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Optimizing Cowpea Cultivation in Saline Hydromorphic Soils: A Sustainable Approach for Kaipad Agroecosystems

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Authors' contributions

This work was carried out in collaboration among all authors. Author SAC did data analysis, conducting experiment and wrote the manuscript. Author NKB conceptualized the study, supervised the work, performed the methodology and edited the manuscript. Author BVU supervised the microbial analysis. Authors SC and NP supervised chemical and physical analysis of soil. All authors read and approved the final manuscript.

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ABSTRACT

Kaipad lands, a distinct coastal agro-ecosystem located in northern Malabar, Kerala, are characterized by saline-prone hydromorphic soils that pose significant challenges for traditional rice cultivation. The unique conditions of periodic waterlogging and salinity necessitate the exploration of alternative crops to enhance agricultural sustainability. This study investigates the suitability of

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cowpea (*Vigna unguiculata* L Walp) as a resilient leguminous crop for cultivation in traditionally organic rice growing problematic soils. Cowpea, known for its adaptability to diverse environmental conditions, nutritional value, and economic importance, presents a promising option for farmers facing the limitations of organic rice production. A pot culture experiment was conducted to assess the impact of potassium solubilizing bacteria (KSB) on cowpea growth and yield in saline hydromorphic soils. Treatments included combinations of KSB with various potassium sources, such as feldspar and mica, used as alternate sources for potassic fertilizers. Results demonstrated that KSB significantly improved growth parameters, including plant height, leaf area, total dry matter production, and pod and grain yields, compared to control. Soil analysis revealed enhanced availability of potassium and other essential nutrients in KSB-treated soils, indicating a synergistic effect on nutrient solubilization in aerobic conditions. The findings suggest that cowpea, supported by KSB application, can be effectively cultivated in problematic Kaipad lands, offering a viable alternative to traditional rice farming while promoting sustainable agricultural practices. This research highlights the potential for diversifying crop production in saline-prone areas, ultimately contributing to food security and economic resilience in coastal agro-ecosystems.

Keywords: Kaipad; saline hydromorphic soils; cowpea yield; potassium fractions; potassium solubilizing bacteria.

1. INTRODUCTION

Saline hydromorphic soils present in northern Kerala represents the Kaipad lands, designated as Agro-Ecological Unit (AEU) 7. This is a distinct coastal agro-ecosystem characterized by seasonal waterlogging, encompassing a total of 24,209 hectares. Primarily located in the northern Malabar coastal wetlands, within the latitudinal and longitudinal range of 11.25°N to 12.5°N and 75.77°E to 75.0°E [1] covering Quilandy Municipality in Kozhikode District, Kalliasseri Block in Kannur District, and Neeleswaram Block in Kasaragod District. Kaipad region is notable for its saline-prone hydromorphic soils, this environment supports a specialized agro-ecosystem adapted to saline soils, sustaining a naturally organic, traditional rice cultivation practice unique to the region, similar to the Pokkali rice systems of South Kerala [1]. These soils experience periodic salinization due to the influx of seawater from an intricate network of backwaters and estuaries, contributing to the saline conditions typical of the area. Soil analysis of this area indicates that potassium (K) levels are consistently elevated [2], while nitrogen (N) levels exhibit variability, ranging from medium to high, and phosphorus (P) levels are generally classified as medium. During the month of April, the soil pH was observed to range between 4.9 and 6.6, reflecting acidic conditions [3]. The slightly acidic nature of the soil is attributed to the deposition of lime shells, which results from recurrent saline water intrusions occurring during the monsoon season, thereby influencing the chemical properties of soil.

The Kaipad agroecosystem is inherently organic, relying on natural processes without addition of synthetic fertilizers or pesticides. The average traditional rice productivity in Kaipad is between 1.5 to 2 tonnes/ha [4] which is very much lower than the state average 2.5 to 3tonnes/ha [5]. After rice cultivation the land is left fallow during the summer period, reducing the utility of land. In addition to this, farmers face challenges such as limited market access for organic rice and the need for infrastructure improvements. In such a scenario the possibility of growing crops other than rice needs to be explored. Cowpea (*Vigna unguiculata* L Walp) is a versatile and resilient leguminous crop, making it an excellent choice for research as a test crop. Its adaptability to various environmental conditions, nutritional value, and economic importance in agriculture provide a rich field for scientific exploration. Its ability to thrive in diverse climatic conditions, its role in sustainable agriculture, and its response to different agronomic practices make it a valuable subject for research. It is well-suited to high temperatures, water deficits, and low fertility soils, making it a viable crop in regions less favorable to other crops [6]. It demonstrates resilience to drought and salinity. Saline hydromorphic soils of Kaipad are also known for its high levels of potassium (K). Growing cowpea in Kaipad soils can be of multiline importance. The fallow period without submergence in Kaipad region during the summer season is marked with aerobic condition which is suitable for cowpea cultivation. Incorporation of another crop like cowpea during alternative seasons can aid in breaking the monocropping system and hence generating yield and generating income throughout the year. Also, in previous studies it was recorded that the N content of the soil is in a margin of sufficiency and deficiency [5]. In such a situation pulse crop rotation with rice can biologically enhance the N availability in soil. Studying the K dynamics in this soil is also important to adapt new strategies to grow crops other than rice.

