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Impact of integrated application of KSB, chemical fertilizers along with organic manures on nutrient uptake and yield of wheat in vertisols of central India

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Abstract
The present field experiment was conducted to study the effect of integrated application of seed inoculation of KSB, chemical fertilizers along with FYM and vermicompost on nutrient uptake and yield on Vertisols during rabi 2024-25 at Research Farm, Dept. of Soil Science, Dr. PDKV, Akola. The experiment was carried out in randomized block design with eight treatments replicated thrice. The treatments comprising of T_1: Absolute Control, T_2: 100% RD), T_3: 100% RDF + KSB, T_4:75% RDF + KSB, T_5: 75% RDF + FYM @ 5t ha^{-1}, T_6: 75% RDF + KSB + FYM @ 5t ha^{-1}, T_7: 75% RDF + Vermicompost @ 2.5 t ha^{-1}, T_8: 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}. The results revealed that, the integrated application of seed inoculation of KSB + 75 % RDF + vermicompost @ 2.5 t ha^{-1} recorded significantly higher nutrient uptake and yield of wheat followed by application of seed inoculation of KSB + 75 % RDF + FYM @ 5 t ha^{-1} which was statistically at par with each other. The lowest nutrient uptake and wheat yield was observed under control treatment. Hence, it can be concluded that the integrated application seed inoculation of KSB and 75 % RDF along with vermicompost @ 2.5 t ha^{-1} or FYM @ 5 t ha^{-1} found beneficial for enhancing nutrient uptake and wheat yield in Vertisols of central India.

Keywords: Integrated nutrient management, K-solubilizing bacteria, nutrient uptake, Vertisols and wheat yield

1. Introduction
Plant absorbs potassium only from the soil and its availability in soil a dependent upon the K dynamics as well as on total K content. With the introduction of high yielding crop varieties/hybrids and the progressive intensification of agriculture, the soil is getting depleted in potassium reserve at a faster rate moreover, due to imbalanced fertilizer application, potassium deficiency becoming one of the major constraints in crop production.
Soil microbes have been reported to play a key role in the neutral K cycle and therefore, KSM present in the soil could provide an alternative technology to make K available for uptake by plants. The use of potassium-solubilizing bacteria (KSB) has emerged as an eco-friendly approach to enhance the solubilization of unavailable forms of K through the production of organic acids, chelating compounds, and enzymes, thereby increasing its availability to crops. KSB not only improve K uptake but also contribute to better root growth and nutrient absorption by improving soil biological activity. In the view of above, the present investigation was conducted study the effect of integrated application of seed inoculation of KSB, chemical fertilizers along with FYM and vermicompost on nutrient uptake and yield on Vertisols.

2. Materials and Methods
The experiment was conducted at Research Farm, Department of Soil Science, Dr. Panjabrao Deshmukh krishi Vidyapeeth, Akola, India situated between 20.7002° N and 77.0082° E latitude and longitude. The altitude of the place is 307.42 m above mean sea level. It represents eastern Maharashtra Plateau, hot moist, semi-arid with medium and deep clay

black soils. The experiment was carried out in randomized block design (RBD) with eight treatments replicated thrice. The treatments consisted of T_1: Absolute Control, T_2: 100% RD), T_3: 100% RDF + KSB, T_4:75% RDF + KSB, T_5: 75% RDF + FYM @ 5t ha^{-1}, T_6: 75% RDF + KSB + FYM @ 5t ha^{-1}, T_7: 75% RDF + Vermicompost @ 2.5 t ha^{-1}, T_8: 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}. The soil of the experimental site is deep black with clay texture and classified as Typic Haplustert of Vertisols. The initial soil properties indicate that the soil is moderately alkaline in pH (8.1), low in available N (214 kg ha^{-1}) and moderate in P (14.47 kg ha^{-1}) and high in available potassium (372 kg ha^{-1}).

