Indian Journal of Agricultural Sciences **95** (7): 746–752, July 2025/Article
https://doi.org/10.56093/ijas.v95i7.149078

Efficacy, selectivity and economics of metolachlor for weed control in maize (*Zea mays*) and its effect on succeeding chickpea (*Cicer arietinum*)

NEESHU JOSHI[1]*, SHOURABH JOSHI[1], SAMARPAL SINGH[2], BISWAJIT PRAMANICK[3], DINESH JINGER[4], JITENDRA KUMAR SHARMA[5], EKTA JOSHI[6] and HARSH VARDHAN SINGH SHEKHAWAT[5]

Agriculture Research Sub-Station (Agriculture University, Jodhpur, Rajasthan), Sumerpur, Pali, Rajasthan 306 902, India

Received: 01 March 2024; Accepted: 04 June 2025

ABSTRACT

The inverse correlation between maize (*Zea mays* L.) yield and weed density has been well-established over time. Among the various weed management strategies, chemical control is recognized as the most efficacious. An experiment was conducted during 2019 and 2020 at Agriculture Research Sub-Station (Agriculture University, Jodhpur, Rajasthan), Sumerpur, Pali, Rajasthan to evaluate superiorr effectiveness of metolachlor @1000 g a.i./ha and 1200 g a.i./ha in managing broad-leaved weeds and certain grass species, when compared to atrazine applied at 1000 g a.i./ha, in maize cultivation. The maize variety 'PHM-4' was selected for the study. The experiment was laid out in a randomized block design (RBD) having three replication. This resulted in a total weed control efficiency of 63.4% and 61.3% across all crop growth stages. However, it's worth noting that a higher dose of metolachlor at 2000 g a.i./ha showed signs of phytotoxicity on maize, which eventually recovered within 15–20 days post-herbicide treatment. The study concluded that metolachlor at 1000 g a.i./ha effectively combats broad-leaved and some grassy weeds in maize. Notably, the maximum net return was observed with metolachlor at 1000 g a.i./ha, amounting to ₹35,150/ha and ₹51,496/ha during both years. In the subsequent chickpea phase, no treatment was applied, and phytotoxicity was observed in metolachlor at 2400 g a.i./ha, causing yellowing and stunting of plants.

Keywords: Hand weeding, Metolachlor, Phytotoxicity,Weed management, Weed control efficiency

Maize (*Zea mays* L.) ranks as the third most important cereal crop in India, contributing about 10% of the nation's total food grain output. Owing to its outstanding genetic potential for high yields, it is often called the "Queen of Cereals." Maize serves dual purposes, it is cultivated both as a grain crop and as fodder. Among various biotic factors, weeds are the leading cause of yield loss in crops. In India, for example, weed infestation can reduce maize yields by 27–60% due to the vigorous growth and persistence of weeds (Jat *et al.* 2012, Kumar *et al.* 2015). Globally, weed competition similarly poses a major challenge to maize production, with potential yield losses ranging from roughly 27% up to more than 60%, depending on the specific weed species, their density, and the management practices used (Kumar *et al.* 2015).

Common weeds in maize fields include a diverse array of grass, broadleaf, and sedge species. For instance, prevalent grassy and sedge weeds are *Cyperus rotundus*, *Cynodon dactylon*, *Commelina benghalensis*, *Digitaria sanguinalis*, and *Echinochloa colona*. Common broadleaf weeds include *Euphorbia hirta*, *Euphorbia geniculata*, *Parthenium hysterophorus*, *Digera arvensis*, *Phyllanthus niruri*, *Celosia argentea*, and *Acalypha indica (*Gopinath and Kundu 2008). Effective weed control in maize typically involves combining both pre-emergence and post-emergence herbicides to keep fields largely weed-free throughout the growing season (Rawal *et al.* 2018). For example, metolachlor is a commonly used pre-emergence herbicide known for its selective control of weeds in crops like soybean, peanut, and sunflower. Metolachlor is effective against certain annual grasses and broadleaf weeds (Chand *et al.* 2014), making it a key tool in maintaining high maize yields by reducing weed competition.

