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Effect of potassium solubilizing bacteria and foliar application of potassium on uptake and nitrogen use efficiency in paddy (*Oryza sativa*) in coastal acid soils of Karnataka

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Abstract

A field experiment was conducted to study the “Effect of potassium solubilizing bacteria and foliar application of potassium on uptake and nutrient use efficiency in paddy (*Oryza sativa*) in coastal acid soils of Karnataka” during the *Kharif* 2021 at Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, Udipi, KSNUAHS, Shivamogga. The experiment was laid out in Randomized Complete Block Design with eleven treatments replicated thrice. The experimental treatments included combinations of recommended doses of nitrogen, phosphorus, and potassium along with soil application of KSB and foliar KCl. The highest concentrations of nitrogen (1.701%), phosphorus (0.536%), and potassium (1.523%) at 90 days after transplanting were observed in the treatment combining KSB and foliar KCl (T_{10}). Nutrient uptake also followed a similar trend, with T_{10} showing the highest uptake of nitrogen (63.87 kg ha⁻¹), phosphorus (20.10 kg ha⁻¹), and potassium (57.31 kg ha⁻¹) in the grain, and nitrogen (43.11 kg ha⁻¹), phosphorus (26.18 kg ha⁻¹), and potassium (84.04 kg ha⁻¹) in the straw. The control treatment, which did not include KSB or foliar KCl, showed significantly lower nutrient concentrations and uptake. The findings suggest that the combination of KSB and foliar KCl enhances nutrient availability and uptake, promoting better growth and yield of paddy. This approach offers a sustainable solution to reduce chemical fertilizer usage while improving nutrient use efficiency in paddy cultivation.

Keywords: Potassium solubilizing bacteria, farm yard manure and coastal acid soils

Introduction

Rice (*Oryza sativa*), cultivated for over 10,000 years, remains the staple food for more than half the global population, providing 21% of the per capita energy and 15% of the per capita protein worldwide. In India, rice cultivation spans 43.79 million hectares with an annual production of 118.87 million tons, forming the foundation of national food security. In Karnataka, rice is grown on 1.45 million hectares, producing 3.72 million tons annually, with productivity varying across districts due to agro-climatic diversity. However, the sustainability of rice production in coastal acid soils is threatened by nutrient deficiencies, inefficient fertilizer use, and environmental constraints, necessitating innovative solutions (Ali *et al.*, 2007)^[3]

Among the macronutrients essential for crop productivity, potassium (K) plays a pivotal role in enhancing photosynthesis, enzyme activation, water regulation, and resistance to abiotic stresses. Despite its significance, potassium deficiency is prevalent in coastal Karnataka, largely due to high rainfall, which exacerbates K leaching. Potassium in soils exists primarily in unavailable forms (fixed or mineral K), with only a small fraction present in exchangeable or solution forms accessible to plants. This imbalance is further aggravated by intensive cropping systems, imbalanced fertilizer application, and the absence of indigenous potassium-bearing minerals in India, leading to heavy dependence on imported K fertilizers such as muriate of potash (MOP).

To address these challenges, potassium-solubilizing bacteria (KSB) offer an eco-friendly alternative for improving K availability in soils. These rhizospheric microorganisms solubilize

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fixed and mineral forms of potassium through mechanisms such as organic acid production, chelation, and acidolysis. Studies have demonstrated the ability of KSB strains, including *Bacillus mucilaginosus* and *Paenibacillus* spp., to enhance K availability, improve nutrient uptake, and boost crop yields. In addition, foliar potassium application (FKA) serves as a complementary approach to soil fertilization, enabling plants to directly absorb nutrients through leaves. Foliar K applications are particularly advantageous under moisture-stress conditions or in soils with limited nutrient mobility, as they enhance nutrient use efficiency and reduce wastage.

