60.22)	5.60 (30.67)	6.01 (35.33)	4.24 (17.33)	5.29 (27.78)
H_4	7.68 (58.00)	7.80 (60.00)	7.54 (56.00)	7.67 (58.00)	5.10 (25.33)	5.25 (26.67)	4.10 (16.00)	4.82 (22.67)
H_5	6.34 (39.33)	6.38 (40.00)	4.47 (19.00)	5.73 (32.78)	3.97 (15.00)	4.10 (16.00)	2.85 (7.33)	3.64 (12.78)
H_6	5.84 (33.33)	5.91 (34.00)	4.40 (18.67)	5.39 (28.67)	3.30 (10.00)	3.40 (10.67)	2.74 (6.67)	3.15 (9.11)
Mean	6.16 (38.78)	6.28 (40.33)	5.17 (28.94)	-	5.00 (25.28)	5.23 (27.89)	4.09 (17.00)	-
Control 1	-	-	-	8.30 (68.00)	-	-	-	7.71(58.67)
Control 2	-	-	-	2.49 (5.33)	-	-	-	2.23 (4.00)
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	0.12	0.09	0.21	0.16	0.10	0.07	0.17	0.12
$CD_{0.05}$	0.35	0.25	0.60	0.32	0.28	0.19	0.48	0.25

Note: Original values are given in parenthesis, which are transformed to $\sqrt{x+1}$

Treatments: Herbicide + adjuvant: H_1: Tembotrione 34.4 % SC 120 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1}; H_2: H_1 + ammonium sulphate @ 2% as adjuvant; H_3: 2,4-D-dimethyl amine 58% SL 0.5 kg ha^{-1}; H_4: H_3 + ammonium sulphate @ 2%; H_5: Halosulfuron methyl 75% WDG 67.5 g ha^{-1} + atrazine 50% WP 0.5 kg ha^{-1} H_6: H_5 + ammonium sulphate @ 2%; Spray carrier (water) quality: W_1: C_3S_1 class (EC, 0.75-2.25 dS m^{-1}; SAR, 0-10); W_2: C_3S_2 class (EC, 0.75-2.25 dS m^{-1}; SAR, 10-18); W_3: Distilled water; External controls: (2): C_1: Unweeded control, C_2: Weed free plot (hand weeding at 20, & 40 DAS)

Table 2: Effect of post-emergence herbicides and spray fluid quality on density (No. m^{-2}) of broadleaved weeds & total density of weeds in *rabi* maize at 30 DAS

Herbicides + adjuvant	Broad leaved weeds – Quality of spray fluid				Total weed density – Quality of spray fluid			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
H_1	5.24 (26.67)	5.38 (28.00)	4.24 (17.33)	4.95 (24.00)	9.46 (88.67)	10.10 (101.33)	7.70 (58.67)	9.09 (82.89)
H_2	4.70 (21.33)	4.85 (22.67)	4.10 (16.00)	4.55 (20.00)	8.45 (70.67)	8.65 (74.00)	7.26 (52.00)	8.12 (65.56)
H_3	4.37 (18.67)	4.49 (19.33)	3.49 (11.33)	4.12 (16.44)	10.54 (110.67)	10.84 (116.67)	9.31 (86.00)	10.23 (104.44)
H_4	3.95 (14.67)	4.01 (15.33)	3.40 (10.67)	3.79 (13.56)	9.94 (98.00)	10.14 (102.00)	9.14 (82.67)	9.74 (94.22)
H_5	3.87 (14.00)	3.93 (14.67)	2.75 (6.67)	3.51 (11.78)	8.31 (68.33)	8.44 (70.67)	5.82 (33.00)	7.52 (57.33)
H_6	3.26 (9.67)	3.35 (10.33)	2.49 (5.33)	3.03 (8.44)	7.34 (53.00)	7.47 (55.00)	5.60 (30.67)	6.81 (46.22)
Mean	4.23 (17.50)	4.33 (18.39)	3.41 (11.22)	-	9.01 (81.56)	9.27 (86.61)	7.47 (57.17)	-
Control 1	-	-	-	7.81 (60.00)	-	-	-	13.69 (186.67)
Control 2	-	-	-	1.83 (2.67)	-	-	-	3.57 (12.00)
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	0.13	0.09	0.23	0.17	0.14	0.10	0.25	0.18
$CD_{0.05}$	0.38	0.27	Ns	0.35	0.41	0.29	0.71	0.37

