Indian Journal of Agronomy **70** (1): 41–47 (March 2025)
DOI: 10.59797/ija.v70.i1.5579

Research Paper

Different planting techniques and potassium management strategies to improve growth and productivity of maize (*Zea mays*) in north plain zone of India

DHEER PRATAP[1], AMBREESH SINGH YADAV[2], MOHAMMAD HASANAIN[3], OM CHANDRA PANDEY[4], ABHINEET[5], TONY MANOJ KUMAR NANDIPAMU[6], DIGVIJAY SINGH[7], SABA SIDDIQUI[8], SANJIV SINGH[9] AND VIJAY SINGH MEENA[10]

Department of Agriculture, IIAST, Integral University, Lucknow 226026, Uttar Pradesh

Received: December 2024; Revised accepted: February 2025

ABSTRACT

The study assessed the impact of crop establishment methods and potassium management practices on maize productivity, growth and physiological parameters. Three crop establishment techniques, *viz.* Raised bed planting RBP, Zero tillage (ZT) and Conventional tillage (CT) and 6 potassium management options, including combinations with potassium-solubilizing bacteria (KSB) were assessed. Results showed that RB planting consistently outperformed ZT and CT in grain and straw yields, dry matter accumulation, and leaf area index. RB enhanced grain yield by 6.5% and 15.2% compared to ZT and CT, respectively. Potassium management, particularly 100% K combined with KSB, significantly improved all measured parameters. This treatment achieved a 19.1% higher grain yield than K (control) and 4.6% over 100% K alone. It was also increased dry matter accumulation and leaf area index by up to 33.2% compared to K (control). The integration of RB planting with 100% K + KSB led to superior canopy development, efficient nutrient utilization and improved harvest index, showcasing their combined potential for sustainable maize production. These findings underscore the importance of optimized agronomic practices in achieving higher yields and resource efficiency in maize cultivation.

Key words: Chlorophyll, Efficiency, Potassium solubilizing bacteria, Productivity, Raised bed planting, Zero tillage

Maize (*Zea mays* L.), known as the “Queen of Cereals,” is a crucial crop globally, contributing significantly to food, feed and industrial sectors due to its numerous uses. Maize farming faces several challenges, such as slow growth and inefficient input use (Hasanain *et al.,* 2024). Traditional maize farming faces challenges like soil compaction, soil resistance, low water retention, low water use efficiency, poor nutrient use efficiency, multiple deficiencies, weed pressure and climate change (Hasanain *et al.,* 2024). Maize production faces challenges such as inadequate fertilizer recommendations, multi-nutrient deficiencies and a mismatch between crop demands and fertilizer inputs. Research in the Indo-Gangetic Plain (IGPs) shows farmers often overuse nitrogen and underuse phosphorus, neglecting micronutrients like potassium and sulfur, hindering maize yield optimization (Bamboriya *et al.,* 2024).

To improve maize productivity in India, a comprehensive approach to planting techniques and K management strategies is needed. Sustaining maize productivity in the maize farming systems of the IGPs requires addressing the mismatch between crop demand and farmers’ fertilizer practices (i) typically applying excess N, (ii) suboptimal P, and (iii) neglecting K. This will close the productivity gap between the potential yield (6.0 t/ha) and the average farmer’s yield (3.1 t/ha) (Hasanain *et al.,* 2024). Planting in raised beds and using zero tillage have become sustainable substitutes for traditional tillage. Zero tillage reduces soil disturbance, improves organic carbon levels and facilitates faster crop establishment, making it beneficial in intensively cultivated regions like the IGPs. Raised-bed planting is an advanced technique that involves growing crops on elevated beds with furrows for irrigation and drainage (Kumar *et al.,* 2020). Raised beds enhance water use efficiency, prevent waterlogging and improve soil aeration, promoting healthier root systems, nutrient absorption and better crop residue incorporation (Hasanain *et al.,* 2024).

Based on a part of Ph.D. Thesis of the first author submitted to the Department of Agriculture, IIAST, Integral University, Lucknow, U.P.

