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Research Article

Bioefficacy of KMB on Growth and Yield of Maize

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Abstract

This study aimed to evaluate the effects of potassium Mobilizing bacteria (Ami KMB) and mineral potassium applications on nutrient availability and maize growth during the Kharif season. The experiment was conducted at the Ami Experimental Farm in Ahmedabad, Gujarat, using a randomized block design. Two treatments were implemented: a control group and a treatment group that received potassium-Solubilizing bacteria supplemented with mineral potassium. Soil samples were collected at various growth stages of maize, which are at 30 days, 45 days, 60 days, and at harvest. Soil parameters, including nitrogen, phosphorus, potassium, pH, electrical conductivity, and organic carbon content, were analyzed using standard methods. The application of potassium-Solubilizing bacteria dramatically increases nitrogen levels, with the treatment group exhibiting 264.31 kg per hectare at 30 days after sowing, compared to 136.6 kg per hectare in the control group. Additionally, phosphorus levels in the treatment group increased to 24.27 kg per hectare at the same interval. Potassium levels consistently exceeded those in the control group throughout the study. Notably, soil pH and electrical conductivity were lower in the treatment group, indicating an improvement in soil health. Organic carbon content increased to 0.53 percent in the treatment group by harvest, in contrast to 0.32 percent in the control group.

Keywords: Ami KMB; *Zea maize* l; Biofertilizers; Maize Growth Parameter

Abbreviations

KMB: Potassium Mobilizing Bacteria; FYM: Farm Yard Manure; RBD: Randomized Block Design; EC: Electrical Conductivity; CD: Critical Difference; DAS: Days After Sowing

Introduction

Maize (*Zea mays L.*) is one of the most important cereal crops, serving as both a staple food and a key raw material for various industries [1]. Maize is widely used to produce feed, bioethanol, and industrial products such as starch, oil, and bio plastics, in addition to serving as an essential source of carbohydrates [2]. Maize is also a vital element in the manufacturing of sweeteners, starch, and other value-added products used in food processing and other industries [3]. Because of its versatility and economic significance, maize farming is vital to global food security and industrial supply chains [4]. Its unique capacity for various agro-climatic conditions has resulted in widespread cultivation in tropical, subtropical, and temperate regions [5]. To meet growing needs and deal with the problems of maize production, appropriate nutrient management solutions are required to sustain output, particularly in nutrient-depleted soil [6].

The availability of essential nutrients, particularly potassium (K), which plays a critical role in plant physiological and biochemical processes, is an important factor in maize production [7]. Potassium is essential for water balance regulation, enzymatic activity, photosynthesis, and glucose translocation, making it necessary for vegetative and reproductive growth [8]. Adequate potassium consumption improves plant tolerance to both abiotic and biotic stresses, enhances root growth, and increases water use efficiency, all are necessary for high maize yields [9]. Despite its importance, potassium receives less attention than nitrogen (N) and phosphorus (P), due to its availability in soils. Inevitably, much of this potassium occurs in unavailable forms to plants, demanding appropriate potassium management techniques to promote crop growth and yield [10].

While chemical fertilizers containing potassium have always been an alternative to potassium deficiency, excessive reliance on such fertilizers has many disadvantages [11]. Excessive chemical fertilizer utilization is associated with soil deterioration, nutrient leaching, and water pollution, which have long-term environmental implications [12]. Additionally, as global potassium salt reserves become increasingly limited, the cost of chemical fertilizers is rising [13]. In this regard, the use of biofertilizers, particularly potassium-Solubilizing bacteria, is a viable alternative for increasing potassium availability in soils [14]. KSB are rhizospheric bacteria that can dissolve insoluble potassium ions and convert them into forms that plants can easily absorb [15]. These bacteria emit organic acids, chelating compounds, and other metabolites that degrade complex potassium compounds, enabling plant roots to absorb more potassium [16]. In maize cultivation, KSB is proven to improve potassium availability, resulting in better plant growth, productivity, and adaptability to environmental challenges [17]. Furthermore, combining biofertilizers such as KSB with conventional fertilization maintains long-term nutrient cycling in agricultural systems [18]. This dual strategy not only promotes soil health and fertility but also corresponds with the global movement toward sustainable farming techniques that prioritize environmental protection alongside productivity [19].