Note: The original values are given in parenthesis, which are transformed to $\sqrt{x+1}$
For treatment details see Table 1

Table 3: Effect of post-emergence herbicides and spray fluid quality on weed density (No. m^{-2}) of grasses and sedges in *rabi* maize at 60 DAS

Herbicides + adjuvant	Grasses – Quality of spray fluid				Sedges – Quality of spray fluid			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
H_1	5.62 (30.67)	6.09 (36.33)	4.42 (18.67)	5.37 (28.56)	7.27 (52.00)	7.80 (60.00)	6.27 (38.67)	7.11 (50.22)
H_2	4.90 (23.33)	4.99 (24.00)	3.95 (14.67)	4.61 (20.67)	6.79 (45.33)	6.89 (46.67)	6.17 (37.33)	6.62 (43.11)
H_3	8.22 (66.67)	8.26 (67.33)	8.02 (63.33)	8.17 (65.78)	6.39 (40.00)	6.79 (45.33)	4.85 (22.67)	6.01 (36.00)
H_4	8.01 (63.33)	8.14 (65.33)	7.93 (62.00)	8.03 (63.56)	5.84 (33.33)	5.95 (34.67)	4.68 (21.00)	5.49 (29.67)
H_5	7.07 (49.00)	7.12 (49.67)	5.13 (25.33)	6.44 (41.33)	4.72 (21.33)	4.83 (22.67)	3.49 (11.33)	4.35 (18.44)
H_6	6.55 (42.00)	6.60 (42.67)	5.06 (24.67)	6.07 (36.44)	3.95 (14.67)	4.00 (15.33)	3.40 (10.67)	3.78 (13.56)
Mean	6.73 (45.83)	6.86 (47.56)	5.75 (34.78)	-	5.83 (34.44)	6.04 (37.44)	4.81 (23.61)	-
Control 1	-	-	-	8.70 (74.67)	-	-	-	8.69 (74.67)
Control 2	-	-	-	3.40 (10.67)	-	-	-	2.98 (8.00)
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	0.13	0.09	0.23	0.17	0.11	0.08	0.19	0.14
$CD_{0.05}$	0.38	0.27	0.65	0.34	0.31	0.22	0.53	0.28

Note: The original values are given in parenthesis, which are transformed to $\sqrt{x+1}$;
For treatment details see Table 1

Table 4: Effect of herbicides + adjuvant and quality of spray carriers on density (No. m^{-2}) of broadleaved weeds & total density of weeds in *rabi* maize at 60 DAS

Herbicides + adjuvant	BL weeds Quality of spray fluid				Total density Quality of spray fluid			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
H_1	6.08 (36.00)	6.13 (36.67)	5.38 (28.00)	5.86 (33.56)	10.93 (118.67)	11.56 (133.00)	9.28 (85.33)	10.59 (112.33)
H_2	5.61 (30.67)	5.74 (32.00)	5.29 (27.33)	5.55 (30.00)	10.01 (99.33)	10.16 (102.67)	8.96 (79.33)	9.71 (93.78)
H_3	5.24 (26.67)	5.38 (28.00)	4.24 (17.33)	4.95 (24.00)	11.58 (133.33)	11.88 (140.67)	10.20 (103.33)	11.22 (125.78)
H_4	4.71 (21.33)	4.84 (22.67)	4.15 (16.33)	4.56 (20.11)	10.89 (118.00)	11.11 (122.67)	10.00 (99.33)	10.67 (113.33)
H_5	4.57 (20.00)	4.72 (21.33)	3.69 (12.67)	4.34 (18.00)	9.55 (90.33)	9.72 (93.67)	7.08 (49.33)	8.78 (77.78)
H_6	4.04 (15.33)	4.07 (15.67)	3.61 (12.00)	3.90 (14.33)	8.53 (72.00)	8.63 (73.67)	6.94 (47.33)	8.03 (64.33)
Mean	5.04 (25.00)	5.14 (26.06)	4.39 (18.94)	-	10.25 (105.28)	10.51 (111.06)	8.74 (77.33)	-
Control 1	-	-	-	8.46 (70.67)	-	-	-	14.86 (220.00)
Control 2	-	-	-	3.20 (9.33)	-	-	-	5.37 (28.00)
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	0.14	0.10	0.24	0.18	0.15	0.11	0.25	0.19
$CD_{0.05}$	0.39	0.28	Ns	0.36	0.41	0.30	0.70	0.38

Note: The original values are given in parenthesis, which are transformed to $\sqrt{x+1}$

For treatment details see Table 1

0.5 kg ha^{-1} + AMS @ 2% at 21 DAS. Among quality of spray fluid, use of distilled water recorded significantly lowest density of broadleaved weeds (11.22 and 18.94 m^{-2} at 30 and 60 DAS) as compared to saline water treatments, emphasizing the importance of quality of spray fluid to be used for spray application of herbicides.

