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Optimum potassium dose for K use efficient cassava genotypes in an Ultisol of Kerala, India

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Abstract

Mineral nutrition is one of the most important strategies to increase crop yields as plant nutrients are one among the critical factors contributing to higher productivity though the efficiency of the applied fertilizers is low. An alternative to this issue is the screening of nutrient use efficient (NUE) genotypes within a crop species which are unique with respect to their efficiency in acquisition, transport and utilization of nutrients. In this regard, the germplasm collection of cassava at ICAR-CTCRI was considered initially in 2008 for screening K use efficient genotypes. Preliminary evaluation of 83 elite genotypes for their physiological efficiency for K resulted in the identification of six genotypes *viz.,* Aniyoor, 7 III E3-5, Sree Sahya, 6-6, CR 43-8 and W-19. These were tested under a split plot design with four levels of K *viz.,* K_2O @ 0, 50,100 and 150 kg ha^{-1} to select the most promising K use efficient genotypes as well as their optimum K application requirement. This paper describes the parameters *viz.,* tuber yield and NUE parameters like agronomic efficiency, physiological efficiency, agro physiological efficiency, apparent recovery efficiency, utilization efficiency, harvest index, K harvest index, K utilization ratio/K utilization for tuber, K uptake ratio and K utilization for biomass considered over three years of experimentation under the above four levels of K in arriving the best level/optimum dose of K application for these genotypes. The above data revealed that all these genotypes performed best under K_2O @ 50 kg ha^{-1} which was on par with either 100 and 150 kg ha^{-1} K_2O elucidating the advantage of reducing the dose of K for these genotypes.

Keywords: Cassava genotypes, Nutrient use efficiency, K efficient, K uptake

Introduction

It is known that most of the cultivated soils of the world are deficient in one or more nutrients needed to support the health of plants. Hence, application of nutrients/ amendments are required for proper nutrient supply and hence better yields. Nutrient use efficient (NUE) crops are a viable option in this regard to be explored which in turn can decelerate environmental degradation due to minimum fertilizer use in increasing food production. According to Graham (1984), NUE of a genotype is the ability to produce a high yield in a soil that is limited in that nutrient for a standard genotype. In addition to the genetic, morphological and physiological components of plants, fertilizer materials especially the rate of application may be evaluated to improve the NUE in plants. In the process of nutrition of crops, the important traits enhancing the nutrient use efficiency of crops are absorption, transport, utilization and mobilization within the plant species which in turn are specific to cultivars/ genotypes. In the case of plants which are efficient in these processes, the use efficiency of both native and applied fertilizers will be enhanced and incidentally the rate of application of external nutrient source can be reduced and hence the cost of fertilizer inputs.

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Among the tropical tuber crops, cassava (*Manihot esculenta* Crantz) is the most important owing to the area under cultivation globally as well as nationally and regionally, suitability of the crop under marginal agro-climatic conditions, resilience to minimum management practices and the diversified uses of cassava starch for many value added products. Cassava being a good feeder of nutrients due to its high biological efficiency manifested in the form of high yield, the crop uptake of nutrients too is high. Under the existing application of nutrients as per package of practices (PoP) recommendation realizing a yield of 30 t ha^{-1}, the nitrogen (N), phosphorus (P) and potassium (K) uptakes were 180-200, 20-30 and 160-180 kg N, P_2O_5 and K_2O, respectively (CTCRI, 1983a). Among the three major nutrients, K is considered as the 'key nutrient', as it affects both tuber yield and tuber quality. Since the source K for crop fertilization purpose (muriate of potash) is an imported one with high cost and there is scarcity of the same at times of need, an attempt was made to screen the elite germplasm of cassava available at ICAR-Central Tuber Crops Research Institute (CTCRI) for identifying K use efficient genotypes so that the rate of application of K can be minimized.

