



RESEARCH ARTICLE

Combined effect of potassium fertiliser and potassium-releasing bacteria on the productivity of kodo millet under irrigated conditions

Jeyasrinivas R¹, C Harisudan^{2*}, K Venkatalakshmi^{1*}, K Sedhupathi², A Gulshan² & M Vijayakumar³

¹Department of Agronomy, Agricultural College and Research Institute, Kudumiyamalai, Pudukkottai 622 104, Tamil Nadu, India

²Regional Research Station, Tamil Nadu Agricultural University, Vriddhachalam 606 001, Tamil Nadu, India

³Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirapalli 620 027, Tamil Nadu, India

*Correspondence email - harisudan@tnau.ac.in; venkatalakshmi@tnau.ac.in

Received: 09 June 2026; Accepted: 14 July 2026; Available online: Version 1.0: 01 August 2026

Cite this article: Jeyasrinivas R, Harisudan C, Venkatalakshmi K, Sedhupathi K, Gulshan A, Vijayakumar M. Combined effect of potassium fertiliser and potassium-releasing bacteria on the productivity of kodo millet under irrigated conditions. Plant Science Today. 2026; 13(sp5): 1-6.
<https://doi.org/10.14719/pst.15977>

Abstract

Potassium (K) is an essential macronutrient that is indispensable for sustaining crop growth, improving productivity and enhancing tolerance to environmental stresses. However, a large proportion of soil potassium remains unavailable to plants due to its occurrence in insoluble mineral forms. Potassium releasing bacteria (KRB) offer a sustainable approach to enhance potassium availability and improve nutrient-use efficiency. A study was undertaken across two consecutive rabi seasons (2024 and 2025) to assess the response of irrigated kodo millet to potassium fertilisation and potassium-releasing bacteria (KRB). Seven treatments comprising different potassium fertiliser levels (10 and 20 kg K ha⁻¹), KRB inoculation (5 kg ha⁻¹) and foliar application of 0.5 % K₂SO₄ were evaluated in a randomised block design (RBD) with 3 replications. The pooled results revealed that the integrated application of 40 : 20 : 10 kg NPK ha⁻¹ + KRB at 5 kg ha⁻¹ + 0.5 % K₂SO₄ foliar spray (T₆) significantly enhanced growth and yield attributes, resulting in the highest grain yield (1851 kg ha⁻¹), straw yield (3270 kg ha⁻¹), dry matter production (4895 kg ha⁻¹) and harvest index (0.32). The same treatment also recorded the highest potassium uptake (69.08 kg ha⁻¹), soil bacterial population (17.54 × 10⁶ CFU g⁻¹ soil) and superior economic returns with a net profit of ₹24090 ha⁻¹ and a BCR of 1.69. The study demonstrates that integrating moderate potassium fertilisation with KRB and foliar potassium supplementation is an effective and economically viable strategy for enhancing the productivity and profitability of irrigated kodo millet cultivation.

Keywords: grain yield; integrated nutrient management; kodo millet; potassium releasing bacteria; potassium uptake

Introduction

Kodo millet (*Paspalum scrobiculatum* L.) is recognised as a climate-resilient small millet capable of maintaining productivity under resource-limited environments while providing superior nutritional benefits (1). It is also known as a drought-tolerant C4 "nutri-cereal" that serves as a staple for millions in the arid and semi-arid regions of the world (2). It is highly valued for its resilience to adverse agro-climatic conditions and its exceptional nutritional profile, which is rich in dietary fibre, proteins and essential minerals (3). Despite its agronomic robustness, the national average productivity of kodo millet remains exceptionally low, primarily because it is conventionally cultivated on marginal, nutrient-deficient soils without the application of scientific nutrient management (4). The adoption of balanced and integrated nutrient management practices has been recognised as an effective strategy for improving nutrient-use efficiency and crop productivity while supporting sustainable production systems.

Potassium (K) is a crucial macronutrient among essential plant nutrients, which regulates several physiological processes, including enzyme activation, osmotic adjustment and assimilate

transport (5). However, while total K is abundant in most agricultural soils, up to 98 % of it is structurally locked in insoluble silicate minerals such as mica and feldspar, rendering it unavailable for direct plant uptake (6, 7). The continuous dependence on chemical K fertilisers may increase production costs and contribute to nutrient imbalance in soils. Inefficient fertiliser use may also reduce nutrient-use efficiency and affect long-term soil health, highlighting the need for integrated nutrient management approaches involving beneficial microorganisms (5).