Considering the fact that the Kaipad tract is organic, addition of chemical inputs is not recommended. Also, the acute shortage of K fertilizers around the state and thereby the exclusion of K fertilizer application by farmers need to be addressed. Hence along with growth trials the effect of potassium solubilizing bacteria on potassium release, growth and yield of cowpea is also a potential research. For which in this study K fertilizers were excluded from recommended NPK dosage and was substituted with K bearing minerals like feldspar and mica. Potassium is a vital macronutrient that regulates various physiological and metabolic processes in plants, including enzyme activation, photosynthesis, and stress tolerance [7]. Despite its abundance in soil, most potassium is in an insoluble form, making it unavailable to plants. This necessitates the use of solubilizing agents like KSB (potaasium solubilizing bacteria) to enhance its availability [8]. KSB solubilize potassium through the production of organic acids such as citric, tartaric, and oxalic acids, which convert insoluble potassium minerals into soluble forms [9,10]. These bacteria include species like *Bacillus, Pseudomonas*, and *Aspergillus*, which are effective in mobilizing potassium from minerals like mica, feldspar, and biotite [10]. The application of KSB has been shown to enhance nutrient uptake, leading to improved plant growth and yield. For instance, studies have demonstrated increased pod and seed production in crops treated with KSB compared to control [11]. KSB not only improves potassium availability but also contributes to improvement of overall soil health, which is beneficial for sustainable crop production [9,12]. KSB offers an eco-friendly alternative to chemical fertilizers, reducing environmental pollution and promoting sustainable agriculture [13,14]. They can also act as biocontrol agents, producing antibiotics and hormones that help plants withstand biotic and abiotic stresses [9].

In these contexts, the present study was conducted to evaluate the suitability of adopting cowpea for crop diversification in problematic Kaipad agro-ecosystem in aerobic condition and for assesssing the efficiency of KSB on solubilizing K fractions for plant uptake and growth, with K fertilization substituted by K-bearing minerals.

2. MATERIALS AND METHODS

A pot culture experiment with soil collected from a site (Lat 12.014253N:Long 75.326251E) encompassing saline hydromorphic soils of traditionally organic rice growing tract of kaipad distributed under agroecological unit 7 (AEU 7) was carried out with cowpea as the test crop. The initial soil analysis recorded that the soil had a strongly acidic pH of 4.18, which may require liming to improve crop growth. Its electrical conductivity (EC) of 2.15 dS/m indicated moderate salinity, potentially limiting the growth of sensitive crops. The soil retains moisture well, with a content of 33.77% as the soil is water saturation on daily basis for few hours due to tidal regime. Nutrient availability varies, with 319.87 $kg.ha^{-1}$ of nitrogen, adequate for plant needs, and 23.52 $kg.ha^{-1}$ of phosphorus, which is slightly high and may necessitate phosphate fertilization due to P fixation owing to the acidic nature of soil. Potassium levels are exceptionally high, with 1603.00 $kg.ha^{-1}$ available, including 661.92 $kg.ha^{-1}$water-soluble potassium for immediate uptake, 642.88 $kg.ha^{-1}$ exchangeable potassium, and 1088.08 $kg.ha^{-1}$ acid-soluble potassium as reserves which calls for an urgent need to study whether the high K poses nutrient imbalance and affects crop growth as the rice yields are low in the region. Cultivation of one season rice crop and next season remaining fallow or under shrimp is the common practice.

Lime application was done 10 days before sowing. And after 5 days of lime application Feldspar and mica was added to soil at the rate $10ml.kg^{-1}$ of soil 3days prior to FYM (farmyard manure) application. Remaining fertilizers were given as basal dose except N as two equal splits during basal application and 14 days after sowing. After 7-8 days after germination stem fly attack was observed, for which thiomethoxam (2 $g.L^{-1}$) was sprayed. After 45-50 days staking was given to support the plants. First harvest was at about 100 to 110 days after sowing in different treatments. Eventhough the variety was of short duration (75 days), the stress condition might have caused the delayed fruit setting. About 4-5 harvest was taken from each replication.

Cowpea variety *Kanakamani* was selected for the experiment and the seeds were procured from Regional Agricultural Research Station, Pattambi. Equal quantity of soil (7.5 kg) was filled in each pot. The experimental design CRD (completely randomized design) was adopted with five treatments including T_1 - Control, T_2 - KAU POP (Kerala Agricultural University Package of Practice. NPK dosage 20:30:10 $kg.ha^{-1}$), 2016 + KSB (*Bacillus* sp.), T_3 - T_2+ feldspar@ 0.1%, T_4 - T_2+ mica@ 0.1% and T_5 - Organic POP 2017. Only 100% nitrogen and phosphorous fertilizers were applied according to the recommended dose and potassium was supplied in the form of potassium bearing minerals like feldspar and mica. KSB was applied as seed treatment at the rate of $10g.kg^{-1}$ of seed in talc based formulation mixed with rice water as adhesive.