Materials and Methods

The six identified physiologically K use efficient cassava cultivars *viz.,* Aniyoor, W-19, 7 Sahya-3, 6-6, CR 43-8 and 7III E3-5 were screened under four levels of K as K_2O @ 0, 50, 100, 150 kg ha^{-1} (Susan John et al. 2020a and b; Susan John and Sheela, 2024). The experiment was done for three seasons in a split plot design with two replications where the genotypes were the main plot treatments and the levels of K were the sub plot treatments. The basic soil parameters of the experimental site (ICAR-CTCRI, Block V) were as follows: pH - 4.9, organic carbon - 0.66%, available N - 153.26 kg ha^{-1}, available P_2O_5 - 83 kg ha^{-1}, and available K_2O - 79.2 kg ha^{-1}. The major observations made were leaf, stem and tuber yield and initial and post harvest soil K and plant K (leaf, stem and tuber K).

Determination of K and in soil and plant NUE parameters

For measuring soil K, it was extracted with neutral normal ammonium acetate and read in a flame photometer (Systronics). The plant K was estimated by using the same equipment following triacid digestion using nitric acid: perchloric acid: sulphuric acid mixture in the ratio 9:4:1. From the observations on yield of different plant parts, plant K contents and soil K, the different NUE parameters were computed (Dobermann, 2007; Fageria et al. 2008; Susan John and Sheela, 2024).

Statistical analysis

The data generated on tuber yield and NUE parameters during the three seasons were analyzed statistically as year wise as well as combined of the three seasons (pooled analysis) using Genstat Discovery Edition.

Results and Discussion

In the humid tropical agro-climatic condition of the soils of the experimental site, where K is low to medium ranging from 100-200 kg ha^{-1}, this study to evaluate the NUE parameters along with tuber yield was initiated to optimize the rate of application of K for the K use efficient genotypes. As crops like cassava are grown by resource poor farmers with low inputs especially in infertile tropical soils like laterites where the present experiment was conducted, it is important to see the response of the identified physiologically K use efficient cassava genotypes under varying levels of K to screen the best genotypes (Susan John and Sheela, 2024) and to standardise the optimum K dose for these genotypes. The independent and combined effect of levels of K on tuber yield and other NUE parameters during the three seasons as well as the interaction effect of K levels over three years of conduct of the experiment (seasons) are presented below.

Tuber yield

Among the three seasons, the effect of levels of K on tuber yield was significant during the first and second seasons. In the pooled analysis, there was significant effect of seasons and levels of K over the three seasons on tuber yield. During all three seasons, all the four levels of K, except no K application, were on par. The same trend was seen in pooled analysis also.

The third season showed lower yields at all levels of K and they were on par. The highest yield was recorded during the first season with K @ 100 kg K_2O per hectare (49.28 t ha^{-1}) and was on par with the yield obtained during first season under all levels except zero K and all levels during second season (Table 1). These results

Table 1. Effect of K levels on tuber yield (Pooled data)

Level of K (kg ha^{-1})	Tuber yield (t ha^{-1})			
	Season 1	Season 2	Season 3	Pooled Mean (K levels)
0	29.24	32.43	21.08	27.59
50	45.99	41.91	20.77	36.22
100	49.28	44.12	23.18	38.86
150	44.47	41.76	20.7	35.64
Pooled Mean (Seasons)	42.24	40.06	21.43	-
CD (0.05) Seasons	-	-	-	20.738
CD(0.05) Levels of K	9.74	5.071	NS	3.566
CD (0.05) Seasons × K Levels	16.418	-	-	-

depicted that the lowest K level tested in the experiment *viz.,* K_2O @ 50 kg ha^{-1} was on par with the other higher levels. The result consistent with the reports of Fageria and Baligar (1994), Gerloff (1977) and Blair (1993) that the efficient responder plants produce high yields at low levels of nutrients.

