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OPTIMISING THE DOSE OF 2, 4-D SODIUM SALT FOR WEED CONTROL AND ECONOMICS OF *RABI* MAIZE (*ZEA MAYS* L.) IN VARANASI, INDIA

Pratik Sanodiya*

Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, India

ABSTRACT

A field trial was conducted during the *rabi* seasons of 2021 and 2022 at the AICRP Maize Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The aim was to assess the effectiveness of varying doses of 2,4-D sodium salt 80% WP on weed control, crop productivity, and economics of *rabi* maize (*Zea mays* L.). Broad-leaved weeds pose significant threats to maize cultivation due to their unique adaptive characteristics and regenerative abilities, highlighting the importance of effective weed management in crop production. The study aimed to identify the optimal dosage of 2,4-D sodium salt 80% WP to minimize biomass accumulation of broad-leaved weeds while maximizing weed control efficiency. Application of 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 days after sowing (DAS) resulted in reduced weed density and dry weight, increased grain and stover yields, and higher harvest index, leading to greater monetary returns. In contrast, application of 2,4-D sodium salt 80% WP @ 2000 g ha^{-1} at 25 DAS exhibited greater phytotoxic effects compared to the 1250 g ha^{-1} dosage.

Keywords: Grain and stover yields, Phytotoxicity, Weed control efficiency, Weed index

Maize (*Zea mays* L.), a significant cereal crop cultivated across diverse climatic conditions, holds an important position in global agriculture. It is also referred to as 'queen of cereals' due to its remarkable yield potential and is cultivated over 193 million hectares across 170 countries. In 2021, global maize production reached approximately 1.2 billion metric tonnes, with leading producers including the United States, China, Brazil, and India (FAO, 2021). Notably, maize contributes significantly to the United States' economy, boasting a productivity surpassing the global average (>10 t ha^{-1}), while in India, productivity lags at half the global average (2.96 t ha^{-1}) (Anonymous, 2020).

In India, maize ranks as the third most important crop following rice and wheat, covering over 9.86 million hectares and yielding approximately 31.51 million tonnes annually, with a productivity of 3195 kg per hectare (Ministry of Agriculture and Farmers' Welfare, GOI, 2021). Maize thrives across various climates, encompassing extreme semi-arid to sub-humid and humid regions, predominantly occupying 83% of cultivation area in the *kharif* season and nearly 17% in the *rabi* season (Anonymous, 2022).

Broad-leaved weeds pose significant threats to crop cultivation, attributed to their distinctive adaptive traits and regenerative capabilities. Consequently, effective weed management emerges as a pivotal aspect of crop production. Presently, numerous selective herbicides with diverse modes of action are available for weed control in maize. Among them, 2,4-D stands out as a prominent herbicide due to its efficacy in controlling emerging broad-leaved weeds post-crop establishment. Its mechanism of action involves interference with cell division and growth processes in vascular tissues responsible for nutrient and water transport (Shaner, 2014).

By disrupting normal regulatory mechanisms governing cell growth cessation and inducing uncontrolled cell division, 2,4-D leads to the extinction of targeted broad-leaved weeds. Mimicking the natural plant hormone auxin, 2,4-D disrupts auxin signaling pathways in susceptible plants, activating genes associated with cell division and elongation, thereby causing excessive growth in affected tissues (Grossmann, 2010).

Given the problem of weeds in maize, an experiment was conducted to determine the optimal dosage of this herbicide for minimizing weed biomass while maximizing weed control efficiency and yields. In addition to this, phytotoxicity levels in maize were assessed following application of varying herbicide dosages at different intervals post-spraying.

MATERIALS AND METHODS

A field experiment was conducted during *rabi* 2021 and 2022 crop seasons at AICRP Maize Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. The soil characteristics were sandy clay loam,