Biometric observations of growth and yield attributes including plant height, leaf area, total dry matter production, test weight, pod yield and grain yield were observed flowering stage and after harvest. The grains were tested for protein content using Kjeldahl's method [15] and amino acids like lysine and histidine [16]. After harvest in order to study the effect of KSB application on soil K fractions, the soil was analysed for four K fractions including available K (flame photometer estimation by Jackson [15], water soluble K was determined with procedure of Black et al. [17] by taking soil and water in 1:2 ratio, exchangeable K was obtained as the difference between available K and water soluble K [18] and non exchangeable or acid soluble K was estimated by treating with 0.1 N HNO_3 [18].

2.1 Plant Analysis

Plant analysis was carried out after weighing 0.5g of plant sample and digested using diacid mixture (HNO_3 and $HClO_4$ in ratio 9:3) and the extract was made up to 100 ml. This was used for the analysis of various nutrients like nitrogen (Kjeldahl's method by Jackson, [15]), potassium (Flame photometry by Chapman and Pratt, [19]), phosphorous (Vanadomolybdate colorimetry by Piper [20], Sulphur (Turbidimetry by Piper [20]), calcium and magnesium (EDTA titration by Scwarzenbach et al., [21]) and micronutrients (Atomic Absorption spectroscopy by Sims and Johnson [22].

2.2 Statistical Analysis

The data collected on growth, yield, and yield attributes were analyzed using the method outlined by Fisher and Yates [23]. The significance of the treatment effects was assessed by comparing the F values between treatment means, along with the critical difference (C.D.) and the standard error of the mean.

3. RESULTS AND DISCUSSION

Cowpea, when grown directly in the soil collected from traditionally rice growing saline hydromorphic Kaipad fields, showed difficulty in germination and growth. The seeds took about 6-7 days to germinate compared to normal germination period of cowpea which is 2-3 days. This may be due to clayey texture,very hard unbreakable clods formed on drying and acidic saline condition of the soil. The germinated plants exhibited stunted growth and reduced leaves. Cowpea seeds germinate best at 30-35°C, achieving high germination percentages and normal seedling rates. Below 20°C, which might be the condition of Kaipad soils due to moisture the process is prolonged, leading to delayed establishment [23]. Also, The lack of microbial activity in saline soils leads to poor seed germination and stunted growth due to increased osmotic pressure and reduced water availability. Microbial inoculation has been shown to improve root length and overall plant biomass, indicating that microbial presence is vital for mitigating salinity effects [24].

In order to investigate the possibility of modifying the soil conditions and study its effect on crop growth the native saline hydromorphic soils of Kaipad was mixed with composted coir pith in the ratio 1:1 (3.5kg soil + 3.5kg coir pith)

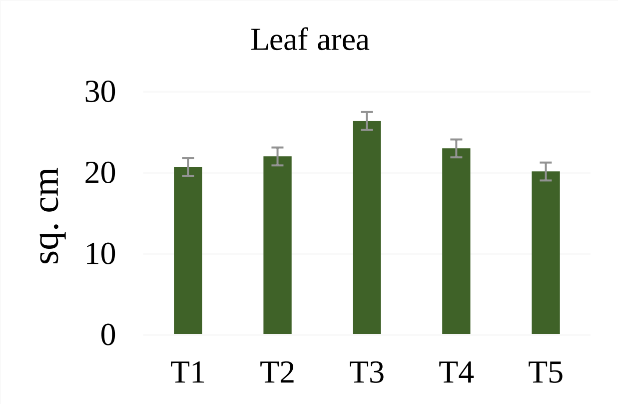
3.1 Growth and Yield of Cowpea

In the study it was recorded that even when cowpea was grown in continuously rice grown soils there was enhancement in its growth and yield which indicates the synergistic effect of KSB along with other microbes in solubilizing nutrients and improving plant growth. In the treatment with mica + KSB, the plants exhibited the greatest height, followed by feldspar + KSB. This aligns with findings by Kundu et al. [25], who observed that in potassium-sufficient soils, applying potassium-solubilizing bacteria (KSB) along with 100% of the recommended K dose in two equal splits resulted in the highest growth and yield of sweet corn. This suggests that KSB can enhance plant height by improving potassium availability, even in soils where potassium is not deficient. Additionally, a combination of potassium feldspar with biochar and compost has been shown to significantly boost vegetative growth in cowpea plants, including increases in plant length, number of leaves, branches, and pod size—key indicators of plant health and productivity [26]. Considering the leaf area the treatment with feldspar + KSB has shown higher leaf area followed by mica + KSB treatment (Fig. 2A). The highest test weight was observed in KSB along with feldspar and mica, followed by KSB alone and then by organic practices (Fig. 3A). This finding aligns with research in maize, where the combination of potassium-solubilizing bacteria (KSB) with mineral sources like biotite significantly enhanced yield attributes, such as grain weight and 100-seed weight, when compared to control treatments. This suggests that KSB may improve the test weight of crops by facilitating better nutrient uptake and utilization [27]. In terms of total dry matter production, feldspar + KSB recorded the highest value at 1386.06 kg.ha^{-1}, followed by mica + KSB (1359.47 kg.ha^{-1}) and KSB alone (1236.17 kg.ha^{-1}), with organic treatment (986.31 kg.ha^{-1}) producing comparatively less dry matter. Similar results have been observed in pulse crops, where potassium application has been shown to enhance dry matter production by improving water relations and nutrient uptake, particularly under stress conditions [28]. The highest pod yield per hectare was also observed in feldspar + KSB (10,570 kg.ha^{-1}), followed by KSB added along with mica (9,166.89 kg.ha^{-1}) (Fig. 3C). Similar results were obtained in grain or seed yield per hectare with highest yield in KSB + feldspar (1,909.87 kg.ha^{-1}) and KSB +mica (1,773.48 kg.ha^{-1}), followed by KSB alone (1,426.13 kg.ha^{-1}) (Fig. 3D). These findings are consistent with studies showing that the combination of feldspar with KSB and organic materials can significantly enhance plant growth and yield like in lentils, the combined application of potassium and KSB has been found to markedly improve key growth parameters such as plant height, the number of pods per plant, and seed yield [29].