[2]**Corresponding author’s Email:** ambreesh@iul.ac.in
[1,4]Research Scholar, [5]Assistant Professor, [2]Associate Professor, [8]Professor and [7]M.Sc. Scholar, Integral University, Lucknow, Uttar Pradesh; [6]Research Scholar, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand; [3]Scientist and [10]Senior Scientist, ICAR-IARI, RS, Pusa, Samastipur, Bihar; [9]Assistant Agronomist, Department of Vegetable Science, ANDUA&T, Ayodhya, Uttar Pradesh

Inadequate K fertilization of high-yielding maize crops degrades soil health in addition to producing yields that are below potential (Jangir *et al.,* 2023). The development of several efficient nutrient management strategies has made it feasible to improve the efficiency of K fertilizer or K use in maize farming (Sattar *et al.,* 2019). The techniques involve incorporating microbes like potassium solubilizing bacteria (KSB) that possess solubilizing minerals, making them accessible in soil solution.

This research hypothesizes that integrating planting techniques and KMOs will significantly enhance maize growth and productivity, thereby alleviating the argumentative impacts of climate change compared to conventional maize farming systems prevalent in the region. The specific objectives of the study are: (i) to evaluate the effect of KMOs on maize growth within a planting techniques in comparison to conventional farming methods; (ii) to enhance the yield of maize under planting techniques+ KMOs of maize farming in the North-western IGPs of India.

MATERIALS AND METHODS

The field experiment was conducted at Instructional Farm Unit 5, IIAST, Integral University, Lucknow, U.P. (India) during *Kharif* season of 2022 and 2023, using maize as the test crop. The experimental site was characterized by sandy clay loam in texture with pH 7.2. The soil was low Walkley–Black carbon (0.36%), oxidizable N (278.6 kg/ ha) and medium in available Olsen's, phosphorous (18.2 kg/ ha) and potassium (223.0 kg/ha), with humid subtropical climate. The study followed a split-plot design (SPD) with 18 treatments and three replications. The treatments included combinations of three planting techniques: conventional tillage (CT), zero tillage (ZT), and raised-bed planting (RBP), along with potassium (K) application rates with potassium solubilizing bacteria (KSB–*Strain*) (50%, 75% and 100% of recommended K_2O/ha alone, 75%+KSB, 100%+KSB and K control). The maize crop was sown under CT conditions, with conventional till sowing using a maize planter with 22 kg seed/ha at 60 cm row spacing and 25 cm plant to plant spacing. A multi crop planter was used for no till plot sowing with 22 kg seed/ha at 60 cm row spacing and 25 cm plant to plant spacing. The bed planter was used to prepare the bed for maize crop and sown with 22 kg seed/ha, at 60 cm row spacing and 25 cm plant to plant spacing. Potassium was applied as Muriate of Potash (60% K) based as per treatment. The seeds were treated with liquid potassium-soluble bacteria (*Bacillus species*). It was applied to maize seeds at a rate of 125 milliliters/ha using a 5% sugar solution. The seeds were then shade dried and sown in the appropriate treatment plots. During the growing season, the 4-5 irrigations were utilized to augment rainfall during periods of precipitation. Glyphosate was applied one week prior to sowing @ 1 kg a.i./ha to create an optimal weed-free environment for the maize crop. In CT plots, hand weeding was done at 20 DAS and in RBP and ZT plots, tembotrione was sprayed @ 120 ml a.i./ha, 25 DAS. Furadan (Carbofuron) granules were applied in a whorl pattern to offer defence against borer attacks.

Plants were harvested at ground level along a 1 meter row length during the knee-high, tasselling and maturity stage. They were then sun dried and oven dried at 65°C until they reached a constant weight in order to determine the above ground biomass of maize. Using a leaf area meter (Model LI-COR-3100) and the following formula, the leaf area index was determined at the harvesting stage:

$$LAI = \frac{Total\ leaf\ area\ (cm^2)}{Ground\ area\ \ (cm^2)}$$

The number of days from sowing to 50% silking stage in DAS was recorded and number days counted in days.

A portable chlorophyll meter, SPAD-502 (Minolta, Japan), was used to measure the amount of chlorophyll in maize leaves. The total amount of chlorophyll in plants is determined using the chlorophyll index (CI). The CI is a useful tool for managing nutrients all season long and is a reasonably reliable measure of plant health.

The cob length, cob girth, number of grains/cob and 1000-grain weight (g) were among the yield variables recorded in the experiment and were stated in standard units. When the maize reached maturity, the grains were separated using a sheller and the cobs were manually plucked from a net plot area. After being picked above ground and allowed to sun dried in the field for four days, the stover was weighed at 13% moisture content.

Analysis of the variance (ANOVA) was the statistical method used to analyzed the data. To determine whether there was a significant difference between treatments, the critical differences were computed at the 0.05% level of probability.

