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Impact of Sowing Methods, Weed Management, and Growth Promoters on the Economics and Nutrient Dynamics of *Kharif* Maize (*Zea mays* L.)

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was carried out during two consecutive *kharif* season in the year 2022 and 2023 at the Students Instructional Farm in the Department of Agronomy of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P). The experiment was laid-out in a split plot design. Sowing methods was done in the main plots and weed management practices in the sub plots along-with growth promoters in three replications. There were two sowing methods *viz*; Conventional methods (S_1) and Ridge methods (S_2). Whereas weed management practices were five; Weed Free (W_1), Weedy Check (W_2), Atrazine Pre-emergence @ 1.25 Kg /ha (W_3), Halosulfuron methyl Post-emergence @ 65g a.i./ha (W_4), Atrazine Pre-emergence @ 0.75 l/ha + Halosulfuron methyl Post-emergence @ 35g ai./ha (W_5). and there was Growth promoters' practices were three *viz*; Gibberellic acid (Sayish) (G_1), Amino acid + Humic acid (Spring ever) (G_2), Cytokinins + Enzymes (Ambition) (G_3). Sowing was done on the 10th and 13th of July during 2022 and 2023, respectively using hybrid maize DKC-9144. The crop was harvested at full ripe stage on 11 October and 14 October, in 2022 and 2023, respectively. The best results in economics of various treatments and available nutrients in soil was observed under S_2 (Ridge method) treatment in case of sowing methods, W_2 (weed free) treatment in weed control practices and G_3 (Cytokinins + Enzymes) in plant growth promoter.

Keywords: Humic acid; cytokinins; gibberellic acid; conventional methods; weed management; economics.

1. INTRODUCTION

Maize (*Zea mays* L.) is a highly adaptable and versatile crop, known for its exceptional genetic yield potential among food grains. It plays a crucial role in agriculture, serving as both a staple food for humans and feed for livestock. Often referred to as the "Queen of cereals," maize is integral to numerous industrial applications, including the production of starch, oil, protein, beverages, food sweeteners, pharmaceuticals, cosmetics, textiles, gums, packaging, and paper. Globally, maize is grown on approximately 207.25 million hectares across 160 countries, with a total production of 1217.30 million tons and an average yield of 5.87 metric tons per hectare. In India, maize ranks as the third most important cereal crop after rice and wheat, covering 10.10 million hectares and yielding 33.60 million tons, with an average productivity of 3.33 metric tons per hectare. In Uttar Pradesh, maize is cultivated in approximately 0.73 million hectares, producing approximately 1.78 million tons with a productivity of about 2448 kg per hectare. This productivity is below the national average [1], despite the state's significant role in maize cultivation.

The sowing method plays a crucial role in boosting maize yields. Traditionally, farmers use the broadcast method, which has several drawbacks including uneven seed distribution, inconsistent planting depth, and seeds being scattered and potentially consumed by birds. Improving planting techniques could lead to higher maize productivity, contributing to food and feed self-sufficiency. Research has shown that maize and sorghum planted on slopes can yield 14 to 106 percent and 6 to 59 percent more, respectively, compared to planting on level beds. Additionally, ridge sowing has been found to enhance plant fresh weight, seedling emergence, and ultimately, grain yield [2]. Various planting methods, including broadcasting, drilling, and dibbling, are used on different terrains. Techniques like flat and ridge sowing are particularly effective [3]. Moreover, appropriate planting methods can improve drainage, helping to reduce flooding during irrigation and heavy pre-monsoon rains. Using methods such as sowing on beds and ridges can help achieve these benefits. Weeds usually reduces crop yield up to 31.5% (22.7% in Rabi and in kharif 36.5%). But as farmers adopt some kind of weeding on their crop field, a conservative estimate of 10% loss in crop yields may be taken as more realistic, hand weeding is most effective if done in time, though it is costly and time consuming. Apart from this, labourers are not available for weeding sowing to other agricultural operation going on simultaneously. Additionally, manual method of weed control cannot be put into practice until weeds have achieved certain heights. In *kharif* maize, problem of severe weed infestation level combined with various species of weeds. Almost every type of weeds namely grassy, broad leaved and sedges infest the

maize fields. As they compete for moisture, nutrients, space, light, shelter for many diseases and pest ultimately disturbs the growth of the plants, reduce the yield and deteriorates the quality of crop, hence reduce the protein and starch content [4].

