Indian Journal of Fertilisers **15** (7) : 748-753, July 2019

Response of Crops to Applied Potassium and Estimation of Critical Limits in Vertisols

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Received : 08/01/2019 Accepted : 06/03/2019

Abstract

Field experiments were conducted to study the response of crops to applied potassium (K) and estimate the critical limit of available K for Vertisols with different cropping systems, namely, soybean-wheat and rice-wheat at Bhopal, rice-wheat at Raipur, rice-rice at Jagtial, and soybean-wheat at Jabalpur with graded doses of K. Nitrogen (N) and phosphorus (P) were supplied as per the requirement of crops. Results revealed that rice responded to applied K in the farmers' fields at different centers. Increase in yield was significant up to 40 kg ha^{-1} at Raipur and *rabi* rice of Jagtial; however, in case of Bhopal all the crops and *kharif* rice at Jagtial responded up to 80 kg ha^{-1} of applied K. In *rabi* season, wheat responded up to 40 kg K ha^{-1} at Jabalpur, whereas at Bhopal response was noted at 80 kg K ha^{-1}. Crop response to applied K during *kharif* was larger than during *rabi* season on the same field. Decline in available status of K occurring due to wetting is probably the reason for larger response of crop during wet season (*kharif*). Critical level of K deficiency in Vertisols computed using Cate and Nelson's graphical procedure for 1N neutral ammonium acetate (1N NH_4OAc, pH 7.0) was 335 kg K ha^{-1} which was closer to 337 kg K ha^{-1} using statistical procedure of the same authors. Higher critical level *vis-à-vis* the current value of 280 kg K ha^{-1} suggests for a reworking of 4Rs of K fertilization as current inadequate K could pose a threat to sustainability of the cropping systems in Vertisols.

Key words: Potassium response, rice, wheat, soybean, Vertisols, *kharif, rabi*, critical limit

Introduction

Potassium (K) is one of the essential plant nutrients required in amounts similar to nitrogen (N) or even more. It catalyzes several biochemical reactions in plants and provides resistance to plants against the drought and pest attack. On an average, a crop with good productivity level removes around 100 kg K from the soil. Continuous mining of K by the crop coupled with removal of crop residues from the field sans its external applications leads to decline in the available K status in the soil. Chen et al. (2000) reported that the continuous absence of K in fertilizer schedule or its addition in suboptimal quantities creates inadequacy of available K in the soils inspite of these being rich in total K; such conditions threaten the realization of the potential yields of crops. Data from long-term fertilizer experiments (LTFE) running in the different agroecological zones of the country have also indicated decline in the yields of crops under the treatments containing sub-optimal-K in the fertilization schedule. Post-Green Revolution era in India experienced the imbalanced use of chemical fertilizers; often urea has been applied in large quantities to the high yielding varieties under irrigated conditions with utter neglect of K. All these factors have accelerated the mining of native K reserves, leading to reduction in the available K contents in many soils. Rainfed crops are more prone to K deficiency than the irrigated crops because the rainwater does not add any K into the soil (Singh and Wanjari, 2012). Hence the rainfed soils are expected to be more responsive to external K applications.

Vertisols are considered to be rich in K status but due to its continuous removal from the soils in quantities larger than the amounts applied, crops grown on these soils have started responding to the applied K. Unlike N and P, recommendation of K is made as a maintenance dose. In general, application of 40-60 kg K_2O ha^{-1} $crop^{-1}$ is recommended which is far less than the amount removed. Situation gets worse when the crop residues are not recycled back into the soil. Resultantly, most of the cropping systems are operating under the negative K balance. Studies on vermiculite-dominated soils indicated that the plant available K content decreased after flooding of the dry soils due to the increased K fixation (Olk et al., 1995). Excessive (Ca + Mg) /K ratio or reduced K concentration in soil solution from preferential K sorption reduces the K uptake by rice (Pasricha, 1993). Singh et al. (2002) reported decline in the K release under continuous cropping in the plots not receiving K fertilizer and increase in cumulative K release where K was added; conjunctive use of fertilizer and manure (FYM or green

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The authors are thankful to the Potash Research Institute of India, Gurgaon, Haryana, India. The authors also thankfully acknowledge the help extended by the International Potash Institute (IPI), Switzerland in conceiving and execution of the study

manure) further increased the K release from non-exchangeable K pool. In the LTFE being conducted on Vertisols of Jabalpur, response of wheat to applied K was recorded after twenty years of cultivation (Dwivedi et al., 2007; Singh et al., 2012) despite the fact that the soil still had available K content higher than the limits fixed for the low category. Singh and Wanjari (2012) revisited the critical limits of K for Vertisols of Jabalpur and Akola by conducting K response trials on the farmers' fields. These experiments yielded a value of ~330 kg K ha^{-1} (147 ppm K) as a critical limit, which is greater than the 280 kg K ha^{-1} (125 ppm K) currently used for making K recommendations in the country. It was felt that to confirm the response of crops to applied K, a large database is required and to generate such a database, field experiments need to be conducted at the farmers' fields varying widely in their available K status. Keeping this in view, present study was conducted to evaluate the response of crops to applied K in Vertisols and work out the critical limits/levels of deficiency.