RESULTS AND DISCUSSION

Dry matter accumulation

Among the establishment techniques. RB planting consistently outperformed ZT and CT in dry matter accumulation (DMA) across all growth stages. At the knee-high stage, RB planting exhibited 3.3% higher DMA than ZT and 6.3% more than CT. At tasseling, RB planting recorded a 5.0% increase over ZT and a 6.8% improvement over CT. By harvest, DMA under RBP was 1.9% higher than ZT and 2.2% higher than CT (Table 1). These results highlight the ability of RBP to support better crop growth by likely providing improved soil aeration and root penetration. Potassium management had a profound impact on DMA, with

Table 1. Effect of plant techniques and potassium management on leaf area and chlorophyll content of maize

Treatment	Dry matter accumulation (g/m^2)			Leaf area (cm^2)		Leaf area index		Days to 50% silking	Chlorophyll content (%)	
	Knee high	Tasselling	Harvest	Knee high	Tasselling	Knee high	Tasselling		Knee high	Tasselling
Crop establishment methods										
Zero tillage (ZT)	36.2 ± 2.9	174.4 ± 16.3	456.6 ± 19.1	2103.3 ± 181.3	4356.5 ± 79.3	1.40 ± 0.12	2.90 ± 0.05	56.7± 0.8	42.84 ± 5.15	71.2 ± 4.5
Raised bed planting (RBP)	37.4 ± 3.2	183.2 ± 18.7	465.1 ± 190	2200.4 ± 205.0	4473.3 ± 108.9	1.46 ± 0.13	2.98 ± 0.07	55.8 ± 0.9	44.87 ± 5.39	74.7 ± 5.2
Conventional tillage (CT)	35.2 ± 3.0	171.4 ± 18.4	454.8 ± 18.1	2040.6 ± 199.8	4236.5 ± 85.6	1.37 ± 0.13	2.82 ± 0.05	58.5 ± 0.9	42.12 ± 5.25	70.8 ± 4.7
CD (P=0.05)	0.79	2.35	4.12	45.50	50.27	0.03	0.07	3.77	1.71	2.12
K management options										
K Control	32.5 ± 0.6	150.8 ± 3.9	434.8 ± 4.3	1854.5 ± 51.9	4311.5 ± 44.2	1.23 ± 0.03	2.87 ± 0.03	57.8 ± 0.5	35.98 ± 0.97	65.8 ± 1.0
50% K	34.5 ± 0.6	162.7 ± 2.4	446.6 ± 5.3	1966.0 ± 43.0	4350.7 ± 68.0	1.31 ± 0.02	2.90 ± 0.04	56.6± 0.4	38.98 ± 1.24	68.7 ± 0.9
75% K	36.2 ± 1.1	179.2 ± 4.5	455.5 ± 5.4	2139.7 ± 68.3	4398.2 ± 58.2	1.42 ± 0.04	2.93 ± 0.03	56.4 ± 0.5	43.13 ± 0.89	72.1 ± 2.1
100% K	38 .6± 0.8	185.6 ± 4.6	465.3 ± 6.5	2232.5 ± 69.7	4427.6 ± 66.1	1.48 ± 0.04	2.95± 0.04	55.4 ± 0.7	45.21 ± 1.15	74.5 ± 1.8
75% K + KSB	39.5 ± 1.0	192.9 ± 4.6	474.7 ± 4.9	2314.5 ± 51.3	4484.8 ± 49.9	1.54 ± 0.03	2.98 ± 0.03	54.6 ± 0.5	48.11 ± 1.56	76.5 ± 1.8
100% K+ KSB	41 ± 1.2	201 ± 6.5	488.9 ± 4.1	2381.2 ± 59.1	4560.4 ± 90.1	1.58 ± 0.03	3.04 ± 0.06	55.2 ± 0.6	50.83 ± 1.00	79.7 ± 1.7
CD (P=0.05)	0.90	2.48	4.27	30.47	34.05	0.02	0.05	3.23	1.52	1.99

