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Effect of potassium and potassium mobilizing bacteria (KMB) with and without FYM on yield of wheat (*Triticum aestivum* L.)

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Abstract
Potassium (K) is considered as an essential macronutrient and a major constituent within all living cells. About 98% of the potassium in the earth's crust exists in insoluble forms as rocks and silicate minerals, resulting in very low concentrations of soluble potassium in the soil for plant growth and development. Naturally, soils contain K in larger amounts than any other nutrients; however most of the K is unavailable for plant uptake. There are certain microorganisms which use a number of biological processes to make potassium available from unavailable forms. These potassium-mobilizing bacteria (KMB) can be used as a promising approach to increase K availability in soils, thus playing an important role for crop establishment under K-limited soils. The experiment comprising twelve-treatment combinations was laid out in Randomized Block Design (factorial) with three replications. The treatment consisted of two levels of FYM *viz*., 0 t ha^{-1} (F_0) and 10 t ha^{-1} (F_1) and two levels of Potassium Mobilizing Bacteria *viz*., without KMB (KMB_0) and with KMB (KMB_1) and three levels of potassium *viz*., 0 kg K_2O ha^{-1} (K_0), 20 kg K_2O ha^{-1} (K_1) and 40 kg K_2O ha^{-1} (K_2). The application of FYM, Potassium Mobilizing Bacteria and potassium showed marked increased in root biomass, dry matter, spike length, total number of tillers and grain yield. Interaction effects between FYM, KMB and potassium were found to be significant. Treatment combination KMB_1K_2 (KMB along with potassium @ 40 kg ha^{-1}) recorded significantly the highest spike length (10.54 cm), Treatment combination $F_1KMB_1K_2$ (FYM @ 10 t ha^{-1} along with KMB and potassium @ 40 kg ha^{-1}) recorded significantly higher grain yield (5640 kg ha^{-1}).

Keywords: Potassium, potassium mobilizing bacteria, FYM, plant and bacteria interaction

Introduction
Feeding a growing world population, as projected to reach 9 billion by 2050, adopting more efficient and sustainable production methods, responding to increased concerns about managing the natural resources, and adapting to climate change and drought conditions in several developing regions are some of the significant challenges that agriculture will face in the 21st century (Haub *et al*., 2012). In order to feed the increasing world population, agriculture must be intensive and sustainable in the future. However, it is well known that the food production by agriculture cannot be generally sustained unless the nutrients removed from soil as a result of increased crop production are replaced. Many agricultural soils lack a sufficient amount of one or more of essential plant nutrients so that plant growth is suboptimal. To obviate this problem and obtain higher plant yields, farmers have become increasingly dependent on chemical sources of fertilizers (Glick, 2012) [11]. While the chemical fertilizers helped plant grow, they did not improve the properties of soil. It is well known that the constant use of chemical fertilizers, mainly phosphorous, nitrogenous, and potassic fertilizers have harmful effects on the environment (Adesemoye and Kloepper, 2009) [1]. The farmers are using high analyzed inorganic fertilizers to get higher yield of wheat, but continuous and uncontrolled use of these chemical fertilizers ultimately deteriorate the soil health. Therefore, integrated nutrient management is highly essential to maintain the soil fertility, productivity and to minimize the land degradation and environmental pollution for sustainable agriculture. The integrated nutrient management thus can play a vital role in agriculture.
After nitrogen (N) and phosphorus (P), potassium (K) is the most important plant nutrient that has a key role in the growth, metabolism and development of plants. In addition to increasing plant resistance to diseases, pests, and abiotic stresses, K is required to activate over 80 different enzymes responsible for plant and animal processes such as energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation (Almeida *et al*., 2015; CecílioFilho *et al*., 2015; Gallegos-Cedillo *et al*., 2016; Hussain *et al*., 2016; White and Karley, 2010; Yang *et al*., 2015) [3, 9, 10, 14, 29, 34]. K is the seventh most abundant element in

Earth's crust. Total K content in soils ranges between 0.04 and 3% K. Although K is present as an abundant element in soil, only 1 to 2% of this element is available to plants (Sparks and Huang, 1985) [27]. The rest are bound with other minerals and therefore are unavailable to plants.

K is present in several forms in the soil, including mineral K, non-exchangeable K, exchangeable K, and solution K. Depending on soil type, from 90 to 98% of soil K is mineral K and most of this K is unavailable for plant uptake (Sparks and Huang, 1985) [27]. Minerals containing K are feldspar (orthoclase and microcline) and mica (biotite and muscovite). The non-exchangeable form of K makes up approximately 1 to 10% of soil K and is trapped between the layers or sheets of certain kinds of clay minerals (Sparks, 1987) [26]. Solution K is the form of K that directly and readily is taken up by plants and microbes in soil. In addition, this form is most subject to leaching in soils. The concentration of soil solution K varies from 2 to 5 mg L^{-1} for normal agricultural soils (Sparks and Huang, 1985) [27].