Potassium-releasing bacteria (KRB) have emerged as extremely effective, environmentally friendly biological agents to solve this dilemma in a sustainable manner. Through several processes, including the production of organic acids, acidolysis and the chelation of metal ions, KRB strains such as *Bacillus*, *Pseudomonas* and *Paenibacillus* can convert the insoluble mineral K into soluble, plant-available forms (8). Furthermore, the integration of KRB as biofertilisers not only enhances the bioavailability of K but also promotes overall plant growth by secreting phytohormones and improving the root-soil interface (5, 8). The optimisation of agronomic techniques such as tillage, crop establishment and

precise nutrient delivery is well documented to have a profound impact on the productivity of sequential and underutilised crops. In fact, an assessment of crop establishment techniques and foliar nutrition for increasing rice fallow sesame (*Sesamum indicum* L.) productivity revealed that certain planting techniques, in addition to foliar nutrient sprays, greatly increased branching, capsule formation and total seed yield (9). In a similar vein, the assessment of the rabi season sesame productivity from graded nutrient doses and tillage regimes in rice fallows of the Indian subcontinent's southern plateau and hills region showed that combining appropriate tillage with suggested fertiliser doses overcomes the nutritional and physical limitations of post-rice soils, guaranteeing increased crop yields (10). Similar to these achievements, customising integrated nutrient management (INM) techniques, particularly integrating organic microbial inoculants like KRB with inorganic K fertilisers, has enormous potential to revolutionise kodo millet production. Therefore, the present study aimed to evaluate the combined effects of graded K fertiliser levels and KRB on growth, yield, nutrient uptake and economics of irrigated kodo millet.

Materials and Methods

The field experiment was conducted during October 2024 to December 2024 and October 2025 to December 2025. The field experiment was carried out at Agricultural College and Research Institute, Kudumiyamalai, which is located at 10.23° N latitude, 78.38° E longitude, at an altitude of approximately 119 m above mean sea level. The study was conducted to investigate the combined effects of K fertiliser and KRB on enhancing the productivity of kodo millet (*Paspalum scrobiculatum*) under irrigated conditions. The treatments consisted of two doses of K (10 and 20 kg) with KRB (*Bacillus mucilaginous*) and foliar application of K_2SO_4 . The treatment structure involves viz., T_1 - Control (40 : 20 : 0 kg NPK ha^{-1}), T_2 - nitrogen-phosphorus-potassium (NPK) (40 : 20 : 10 kg NPK ha^{-1}), T_3 - NPK (40 : 20 : 20 kg NPK ha^{-1}), T_4 - T_2 + KRB at 5 kg ha^{-1} , T_5 - T_3 + KRB at 5 kg ha^{-1} , T_6 - T_2 + KRB at 5 kg ha^{-1} + foliar application of 0.5 % K_2SO_4 , T_7 - T_3 + KRB at 5 kg ha^{-1} + foliar application of 0.5 % K_2SO_4 . Three replications and a randomised-block design (RBD) were used to set up the experiment. According to the treatment plan, foliar application of 0.5 % K_2SO_4 was applied during the flowering stage at 60 days after sowing (DAS) and varying concentrations of K fertiliser with KRB at 5 kg ha^{-1} were utilised. The inorganic nutrition sources such as nitrogen (N) was supplied through urea, phosphorus (P) through single superphosphate (SSP) and K through muriate of potash (MOP). Every other agronomic management technique was used to the crop as usual. Irrigation was provided immediately after sowing and subsequently at critical growth stages according to crop requirements. Weeds were controlled through manual weeding as per treatment schedule. Recommended plant protection measures were adopted whenever necessary to keep the crop free from insect pests and diseases. At harvest, kodo millet growth and yield characteristics were documented. A statistical analysis was performed on the data pertaining to various growth and yield characteristics. Prior to sowing, soil samples were analysed and characterised as red sandy loam with acidic reaction (pH 4.7), low soluble salts (0.30 dS m^{-1}), organic carbon content of 6.75 g kg^{-1} , available N of 226 kg ha^{-1} , P of 23.0 kg ha^{-1} and K of 374 kg ha^{-1} . The initial bacterial population of the soil was 13.8×10^6 g. The seed rate was 10 kg ha^{-1} and row and plant spacing were 45 and 10 cm, respectively for the variety of kodo millet, ATL 1.

Observations recorded

Growth, yield, nutrient uptake and soil biological properties were evaluated during the experiment. At harvest, five randomly chosen plants in each plot were measured for plant height (cm), leaf area index, number of productive tillers/hill, panicle length (cm) and number of grains/panicle. The mean data were then subjected to statistical analysis. Grain yield, straw yield, total dry matter production and harvest index were measured at harvest. Plant samples were digested using a diacid mixture (HNO_3 : $HClO_4$, 9 : 4) and K concentration was determined using a flame photometer following standard procedures (11).