Nutrient use efficiency parameters

Agronomic efficiency (AE)

The levels of K imparted significant effect on AE as seen from the data of each of the three seasons and the pooled data of three seasons. The pooled analysis also showed significant effect of years of conduct of the experiment on AE. In all the three years, K_2O @ 100 kg ha^{-1}` was on par with K_2O @ 50 and 150 kg ha^{-1}. The pooled mean of AE showed that K_2O @ 50 kg ha^{-1} was the optimum for highest AE (Table 2). The variation in AE noticed with different levels of K could be attributed to the fact that levels of fertilizer application influence the total dry matter accumulation thereby affecting the nutrient demand (Craswell and Vlek, 1979; Dobermann, 2007). de Wit (1992) also reported decrease in NUE with increasing levels of nutrient addition. Omondi et al. (2018) reported decreased agronomic nutrient use efficiency in cassava with increase in fertigation solution concentration and the reason being the low conversion of nutrients to root yield.

There was a significant effect of seasons and the first season showed the highest followed by second and third seasons (Table 2). This is because of the significant effect of environmental factors especially intensity and quality of light, temperature, moisture including rainfall, humidity and drought in affecting the NUE in plants (Baligar and Fageria, 1997).

Table 2. Effect of K levels and seasons on Agronomic Efficiency (pooled data)

Level of K (kg ha^{-1})	Agronomic Efficiency (kg tuber produced kg^{-1} K applied)			
	Season 1	Season 2	Season 3	Pooled Mean (K levels)
50	535	316	185	345
100	334	195	105	211
150	169	104	62	112
Pooled Mean (Seasons)	346	205	117	-
CD (0.05) Seasons	94.6	-	-	-
CD(0.05) Levels of K	237.2	122.7	63.1	94.6

Physiological efficiency (PE)

Pooled analysis of data showed that seasons only imparted significant effect on PE. It is seen that PE during the third season was significantly higher (197 kg plant biomass per kg K uptake) over the other two seasons and second season indicated significantly lower PE (57 kg plant biomass per kg K uptake). This effect could be attributed to the effect of biotic and abiotic stresses which the crop underwent during the three seasons which in turn had a detrimental effect in the quantum of biological yield produced by the crop. Fageria et al. (2008) reported PE as one of the NUE parameters, which in turn, is the biological yield per unit of nutrient uptake.

Agro-physiologica*l efficiency (APE)*

The pooled analysis of data indicated significant effect for seasons as well as the interaction effect of seasons and K levels on APE. The first season registered the highest APE followed by third and second seasons. With respect to the interaction effect of seasons and K levels, K_2O @ 100 kg ha^{-1} during the first season resulted in the highest APE on par with the same season @ 150 kg ha^{-1} (Table 3).

Table 3. Effect of levels of K and seasons on Agro-Physiological Efficiency (pooled data)

Level of K (kg ha^{-1})	Agro-physiological efficiency (kg tuber produced kg^{-1} K uptake)		
	Season 1	Season 2	Season 3
50	90.4	27.2	88.1
100	169.6	27.2	72.8
150	136.8	27.7	37.0
Pooled Mean (Seasons)	132.3	27.4	65.9
CD (0.05) Seasons	-	45.12	-
CD(0.05) Seasons K levels	-	78.15	-

Since APE is an index of economic produce per unit of nutrient uptake, the variation noticed with respect to the interaction of K levels and seasons can be attributed to the difference in harvested portion per unit time, area applied with nutrient which might have affected differences in nutrient concentrations in plant parts as per the reports of Clark (1990) and Fageria et al., (2006) in rice genotypes.

Apparent recovery efficiency (ARE)

The first season as well as combined data showed that K levels imparted significant effect on ARE. During the first season, ARE differed significantly among the three levels of K, with K @ 50 kg ha^{-1} K_2O registering significantly higher (2.74 kg total plant K uptake kg^{-1} K applied). Though the pooled analysis also showed the same trend, ARE was on par at 100 (1.77) and 150 (1.04) kg ha^{-1} K_2O. The ARE was higher with lower level of K_2O further affirming a need of lower rate of application of K for K use efficient genotypes. The effect of K levels over years on ARE could be due to the variation in the quantity of nutrients absorbed per unit of nutrient applied as well as the synergistic and antagonistic effect of nutrients on NUE among various plant species or within cultivars of the same species (Fageria and Baligar, 2003)

Utilization efficiency (UE)