KSB, Potassium Solubilizing Bacteria, Data of 2 years were pooled and presented. Values are means of ± SEd

the highest values observed under 100% K combined with KSB. At the knee-high stage, this treatment produced 26.2% higher DMA than K control and 18.8% more than 50% K. At tasseling, 100% K + KSB showed a 33.2% increase over K control and a 23.5% improvement over 50% K. At harvest, DMA under 100% K + KSB was 12.4% higher than K control and 9.4% higher than 50% K. This treatment also outperformed 75% K by 6.8%, indicating the synergistic benefits of integrating KSB with a full dose of potassium for maximizing crop biomass (Table 1). These improvements demonstrate that bio-augmentation with KSB boosts chlorophyll synthesis, corroborating findings by Sattar *et al*. (2019). The performance of RBP in improving vegetative parameters is primarily due to its role in enhancing soil structure, aeration, and water management, leading to optimal plant growth conditions (Goswami *et al*., 2020). The addition of KSB to K fertilizer proved superior in promoting nutrient uptake and utilization, resulting in healthier and more vigorous growth and development of maize plants (Sattar *et al*., 2019). Together, these practices emphasize the potential of integrated approaches in achieving higher productivity while maintaining sustainability.

Leaf area and Leaf area index

Similarly, RB planting exhibited superior leaf area compared ZT and CT at both knee-high and tasseling stages. At the knee-high stage, RB planting recorded a 4.6% increase in leaf area over ZT and 7.8% improvement over CT (Table 1). By tasseling, RBP demonstrated 2.7% higher leaf area compared to ZT and 5.6% more than CT. The enhanced performance of RBP planting is likely due to better soil moisture retention and aeration, creating optimal conditions for leaf expansion. Among potassium management practices, 100% K + KSB resulted in the highest leaf area at both growth stages (Table 1). At the knee-high stage, 100% K + KSB had a 28.4% larger leaf area compared to K control, 19.5% more than 50% K, and 10.8% more than 75% K. Similarly, at tasseling, 100% K + KSB showed a 33.2% increase over K control, 23.5% more than 50% K, and 12.1% more than 75% K. While 75% K + KSB also performed well, it was 3.3% lower than 100% K + KSB at tasseling, indicating the full potassium dose with KSB as the most effective combination to enhance leaf area. On the other hand, RB planting showed the highest LAI among establishment methods at both knee-high and tasseling stages. At the knee-high stage, RB planting exhibited a 4.3% increase in LAI compared to ZT and 6.6% over CT. Similarly, at the tasseling stage, RB planting achieved a 2.8% higher LAI than ZT and a 5.7% increase compared to CT. The increased LAI in RB planting can be attributed to improved resource distribution and better soil structure, supporting enhanced canopy development and photosynthetic efficiency. In potassium management practices, 100% K + KSB recorded the highest LAI across both stages. At the knee-high stage, 100% K + KSB demonstrated 28.5% improvement in LAI over K control, 20.6% over 50% K, and 11.3% over 75% K. At tasseling, 100% K + KSB was 5.8% higher than 75% K + KSB and 30.3% more than K control. The combination of 75% K + KSB also showed a substantial improvement in LAI over 100% K without KSB, being 4.2% higher at tasseling. These results highlight the synergistic role of KSB in enhancing potassium uptake and optimizing canopy development. Soil applied potassium plays a crucial role in boosting the leaf area by activating essential enzymes needed for photosynthesis and starch production, which in turn promotes leaf growth (Rawat *et al*., 2022). Potassium also helps manage water use by regulating stomatal function, allowing the plant to take in CO_2 more efficiently. As potassium levels increase, a corresponding rise in LAI results in better uptake of other nutrients like nitrogen and phosphorus, leading to larger leaves (Rawat *et al*., 2016). Additionally, adequate potassium delays leaf aging, keeping the plant photosynthetically active for longer periods. Overall, managing potassium effectively is key to maximizing maize growth and yield, especially in challenging conditions.

Days to 50% flowering

RB planting led to earlier silking compared to other establishment methods, with a 1.6% reduction in days compared to ZT and a 4.6% reduction compared to CT (Table 1). RB planting facilitated uniform emergence and better resource availability, contributing to early silking. In contrast, CT recorded the longest duration to reach 50% silking, likely due to suboptimal soil conditions impacting early growth stages. In potassium management, 100% K + KSB achieved the shortest duration to 50% silking, showing a 4.5% reduction compared to K control and 2.4% decrease relative to 50% K (Table 1). It also shortened the silking period by 1.1% compared to 75% K + KSB, demonstrating the efficiency of bioaugmentation in enhancing potassium availability and uptake. Conversely, K control resulted in the longest duration to silking, underscoring the importance of adequate potassium in promoting timely reproductive development. Potassium (K) is crucial for maize flowering, influencing both timing and success. Adequate potassium enhances photosynthesis and growth, leading to earlier silking and tasseling, while deficiency can delay flowering and reduce yields. Effective potassium management is essential for optimizing production and ensuring timely reproductive development.