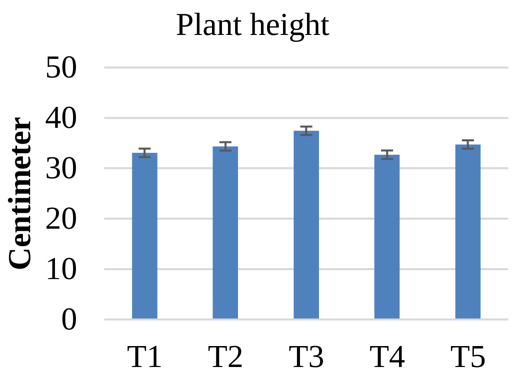
3.2 Plant Nutrient Content

The combination of potassium solubilizing bacteria (KSB) with feldspar and mica enhanced nutrient uptake in plants, thereby minimizing the risk of deficiencies. The control treatment recorded the lowest nutrient levels. The use of KAU POP 2016 combined with KSB improved nutrient levels, while adding feldspar at 0.1% resulted in the highest nitrogen (2.15%) and phosphorus (0.68%), indicating a significant enhancement. Incorporating mica at 0.1% also

Fig. 1. A) Cowpea grown in native Kaipad soil B) Cowpea grown in Kaipad soil mixed with coirpith



A)



B)

Fig. 2. Effect of treatments on growth of cowpea A) effect on leaf area B) effect on plant height

boosted nutrient levels but slightly less effectively than feldspar. The organic practices showed moderate improvement in nitrogen (1.89%) and phosphorus (0.62%) but slightly reduced potassium (0.20%). Overall, feldspar supplementation yielded the best nutrient enrichment. Research indicates that pairing KSB with half the recommended dose of chemical fertilizers leads to improved nutrient use efficiency and nutrient remobilization to grains, especially under flooded irrigation conditions [30]. An experiment involving cucumber plants demonstrated that the application of KSB in conjunction with feldspar significantly enhanced nutrient uptake, particularly of nitrogen and phosphorus, likely due to increased microbial activity that fostered better root development and nutrient absorption capabilities [31].

Potassium, which was observed to be generally below the optimal range (1-5%) for all treatments indicated that high K levels in soil do not guarantee increased plant uptake due to competition with other nutrients and potential imbalances, which can hinder optimal growth [32]. Seasonal dynamics of K uptake can also lead to fluctuations in K concentration in plants, particularly during critical growth periods. Phosphorus levels are above the optimal range (0.1-0.4%) across all treatments, which may indicate an excess or the potential for nutrient imbalances. KSB promote the growth of beneficial microorganisms that solubilize P from insoluble sources, increasing the bioavailability of P in the soil [33]. The addition of K minerals can alter soil pH and reduce P sorption capacity, facilitating greater P mobility and availability

Table 1. Effect of treatments on nutrient content of cowpea

Treatment	N%	P%	K%
T_1	1.75 ^{c}	0.42 ^{c}	0.21 ^{bc}
T_2	1.98 ^{abc}	0.58 ^{ab}	0.23 ^{a}
T_3	2.15 ^{a}	0.68 ^{a}	0.22 ^{ab}
T_4	2.05 ^{ab}	0.53 ^{bc}	0.21 ^{b}
T_5	1.89 ^{bc}	0.62 ^{ab}	0.20 ^{c}
Se(M)	0.082	0.03	0.004
CD	0.247	0.11	0.01

Table 2. Biochemical assay of grains

Treatment	Lysine (ɱg/L)	Histidine (ɱg/L)	Protein (mg/g)
T1	0.024 ^{b}	0.013	161.61 ^{c}
T2	0.075 ^{a}	0.044	175.81 ^{b}
T3	0.081 ^{a}	0.042	171.44 ^{bc}
T4	0.077 ^{a}	0.040	187.82 ^{a}
T5	0.022 ^{b}	0.035	149.60 ^{d}
Se(M)	0.012	0.008	10.78
CD	0.004	NS	3.570