Minimum density of sedges and total weed density (6.67, 30.67 m^{-2} and 10.67, 47.33 m^{-2} at 30 and 60 DAS) was recorded with tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with distilled water *fb* tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} at 21 DAS with distilled water and significantly superior to other combination, which might be attributed to application of adjuvants in combination with herbicides and use of salts free spray carrier increased the herbicide efficacy by prolonged retention of herbicide on the surface of leaf and penetration through cuticle and increased toxicity to weed species for effective control of weeds and these results are in agreement with (Nalewaja and Matysiak, 1993) who reported that ammonium sulphate as adjuvant and distilled water enhanced herbicides toxicity and promoted dry weight reduction of weeds.

Weed dry weight (g m^{-2})

Minimum weed dry weight (3.03 and 11.59 g m^{-2} at 30 and 60 DAS) (Table 5) was noticed with tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with distilled water *fb* tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} at 21 DAS with distilled water, significantly superior to other combination that might be the result of improved absorption of the herbicide with the use of adjuvant, this enhanced bio-efficacy against weeds and results corroborate with the findings of (Abouziena *et al*., 2013; Naveed *et al*., 2008). Among herbicides + adjuvant and saline water treatments combination, tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with C_3S_1

Table 5: Effect of post-emergence herbicides and spray fluid quality on weed dry weight (g m^{-2}) in *rabi* maize at 30 and 60 DAS

Herbicides + adjuvant	30 DAS Quality of spray fluid W_1	W_2	W_3	Mean	60 DAS Quality of spray fluid W_1	W_2	W_3	Mean
H_1	3.66 (12.39)	4.07 (15.60)	2.63 (5.92)	3.45 (11.30)	5.64 (30.88)	6.05 (35.55)	4.67 (20.88)	5.45 (29.10)
H_2	2.99 (7.95)	3.16 (8.99)	2.44 (5.01)	2.86 (7.32)	5.26 (26.67)	5.41 (28.35)	4.10 (15.79)	4.92 (23.60)
H_3	4.42 (18.56)	4.66 (20.71)	3.59 (12.09)	4.22 (17.12)	6.53 (41.63)	6.13 (36.65)	5.49 (29.15)	6.05 (35.81)
H_4	4.02 (15.17)	4.27 (17.27)	3.56 (11.74)	3.95 (14.73)	5.55 (29.88)	5.74 (32.03)	5.21 (26.21)	5.50 (29.38)
H_5	3.09 (8.61)	3.19 (9.16)	2.17 (3.73)	2.81 (7.17)	4.80 (22.10)	5.02 (24.26)	3.61 (12.10)	4.48 (19.49)
H_6	2.59 (5.77)	2.71 (6.39)	2.00 (3.03)	2.44 (5.07)	4.31 (17.61)	4.35 (18.01)	3.54 (11.59)	4.07 (15.74)
Mean	3.46 (11.80)	3.68 (13.41)	2.73 (7.31)	-	5.35 (28.13)	5.45 (29.14)	4.44 (19.90)	-
Control 1	-	-	-	6.04 (35.46)	-	-	-	7.61 (56.87)
Control 2	-	-	-	1.61 (1.60)	-	-	-	2.80 (6.85)
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	0.06	0.04	0.11	0.08	0.09	0.07	0.16	0.12
$CD_{0.05}$	0.18	0.13	0.31	0.17	0.27	0.19	0.46	0.24

Note: The original values are given in parenthesis, which are transformed to $\sqrt{x+1}$
For treatment details see Table 1

saline water recorded significantly lower weed dry matter (5.77 and 17.61 g m^{-2} at 30 and 60 DAS) compared to other saline water combinations.

Crop resistance index

The crop resistance index (Fig. 1) indicating increased vigour of crop plant due to weed management measures indicated that hand weeding at 20 and 40 DAS *fb* tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with distilled water recorded higher crop resistance index at all the developmental stages of the crop. Among saline water treatments, tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with C_3S_1 saline water recorded higher CRI over other herbicide treatments. Whereas, weedy check recorded the lowest value of CRI (1.0) indicating the harmful effect on crop and these results are in agreement with the findings of (Gupta *et al.*, 2019).