Chlorophyll content and chlorophyll index

RB planting recorded the highest chlorophyll content and chlorophyll index (CI) among the establishment methods, reflecting improved photosynthetic capacity (Table 1) (Fig. 1). At the knee-high stage, RBP exhibited 4.7% increase in chlorophyll content compared to ZT and 2.8% higher than CT. At tasseling, RB achieved 2.2% improvement over ZT and a 4.7% increase over CT. CI had maximum with RBP (15.6) over ZT (15.2) and CT (15.0) respectively. The improved chlorophyll content and index in RB are likely due to improved soil aeration and moisture availability, facilitating efficient nutrient uptake and maintaining leaf greenness. RB planting enhances maize's chlorophyll content, a crucial factor for photosynthesis and overall plant health (Harish *et al*., 2022). The potassium management significantly influenced chlorophyll content, with 100% K + KSB exhibiting the highest values (Table 1). At the knee-high stage, chlorophyll content under 100% K + KSB was 41.3% higher than K control, 30.3% higher than 50% K and 18.1% higher than 75% K. At tasseling, 100% K + KSB showed 21.1% increase over K control, 13.3% over 50% K and 9.5% over 75% K (Table 1). Mean of CI (16.2) had reported maximum with 100% K + KSB (K6) followed by K5>K4>K3>K2 and K1 management options (Fig. 1). KSB enhances potassium solubility, enhancing chlorophyll synthesis and photosynthetic efficiency, while treatments without KSB, particularly K control, show the lowest chlorophyll values. Potassium significantly enhances the chlorophyll content in maize, a crucial element for photosynthesis and overall plant health (Mahmood *et al*., 2024). Studies have found that higher potassium levels, up to 120 kg K_2O/ha, lead to increased concentrations of chlorophyll (Ngennoy *et al*., 2022; Mahmood *et al*., 2024). Potassium enhances photosynthe-

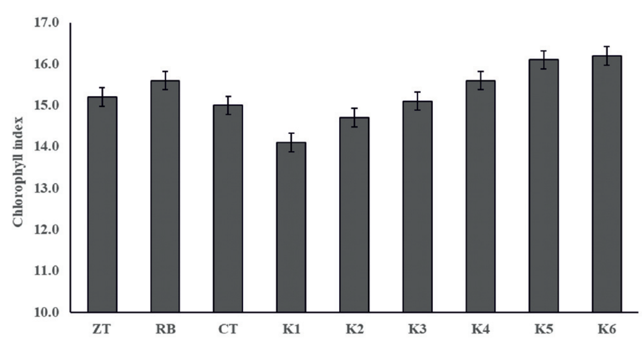

Fig. 1. Effect of establishment methods and potassium management on chlorophyll content of maize

CT, conventional tillage; ZT, zero tillage; RBP: raised-bed planting; K_1, control; K_2, 50% recommended dose of potassium, K_3, 75% recommended dose of potassium; K_4, 100% of recommended dose of potassium; K_5, 75% recommended dose of potassium + KSB; K_6, 100% recommended dose of potassium + KSB.

sis by activating essential enzymes and improving the uptake of nutrients like nitrogen, which is essential for chlorophyll production (Rawat *et al*., 2016). Potassium management is crucial for maize production, as increased chlorophyll leads to better growth and higher grain yields, emphasizing its importance.