*Corresponding author: prsanodiya10@gmail.com
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with a pH of 7.40, low levels of available organic carbon (0.41%), available nitrogen (207.47 kg ha^{-1}), and medium levels of available phosphorus (23.85 kg ha^{-1}) and potassium (219.60 kg ha^{-1}). The experimental design was a randomized block design consisting of 7 treatments: weedy, two hand weedings at 20 and 40 days after sowing (DAS), atrazine 50% WP @ 1000 g ha^{-1} as PE, 2, 4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS, 2, 4-D sodium salt 80% WP @ 1000 g ha^{-1}, 2, 4-D sodium salt 80% WP at 750 g ha^{-1}, and weed-free, each replicated thrice. The maize variety 'DHM-121' was manually sown during the first week of December with a seed rate of 25 kg ha^{-1} and row-to-row and plant-to-plant spacing of 60 × 20 cm. A recommended fertilizer dose (150 kg N, 70 kg P_2O_5, and 60 kg K_2O) was applied using urea, single super phosphate, and muriate of potash. Phosphorus and potassium were applied entirely as basal application, while nitrogen was split into two equal parts, applied half as basal and the remaining half in two equal splits at knee-high and tasseling stages of maize. Post-emergence herbicide application was carried out according to the treatments using a knapsack sprayer fitted with an even-fan nozzle @ 300 L ha^{-1}. The crop was cultivated under irrigated conditions following recommended package of practices. Weed biomass (species wise) was measured at 30, 45, and 60 DAS using a quadrat of 0.50 m^2 placed randomly at 2 locations within each plot. Data on weed density and biomass were subjected to square root transformation before analysis. Biometric parameters including yield attributes, grain and stover yields, and crop nutrient uptake were recorded at harvest. The prevailing market prices of inputs during 2022 were utilized to evaluate the economics of integrated weed management treatments. Net return and benefit-cost ratio (BCR) were calculated based on gross returns (Rs ha^{-1}) and cost of cultivation (Rs ha^{-1}). The seed grain price was considered as Rs. 14/kg for gross returns calculation. Differences among treatment means were analyzed using the 'Critical Difference' (CD) method, and means were separated using Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) with the help of software 'Statistical Package for Social Science' (SPSS, IBM Corporation).

Weed control efficiency (%)

Weed control efficiency was determined by calculating the percentage based on the disparity in dry matter production between the treated plots and the control plots (Tripathi and Mishra, 1971).

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

where,

WCE=weed control efficiency (%)

DMC=Dry weight of weeds in untreated control plot (g)

DMT=Dry weight of weeds in treated plot (g)

Weed index (%)

The weed index represents the percentage reduction in grain yield caused by weeds compared to the total yield of the weed-free treatment. It was calculated by the following formula given by Gill and Kumar (1969).

$$\text{Weed Index (\%)} = \frac{\text{Xc - Yt}}{\text{DMC}} \times 100$$

Table 1. Effect of herbicidal treatments on total weed dry weight (g/m²), weed control efficiency (%) and weed index (%) in *rabi* maize (Pooled data of 2021 and 2022)

Treatments	Total weed dry weight (g m^{-2})			Weed control efficiency (%)			Weed index (%)
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	
T_1: Weedy check	28.72	33.95	43.98	0.00	0.00	0.00	75.14
T_2: Hand weeding twice at 20 and 40 DAS	9.45	7.26	7.34	67.09	78.64	83.31	16.79
T_3: Atrazine 50% WP 1000 g ha^{-1} as PE	10.16	9.78	8.80	64.62	71.22	80.08	28.41
T_4: 2,4-D sodium salt 80% WP 750 g ha^{-1} at 25 DAS	17.07	15.54	12.91	40.49	54.28	70.64	58.46
T_5: 2,4-D sodium salt 80% WP 1000 g ha^{-1} at 25 DAS	14.77	13.61	11.10	48.57	59.95	74.76	43.24
T_6: 2,4-D sodium salt 80% WP 1250 g ha^{-1} at 25 DAS	13.66	12.30	9.98	52.43	63.81	77.30	34.92
T_7: Weed free	0.0	0.0	0.0	100.00	100.00	100.00	0.0
CD (0.05)	1.42	1.33	1.10	-	-	-	-
SEm$\pm$	0.41	0.39	0.36	-	-	-	-
CV (%)	7.54	6.41	5.64	-	-	-	-

Table 2. Effect of herbicide treatments on nutrients uptake by *rabi* maize (Pooled data of 2021 and 2022)

