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Impact of Weed Management Practices on Growth and Yield of Spring Maize under Different Irrigation Levels

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ABSTRACT: A field experiment was conducted at G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India, during the Spring seasons of 2022 and 2023 to assess the impact of moisture regimes and herbicide efficacy in maize (*Zea mays* L.). The experiment employed a split-plot design, with the main plots assigned to two irrigation levels: IW/CPE 0.8 and IW/CPE 1.2. Within each main plot, eight weed management treatments were evaluated, including atrazine 1000 g/ha, tembotrione 120 g/ha, topramezone 25.2 g/ha, atrazine 1000 g/ha followed by hand-weeding, atrazine 1000 g/ha followed by tembotrione 120 g/ha, atrazine 1000 g/ha followed by topramezone 25.2 g/ha, a weed-free control, and a weedy check. Each treatment was replicated three times in subplots. The economic analysis revealed that irrigation at an IW:CPE ratio of 1.2 recorded significantly higher net returns of ₹72232/ha. Among the weed management treatments, Atrazine 1000 g/ha followed by Topramezone 25.2 g/ha resulted in the lowest nutrient removal by weeds and attained the highest net income of ₹77961/ha, with Atrazine 1000 g/ha followed by Tembotrione 120 g/ha generating the next highest net income of ₹72651/ha. The two-year investigation concluded that the optimal approach for effective herbicide efficacy, increased maize productivity and maximized net returns in the *Tarai* region of Uttarakhand is the pre-emergence application of Atrazine 1000 g /ha followed by post-emergence Topramezone 25.2 g/ha, coupled with irrigation at an IW/CPE ratio of 1.2.

Keywords: Economics, Herbicides, Herbicide efficiency index, Irrigation levels, Maize.

INTRODUCTION

Maize is the third most important cereal crop worldwide, largely due to its high productivity potential and adaptability to diverse environments. Grown year-round, it ranks as one of India's major cereal crops after rice and wheat. With a cultivation area exceeding 9.89 million hectares, India's maize productivity stands at 3,100 kg/ha, resulting in a total production of 31.65 million tonnes. This significant output contributes approximately 9% to the country's overall food supply (IIMR, 2021). By 2050, global demand for maize is projected to double (Tilman *et al.,* 2011). However, there is a big gap between maize grain yield in India and the major maize producing countries which is attributed to many biotic and abiotic challenges in maize cultivation in India. The initial slow growth and wide spacing of maize plants render them susceptible to heavy weed infestations, which can substantially diminish yields. Mukhtar *et al.* (2007) underscores that unchecked weed growth in maize fields can lead to yield reductions ranging from 67% to 79% during the summer season. Additionally, under weedy conditions, maize plants may experience an average reduction of 65% in plant height, further exacerbating yield losses. Moreover, a concerning report on maize yield losses in India, documented by Zaidi *et al.* (2010), indicates that approximately 25-30% of the maize crop is lost annually due to drought and waterlogging events. Under drought conditions, herbicide application rates may need to be increased by 25-50% to achieve effective weed control compared to moist conditions (Ibrahim *et al.,* 2021). These losses underscore the pressing need for implementing climate-resilient agricultural strategies to mitigate the impact of adverse climatic conditions on maize production. Precipitation and soil moisture significantly influence herbicide uptake, either by washing the spray droplets off leaf surfaces or by diluting the herbicide to a less effective form (Varanasi *et al.,* 2016). Conversely, moisture stress throughout the growing season may adversely affect both plant growth and herbicide efficacy. Maintaining optimal soil moisture levels through appropriate irrigation and timing herbicide applications in anticipation of precipitation events are critical strategies for maximizing herbicide efficacy and achieving effective weed control. The IW/CPE ratio, a recognized irrigation scheduling factor, plays a pivotal role in optimizing herbicide efficacy. By aligning irrigation practices with cumulative pan evaporation, this technique ensures that soil moisture levels are maintained at an optimal level for effective weed control while minimizing water loss. Consequently, the objective of this research was to reduce weed density while enhancing spring maize yield by optimizing the irrigation levels and identifying the most effective herbicide treatments.