In order to evaluate the initial fertility status of the soil, composite soil samples from (0-15 cm depth) were randomly collected from the experimental field with the help of screw auger prior to the experimentation. The recommended dose of fertilizer as 120:60:60 N, P_2O_5 and K_2O kg ha^{-1} applied as per treatment wise. The treatment wise grain and plants samples were collected randomly from each plot at harvest of the sorghum. The grain and plant samples were processed as per standard procedures to analyze nutrient content and uptake (Piper 1966). The data were subjected to statistical analysis (Panse and Sukhatme, 1978).

3. Results and Discussion

3.1 Grain and straw yield of wheat: The effect of integrated application of KSB, chemical fertilizers along with organic manures was found significant on grain and straw yield of wheat (Table 1). The results indicated that significantly highest grain yield of wheat (24.90 q ha^{-1}) was recorded with the application of 75% RDF + KSB + vermicompost @ 2.5 t ha^{-1} (T_8) which was statistically at par with all treatments except absolute control and RDF. The lowest grain yield of wheat (10.23 q ha^{-1}) was observed under absolute control treatment (T_1). This finding clearly indicates that the integrated nutrient management (INM) approach, combining reduced chemical fertilizer with KSB and organic amendments, is more effective in enhancing wheat productivity compared to sole chemical fertilization.

The superior yield performance under 75% RDF + KSB along with either vermicompost @ 2.5 t ha^{-1} or FYM @ 5 t ha^{-1} attributed due to the continuous supply of nutrients throughout the crop growth cycle. The inoculation with potassium solubilizing bacteria further enhances the availability of potassium, a critical nutrient for wheat growth, by solubilizing unavailable potassium forms in the soil (Kumar *et al.*, 2018) [3]. Meena *et al.* (2015) [4] also reported that KSB strains have the capacity to release potassium from silicate and mica-rich minerals through the production of organic acids and enzymes, thereby enhancing plant potassium uptake and improving biomass accumulation.

More or less similar trend was observed incase of straw yield of wheat due to various treatments.

Table 1: Effect of seed inoculation of KSB on grain and straw yield of wheat

Treat No.	Treatment details	Yield (q ha^{-1})	
		Grain	Straw
T_1.	Absolute control	10.23	12.59
T_2.	100 % RDF	22.15	27.88
T_3.	100 % RDF + KSB	23.50	28.61
T_4.	75% RDF + KSB	23.39	28.55
T_5.	75% RDF + FYM @ 5t ha^{-1}	23.80	29.00
T_6.	75% RDF + KSB + FYM @ 5t ha^{-1}	24.10	29.20
T_7.	75% RDF + Vermicompost @ 2.5 t ha^{-1}	24.15	29.76
T_8.	75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}	24.90	30.12
	S.E(m)	0.51	0.75
	C.D at 5%	1.54	2.28

3.3 Nitrogen uptake by wheat

Nitrogen uptake is a product of biomass and nitrogen content. The data on nitrogen uptake by grain, straw and total are presented in Table 2 and revealed that the effect of various treatments have significant effect on nitrogen uptake by wheat at during course of investigation.

The application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} recorded significantly highest N uptake by wheat grain (55.87 kg ha^{-1}) followed by 75% RDF + KSB + FYM @ 5t ha^{-1} (52.96 kg ha^{-1}), 75% RDF + Vermicompost @ 2.5 t ha^{-1} (52.41 kg ha^{-1}) and 75% RDF + FYM @ 5t ha^{-1} (50.37 kg ha^{-1}) which was statistically at par with each other. Whereas application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} recorded significantly highest N uptake (15.86 kg ha^{-1}) by wheat straw followed by 75% RDF + KSB + FYM @ 5t ha^{-1} (14.98 kg ha^{-1}) which was statistically at par with each other.