The usage of KSB has become particularly important in maize production due to its high nutritional requirements [20]. Maize requires large amounts of nutrients and quickly reduces soil potassium levels, especially in intensive farming systems where crops are grown repeatedly [21]. By incorporating potassium-Solubilizing bacteria into their fertilization practices, farmers can enhance potassium use efficiency, promote improved root development, and increase overall growth and yield of maize, even in nutrient-deficient environments [22].

A comparison study was conducted to determine the impact of the integrated use of potassium fertilizers along with KMB or in combination with FYM (Farm yard manure) significantly improved the maize grain, nutrient uptake, yield, and plant height [23]. The current study aims to examine the bioefficacy of potassium-Solubilizing bacteria to improve maize growth and production. The study investigates how (Ami KMB) helps to improve potassium intake, potentially lowering the demand for chemical fertilizers and encouraging sustainable agriculture practices.

Materials and method

Experimental field

The experiment was conducted at Ami Experimental Farm, located in Ahmedabad, Gujarat.

Experimental design

The study involved Potassium Mobilizing Bacteria (KMB) and mineral potassium applications on maize (*Zea mays L*.,) during the Kharif season of 2020-2021. The experimental study utilized a randomized block design (RBD). The treatments were defined as follows: T1 (Control), T2 Ami KMB isolate supplemented with mineral potassium).

Soil sampling and analysis

Samples were taken from the experimental location to evaluate the initial soil characteristics. A combined soil sample was created by integrating samples collected from three different places, each taken from a depth of 0-15 cm and a composite soil sample was prepared after the harvest by collecting soil from five separate plots for each treatment. These samples were dried in air, crushed, and sieved through a 2 mm filter for further analysis. Key soil parameters such as electrical conductivity (EC), organic carbon content, pH, and available phosphorus, potassium, and nitrogen have been tested using standard procedures described in related scientific literature. The analysis was performed using the following methods:

Soil pH

A soil-water suspension was prepared at a ratio of 1:2.5 (10 g of soil with 25 mL of distilled water). The pH was measured using a digital pH meter, calibrated with reference buffers (pH 4.0 and pH 9.2).

Electrical conductivity (EC)

Electrical conductivity was measured to calculate the total concentration of soluble salts in soil. The same soil-water suspension used for pH testing was used to estimate electrical conductivity, which shows the overall concentration of soluble salts in the soil. Once settling, the clear supernatant was tested with a conductivity meter.

Organic carbon

Soil organic carbon was measured using the procedure described by [24]. A 1-gram air-dried soil sample was placed in a 500-ml Erlenmeyer flask, followed by 10 ml of 1 N potassium dichromate solution and 20 ml of concentrated solution. Sulphuric acid (H_2SO_4) was added to the solution and shaken for mixing. The mixture was allowed to stand for 30 minutes. Then, 200 mL of distilled water, 10 ml of orthophosphoric acid, and 1 mL of diphenylamine indicator were added. The solution was then titrated with ferrous ammonium sulphate (0.5 N). At the endpoint, the color changed from violet to blue to vivid green. A blank titration was also conducted.

Calculation

% Organic 'C' in soil = (B-T) × 0.003 × 10 x 1 x 100%/B x wt. of soil

Where,

Strength of $K_2Cr_2O_7$ used = 1 N

Volume of $K_2Cr_2O_7$ taken = 10

B = Volume of 0.5 N FAS solution used for blank titration

T = Volume of 0.5 N FAS solution used for sample titration.

Available nitrogen

The available nitrogen was evaluated using the Kjeltec Semi-Auto Nitrogen Analyser and the alkaline potassium permanganate technique [25]. Due to its rapidness and uniformity, this method has become common to obtain an accurate estimation of nitrogen availability in soil.