MATERIALS AND METHODS

Study site: The experiment was conducted at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, during the spring seasons of 2022 and 2023. It utilized a split-plot design with 16 treatment combinations, comprising two irrigation levels and eight weed management treatments. The primary plot factor included two irrigation levels: IW/CPE: 0.8 (I_1) and IW/CPE: 1.2 (I_2) cumulative pan evaporation (CPE) intervals. The sub-plots were assigned the following weed management treatments: atrazine 1000 g/ha (W_1), tembotrione 120g/ha (W_2), topramezone 25.2g/ha (W_3), atrazine 1000 g/ha followed by hand-weeding (35 DAS) (W_4), atrazine 1000 g/ha followed by tembotrione 120g/ha (W_5), atrazine 1000 g/ha followed by topramezone 25.2g/ha (W_6), weed-free (W_7) and weedy check (W_8). Each treatment combination was replicated three times. The soil was characterized as sandy loam with a pH of 7, electrical conductivity of 0.25 dS/m, organic matter content of 0.72%, available nitrogen of 281 kg/ha, available phosphorus of 25 kg/ha, and extractable potassium of 184 kg/ha. Maize hybrid Pioneer-1899 was sown on February 19th, 2022, and February 28th, 2023, with a seed rate of 20 kg/ha and a spacing of 60×20 cm. The crop received fertilization at a rate of 120:60:40 N, P_2O_5, and K_2O kg/ha. Daily pan evaporation and rainfall data were collected from the meteorological observatory at the research farm of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, to compute the Cumulative Pan Evaporation (CPE) values. During the maize crop seasons of 2022 and 2023, 98.6 mm and 223.0 mm of rainfall were recorded, respectively, accompanied by corresponding pan evaporation values of 486.4 mm and 668.4 mm. Nutrient uptake by weeds (Nye and Tinker 1977), growth parameters, yield and economics were determined following the standard procedures.

Statistical analysis. The recorded data of the present study were analyzed OPSTAT statistical program developed by HISAR (Sheoran *et al.,* 1998).

RESULTS AND DISCUSSIONS

A. Nutrient removal by weeds

In 2022, varying irrigation levels significantly impacted NPK uptake by weeds at harvest. Higher weed density and biomass under the IW/CPE 0.8 regime led to more pronounced NPK depletion compared to IW/CPE 1.2, where sufficient soil moisture likely enhanced herbicide efficacy (Table 1). Under moisture-stressed conditions in IW/CPE 0.8, *Cyperus rotundus* demonstrated competitive dominance over other weed species due to its deep-water access and efficient tuber-based water storage mechanisms. Weeds in IW/CPE 0.8 likely developed more extensive root systems to exploit limited soil moisture and nutrients, thereby intensifying competition with the crop for NPK resources. Murthy *et al.* (2013) reported similar findings of increased nutrient uptake by weeds under IW/CPE 0.8 compared to the higher irrigation level of IW/CPE 1.2. In 2023, no significant differences were observed between the irrigation levels, likely due to the combination of irrigation with erratic rainfall during critical crop growth stages, which exacerbated weed density and biomass across both irrigation regimes (Table 1).

All weed management treatments significantly mitigated NPK removal by weeds at the crop's harvest stage compared to the untreated control. Among these treatments, the lowest NPK uptake was observed with the application of atrazine at 1000 g/ha *fb* topramezone at 25.2 g/ha, which was comparable to atrazine at 1000 g/ha *fb* tembotrione at 120 g/ha (Table 1). Similar findings were reported by Rani *et al.* (2022); Kumar *et al.* (2022). Sole applications of topramezone at 25.2 g/ha and tembotrione at 120 g/ha were initially effective in controlling emerged weeds but failed to address the weed seed bank, allowing subsequent emergence and proliferation of weeds in later crop growth stages. The highest nutrient removal was recorded in the weedy check plot, which was significantly greater than all other treatments.