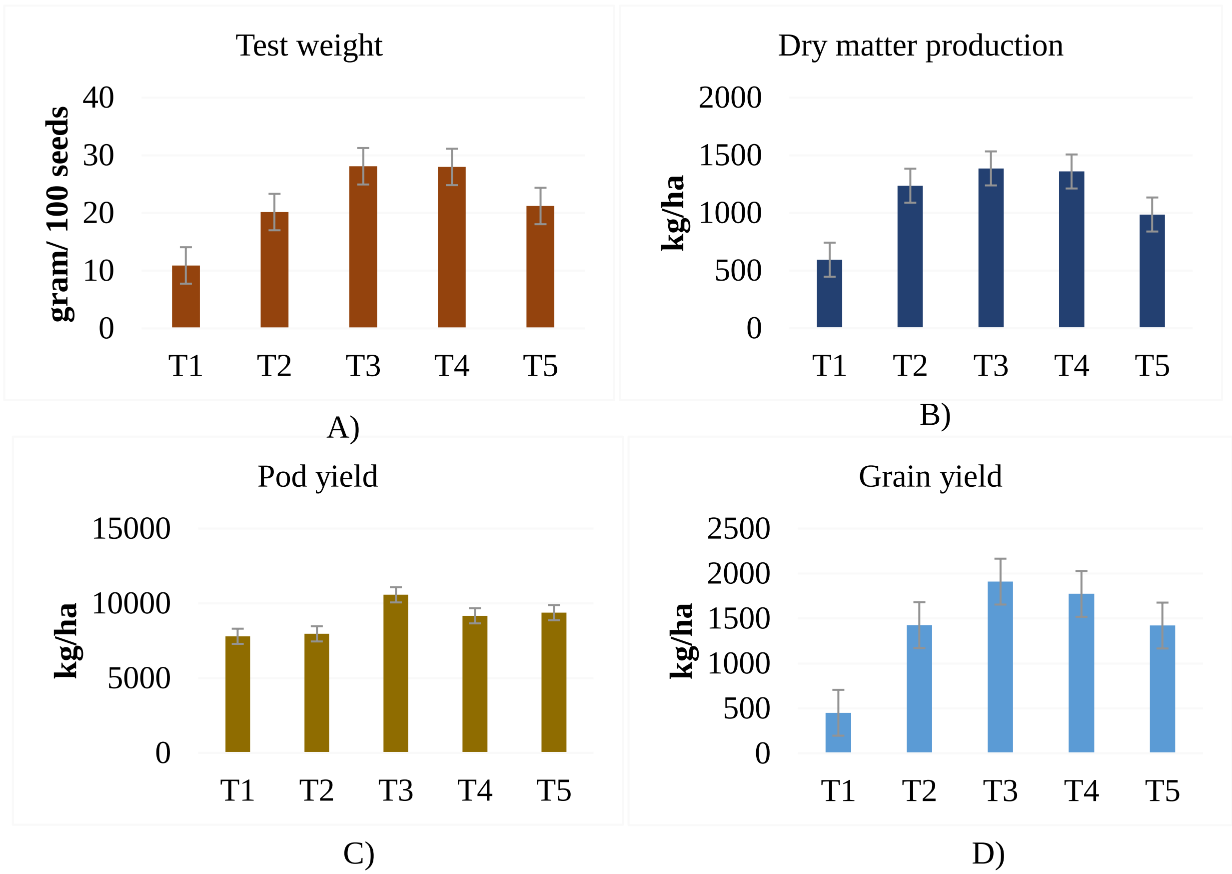


Fig. 3. Effect of treatments on yield parameters of cowpea A) effect on test weight B) effect on dry matter production C) effect on pod yield D) effect on grain yield

Table 3. Effect of treatments on potassium fractions ($kg.ha^{-1}$) of saline hydromorphic soils

Treatment	Available K	Water soluble K	Acid soluble K	Exchangeable K
T_1	756.28 ^{b}	402.612 ^{c}	501.20 ^{b}	353.66 ^{c}
T_2	853.16 ^{a}	419.860 ^{b}	531.86 ^{ab}	433.30 ^{a}
T_3	831.18 ^{a}	430.108 ^{a}	375.06 ^{c}	401.07 ^{abc}
T_4	831.74 ^{a}	405.216 ^{c}	485.10 ^{b}	426.52 ^{ab}
T_5	800.94 ^{ab}	426.636 ^{ab}	563.36 ^{a}	374.30 ^{bc}
Se(M)	18.832	2.69	15.518	18.948
CD	56.766	8.108	46.77	57.11

Table 4. Effect of treatments on cation exchange capacity (CEC) and effective cation exchange capacity (ECEC) of saline hydromorphic soils

Treatment	CEC($cmol(+)kg^{-1}$	ECEC ($cmol(+)kg^{-1}$
T_1	7.10 ^{c}	10.83 ^{b}
T_2	8.20 ^{a}	11.12 ^{b}
T_3	8.35 ^{a}	12.55 ^{a}
T_4	7.54 ^{b}	13.24 ^{a}
T_5	6.92 ^{c}	11.53 ^{b}
Se(M)	0.12	0.238
CD	0.361	0.718

also KSB can stimulate soil enzymes that mobilize P, further increasing its availability [34]. Long-term fertilization with K and P sources has shown significant increases in total and available P, indicating a synergistic effect between these nutrients [35]. Also, the synergistic effect due to increase in Ca by liming also might have increased P availability. These all together must have increased P uptake in plants.

These observations can guide further treatment modifications, especially for K, optimize soil fertility. All other nutrients were observed to be above threshold levels indicating the nutrient richness of the soil acted upon by KSB (potassium solubilizing bacteria) which might have synergistically affected nutrient solubilization other than potassium which was similar to results of the study involving three KSB strains—*Pantoea agglomerans*, *Rahnella aquatilis*, and *Pseudomonas orientalis*— which demonstrated that bioinoculation increased the uptake of potassium (K), nitrogen (N), and phosphorus (P) in rice [30].