Procedure

A 5 g soil sample was accurately weighed and transferred into a distillation tube. To remove any soil adhering to the neck of the flask, 5 ml of distilled water was added. Following this, 25 ml of a 0.32% potassium permanganate ($KMnO_4$) solution was added into the tube. A 250 ml conical flask containing 20 ml of a 2% boric acid solution, mixed with an appropriate indicator, was placed under the receiver tube. Continuous tap water flow was maintained through the condenser. Subsequently, 25 ml of 2.5% sodium hydroxide (NaOH) solution was added to the distillation tube, and the distillation was continued for 9 minutes. During this process, nitrogen was released as ammonia, which was trapped in the boric acid solution, resulting in a green colour change. The distillate was then collected and titrated with 0.02 N sulphuric acids (H_2SO_4) until a pink endpoint was observed.

Calculation

Mineralizable N (kg/ha) = (S-V) × 0.02× 14× 106×2.24/1000×5

Mineralizable N (kg/ha) = (S-V) × 125.44

Where,

S = Sample titration reading

V = Blank titration reading.

Available phosphorus

Available phosphorus was measured using Olsen's method [26].

Procedure

Initially, reagent A was made by combining ammonium molybdate, antimony potassium tartrate, and sulphuric acid (H_2SO_4). Then reagent B was made with the aid of reagent A. In a 150-ml conical flask, 2.5 g of soil was mixed with a pinch of Darco G-60 and 50 ml of Olsen's reagent (0.5 M $NaHCO_3$). It was then shaken for 30 minutes on a mechanical shaker, and the suspension was filtered through the Whatman No. 1 filter paper. 5 ml of filtrate was then transferred to a 25 ml flask and neutralized with 2.5 M H_2SO_4 to a pH of 5.0 after adding 20 ml of distilled water and 4 ml of reagent B. After 10 minutes, the intensity of the blue colour was measured using a spectrophotometer at 882 nm. A blank test was also performed at the same time. An initial standard reading was taken, followed by the sample reading.

Calculation

2.5 g of soil sample is diluted in 50 ml of 0.5N $NaHCO_3$ solution.

Hence, dilution factor =50/2.5 = 20 times

5 mL of aliquot is taken in 25 ml volumetric flask.

Hence, dilution factor =25/5 = 5 times

Therefore, total dilution factor (DF) =20 x 5 = 100 times

Hence, Concentration of Phosphorus (mg/kg) = y (absorbance from standard curve)/m (slope of the standard curve) ×100

Available Phosphorus (kg/ha) = Concentration of Phosphorus (mg/kg) x 2.24

Available potassium

The available potassium level in the soil was determined using the flame photometer method [27] with separation enhanced by 1 N ammonium acetate solution. A 5-gram soil sample was added to a 100-ml conical flask, followed by 25 ml of 1 N ammonium acetate. The mixture was stirred for 5 minutes to ensure that potassium was effectively separated. The suspension was then filtered with Whatman No. 1 filter paper. The potassium concentration in the filtrate was then measured using a flame photometer. The equipment was calibrated first using standard solutions, and then the sample readings were recorded.

Calculation

Dilution factor = 25/5 = 5 times

Concentration of K in the sample from standard curve against the reading R = C

Available K (kg/ha) = C x dilution factor x 2.24 = C x 5 x 2.24

Statistical analysis

The raw data produced in the experiment were statistically analyzed using the Randomized Block Design (RBD) and the applicable ANOVA table. The F-test was used to determine the average of the treatments, and further comparisons were made using the critical difference (CD) at a 5% significance level to identify meaningful differences among treatments.

Result and Discussion

Available nitrogen in maize

Figure 1 illustrates the effect of potassium and Ami KMB on available nitrogen and phosphorus levels within maize at different stages of development. The data show variations in nitrogen availability between the control and treatment groups at various periods: 30 days after sowing (DAS), 45 DAS, 60 DAS, and harvest. At 30 DAS, the treated group had a higher available nitrogen concentration (264.31 ± 2.7 kg/ha) than the control group (136.6 ± 1.5 kg/ha). At 45 DAS, the treated group produced higher nitrogen levels (233 ± 0.12 kg/ha) than the control (144 ± 1.2 kg/ha). However, after 60 days, both groups had a decline in available nitrogen levels. The treated group recorded 165 ± 1.3 kg/ha, greater than the control 127 ± 0.9 kg/ha. At harvest, the treated group had an accessible nitrogen concentration of 141 ± 1.4 kg/ha, while the control group had 130 ± 1.3 kg/ha. In a related study on the impact of potassium mobilizing bacteria (KMB) on maize, the treatment with 100% of the recommended fertilizer dose resulted in