[1]College of Agriculture (Agriculture University, Ujwa, Rajasthan), Nagaur, Rajasthan; [2]Krishi Vigyan Kendra (National Horticultural Research and Development Foundation), Ujwa, New Delhi; [3]Dr. Rajendra Prasad Central Agricultural University, Sabour, Bihar; [4]ICAR-Indian Institute of Soil and Water Conservation, Vasad, Anand, Gujarat; [5]Agriculture Research Sub-Station (Agriculture University, Jodhpur), Sumerpur, Pali, Rajasthan; [6]Rajmata Vijyaraje Scindia Krishi Vishva Vidhyalaya, Gwalior, Madhya Pradesh. *Corresponding author email: neeshu.joshi@gmail.com

Atrazine, commonly used as a pre-emergence herbicide in maize cultivation, is effective against many broad-leaved and some grassy weeds. However, it exhibits limited efficacy against certain weed species, notably the sedge *Cyperus rotundus* (purple nutsedge) (Singh *et al.* 2022). Therefore, for the broad spectrum control of weeds, Diuron was applied as a pre-emergent herbicide for selective use against both annual and perennial weeds. A study found that diuron applied at 1.68 kg/ha effectively controlled both broadleaved and grassy weeds in maize; however, it exhibited a significant carry-over effect on the succeeding cowpea crop (Sondhia 2007). Diuron is a PS-II inhibiting herbicide which causes loss of chlorophyll (Richburg *et al.* 2020). The primary objective of this study was to evaluate the efficacy of metolachlor at varying application rates (1000, 1200, and 2000 g a.i./ha) in controlling broad-leaved and certain grassy weeds in maize cultivation. The study aimed to compare these treatments with the standard application of atrazine at 1000 g a.i./ha, assessing their impact on weed control efficiency, maize yield, and economic returns. Additionally, the research sought to observe any phytotoxic effects of higher herbicide doses on maize and potential residual impacts on subsequent crops, such as chickpea.

MATERIALS AND METHODS

Field site and experimental design: An experiment was conducted during 2019 and 2020 at Agriculture Research Sub-Station (Agriculture University, Jodhpur, Rajasthan), Sumerpur (25.140°N latitude and 73.100°E longitude), Pali, Rajasthan. During the cropping seasons, the region received a cumulative rainfall of 601.38 mm, with maximum and minimum temperatures fluctuating between 37.0°C and 23.5°C from June to September. Maize was sown on 24th July in 2019 and on 4th July in 2020. Irrigation was scheduled immediately after sowing, and subsequently at 20 and 45 days after sowing (DAS). The experimental soil was classified as sandy clay loam, exhibiting low organic carbon content (0.22%). The particle composition of the soil comprised 55% sand, 35% silt, and 10% clay, with a *p*H level of 7.98. The nutrient status of the soil included available nitrogen, phosphorus, and potassium levels of 152.5 kg/ha, 45.2 kg/ha, and 265 kg/ha, respectively.

The preceding crop grown in the field was chickpea. Following its harvest, a harrowing operation was carried out in May. Prior to maize sowing, primary tillage was performed using a chisel plough, followed by secondary tillage with harrowing and planking to prepare the seedbed.

The maize variety ‘PHM-4’ was sown using a seed rate of 20 kg/ha. Manual sowing was carried out using a spacing of 60 cm × 25 cm, with each experimental plot measuring 5 m × 6 m during both study years. Each plot contained 10 rows of maize. A fertilizer regime consisting of 90 kg/ha nitrogen (N) and 30 kg/ha phosphorus (P) was followed. The full dose of phosphorus was applied as a basal application, while nitrogen was supplied in three split doses using urea. These nitrogen applications corresponded to the BBCH growth stages for maize, as described by SMAP (2011); 50% at stage 0 (germination), 25% at stage 3 (stem elongation), and 25% at stage 5 (inflorescence emergence/heading). The experiment was laid out in a randomized block design (RBD) with three replications. The treatments consisted of Metolachlor 50% EC at 800 g a.i./ha (pre-emergence, PE); Metolachlor 50% EC at 1000 g a.i./ha (PE), Metolachlor 50% EC at 1200 g a.i./ha (PE), Metolachlor 50% EC at 2000 g a.i./ha (PE), Diuron 80% WP at 800 g a.i./ha (PE), Atrazine 50% WP at 1000 g a.i./ha (PE), Hand weeding at 20 and 40 days after sowing (DAS), Weedy check (untreated control). Herbicide treatments were applied using a knapsack sprayer fitted with a flat-fan nozzle, delivering a spray volume of 500 L/ha. Application were done on 26 July 2019 and 06 July 2020.