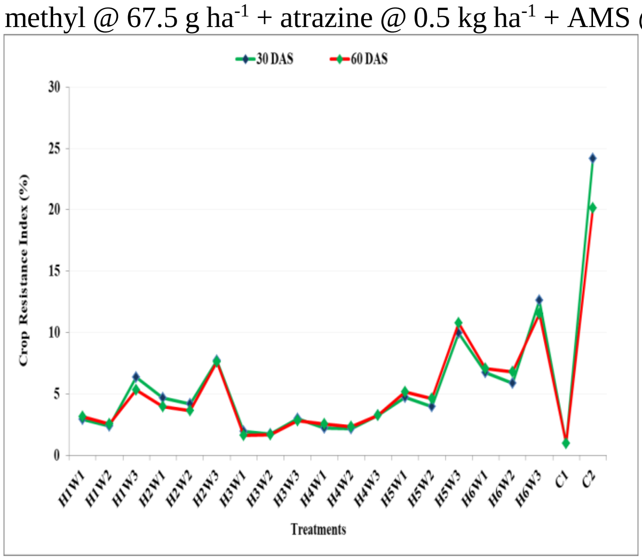


Fig. 1: Crop resistance index (%) as influenced by post-emergence herbicides and spray fluid quality in *rabi* maize (For treatment details see Table 1)

Herbicide efficiency index

The data on herbicide efficiency index depicted in Table 6 indicated that hand weeding at 20 and 40 DAS *fb* tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2%

at 21 DAS with distilled water and tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} with distilled water at 21 DAS recorded highest herbicide efficiency index of 3.39, 2.19 and 2.05, respectively. Whereas, tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with C_3S_1 saline water recorded higher HEI (1.78) than that of other herbicidal treatments with saline water.

Weed index (%)

The weed index worked out in different weed treatments (Table 6) revealed that tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine@ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with distilled water and tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} with distilled water at 21 DAS recorded lowest weed index of 1.77 and 3.38%, respectively. The above results are attributed to the reduced competition and stress by weeds due to better WCE and ultimately transpiring into higher corn yields. Therefore, the yield attributes in crop were superior which ultimately resulted into increased yield and lower weed index (Pratik *et al*., 2013). The application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with C_3S_1 saline water as spray fluid recorded lowest weed index (10.30%) among other saline water combinations.

Table 6: Weed index (%) and herbicide efficiency index (HEI) as influenced by post-emergence herbicides and spray fluid quality in *rabi* maize

Treatments	Weed index (%)	Herbicide efficiency index (HEI)
H_1W_1	36.52	1.01
H_1W_2	42.25	0.88
H_1W_3	22.05	1.40
H_2W_1	27.98	1.19
H_2W_2	29.35	1.14
H_2W_3	12.63	1.66
H_3W_1	60.90	0.39
H_3W_2	66.44	0.22
H_3W_3	48.63	0.71
H_4W_1	54.60	0.58
H_4W_2	55.21	0.55
H_4W_3	48.02	0.74
H_5W_1	19.21	1.55
H_5W_2	20.27	1.45
H_5W_3	3.38	2.05
H_6W_1	10.30	1.78
H_6W_2	11.36	1.70
H_6W_3	1.77	2.19
C_1	71.89	-
C_2	-	3.39

For treatment details see Table 1

Phytotoxicity

The effect of herbicides + adjuvant and spray fluids on phytotoxicity of *rabi* maize were studied 3, 7 and 15 days after herbicide application. The application of halosulfuron methyl + atrazine, tembotrione + atrazine and 2,4-D-dimethylamine alone and in combination with adjuvant with different qualities of spray fluids did not show any phytotoxicity effects on *rabi* maize like yellowing, chlorosis, necrosis, epinasty, hyponasty, scorching and stunting.

Yield

The herbicides + adjuvant and spray fluid combinations showed significant influence on *rabi* maize yield (Table 7). Tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with distilled water gave higher grain and stover yield (5482 and 8547 kg ha^{-1}) followed by tank mix application of halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} with distilled water which were superior to all other treatment interactions. With regard to herbicides + adjuvant and saline water combinations, significantly higher grain and stover yields (5006 and 8154 kg ha^{-1}, respectively) was noted with halosulfuron methyl @ 67.5 g ha^{-1} + atrazine @ 0.5 kg ha^{-1} + AMS @ 2% at 21 DAS with C_3S_1 saline water.