Potassium uptake =

$$\frac{\text{Potassium concentration (\%)} \times \text{Dry mater yield (kg ha}^{-1}\text{)}}{100}$$

Each experimental plot's post-harvest soil samples were collected and their K status was examined. Rhizosphere soil samples were serially diluted up to 10^6 , plated on nutrient agar medium and incubated at $28 \pm 2^\circ C$ for 48 hr. Colonies were counted and expressed as colony-forming unit (CFU) $\times 10^6$ g^{-1} soil. The market prices of inputs and outputs were used to generate economic metrics such as cost of cultivation, gross returns, net returns and benefit cost ratio to assess the economic feasibility of different K management techniques.

Statistical analysis

Experimental observations recorded during both years, rabi 2024 and 2025 were analysed using analysis of variance suitable for a RBD (12). Individual year data were initially analysed separately to test treatment effects and since treatment $\times$ year interactions were non-significant, pooled analysis was performed after confirming homogeneity between years. Treatment means were compared using the critical difference (CD) test at the 5 % probability level ($p=0.05$). Standard error of difference (S.Ed) values were calculated for all measured parameters. Statistical computations were carried out using OPSTAT software.

Results and Discussion

Growth and yield attributes of kodo millet

The influence of different levels of K fertiliser with KRB at 5 kg ha^{-1} and foliar application of K_2SO_4 at 0.5 % significantly increased the plant height, which reached a maximum of 82.8 cm under the integrated potassium management treatment (T_6) which consistently produced superior performance compared with the control and other nutrient combinations. The best treatment (T_6) was on par with the treatment (T_7), while the recommended dose of N and P without K recorded lowest plant height. The same trend was observed in number of productive tillers/hill, length of the panicle and grains/panicle (Table 1). Better nutrient-use efficiency and increased rhizosphere K availability under integrated application of K fertiliser, KRB and foliar application of K_2SO_4 could be responsible for the significant increase in plant height, productive tillers, panicle length and grains per panicle. The KRB mobilise K primarily through the secretion of low-molecular-weight organic acids such as citric, oxalic, gluconic and tartaric acids. These organic acids lower the rhizosphere pH and chelate aluminium, silicon and iron ions associated with K-bearing minerals such as feldspar and mica. This process accelerates mineral weathering and releases exchangeable K ions into the soil solution, thereby

Table 1. Synergistic interaction of potassium fertiliser and potassium releasing bacteria on the growth and yield attributes of kodo millet (Pooled analysis)

Treatment	Plant height (cm)	Leaf area index	Number of productive tillers/hill	Number of grains/panicle	Length of the earhead (cm)	TDMP (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index
T ₁ - Control (40 : 20 : 0 kg NPK ha ⁻¹)	81.70	3.07	10.20	138.80	10.1	2837	1182	1715	0.28
T ₂ - NPK (40 : 20 : 10 kg NPK ha ⁻¹)	87.00	4.03	12.10	148.50	11.8	3655	1348	2447	0.28
T ₃ - NPK (40 : 20 : 20 kg NPK ha ⁻¹)	88.60	4.60	12.90	157.90	12.4	4043	1480	2613	0.29
T ₄ - T ₂ + KRB at 5 kg ha ⁻¹	91.20	5.47	13.60	164.90	13.4	4343	1620	2873	0.29
T ₅ - T ₃ + KRB at 5 kg ha ⁻¹	91.30	6.19	14.10	173.30	13.9	4415	1680	2898	0.29
T ₆ - T ₂ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	94.90	6.49	15.40	184.80	14.6	4895	1851	3270	0.32
T ₇ - T ₃ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	94.40	6.39	14.70	177.70	14.2	4714	1746	3180	0.30
S.Ed	1.62	0.17	0.27	5.00	0.54	179.97	65.40	93.95	
CD (0.05)	3.53	0.37	0.5	10.90	1.18	392.12	142.50	204.70	

NPK: nitrogen, phosphorus and potassium; KRB: potassium-releasing bacteria; K₂SO₄: potassium sulphate; TDMP: total dry matter production; S.Ed: standard error of difference; CD (0.05): critical difference at the 5 % level of significance.

increasing K availability for plant uptake (8). Similarly, sorghum had greater biomass production and nutrient uptake when inoculated with *Bacillus mucilaginosus* because of its enhanced ability to solubilise and make K available (13). Higher dry matter production (DMP) of 4895 kg ha⁻¹ were recorded under the treatment (T₆) which was on par with (T₇), while lower DMP was recorded in the control treatment (T₁).