B. Herbicide efficiency index

Pooled data analysis revealed that herbicide efficiency index was not significantly influenced by irrigation levels. In 2022, applying irrigation based on IW/CPE 1.2 shortly after herbicide application likely enhanced absorption, translocation and metabolism, boosting foliar herbicide effectiveness compared to IW/CPE 0.8 (Table 3). Conversely, irrigation at IW/CPE 0.8, applied two weeks post-herbicide application, may have increased herbicide adsorption to soil particles, reducing root uptake. Additionally, water-deficit conditions in IW/CPE 0.8 could have thickened leaf cuticles, altered epicuticular wax composition, and increased total wax content, inhibiting post-emergent herbicide absorption and penetration (Peerzada, 2021). However in 2023, no substantial variance in herbicide efficiency index was observed, likely due to heavy rainfall shortly after post-emergence herbicide application, diminishing the rainfastness of water-soluble herbicides and leading to equitable efficacy across irrigation levels. Differences in rainfall between the two years likely influenced herbicide efficacy.

Among the weed management treatments, at 45 DAS, the highest herbicide efficiency index was achieved with atrazine 1000g/ha *fb* hand-weeding at 35 DAS (3.0), likely due to the complete removal of existing weeds, reducing overall weed dry matter accumulation (Table 3). The next best treatment in increasing the efficacy of herbicide was sequential application of atrazine 1000g/ha *fb* topramezone 25.2g/ha (2.54), closely followed by atrazine 1000g/ha *fb* tembotrione 120g/ha (2.34). This success is attributed to the sequential application of herbicides with diverse modes of action, targeting different biochemical pathways of weeds throughout the growing season.

C. Growth attributes and yield

Pooled data from two years revealed a significant impact of different irrigation levels on growth attributes and yield. Irrigation at IW/CPE 1.2 markedly influenced plant height (61.8 cm), leaf area index (2.16), stem girth (6.89 cm), dry matter accumulation (509.8g) and grain yield (6.8 t/ha) (Table 2 & 3). Frequent irrigation at IW/CPE 1.2 ensured consistent soil moisture throughout the growing season, facilitating the expansion of leaf surface area, optimizing photosynthetic efficiency, and enhancing carbohydrate production. Optimal irrigation at IW/CPE 1.2 prolongs the vegetative growth period of plants, allowing for more extensive dry matter accumulation before reaching maturity compare to water stress induced in lower level of irrigation IW/CPE 0.8.Present results have been found to be in close agreement with Singh *et al.* (2016); Brar and Vasisht (2020) who reported higher dry matter in spring maize at under well-watered condition compare to water stress. This resulted in the development of larger, more robust ears with well-filled kernels. Similar findings regarding increased plant height and stem girth with more frequent irrigation were reported by Parmar *et al.* (2016); Ahirwar *et al.* (2023).

Plant height (69 cm) at 30 DAS, stem girth (6.38 cm) at 45 DAS, dry matter accumulation at 45 DAS (557.08g) and grain yield (6.8 t/ha) were significantly higher in the weed-free plot, which was statistically comparable to the treatments of atrazine at 1000 g/ha *fb* topramezone at 25.2 g/ha and atrazine at 1000 g/ha *fb* tembotrione at 120 g/ha (Table 2 & 3). Negalur *et al.* (2020) also documented an increase in plant dry matter with the sequential application of pre-emergence atrazine followed by post-emergence topramezone or tembotrione. Growth attributes and grain yield in the weedy check were significantly lower in both years. During the initial stages of crop growth, atrazine effectively inhibits weed seed germination or disrupts early seedling development, thereby significantly reducing weed populations in the field. Post-emergence herbicides, topramezone and tembotrione, further controlled all weed species, including those that survived the initial atrazine application, by depleting carotenoids and inhibiting chloroplast development, leading to foliar bleaching and necrosis (Fluttert *et al.,* 2022). This reduction in weed competition enhances the crop's vegetative and reproductive potential by physically suppressing weed emergence and growth, depriving them of essential resources such as nutrients, moisture, light, and space. These findings align with those reported by Verma *et al.* (2020); Rani *et al.* (2022).