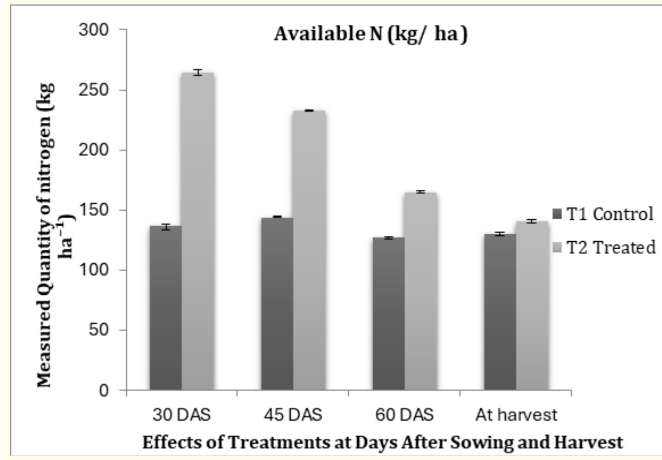

Figure 1: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

the maximum available nitrogen level in the soil, at 113.41 mg/kg [28]. Another study on maize cultivated in calcareous soils found an available nitrogen level of 42.38 mg/kg after using potassium sources and biofertilizers [29].

Available phosphorus in maize

Table 1 shows the effects of Ami KMB on mineral potassium. At 30 DAS, the treated group had notably higher phosphorus content (24.27 ± 0.8 kg/ha) than the control group (16.29 ± 0.5 kg/ha). At 45 DAS, the treated group had a phosphorus level of 26.22 ± 1.1 kg/ha, higher than the control group, with a value of 17.67 ± 1.1 kg/ha. By 60 DAS, the treated group exhibited increased phosphorus levels at 26.90 kg/ha ± 0.9. The control group consistently showed a lower mean value of 15.34 ± 0.8 kg/ha throughout the study. At harvest, the treated group had a final measurement of 25.01 ± 0.7 kg/ha, while the control had 15.80 ± 0.9 kg/ha. In another study, phosphorus-loaded biochar had the highest available phosphorus level in maize, measuring 3116.67 ± 11 mg/kg, surpassing all the other methods used in the experiment [30]. In earlier research, incorporating 13,500 kg/ha of maize straw with chemical fertilizers achieved the highest yield and increased available phosphorus in the soil by 6.2-18% compared to previous years [31].

Available potassium in maize

The treated group continually surpassed the control group in potassium levels throughout the analysis. (Figure 3) At 30 days after sowing (DAS), the treated group had an elevated potassium content of 376.12 ± 1.4 kg/ha, whereas the control group only had 196.04 ± 0.12 kg/ha. At 45 DAS, the treated groups produced 414.32 ± 1.6 kg/ha, while the control group only reached 204.14 ± 0.56 kg/ha. By 60 DAS, the treated group maintains a potassium level of 243.22 ± 1.8 kg/ha, much higher than the fall of the control to 148.11 ± 0.14 kg/ha. At harvest, the treated group had a potassium availability of 235.13 ± 1.5 kg/ha, while the control had 151.06 ± 1.1 kg/ha. Our results are consistent with other research. The utilization of organic matter at level M1, combined with reduced water irrigation at level W3, resulted in an available potassium concentration of 520.52 mg/kg in the soil throughout the growth of maize (*Zea mays L.*) [32]. Also other study on maize, the application of CRK1 at a high dose, consisting of potassium fertilizer (K2O) applied at a rate of 113 kg/ha, resulted in the highest levels of available potassium (mg/kg) in the soil at a depth of 0-20 cm [33].