Treatments	Nutrients uptake by grains (kg ha^{-1})			Nutrients uptake by stover (kg ha^{-1})		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1: Weedy check	17.57	4.89	3.88	9.92	4.06	32.03
T_2: Hand weeding twice at 20 and 40 DAS	61.21	18.31	16.38	27.81	13.32	84.60
T_3: Atrazine 50% WP 1000 g ha^{-1} as PE	52.66	15.34	13.68	24.19	11.08	73.08
T_4: 2,4-D sodium salt 80% WP 750 g ha^{-1} at 25 DAS	29.60	8.58	7.22	15.22	6.79	46.62
T_5: 2,4-D sodium salt 80% WP 1000 g ha^{-1} at 25 DAS	40.78	11.84	10.52	19.20	9.18	60.09
T_6: 2,4-D sodium salt 80% WP 1250 g ha^{-1} at 25 DAS	47.12	13.95	12.44	22.14	10.83	68.30
T_7: Weed free	74.15	22.01	19.69	32.20	16.10	97.95
CD (0.05)	3.23	0.96	0.85	1.89	0.96	5.77
SEm$\pm$	1.06	0.31	0.28	0.62	0.32	1.90
CV (%)	4.11	4.17	4.18	5.16	5.54	5.10

where,

X_c = Maximum yield treatment or Grain yield from weed free plot

Y_t = Grain yield from treatment for which weed index is to be worked out.

RESULTS AND DISCUSSION

At 30, 45, and 60 days after sowing (DAS), the dry weight of weeds was lower in plots where hand weeding was done twice at 20 and 40 DAS compared to those treated with atrazine 50% WP @ 1000 g ha^{-1} as pre-emergence (PE). Similarly, the total weed dry weight was observed to be lower in plots treated with 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS compared to those treated with 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS. The highest weed control efficiency was found at 30, 45, and 60 DAS in plots treated with hand weeding twice at 20 and 40 DAS, followed by atrazine 50% WP @ 1000 g ha^{-1} as PE, 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS, 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS, and 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS. This study was supported by Kumar *et al.* (2023). The weed index was lower in plots treated with 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS compared to those treated with 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS and was also lower compared to plots treated with 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS, based on the pooled data from 2021 and 2022 (Table 1). Nutrient uptake by grains, specifically NPK, was higher in plots where hand weeding was done twice at 20 and 40 DAS compared to those treated with atrazine 50% WP @ 1000 g ha^{-1} as PE, followed by 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS, 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS, and 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS during both the years (Table 2). Nitrogen (N) and potassium (K) uptake in plots treated with 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS were observed to be higher compared to those treated with 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS, with both treatments being statistically similar to each other. Additionally, plots treated with 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS showed higher N and K uptake compared to those treated with 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS, with both treatments being statistically similar (Table 2). Phosphorus (P) uptake was recorded

Table 3. Phytotoxicity evaluation (0-10 scale) of 2,4-D sodium salt in *rabi* maize at 1, 2, 5, 7 and 10 days after herbicide application (2021)

Treatment	Yellowing					Stunting					Necrosis					Epinasty				
	1	2	5	7	10	1	2	5	7	10	1	2	5	7	10	1	2	5	7	10
Weedy check	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
2,4-D sodium salt 80% WP 1250 g ha^{-1}	4	3	2	3	3	0	0	0	0	0	5	4	3	3	3	1	2	2	1	1
2,4-D sodium salt 80% WP 2000 g ha^{-1}	9	4	5	3	3	0	0	0	0	0	9	7	6	5	4	2	2	2	2	2

Scale: 0–10 where: 0=0%, 1=1–10%; 2=11–20%; 3=21–30%; 4=31–40%; 5= 41–50%; 6=51–60%; 7=61–70%; 8=71–80%; 9=81–90%; 10=91–100%

Table 4. **Phytotoxicity evaluation (0-10 scale) of 2,4-D sodium salt in *rabi* maize at 1, 2, 5, 7 and 10 days after herbicide application (2022)**

Treatment	Yellowing					Stunting					Necrosis					Epinasty				
	1	2	5	7	10	1	2	5	7	10	1	2	5	7	10	1	2	5	7	10
Weedy check	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
2,4-D sodium salt 80% WP 1250 g ha^{-1}	4	4	3	3	3	0	0	0	0	0	6	5	4	3	3	1	2	2	1	1
2, 4-D sodium salt 80% WP 2000 g ha^{-1}	10	5	5	3	3	0	0	0	0	0	10	8	7	5	4	2	2	2	2	2

Scale: 0–10 where: 0=0%, 1=1–10%; 2=11–20%; 3=21–30%; 4=31–40%; 5= 41–50%; 6=51–60%; 7=61–70%; 8=71–80%; 9=81–90%; 10=91–100%