D. Chlorophyll content index

The higher Leaf Area Index (LAI) and increased dry matter accumulation under IW/CPE 1.2 may have contributed to elevated chlorophyll content in leaves at 45 DAS compared to IW/CPE 0.8 (Table 2). Plants under water stress conditions of IW/CPE 0.8 often experience leaf damage, wilting, or premature senescence, which limits CO_2 availability for chlorophyll synthesis, resulting in reduced chlorophyll content. Similar declines in chlorophyll content under water stress conditions have been reported by Ramachandiran and Pazhanivelan (2016); Kapoor *et al.* (2020).

Weed management significantly influenced maize chlorophyll content index (CCI). At 45 DAS, sequential atrazine 1000g/ha *fb* topramezone 25.2g/ha (25.87) application achieved the highest CCI, ensuring continuous weed control and maximizing chlorophyll content (Table 2). Treatments with atrazine 1000g/ha *fb* tembotrione 120g/ha (25.40) and atrazine 1000g/ha *fb* hand-weeding at 35 DAS (25.15) showed comparable CCI values, indicating their effectiveness in promoting chlorophyll synthesis. Weedy check plots exhibited the lowest Chlorophyll Content Index (CCI), highlighting the detrimental effects of weed competition on maize chlorophyll levels. This observation aligns with the findings of Tawaha and Mohammad (2021); Singh *et al.* (2023), who similarly reported reduced chlorophyll content in weedy check plots compared to those treated with herbicides.

E. Economics

The net monetary returns (₹72232/ha) in maize were significantly higher with irrigation at IW/CPE 1.2 (Table 3). The optimal soil moisture conditions provided by IW/CPE 1.2 fostered vigorous growth and development of maize plants, leading to superior crop performance and higher grain yields, which more than compensated for the additional costs associated with frequent irrigation.

Among the weed management treatments, the highest net return (₹77961/ha) was achieved with the application of atrazine at 1000 g/ha *fb* topramezone at 25.2 g/ha, closely followed by the weed-free treatment and atrazine at 1000 g/ha *fb* tembotrione at 120g/ha (Table 3). The lowest net return (₹32867/ha) was observed in the weedy check, attributed to severe weed infestation and consequent yield reduction. These findings are consistent with the results reported by Rani *et al.* (2022); Reddy *et al.* (2022); Kaul *et al.* (2023).

CONCLUSIONS

The study concluded that irrigation scheduled at IW/CPE 1.2, coupled with a sequential application of a pre-emergence (PE) treatment of atrazine at 1000 g/ha followed by a post-emergence (PoE) application of topramezone at 25.2 g/ha (25 DAS), was the most effective treatment combination for reducing nutrient removal by weeds, enhancing herbicide efficacy, and achieving higher maize productivity. This approach maximized maize grain yield and economic returns, proving particularly beneficial for improving the productivity and profitability of spring-planted maize under various irrigation levels and weed management practices.

Table 1: Effect of irrigation levels and weed management on nutrient uptake (kg/ha) by weeds in spring-planted maize at harvest.

Treatment	2022			2023		
	N	P	K	N	P	K
Irrigation level						
IW: CPE 0.8	28.0	14.0	24.0	24.2	11.1	21.3
IW: CPE 1.2	23.4	10.4	20.6	28.4	14.8	24.3
SEm (±)	0.42	0.47	0.49	0.39	0.51	0.38
CD (5%)	2.56	2.88	3.00	2.40	3.10	2.31
Weed management treatment						
Atrazine 50% WP (1000g/ha)	49.5	17.7	36.3	49.8	18.3	37.0
Tembotrione 34.4% SC (120g/ha)	20.8	13.0	15.7	21.9	13.9	16.1
Topramezone 33.6% SC (25.2 g/ha)	21.2	12.9	15.8	22.1	13.5	16.1
Atrazine 50% WP (1000g/ha) *fb* one hand weeding at 35 DAS	18.6	12.7	36.6	18.3	13.4	37.0
Atrazine 50% WP (1000g/ha) *fb* Tembotrione 34.4% SC (120g/ha)	12.0	8.1	11.3	12.1	8.4	11.2
Atrazine 50% WP (1000g/ha) *fb* Topramezone 33.6% SC (25.2g/ha)	12.0	8.0	11.0	12.1	8.1	11.3
Weed free	0.00	0.00	0.00	0.00	0.00	0.00
Weedy check	71.2	25.6	52.1	74.2	28.0	53.7
Sem (±)	0.72	0.88	0.59	0.73	0.90	0.58
CD (5%)	2.07	2.55	1.70	2.12	2.60	1.68