Gibberellins are probably one of the growth regulators that have a significant effect on flowering. Dwarfing depends upon gibberellin deficiency and dwarfing gene effects on gibberellin biosynthesis. Thus, dwarf maize mutants were treated with gibberellic acid, and after hormone treatment, their growth returned to normal. Tall stems also contain more bioactive gibberellin than short stems do [5]. The method of spraying plant growth regulators (PGRs) is used to promote the formation of maize biomass; therefore, high-quality maize can be produced. By controlling the transmission and metabolism of plant endogenous hormone signals, PGRs can improve plant shape and yield [6].

The land configuration practices of furrow sowing reduced maximum gross income (Rs. 78923.50 ha), not (Rs. 58966.9 ha) and BC ratio (2.96 ha). Ridge bed sowing and BBF sowing, on the other hand, recorded higher gross income (Rs. 77292.50 ha, Rs. 76630.50 ha), net income (Rs. 57337.9 ha, Rs. 56675.9 ha), and BC ratio (2.87, 2.84), respectively, minimum gross return (Rs. 75301.50 ha), (Rs. 55546.9 ha), and BC ratio (2.81) with flatbed broad casting. Kumar et al..[7].

2. METHODS AND MATERIALS

Experimental site: A field experiment was conducted during two consecutive *kharif* season of 2022 and 2023 at Student's Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The Kanpur Nagar is a city in central Uttar Pradesh situated at 125.9 meters above sea level on the alluvial tract of the Gangetic plains. It is coordinated at 25° - 28° North latitude and 79°- 80° East longitude. This northern zone is characterized by the semi-arid climate and rich alluvial soil s. About 935 mm of rainfalls is received each year on average. The soil of experiment plot was sandy loam in texture having 0.45% organic carbon, 190.7 kg/ha available N, 11.85 kg/ha available P and 171.16kg ha^{-1} K in both the years. To assess the most suitable hybrid maize variety for effect of sowing methods, weed management and growth promoters on weed dynamics, growth, and economics. The experiment was implemented on the10th and 13th of July during the year 2022 2023, respectively using hybrid maize DKC-9144. The crop was harvested at full ripe stage on the 11th of October and 14th of October in 2022 and 2023, respectively.

Treatment details: The experiment was laid-out in a split plot design in 3 factors with 3 replications. Main plot: Sowing Method-2 *i.e.* (S_1) Conventional Method, (S_2) Ridge Method. Sub Plot: Weed Management- 5. (W_1) Weed Free, (W_2) Weedy Check, (W_3) Atrazine Pre-emergence @ 1.25 Kg/ha), (W_4) Halosulfuron methyl Post-emergence @ 65g a.i./ha, (W_5) Atrazine Pre-emergence @ 0.75 l/ha + Halosulfuron methyl Post-emergence @ 35g ai./ha and Sub-Sub Plot Treatments:- Growth Promoters- 3 (G_1) Gibberellic acid (Sayish), (G_2) Amino acid + Humic acid (Spring ever), (G_3) Cytokinins + Enzymes (Ambition).

Fertilizer Application: The recommended dose of fertilizer (NPK: 120:60:40 Kg ha^{-1} was applied uniformly in each plot. Nitrogen was applied as treatments through urea, half as basal dose and remaining half at 45 days ofter sowing. Phosphorus and potassium were applied respectively.

Economics: The gross monetary returns in rupees per hectare were worked out on the basis of maize yield and green biomass yield. The prevailing market price of maize grains and stover were considered.

Cost of cultivation (ha^{-1}): Cost of cultivation for different treatments were worked out by considering all the expenses incurred in the cultivation of experimental crop and added with variable cost due to treatment.

Gross monetary returns (ha^{-1}): The gross monetary returns were calculated by considering the prices of maize cobs and stover yield prevailing in the market at the time of harvest. The money value of both grain and stover yield was added together in order to achieve gross monetary return ha^{1}.

Net monetary returns (ha^{-1}): The net monetary return was calculated by deducting the cost of cultivation from the gross monetary returns.