Table 5. Effect of herbicidal treatments on grain and stover yields and economics in *rabi* maize (pooled data of 2021 and 2022)

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B: C
T_1: Weedy check	1440	2255	36045.0	41793.0	5748.0	1.16
T_2: Hand weeding twice at 20 and 40 DAS	4820	5794	52065.0	126448.0	74383.0	2.42
T_3: Atrazine 50% WP 1000 g ha^{-1} as PE	4147	5040	37743.0	109089.0	71346.0	2.89
T_4: 2,4-D sodium salt 80% WP 750 g ha^{-1} at 25 DAS	2406	3237	37245.0	65027.0	27782.0	1.74
T_5: 2,4-D sodium salt 80% WP 1000 g ha^{-1} at 25 DAS	3288	4173	37288.0	87482.0	50194.0	2.34
T_6: 2,4-D sodium salt 80% WP 1250 g ha^{-1} at 25 DAS	3770	4710	37332.0	99885.0	62553.0	2.67
T_7: Weed free	57.3	6709	62745.0	150562.0	87817.0	2.39
CD (0.05)	2.54	3.94	-	-	-	-
SEm$\pm$	0.83	1.30	-	-	-	-
CV (%)	4.06	5.05	-	-	-	-

to be higher in plots treated with 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS compared to those treated with 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS. Furthermore, P uptake was higher in plots treated with 2,4-D sodium salt 80% WP at 1000 g ha^{-1} at 25 DAS compared to those treated with 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS.

Visual phytotoxicity was observed at 1, 2, 5, 7, and 10 days following herbicide application, using a 1-10 scale. This scale ranged from 1 (0-10% phytotoxicity) to 10 (91-100% phytotoxicity). Initially, minimal phytotoxic effects were detected in the maize crop. However, a statistically significant decrease in phytotoxicity was observed over time, from 2 to 10 days after herbicide application. This trend indicated that as the crop advanced through its growth stages, the visual symptoms of phytotoxicity gradually disappeared. Specifically, 2,4-D sodium salt 80% WP applied @ 2000 g ha^{-1} at 25 DAS exhibited higher phytotoxic effects compared to 2,4-D sodium salt 80% WP applied at 1250 g ha^{-1} (Tables 3 and 4) (Kumar *et al.*, 2022).

Higher grain and stover yields were obtained through the practice of hand weeding twice, initially at 20 and subsequently at 40 DAS, followed by the application of atrazine 50% WP @ 1000 g ha^{-1} as pre-emergence (PE), along with 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS, 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS, and 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS. This outcome can be attributed to reduced weed dry weight, improved weed control efficiency, enhanced growth parameters, and better yield indicators (Table 5).

Moreover, greater gross and net returns were realized with the aforementioned method of hand weeding twice at 20 and 40 DAS, followed by atrazine 50% WP @ 1000 g ha^{-1} as PE, combined with the various doses of 2,4-D sodium salt 80% WP @ 25 DAS. Notably, the highest benefit-to-cost (B:C) ratio was associated with the application of atrazine 50% WP @ 1000 g ha^{-1} as PE, followed by 2,4-D sodium salt 80%

WP @ 1250 g ha^{-1} at 25 DAS, hand weeding twice at 20 and 40 DAS, 2,4-D sodium salt 80% WP @ 1000 g ha^{-1} at 25 DAS, and 2,4-D sodium salt 80% WP @ 750 g ha^{-1} at 25 DAS. This trend can be attributed to the higher economic yield and relatively lower cultivation costs (Sanodiya *et al.*, 2013).

Based on the two consecutive seasons study, it can be concluded that the application of 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS effectively managed weeds in *rabi* hybrid maize fields. This treatment not only resulted in superior weed control but also yielded higher net returns, achieving a B:C ratio of 2.67. Therefore, for optimal weed control, enhanced nutrient uptake, and increased yields of *rabi* maize in the agro-climatic conditions of Varanasi, Uttar Pradesh, situated within the North Indian plains, the application of 2,4-D sodium salt 80% WP @ 1250 g ha^{-1} at 25 DAS is suggested.

Authors' contribution

Planning and execution of research in the field, data collection, analysis of the data, and manuscript writing (PS).

Conflict of interest

Author declares that there is no conflict of interest.

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