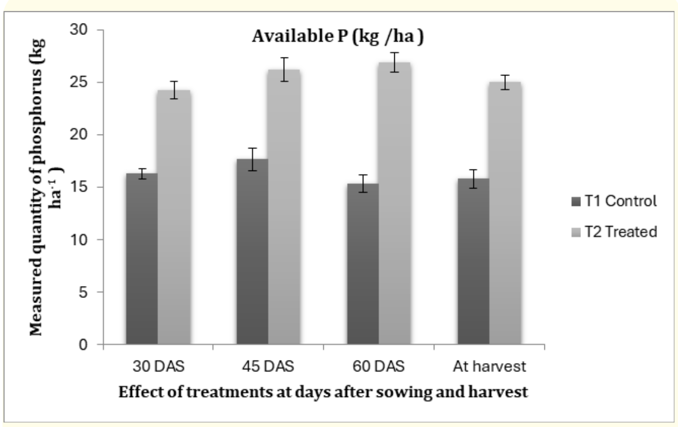

Figure 2: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

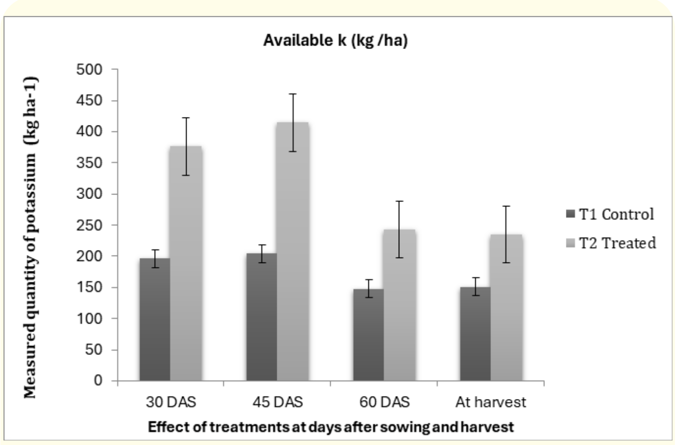

Figure 3: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

Soil pH of maize

The effects of mineral potassium and Ami KMB on soil pH throughout different phases of maize development are summarized in Figure 4. Studies show that the treated group constantly had lower soil pH values than the control group throughout the trial period. At 30 days after sowing (DAS), the control group had a pH of 7.44, but the treated group exhibited a considerably lower pH of 7.05, displaying the swift effects of the treatment. At 45 DAS, the control group recorded a pH of 7.31, while the treatment group had a pH of 7.00. The pH levels keep deviating as the growth period goes on; by 60 DAS, the treated group had further declined to 6.98, while the control group showed a slight decrease to 7.10 at that point. In a study on the effects of potassium sources and biofertilizers on maize, treatments included bacterial seed inoculation and the application of nitrogen and potassium with K_2O. This resulted in a soil pH of 8.6, the highest among all analyzed treatments [29]. This result is in close agreement with a previous study on maize, where applying 50% of the recommended potassium dose combined with potassium-solubilizing bacteria resulted in a soil pH of 8.05 [34].