Table 2: Effect of seed inoculation of KSB on N uptake by wheat

Treat. No	Treatment details	N uptake (kg ha^{-1})		
		Grain	Straw	Total
T_1.	Absolute control	16.02	5.57	21.59
T_2.	100 % RDF	41.76	13.16	54.92
T_3.	100 % RDF + KSB	45.14	13.25	58.39
T_4.	75% RDF + KSB	42.95	12.86	55.81
T_5.	75% RDF + FYM @ 5t ha^{-1}	50.37	14.11	64.49
T_6.	75% RDF + KSB + FYM @ 5t ha^{-1}	52.96	14.98	67.94
T_7.	75% RDF + Vermicompost @ 2.5 t ha^{-1}	52.41	14.86	67.27
T_8.	75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}	55.87	15.86	71.73
	S.E(m)	2.07	0.39	2.26
	C.D at 5%	6.27	1.17	6.85

The significantly highest total N uptake by wheat (71.73 kg ha^{-1}) was observed in treatment receiving 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} which was found to be at par with 75% RDF + KSB + FYM @ 5t ha^{-1} (67.94 kg ha^{-1}) and 75% RDF + Vermicompost @ 2.5 t ha^{-1} (67.27 kg ha^{-1}). The significantly lowest N uptake (16.02, 5.57 and 21.59 kg ha^{-1} respectively by grain, straw and total) was noticed in absolute control.

The increased in N uptake by wheat under INM treatments was attributed to Vermicompost/FYM improved soil physical properties and microbial activity, which helps in better nutrient mineralization and availability (Subbiah *et al*., 2017) [14]. Moreover, organic inputs increase CEC and microbial biomass, which promote sustained N availability during crop growth (Ramesh *et al*., 2014) [7]. Similarly, KSB enhances potassium and other nutrient absorption (Shivay *et al*., 2013; Basak *et al*., 2015) [11, 1]. This clearly demonstrates the importance of integrated nutrient management practices for enhancing nutrient use efficiency in wheat cultivation (Yadav *et al*., 2018) [15]. These results are consistent with the findings of Singh *et al*., (2016) [12], who reported that combined application of inorganic fertilizers with organic and microbial inoculants significantly increased nitrogen uptake in wheat.

3.4 Phosphorus uptake by wheat

Phosphorous uptake is a product of biomass and phosphorous content. The scrutiny of data on P uptake by grain, straw and total are presented in Table 3. The effect of various treatments on P uptake by wheat was found to be significant. The significantly highest P uptake by grain of wheat (10.37 kg ha^{-1}) was recorded with treatment receiving 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} followed by 75% RDF + Vermicompost @ 2.5 t ha^{-1} (9.62 kg ha^{-1}), 75% RDF + KSB + FYM @ 5t ha^{-1} (9.40 kg ha^{-1}) and 75% RDF + FYM @ 5t ha^{-1} (9.11 kg ha^{-1}) which was statistically at par with each other. The application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} was recorded highest P uptake (6.12 kg ha^{-1}) by wheat straw and this treatment was par with 75% RDF + KSB + FYM @ 5t ha^{-1} (5.15 kg ha^{-1}).

While, in case of total P uptake, the highest total P uptake (16.49 kg ha^{-1}) by wheat was observed with the application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} followed by 75% RDF + Vermicompost @ 2.5 t ha^{-1} (14.68 kg ha^{-1}), 75% RDF + KSB + FYM @ 5t ha^{-1} (14.55 kg ha^{-1}) which were found to be at par with each other. The lowest P uptake by grain, straw and total was recorded in absolute control.

The minimal phosphorus availability in untreated plots likely limited the uptake potential of the crop. These results align with the findings of Kumar *et al.* (2018) [3], who noted significantly lower P uptake in control treatments due to nutrient-deficient conditions. Similar increase in P uptake by wheat also observed by Dwivedi *et al.* (2016) [2], with integrated use of organic manures, biofertilizers, and reduced chemical fertilizers.