Crop sampling and observations: Forty-five days after herbicide application, plant sampling was conducted. Four quadrats of 0.25 m² each were randomly placed in each plot and marked with pegs for consistent data collection. Parameters recorded included plant population, weed density, weed dry weight, and weed control efficiency (WCE). Post-harvest, threshing was carried out individually for each plot, and grain yield was recorded in kg/plot. Yield and its components were computed on a net plot basis and expressed in t/ha. Additionally, the economic viability of each treatment was assessed by calculating the net returns and benefit-cost ratio.

WCE (Rao 1986) = [(Weed density in control plot - Weed density in treated plot)/ Weed density in control plot] × 100

The succeeding chickpea crop, variety RSG-974, was sown in mid-November during both study years (2019 and 2020). At the time of sowing, a starter dose of fertilizers comprising 20 kg nitrogen (N)/ha and 40 kg phosphorus (P_2O_5)/ha was applied. All other agronomic practices were carried out in accordance with the standard recommendations for chickpea cultivation.

The yield parameters and overall yields were meticulously recorded and subjected to analysis following the methodology outlined by Rao (1986). Treatment comparisons were made using a t-test with a significance level of 5%. The economic aspects of the study were computed based on the current local market price of maize grains and the associated input costs.

To evaluate the phytotoxicity, a grading system was employed, and the degrees of injury are classified as follows, No injury (0); little stunting, damage or discolouration (1); some loss of standing,stunting/discolouration (2); more pronounced but permanent damage (3); moderate injury, probability of recovery (4); longer injury, recovery (5); serious injury, no recovery (6); serious injury, plant loss (7); almost extinction of few surviving plants (8); few plants alive (9); total destruction (10).

The numerical values provided in the corresponding column represent the phytotoxicity classes corresponding to the observed phytotoxicity symptoms, as outlined by Das (2008). This classification system facilitates a detailed assessment of the impact of various treatments on the plants, aiding in a comprehensive understanding of their effects.

Statistical analysis: Data were statistically analyzed using the standard methodology appropriate for a randomized block design (RBD) with the aid of Single Touch Payroll Reporting (STPR) software. Prior to analysis, the values for weed density and weed dry weight were subjected to a square root transformation using the formula ($\sqrt{x + 1}$), where 'x' denotes the original data. This transformation was performed to improve the data's conformity to the assumptions of normality and homogeneity of variance, facilitating accurate statistical interpretation. An Analysis of Variance (ANOVA) was carried out to evaluate the effects of treatments, following the procedures outlined by Gomez and Gomez (1984). When significant differences among treatments were detected through ANOVA, the treatment means were further compared using Fisher's Least Significant Difference (LSD) test at a 5% level of significance (p<0.05).

RESULTS AND DISCUSSION

Relative weed density prior to herbicide application: An assessment of relative weed density prior to herbicide application in maize fields during the 2019 and 2020 seasons revealed the prevalence of a diverse spectrum of weed species in the untreated control plots. The weed flora primarily comprised grasses, broad-leaved weeds, and sedges. Among the grassy weeds, the relative density in 2019 and 2020 was as follows; *Eleusine indica* (9.0% and 11.8%), *Dactyloctenium aegyptium* (8.1% and 6.9%), *Echinochloa colona* (2.7% and 2.4%), and *Digitaria sanguinalis* (5.4% and 6.4%). The dominant broad-leaved weed species included *Amaranthus viridis* (12.5% in 2019 and 22.8% in 2020), *Digera arvensis* (6.3% and 16.3%), *Euphorbia hirta* (6.3% and 9.8%), *Phyllanthus niruri* (4.7% and 11.4%), and *Cleome viscosa* (6.2% and 7.8%). In terms of sedge species, *Cyperus rotundus* was most dominant, with a relative density of 12.6% in 2019 and 10.8% in 2020, followed by *Cyperus iria* (4.5% and 9.9%). Additionally, *Fumaria parviflora* was also present with 7.3% and 9.2% relative density across the two years, respectively.

Density and dry weight of BLWs, grasses, sedges and total weeds and weed indices: In the maize crop during 2019, the application of metolachlor 50% EC at all doses and the standard check effectively controlled broad-leaved weeds (BLWs), grasses, and sedges, except for specific species like *Eleusine indica, Digitaria sanguinalis, Amaranthus viridis,* and *Euphorbia hirta*. The lower dose of metolachlor at 1000 g a.i./ha was effective in controlling these resistant species. Hand weeding at 20 and 40 days after sowing (DAS) proved to be successful in controlling all weed species. The standard check with atrazine at 1000 g a.i./ha controlled all broad-leaved weeds except *Amaranthus viridis*. Additionally, diuron at 800 g a.i./ha controlled some broad-leaved weeds and grasses, excluding *Digitaria sanguinalis* and *Eleusine indica* (Joshi *et al.* 2016).