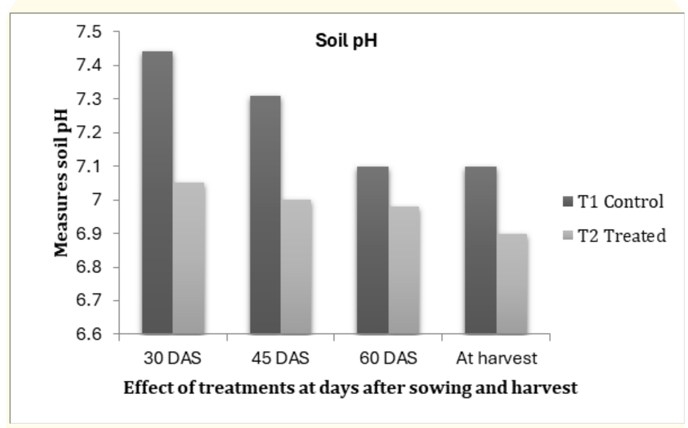

Figure 4: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

Electrical conductivity of maize

The effects of mineral potassium and Ami KMB on electrical conductivity (EC) during different phases of maize development are shown in Figure 5. The data show variations in EC between the treatment and control groups across this study. At 30 days after sowing (DAS), the control group had a significantly higher EC of 2.1 ds/m. In comparison, the treated group had a much lower EC of 0.34 dS/m. As the growth period proceeds to 45 DAS, the control group's EC decreases to 0.25 dS/m, although the treatment group's EC slightly increases to 0.35 dS/m. At 60 DAS, the control group's EC reduces to 0.23 dS/m, whereas the treated group's EC is lower at 0.32 dS/m. At harvest, the control group has an EC of 0.20 dS/m, although the treatment group has a substantial increase to 0.45 dS/m. In another study, applying potash, potassium-Solubilizing bacteria (KSB), and farmyard manure (FYM) in forage maize cultivation resulted in an electrical conductivity of 0.18 dS/m in the soil [35].

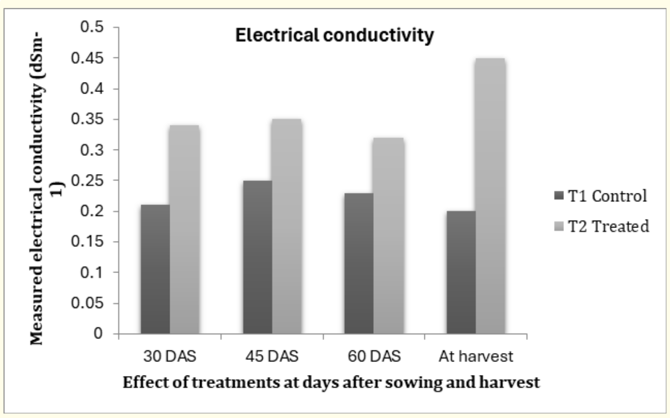

Figure 5: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

Organic carbon content of maize

Figure 6 depicts the impact of Ami KMB and mineral potassium on organic carbon content in maize at various growth stages. The treated group had higher organic carbon percentages than the control group. At 30 days after sowing (DAS), the control group had 0.36%, whereas the treated group has resulted in 0.51%. By 45 days after sowing (DAS), the organic carbon of the control group has increased to 0.40%, whereas the treated group remains steady at 0.45%. At 60 DAS, the control reaches 0.45%, and the treated group maintains 0.50%. Notably, after harvest, the control group reduces to 0.32%, but the treatment group increases to 0.53%, proving the long-term beneficial effect of Ami KMB and mineral potassium on organic carbon retention. In Other investigations, maize crops treated with 25 kg of K_2O, potassium-solubilizing bacteria (KSB), and a 2% foliar application of K_2SO_4 achieved the highest soil organic carbon content, recorded at 6.9 g/kg [36].

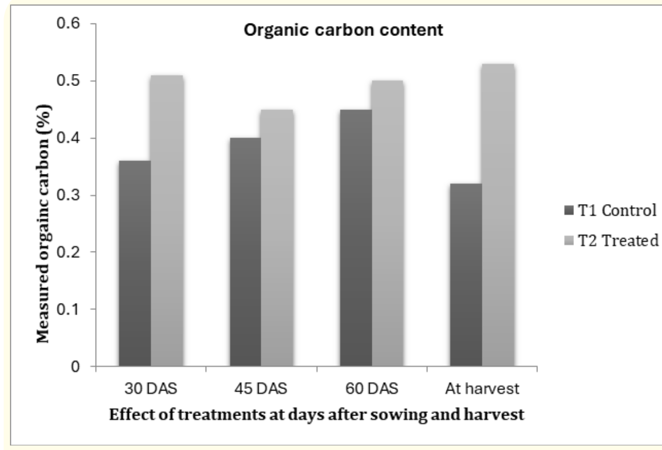

Figure 6: Effect of KMB and Mineral K on Nitrogen Availability in Maize.

Conclusion

The present study demonstrated that the integrated use of Potassium-Solubilizing Bacteria (Ami KMB) and mineral potassium notably improved the availability of key nutrients, such as nitrogen, phosphorus, and potassium, in maize, while also enhancing soil health parameters, including organic carbon content and pH stability. These improvements resulted in considerably higher maize growth, nutrient uptake, and yield than the control, thereby confirming the efficacy of Ami KMB in nutrient mobilization and soil fertility enhancement. The results show the potential of Ami KMB as a sustainable alternative to chemical fertilizers, particularly in nutrient-depleted soils.