Yield attributes

Among the establishment methods, the RB planting consistently outperformed ZT and CT across most yield contributing parameters (Table 2) RBP recorded 26.8% higher number of cobs/plant compared to ZT and 35.7% increase over CT, demonstrating superior reproductive performance. Cob length was highest under RBP, exceeding ZT and CT by 0.9% and 1.8%, respectively. Grain-filled cob length also showed a marginal advantage under RBP, with 1.0% and 3.0% increase over ZT and CT. Unfilled cob length was lowest in RBP, 11.1% shorter than CT, reflecting efficient resource partitioning toward grain filling. Cob girth was similar between RBP and ZT, both of which were 10.9% larger than CT. RB planting resulted in 9.8% more grainscob than ZT and 6.1% more than CT, while grain yield/cob in RBP exceeded ZT by 6.5% and CT by 15.2%. RB improves soil aeration, moisture retention and nutrient availability, leading to better cob development and grain filling. It optimizes resource allocation, increases grains/cob and enhances chlorophyll content (Sattar *et al*., 2019). The implementation of RB planting and optimal potassium application significantly enhances maize productivity, highlighting the benefits of innovative agricultural practices. Potassium management strategies significantly impacted yield attributes, with the 100% K + KSB combination consistently outperforming other treatments (Table 2). Cobs/plant under 100% K + KSB were 51.5% higher than K Control and 35.4% and 25.4% higher than 50% K and 75% K, respectively. Cob length and grain-filled cob length under this treatment were 13.9% and 17.0% longer than K control, respectively, highlighting the positive effects of potassium sufficiency and microbial activity. Unfilled cob length was reduced by 15.0% compared to K control, indicating fewer aborted grains. Cob girth and grains/cob also reached their maximum under 100% K + KSB, with 9.1% and 4.0% increases over K control. Grain yield/cob was 19.1% higher than K control, further emphasizing the effectiveness of the synergistic application of potassium and KSB (Table 2). The study reveals that combining potassium with KSB improves nutrient efficiency, reduces stress during reproductive stages and optimizes grain formation, thereby enhancing maize yield. High potassium levels are linked to earlier silking and increased grain yield/cob and using recommended rates enhances growth and supports reproductive development. The study underscores

Table 2. Effect of plant techniques and potassium management on yield attributes of maize

Treatment	Cobs/Plant (no.)	Cob length (cm)	Grain filled cob length (cm)	Unfilled cob length (cm)	Cob girth (cm)	Rows/Cob (no)	Grains/Cob (no)	Grain yield/Cob (g)
Crop establishment methods								
Zero tillage (ZT)	1.23 ± 0.51	22.0 ± 1.1	20.4 ± 0.8	1.60 ± 0.7	14.3 ± 0.5	14.5 ± 0.6	431.1 ± 43.5	124.6 ± 8.1
Raised Bed planting (RB)	1.56 ± 0.58	22.2± 1.0	20.6 ± 0.9	1.60± 0.7	15.5 ± 0.5	14.3 ± 1.2	457.9 ± 45.9	132.7 ± 7.5
Conventional Tillage (CT)	1.15 ± 0.51	21.8 ± 1.0	20.0 ± 0.8	1.80 ± 0.7	13.8 ± 0.5	13.0 ± 0.8	417.5 ± 41.2	115.2 ± 7.8
CD (P=0.05)	0.15	0.19	0.17	0.14	1.35	0.21	11.32	4.14
K management options								
K Control	1.01 ± 0.33	20.2 ± 0.5	18.2 ± 0.2	2.00± 0.2	14.3 ± 0.3	13.0 ± 0.1	474.3 ± 12.7	111.3 ± 3.4
50% K	1.13 ± 0.54	20.9 ± 0.4	19.0 ± 0.3	1.90± 0.3	14.6 ± 0.3	13.2 ± 0.4	496.5 ± 18.6	115.2 ± 4.5d
75% K	1.22 ± 0.55	21.6 ± 0.4	19.8 ± 0.4	1.80 ± 0.3	14.8 ± 0.3	13.7 ± 0.4	420.7 ± 21.8	119.2 ± 5.0
100% K	1.31 ± 0.12	22.2 ± 0.3	20.4 ± 0.4	1.80 ± 0.3	15.1 ± 0.3	14.1 ± 0.3	453.2 ± 20.7	122.8 ± 5.4
75% K + KSB	1.46 ± 0.33	22.6 ± 0.3	20.9 ± 0.4	1.70 ± 0.4	15.3 ± 0.2	14.6 ± 0.7	474 ± 21.7	128.8 ± 5.4
100% K+ KSB	1.53 ± 0.51	23.0 ± 0.5	21.3 ± 0.4	1.70 ± 0. 4	15.6± 0.2	15.1 ± 1.2	493.2 ± 16.1	132.5 ± 5.6
CD (P=0.05)	0.09	0.14	0.12	0.09	1.21	0.16	9.45	3.25

KSB, Potassium Solubilizing Bacteria, Data of 2 years were pooled and presented. Values are means of ± SEd the significance of effective potassium management in enhancing maize productivity, emphasizing the necessity of strategic nutrient practices in agriculture.