Rice production in India, particularly in Karnataka's coastal acid soils, faces compounding challenges of declining soil fertility, reduced nutrient use efficiency, and imbalanced fertilizer application. Nitrogen (N), a critical nutrient for rice, is often applied inefficiently, leading to significant losses through leaching and volatilization, further lowering its use efficiency. Integrating KSB with foliar potassium applications not only addresses potassium deficiency but also enhances nitrogen use efficiency (NUE) by optimizing nutrient availability and uptake. This integration has the potential to improve crop productivity while sustaining soil health.

Materials and Methods

Description of the experimental site

The experiment was conducted at Seed Farm, Zonal Agricultural and Horticultural Research Station, Brahmavar, Udupi district, Karnataka. The experimental site is situated between 130 25' N latitude and 740 45' E longitude with an altitude of 10 meters above mean sea level. It comes under the coastal zone (agro-climatic zone 10) of Karnataka.

Experiment details

Composite soil samples were drawn at a depth of 0 to 15 cm soil layer and a representative sample was obtained by standard procedures. The soil was analyzed for its chemical properties viz., pH, EC, organic carbon, available nitrogen, phosphorus and potassium and for biological properties viz., Bacteria, Fungi, Actinomycetes and K-solubilizers. The results of the analysis are given in Table 1. Experimental design is RCBD with eleven treatment and three replication. The cropping season is *kharif* with spacing 20 × 10 cm, seed rate 25 kg acre⁻¹ and variety MO-4. Treatment details are T1: Recommended dose of nutrients (60: 30: 60 kg per ha) + 5 tonnes of FYM, T2: T1 + soil application of KSB @ 5 kg per ha, T3: T1+ 2% KCl @ 30 and 60 DAT, T4: T1 + soil application of KSB @ 5 kg per ha + 2% KCl @ 30 and 60 DAT, T5: Recommended dose of N and P₂O₅ + 50% K₂O + soil application of KSB @ 5 kg per ha, T6: Recommended dose of N and P₂O₅ + 50% K₂O + 2% KCl @ 30 and 60 DAT, T7: Recommended dose of N and P₂O₅ + 50% K₂O + soil application of KSB @ 5 kg per ha + 2% KCl @ 30 and 60 DAT, T8: Recommended dose of N and P₂O₅ + 75% K₂O + KSB @ 5 kg per ha, T9: Recommended dose of N and P₂O₅ + 75% K₂O + 2% KCl @ 30 and 60 DAT, T10: Recommended dose of N and P₂O₅ + 75% K₂O + soil application of KSB @ 5 kg per ha + 2% KCl @ 30 and 60 DAT and T11: Absolute control. Note: FYM: Farm yard manure, KSB: Potassium solubilizing bacteria, KCl: Muriate of potash, Urea, rock phosphate and muriate of potash were used as inorganic source of N, P and K fertilizers. Five hills were selected randomly from the net plot and labelled for recording the observations in each treatment. Fisher's method of analysis of variance was applied for analysis and interpretation of data as given by Panse and Sukhatme (1967) [13]. The level of

significance used in 'F' and 't' tests was P=0.05. Critical difference values were calculated wherever the 'F' test was significant.

Soil sample analysis

Soil samples were collected prior to treatment application and at harvest to assess changes in soil properties. These samples were air-dried in shade, finely powdered using a wooden mallet, sieved through a 2 mm mesh, and stored in polythene bags for subsequent analysis. Chemical properties of the soil, including pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium, exchangeable calcium and magnesium, available sulfur, and DTPA-extractable micronutrients (iron, manganese, zinc, and copper), were analyzed following standard protocols.

The soil pH was measured using a 1:2.5 soil-to-water suspension and a digital pH meter with a combined electrode (Jackson, 1973) [9]. Electrical conductivity was determined using a conductivity bridge on a similar suspension, with results expressed as dS m⁻¹ at 25°C. Organic carbon was quantified via Walkley-Black's wet oxidation method. Available nitrogen was measured by distilling soil with potassium permanganate and sodium hydroxide, trapping the released ammonia in boric acid, and titrating against sulfuric acid (Subbiah and Asija, 1956) [18]. Available phosphorus was extracted using Bray's No.1 extractant and quantified by the chlorostannous-reduced molybdophosphoric acid blue color method at 660 nm (Bray and Kurtz, 1945) [6]. Available potassium was measured using a flame photometer after ammonium acetate extraction. Exchangeable calcium and magnesium were estimated by titration with EDTA, and available sulfur was measured turbidometrically using calcium chloride as an extractant (Jackson, 1973) [9]. DTPA-extractable micronutrients were determined using an atomic absorption spectrophotometer (Lindsay and Norwell, 1978).