Net monetary returns = Gross monetry income - Total cost of cultivation

Benefit: cost ratio (B: C ratio): The benefit cost ratio was calculated as follows;

B: C ratio = Gross monetary returns (ha^{1}) / Cost of cultivation (ha^{1})

Available Nutrients:

Available nitrogen: Total nitrogen was determined by alkaline potassium permanganate as advocated by Subbiah and Asija [8].

Available phosphorus: - Available phosphorous was determined calorimetrically extracting by 0.5 M NaHCO3 (pH 8.3) extracting as given by Olsen et al. [9].

Available potassium: - Available potassium was first extracted by using 1 N NH_2OAC (pH 7.0) Morgan's solution and estimated by Flame photometer as described by Jackson [10].

3. RESULTS AND DISCUSSION

3.1 Cost of Cultivation

The data was depicted in Table 1. Effect of different sowing methods on cost of cultivation of maize during kharif season recorded of non-significant. At different days after sowing the ridge method recorded highest cost of cultivation in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 51475 (Rs. ha^{-1}) of cost of cultivation which is greater than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 54454 (Rs. ha^{-1}) of cost of cultivation which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher cost of cultivation in comparison of conventional method of sowing which are 55181 (Rs. ha^{-1}).

In a study on weed management practices, the cost of cultivation varied significantly across treatments over two years. In 2022, the weed-free treatment (W_2) had the highest cost at 53,690 Rs ha^{-1}, while the lowest cost was observed in the weedy check (W_1) at 46,556 Rs ha^{-1}. In 2023, the weed-free treatment (W_2) again recorded the highest cost at 56,673 Rs ha^{-1}, with the weedy check (W_1) at 49,533 Rs ha^{-1}. The pooled data confirmed that the weed-free treatment (W_2) had the highest average cost of 55,181 Rs ha^{-1}. Among herbicide treatments, Atrazine pre-emergence at 0.75 l/ha combined with Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) had the next highest costs, reporting 50,852 Rs ha^{-1} in 2022 and 53,829 Rs ha^{-1} in 2023, with a pooled average of 52,340 Rs ha^{-1}. These findings underscore the financial implications of different weed management strategies in maize cultivation, highlighting the trade-offs between cost and weed control effectiveness.

Among all the growth promoters applied treatment the treatment Cytokinins + Enzymes (Ambition) (G_3) recorded superior cost of cultivation 50210 (Rs. ha^{-1}) in 2022. And 53187 (Rs. ha^{-1}) in 2023 respectively. The pooled data of cost of cultivation of experiment also showed superior in Cytokinins + Enzymes (Ambition) (G_3) treatment which is 51698 (Rs. ha^{-1}) in comparison of other treatment. While statistically the effect of all the growth promoters on cost of cultivation of maize at days after sowing recorded significant.

The interaction of all effect of sowing methods, weed management and growth promoters on yield to produce non-significant variation in cost of cultivation (primary and secondary) in both year and pooled data of study.

3.2 Gross Return (Rs/ha)

The effect of different sowing methods on gross return of maize during kharif season recorded of non-significant (Table 1.). At different days after sowing the ridge method recorded greater gross return in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 141107 (Rs/ha) of gross return which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 129131 (Rs/ha) gross return which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher gross return in comparison of conventional method of sowing which are 135119 (Rs/ha). Kumar et al. [7], CRIDA [11], Meena et al. [12].

In a study assessing various weed management practices in maize during the kharif season, the weed-free treatment (W_2) consistently achieved the highest gross returns. In 2022, W_2 recorded a gross return of 142,834 Rs/ha, which decreased to 131,224 Rs/ha in 2023, resulting in a pooled average of 137,029 Rs/ha. Among herbicide treatments, Atrazine pre-emergence at 0.75 l/ha

combined with Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) showed notable performance, with gross returns of 141,943 Rs/ha in 2022 and 129,681 Rs/ha in 2023, averaging 135,812 Rs/ha. In contrast, the lowest gross returns were recorded for the Atrazine pre-emergence at 1.25 kg/ha (W_3) treatment. These findings highlight the effectiveness of weed-free management and specific herbicide combinations in maximizing gross returns in maize cultivation, emphasizing the importance of selecting appropriate weed management strategies for improved economic outcomes. Nagdeote et al. [13].