It is proven that microbial soil community is able to influence soil fertility through soil processes *viz*. decomposition, mineralization, and storage/release of nutrients (Parmar and Sindhu, 2013) [21]. Among these microorganisms, K mobilizing bacteria (KMB) have attracted the attention of agriculturists as soil inoculum to promote the plant growth and yield. The KMB are effective in releasing K from inorganic and insoluble pools of total soil K through solubilization (Archana *et al.*, 2013; Gundala *et al.*, 2013; Keshavarz Zarjani *et al.*, 2013; Meena *et al.*, 2014; Meena *et al.*, 2015b; Parmar and Sindhu, 2013; Saha *et al.*, 2016; Zeng *et al.*, 2012; Zhang *et al.*, 2013) [4, 12, 17, 19, 20, 21, 23, 35, 36]. It had been reported that inoculation with KSB produced beneficial effect on growth of different plants (Ahmad *et al.*, 2016; Bakhshandeh *et al.*, 2017; Xiao *et al.*, 2017) [2, 8, 31]. In wheat, potassium application is not regularly practiced, but plays equally important role as nitrogen and phosphorus in plants for their growth and development. Potassium is one of the most abundantly absorbed cation in higher plants. By introduction of high yielding varieties and hybrids during green revolution and with the progressive intensification of agriculture, the soils are getting depleted in potassium reserve at a faster rate. As a consequence, potassium deficiency is becoming one of the major constraints in crop production, especially in coarse textured soils. Even in fine textured soils the available fraction is low compared to total K in them, crops do respond to K fertilization in soils with high available K. Excessive usage of fertilizers leads to the leaching of nutrients from the soil and contributes to environmental pollution, without corresponding increases in yield. Potassium fixed with in soil and not easily meet to crop. Although most agricultural soils have large amounts of K, these are immobilized and mostly become unavailable. Hence, very limited concentration of K is available to plants. Although K deficiency is not as wide spread as that of nitrogen and phosphorus, many soils which were initially rich in K become deficit in due course due to heavy utilization by crops and inadequate K application, runoff, leaching and soil erosion (Sheng and Huang, 2002).

Materials and Method

Experimental details

The present experiment was carried out at Agronomy Farm, B. A. College of Agriculture, Anand Agricultural University, Anand during *rabi* season of the year 2019-20. The experimental site was alkaline in reaction with low in organic carbon and nitrogen, medium in available phosphorus and potassium. With respect to DTPA-extractable micronutrients Zn, Mn, Fe and Cu were in sufficient (Table 1.0).

The treatments were comprised of two levels of FYM (F_0 and F_1), two levels of KMB (with KMB (KMB_1) and without KMB (KMB_0) and three levels of potassium (K_0, K_1 and K_2). Seed treatment with KMB @ 5 mL kg^{-1} of seed and application of @ 1.0 L ha^{-1} at second irrigation. The treatments were tested against the control. The field experiment was laid out in Randomized Block Design (Factorial) with three replications. Wheat variety GW 451 was raised under recommended dose of fertilizer (120 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1}). Basal dose of 60:60 kg N-P_2O_5 ha^{-1}, common to all plot was applied in the furrows before sowing. Remaining 50% N was applied in two splits at 30 and 45 DAS. As per treatments, the crop was fertilized with potassium @ 0, 20, 40 kg ha^{-1} in the form of MOP in soil were done. Nitrogen and Phosphorus were applied from the source of urea and DAP. Before sowing, seeds were uniformly treated with KMB @ 5 mL kg^{-1} of seeds and application @ 1.0 L ha^{-1} at 2nd irrigation.

Table 1: Properties of the experimental plot

Parameter	value
Clay (%)	5.10
Silt (%)	10.33
Fine sand (%)	83.50
Coarse sand (%)	0.66
Bulk density (g/cc)	1.51
Water holding capacity (%)	38.05
Soil Texture	Loamy sand
pH (1:2.5)	8.12
EC (1:2.5) (dS m^{-1})	0.17
Organic carbon (%)	0.39
Available N (kg ha^{-1})	150
Available P_2O_5 (kg ha^{-1})	37.22
Available K_2O (kg ha^{-1})	247
Available S (mg kg^{-1})	6.30
DTPA- Fe (mg kg^{-1})	7.22
DTPA-Mn(mg kg^{-1})	7.99
DTPA- Zn (mg kg^{-1})	1.33
DTPA- Cu (mg kg^{-1})	2.94

Growth, yield and yield attributes

Plant population was recorded at 20 DAS. plant height, spike length and total number of tillers was recorded at harvest for five randomly selected tagged plants in each net plot and average was calculated and recorded separately. Dry matter per plant, root length was recorded at 30 DAS. Five normal seedlings were used for measurement of root length, were enveloped in a paper packet and dried in an oven at 60 + 5^0C for 24 hours. After 24 hours paper packets were removed and weighed. The dry weight per seedling was expressed in gram. At harvest of the crop, grain, straw yield and test weight were computed and respective.

