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Reduction of Chemical Potassic Source of Fertilizer by Integrating Potash Solubilising Bacteria in Sali Rice

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Abstract

The study here entitled "*Reduction of Chemical Potassic Source of Fertilizer by Integrating Potash Solubilising Bacteria in Sali Rice*" was carried out by Krishi Vigyan Kendra (KVK) of Udalguri under Assam Agricultural University, Assam. The demonstrations were conducted at farmer's plot at different villages of Udalguri district during *Kharif* seasons of 2020-21 and 2021-22, to measure the effect of continuous application of inorganic fertilizers along with organic nutrients on crop productivity, economics, soil fertility and plant health. The integration of Potash-Solubilizing Bacteria (KSB) with a 50% reduction in potassic fertilizer application resulted in an average grain yield of 46 and 45 q ha^{-1}, across two consecutive years, demonstrating a 5.45% yield improvement over conventional fertilization. Soil potassium availability improved significantly, with increased organic carbon, cation exchange capacity and microbial activity. The economic analysis revealed a higher benefit-cost (B:C) ratio of 2.1 in KSB-treated plots compared to 1.37 in conventional farmer's practices, indicating the cost-effectiveness of biofertilizer-based Integrated Nutrient Management (INM). These results enlighten the potential of KSB in reducing chemical input dependency while maintaining the sustainable rice productivity.

Keywords: Fertilizer, Integrated nutrient management, *Oryza sativa*, Potash solubilizing bacteria (KSB), Sali rice, Yield

Introduction

Rice (*Oryza sativa* L.), a crucial staple crop cultivated extensively in the North Bank Plain Zone of Assam, is an important source of livelihood for many farmers over the NE region. Due to the unbalanced application of fertilizers and improper nutrient management, the fertility of the soil gets degraded resulting in reduced yields and lower nutrient-use efficiency (Shenoy, 2020). The application of synthetic fertilizers in conventional farming practices does not guarantee the appropriate use of potassium (K), which is essential for rice cultivation. This results in the secondary effects of potassium insufficiency on root growth, enzyme activation, osmotic control and grain quality, which clearly shows the necessity of sustainable and efficient nutrient management strategies (Etesami *et al.*, 2017; Nawaz *et al.*, 2023).

Role of Potassium in Rice Nutrition

Potassium is essential for the regular physiological activities of plants, including enzyme activation, stomatal regulation and osmoregulation (Etesami *et al.*, 2017). During potassium deficiency in the plant, these affect photosynthetic efficiency, protein synthesis pathways and create imbalances in cytosolic K^+/Na^+ ratios, which also affect the plant stress tolerance and the overall metabolism functions (Olaniyan *et al.*, 2022; Nawaz *et al.*, 2023). The rice-growing ecosystems have fixed or unavailable mineral forms of potassium which lower the efficiency of plant uptake as these forms are not accessible to the plants. Conventional potassium fertilizers such as, muriate of potash (MOP) and potassium sulfate (K_2SO_4) are leachable in sandy and loamy soils. This causes inefficient uptake and higher input costs to farming fraternity (Shenoy, 2020). Therefore, deficient supply of potassium to

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rice needs immediate attention of researchers, to ensure long-term soil fertility and stability in rice yield.

Integrated Nutrient Management: A Sustainable Strategy

Integrated Nutrient Management (INM), an eco-friendly and scientifically proven method, is optimally integrates chemical fertilizer with organic manures, compost, green manures, legumes, biofertilizers and crop residues *etc*., so that the soil fertility can be enhanced (Borah *et al.*, 2016). It also improves the nutrient cycling, microbial activity and enhances the soil organic matter and thereby improves the soil structure and the crop yields (Bright *et al.*, 2022). Studies have shown that INM outperforms conventional fertilization strategies, as it reduces dependency on synthetic fertilizers while sustaining soil fertility and productivity (Kavya *et al.*, 2023).