3.3 Grain Quality

In grain quality estimated by analysing the amino acids like lysine content was observed to be highest in all KSB (potassium solubilizing bacteria) applied treatments. Cowpea is recognized for its high protein content, particularly rich in lysine compared to other legumes. The amino acid profile of cowpea typically shows that lysine is one of the most abundant essential amino acids. While specific studies of KSB's direct impact on lysine content are scarce, improved nutrient uptake from KSB application can enhance overall protein synthesis, potentially increasing lysine levels in the grains. Plant samples from saline hydromorphic soil pot culture study indicated that treatment T_4 had the highest protein content, measuring 187.824 $mg.kg^{-1}$. Studies indicate that inoculation with specific strains of KS bacteria can lead to significant increases in protein content in various pulse cultivars [36]. Earlier on inoculating legume seeds with *Rhizobium* sp. was found to increase protein content. This effect was observed across different cultivars of faba beans and peas. Pulses, when enriched with KS bacteria, can provide a more balanced amino acid profile, making them a better dietary protein source [37].

3.4 Soil Properties

The KAU POP combined with KSB (potassium solubilizing bacteria) treatment resulted in the highest available potassium (853.16 $kg.ha^{-1}$) and exchangeable potassium (433.30 $kg.ha^{-1}$), indicating significant improvement in plant-available potassium forms. Adding feldspar at 0.1% produced the highest water-soluble potassium (430.11 $kg.ha^{-1}$) but reduced acid-soluble potassium levels. Incorporating mica at

0.1% moderately improved exchangeable potassium (426.52 $kg.ha^{-1}$) while maintaining stable levels for other forms. The organic practice from 2017 showed the highest acid-soluble potassium (563.36 $kg.ha^{-1}$) and a significant increase in water-soluble potassium (426.64 $kg.ha^{-1}$).

Available potassium (K) was highest across all treatments that included potassium-solubilizing bacteria (KSB), followed by soils treated with organic amendments which was in concordance with a study in tea plants, where the application of *Bacillus pseudomycoides* along with mica waste increased potassium availability, enhancing plant growth [38]. Water-soluble potassium recorded dominant in treatments with KSB along with feldspar which in turn was closer to values in organic treatment and KSB alone. This might be due to the saline and acidic conditions affecting the release of water-soluble K, where feldspar and KSB together promote potassium release. Exchangeable K recorded elevated concentration in treatments with KSB seed treatment, where KSB facilitated potassium solubilization from both the external sources and native potassium in the soil. The presence of K-feldspar, along with minerals such as illite and smectite, acts as a potassium buffer. Enhanced weathering of these minerals through agricultural practices releases substantial amounts of potassium, making it available for plant uptake. The application of feldspar and KSB amplifies this process, thereby increasing the pool of exchangeable potassium [39]. The non-exchangeable potassium fraction was highest in organic treatments, followed by the control, while the lowest values were observed in the feldspar + KSB treatment. This suggests that KSB efficiently converts non-exchangeable potassium into an available form, thereby increasing its concentration in the soil. Long-term field experiments have shown that non-exchangeable potassium can contribute to the available potassium pool [40]. Also, it could be identified that feldspar and mica contribute to K supply through weathering, releasing K that was previously deemed unavailable. Long-term studies indicate that K from these minerals can buffer excess K from fertilizers, maintaining soil health. Long-term K management strategies, including the use of feldspar and mica, can lead to sustainable agricultural practices that enhance soil fertility and crop productivity [41].

The highest CEC values were seen in treatments T_2 (8.355 $cmol(+)kg^{-1}$) and T_3 (8.2 $cmol(+)kg^{-1}$). Microbial residues, particularly those from bacteria, make a considerable contribution to SOC (soil organic carbon) in saline soils. As salinity increases, as in saline hydromorphic soils, bacterial residues become more prevalent, increasing SOC accumulation, which is critical for improving soil structure and fertility [42]. In the case of ECEC, KSB applied treatments with greater levels. The use of KSBacteria can drastically change soil structure by encouraging the production of soil aggregates. Bacteria produce extracellular polysaccharides that bind soil particles together, increasing soil porosity and stability [43]. Improved soil structure allows for better water infiltration and retention, which is critical in saline soils. This structural modification has the potential to increase ECEC by making more exchange sites available for cations.

4. CONCLUSION

The study demonstrated that cowpea is a viable crop for diversification in the Kaipad agro-ecosystem, particularly under aerobic conditions during the fallow period after rice cultivation. The research highlighted the potential of potassium-solubilizing bacteria (KSB) in enhancing potassium availability from naturally occurring potassium-bearing minerals like feldspar and mica, which is particularly important for saline hydromorphic soils that are typically high in potassium but low in plant-available forms. KSB treatments significantly improved growth parameters such as plant height, leaf area, dry matter production, and pod yield, with the feldspar + KSB treatment yielding the best results. These findings underscore the synergistic effect of KSB in releasing potassium and other nutrients from soil minerals, thus facilitating better plant growth and yield.