Productivity

Grain yield, straw yield and harvest index were significantly influenced by different crop establishment methods (Fig. 2). RB planting recorded the highest grain yield, demonstrating 6.5% increase over ZT and 15.2% improvement compared to CT. The enhanced grain yield under RBP can be attributed to better soil aeration, reduced compaction and improved water management, which likely facilitated optimal root growth and nutrient uptake. Straw yield under RBP was also the highest, exceeding ZT and CT by 7.8% and 13.9%, respectively (Fig. 2). The elevated straw yield indicates superior biomass accumulation under this system, likely due to the favourable growing environment and efficient use of resources. In terms of harvest index, RB planting showed 1.3% and 2.6% improvement over ZT and CT, respectively indicating a more efficient partitioning of assimilates towards grain production (Fig. 2). Raised bed planting improves crop productivity by balancing vegetative and reproductive stages, increasing maize yields and optimizing grain development by allocating resources and boosting chlorophyll content. RB planting enhances crop growth by reducing soil compaction, improving water management and increasing grain yields, making it a valuable practice for maize cultivation. Potassium management practices significantly affected grain yield, straw yield and harvest index, with the combination of 100% K + KSB proving to be the most effective (Fig. 2). Grain yield under 100% K + KSB was 19.1% higher than K control and showed significant increase of 13.6%, 8.2%, and 4.6% compared to 50% K, 75% K and 100% K, respectively (Fig. 2). The improvement is attributed to the synergistic effect of potassium solubilizing bacteria (KSB), which improves soil potassium availability, promotes nutrient uptake and supports key physiological processes. Straw yield followed a similar trend, with 100% K + KSB surpassing K control by 18.2% and showing increases of 12.7%, 8.9% and 4.5% over 50% K, 75% K and 100% K, respectively (Fig. 2). The study indicates that enhanced potassium availability and enhanced microbial activity have significantly enhanced biomass production. Harvest index, reflecting the efficiency of assimilate distribution towards grain was also highest under 100% K + KSB, showing a 7.7% increase over K control and increments of 5.2%, 2.4% and 1.2% compared to 50% K, 75% K and 100% K, respectively. The study suggests that optimal potassium dose and microbial inoculants improves maize grain and straw yields, enhancing growth, leaf area index and yield potential through innovative farming methods. The use of RB planting and proper potassium application significantly boosts maize productivity, highlighting the advantages of innovative farming methods (Ju *et al*., 2021; Rawat *et al*., 2022).

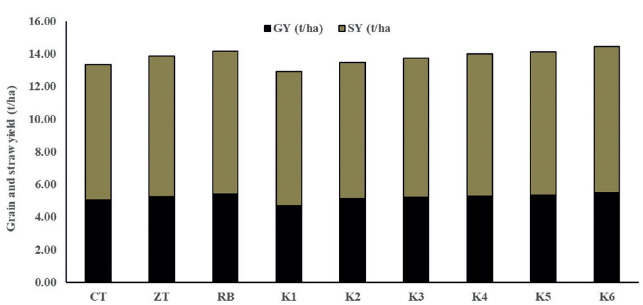

Fig. 2. Effect of establishment methods and potassium management on grain and straw yield of maize

CT, conventional tillage; ZT, zero tillage; RB: raised-bed planting; K_1, control; K_2, 50% recommended dose of potassium, K_3, 75% recommended dose of potassium; K_4, 100% of recommended dose of potassium; K_5, 75% recommended dose of potassium + KSB; K_6, 100% recommended dose of potassium + KSB.

The study reveals that effective maize growth and production can be enhanced through proper planting methods and potassium management strategies with RB planting consistently outperforming ZT and CT. RB planting improved grain yield by 15.2% compared to CT and 6.5% compared to ZT with potassium management significantly impacting maize performance. The synergistic approach led to significant increases in grain yield (19.1%) and straw yield (18.2%) compared to the K control. The study suggests that combining RB planting with 100% K + KSB is a sustainable method for enhancing maize productivity and resource efficiency. Sustainable agriculture *viz*; raised bed planting and potassium management strategies to improves yield, soil health and nutrient cycling, but future studies should explore long term effects on crop resilience, soil fertility and system level sustainability.

REFERENCES

Bamboriya, S., Dhar, S., Upadhyay, P.K., Dass, A., Bamboriya, S. D., Garg, K. and Meena, R. 2024. Effects of nitrogen supply on defensive changes in maize against biotic stressors. *Indian Journal of Agronomy* **69**(3):

Goswami, M., Malakar, C. and Deka, S. 2020. Rhizosphere microbes for sustainable maintenance of plant health and soil fertility. *Rhizosphere Microbes: Soil and Plant Functions* 35–72.