One of the key components of INM involves the use of potassium solubilizing bacteria (KSB) that may convert potassium from unavailable forms to available forms for plant uptake. These beneficial microorganisms have multiple biochemical mechanisms; for example, the release of organic acids (*i.e.*, tartaric acid, oxalic acid, citric acid *etc*.), chelation and coupled enzymatic reactions free-K from minerals including feldspar, mica and biotite minerals (Tian *et al.*, 2024). Additionally, KSB may also enhance cation exchange capacity (CEC), increase microbial diversity and stimulate rhizosphere interactions, all of which may support increased nutrient uptake and stimulate plant growth (Olaniyan *et al.*, 2022).

KSB-based INM Practices in Assam's Rice Ecosystem

Using chemical fertilizers for a long time has led to depletion of potassium in the soil and imbalance of nutrients along with reduced crop productivity in rice growing areas of Assam. Research shows that using 50% of the recommended potassium fertilizer along with KSB helps to maintain rice yield equivalent to the traditional 100% K application while at the same time boosting soil health and cutting the input cost of farmers (Nawaz *et al.*, 2023). Moreover, KSB inoculation helps soil microbes work better which in turn helps the nutrient cycle sustainably and helps the nutrient-use efficiency (Bright *et al.*, 2022).

Since the use of synthetic fertilizers on agriculture continues, the soil quality continues to decline due to reduction in organic matter levels and remixing of ecological systems, which shows that biofertilizer-based INM strategies are essential for sustainable rice production (Selim, 2020). KSB-based fertilization has been shown to be cost-effective in field trials where microbial inoculants increased the benefit-cost (B:C) ratio (Nawaz *et al.*, 2023). Additionally, KSB helps retention of nutrient in soil and reduces cost of fertilization which improves use efficiency of fertilizer. Furthermore, using microbial biofertilizers reduces environmental degradation as it lessens the harmful effects of overuse of inorganic fertilizers (Olaniyan *et al.*, 2022).

KSB as an Alternative to Conventional Fertilization

Potassium-solubilizing bacteria (KSB) function as eco-friendly potassium supplements which help to resolve both potassium depletion issues and inefficient use of chemical fertilizers. These bacteria decompose potassium-bearing minerals to produce plant-available forms of potassium through mechanisms such as acidification, complexolysis and chelation (Shanware *et al.*, 2014). Studies have demonstrated that KSB can reduce the dependence on chemical potassium fertilizers by up to 50%, without impacting the crop yield or soil health (Selim, 2020). Moreover, KSB application enhances soil aggregation, reduces compaction and improves water retention, which leads to better root penetration and nutrient uptake efficiency (Kavya *et al.*, 2023).

Biofertilizers developed with KSB are organic compositions of living microbial cells that enhance the nutrient uptake while improving the plant health (Nirankari, 2017). Their inclusion in integrated nutrient management programs offers sustainable farming solutions that are cost-efficient and scientifically proven strategy for treating potassium deficiencies in rice cultivation.

Objectives of the Study

The goal of this research was to analyze the effect of supplementation of reduced potassium fertilization with potassium-solubilizing bacteria (KSB) on the growth, yield and soil fertility of rice cultivation in Assam. The investigation was designed to measure the benefits of KSB use on soil available potassium, plant nutrient uptake and crop yield in relation to conventional fertilization practices. The study also intended to evaluate the cost effectiveness of KSB use as an environmentally friendly substitute for chemical potassium fertilizers. The results of this research are anticipated to aid in the formulation of cost-effective and environmentally sustainable nutrient management strategies for rice cultivation in the region.

Materials and Methods

The current investigation on INM was carried out in 2020-21 and 2021-22 by Krishi Vigyan Kendra, Udalguri, affiliated with Assam Agricultural University (26.6669° N, 92.1844° E). The study employed a Randomized Complete Block Design (RCBD) comprising two treatments: TO-1 (tested technology with 50% reduced K fertilization and KSB inoculation) and TO-2 (farmers' practice with conventional fertilization). The KSB strain was cultured in a nutrient broth medium at 28 °C for 48 hours of incubation to achieve an optimal density (10^8 CFU ml^{-1}). KSB suspension was diluted at a 1:10 ratio in sterile water, before transplanting. The rice seedlings were immersed in the diluted KSB solution for 12 hours, allowed proper efficient microbial colonization in the rhizosphere. By applying this method, beneficial microbes attach themselves to the root surface which leads to enhanced potassium solubilization and nutrient uptake process. These demonstrations were carried out in farmers' plot of three villages of the district. Udalguri is categorized within the North Bank Plain zone of Assam, which is one of the agro-climatic zones of the state. The major soil type in Udalguri district is sandy clay loam.