The study also indicated that KSB not only enhances potassium availability but also improves the overall nutrient uptake of nitrogen and phosphorus, ensuring a balanced nutritional profile for cowpea cultivation. The highest nutrient content was observed in treatments combining KSB with feldspar and mica, which contributed to the enhanced soil fertility and plant health, without the need for synthetic fertilizers. This makes KSB a promising sustainable alternative for improving soil fertility in organic farming systems, like the one in Kaipad. Additionally, cowpea’s ability to thrive in Kaipad’s saline conditions, its high nutritional value, and its potential for improving soil nitrogen content through biological fixation make it an excellent candidate for crop rotation with rice. This approach could help reduce the fallow period, increase annual productivity, and improve the sustainability of the agro-ecosystem. Overall, the study suggests that integrating KSB and potassium-bearing minerals could offer a sustainable, eco-friendly solution to enhancing crop productivity in saline-prone soils like those in Kaipad.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Vanaja T. KAIPAD–a unique, naturally organic, saline prone rice ecosystem of Kerala, India. American Journal of Environmental Protection. 2013;2(2):42-6.
2. Unnikrishnan BV, Binitha N, Mohan M. Distinct microbiome and nutrient status of a saline hydromorphic soil under rice cultivation in comparison with laterite soil. Ecological Genetics and Genomics. 2022;24:100133.
3. Santhi G. Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad: Kerala Agricultural University; 2017.
4. Vanaja T, Neema V, Mammootty K, Balakrishnan P, Jayaprakash Naik B. A high yielding organic rice variety suited for coastal saline and non-saline fields: 'Ezhome-2'. Journal of organics. 2017;4(1):21-8.
5. Directorate of agriculture development and farmers. A compendium of agricultural statistics: Kerala 2023: keralaagriculture.gov.in.; 2023. Available:https://keralaagriculture.gov.in/wp content/uploads/2023/04/AGRICULTURAL >-STATISTICS-2023.pdf
6. Franco AAN, Okumura RS, de Carvalho AJ, de Moura Rocha M, Ormond ATS, Cogo FD, et al. Agronomic performance of cowpea cultivars in first crop in Southwest of Minas Gerais, Brazil. Caderno Pedagógico. 2024;21(7):e5819-e.
7. Yasin M, Munir I, Faisal M. Can Bacillus spp. enhance K+ uptake in crop species. Potassium solubilizing microorganisms for sustainable agriculture. 2016:163-70.
8. Bahadur I, Maurya R, Roy P, Kumar A. Potassium-solubilizing bacteria (KSB): a microbial tool for K-solubility, cycling, and availability to plants. Plant Growth Promoting Rhizobacteria for Agricultural Sustainability: From Theory to Practices. 2019:257-65.
9. Olaniyan FT, Alori ET, Adekiya AO, Ayorinde BB, Daramola FY, Osemwegie OO, et al. The use of soil microbial potassium solubilizers in potassium nutrient availability in soil and its dynamics. Annals of Microbiology. 2022;72(1):45.
10. Teotia P, Kumar V, Kumar M, Prasad R, Sharma S. Probiotic microbiome: potassium solubilization and plant productivity. Probiotics in Agroecosystem. 2017;451-67.
11. Verma A, Patidar Y, Vaishampayan A. Isolation and purification of potassium solubilizing bacteria from different regions of India and its effect on crop's yield. Indian J Microbiol Res. 2016;3(4):483-8.
12. Khati P, Mishra PK, Parihar M, Kumari A, Joshi S, Bisht JK, et al. Potassium solubilization and mobilization: Functional impact on plant growth for sustainable agriculture. Advances in Plant Microbiome and Sustainable Agriculture: Functional Annotation and Future Challenges. 2020; 21-39.
13. Sindhu SS, Parmar P, Phour M. Nutrient cycling: potassium solubilization by microorganisms and improvement of crop growth. Geomicrobiology and biogeochemistry: Springer. 2013;175-98.
14. Rajawat MVS, Ansari WA, Singh D, Singh R. Potassium solubilizing bacteria (KSB). Microbial Interventions in Agriculture and Environment: Soil and Crop Health Management. 2019;3:189-209.