Table 3: Effect of seed inoculation of KSB on P uptake by wheat

Treat. No.	Treatment details	P uptake (kg ha^{-1})		
		Grain	Straw	Total
T_1.	Absolute control	2.89	1.41	4.30
T_2.	100 % RDF	7.56	3.90	11.46
T_3.	100 % RDF + KSB	8.52	4.22	12.75
T_4.	75% RDF + KSB	7.60	4.02	11.62
T_5.	75% RDF + FYM @ 5t ha^{-1}	9.11	4.77	13.88
T_6.	75% RDF + KSB + FYM @ 5t ha^{-1}	9.40	5.15	14.55
T_7.	75% RDF + Vermicompost @ 2.5 t ha^{-1}	9.62	5.06	14.68
T_8.	75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}	10.37	6.12	16.49
	S.E(m)	0.50	0.30	0.65
	C.D at 5%	1.50	0.90	1.97

3.5 Potassium uptake by wheat

Potassium uptake is a product of biomass and potassium content. The scrutiny of data on K uptake by grain, straw and total are presented in Table 4 and revealed that different treatments have significant effect on K uptake by wheat.

The significantly highest K uptake by grain (19.27 kg ha^{-1}) was observed in treatment receiving 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} followed by 75% RDF + KSB + FYM @ 5t ha^{-1} (17.83 kg ha^{-1}) and 75% RDF + Vermicompost @ 2.5 t ha^{-1} (17.24 kg ha^{-1}) which were found to be at par with each other.

While the application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} recorded significantly highest K uptake by straw (31.13 kg ha^{-1}) followed by application of 75% RDF + Vermicompost @ 2.5 t ha^{-1} (29.90 kg ha^{-1}), 75% RDF + KSB + FYM @ 5t ha^{-1} (28.71 kg ha^{-1}) and 75% RDF + FYM @ 5t ha^{-1} (27.51 kg ha^{-1}) which were statistically at par with each other. Whereas in case of total K uptake by wheat, highest total K uptake (50.50 kg ha^{-1}) was noticed with the application of 75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1} followed by of 75% RDF + Vermicompost @ 2.5 t ha^{-1} (47.14 kg ha^{-1}), 75% RDF + KSB + FYM @ 5t ha^{-1} (46.54 kg ha^{-1}) and 75% RDF + FYM @ 5t ha^{-1} (43.93 kg ha^{-1}) which were statistically at par with each other. The lowest K uptake by grain, straw and total was recorded in absolute control (T_1).

Table 4: Effect of seed inoculation of KSB on K uptake by wheat

Treat. No.	Treatment details	K uptake (kg ha^{-1})		
		Grain	Straw	Total
T_1.	Absolute control	6.24	10.30	16.54
T_2.	100 % RDF	14.63	24.06	38.69
T_3.	100 % RDF + KSB	16.43	26.18	42.61
T_4.	75% RDF + KSB	15.79	25.40	41.19
T_5.	75% RDF + FYM @ 5t ha^{-1}	16.42	27.51	43.93
T_6.	75% RDF + KSB + FYM @ 5t ha^{-1}	17.83	28.71	46.54
T_7.	75% RDF + Vermicompost @ 2.5 t ha^{-1}	17.24	29.90	47.14
T_8.	75% RDF + KSB + Vermicompost @ 2.5 t ha^{-1}	19.27	31.13	50.40
	S.E(m)	0.81	1.13	1.67
	C.D at 5%	2.47	3.42	5.05

The increased uptake observed in the T_8 treatment due to the application of KSB significantly contributes to the mobilization of insoluble forms of potassium in the soil. These bacteria produce organic acids (such as citric, oxalic, and gluconic acids), which help in releasing potassium from feldspar and mica minerals (Parmar & Sindhu., 2013) [5]. This result is in close conformity with the findings of Sharma *et al.*, (2017) [10] and Rai *et al.*, (2020) [6], who reported significant improvement in potassium uptake by wheat with the combined application of RDF, KSB, and organic manures.

4. Conclusion

Hence, based on result of present investigation, it can be concluded that the integrated application seed inoculation of KSB and 75 % RDF along with vermicompost @ 2.5 t ha^{-1} or FYM @ 5 t ha^{-1} found beneficial for enhancing nutrient uptake and yield of wheat yield in Vertisols of central India.

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