Plant sample analysis

Plant samples were collected at 30, 60, and 90 days after transplanting (DAT) and at harvest to analyze nutrient concentrations and uptake. The collected samples, including grain, leaf, and straw, were initially air-dried at room temperature and then dried at 60°C in a hot air oven for 48 hours. The dried samples were powdered using a grinder with stainless steel blades and stored in polythene bags for further analysis of nitrogen (N), phosphorus (P), and potassium (K).

Total nitrogen content in the plant samples was determined using the Kjeldahl method, where 0.5 g of the sample was digested with concentrated sulfuric acid and a digestion mixture containing potassium sulfate, copper sulfate, and selenium in a 100:20:1 ratio. The digested material was distilled in an alkaline medium, and the liberated ammonia was titrated against standard sulfuric acid. Nitrogen uptake (kg ha⁻¹) was calculated by multiplying nitrogen concentration with dry matter production and dividing by 100.

For phosphorus and potassium analysis, 1 g of the powdered plant sample was pre-digested with concentrated nitric acid overnight. Subsequently, the sample was digested with a di-acid mixture (HNO₃: Perchloric acid in a 10:4 ratio) until a white residue was obtained. The digested material was diluted to 100 ml with distilled water for further analysis. Total phosphorus was determined using the vanadomolybdate phosphoric yellow color method in the nitric acid system, as described by Jackson (1973) [9]. Total potassium was measured using a flame photometer after diluting the di-acid digest. Uptake values for

phosphorus and potassium were computed using their respective concentrations and dry matter production.

Nutrient uptake

The nutrient uptake by paddy at harvest was worked out using the following equation.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient content (\%)} \times \text{Dry matter production (kg ha}^{-1}\text{)} \times 100$$

Nutrient use efficiency

Recovery efficiency (RE)

Recovery efficiency of nitrogen, phosphorus and potassium was worked out for paddy and groundnut during both the years. The formula used to find out the efficiency is as follows.

$$\text{RE (\% of nutrient taken up by a crop)} = \frac{(\text{Nuf} - \text{NuC})}{\text{Na}} \times 100$$

Where,

RE= Recovery efficiency

Nuf = Amount of nutrients taken up by a crop in fertilized plot (kg ha⁻¹)

NuC = Amount of nutrients taken up by a crop in control plot (kg ha⁻¹)

Na = Amount of nutrient applied (kg ha⁻¹)

Results and Discussion

This study investigated the combined effect of potassium solubilizing bacteria (KSB) and foliar application of potassium chloride (KCl) on the concentration and uptake of key nutrients *i.e.*, nitrogen (N), phosphorus (P), and potassium (K) in paddy plants at various growth stages (30, 60, 90 days after transplanting, and at harvest). The findings contribute to understanding how integrated nutrient management strategies, including microbial inoculants, enhance nutrient availability and uptake in paddy systems.