Grain yield (kg ha⁻¹)

Application of 40 : 20 : 10 kg NPK ha⁻¹ + KRB at 5 kg ha⁻¹ + foliar application of 0.5 % K₂SO₄ (T₆) recorded the significantly higher grain of 1851 kg ha⁻¹ (Fig. 1). This was on par with treatment (T₇) which is also on par with treatments T₄ and T₅. Low grain yield was recorded under control (T₁). The higher grain yield obtained under T₆ could be attributed to improved K nutrition resulting from the combined effect of inorganic K, KRB and foliar K₂SO₄ application. The grain yield of 1851 kg ha⁻¹ recorded under T₆ was considerably higher than the yield obtained with K fertiliser alone, suggesting that the combined treatment generated a super-additive effect on crop productivity. The foliar application of K₂SO₄ at the reproductive stage likely played a critical role in sustaining K availability during periods of peak nutrient demand. Potassium mobility within the plant facilitates efficient translocation of photosynthates to developing grains, thereby improving grain filling and final yield (14). The

combined contribution of soil-applied K, microbial K release and foliar K supplementation ensured continuous nutrient availability throughout the crop growth cycle. This integrated nutrient supply mechanism explains the superior growth attributes, increased productive tillers, greater panicle length, higher grain number per panicle and ultimately enhanced grain yield observed under T₆.

An important finding of the present investigation was that the moderate K dose of 10 kg K ha⁻¹ integrated with KRB and foliar K application (T₆) outperformed the higher K dose treatment (T₇). This observation indicates that nutrient-use efficiency rather than fertiliser quantity was the major determinant of crop productivity. Excess K application may not necessarily translate into proportional yield gains because part of the applied nutrient can become fixed within soil mineral fractions, reducing its immediate availability to plants. In contrast, the biological mobilisation of native soil K by KRB and the timely foliar supplementation improved K-use efficiency and synchronised nutrient supply with crop demand. Consequently, the crop was able to utilise available K more effectively, resulting in higher yield and nutrient uptake with a relatively lower fertiliser input.

The findings of the present study are in agreement with reports from various millet-growing regions of India. Studies conducted on small millets in Tamil Nadu have demonstrated that

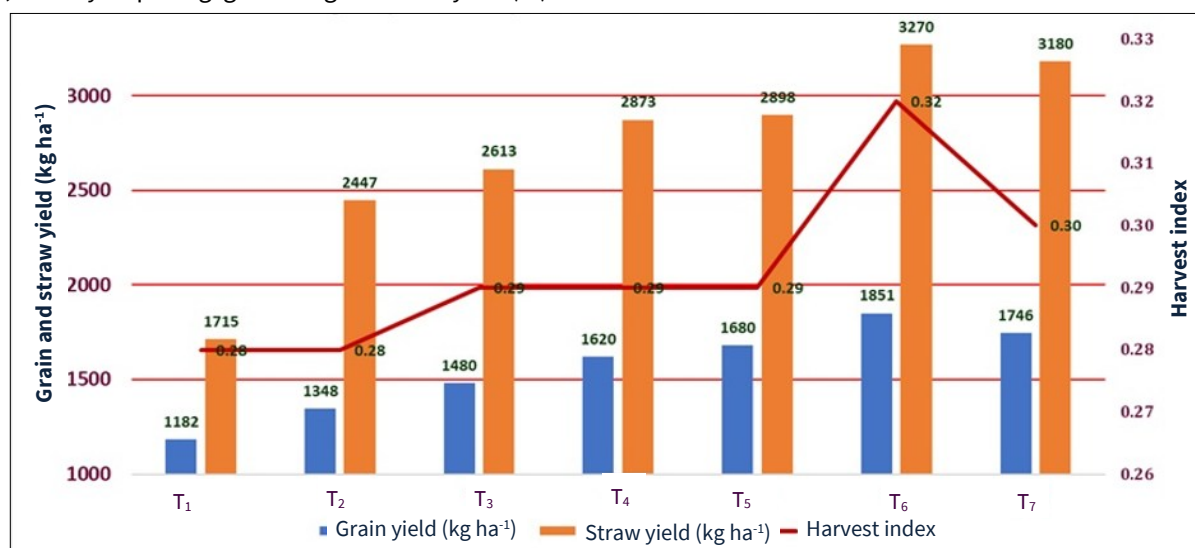


Fig. 1. Synergistic interaction of potassium fertiliser and potassium releasing bacteria on grain yield Straw yield and harvest index of kodo millet.

balanced K fertilisation significantly enhances growth, nutrient uptake and grain yield through improved physiological efficiency and assimilate partitioning. Potassium fertilisation improved plant growth, biomass production and grain yield in small millets, emphasising the importance of adequate K nutrition for realising yield potential (15). Similar responses have been reported in finger millet cultivation in Karnataka, where integrated nutrient management involving inorganic fertilisers and beneficial microorganisms improved nutrient-use efficiency and productivity. Research on pearl millet in Rajasthan and sorghum-growing regions of central India has likewise shown that K supplementation contributes to improved drought tolerance, photosynthetic efficiency and grain formation, resulting in higher economic yields.