Statistical Analysis

The data were statistically analysed as per the methods by steel and torrie (1982). The value of 'F' was worked out and compared with value of 'F' at 5 per cent level of significance. The value of standard error mean (S.Em.±), critical difference (C. D.) and coefficient of variation (C. V. %) were also calculated and appropriately used for interpretation of data.

Results and Discussion

Effect of FYM on yield and yield attributes

Plant population at 20 DAS was not affected significantly due to different levels of FYM. Root biomass and dry matter of wheat at 30 DAS significantly altered with the application of FYM. The results revealed that the application of 10 t FYM ha^{-1} was found significantly the highest root biomass (0.482 g $plant^{-1}$) and dry matter (3.638 g $plant^{-1}$) of wheat at 30 DAS. The similar results were supported by Jat *et al*., (2013) [16] in wheat, Ibrahim *et al*., (2013) [15] in sweet corn and also Bagyalakshmi *et al*., (2012) [7] in tea. The increased root biomass and dry matter with FYM might be due to mainly the positive effect of FYM on increasing the available moisture content and hence increasing the availability of nutrients in the soil solution. Whereas in case of root length; treatment effect was found to be non-significant. Plant height at harvest showed non-significant response with different levels of FYM. Spike length and total number of tillers were significantly influenced by different levels of FYM. Significantly the highest spike length (8.59 cm) and total number of tillers (334) were observed under treatment F_1 (FYM @10 t ha^{-1}) as compared to treatment F_0 (0 t ha^{-1}). The similar results were also found by Singh *et al.*, (2019) [25] and Arif *et al*., (2017) [6] in wheat, Ram and Mir (2006) [22] in wheat crop. It is obvious that FYM proved more useful in case of plant growth of wheat crop, it may be due to slow mineralization and availability of nutrients along with moisture holding capacity of soil by FYM.

Significantly the highest grain yield (5100 kg ha^{-1}) was recorded under treatment F_1 (FYM @ 10 t ha^{-1}) as compared to treatment F_0 (FYM @ 0 t ha^{-1}). The Similar results were also found by Singh *et al*., (2019) [25] in wheat. However, treatment effect was not found significant in case of straw yield as well as test weight of wheat.

Effect of KMB on yield and yield attributes

The yield attributes *viz*., plant population at 20 DAS, Root biomass, dry matter, root length of wheat at 30 days after sowing and plant height at harvest did not influenced significantly due to different levels of KMB. Significantly the highest spike length (8.97 cm) was observed under treatment KMB_1 (with KMB) as compared to treatment KMB_0 (without KMB). This may be attributed to greater mobilization of K from organic materials through composting process. Addition of KMB significantly enhanced higher available-K and increase spike length. However, treatment effect was found to be non-significant with KMB application in case of total number of tillers. Significantly the highest grain yield (5046 kg ha^{-1}) was recorded under the treatment KMB_1 (with KMB application) as compared to KMB_0 (without KMB application). Similar results were also found by Singh *et al*., (2000) [24] in wheat. This result also close conformity with Archna *et al.*, (2008) [5] who reported that KMB is able to solubilize inorganic source of K like muriate of potash by means of production of organic acids in order to improve yield in maize. Bagyalakshami *et al.* (2012) [7] reported that application of indigenous KMB formulation with various doses of potash fertilizers and N and P enhanced green leaf yield and productivity in tea. The increase in yield might be due to the solubilization of nutrients in the soil by producing organic acids by KMB. However, treatment effect was found to be non-significant in case of straw yield as well as test weight of wheat.

Table 2: Effect of FYM, KMB and potassium levels on plant population, root biomass, dry matter, root length and plant height of wheat

Treatments	Plant population (per meter row length) (At 20 DAS	Root biomass	Dry matter	Root length	Plant height (At harvest)
		At 30 DAS			
		(g $plant^{-1}$)		(cm)	
Level of FYM					
F_0	34	0.443	3.342	9.04	74.83
F_1	35	0.482	3.638	9.48	79.43
S. Em. ±	1.0	0.013	0.097	0.29	1.83
CD (P=0.05)	NS	0.038	0.284	NS	NS
Level of KMB					
KMB_0	34	0.448	3.371	8.89	74.83
KMB_1	35	0.478	3.611	9.63	79.42
S. Em. ±	1.0	0.013	0.097	0.29	1.83
CD (P=0.05)	NS	NS	NS	NS	NS
Level of Potassium					
K_0	34	0.453	3.400	8.89	75.48
K_1	34	0.466	3.486	8.95	77.09
K_2	35	0.470	3.587	9.95	78.81
S. Em. ±	1.0	0.016	0.119	0.36	2.24
CD (P=0.05)	NS	NS	NS	NS	NS
Sig. Interaction	-	-	-	-	-
CV %	7.78	11.73	11.78	13.28	10.5