Nitrogen Concentration

- **Vegetative Growth Stages:** Among all treatments, the combination of the recommended dose of nitrogen (N), phosphorus (P₂O₅), 75% potassium oxide (K₂O), soil application of KSB (5 kg ha⁻¹), and foliar application of 2% KCl (T₁₀) resulted in the highest nitrogen concentrations of 1.291%, 1.294%, and 1.701% at 30, 60, and 90 days after transplanting (DAT), respectively as given in Table 2. These results reflect enhanced nitrogen availability due to microbial activities. KSB has been widely recognized for its role in promoting nitrogen availability through nitrogen fixation, which improves nitrogen assimilation by plants (Aziz *et al.*, 2010) [4]. Additionally, potassium is known to regulate the enzymes involved in nitrogen metabolism, which further increases nitrogen uptake (Sarwar *et al.*, 2012) [15].
- **Grain and Straw:** At harvest, nitrogen concentrations in the grain and straw were highest under T₁₀ (1.175% in grain and 0.609% in straw) (Table 2). The control treatment, without KSB and foliar KCl, recorded significantly lower nitrogen concentrations (grain: 0.996%, straw: 0.471%), suggesting that KSB and foliar KCl applications significantly enhanced nitrogen assimilation and storage in both vegetative and reproductive organs. The findings corroborate those of Surekha *et al.* (2003) [19], who observed that KSB and foliar applications lead to an increase in

nitrogen content in rice.

Nitrogen Uptake

Grain and Straw Uptake: Nitrogen uptake was highest under T₁₀, with a total of 63.87 kg ha⁻¹ in the grain and 43.11 kg ha⁻¹ in the straw. Other treatments with KSB and foliar KCl also exhibited higher nitrogen uptake compared to the control (Table 3). These results reflect the synergistic effect of microbial inoculation and potassium supplementation in improving the uptake of nitrogen by enhancing root growth, which facilitates better nutrient absorption from the soil (Dadarwal *et al.*, 2009) [7]. In contrast, the control treatment recorded the lowest nitrogen uptake (grain: 46.67 kg ha⁻¹; straw: 27.26 kg ha⁻¹), highlighting the importance of balanced fertilization and microbial activity in nutrient mobilization.

Phosphorus Concentration

- **Vegetative Growth Stages:** The phosphorus concentrations were highest under T₁₀ (0.536%, 0.537%, and 0.521% at 30, 60, and 90 DAT, respectively). Treatments that included KSB and foliar KCl (such as T₈ and T₇) (Table 2) also exhibited higher phosphorus concentrations compared to the control, confirming the positive impact of KSB on phosphorus availability. KSB not only solubilizes insoluble phosphorus but also aids in enhancing microbial mineralization of organic phosphorus (Badr *et al.*, 2006) [5]. Moreover, foliar potassium application has been shown to help in the mobilization of phosphorus from soil reserves, as potassium ions play a key role in enhancing the activity of phosphorus-mobilizing microorganisms (Meena *et al.*, 2014) [11].
- **Grain and Straw:** At harvest, phosphorus concentrations in grain (0.370%) and straw (0.328%) were highest in T₁₀, indicating better nutrient translocation and assimilation. The control treatment, with no KSB or foliar application, exhibited significantly lower phosphorus content (grain: 0.218%, straw: 0.173%) (Table 2). This underscores the critical role of KSB in phosphorus solubilization, as noted in similar studies by Kuotsu *et al.* (2016) [10], which showed that microbial inoculants improve phosphorus uptake by reducing the fixation of phosphorus in soils.

Phosphorus Uptake

Grain and Straw Uptake: The uptake of phosphorus in both grain and straw was significantly higher in the T₁₀ treatment, with 20.10 kg ha⁻¹ in the grain and 26.18 kg ha⁻¹ in the straw (Table 3). Other treatments also exhibited elevated phosphorus uptake, indicating the beneficial role of microbial inoculation and foliar potassium in improving phosphorus uptake from both organic and inorganic pools in the soil. The control treatment showed the lowest phosphorus uptake (grain: 12.92 kg ha⁻¹, straw: 17.92 kg ha⁻¹), indicating the necessity of both microbial activity and foliar nutrients for improved phosphorus utilization. Studies have confirmed that microbial inoculants, such as KSB, enhance phosphorus uptake by increasing phosphorus solubilization in the rhizosphere (Badr *et al.*, 2006) [5].