Higher straw yield (3270 kg ha⁻¹) was obtained in the treatment (T₆) which was on par with the treatment (T₇). The above treatment was on par with T₄ and T₅ treatments. Low straw yield was recorded in control treatment (T₁). Higher percentage of harvest index was recorded in the treatments (T₆) and (T₇). Lower percentage of harvest index was recorded in control (T₁). The beneficial effect of integrated nutrient management on grain yield has been widely reported in finger millet, where the combined application of fertilisers and beneficial microorganisms improved nutrient availability, photosynthetic efficiency and assimilate partitioning, resulting in higher productivity and improved soil fertility (16).

Economic evaluation of the different sources of potassium fertilisers

The treatment (T₆) registered a higher net return of ₹24090 ha⁻¹ and a higher return per rupee invested of ₹1.69 in kodo millet. This could be due to higher yield and marked value of kodo millet. The treatment T₇ recorded net return of ₹20833 and return per rupee invested of ₹1.60. The low net return ₹4705 ha⁻¹ and return per rupee invested of ₹1.14 was observed in control plot. The economics of the experiment are mentioned in Table 2. Higher net returns and benefit-cost ratio (BCR) obtained in T₆ demonstrate the economic advantage of integrating K-releasing bacteria with fertiliser application. Similar economic benefits were reported where microbial consortium application produced higher yields and improved profitability compared with conventional fertiliser management (17).

Potassium uptake by kodo millet

Different levels of K fertiliser with KRB at 5 kg ha⁻¹ and foliar application of K₂SO₄ 0.5 % significantly influenced the uptake of K by kodo millet. Potassium uptake was higher in recommended dose of N and P along with 10 kg of K addition with KRB at 5 kg ha⁻¹ + foliar application of 0.5 % K₂SO₄ (T₆) which was on par treatment (T₇). The higher K uptake recorded under T₆ (69.08 kg ha⁻¹) may be attributed to the combined effect of K fertilisation, K releasing bacteria and foliar K application, which collectively enhanced K

availability and absorption by the crop. Potassium is essential for regulating enzyme activity, osmotic balance, photosynthate translocation and stomatal functioning, thereby improving nutrient acquisition and biomass production.

The inoculation of K releasing microorganisms can accelerate the release of non-exchangeable K from soil minerals through the production of organic acids and other metabolites, resulting in greater K availability in the rhizosphere. Enhanced root growth and improved nutrient acquisition under microbial inoculation further contribute to increased K uptake. Similar findings were also observed with increased K availability and nutrient uptake following inoculation with K releasing microorganisms in agricultural soils (18). Likewise, previous findings reported that microbial solubilisation of mineral-bound K significantly improved K nutrition and crop productivity (19). The higher uptake observed in the present study also corroborates the findings that demonstrated KRB improved nutrient uptake and growth performance by increasing K mobilisation and root nutrient absorption (20). Therefore, the integrated use of K fertiliser, KRB bacteria and foliar K supplementation appears to be an effective strategy for maximising K uptake and nutrient-use efficiency in irrigated kodo millet cultivation.

Post-harvest soil potassium status

Among the different levels of K fertiliser with KRB at 5 kg ha⁻¹ and foliar application of K₂SO₄ 0.5 % influenced the soil available K by kodo millet. Recommended dose of N and P along with 10 kg of K addition with KRB at 5 kg ha⁻¹ + foliar application of 0.5 % K₂SO₄ (T₆) recorded low available K in post-harvest of the soil. Post-harvest soil available K was significantly influenced by the integrated application of K fertiliser, KRB and foliar K supplementation. The lowest post-harvest available K content recorded under T₆ (110 kg ha⁻¹) indicates greater depletion of available K from the soil solution due to enhanced crop uptake and utilisation. The higher biomass production, grain yield and K uptake observed under this treatment suggest that a substantial proportion of available K was absorbed by the crop and translocated to economically important plant parts. This finding demonstrates the effectiveness of integrated K management in improving nutrient-use efficiency and maximising nutrient recovery by kodo millet.