Among all the growth promoters applied treatment the treatment Cytokinins + Enzymes (Ambition) (G_3) recorded superior gross return of 140587 (Rs/ha) in 2022. Similarly, in 2023 the treatment Cytokinins + Enzymes (Ambition) (G_3) recorded greater gross return of 129513 (Rs/ha) in comparison of rest of the treatment. The pooled data of gross return of experiment also showed superior in Cytokinins + Enzymes (Ambition) (G_3) treatment which is gross return of 135050 (Rs/ha) in comparison of other treatment. The least gross return of maize under among growth promoters' practices during both the year of experiment recorded from Amino acid + Humic acid (Springever) (G_2) treatment. While statistically the effect of all the growth promoters on gross return of maize at days after sowing recorded significant. Further the data also reverent that the gross return was lower during second years of study as compared to first years Giannakoula et al. (2012)

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth and yield (Appendices) to produce non-significant variation in gross return (primary and secondary) in both year and pooled data of study.

3.3 Net Return (Rs/ha)

The effect of different sowing methods on Net return of maize during kharif season recorded of non-significant (Table 2). At different days after sowing the ridge method recorded greater Net return in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 78655 (Rs/ha) of Net return which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 86652 (Rs/ha) Net return which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher Net return in comparison of conventional method of sowing which are 82653 (Rs/ha). Kumar et al. [7], Nagdeote et al. [13], CRIDA [11].

Table 1. Effect of sowing methods, weed management and growth promoters on economics return (Rs/ha) of maize during 2022 and 2023

Treatment	Cost of cultivation			Gross return (Rs/ha)		
	2022	2023	Pooled	2022	2023	Pooled
Sowing Method						
S_1	49710	52726	51218	137641	126994	132317
S_2	51475	54454	52964	141107	129131	135119
SE(d)	-	-	-	1348.63	623.67	415.39
CD at 5 %	-	-	-	2697.26	1247.34	1812.13
Weed management						
W_1	46556	49533	48089	131530	120806	126168
W_2	53690	56673	55181	142834	131224	137029
W_3	49364	52341	50852	138381	126658	132519
W_4	50098	53075	51586	193682	127994	160838
W_5	50852	53829	52340	141943	129681	135812
SE(d)	-	-	-	1061.16	1138.05	1187.87
CD at 5 %	-	-	-	2126.20	2280.30	2380.12
Growth Promoters						
G_1	50111	53092	51601	139422	127556	133489
G_2	50015	52992	51503	136613	124819	130716
G_3	50210	53187	51698	140587	129513	135050
SE(d)	-	-	-	821.97	881.53	920.12
CD at 5 %	-	-	-	1646.96	1766.31	1843.63
CD at 5 % for interactions	NS	NS	NS	NS	NS	

Table 2. Effect of sowing methods, weed management and growth promoters on economics return (Rs/ha) of maize during 2022 and 2023

Treatment	Net return (Rs/ha)			B:C ratio (%)		
	2022	2023	Pooled	2022	2023	Pooled
Sowing Method						
S_1	76644	84914	80779	2.54	2.61	2.57
S_2	78655	86652	82653	2.54	2.62	2.58
SE(d)	587.31	192.80	330.93	0.011	0.008	0.006
CD at 5 %	1174.62	841.10	661.86	0.022	0.016	0.012
Weed management						
W_1	71441	79189	75315	2.72	2.79	2.75
W_2	80101	88868	84484	2.44	2.51	2.74
W_3	77091	85853	81472	2.58	2.67	2.62
W_4	77534	86160	81874	2.51	2.59	2.55
W_5	79582	88847	84214	2.44	2.52	2.48
SE(d)	630.09	860.02	721.91	0.024	0.023	0.023
CD at 5 %	1262.49	1723.21	1446.47	0.047	0.046	0.046
Growth Promoters						
G_1	77440	86430	81935	2.55	2.63	2.59
G_2	74707	83521	79114	2.58	2.64	2.61
G_3	79303	87399	83351	2.49	2.57	2.53
SE(d)	488.06	5.815	559.18	0.018	0.018	0.018
CD at 5 %	977.92	666.17	1120.43	0.037	0.036	0.036
CD at 5 % for interactions	NS	NS	NS	NS	NS	NS