Potassium Concentration

- **Vegetative Growth Stages:** Potassium concentrations were highest under T₁₀ (1.113%, 1.120%, and 1.523% at 30, 60, and 90 DAT, respectively). The positive impact of KSB and foliar KCl on potassium concentration was evident across growth stages (Table 2). Potassium is essential for enzyme activation and photosynthesis, both of which are crucial for

plant growth. The availability of potassium was significantly enhanced in treatments involving KSB, as KSB is known to release potassium from insoluble mineral sources through the production of organic acids (Sheng & He, 2006)^[17].

- **Grain and Straw:** At harvest, potassium content was highest in grain (1.064%) and straw (1.187%) under T₁₀, indicating efficient nutrient translocation (Table 2). Other treatments with KSB and foliar KCl also exhibited significant potassium content, emphasizing the role of KSB in potassium solubilization and availability. The control treatment showed the lowest potassium content, underscoring the importance of microbial intervention in enhancing potassium uptake in paddy.

Potassium Uptake

Grain and Straw Uptake: Potassium uptake was highest under T₁₀, with 57.31 kg ha⁻¹ in the grain and 84.04 kg ha⁻¹ in the straw. These values were significantly higher than those in the control treatment (grain: 41.26 kg ha⁻¹, straw: 58.25 kg ha⁻¹), demonstrating the critical role of KSB and foliar KCl in enhancing potassium uptake (Table 3). Potassium solubilizing bacteria aid in the mobilization of potassium from non-exchangeable forms in the soil, thus improving its uptake by the roots (Meena *et al.*, 2014)^[12]. This result aligns with findings by Kuotsu *et al.* (2016)^[10], who showed that KSB treatment led to improved potassium uptake in rice.

Key Findings and Implications

1. **Synergistic Effects of KSB and Foliar KCl:** The integration of KSB with foliar KCl significantly enhanced the concentration and uptake of all three key nutrients—nitrogen, phosphorus, and potassium—across the growth stages of paddy. This synergistic effect was evident in higher nutrient content in both grain and straw at harvest. The positive influence of KSB on nutrient availability is well-documented, as KSB not only enhances potassium availability through solubilization but also influences nitrogen and phosphorus dynamics in the soil (Meena *et al.*, 2014)^[11]. The addition of foliar potassium application ensures efficient nutrient translocation, promoting better growth and yield.
2. **Optimizing Potassium Fertilization:** The 75% K₂O dose combined with KSB and foliar KCl yielded the highest nutrient uptake, indicating that reduced potassium application can still achieve optimal nutrient use efficiency when combined with biofertilizers. This finding suggests that farmers can achieve high yields with lower chemical fertilizer inputs, promoting sustainable agriculture practices (Sarwar *et al.*, 2012)^[15]. The study emphasizes the potential for optimizing potassium fertilization, particularly in regions with limited access to chemical fertilizers.
3. **Microbial Mechanisms in Nutrient Cycling:** The results highlight the critical role of microbial inoculants in enhancing nutrient solubilization and availability in paddy cultivation. The improved nutrient uptake is likely a result of KSB-induced solubilization of insoluble phosphorus and potassium as well as their role in nitrogen fixation (Aziz *et al.*, 2010)^[4]. Microbial activity also improves soil health by stimulating nutrient cycling, which ultimately leads to better nutrient utilization and crop growth.
4. **Enhanced Nitrogen Use Efficiency:** The study shows that the combination of KSB and foliar KCl improves nitrogen

uptake and assimilation. Potassium is essential for nitrogen metabolism as it regulates the activity of nitrate reductase and other enzymes involved in nitrogen assimilation. This synergistic interaction suggests that optimizing potassium nutrition could improve nitrogen use efficiency, reducing the need for excessive nitrogen fertilization (Aziz *et al.*, 2010)^[4].

Nitrogen Use Efficiency of Paddy as Influenced by KSB and Foliar Application of 2% KCl

The study indicate that the integration of KSB with foliar potassium application led to significant improvements in both total nitrogen uptake and NUE across treatments, with synergistic effects observed in the combined use of biofertilizers and potassium supplementation.