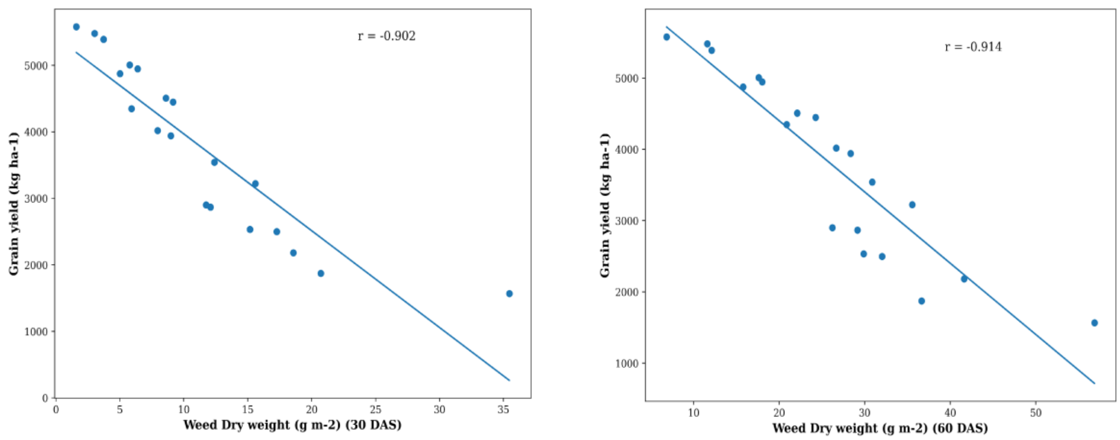
Correlation studies between weed dry weight at 30, 60 DAS and maize grain yield

The scatter plot (Fig. 2a & b) depicting the relationship between weed dry weight at 30 and 60 DAS and maize grain yield showed a strong, statistically significant negative association. The correlation analysis revealed a coefficient of r = -0.902 (a) & -0.914 (b), indicating that early-season weed proliferation markedly compromises yield potential. The pronounced negative slope suggests that the

Table 7: Effect of post-emergence herbicides and spray fluid quality on the yield of *rabi* maize

Herbicides + adjuvant	Grain yield (kg ha^{-1}) Quality of spray fluid				Stover yield (kg ha^{-1}) Quality of spray fluid			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
H_1	3542	3223	4350	3705	6925	6576	7698	7067
H_2	4019	3943	4875	4279	7350	7272	8119	7580
H_3	2182	1873	2867	2307	5463	5454	6199	5706
H_4	2534	2499	2901	2645	5850	5807	6233	5964
H_5	4508	4449	5391	4783	7764	7724	8501	7996
H_6	5006	4947	5482	5145	8154	8140	8547	8280
Mean	3632	3489	4311	-	6918	6829	7549	-
Control 1	-	-	-	1568	-	-	-	5302
Control 2	-	-	-	5580	-	-	-	8577
	H	W	H x W	Control vs Rest	H	W	H x W	Control vs Rest
SEm±	61.99	43.83	107.36	80.02	57.60	40.73	99.76	74.36
$CD_{0.05}$	177.43	125.46	307.32	161.97	164.87	116.58	285.56	150.50

For treatment details see Table 1



A **B**

Fig. 2: Correlation between weed dry weight and maize grain yield at (a) 30, (b) 60 DAS

incremental increase in weed biomass during the early vegetative stages disproportionately suppress maize growth and yield, likely due to competitive interference for light interception, soil nutrients, and moisture (Soltani *et al*., 2016; Rani *et al*., 2022), which are critical for establishing the optimum leaf area and photosynthetic capacity (Saeed *et al*., 2010). The weed competition before canopy closure significantly limits yield formation in maize systems. Efficient suppression of weed biomass prior to this threshold has been shown to improve resource capture, enhance radiation use efficiency, and stabilize grain yield outcomes.

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Author's contribution: KB conducted field experiment, collected data, performed statistical analysis, and prepared the original manuscript. KS designed the experiment, supervised field operations, validated results, and contributed to paper revisions. TRP coordinated laboratory and field resources, supported data interpretation, and guided methodology refinement, and reviewed the manuscript.

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