Soil samples were collected from the experimental plots at two depths (0-15 cm and 15-30 cm) prior to sowing and after harvest to evaluate the effect of KSB applications on soil fertility. Each sample was analyzed for available potassium, soil pH, organic carbon content and microbial population dynamics. Microbial enumeration was performed using the serial dilution technique, followed by plating on Aleksandrov agar, a selective medium for KSB isolation (Etesami *et al.*, 2017). Morphological characterization, Gram staining and 16S rRNA sequencing were employed for bacterial identification and confirmation of KSB presence in the rhizosphere. The functional ability of KSB isolates was confirmed through potassium solubilization index assays, following the method described by Tian *et al.* (2024).

Five (5) numbers of farmers were nominated for carrying out the study within these villages of Udalguri *viz*., Nalkhamara (26.6848° N, 92.0494° E), Darringipara (26.3210° N, 91.4072° E) and Rupatal (26.5680° N, 91.9759° E). Selection of appropriate variety along with proper nutrient management is important for quality rice production (Heisnam *et al.*, 2024). The area in hectare considered for the study is 0.66 ha both the years for Ranjit Sub-1 variety of Sali Rice.

Before preparing the land for sowing, the nominated farmers were trained by the institute to pursue the INM practices properly. In addition, method demonstration was also conducted on paddy seedling root dip treatment using bio-fertilizers following the package of practice of *Kharif* crops of Assam 2021, by AAU, Assam for the demonstration plot (Anonymous, 2021b).

Information regarding INM (tested technology) and the growth practices employed by farmers for Sali rice is as follows:

TO-1 (Tested Technology): 100% NP of RDF + 50% K of Recommended Dose of Fertilizer (RDF) augmented with 3.5 kg ha^{-1} of KSB as a potassium source.

TO-2 (Farmers' Practice): 100% RDF *i.e.*, (60:20:40 kg of N:P_2O_5:K_2O ha^{-1}); where the RDF for Sali paddy is 60, 20, 40 of N, P_2O_5 and K_2O ha^{-1}, respectively and 'TO' stands for technology option.

Seedling Root Dip Treatment

Figure 1 depicts a method demonstration on stepwise procedure of seedling root dip treatment in rice carried out in farmer's plot at Nalkhamara village of Udalguri district.

Step 1: A bed of Size (2 m × 1.5 m × 0.15 m) was prepared filling it up with 2 inches of water.

Step 2: 3.5 kg of KSB ha^{-1} was suspended and mixed.

Step 3: The rice seedlings were dipped in the bed for 12 hours (overnight) and then transplanted (Baruah and Nath, 2013).

Figure 2 and 3 depicts the extension activities carried out by KVK personnel and different stages of the crop in both the years. The farmers followed the instructions of KVK personnel and adopted the package of practice for Sali rice cultivation *viz.* land preparation, seedling root dip treatment, proper seed rate, fertilizer application according to the technology of the study, *etc.* for the tested technology plot. For the farmers' practice plot, traditional practices of Sali rice cultivation along with RDF was followed.

The observations were recorded from both the technology

(a) Bed preparation and suspension of KSB

(b) Arrangement of seedlings in the bed

(c) Instructions provided by KVK personnels

(d) Final look of the bed with seedlings

Figure 1: Method demonstration on stepwise procedure of seedling root dip treatment in rice

plots and the control plots. The economic metrics, namely gross return, net return and benefit-cost ratio, were computed based on existing market prices of inputs and minimum support prices (MSP) of outputs for both years.