Weed density and dry weight of broad-leaved weeds, grasses, and sedges treated with metolachlor at 1000 g a.i./ha were comparable to metolachlor at 1200 g a.i./ha and atrazine at 1000 g a.i./ha during both years (Table 1). Application of metolachlor at 1200 g a.i./ha and twice hand weeding at 20 and 40 DAS showed similar efficacy in total weed density. The observed reduction in weed density in plots subjected to two hand weedings and pre-emergence herbicide treatments is attributed to the effective weed control achieved by these practices (Kebede and Anbasa 2017).

In maize during 2020, at 45 days after application, *Echinochloa colona, Trianthema portulacastrum* and *Cyperus iria* were controlled with the application of metolachlor @1000 g a.i./ha and 1200 g a.i./ha. However, all other species of broad-leaved weeds (BLWs), grasses, and sedges were effectively controlled by all tested doses of metolachlor 50% EC, with the exception of the lowest dose at 800 g a.i./ha, which did not achieve satisfactory control. Twice hand weeding (20 and 40 DAS) controlled almost all the species of weeds. Standard check atrazine @1000 g a.i./ha controlled *Phyllanthus niruri* and *Trianthema monogyna* at this stage and diuron @800 g a.i./ha controlled *Amaranthus viridis* at this stage (Table 1). The most effective weed control, measured by the efficiency against the total weed species at 45 days after application, was observed in the treatment involving hand weeding twice once at 20 days and again at 40 DAS, with control rates reaching 56.46% and 61.19% for the respective years. This performance was comparable to the effectiveness achieved with metolachlor applied at a rate of 1200 g/ha (Table 1). Like the previous season, both lower rates of metolachlor had a high density of broadleaf weeds (*Amaranthus viridis* and *Euphorbia hirta*) compared with atrazine which recorded lower density of *Amaranthus viridis* and *Euphorbia hirta* (Kashe *et al.* 2020).

Yield and yield attributes: Yield and yield characteristics of maize i.e. plant height (cm), seed number/plant, grain number/seed, grain weight/plant (g) and grain yield (t/ha) were significantly affected by different treatments (Table 2). Yield attributing characters like cob length, height at harvest and number of cobs/plant were found at par among the treatments metolachlor @1000 g a.i./ha, metolachlor @1200 g a.i./ha and hand weeding (20 and 40 DAS). During 2019 and 2020, the highest yields (3.25 t/ha and 4.12 t/ha) were obtained from treatment hand weeding (20 and 40 DAS) as compared to metolachlor @1000 g a.i./ha (3.25 t/ha and 4.12 t/ha). The higher yields of these processes are mainly due to more plants per unit area, longer cobs and more cobs/plant. The reduction in weed density resulting from herbicide applications has been correlated with an increase in cob length, leading to a subsequent rise in the number of grains per cob. The enhanced characteristics of the cob are attributed to reduced weed competition and an improved ability of corn to efficiently utilize nutrients, thereby generating greater photosynthetic assimilate (Alptekin *et al.* 2023). Shambulinga and Guggari (2017) reported that the application of atrazine at 1.0 kg/ha as a pre-emergence herbicide, followed by one hand weeding

Table 1 Effect of different weed control treatments on weed density and dry weight of BLWs, grasses and sedges and total weed density and dry weight and WCE in maize (2019 and 2020)