15. Jackson ML. Soil Chemical Analysis. New Delhi: Prentice Hall of India Pvt. Ltd. 1973;498.
16. Sadasivam S. Biochemical methods. New Age International Publishers, New Delhi, India; 1996.
17. Black CA, Evans D, Ensminger L, White J, CLARK F. Methods of soil analysis: ASA; 1983.
18. Wood LK, DeTurk EE. The absorption of potassium in soil in non-replaceable form. Soil Sci Soc Am J. 1940;5((C)):152–61.
19. Piper C. Soil and plant analysis. Bombay: Hans Publishers. 1945;263.
20. SCH~Varzenbaci: IG, Biedermann W, Bangerter F. New Simple Titration Methods for Determining the Hardness of Water. Helv Chim Acta. 29:811.
21. Sims J, Johnson G. Micronutrient soil tests. Micronutrients in Agriculture. 1991;4:427-76.
22. Fichers R, Yates Y. Report on coordination of fishers statistics in India. A Handbook of Agricultural Statistics. 1958;17:47.
23. Barros JRA, Angelotti F, SANTOS JDO, SILVA RME, DANTAS B, MELO NFD. Optimal temperature for germination and seedling development in cowpea seeds. Revista Colombiana de Ciencias Hortícolas. 2020;14(2):231-9.
24. Kapadia C, Patel N, Rana A, Vaidya H, Alfarraj S, Ansari MJ, et al. Evaluation of plant growth-promoting and salinity ameliorating potential of halophilic bacteria isolated from saline soil. Frontiers in Plant Science. 2022;13:946217.
25. Kundu S, Sudhakar KS, Laxminarayana P, Gade KR. Effect of Potassium Solubilizing Bacteria (KSB) on the Performance of Sweet Corn (Zea mays L. saccharata) in Potassium Sufficient Soils of Semi-arid Tropic. International Journal of Environment and Climate Change. 2023; 13(10):3031-8.
26. Doaa M, Ashmawi A. Effect of Feldspar, Compost and Biochar on Cultivating Cowpea (*Vigna unguiculata* ssp. unguiculata) Plant and Soil Sandy Clay Loam Properties. Asian Soil Research Journal. 2022;6(1):42-57.
27. Goswami SP, Maurya B. Impact of potassium solubilizing bacteria (KSB) and sources of potassium on yield attributes of maize (*Zea mays* L). Journal of Pharmacognosy and Phytochemistry. 2020; 9(1):1610-3.
28. Kurdali F, Al-Ain F, Al-Shamma M. Nodulation, dry matter production, and N2 fixation by fababean and chickpea as affected by soil moisture and potassium fertilizer. Journal of Plant Nutrition. 2002;25(2):355-68.
29. Bhat TA, Kanth RH, Jan S, Nazir A, Jan B, Mir MS, et al. Response of lentil to application of potassium and potash solubilizing bacteria: Effect of potassium on lentil performance. Journal of AgriSearch. 2022;9(1):24-8.
30. Yaghoubi Khanghahi M, Pirdashti H, Rahimian H, Nematzadeh G, Ghajar Sepanlou M. Nutrient use efficiency and nutrient uptake promoting of rice by potassium solubilizing bacteria (KSB. Cereal Research Communications. 2018; 46:739-50.
31. Prajapati K, Modi H. Growth promoting effect of potassium solubilizing Enterobacter hormaechei (KSB-8) on cucumber (*Cucumis sativus*) under hydroponic conditions. Int J Adv Res Biol Sci. 2016;3(5):168-73.
32. Chen B, Fang J, Piao S, Ciais P, Black TA, Wang F, et al. A meta-analysis highlights globally widespread potassium limitation in terrestrial ecosystems. New Phytologist. 2024;241(1):154-65.
33. Saritha M, Kumar P, Panwar NR, Burman U. Plant response to novel organo-mineral fertilizers based on selective enrichment of P-and K-solubilizing microorganisms in soil. Journal of Soil Science and Plant Nutrition. 2021;21(3):2392-402.
34. Lei J, Yin J, Chen S, Fenton O, Liu R, Chen Q, et al. Understanding phosphorus mobilization mechanisms in acidic soil amended with calcium-silicon-magnesium-potassium fertilizer. Science of The Total Environment. 2024;916:170294.
35. Mazur Z, Mazur T. Influence of Long-Term Fertilization on Phosphorus, Potassium, Magnesium, and Sulfur Content in Soil. Polish Journal of Environmental Studies. 2015;24(1).
36. Šenberga A, Dubova L, Alsiņa I, Strauta L. –a Potential Tool for Improving Protein Content in Peas and Faba Beans. Rural Sustainability Research. 2017;37(332):2-9.
37. Vinutha T, Kumar RR, Bansal N, Rama Prashat G, Goswami S, Mishra GP, et al. Legumes and pulses: Ways and means to enhance the protein quality.

Conceptualizing Plant-Based Nutrition: Bioresources, Nutrients Repertoire and Bioavailability: Springer. 2022;107-21.
38. Pramanik P, Goswami A, Ghosh S, Kalita C. An indigenous strain of potassium-solubilizing bacteria Bacillus pseudomycoides enhanced potassium uptake in tea plants by increasing potassium availability in the mica waste-treated soil of North-east India. Journal of Applied Microbiology. 2019; 126(1):215-22.
39. Zaarur S, Erel R. The effect of soil mineral composition on K availability to plants. European Geosciences Union General Assembly 2024 (EGU24); April 01, 2024; Vienna, Austria. 2024;21838.
40. Balík J, Kulhánek M, Černý J, Sedlář O, Suran P. Potassium fractions in soil and simple K balance in long-term fertilising experiments. Soil & Water Research. 2020; 15(4).
41. Rani K, Datta A, Jat H, Choudhary M, Sharma P, Jat M. Assessing the availability of potassium and its quantity-intensity relations under long term conservation agriculture based cereal systems in North-West India. Soil and Tillage Research. 2023;228:105644.
42. Chen J, Wang H, Hu G, Li X, Dong Y, Zhuge Y, et al. Distinct accumulation of bacterial and fungal residues along a salinity gradient in coastal salt-affected soils. Soil Biology and Biochemistry. 2021; 158:108266.
43. Cong P, Ouyang Z, Hou R, Han D. Effects of application of microbial fertilizer on aggregation and aggregate-associated carbon in saline soils. Soil and Tillage Research. 2017;168:33-41.

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