Total Nitrogen Uptake

The total nitrogen uptake, including both grain and straw nitrogen, showed substantial variation across treatments. The highest nitrogen uptake (106.97 kg ha⁻¹) was observed in treatment T₁₀, which combined 75% potassium oxide (K₂O) with soil-applied KSB and foliar sprays of 2% KCl at 30 and 60 days after transplanting (DAT) (Table 4). This treatment demonstrated the effectiveness of combining KSB with potassium supplementation in enhancing nitrogen uptake. The second-highest nitrogen uptake was recorded in T₈ (104.78 kg ha⁻¹), where KSB was applied with 75% K₂O but without the foliar potassium spray. The absence of the foliar application slightly reduced nitrogen uptake, indicating the critical role of foliar potassium in improving nutrient translocation.

Conversely, the absolute control (T₁₁), which lacked any nutrient input, exhibited the lowest nitrogen uptake at 24.55 kg ha⁻¹, highlighting the importance of nutrient supplementation for optimizing nitrogen assimilation in paddy crops. Grain nitrogen uptake, a key factor in total nitrogen uptake, was highest in T₁₀ (63.87 kg ha⁻¹), further supporting the beneficial effects of combining KSB and foliar potassium (Adam *et al.*, 2011)^[1]

Nitrogen Use Efficiency (NUE)

NUE values reflected the efficiency with which nitrogen was converted into plant biomass. The highest NUE (178.28) was observed in T₁₀, where the combination of KSB, potassium supplementation, and foliar potassium application enhanced both nitrogen uptake and utilization (Table 4). This indicates that the integrated approach significantly improved nitrogen use efficiency. Treatment T₈, which lacked the foliar potassium spray but included KSB and 75% K₂O, exhibited a high NUE of 174.63, emphasizing the role of KSB in enhancing nutrient use even in the absence of foliar potassium.

On the other hand, T₁₁, which received no nutrient inputs, showed the lowest NUE (40.92), underscoring the inefficiency of nitrogen use when fertilizers or biofertilizers are not applied. Interestingly, treatments with reduced potassium inputs, such as T₇ (161.68) and T₅ (157.43), also achieved high NUE values. This highlights that KSB can improve NUE even with lower potassium doses, offering a more cost-effective and sustainable alternative to full potassium fertilization (Adenawoola *et al.*, 2005)^[2]

Enhanced Nutrient Solubilization by KSB

The significant improvements in nitrogen uptake and NUE can be attributed to several mechanisms facilitated by KSB. KSB are known to solubilize unavailable potassium from soil minerals,

increasing the potassium pool in the rhizosphere. Potassium is crucial for plant growth, as it regulates enzyme activation, photosynthesis, and nutrient translocation. By improving potassium availability, KSB indirectly support better nitrogen uptake, as potassium enhances the activity of nitrate reductase and other enzymes involved in nitrogen assimilation (Meena *et al.*, 2014) [12].

Microbial Activity and Nutrient Cycling

KSB also contribute to enhanced microbial activity in the soil, which is essential for efficient nutrient cycling. The increased microbial population facilitates the breakdown of organic matter, releasing nitrogen and other nutrients that are subsequently available to plants. This microbial activity not only supports better nitrogen uptake but also improves soil fertility by enhancing the mineralization of nitrogen and other essential nutrients (Sheng *et al.*, 2010) [16]. Therefore, KSB help maintain a healthy soil ecosystem that supports efficient nutrient utilization and cycling.

Foliar Potassium Application

Foliar application of 2% KCl at critical growth stages (30 and 60 DAT) further optimized nutrient availability. Potassium applied in this manner reduces nutrient leaching and ensures that the plant can effectively absorb and utilize nitrogen during key phases of growth. Potassium is involved in the synthesis of amino acids, proteins, and chlorophyll, and plays a vital role in nitrogen metabolism. The foliar application of potassium enhances the efficiency of nitrogen assimilation and translocation, ensuring that the plant utilizes the available nitrogen to its fullest potential (Parmar & Sindhu, 2013) [14].