Treatments	Active substance (g a.i./ha)	Dose (ml/ha)	Weed density (no./m^2)						Weed dry weight (g/m^2)						Total weed density (no./m^2)		Total weed dry weight (g/m^2)		WCE (%)	
			BLWs		Grassy		Sedges		BLWs		Grassy		Sedges							
			2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Metolachlor 50% EC	800	1600	11.49 (131.66)	7.97 (62.66)	9.19 (83.66)	6.52 (42.00)	7.69 (59.00)	6.35 (39.66)	6.15 (37.22)	7.33 (53.18)	6.66 (43.47)	4.55 (19.95)	6.66 (43.95)	3.67 (12.63)	9.60 (91.44)	7.00 (48.12)	6.51 (41.55)	5.42 (28.58)	30.74	58.11
Metolachlor 50% EC	1000	2000	11.01 (120.66)	8.78 (76.33)	8.06 (64.33)	6.30 (39.00)	6.34 (39.33)	5.71 (32.00)	5.92 (34.63)	7.94 (62.21)	5.52 (29.88)	4.49 (19.58)	5.36 (28.10)	3.40 (10.67)	8.69 (74.78)	7.07 (49.06)	5.62 (30.87)	5.63 (30.82)	43.00	57.16
Metolachlor 50% EC	1200	2400	10.06 (100.33)	8.77 (76.00)	8.04 (64.00)	5.89 (34.00)	5.93 (34.33)	5.65 (31.33)	5.12 (25.21)	7.97 (62.74)	5.78 (32.51)	3.99 (15.41)	5.16 (25.73)	3.29 (9.89)	8.19 (66.22)	6.93 (47.13)	5.36 (27.82)	5.50 (29.34)	49.80	58.73
Diuron 80% WP	800	1000	13.12 (171.33)	8.80 (76.66)	7.96 (65.53)	6.61 (43.00)	8.19 (66.33)	6.41 (41.00)	6.67 (43.56)	8.00 (63.41)	6.73 (47.22)	4.62 (20.39)	7.40 (54.24)	4.00 (15.59)	10.10 (101.07)	7.38 (53.54)	7.01 (48.34)	5.84 (33.13)	23.31	53.28
Atrazine 50% WP	1000	2000	11.28 (126.66)	8.65 (74.00)	7.21 (56.07)	6.17 (37.33)	7.13 (50.33)	5.92 (34.66)	5.88 (33.70)	8.03 (63.66)	5.02 (26.65)	4.17 (16.70)	6.39 (40.58)	3.44 (11.04)	8.83 (77.69)	7.04 (48.73)	5.85 (33.64)	5.59 (30.47)	41.21	57.71
Hand weeding	-	20 and 40 DAS	9.72 (93.66)	8.42 (70.00)	6.72 (44.33)	5.84 (33.33)	5.87 (33.66)	5.53 (30.00)	4.94 (23.48)	7.76 (59.33)	5.09 (25.18)	3.81 (13.72)	4.96 (23.85)	3.22 (9.43)	7.63 (57.22)	6.73 (44.37)	5.01 (24.17)	5.33 (27.49)	56.46	61.19
Weedy check	-	-	13.95 (193.66)	13.30 (176.00)	10.41 (107.66)	9.40 (87.66)	9.74 (94.00)	9.02 (80.66)	7.02 (48.33)	10.59 (111.22)	9.07 (81.77)	6.99 (48.43)	9.17 (83.40)	5.31 (27.65)	11.52 (131.78)	10.76 (114.87)	8.49 (71.17)	7.95 (62.43)	0.00	0.00
Metolachlor 50% EC	2000	4000	8.15 (65.66)	8.10 (64.00)	6.68 (44.00)	5.66 (31.33)	5.24 (26.66)	5.06 (25.00)	4.14 (16.23)	6.77 (44.85)	4.84 (22.54)	3.74 (13.14)	4.40 (18.44)	2.93 (7.63)	6.81 (45.44)	6.43 (40.37)	4.47 (19.07)	4.78 (21.87)	65.43	64.84
SEM (d)			0.38	0.26	0.72	0.38	0.39	0.45	0.25	0.27	0.58	0.39	0.44	0.29	0.29	0.18	0.26	0.19	3.68	2.13
CD (p=0.05)			1.17	0.81	2.21	1.16	1.21	1.38	0.77	0.83	1.79	1.19	1.35	0.90	0.89	0.56	0.81	0.60	11.28	6.54

*Original values are given in parenthesis. BLF, Broad leaf weeds; WCE, Weed control efficiency.

Table 2 Effect of different weed control treatments on yield attributing characters and yield of maize

Treatments	Active substance (g a.i./ha)	Dose (ml/ha)	Cob length (cm)		Height (cm) at harvest		No. of cobs/ plant		Grain yield (t/ha)	
			2019	2020	2019	2020	2019	2020	2019	2020
Metolachlor 50% EC	800	1600	22.95	23.93	193.67	196.74	0.87	1.17	2.61	3.22
Metolachlor 50% EC	1000	2000	26.87	27.20	210.07	215.27	1.53	1.77	3.25	4.07
Metolachlor 50% EC	1200	2400	26.26	25.60	196	213.33	1.20	1.80	3.02	3.94
Diuron 80% WP	800	1000	24.17	24.67	186.33	190.80	0.73	1.10	2.513	2.92
Atrazine 50% WP	1000	2000	24.80	24.67	185.4	203.19	1.10	1.30	3.176	3.88
Hand weeding	-	20 and 40 DAS	27.33	26.13	195.73	204.16	1.43	1.67	3.15	4.12
Weedy check	-	-	21.69	22.40	137	187.53	0.37	0.60	2.129	2.15
Metolachlor 50% EC	2000	4000	25.03	23.93	181.47	193.00	0.80	1.10	3.004	3.68
SEM (d)				0.77	6.46	5.95	0.12	0.19	0.035	0.27
CD (p=0.05)			NS	2.34	19.77	18.05	0.39	0.60	0.109	0.83