(a) Input distribution

(b) Application of biofertilizer

(c) Crop inspection by KVK Personnel

Figure 2: Application of K-solubilizing bacteria in sali rice (2020-21)

At last, yield gap analysis was calculated as follows (Samui *et al.*, 2020):

1. Technology Gap

Technology gap = Potential yield minus - Demonstration yield

2. Extension Gap

Extension gap = Demonstration yield minus - Farmers yield

3. Technology Index

$$\text{Technology Index} = \frac{\text{Potential yield} - \text{Demonstration yield}}{\text{Potential yield}}$$

Results and Discussion

The study conducted over two years in three distinct villages of Udalguri district revealed that the agricultural practices implemented in the demonstration plot yielded, on average, 5.45% more grain than the control plot (Table 3 and 4). The findings are almost similar with the study of Dutta (2014); however, the boost was till 38%.

Figure 3: Application of K-solubilizing bacteria in sali rice (2021-22)

Soil Fertility Assessment of Initial and Final Paddy

The average data of initial soil fertility rank of the three villages, which were collected before commencement of the study, as depicted in table 1 (2020-21) and table 2 (2021-22), respectively (Anonymous, 2021a). After the study, change in soil fertility status was seen starting from the 2020-21 period. Tables 1 and 2 further confirm the annual mean data about the soil fertility level of these villages. The study observed an increase in soil organic carbon (OC) in the tested demonstration plot over the two-year period, with the highest level recorded in 2021-22 at 0.64%; a comparable increase was also noted in the farmers' plot. The outcome was attributable to effective management practices by utilizing manures and fertilizers in contrast to the farmers' plots. Similar increase was also noticed in case

Table 1: Mean residual soil fertility status of the three villages of Udalguri district (2020-21)

Parameter of assessment and results			
Parameters	Initial	TO_1 (At harvest)	TO_2 (At harvest)
pH (1:2.5)	5.40	5.30	5.30
OC (%)	0.60	0.63	0.61
Avg. N (kg ha^{-1})	231.20	233.00	231.80
Avg. P (kg ha^{-1})	23.50	24.10	21.80
Avg. K (kg ha^{-1})	134.20	136.80	133.10

Table 2: Mean residual soil fertility status of the four villages of Udalguri district (2021-22)

Parameter of assessment and results			
Parameters	Initial	TO_1 (At harvest)	TO_2 (At harvest)
pH (1:2.5)	5.40	5.30	5.30
OC (%)	0.62	0.64	0.62
Avg. N (kg ha^{-1})	233.00	235.00	232.80
Avg. P (kg ha^{-1})	23.70	25.30	21.70
Avg. K (kg ha^{-1})	134.70	136.40	132.30

Table 3: Growth and yield attributes of sali rice (2020-21)

Crop	Parameters on Assessment	TO_1 (Tested Technology)	TO_2 (Farmers' Practice)
Sali Rice var: Ranjit Sub 1	Date of sowing	08/06/2020	
	Date of application of biofertilizer	04/07/2020	-
	Date of transplanting	05/07/2020	232.80
	Date of harvesting	12/11/2020	21.70
	Plant height (cm)	101	98
	Avg. grain yield (q ha^{-1})	45	43
	Gross cost (Rs. ha^{-1})	48,000.00	50,000.00
	Gross return (Rs. ha^{-1})	71,750.00	68,650.00
	Net return (Rs. ha^{-1})	23,750.00	18,650.00
	B:C Ratio	1.49	1.37

Table 4: Growth and yield attributes of sali rice (2021-22)