Materials and Methods

To study the response of crops to applied K on Vertisols, experiments at the farmers' fields were conducted for two years (2016-2018) at different locations. Locations selected were Bhopal for soybean-wheat and rice-wheat, Raipur for rice-wheat, Jagtial for rice-rice, and Jabalpur for soybean-wheat cropping sequences. Graded doses of K under constant optimum N and P supply were given to the crops. Physico-chemical properties of the soils selected for experimentation are presented in **Table 1**. The pH and electrical conductivity (EC) of soil samples were determined using method described in Jackson (1973). For estimation of soil organic carbon, Walkley and Black's wet digestion method was followed (Walkley and Black, 1934). Available phosphorus (P) was determined by Olsen's method (Olsen et al., 1954) and available K was determined in extract of neutral normal ammonium acetate method as described by Kumar et al. (2018).

At all the sites, experiments were conducted in a randomized block design with multiple replications. The number of replications varied with sites depending upon the space available in the plot selected. But it was made sure that the number of replications were large enough to i) minimize the experimental error, ii) have larger error degree of freedom to fulfill the requirements of the statistical design, and iii) compare the results of different treatments. Minimum of five replications were maintained. Treatment details followed are given in **Table 2**. During the rainy season (June to September), crops were sown with the onset of the monsoons; need-based irrigations were given in the event of an early

Table 1. Initial soil properties and nutrient status at selected sites

Location and soil type	pH	EC ($dS\ m^{-1}$)	OC ($g\ kg^{-1}$)	Available nutrient status ($kg\ ha^{-1}$)		
				N	P	K
Bhopal, Typic Chromustert	7.43	0.24	6.00	235.2	22.5	355.3
Jabalpur, Typic Chromustert	7.45	0.16	6.61	252.5	16.0	476.7
Raipur, Typic Haplustert	7.46	0.19	4.59	154.0	7.5	366.7
Jagtial, Typic Tropaquept	7.78	0.37	7.80	185.4	45.5	382.4
Critical limit*				280-560	11-25	121-280

*As summarized by Singh et al. (2005)

Table 2. Nutrient rates used under various cropping systems at selected sites

Location and soil type	Cropping system	Fertilizer rate as per treatment details			
		NPK_0	NPK_{40}	NPK_{80}	NPK_{FP}
		($kg\ ha^{-1}$)			
Bhopal,	Soybean	20:26:0	20: 26:40	20: 26:80	20:17:00
Typic Chromustert	Rice	120:26:0	120: 26:40	120: 26:80	112:22:00
	Wheat	120:26:0	120: 26:40	120: 26:80	116:22:00
Jabalpur,	Soybean	20:15:0	20:15:40	20:15:80	20:13:00
Typic Chromustert	Wheat	120:35:0	120:35:40	120:35:80	80:26: 10
Raipur,	Rice	100:26:0	100:26:40	100:26:80	100:26:20
Typic Haplustert	Wheat	100:26:0	100:26:40	100:26:80	100:26:20
Jagtial,	Rice	170:39:0	170:39:48	170:39:96	170:39:20
Typic Tropaquept	Rice	170:39:0	170:39:48	170:39:96	170:39:20

Note : FP - Nutrient applied as per farmers' practice

Table 3. Effect of potassium on grain yield (kg ha^{-1}) of rice and wheat at Bhopal (2016-18)

K treatment (kg K_2O ha^{-1})	Rice	Wheat
T_1 = 0	4702±307	4713±205
T_2 = 40	4941±306	4993±245
T_3 = 80	5462±346	5267±271
T_4 = FP*	4243±273	4340±271
CD (*P*=0.05)	272	281

Note: *Farmers' practice; rice yield is average of two years (2016-18), six farmers and 5 replications, whereas wheat yield is average of nine farmers, two years and 4 replications.

withdrawal of monsoons or in the case of a prolonged dry period between the two rain events. The second crop (November-April) was grown exclusively under assured irrigation conditions. Intercultural operations such as weeding, insect and pest control were done as and when required. At maturity, crops were harvested and grain yields were recorded and the same have been linearized to a constant moisture content of 11%. The data were analyzed using appropriate statistical tools for drawing inferences.