The reduction in post-harvest soil K under KRB-inoculated treatments may be attributed to increased mobilisation of non-exchangeable potassium pools and subsequent absorption by plants. Potassium releasing microorganisms release organic acids, polysaccharides and chelating substances that facilitate the weathering of K-bearing minerals and convert unavailable forms of K into plant-accessible forms. As a result, greater quantities of K become available in the rhizosphere and are subsequently utilised by the crop, leading to lower residual soil K after harvest. In wheat,

Table 2. Synergistic interaction of potassium fertiliser and potassium releasing bacteria on cost economics of kodo millet (Pooled analysis)

Treatments	CoC (₹ ha ⁻¹)	Gross income (₹ ha ⁻¹)	Net profit (₹ ha ⁻¹)	B : C
T ₁ - Control (40 : 20 : 0 kg NPK ha ⁻¹)	32590	37295	4705	1.14
T ₂ - NPK (40 : 20 : 10 kg NPK ha ⁻¹)	33540	41687	8147	1.24
T ₃ - NPK (40 : 20 : 20 kg NPK ha ⁻¹)	33590	44343	10753	1.32
T ₄ - T ₂ + KRB at 5 kg ha ⁻¹	34790	50903	16113	1.46
T ₅ - T ₃ + KRB at 5 kg ha ⁻¹	34840	53298	18458	1.53
T ₆ - T ₂ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	34890	58980	24090	1.69
T ₇ - T ₃ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	36940	55773	20833	1.60

CoC: cost of cultivation; NPK: nitrogen, phosphorus and potassium; KRB: potassium-releasing bacteria; K₂SO₄: potassium sulphate; B : C: benefit : cost ratio.

similar observations also reported that KRB enhanced the release of mineral-bound K and increased K uptake by plants, thereby reducing residual available K in soil (21).

The present findings further indicate that integrated nutrient management practices can improve K cycling within the soil-plant system. Enhanced biological activity in the rhizosphere promotes nutrient transformation processes and increases the efficiency of fertiliser utilisation. The inoculation with K-mobilising microorganisms significantly accelerated K release from feldspar and mica minerals, resulting in improved nutrient availability and greater plant uptake (22). Likewise, previous researchers observed that microbial inoculation increased K utilisation efficiency and reduced the accumulation of residual potassium in soil due to enhanced nutrient absorption by crops (23).

The lower post-harvest K status observed under T₆ should therefore be interpreted because of improved nutrient acquisition rather than nutrient depletion. Such efficient utilisation of available K is desirable in intensive cropping systems because it reflects effective conversion of soil and fertiliser K into crop biomass and yield. The results clearly demonstrate that the combined application of K fertiliser, KRB and foliar K supplementation enhances K dynamics in the rhizosphere and promotes efficient K utilisation by kodo millet under irrigated conditions.

Soil microbial population

The influence on bacterial count in different levels of K fertiliser with KRB at of 5 kg ha⁻¹ and foliar application of K₂SO₄ 0.5 % in post-harvest soil of kodo millet field is mentioned in Table 3. Among the different levels of K fertiliser treatment (T₆) recorded higher bacterial population of (17.5 × 10⁶ CFU/g of soil). The higher bacterial population observed in treatments receiving KRB inoculation demonstrates successful establishment and proliferation of beneficial microorganisms in the rhizosphere. The KRB not only increase K availability but also improve soil biological activity and microbial diversity. Previous studies have reported increased rhizospheric microbial populations following inoculation with potassium releasing microorganisms due to improved root exudation and favourable soil biological conditions (24). The beneficial effect of integrated nutrient management on grain yield has been widely reported in millet crops, where the combined application of fertilisers and beneficial microorganisms improved nutrient availability, photosynthetic efficiency and assimilate partitioning, resulting in higher productivity and improved soil fertility (25).

Table 3. Synergistic interaction of potassium fertiliser and potassium releasing bacteria on the uptake, post-harvest potassium status and bacterial population (Pooled analysis)

Treatments	K uptake (kg ha ⁻¹)	Post-harvest soil available K (kg ha ⁻¹)	Bacterial population (× 10 ⁶ /g of soil)
T ₁ - Control (40 : 20 : 0 kg NPK ha ⁻¹)	44.12	120.00	15.50
T ₂ - NPK (40 : 20 : 10 kg NPK ha ⁻¹)	48.66	126.00	15.83
T ₃ - NPK (40 : 20 : 20 kg NPK ha ⁻¹)	51.75	132.00	15.85
T ₄ - T ₂ + KRB at 5 kg ha ⁻¹	59.56	118.00	17.20
T ₅ - T ₃ + KRB at 5 kg ha ⁻¹	62.50	128.00	17.27
T ₆ - T ₂ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	69.08	110.00	17.54
T ₇ - T ₃ + KRB at 5 kg ha ⁻¹ + foliar application of 0.5 % K ₂ SO ₄	62.21	115.00	17.50
S.Ed	1.83	5.87	-
CD (0.05)	3.99	12.79	-

NPK: nitrogen, phosphorus and potassium; KRB: potassium-releasing bacteria; K₂SO₄: potassium sulphate; S.Ed: standard error of difference; CD (0.05): critical difference at the 5 % level of significance.