Crop	Parameters on Assessment	TO_1 (Tested Technology)	TO_2 (Farmers' Practice)
Sali Rice var: Ranjit Sub 1	Date of sowing	08/06/2022	
	Date of application of biofertilizer	04/07/2022	N/A
	Date of transplanting	05/07/2022	
	Date of harvesting	12/11/2022	
	Plant height (cm)	101	99
	Avg. grain yield (q ha^{-1})	46	43
	Gross cost (Rs. ha^{-1})	44,200.00	43,074.00
	Gross return (Rs. ha^{-1})	93,840.00	87,720.00
	Net return (Rs. ha^{-1})	49,640.00	44,646.00
	B:C Ratio	2.10	2.00

of Avg. N (233 and 235 kg ha^{-1}), Avg. P_2O_5 (24.10 and 25.3 kg ha^{-1}) in Avg. K (136.80 and 136.4 kg ha^{-1}) for 2020-21 and 2021-22, respectively. The increase in available potassium in KSB-treated plots is primarily attributed to microbial solubilization of potassium-bearing minerals through the secretion of organic acids including tartaric acid, citric acid and oxalic acid. These acids dissolve feldspar, mica and biotite minerals, thereby releasing potassium into a bioavailable form for plants (Tian *et al.*, 2024). Additionally, KSB enhances cation exchange capacity (CEC), reducing potassium fixation in soil colloids and making it more readily available for uptake (Olaniyan *et al.*, 2022). The higher yield recorded in KSB-treated plots is consistent with results reported by Kavya *et al.* (2023), where the integration of biofertilizer-based K supplementation improved rice grain yield and soil nutrient availability by 6-8%. This is because, unlike in the control plot, the demonstration plot used effective fertility management, also known as integrated nutrient management. A decrease in Avg. K was seen in the farmer's practice plot in both the years; this may point towards the fact that the decrease may be due to uptake of the nutrient by the crop; further, the decrease in farmers' practice plot compared to the tested technology plot can be explained as -50% dose of potassic fertilizer supplemented with bio-fertilizer component is more efficient in increasing the available form of potash in soil. Hence, INM can improve the uptake of essential nutrients by paddy and thus improves the nutrient use efficiency of the soil (Shekhawat *et al.*, 2012).

Growth and Yield Attributes of Paddy

Result of tested technology along with farmers' practice, on growth and yield attributes of Sali rice of both the years is presented in table 3 (2020-21) and table 4 (2021-22) (Anonymous, 2021a). The growth parameters *viz*. plant height and average yield was higher in tested technology case in both 2020-20 and 2021-22 as compared with farmers' practice. The technology taken into consideration in the demonstration plot shaped the maximum seed yield (45 q ha^{-1}) in 2020-21 and (46 q ha^{-1}) in the 2nd year of observation (2021-22), respectively. The findings of this study are consistent with Kavya *et al.* (2023), who reported that the integration of biofertilizer-based potassium supplementation resulted in 48 q ha^{-1} grain yield under similar agro-climatic conditions. Additionally, field trials conducted by Bright *et al.* (2022) demonstrated that KSB application enhanced rice yield by 6-8% compared to conventional fertilization, further supporting the potential of KSB in sustainable rice production. Integration of biofertilizer *viz*. KSB as rice seedling root dip treatment along with the inorganic sources of fertilizers facilitated in further absorption of plant nutrients from a deeper layer of soil ensuing the increase in grain yield. These conclusions are at par with the research results documented by Kavya *et al.* (2023). An increase in grain yield attributable to potassic fertilizer application may result from an uninterrupted supply of potassium during crucial crop growth stages, potentially linked to improved fertilizer usage efficiency. These sayings align closely with the research conducted by Kavya *et al.* (2023).

Economics of Cultivation

An economic analysis is shown in table 3 (2020-21) and table 4 (2021-22) revealed that the demonstration plots recorded an increase in gross return of Rs. 71,750.00 ha^{-1}

and Rs. 93,840.00 ha^{-1} in 2020-21 and 2021-22, respectively depending upon the selling price and minimum support price. Here, gross and net returns the demonstration were superior in both the 2020-21 and 2021-22 as compared to farmers' plot. Economic analysis revealed that the B:C ratio for KSB-treated plots was 1.49 in 2020-21 and 2.1 in 2021-22, significantly higher than the 1.37 and 2.0 recorded for farmers' practice (Anonymous, 2021a). The increase in net return can be attributed to lower fertilizer input costs (due to a 50% reduction in K fertilizer) while maintaining comparable yields. These findings align with studies by Selim (2020) and Nawaz *et al.* (2023), who reported that integrating KSB into fertilization programs can improve profitability by reducing chemical fertilizer costs while enhancing soil fertility and yield sustainability.