Bibliography

1. Deepak Thalli Satyanarayana and Padmanabhan Appukuttan Jayadeep. "Prospects of maize (corn) wet milling by-products as a source of functional food ingredients and nutraceuticals". *Food Technolog and Biotechnology* 60.1 (2022): 109-120.

2. Maitra Shraddha and Vijay Singh. "Invited review on 'maize in the 21st century'Emerging trends of Maize biorefineries in the 21st century: Scientific and technological advancements in biofuel and bio- sustainable market". *Journal of Cereal Science* 101 (2021): 103272.

3. Adigwe Obi Peter., *et al*. "Starch: A veritable natural polymer for economic revolution". Starch-Evolution and Recent Advances". *IntechOpen* (2022).

4. Chari F., *et al*. “Sustainability of maize supply chains: The role of supplier development in the form of command farming in Mazowe district, Zimbabwe”. *Journal of Future Sustainability* 3.2 (2023): 97-106.

5. Erenstein Olaf., *et al*. “Global maize production, consumption and trade: trends and R&D Implications”. *Food Security* 14.5 (2022): 1295-1319.

6. Kafesu Nyasha., *et al*. “Comparative fertilization effects on maize productivity under conservation and conventional tillage on sandy soils in a smallholder cropping system in Zimbabwe”. *Field Crops Research* 218 (2018): 106-114.

7. Ortas Ibrahim. “Influence of potassium and magnesium fertilizer application on the yield and nutrient accumulation of maize genotypes under field conditions”. *Journal of Plant Nutrition* 41.3 (2018): 330-339.

8. Zhang Meiling., *et al*. “Potassium nutrition of maize: Uptake, transport, utilization, and role in stress tolerance”. *The Crop Journal* 11.4 (2023): 1048-1058.

9. Javed Syed Ayyaz., *et al*. “Optimization of nitrogen regulates the ionic homeostasis, potassium efficiency, and proline content to improve the growth, yield, and quality of maize under salinity stress”. *Environmental and Experimental Botany* 226 (2024): 105836.

10. Bashir Zaffar., *et al*. “Potassium-solubilizing microorganisms for sustainable agriculture”. Applied Agricultural Practices for Mitigating Climate Change [Volume 2]”. *CRC Press* (2019): 17-28.

11. Basak BB., *et al*. “Potassium supply in agriculture through biological potassium fertilizer: A promising and sustainable option for developing countries”. *Archives of Agronomy and Soil Science* 68.1 (2022): 101-114.

12. Hossain Mohammad Enayet., *et al*. “Chemical fertilizers and pesticides: impacts on soil degradation, groundwater, and human health in Bangladesh”. *Environmental Degradation: Challenges and Strategies for Mitigation. Cham: Springer International Publishing*, (2022): 63-92.

13. Randive Kirtikumar., *et al*. “An overview of the global fertilizer trends and India’s position in 2020”. *Mineral Economics* (2021): 1-14.

14. Misra Modhurima., *et al*. “Current aspects and applications of biofertilizers for sustainable agriculture”. *Plant Microbiomes for Sustainable Agriculture* (2020): 445-473.

15. SIDDIQUI Ali Raza., *et al*. “K-SOLUBILIZING RHIZOBACTERIA AND RHIZOBIA FOR ECOLOGICAL AGRICULTURE”. *Water-Air-Soil for Sustainable Agriculture and People Well-being* 114.

16. Kour Divjot., *et al*. “Potassium solubilizing and Solubilizing microbes: biodiversity, mechanisms of solubilization, and biotechnological implication for alleviations of abiotic stress. &; New and future developments in microbial biotechnology and bioengineering”. Elsevier, (2020): 177-202.

17. Asante-Badu Bismark., *et al*. “Maize (Zea mays L.) response to potassium application and K+ uptake in the soil: A review”. *Agricultural Reviews* 41.3 (2020): 201-215.