During the first and second seasons as well as in the pooled analysis, levels of K significantly influenced K utilization efficiency. During the first season, the UE was highest with K_2O @ 50 kg ha^{-1} (214 kg plant biomass produced kg^{-1} K applied) and was on par with K_2O @100 kg ha^{-1} (161 kg kg^{-1}). The second year data showed significant difference between K_2O @ 50 (169 kg kg^{-1}) and 150 kg ha^{-1} (67 kg kg^{-1}) in affecting the UE where there was a gradual decline in UE with increase in K levels. In the case of pooled data of three seasons, all the three levels of K differed significantly in UE and K_2O @ 50 kg ha^{-1} showed significantly higher yield (191 kg kg^{-1}), followed by K_2O @ 100 (134 kg kg^{-1}). This result also underscores the requirement of a lower dose of K for the NUE genotypes. Since UE being the product of PE and ARE, the various factors affecting the two might have contributed to the differences noted for the effect of levels of K, seasons and their interactions. Confirming the above results, some researchers (Baligar and Fageria, 1997; Duncan and Baligar, 1990) reported that soil, fertilizer, plant as well as climate factors affect nutrient acquisition, nutrient movement in the root, nutrient accumulation and remobilization in shoot and nutrient utilization for growth.

Harvest Index (HI)

Levels of K imparted significant effect on HI during the first and third seasons as well as in the pooled analysis. During the first season, K_2O @ 50 kg ha^{-1} showed the highest HI, which was on par with K_2O @ 100 and 150 kg ha^{-1}, while no K application resulted in significantly lower HI (Table 4). However, in the third season, non-application of K resulted in the highest HI on par with all K levels except K_2O @ 150 kg ha^{-1}. The pooled analysis data indicated that HI under K_2O @ 50 kg ha^{-1} was on par with that at 100 kg ha^{-1}K_2O. This result on HI also highlighted the need of a lower K rate @ 50 kg ha^{-1} K_2O for the selected NUE genotypes. HI involves total biomass yield and is the sum of the yield of the different plant parts. It is governed by the availability, acquisition, transport and utilization for the formation and development of the different plant parts. Omondi et al. (2018) and Metwally et al. (2011) got similar results of decreased HI with increased levels of fertigation solution in cassava and in Egyptian hybrid rice, respectively.

Table 4. Effect of levels of K on HI over three years (Pooled data)

Level of K (kg ha^{-1})	Seasons 1	2	3	Pooled mean (Seasons)
0	0.358	0.479	0.461	0.433
50	0.465	0.503	0.458	0.475
100	0.451	0.467	0.426	0.448
150	0.445	0.475	0.367	0.429
Pooled mean (Level of K)	0.430	0.481	0.428	0.446
CD (0.05) Level of K	0.0731	NS*	0.0606	0.031
CD (0.05) Season	NS*	-	-	-
CD (0.05) Season × Level of K	0.003	-	-	-

*NS: Non-significant

Percent K utilization for tuber (% KUT)

Levels imparted significant effect during the first and third seasons. The interaction effect of seasons and K levels was significant in the pooled analysis. During the first season, %KUT was highest at K_2O@ 50 kg ha^{-1} (46.5%), which was on par with all levels except non application of K. During the third season, the highest % KUT (46.1%) was obtained in treatment without K and it was on par with all K levels except K_2O @150 kg ha^{-1}. The pooled data showed the highest % KUT with K_2O@ 50 kg ha^{-1} during the second season (50.04%). The findings of this study agree with the reports of Rengel and Damon (2008) and (White, 2013), that K use efficient plants can tolerate low K availability in the soil owing to their better uptake and utilization efficiency. This in turn determines their temporal K demand related to their individual phenology which is synchronized with their K demand to achieve maximum yield even with low K supply.