In a study on weed management practices in maize during the kharif season, the weed-free treatment (W_2) consistently achieved the highest net returns. In 2022, W_2 recorded a net return of 80,101 Rs/ha, increasing to 88,868 Rs/ha in 2023, resulting in a pooled average of 84,484 Rs/ha. Among herbicide treatments, Atrazine pre-emergence at 0.75 l/ha combined with Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) yielded the next highest net returns, with 79,582 Rs/ha in 2022 and 88,847 Rs/ha in 2023, averaging 84,214 Rs/ha. Conversely, the lowest net returns were recorded for the treatment using Atrazine pre-emergence at 1.25 kg/ha (W_3). These findings indicate that effective weed management practices significantly influence net returns in maize cultivation, highlighting the benefits of both weed-free treatments and specific herbicide combinations. Duary et al. [14], Sheela et al. [15].

Among all the growth promoters applied treatment the treatment Cytokinins + Enzymes (Ambition) (G_3) recorded superior Net return of 79303 (Rs/ha) in 2022. Similarly, in 2023 the treatment Cytokinins + Enzymes (Ambition) (G_3) recorded greater Net return of 87399 (Rs/ha) in comparison of rest of the treatment. The pooled data of Net return of experiment also showed superior in Cytokinins + Enzymes (Ambition) (G_3) treatment which is Net return of 83351 (Rs/ha) in comparison of other treatment. The least Net return of maize under among growth promoters' practices during both the year of experiment recorded from Amino acid + Humic acid (Springever) (G_2) treatment. While statistically the effect of all the growth promoters on Net return of maize at days after sowing recorded significant. Further the data also reverent that the Net return was lower during second years of study as compared to first years. Giannakoula et al. (2012)

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth and yield (Appendices) to produce non-significant variation in Net return (primary and secondary) in both year and pooled data of study.

3.4 B: C Ratio (%)

The effect of different sowing methods on B:C ratio of maize during kharif season recorded of non-significant (Table 2). At different days after sowing the ridge method recorded greater B:C ratio in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 2.54 (%) of B:C ratio which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 2.62 (%) B:C ratio which is also higher than conventional

method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher B:C ratio in comparison of conventional method of sowing which are 2.58 (%). Kumar et al. [7], Nagdeote et al. [13], CRIDA [11], Meena et al. [12] Swetha et al. [16].

In a study evaluating various weed management practices in maize during the kharif season, the weed-free treatment (W_2) consistently achieved the highest benefit-to-cost (B:C) ratio. In 2022, (W_2) recorded a B:C ratio of 2.44, which increased to 2.51 in 2023, resulting in a pooled average of 2.74. Among the herbicide treatments, Atrazine pre-emergence at 0.75 l/ha combined with Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) showed the next best results, with B:C ratios of 2.44 in 2022 and 2.52 in 2023, averaging 2.48. Conversely, the treatment using Atrazine pre-emergence at 1.25 kg/ha (W_3) recorded the lowest B:C ratio across both years. Overall, these findings highlight the effectiveness of the weed-free treatment and specific herbicide combinations in enhancing the economic viability of maize cultivation. Duary et al. [14], Sheela et al. [15]. Swetha et al. [16].

The treatment using Cytokinins + Enzymes (Ambition) (G_3) achieved the highest benefit-to-cost (B:C) ratio, recording 2.49 in 2022 and 2.57 in 2023, with a pooled average of 2.53. In contrast, the Amino acid + Humic acid (Springever) (G_2) treatment had the lowest B:C ratio across both years. Significant differences in B:C ratios were observed among all growth promoters, with overall ratios lower in the second year compared to the first Giannakoula et al. (2012)

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth, and yield (Appendices) to produce non-significant variation in B:C ratio (primary and secondary) in both year and pooled data of study.

3.5 Available Nitrogen in Soil (kg ha^{-1})

The effect of different sowing methods on available nitrogen in soil of maize during kharif season recorded of non-significant (Table 3). At different days after sowing the ridge method recorded greater available nitrogen in soil in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 218.99 (kg ha^{-1}) of available nitrogen in soil which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 221.41 (kg ha^{-1}) available nitrogen in soil which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher available nitrogen in soil in comparison of conventional method of sowing which are 220.19 (kg ha^{-1}).