Effect of potassium on yield and yield attributes

The yield and yield attributing characters *viz*., plant population at 20 DAS, root biomass, dry matter and root length of wheat at 30 days, plant height at harvest and total number of tillers as well as grain and straw yield of wheat did not differ significantly due to different levels of potassium. but the treatment of application of potassium @ 40 kg ha^{-1} (K_2) was registered significantly the highest spike length (8.90 cm) as compared to treatment K_1 and K_0.

Table 3: Effect of FYM, KMB and potassium levels on spike length, total number of tiller, grain yield, straw yield and test weight of wheat

Treatments	Spike length (cm)	Total number of tillers (per meter row length)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Test weight (g)
Level of FYM					
F_0	7.67	308	4678	6258	44
F_1	8.59	334	5100	6534	46
S. Em. ±	0.23	8	102	190	0.7
CD (P=0.05)	0.67	25	300	NS	NS
Level of KMB					
KMB_0	7.28	312	4728	6251	44
KMB_1	8.97	329	5046	6540	46
S. Em. ±	0.23	8	102	190	0.7
CD (P=0.05)	0.67	NS	300	NS	NS
Level of Potassium					
K_0	7.51	314	4813	6329	44
K_1	7.98	321	4809	6465	45
K_2	8.90	327	5038	6393	46
S. Em. ±	0.28	10	125	233	0.9
CD (P=0.05)	0.82	NS	NS	NS	NS
Sig. Interaction	KMB×K	-	F×KMB×K	-	-
CV %	11.91	11.25	8.88	12.63	7.11

Table 4: Interaction effect of KMB and potassium levels on spike length (cm) of wheat

KMB (lit ha^{-1}) / Potassium (kg ha^{-1})	KMB_0 (without KMB)	KMB_1 (with KMB)
K_0	7.20	7.81
K_1	7.24	8.55
K_2	7.40	10.54
S. Em. ±	0.40	
CD (P=0.05)	1.16	
CV%	11.91	

Interaction effect

Treatment combination KMB_1K_2 (KMB along with potassium @ 40 kg ha^{-1}) recorded significantly the highest spike length (10.54 cm) as compared to other treatment combinations.

Table 5: Interaction effect of FYM, KMB and potassium levels on grain yield (kg ha^{-1}) of wheat

FYM (t ha^{-1})	Potassium (kg ha^{-1})	KMB_0 (without KMB)	KMB_1 (with KMB)
F_0	K_0	4111	4603
	K_1	4366	4789
	K_2	4967	4873
F_1	K_0	4690	4857
	K_1	4757	5516
	K_2	5141	5640
S. Em. ±	251		
CD (P=0.05)	736		
CV %	8.88		

The similar results were supported by Ram and Mir (2006) [22] in wheat. And also interaction effect between FYM, KMB and potassium was found nonsignificant. It may be due to KMB Adequately and timely supply of K might have favored net assimilation and partitioning of photosynthates to various metabolic sinks, which ultimately increased growth and yield. treatment combination $F_1KMB_1K_2$ (FYM @10 t ha^{-1} along with KMB and potassium @ 40 kg ha^{-1}) recorded significantly higher grain yield (5640 kg ha^{-1}) than treatment combination with $F_0KMB_0K_0$ but it was at par with treatment combination with $F_1KMB_0K_1$, $F_1KMB_1K_0$ and $F_0KMB_0K_2$. However, former significant treatment combination was improved grain yield by 27.10% as compared to treatment combination with $F_0KMB_0K_0$. The increased yield with K fertilization might be due to increased availability, absorption and translocation of K nutrient. As the K is essential for grain development, the favorable effect of high doses of K on growth and yield attributes was mainly responsible for higher grain and straw yields. Significant effect of K application in sesame, mustard, groundnut and wheat was also reported by Yadav *et al.* (2012) [32].

The overall development of plant in terms of root and shoot which might have absorbed more nutrient and enhanced photosynthesis and production of assimilates, which in turn increased the yield of wheat. The results obtained in present investigation are in line with the findings of Singh *et al.*, (2019) [25] in wheat, also Tarafdar and Rao (2001) [28], Yadav *et al.*, (2005) [33] and Meena *et al.*, (2007) [18] in vegetable crops.

Conclusion

The finding of the present study suggested that application of 10 t FYM ha^{-1} along with potassium mobilizing bacteria (KMB) was beneficial to enhance the wheat grain yield.

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