Sustainable Input Management

The results also suggest that reduced potassium inputs can still result in high NUE when KSB is used. Treatments like T7, which involved reduced potassium application, achieved high NUE values, demonstrating that KSB can enhance nutrient efficiency even with lower potassium doses. This is a promising finding for sustainable agricultural practices, as it indicates that KSB can help farmers reduce their reliance on chemical fertilizers while still achieving optimal crop performance. The integration of biofertilizers like KSB with reduced chemical inputs offers a cost-effective and environmentally friendly alternative to conventional farming practices (Ali *et al.*, 2005)

Table 1: Initial soil chemical and biological properties

Chemical properties of soil	
pH (1:2.5)	5.62
EC (1:2) (dS m ⁻¹) at 25 oC	0.058
Organic carbon (per cent)	1.14
Available nitrogen (kg ha ⁻¹)	272.00
Available P ₂ O ₅ (kg ha ⁻¹)	60.30
Available K ₂ O (kg ha ⁻¹)	110.25
Exchangeable calcium [cmol (p+) kg ⁻¹]	0.98
Exchangeable magnesium [cmol (p+) kg ⁻¹]	0.29
Available sulphur (mg kg ⁻¹)	11.46
DTPA Fe (mg kg ⁻¹)	14.31
DTPA Mn (mg kg ⁻¹)	4.12
DTPA Zn (mg kg ⁻¹)	1.45
DTPA Cu (mg kg ⁻¹)	1.92
Biological properties of soil	
Bacteria (cfu ×10 ⁵ g ⁻¹ of soil)	13.15
Fungi (cfu ×10 ⁴ g ⁻¹ of soil)	18.72
Actinomycetes (cfu ×10 ² g ⁻¹ of soil)	12.45
K Solubilizers (cfu ×10 ² g ⁻¹ of soil)	4

Table 2: Nitrogen, Phosphorus and Potassium content (%) of paddy as influenced by soil application of KSB and foliar application of 2% KCl

Treatments	Nitrogen content (%)					Phosphorus content (%)					Potassium content (%)				
	30 DAT	60 DAT	90 DAT	Grain	Straw	30 DAT	60 DAT	90 DAT	Grain	Straw	30 DAT	60 DAT	90 DAT	Grain	Straw
T ₁	1.150	1.153	1.539	0.996	0.471	0.263	0.263	0.417	0.277	0.222	0.839	0.844	1.291	0.881	1.006
T ₂	1.274	1.277	1.664	1.170	0.586	0.349	0.351	0.515	0.361	0.315	0.973	0.979	1.510	1.039	1.183
T ₃	1.214	1.216	1.569	1.065	0.489	0.246	0.247	0.421	0.338	0.263	0.928	0.933	1.463	0.973	1.036
T ₄	1.208	1.210	1.538	1.088	0.492	0.262	0.262	0.47	0.341	0.270	0.941	0.947	1.500	0.966	1.058
T ₅	1.255	1.257	1.650	1.164	0.574	0.326	0.327	0.457	0.349	0.298	0.946	0.952	1.494	0.959	1.175
T ₆	1.232	1.235	1.619	1.138	0.553	0.285	0.286	0.471	0.345	0.292	0.935	0.941	1.164	1.002	1.113
T ₇	1.271	1.274	1.659	1.167	0.580	0.342	0.343	0.497	0.353	0.309	0.966	0.973	1.505	1.034	1.178
T ₈	1.288	1.291	1.688	1.173	0.604	0.334	0.335	0.491	0.366	0.322	1.007	1.014	1.514	1.064	1.184
T ₉	1.235	1.238	1.616	1.104	0.496	0.264	0.264	0.444	0.343	0.289	0.998	1.004	1.472	1.007	1.107
T ₁₀	1.291	1.294	1.701	1.175	0.609	0.356	0.357	0.521	0.370	0.328	1.113	1.120	1.523	1.054	1.187
T ₁₁	1.028	1.030	1.309	0.739	0.242	0.188	0.189	0.348	0.207	0.149	0.723	0.728	1.075	0.748	0.867
S.Em.±	0.039	0.039	0.040	0.057	0.036	0.023	0.024	0.026	0.025	0.027	0.042	0.042	0.069	0.042	0.058
C.D. at 5%	0.113	0.114	0.117	0.170	0.107	0.069	0.070	0.077	0.075	0.078	0.124	0.124	0.206	0.126	0.173