Hasanain, M., Singh, V.K., Rathore, S.S., Meena, V.S., Meena, S.K., Shekhawat, K., Singh, R.K., Dwivedi, B.S., Singh, R., Babu, S., Upadhyay, P.K., Kumar, A., Kumar, A., Fatima, A., Verma, G. and Kumar, S. 2024. Crop establishment and nutrient management options: Optimizing productivity, maximize profitability and mitigating adverse climatic conditions in the maize-based production system of Northwest India. *Field Crops Research* **318**: 109606.

Hasanain, M., Singh, V.K., Rathore, S.S., Shekhawat, K., Singh, R.K., Dwivedi, B.S., Upadhyay, P.K. and Singh, S. 2021. Effect of site-specific nutrient management in conservation agriculture-based maize in north-western India. *Indian Journal of Agronomy* **66**(2): 136–142.

Jangir, R., Maurya, B.R., Yadav, M., Goswami, S.P. and Yadav, S.L. 2023. Impact of Potassium Inoculants and biotite on soil microbial population and enzymatic activity under maize (*Zea mays* L.) Cultivation in Gangetic Plains. *International Journal of Environment and Climate Change* **13**(11): 498–504.

Ju, F., Pang, J., Huo, Y., Zhu, J., Yu, K., Sun, L. and Tang, Q. 2021. Potassium application alleviates the negative effects of salt stress on cotton (*Gossypium hirsutum* L.) yield by improving the ionic homeostasis, photosynthetic capacity and carbohydrate metabolism of the leaf subtending the cotton boll. *Field Crops Research* **272**: 108, 288.

Kumar, S., Kumar, R., Kumar, V. and Singh, D. 2020. Performance of maize under raised bed planting and its impact on water use efficiency and nutrient dynamics. *Journal of Agricultural Research* **58**(3): 208–216. https://doi.org/10.1016/j.jar.2020.07.003

Kumari, V.V., Banerjee, P., Verma, V. C., Sukumaran, S., Chandran, M.A.S., Gopinath, K.A. and Awasthi, N.K. 2022. Plant nutrition: An effective way to alleviate abiotic stress in agricultural crops. *International Journal of Molecular Sciences* **23**(15): 8,519.

Mahmood, S., Al-Solaimani, S.G., Shams, S., Naveed, S., Haider, B., Naveed, M. and Waqas, M. 2024. Silicon and biochar synergistically stimulate nutrients uptake, photosynthetic pigments, gaseous exchange and oxidative defense to improve maize growth under salinity. *Water, Air, and Soil Pollution* **235**(6): 413.

Sattar, A., Naveed, M., Ali, M., Zahir, Z.A., Nadeem, S.M., Yaseen, M., and Meena, H.N. 2019. Perspectives of potassium solubilizing microbes in sustainable food production system: A review. *Applied Soil Ecology* **133**: 146–159.

Sharma, S., Singh, P., Ali, H.M., Siddiqui, M.H. and Iqbal, J. 2023. Tillage, green manuring and crop residue management impacts on crop productivity, potassium use efficiency and potassium fractions under rice-wheat system. *Heliyon* **9**(7): e17, 828.

Singh, D., Hasanain, M., Verma, G., Pratap, D., Pandey, O.C., Kumar, S., Kumar, A., Singh, R., Singh, V.K. and Singh, A. 2024. Tillage and nutrient management strategies for improving productivity and profitability of maize (*Zea mays* L.). *Indian Journal of Agronomy* **69**(2): 216–219.

Singhal, R.K., Fahad, S., Kumar, P., Choyal, P., Javed, T., Jinger, D. and Nawaz, T. 2023. Beneficial elements: New Players in improving nutrient use efficiency and abiotic stress tolerance. *Plant Growth Regulation* **100**(2): 237–265.

Sukanta, K. Sarangi, B. Maji, U.K. Mandal, Mandal, S. and Sharma, P.C. 2024. Effect of establishment methods in rainy season (kharif) and tillage practices in winter season (rabi) on yield and economics of rice (*Oryza sativa*)–maize (*Zea mays*) cropping system under coastal saline ecosystem. *Indian Journal of Agronomy* **62**(4): 407–416. doi:10.59797/ija.v62i4.5543