For assessing the effect of wetting on available K status, a set of four soil samples varying in available K with six replicates were selected. Five-gram soil sample each was weighed in a conical flask to which 5 mL of distilled water was added. These flasks were kept at room temperature. After 24 hours, 20 mL of neutral normal ammonium acetate (1*N* NH_4OAc, pH 7.0) of little higher concentration (96.00 g instead of 77.08 g) was added so as to compensate for the amount of ammonium acetate going in flask on addition of 25 mL of neutral normal ammonium acetate. Thus, similar salt concentration and soil solution ratio both were maintained in the wet and dry soil. The K content in the soil extracts was determined on flame photometer.

Results and Discussion

Soil Nutrient Status

Soils of all the selected sites at all the places were alkaline in reaction and non-saline (**Table 1**). Organic carbon content in the soils of Bhopal, Jabalpur and Jagtial was in the medium range whereas, in Raipur it was low. Soils at all the sites used for experimentation were low in the available N content. Initial available P content was in normal range in all the soils except in Vertisols of Raipur, where the available P was less than the critical value. The mean available K content in soils was in a high range.

Crop Productivity

Data on rice yield at Bhopal revealed that application of K resulted in an increase in grain yield of rice **(Table 3**). Rice responded to applied K at all the sites; yield differences were statistically significant. Rice responded up to the application of 80 kg K ha^{-1}. These results indicate that inspite of the higher available K status of soil, crop still responded to the application of K which could be attributed to the decline to the tune of 50 kg ha^{-1} in available K on wetting of the soil (**Table 4**). Based on the review of literature, Khan et al. (2014) concluded that 2 to 3 times reduction in available K status could occur due to wetting of the soil. Thus, it is reasonable to infer that to sustain yields at higher level, there is a need for K application on otherwise "K-rich Vertisols". After harvest of *kharif* rice, wheat was sown in *rabi* season on the same field and some additional farmers were also included during *rabi* season. Perusal of yield data in **Table 3** indicates that wheat responded to applied K on less number of sites compared to the sites during *kharif* when the data were analyzed for individual sites (data of individual farmer is not reported). This shows that for realization of higher yields, K fertilizer needs to be added even on the soils measuring high in available K because of higher crop demand for K. At some of the sites, crop did not respond to K; however, farmers informed that though the crop might not have responded to the application of K but it was beneficial in terms of quality of grains (*e.g.*, shining). Some of the farmers noted that application of K was responsible for the decline in pest attack in rice crop and led to the savings on expenditure which had otherwise to be incurred on pesticides.

Data presented in **Table 5** for Jabalpur revealed that the application of K increased the wheat yield over control (K_0). Wheat responded up to application of 40 kg K_2O ha^{-1}. Higher yield in the control plot compared to farmers' practice at Jabalpur is due to application of more amount of N and P in the former. Response to applied K in wheat was recorded at all the locations.

Table 4. Effect of wetting on availability of K (kg ha^{-1}) in Vertisols

Soil (A) Replication (B)	Available K content (kg ha^{-1}) under		
	Dry condition	Wet condition	Mean difference
Soil-1	652	616	36
Soil-2	293	236	52
Soil-3	403	349	57
Soil-4	490	434	54
Mean	460	409	51

CD (P=0.05) : Soils (A) = 5.6, Replications (B) = 7.9, Interaction (A x B) = 11.2

Table 5. Effect of potassium on grain yield (kg ha^{-1}) of rice and wheat at Raipur and Jabalpur (2016-17)

K Treatment (kg K_2O ha^{-1})	Wheat at Jabalpur	Rice at Raipur
T_1 = 0	3804±175	3350±122
T_2 = 40	4375±091	3690±102
T_3 = 80	4004±119	3704±094
T_4 = FP*	3488±107	3611±098
CD (P=0.05)	251	305

Note: *Farmer practice, wheat yield is average of six farmers whereas rice yield is average of nine farmers

Table 6. Effect of potassium on grain yield of *kharif* and *rabi* rice at Jagtial

K Treatment (kg K_2O ha^{-1})	Grain yield (kg ha^{-1}) of	
	Kharif rice	*Rabi* rice
T_1 = 0	6390±336	5387±265
T_2 = 40	6767±292	6354±315
T_3 = 80	6985±341	6305±371
T_4 = FP*	6633±365	6157±309
CD (P=0.05)	293	241

Note: *Farmer practice; *kharif* rice yield is an average of two years (2016-18) and both *kharif* and *rabi* rice yields are average obtained by five farmers.