Table 3: Total nitrogen, phosphorus and potassium uptake of paddy as influenced by soil application of KSB and foliar application of 2% KCl

Treatments	Total nitrogen uptake (kg ha ⁻¹)			Total phosphorus uptake (kg ha ⁻¹)			Total potassium uptake (Kg ha ⁻¹)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁	46.67	27.26	73.93	12.97	16.03	29.00	41.26	58.25	99.51
T ₂	60.71	39.37	100.07	18.72	24.21	42.93	53.92	79.42	133.34
T ₃	50.69	28.80	79.49	16.10	19.90	36.00	46.31	60.97	107.28
T ₄	52.51	29.48	81.99	16.47	20.43	36.90	46.64	63.37	110.01
T ₅	57.84	36.62	94.46	17.37	22.28	39.65	47.68	74.92	122.61
T ₆	56.27	34.26	90.53	17.07	21.40	38.48	49.55	68.96	118.51
T ₇	59.29	37.72	97.01	17.96	22.98	40.94	52.54	76.57	129.11
T ₈	63.09	41.69	104.78	19.68	25.25	44.93	57.21	81.75	138.97
T ₉	53.72	30.28	84.00	16.70	20.98	37.67	49.00	67.68	113.67
T ₁₀	63.87	43.11	106.97	20.10	26.18	46.29	57.31	84.04	141.35
T ₁₁	17.25	7.30	24.55	4.84	6.25	11.09	17.47	26.14	43.61
S.Em.±	3.67	1.64	5.53	1.06	1.37	2.67	2.20	3.30	5.80
C.D. at 5%	10.94	4.89	16.48	3.16	4.09	7.98	6.58	9.84	17.29

Table 4: Nitrogen use efficiency of paddy as influenced by soil application of KSB and foliar application of 2% KCl

Treatments	Total nitrogen uptake (kg ha ⁻¹)			Nitrogen use efficiency
	Grain	Straw	Total	
T ₁	46.67	27.26	73.93	82.30
T ₂	60.71	39.37	100.07	157.57
T ₃	50.69	28.80	79.49	105.02
T ₄	52.51	29.48	81.99	136.65
T ₅	57.84	36.62	94.46	157.43
T ₆	56.27	34.26	90.53	150.88
T ₇	59.29	37.72	97.01	161.68
T ₈	63.09	41.69	104.78	174.63
T ₉	53.72	30.28	84	140.00
T ₁₀	63.87	43.11	106.97	178.28
T ₁₁	17.25	7.30	24.55	40.92

Conclusion

The integration of potassium solubilizing bacteria (KSB) with foliar potassium chloride (KCl) significantly enhances nutrient dynamics and uptake efficiency in paddy cultivation. This synergistic approach improves the concentration and uptake of essential nutrients like nitrogen, phosphorus, and potassium across various growth stages, leading to better plant growth and higher rice yields. By solubilizing unavailable potassium and improving nutrient availability in the rhizosphere, KSB facilitates nutrient cycling and uptake. The addition of foliar potassium ensures efficient nutrient absorption during critical growth periods, minimizing nutrient losses and addressing deficiencies effectively.

This combination not only enhances soil biological activity and fertility but also supports sustainable farming practices by reducing reliance on chemical fertilizers. As a cost-effective and eco-friendly solution, the integration of microbial inoculants like KSB with foliar nutrient application promotes higher productivity while maintaining long-term soil health. It represents a practical and sustainable strategy for improving paddy cultivation in nutrient-depleted soils.

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