K uptake ratio (KUR)

Levels of K imparted significant effect during all the three seasons and also in the pooled analysis. The effect of years, interaction effect of years and K levels were significant in the pooled analysis. Among the four levels, the KUR was significantly lowest under K_2O @ 150 kg ha^{-1} followed by non-application of K, which was on par with the other two levels. In the case of the interaction effect of K levels and years, the lowest KUR was recorded during third season under K_2O @150 kg ha^{-1}, which was on par with 0 and 150 kg ha^{-1} K_2O during the second season and 50 and 100 kg ha^{-1} K_2O during the third season. The highest KUR was seen with K_2O @100 kg ha^{-1} during the first season and was on par with K_2O @50 kg ha^{-1} during the

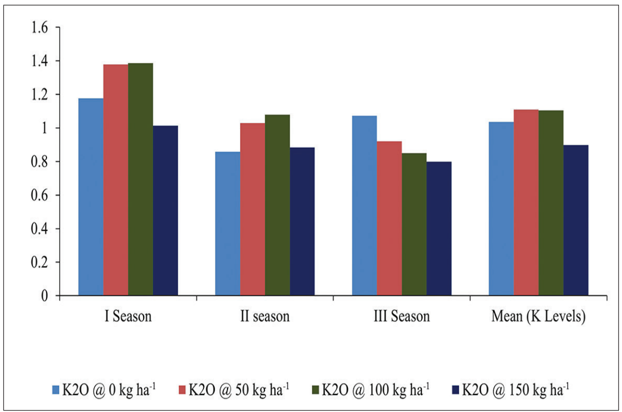

Fig.1. Effect of levels of K on K uptake ratio over three years (Pooled)

same season (Fig. 1) revealing the significance of a lower dose of K for K use efficient genotypes.

In the present study, the differences noticed with levels and their interaction with three seasons with respect to KUR can be justified as per the findings of White (2013) and White et al. (2017) that these differences can be either due to the capacity of the root cells to take up K^+ at low rhizosphere K^+ concentrations, their ability to proliferate and exploit the soil volume effectively or their ability to acquire non exchangeable K from the soil (Samal et al. 2010).

K Efficiency ratio (KER)

Levels of K imparted significant effect on KER during the first and third seasons and in the pooled analysis. The interaction effect of years with K levels was also significant in the pooled analysis. The pooled analysis data indicated significantly higher KER under non-application of K (0.576) followed by K_2O @ 50 kg ha^{-1} (0.524) and the other two levels resulted in significantly lower KER and were on par. The non-application of K during the second season resulted in the highest KER (0.73) on par with application of K_2O @ 50, 100, 150 kg ha^{-1} during the second and third seasons clearly showing low requirement of K for K use efficient genotypes. In this regard, White (2013) and White and Bell (2017) found that there was variation among genotypes, plant species and K supply in affecting the K uptake, transport and utilization finally causing variation in their efficiencies.

K Harvest Index (KHI)

Among the three seasons of the conduct of the experiment, levels of K significantly affected KHI only during the third season. Non-application of K resulted in the highest KHI (0.493) on par with all levels except K @ 150 kg ha^{-1}K_2O (0.417). But Alemu (2021) and Amanullah et al. (2015) found that application of K at a highest rate of 90 kg ha^{-1} in maize increased the KHI as the higher K level resulted in more dry matter partitioning in the reproductive parts.

Percent K Utilization for Biomass (% KUB)

In the case of % KUB, levels of K imparted significant effect during the second and third seasons and in the pooled analysis. The interaction effect of seasons and levels of K was significant in the combined analysis. In the case of the effect of levels of K on % KUB, the pooled data showed significantly the highest with non-application of K and the % KUB at 50 and 100 kg ha^{-1} K_2O were on par as well as at 100 and 150 kg ha^{-1} K_2O were on par (Table 5). As regards to the interaction effect of levels of K over years, non-application of K during the second season resulted in significantly the highest followed by the same treatment during the third season. Application of K @ 100 kg ha^{-1} K_2O resulted in the lowest %KUB and was on par with K_2O @ 150 kg ha^{-1} during the same season. In this regard, White et al. (2009) reported that though the seed K concentration of a particular genotype is often relatively insensitive to plant K nutrition, tuber K concentration vary with plant K nutrition.