In a two-year study on weed management in maize during the kharif season, the weed-free treatment (W_2) consistently showed the highest available nitrogen in soil, recording 219.53 kg ha^{-1} in 2022 and 222.26 kg ha^{-1} in 2023, with a pooled average of 220.89 kg ha^{-1}. Among herbicide treatments, Atrazine pre-emergence at 0.75 l/ha combined with Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) also performed well, yielding 216.50 kg ha^{-1} in 2022 and 219.27 kg ha^{-1} in 2023, with a pooled average of 217.88 kg ha^{-1}. Conversely, the treatment using Atrazine pre-emergence at 1.25 kg/ha (W_3) resulted in the lowest available nitrogen levels. These results indicate that effective weed management practices significantly influence nitrogen availability in maize cultivation.

The treatment using Cytokinins + Enzymes (Ambition) (G_3) consistently recorded the highest available nitrogen in soil, with 219.78 kg ha^{-1} in 2022 and 222.61 kg ha^{-1} in 2023, yielding a pooled average of 221.20 kg ha^{-1}. Conversely, the Amino acid + Humic acid (Springever) (G_2) treatment had the lowest nitrogen levels. Overall, significant differences in nitrogen availability were noted among the growth promoters, with lower levels observed in the second year.

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth, and yield (Appendices) to produce non-significant variation in available nitrogen in soil (primary and secondary) in both year and pooled data of study.

3.6 Available Soil Phosphorus (kg ha^{-1})

The effect of different sowing methods on available phosphorus in soil of maize during kharif season recorded of non-significant (Table

3). At different days after sowing the ridge method recorded greater available phosphorus in soil in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 14.91 (kg ha^{-1}) of available phosphorus in soil which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 14.31 (kg ha^{-1}) available phosphorus in soil which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher available phosphorus in soil in comparison of conventional method of sowing which are 14.16 (kg ha^{-1}).

Different weed management practices significantly influenced the available phosphorus in soil during the experiment. The weed-free treatment (W_2) consistently showed the highest phosphorus levels, recording 15.90 kg ha^{-1} in 2022 and 14.61 kg ha^{-1} in 2023, leading to a pooled average of 14.45 kg ha^{-1}. Among herbicide treatments, Atrazine Pre-emergence at 0.75 l/ha + Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) had the next highest phosphorus levels, with 14.54 kg ha^{-1} in 2022 and 14.20 kg ha^{-1} in 2023, resulting in a pooled average of 14.30 kg ha^{-1}. The least available phosphorus was found in the Atrazine Pre-emergence at 1.25 kg/ha (W_3) treatment. The data indicate that the weed-free treatment was the most effective for maintaining higher available phosphorus levels in maize soil, while W_5 provided a significant alternative among herbicide applications. Overall, the findings highlight the importance of effective weed management practices for optimizing soil nutrient availability.

The treatment of Cytokinins + Enzymes (Ambition) (G_3) consistently recorded the highest available phosphorus in soil, with 14.65 kg ha^{-1} in 2022 and 14.46 kg ha^{-1} in 2023, resulting in a pooled average of 14.29 kg ha^{-1}. In contrast, the lowest phosphorus levels were observed in Amino acid + Humic acid (Springever) (G_2). Overall, available phosphorus decreased in the second year.

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth, and yield (Appendices) to produce non-significant variation in available phosphorus in soil (primary and secondary) in both year and pooled data of study.

3.7 Available Potassium in Soil (kg ha^{-1})

The effect of different sowing methods on available potassium in soil of maize during kharif season recorded of non-significant (Table 3). At different days after sowing the ridge method recorded greater available potassium in soil in both the year 2022 and 2023 of experiment over the conventional method of sowing. In 2022, the ridge method (S_2) recorded 176.59 (kg ha^{-1}) of available potassium in soil which is higher than conventional methods (S_1) method of sowing. In 2023 the ridge method recorded 177.90 (kg ha^{-1}) available potassium in soil which is also higher than conventional method of sowing. Similarly, in pooled data of both the year the ridge method recorded higher available potassium in soil in comparison of conventional method of sowing which are 177.21 (kg ha^{-1}).