Table 2: Effect of irrigation level and weed management on growth attributes at 45 DAS and chlorophyll content index of spring planted maize (Pooled data).

Treatment	Plant height (cm)	Leaf area index	Stem girth (cm)	Dry matter accumulation (g)	Chlorophyll content index
Irrigation level					
IW: CPE 0.8	68.7	2.02	6.12	464.8	21.85
IW: CPE 1.2	61.8	2.16	6.89	509.8	25.87
SEm (±)	0.69	0.02	0.07	4.66	0.36
CD (5%)	NS	0.08	0.54	17.30	1.33
Weed management treatment					
Atrazine 50% WP (1000g/ha)	60.8	2.03	6.14	454.47	21.37
Tembotrione 34.4% SC (120g/ha)	58.7	2.08	6.27	479.83	22.95
Topramezone 33.6% SC (25.2 g/ha)	59.2	2.08	6.44	476.51	23.53
Atrazine 50% WP (1000g/ha) *fb* one hand weeding at 35 DAS	60.8	2.18	6.72	500.48	25.15
Atrazine 50% WP (1000g/ha) *fb* Tembotrione 34.4% SC (120g/ha)	63.2	2.14	6.68	498.55	25.40
Atrazine 50% WP (1000g/ha) *fb* Topramezone 33.6% SC (25.2g/ha)	63.4	2.16	6.74	499.62	25.51
Weed free	69.0	2.21	7.14	557.08	26.98
Weedy check	55.0	1.83	5.98	431.76	19.96
Sem (±)	1.38	0.04	0.13	8.62	0.53
CD (5%)	3.89	0.11	0.35	24.36	1.49

Table 3: Effect of irrigation interval and weed management on herbicide efficiency index at 45 DAS, yield and economics in spring planted maize (pooled mean).

Treatment	Herbicide efficiency index (%)	Grain yield (t/ha)	Net return (₹/ha)
Irrigation level			
IW: CPE 0.8	1.44	5.27	57512
IW: CPE 1.2	1.37	6.04	72232
SEm (±)	0.25	0.05	-
CD (5%)	NS	0.17	-
Weed management treatment			
Atrazine 50% WP (1000g/ha)	0.61	4.94	56734
Tembotrione 34.4% SC (120g/ha)	1.28	5.60	65620
Topramezone 33.6% SC (25.2 g/ha)	1.46	5.81	69813
Atrazine 50% WP (1000g/ha) *fb* one hand weeding at 35 DAS	3.00	5.97	71023
Atrazine 50% WP (1000g/ha) *fb*Tembotrione 34.4% SC (120g/ha)	2.34	6.04	72651
Atrazine 50% WP (1000g/ha) *fb* Topramezone 33.6% SC (25.2g/ha)	2.54	6.32	77961
Weed free	0.00	6.91	72307
Weedy check	0.00	3.63	32867
Sem (±)	0.12	0.12	-
CD (5%)	0.33	0.35	-

FUTURE SCOPE

The future scope for weed management strategies in spring-planted maize across varying irrigation levels in the Tarai region of India encompasses region-specific herbicide efficacy trials, tailored to local climatic and edaphic conditions. Monitoring herbicide resistance and enhancing water use efficiency through precise irrigation scheduling will be essential. Moreover, farmer education and the integration of precision agriculture technologies will be pivotal in advancing sustainable weed control in the region.

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Conflict of Interest. None.

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