Conclusion

The present investigation demonstrated that integrating moderate potassium (K) fertilisation with potassium-releasing bacteria (KRB) and foliar K supplementation significantly improved crop performance, nutrient uptake and profitability of irrigated kodo millet. The integrated approach enhanced K-use efficiency while promoting greater microbial activity in the rhizosphere, indicating its suitability for sustainable millet production systems. Among the evaluated treatments, the application of the recommended dose of nitrogen (N) and phosphorus (P) along with 10 kg K ha⁻¹, K-releasing bacteria and foliar application of 0.5 % K₂SO₄ proved to be the most effective in improving productivity and economic returns. Therefore, this integrated K management strategy can be recommended for sustainable and profitable cultivation of irrigated kodo millet.

Acknowledgements

The authors extend their sincere thanks to Tamil Nadu Agricultural University, Coimbatore, for providing essential technical assistance and expert guidance.

Authors' contributions

JR wrote the first draft of the manuscript. CH and KV provided guidance and contributed to the overall correction and improvement of the manuscript. KS, AG and MV assisted with literature collection and formatting. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflicts of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grammarly to correct the grammar and maintain the academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

1. Rawat L, Karnatak AK, Bisht TS, Kukreti A. Minor millets: profile and ethnobotanical scenario. In: *Millet and Millet Technology*. Singapore: Springer; 2021. p. 51–80. https://doi.org/10.1007/978-981-16-0676-2_3
2. Ashoka P, Raut D, Sudeepthi B, Gawande KN, Reddy Gurralla SV, Padhan SR, et al. Millet's role as a climate resilient staple for future food security: a review. *Int J Environ Clim Change*. 2023;13(11):4542–52. <https://doi.org/10.9734/ijecc/2023/v13i113634>
3. Anitha S, Kane-Potaka J, Botha R, Givens DI, Sulaiman NLB, Upadhyay S, et al. Millets can have a major impact on improving iron status, haemoglobin level and in reducing iron deficiency anemia: a systematic review and meta-analysis. *Front Nutr*. 2021;8:725529. <https://doi.org/10.3389/fnut.2021.725529>
4. Yadav OP, Gupta SK, Govindaraj M, Sharma R, Varshney RK, Srivastava RK, et al. Genetic gains in pearl millet in India: insights into historic breeding strategies and future perspective. *Front Plant Sci*. 2021;12:645038. <https://doi.org/10.3389/fpls.2021.645038>
5. Sattar A, Naveed M, Ali M, Zahir ZA, Nadeem SM, Yaseen M, et al. Perspectives of potassium solubilizing microbes in sustainable food production system: a review. *Appl Soil Ecol*. 2018;133:146–59. <https://doi.org/10.1016/j.apsoil.2018.09.012>
6. Meena VS, Bahadur I, Maurya BR, Kumar A, Meena RK, Meena SK, et al. Potassium-solubilizing microorganism in evergreen agriculture: an overview. In: *Potassium Solubilizing Microorganisms for Sustainable Agriculture*. New Delhi: Springer; 2016. p. 1–20. https://doi.org/10.1007/978-81-322-2776-2_1
7. Olaniyan FT, Alori ET, Adekiya AO, Ayorinde BB, Daramola FY, Osemwegie O, et al. The use of soil microbial potassium solubilizers in potassium nutrient availability in soil and its dynamics. *Ann Microbiol*. 2022;72(1):1–14. <https://doi.org/10.1186/s13213-022-01701-8>
8. Etesami H, Emami S, Alikhani HA. Potassium solubilizing bacteria (KSB): mechanisms, promotion of plant growth and future prospects: a review. *J Soil Sci Plant Nutr*. 2017;17(4):897–911. <https://doi.org/10.4067/S0718-95162017000400005>
9. Harisudan C, Sapre N. Evaluation of crop establishment methods and foliar nutrition for enhancing productivity of rice fallow/follow sesame (*Sesamum indicum* L.). *J Oilseeds Res*. 2019;36(2). <https://doi.org/10.56739/jor.v36i2.126932>