Various weed management practices significantly affected the available potassium in soil during the experiment. The weed-free treatment (W_2) consistently showed the highest potassium levels, recording 177.98 kg ha^{-1} in 2022 and 179.61 kg ha^{-1} in 2023, with a pooled average of 178.68 kg ha^{-1}. Among herbicide treatments, Atrazine Pre-emergence at 0.75 l/ha + Halosulfuron methyl post-emergence at 35 g ai/ha (W_5) achieved the next highest potassium levels, with 176.38 kg ha^{-1} in 2022 and 178.09 kg ha^{-1} in 2023, resulting in a pooled average of 177.19 kg ha^{-1}. The least available potassium was recorded in the Atrazine Pre-emergence at 1.25 kg/ha (W_3) treatment. Overall, the weed-free treatment was the most effective for maintaining higher available potassium levels in maize soil, while W_5 provided a significant alternative among herbicide applications. These findings highlight the importance of weed management practices on soil nutrient availability.

The treatment of Cytokinins + Enzymes (Ambition) (G_3) consistently recorded the highest available potassium in soil, with values of 177.35 kg ha^{-1} in 2022 and 179.44 kg ha^{-1} in 2023, leading to a pooled average of 178.45 kg ha^{-1}. In contrast, Amino acid + Humic acid (Springever) (G_2) showed the lowest levels. Available potassium was lower in the first year compared to the second.

The interaction of all effect of sowing methods, weed management and growth promoters on weed dynamics, growth, and yield (Appendices) to produce non-significant variation in available potassium in soil (primary and secondary) in both year and pooled data of study.

Table 3. Effect of sowing methods, weed management and growth promoters on available N, P, K (kg ha^{-1}) of maize during 2022 and 2023

Treatment	Available nutrients (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Sowing Method									
S_1	209.19	211.92	210.56	13.40	13.80	13.66	174.55	176.49	175.52
S_2	218.99	221.41	220.19	14.91	14.31	14.16	176.59	177.90	177.21
SE(d)	0.452	0.486	0.442	0.022	0.018	0.021	0.192	0.139	0.162
CD at 5 %	1.972	2.120	1.928	0.096	0.080	0.090	0.385	0.604	0.706
Weed management									
W_1	206.65	208.99	207.82	12.40	13.41	13.27	173.54	175.14	174.42
W_2	219.53	222.26	220.89	15.90	14.61	14.45	177.98	179.61	178.68
W_3	212.48	214.93	213.70	14.17	14.00	14.09	174.46	176.03	175.22
W_4	215.30	217.83	216.57	14.43	14.06	14.20	175.51	177.09	176.31
W_5	216.50	219.27	217.88	14.54	14.20	14.30	176.38	178.09	177.19
SE(d)	0.181	0.191	0.187	0.014	0.015	0.015	0.125	0.064	0.065
CD at 5 %	0.364	0.383	0.375	0.028	0.030	0.029	0.150	0.128	0.131
Growth Promoters									
G_1	215.31	217.96	216.63	13.93	14.21	14.05	175.66	17714	176.35
G_2	207.18	209.40	208.29	12.04	13.50	13.38	173.72	175.01	174.30
G_3	219.78	222.61	221.20	14.65	14.46	14.29	177.35	179.44	178.45
SE(d)	0.141	0.148	0.145	0.011	0.012	0.011	0.048	0.049	0.050
CD at 5 %	0.282	0.297	0.291	0.022	0.024	0.023	0.098	0.099	0.101
CD at 5 % for interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS

4. CONCLUSION

The two years of experimentation in sandy loam soil of central Uttar Pradesh, ridge sowing methods were most effective in minimizing weeds and enhancing economics, resulting in the highest cost of cultivation, gross return, net return, available nitrogen, available phosphorus and available potassium but the lowest B:C ratio. The weed-free treatment (W_2) also significantly reduced weed competition and improved returns. Among herbicides, Atrazine pre-emergence at 0.75 l/ha combined with Halosulfuron methyl post-emergence (W_5) performed well. Additionally, Cytokinins + Enzymes (Ambition) (G_3) proved effective as a growth promoter, enhancing yield and economic returns.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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