18. Reddy G Chandramohan., *et al*. “Biofertilizers toward sustainable agricultural development”. *Plant Microbe Symbiosis* (2020): 115-128.

19. Diop Massamba., *et al*. “Soil and water conservation in Africa: State of play and potential role in tackling soil degradation and building soil health in agricultural lands”. *Sustainability* 14.20 (2022): 13425.

20. Meena Vijay Singh., *et al*. “Evaluation of potassium solubilizing rhizobacteria (KSR): enhancing K- bioavailability and optimizing K-fertilization of maize plants under Indo-Gangetic Plains of India”. *Environmental Science and Pollution Research* 25 (2018): 36412-36424.

21. Rao Ch Srinivasa and K Srinivas. “Potassium dynamics and role of non-exchangeable potassium in crop nutrition”. *Indian Journal of Fertility* 13.4 (2017): 80-94.

22. Samtani Preeti and Suhani Parekh. “Review on Symbiotic Synergy: Mycorrhizal Diversity and its Role in Sustainable NPK Management in Agroecosystems”. (2024).

23. Chaudhary Nisha., *et al*. "Effect of Integrated Potassium Application on Growth, Yield and Micronutrient Uptake by Forage Maize (Zea mays L.)". *International Journal of Environment and Climate Change* 11.10 (2021): 178-184.

24. Sepahvand H., *et al*. "Comparison of different methods for the determination of organic carbon in calcareous soils under different land uses of Lorestan province". *Water and Soil* 34.1 (2020): 169-177.

25. Jangir RADHESHYAM., *et al*. "Effect of potassium inoculants and black mica on rhizospheric soil properties of maize (Zea mays L.)". *Asian Journal of Microbiology, Biotechnology & Environmental Sciences* 23.3 (2021): 372-380.

26. Khan Asif., *et al*. "Phosphorus efficiency, soil phosphorus dynamics and critical phosphorus level Under long-term fertilization for single and double cropping systems". *Agriculture, Ecosystems & Environment* 256 (2018): 1-11.

27. Ullah Rehmat., *et al*. "Method development and validation for the determination of potassium (K2O) in fertilizer samples by flame photometry technique". *Journal of King Saud University-Science* 34.5 (2022): 102070.

28. Meena Vijay Singh., *et al*. "Evaluation of potassium solubilizing rhizobacteria (KSR): enhancing K-bioavailability and optimizing K-fertilization of maize plants under Indo-Gangetic Plains of India". *Environmental Science and Pollution Research* 25 (2018): 36412-36424.

29. Rashwan Basma RA and Alaa Eldeen A Shaheen. "The impact of potassium sources and bio on corn plant and potassium availability in calcareous soil". *Asian Soil Research Journal* 5 (2021): 27-37.

30. Munir Ahmad Munir Ahmad., *et al*. "Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (Zea mays L.) plants". (2018): 327-339.

31. Wang Xiaojuan., *et al*. "Changes in soil characteristics and maize yield under straw returning system in dryland farming". *Field Crops Research* 218 (2018): 11-17.

32. Bader Basem Rahem., *et al*. "Potassium availability in soil amended with organic matter and phosphorous fertiliser under water stress during maize (Zea mays L) growth". *Journal of the Saudi Society of Agricultural Sciences* 20.6 (2021): 390-394.

33. "Potassium Availability in Soil Amended with Organic Matter and Phosphorus Fertilizer under Water Stress during Maize (Zea mays L.) Growth". *Journal of Saudi Society of Agricultural Sciences* 20.6 (2021): 390-394.

34. Li Zeli., *et al*. "Long-term effects of controlled-release potassium chloride on soil available potassium, nutrient absorption and yield of maize plants". *Soil and Tillage Research* 196 (2020): 104438.

35. Madar Raghavendra., *et al*. "Potassium and residue management options to enhance productivity and soil quality in zero till maize–wheat rotation". *CLEAN–Soil, Air, Water* 48.3 (2020): 1900316.

36. Achary V M M., *et al*. "Potassium Bioavailability and Its Influence on Plant Nutrition". *Frontiers in Plant Science* 10 (2019): 485.