10. Chandrasekaran H, Ramesh K, Yadav P, Pasala R, Sathiah E, Indiragandhi P, et al. Evaluation of rabi season sesame productivity from graded doses and tillage regimes in rice fallows of southern plateau and hills region of the Indian sub-continent. *PeerJ*. 2024;12:e17867. <https://doi.org/10.7717/peerj.17867>
11. Jackson ML. *Soil Chemical Analysis*. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
12. Gomez KA, Gomez AA. *Statistical Procedures for Agricultural Research*. New York: John Wiley & Sons; 1984.
13. Basak BB, Biswas DR. Influence of potassium solubilizing microorganism (*Bacillus mucilaginosus*) and waste mica on potassium uptake dynamics by Sudan grass (*Sorghum vulgare* Pers.) grown under two Alfisols. *Plant Soil*. 2009;317(1):235–55. <https://doi.org/10.1007/s11104-008-9805-z>
14. Shahzad AN, Fatima A, Sarwar N, Bashir S, Rizwan M, et al. Foliar application of potassium sulfate partially alleviates pre-anthesis drought-induced kernel abortion in maize. *Int J Agric Biol*. 2017;19:495–501. <https://doi.org/10.17957/IJAB/15.0317>
15. Sathiya K, Sukanya TS, Nirmalakumari A, Vanitha C, Ayyadurai P, Shri Rangasami SR, et al. Impact of potassium fertilization on growth and yield of small millets. *Asian Res J Agric*. 2024;17(4):108–15. <https://doi.org/10.9734/arja/2024/v17i4505>
16. Prabhakar M, Gopinath KA, Sai Sravan U, Srasvan Kumar G, Thirupathi M, Samba Siva G, et al. Potential for yield and soil fertility improvement with integration of organics in nutrient management for finger millet under rainfed Alfisols of Southern India. *Front Nutr*. 2023;10:1095449. <https://doi.org/10.3389/fnut.2023.1095449>
17. Parameswari K, Brindavathy R, Gayathry G, Tamilselvi C, Syed Abul HH, Vijaya Geetha V, et al. Impact of a liquid consortium of plant growth-promoting bacteria on biometrics and yield attributes in sesame (*Sesamum indicum* L.). *Plant Sci. Today*. 2025;12(2):1–9. <https://doi.org/10.14719/pst.5698>
18. Meena VS, Maurya BR, Verma JP. Does a rhizospheric microorganism enhance K⁺ availability in agricultural soils? *Microbiol Res*. 2014;169(5–6):337–47. <https://doi.org/10.1016/j.micres.2013.09.003>
19. Prajapati K, Modi HA. The importance of potassium in plant growth: a review. *Indian J Plant Sci*. 2012;1(2–3):177–86.
20. Keshavarz Zarjani J, Aliasgharzad N, Oustan S, Emadi M, Ahmadi A. Isolation and characterization of potassium solubilizing bacteria in some Iranian soils. *Arch Agron Soil Sci*. 2013;59(12):1713–23. <https://doi.org/10.1080/03650340.2012.756977>
21. Sheng XF, He LY. Solubilization of potassium-bearing minerals by a wild-type strain of *Bacillus edaphicus* and its mutants and increased potassium uptake by wheat. *Can J Microbiol*. 2006;52(1):66–72. <https://doi.org/10.1139/w05-117>
22. Wang JG, Zhang FS, Zhang XL, Cao YP. Release of potassium from K-bearing minerals: effect of plant roots under P deficiency. *Nutr Cycl Agroecosyst*. 2000;56(1):45–52. <https://doi.org/10.1023/A:1009894427550>
23. Liu D, Lian B, Dong H. Isolation of *Paenibacillus* sp. and assessment of its potential for enhancing mineral weathering. *Geomicrobiol J*. 2012;29(5):413–21. <https://doi.org/10.1080/01490451.2011.576602>
24. El-Egami HM, Hegab RH, Montaser H, El-Hawary MM, Hasanuzzaman M. Impact of potassium-solubilizing microorganisms with potassium sources on the growth, physiology and productivity of wheat crop under salt-affected soil conditions. *Agronomy*. 2024;14(3):423. <https://doi.org/10.3390/agronomy14030423>
25. Louhar GA, Bana RS, Kumar V, Kumar H. Nutrient management technologies of millets for higher productivity and nutritional security. *Indian J Agric Sci*. 2020;90(12):2243–50. <https://doi.org/10.56093/ijas.v90i12.110267>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc. See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.