with inter-cultivation at 45 DAS, resulted in the lowest total weed population and weed dry weight/m^2. This integrated weed management approach also led to higher weed control efficiency, as well as improvements in key yield attributes such as cob length, cob girth, grain weight/cob, and overall grain and straw yields of maize. The results of different treatments are shown in Fig. 1.

Yield and yield attributing characters of succeeding crop gram: In both experimental years (2019 and 2020), the subsequent chickpea crop exhibited lower yields, ranging from 1.82 t/ha in the weedy check to 2.35 t/ha in the case of metolachlor at 1000 g a.i./ha. This decline in yield could potentially be attributed to the diminished nutrient availability in the soil, likely depleted by the preceding maize cultivation (Table 3). Interestingly, there were no significant differences observed among the various treatments in chickpea with respect to plant population, plant height, number of pods/plant, number of seeds/pod, seed yield/plant, and overall seed yield during both the years 2019 and 2020 (Table 3). This suggested a uniformity in the performance of the different treatments when it comes to chickpea, emphasizing the need for further investigation into the specific soil nutrient dynamics and management practices that may have influenced the observed trends in yield.

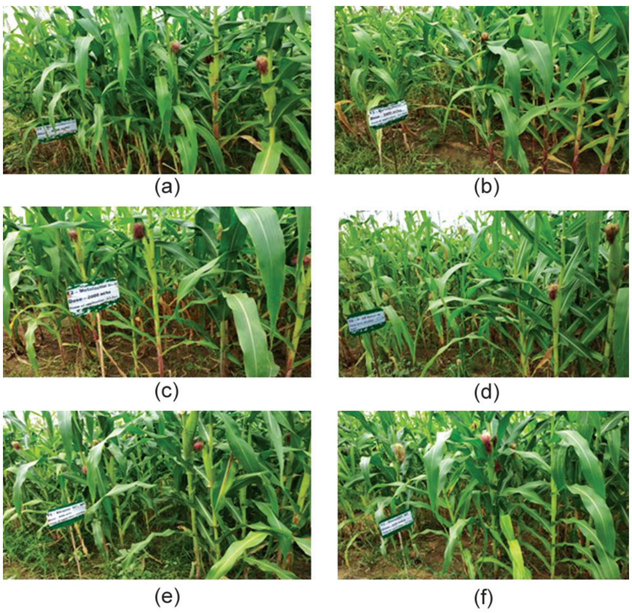

Fig. 1 Effect of different treatments after application of herbicides. (a) Metolachlor @2000 g a.i./ha; (b) Metolachlor @1200 g a.i./ha; (c) Metolachlor @1000 g a.i./ha; (d) Hand weeding at 15 and 30 DAS; (e) Atrazine @1000 g a.i./ ha; (f) Diuron @800 g a.i./ha.

Phytotoxicity symptoms: These were prominently observed in the maize crop treated with metolachlor at 2000 g/ha, resulting in significant yellowing and stunting of plants. Despite efforts to mitigate phytotoxicity, the adverse effects on the plants did not showed signs of recovery. The manifestation of symptoms, such as yellowing and stunting, had a detrimental impact on the photosynthetic activity of the plants. This, in turn, led to a decline in their dry matter production rate, ultimately contributing to a reduction in maize yield. These findings align with similar observations reported by Bahar *et al.* (2009), emphasizing the negative repercussions of phytotoxicity on crop productivity.

It is noteworthy that the results suggested compatibility among all the pre-emergence herbicides employed in the experiment. This compatibility not only increased their overall efficiency but also surpassed the potential phytotoxic effects commonly associated with post-emergence herbicide applications. These insights, as highlighted by Alptekin *et al.* (2023), underscore the importance of understanding herbicide interactions and their implications for crop health and productivity.