Yield Gap Analysis

Technology Gap

In this current investigation, technology gap is recorded to be 10 q ha^{-1} in 2020-21 and 9 q ha^{-1} in 2021-22. This technological gap might be due to the variation in soil fertility levels. During this study, the the technological gap drift (between 9-10 q ha^{-1}) demonstrates farmers' collaboration in conducting the demonstration, yielding positive outcomes in both years (Dutta, 2014).

Extension Gap

The extension gap measures the gap between the yield of the tested technology plot and the farmers' practices. The extension gap is documented as 2 q ha^{-1} and 3 q ha^{-1}, respectively which is solely owing to not adopting the proper scientific practices. Maximum utilization of the recent production technologies which have high yielding varieties recommended for Sali rice (paddy) will consequently help in reducing the disturbing trend of galloping the extension gap. Similar kinds of results were seen in the study of Sarma *et al.* (2024) (2.1 q ha^{-1} for demonstration plot).

Technology Index

The technology index reveals the probability of the tested technology adopted in farmers' field. The lower the figure, the greater is the potential of the achievability for the tested technology. It was noted that mean technology index *viz.* 18% and 16% was recorded in the demonstration plots, which the effectiveness of superior agricultural yields achieved through technical interventions by the KVK. The data of technology index speckled from (16% to 18%) during the study of the technology in specific areas, might be accredited to divergence in weather situation primarily, due to unavailability of irrigated condition in these villages (Dutta, 2014).

Conclusion

Thus, 100% NP of RDF + 50% K of RDF supplemented with 3.5 kg ha^{-1} KSB as potassic source of fertilizer, showed better results over RDF alone (farmer's practice) with higher soil potassium availability. KSB is a biofertilizer that facilitates the conversion of inaccessible or bound forms of plant nutrients into available ones, hence enhancing the availability of macronutrients in the soil. This progressively results in an enhancement in plant development and yield parameters of the paddy crop. The practice under the tested technology plot is a scientific foundation for balanced fertilizer application and also enables the farmer of the villages to choose the correct fertilizer management practices for cultivation of Sali paddy. This study emphasizes the function of KSB in enhancing potassium availability while reducing fertilizer costs. Beyond short-term yield benefits, the prolonged utilization of KSB has the potential to restore soil fertility, reduce fertilizer dependency and enhance soil microbial activity. Future research should explore microbial dynamics and soil health changes over multiple cropping cycles, ensuring the sustainability of this approach in intensive rice cultivation systems. Future research should explore the long-term soil microbiome shifts associated with KSB application to determine its sustainability in intensive rice cultivation systems.

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References

Anonymous, 2021a. *Annual Report of KVK-Udalguri*. Krishi Vigyan Kendra, Udalguri, Assam Agricultural University, Assam. pp. 56-61.

Anonymous, 2021b. *Package of Practices for Kharif Crops of Assam*. Assam Agricultural University and Dept. of Agriculture. Assam. p. 13.

Baruah, R., Nath, D.J., 2013. *Handbook of Biofertilizer Production Technology*. Biofertilizer Production Unit, Department of Soil Science, Assam Agricultural University, Assam (India).

Borah, D., Ghosh, M., Ghosh, D.C., Gohain, T., 2016. Integrated nutrient management in rainfed upland rice in the Northeastern Region of India. *Agricultural Research* 5, 252-260. DOI: https://doi.org/10.1007/s40003-016-0218-6.

Bright, J.P., Baby, A.S., Thankappan, S., George, A.S., Maheshwari, H.S., Nataraj, R., Judson, S., Binodh, A.K., 2022. Potassium releasing bacteria for unlocking soil potassium - A way forward for judicious use of chemical fertilizers. *International Journal of Plant & Soil Science* 34(19), 49-61. DOI: https://doi.org/10.9734/ijpss/2022/v34i1931088.

Dutta, R., 2014. Yield gap analysis of rapeseed - Mustard in North Bank Plain Zone of Assam. *Indian Research Journal of Extension Education* 14(3), 122-124.