Grain yield of rice recorded at Raipur (**Table 5**) was found to be statistically significant with application of 40 kg K ha^{-1}. Larger rice yields under farmers' practice compared to control is due to application of 20 kg K ha^{-1} by the farmers.

In Karim Nagar and Warangal districts of the newly created Telangana state, farmers take two rice crops in a year. Yield data for both the seasons at Jagtial revealed that successive increments in K rates was associated with a corresponding increase in the grain yield of rice (**Table 6**). In *kharif* season, rice responded only to the higher dose of K (80 kg ha^{-1}) whereas in *rabi* response to K application was found even at the lower dose (40 kg ha^{-1}). This is attributed to the fact that during *rabi* season many a times plots experience dry condition due to unavailability of water in canal which increases the availability of K. Data further indicates that yields recorded under farmers' practice (FP) are also very good and comparable with the other treatments. It is due to the application of nutrients in quantities by the farmers almost similar to those used in the research experiments. These results conclusively show that to sustain the yields at higher level, there is a need for application of K in the Vertisols.

Effect of Wetting on Available Potassium Content

Observations made by Khan et al. (2014) showed that on wetting, the available status of K reduces drastically. To confirm the phenomenon, an attempt was made to estimate the available K under wet and dry conditions. Results obtained (**Table 4**) indicated an average reduction of 50 kg available K content in Vertisols on wetting. Magnitude of decline depends on type and proportion of clay present in the soil. Wetting is responsible for K response in crops, particularly on the soils which are more or less near to the critical value of 280 kg ha^{-1} of NH_4OAc-extractable K. Different mechanisms have been proposed for explaining this phenomenon (Jackson and Luo, 1986; Luo and Jackson, 1985; Attoe, 1947; Aleksandrov, 1950; deMumbrum and Hoover, 1958; Scott et al., 1957). The most convincing is protonation theory given by Jackson and Luo (1986). Due to protonation of water, H^+ replaces K^+ during drying in

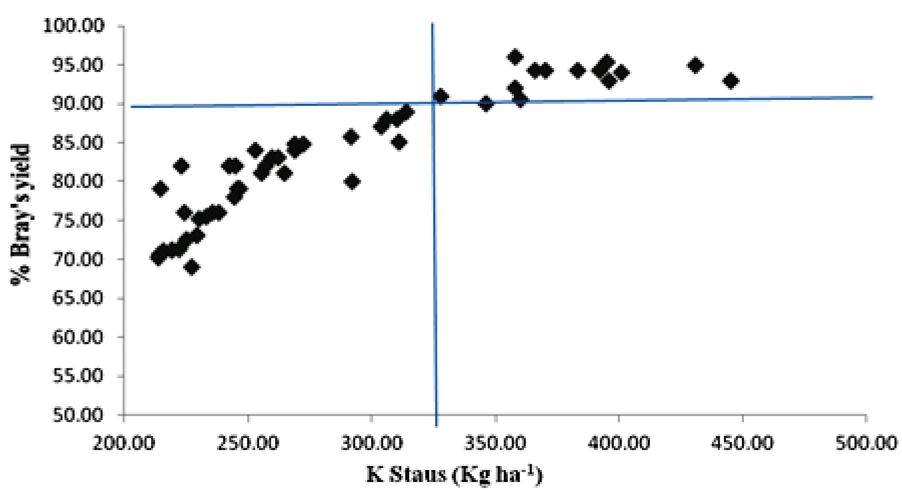

Figure 1. Critical limit of potassium in Vertisols with rice and wheat as test crops at different locations

the following way and K increases in solution.

SiOK + H OH ——————> SiOH + K (solution)

The other one is assimilation of K by soil microorganisms as a result of growth on getting moisture (deMumbrum and Hoover, 1958). However, none of them is yet conclusive.

Critical Limit of K in Vertisols

To estimate the critical limits of K in Vertisols, response trials conducted on soils varying in available K status and yields of the test crops were recorded. The yields were harmonized by converting them into Bray's per cent yield. Bray's per cent yield (BY) was computed by the relationship: BY = (Yield under nil K/Yield under applied K) × 100. Bray's per cent yield was plotted against the available K status by using Cate and Nelson (1965) scattered diagram procedure. Results in **Figure 1** show 335 kg NH_4OAc-K ha^{-1} as critical limit when rice and wheat were grown as test crops at different locations [Bhopal (MP), Jagtial (Telangana) and Raipur (Chhattisgarh)]. When the same data was subjected to statistical procedure of the same authors (Cate and Nelson, 1971), critical level worked out to be 337 kg K ha^{-1} with R^2 value of 0.58**. This value is more or less similar to that given by graphical method. It can thus be concluded that the critical level of K deficiency assessed with 1*N* NH_4OAc (pH 7.0) in Vertisols is 335 kg ha^{-1} which is much higher than 280 kg K ha^{-1} used so far for making fertilizer-K recommendations.