Economics: The highest net returns were recorded with the application of metolachlor @1000 g a.i./ha, yielding ₹35,150/ha in 2019 and ₹51,496/ha in 2020. This was followed by metolachlor @1200 g a.i./ha, which resulted in returns of ₹30,760/ha and ₹48,834/ha in 2019 and 2020, respectively. In terms of economic efficiency, the maximum benefit-cost (B:C) ratio was observed with atrazine

Table 3 Residual study of different herbicidal treatments on growth, yield and yield attributes of succeeding crop gram followed by maize and economics in maize for both years

Treatments (Applied to maize crop)	Active substance (g a.i./ha)	Dose (ml/ha)	No. of pods/ plant		No. of seeds/ pod		Seed weight/ plant (g)		Seed yield (t/ha)		Cost of cultivation (₹/ha)	Gross returns (₹/ha)		Net returns (₹/ha)		B:C ratio	
			2019	2020	2019	2020	2019	2020	2019	2020		2019	2020	2019	2020	2019	2020
Metolachlor 50% EC	800	1600	49.96	48.80	68.89	69.00	13.10	13.20	1.93	2.00	19620	44370	56778	24750	37158	1.26	1.89
Metolachlor 50% EC	1000	2000	60.91	61.00	80.91	81.10	14.87	14.67	2.35	2.40	20100	55250	71597	35150	51497	1.75	2.56
Metolachlor 50% EC	1200	2400	56.68	56.98	78.32	78.43	14.21	14.34	2.14	2.32	20580	51340	69414	30760	48834	1.49	2.37
Diuron 80% WP	800	1000	52.65	52.56	73.32	73.45	13.67	13.76	1.90	1.87	17718	42721	51374	25003	33656	1.41	1.90
Atrazine 50% WP	1000	2000	54.40	54.65	77.87	78.00	14.51	14.68	2.11	2.33	18060	53992	68341	35932	50281	1.99	2.78
Hand weeding	-	20 and 40 DAS	51.12	52.00	76.17	76.32	13.67	13.77	2.07	2.11	23700	53550	72547	29850	48847	1.26	2.06
Weedy check	-	-	53.48	53.60	76.01	76.40	13.42	13.56	2.09	2.16	17700	36193	37875	18493	20175	1.04	1.14
Metolachlor 50% EC	2000	4000	47.75	47.43	66.59	66.78	11.92	11.56	1.82	1.90	22500	51068	64733	28568	42233	1.27	1.88
SEM (d)			0.54	1.00	1.00	0.97	0.97	0.22	0.22	0.04	-	-	-	-	-	-	-
CD (p=0.05)			1.59	2.93	2.93	2.84	2.84	0.65	0.65	0.11	-	-	-	-	-	-	-

@1000 g a.i./ha, achieving 1.99 in 2019 and 2.78 in 2020. This was closely followed by metolachlor at 1000 g a.i./ha, with a B:C ratio of 1.75 in 2019 and 2.56 in 2020 (Table 3). These findings are in line with those of Kamble *et al.* (2015), who reported that the most cost-effective and efficient weed management strategy in maize was the pre-emergence application of atrazine at 1.0 kg/ha, supplemented by one hoeing and one manual weeding at 20 DAS. This integrated approach contributed to a notably higher cost-benefit ratio.

In Transitional plain of Luni basin (Zone IIb) of Rajasthan, and situated in south-west part of Rajasthan, maize crop has considerable area and reducing weed pressure for increased yield is a challenge. According to the current study, metolachlor @1000 g a.i./ha showed reduced weed pressure when applied as a pre-emergence herbicide which improved the development of crops and economic yield. Among the various treatments, metolachlor @1000 g a.i./ha also gave maximum net return and B:C ratio. Also, it recorded maximum weed control efficiency and herbicide efficiency index and weed persistence index, during both years as compared to other treatments. In the following chickpea season, no phytotoxic effects were observed in plots previously treated with this herbicide rate, resulting in a commendable seed yield of 2.35 t/ha. This indicates that metolachlor at this dosage does not leave harmful residues that could adversely affect the succeeding crop. Additionally, metolachlor at 1000 g a.i./ha proved effective in controlling a wide range of weed species. This included grassy weeds such as *Echinochloa colona* and *Digitaria sanguinalis*, broad-leaf weeds like *Phyllanthus niruri* and *Trianthema portulacastrum* the latter of which was completely suppressed as well as sedges, notably species of *Cyperus*. This broad-spectrum efficacy underscores its suitability as a pre-emergence herbicide in maize cultivation. This study contributes to the understanding of optimal herbicide application rates for effective weed management in maize, balancing efficacy, crop safety, and economic viability.