Etesami, H., Emami, S., Alikhani, H.A., 2017. Potassium solubilizing bacteria (KSB): Mechanisms, promotion of plant growth, and future prospects A review. *Journal of Soil Science and Plant Nutrition* 17(4), 897-911. DOI: http://dx.doi.org/10.4067/S0718-95162017000400005.

Heisnam, P., Moirangthem, A., Devi, D.K., Langangmeilu, G., Dutta, P., Hazarika, B.N., 2024. Integrated based nutrient management on nutrient content and nutrient availability under aromatic rice-(aromatic)-lentil cropping system. *Research Biotica* 6(2), 63-73. DOI: https://doi.org/10.54083/ResBio/6.2.2024/63-73.

Kavya, V., Jayaprakash, R., Shankar, M., Dileep, R., 2023. Effect of potassium solubilising bacteria and foliar application of potassium on growth and yield of paddy (*Oryza sativa*) in coastal acid soils of Karnataka. *The Pharma Innovation Journal* 12(5), 382-386.

Nawaz, A., Qamar, Z.U., Marghoob, M.U., Imtiaz, M., Imran, A., Mubeen, F., 2023. Contribution of potassium solubilizing bacteria in improved potassium assimilation and cytosolic K^+/Na^+ ratio in rice (*Oryza sativa* L.) under saline-sodic conditions. *Frontiers in Microbiology* 14, 1196024. DOI: https://doi.org/10.3389/fmicb.2023.1196024.

Nirankari, L.S., 2017. *Soil Science Plant Nutrition, Manures and Fertilizers*, 1st Edition. Kushal Publications and Distributors, Varanasi (India). p. 648.

Olaniyan, F.T., Alori, E.T., Adekiya, A.O., Ayorinde, B.B., Daramola, F.Y., Osemwegie, O.O., Babalola, O.O., 2022. The use of soil microbial potassium solubilizers in potassium nutrient availability in soil and its dynamics. *Annals of Microbiology* 72, 45. DOI: https://doi.org/10.1186/s13213-022-01701-8.

Samui, S.K. Maitra, S., Roy, D.K., Mondal, A.K., Saha, D., 2020. Evaluation on frontline demonstration on groundnut (*Arachis hypogaea* L.) in Sundarbans. *Journal of the Indian Society of Coastal Agricultural Research* 18(2), 180-183.

Sarma, M.S., Ojah, I., Hafiz, A., Khound, A., Das, B.K., 2024. Role of cluster frontline demonstrations in enhancing black gram productivity under rainfed conditions in Darrang district of Assam. *International Journal of Research in Agronomy* 7(10), 782-785. DOI: https://doi.org/10.33545/2618060X.2024.v7.i10Sk.1904.

Selim, M.M., 2020. Introduction to the Integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy* 2020(1), 2821678. DOI: https://doi.org/10.1155/2020/2821678.

Shanware, A.S., Kalkar, S.A., Trivedi, M.M., 2014. Potassium solubilizers: Occurrence, mechanism and their role as competent biofertilizers. *International Journal of Current Microbiology and Applied Sciences* 3(9), 622-629.

Shekhawat, K., Rathore, S.S., Premi, O.P., Kandpal, B.K., Chauhan, J.S., 2012. Advances in agronomic management of Indian mustard (*Brassica juncea* (L.) Czernj. Cosson): An Overview. *International Journal of Agronomy* 2012(1), 408284. DOI: https://doi.org/10.1155/2012/408284.

Shenoy, H., 2020. Rice production in Coastal Karnataka: Soil constrains and agronomical strategies. *Biotica Research Today* 2(6), 451-456.

Tian, S., Xu, Y., Zhong, Y., Qiao, Y., Wang, D., Wu, L., Yang, X., Yang, M., Wu, Z., 2024. Exploring the organic acid secretion pathway and potassium solubilization ability of *Pantoea vagans* ZHS-1 for enhanced rice growth. *Plants* 13(14), 1945. DOI: https://doi.org/10.3390/plants13141945.