Conclusions

From the results, it is concluded that the crop response to applied K, in spite of higher native K status is due to decline in available K content on wetting. Critical limit of 335 kg NH_4OAc-K ha^{-1} should be used for recommending fertilizer K applications in Vertisols.

References

Aleksandrov, V.C. 1950. Fixation and mobilization of potash in sierozems and chernozems (in Russian). *Soviet. Agron*. **1**, 33-42. (Original not available for examination; abstracted in *Soils and Fertilizers* **13**, 902).

Attoe, O.J. 1947. Potassium fixation and release in soils occurring under moist and drying conditions. S*oil Science Society of America Proceedings* **11**, 145-149.

Chen, F., Lu, J.W. and Wan, Y.F. 2000. Effect of long-term potassium application on soil potassium content and forms. *Acta Pedologica Sinica* **37(2)**, 233-241.

Cate, R.B. Jr., and Nelson, L.A. 1965. A rapid method for correlation of soil test analysis with plant response data. *International soil Testing Series* **Bulletin No. 1**, North Carolina Agriculture Expermental Station.

Cate, R.B. Jr., and Nelson, L.A. 1971. A simple statistical procedure for partitioning soil test correlation data into two classes. *Soil Science Society of America. Proceedings* **35**, 658-659.

deMumbrum, L.E. and Hoover, C.D. 1958. Potassium release and fixation related to illite and vermiculite as single minerals and in mixtures. *Soil Science Society of America Proceedings* **22**, 222-225.

Dwivedi, A.K., Singh, M., Kauraw, D.L., Wanjari, R.H. and Chauhan, S.S. 2007. *Impact of Fertilizer and Manure Use for Three Decades on Crop Productivity and Sustainability, and Soil Quality under Soybean–Wheat System on Vertisol in Central India*. **Research Bulletin**. pp. 1-51.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Indian Edition. Prentice Hall of India Ltd., Delhi.

Jackson, M.L. and Luo, J.N. 1986. Potassium-release mechanism on drying soils: non-exchangeable to exchangeable potassium by protonation of micas. *Soil Science* **141**, 225-229.

Khan, S.A., Mulvaney, R.L. and Ellsworth, T.R. 2014. The potassium paradox: implications for soil fertility, crop production and human health. *Renewable Agriculture and Food Systems* **29(1)**, 3-27.

Kumar, U., Mishra, V.N., Kumar, N. and Rathiya, G.R. 2018. *Methods of Soil Analysis.* pp. 17-22. Kalyani Publishers, Ludhiana.

Luo, J.N. and Jackson, M.L. 1985. Potassium release on drying of soil samples from a variety of weathering regimes and clay mineralogy in China. *Geoderma* **35**, 197-208

Olk, D.C., Cassman, K.G. and Carlson, R.M. 1995. Kinetics of potassium fixation in vermiculite soil under different moisture regimes. *Soil Science Society of America Journal* **59**, 423-429.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. **USDA Circular 939**. U.S. Government Printing Office, Washington D.C.

Pasricha, N.S. 1993. Cation activity ratios in the soil solution and availability of potassium to rice in a submerged soil. *Journal* of *Agricultural Science Cambridge* **100**, 1-6.

Scott, A.D., Hanway, J.J. and Stickney, E.M. 1957. Soil potassium moisture relations: I. Potassium release observed on drying Iowa soils with added salts or

HCl. *Soil Science Society of America Proceedings* **21**, 498-501.

Singh, D., Chhonkar, P.K. and Dwivedi, B.S. 2005. *Manual on Soil, Plant and Water Analysis*. Westville Publishing House, New Delhi.

Singh, M., Tripathi, A.K. and Reddy, D.D. 2002. Potassium balance and release kinetics of non-exchangeable K in Typic Haplustert as influenced by cattle manure application under soybean-wheat system. *Australian Journal of Soil Research* **40**, 533-541.

Singh, M. and Wanjari, R.H. 2012. Potassium responses and requirement of crops grown in Vertisols: experiences from long-term fertilizer experiment. *Indian Journal of Fertilisers* **8(3)**, 26-32.

Singh, M., Wanjari, R.H., Dwivedi, A. and Dalal, R. 2012. Yield response to applied nutrients and estimates of N_2 fixation in 33-year-old soybean-wheat experiment on a Vertisol. *Experimental Agriculture* **48**, 311-325.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25**, 259-260.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38. ■