REFERENCES

Alptekin H, Ozkan A, Gurbuz R and Kulak M. 2023.Management of weeds in maize by sequential or individual applications of pre- and post-emergence herbicides. *Agriculture* ***13:*** 421. https://doi.org/10.3390/agriculture13020421

0Bahar F A, Singh K N and Malik M A. 2009. Integrated weed management in maize (*Zea mays* L.) under different nitrogen level. *The Indian Journal of Agricultural Sciences* **79**(8): 641–44.

Chand M, Samar S, Dharam B, Narender S and Vijay K. 2014. Halosulfuron Methyl: A new post emergence herbicide in India for effective control of *Cyperus rotundus* in sugarcane and its residual effects on the succeeding crops. *Sugar Technology* **1**: 1–14.

Das T K. 2008. *Weed Science: Basics and Applications*, 1st edn, pp. 901. Jain Brothers Publishers, New Delhi.

Earth Observation Research Branch Team Agriculture and Agri-Food Canada. Crop Identification and BBCH Staging Manual: SMAP-12. 2011**.** Field Campaign, Oklahoma State University. https://smapvex12.espaceweb.usherbrooke.ca/BBCH_STAGING_MANUAL_CEREALS_CORN.pdf

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research,* 2nd edn, pp. 680. John Wiley and Sons, New York.

Gopinath K A and Kundu S. 2008. Effect of dose and time of atrazine application on weeds in maize (*Zea mays*) under mid-hill conditions of north-western Himalayas. *The Indian Journal of Agricultural Sciences* **78**(3): 254–57.

Jat R K, Gopar R and Gupta R. 2012. Conservation agricultural in maize wheat cropping systems of eastern India: Weed dynamics and system productivity. Extended summaries. *(In) 3rd International Agronomy Congress*, New Delhi, India, November 26–30, Vol 3.

Joshi N, Singh V P, Dhyani V C, Singh S P and Pratap T. 2016. Effect of planting geometry and weed management practices on crop growth and yield of direct seeded (Aerobic) rice (*Oryza sativa* L.). *Ecology Environment and Conservation* **22**(April Suppl.): S371–76.

Kamble A S, Yogeesh L N, Prashanth S M, Channabasavanna A S and Channagoudar R F. 2015. Effect of weed management practices on weed growth and yield of maize. *International Journal of Science, Environment and Technology* **4**: 1540–45.

Kashe K, Ketumile D, Kristiansen P, Mahilo C and Moroke T S. 2020. Evaluation of pre-emergence herbicides for weed control in maize. *Welwitschia International Journal of Agricultural Sciences* **2**: 5–19.

Kebede Megersa and Anbasa Fufa. 2017. Efficacy of pre-emergence herbicides for the control of major weeds in maize (*Zea mays* L.) at Bako, Western Oromia, Ethiopia. *American Journal of Agriculture and Forestry* **5**(5): 173–80. doi: 10.11648/j.ajaf.20170505.15

Kumar A, Kumar J, Puniya R, Mahajan A and Lobzang, S. 2015. Weed management in maize-based cropping system. *Indian Journal of Weed Science* **47**(3): 254–66.

Rao V S. 1986. *Principles of Weed Science*, pp. 450. Oxford and IBH Publishing Co. Private Limited, New Delhi.

Rawal S, Dhindwal A S and Punia S S. 2018. Response of furrow irrigated raised bed planted maize (*Zea mays*) to different moisture regimes and herbicides treatments under semi-arid conditions. *The Indian Journal of Agricultural Sciences* **88**(3): 354–60.

Richburg J T, Norsworthy J K, Barber T, Roberts T L Richburg J T, Norsworthy J K, Barber T, Roberts T L and Gbur E E. 2020. Tolerance of corn to pre- and post-applied photosystem-II inhibiting herbicides. *Weed Technology* **34**: 277–83. doi: 10.1017/wet.2019.119.

Shambulinga K M and Guggari A K. 2017. Effect of post emergence herbicides on weed growth and yield of irrigated maize. *Journal of Farm Science* **30**(3): 421–23.

Singh V P, Paliwal A, Pratap T, Singh S P, Kumar A and Shyam, R. 2022. Bio-efficacy of nicosulfuron against mixed weed flora in maize and its residual effect on succeeding crops. *Indian Journal of Weed Science* **54**(3): 251–56.

Sondhia S. 2007. Persistence and leaching behaviour of diuron in a sandy loam soil. *Environmental Monitoring and Assessment* **129**(1–3): 77–83. https://doi.org/10.1007/s10661-006-9428-z