Table 5. Effect levels of K and seasons on % K utilization for biomass (Pooled data)

Levels of K (kg ha^{-1})	Seasons 1	2	3	Mean (Levels of K)
0	101.5	148.5	137.8	129.2
50	95.9	122.4	111.0	109.8
100	93.5	111.8	104.7	103.3
150	94.2	108.9	97.7	100.3
Pooled Mean (Seasons)	96.3	122.9	112.8	-
CD (0.05) (Levels of K)	NS	12.37	11.64	6.44
CD (0.05) (Seasons)	15.01	-	-	-
CD (0.05) (Levels of K × Seasons)	12.69	-	-	-

These findings conform to the reports of Rengel and Damon (2008) who interpreted the combined effect of plant species and K availability in soil with respect to K use efficiency of plants in terms of parameters like uptake and utilization efficiencies. Hence, it is vivid from the present study that all the NUE parameters computed were highest at low levels of K_2O @50 kg ha^{-1}. Hence, it can be very well confirmed from the present study that the level of application of K can be reduced by 50% over the recommended dose in the case of K use efficient genotypes.

Conclusion

Among the many resources to save the environment from excessive use of fertilizers and incidentally to reduce the cost on agricultural inputs particularly, and thereby the cost of cultivation, planting of nutrient use efficient varieties of crops is a viable alternative. These genotypes can perform well with respect to their growth and yield under nutrient deficient soil environments. This is due to the physiological mechanisms particularly with respect to root and leaf architecture in harnessing and partitioning more of the unavailable nutrients from the deeper soil layers. Studies conducted since 2008 to identify potassium use efficient genotypes and the level of potassium at which they perform best resulted in arriving Aniyoor and 7III E3-5 as the most efficient among the six genotypes screened out of 83 elite genotypes of cassava subjected to preliminary evaluation. The present study was aimed at determining the optimum level of application of K for the selected genotypes based on tuber yield and nutrient use efficiency parameters over three seasons continuously. With respect to tuber yield, K_2O@ 50 kg ha^{-1} was found best, which in turn was on par with the higher levels *viz.,* 100 and 150 kg ha^{-1} K_2O. Similarly, all the NUE parameters computed *viz.,* agronomic efficiency, physiological efficiency, agro-physiological efficiency, K uptake efficiency, K utilization efficiency, apparent recovery efficiency, harvest index, K harvest index, K utilization ratio, K uptake ratio, K efficiency ratio, percent K utilization for tuber and percent K utilization for biomass were found significantly highest either at 50 kg ha^{-1} K_2O or will be higher at 100 or 150 kg ha^{-1} K_2O which was on par with 50 kg ha^{-1} clearly proving the necessity of a lower level of K for K use efficient genotypes. It is understood from these studies that, in addition to identifying such nutrient efficient genotypes, the molecular markers related to nutrient efficiency if identified, can go a big way in developing potential NUE varieties with a multitude of beneficial traits so that in addition to realizing better yield, the concept of low input too can be merged for a better safer environment with minimum production cost.

References

Alemu, G.A. 2021. The role of harvest index in improving crop productivity; A review. *J. Nat. Sci. Res.*, **9**(6): 24-28

Amanullah, A., Iqbal, A., Iqbal, M. 2015. Impact of potassium rates and their application time on dry matter partitioning, biomass and harvest index of maize (*Zeamays*) with and without cattle dung application. *Emirates Journal of Food and Agriculture*, **27**: 447-453.

Blair, G. 1993. Nutrient efficiency-what do we really mean. Genetic aspects of plant mineral nutrition. In: P.J. Randall, E. Delhaize, R.A. Richards, and R. Munns. (Eds.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 205-213.

Baligar, V.C. and Fageria, N.K. 1997. Nutrient use efficiency in acid soils: Nutrient management and plant use efficiency. In: A.C. Monitz, A.M.C. Furlani, N.K. Fageria, C.A. Rosolem and H. Cantarells, (Eds.), Plant-Soil Interactions at low pH: Sustainable agriculture and forestry production. Brazilian Soil Science Society Compinas, Brazil, pp. 75-93.

Clark. R.B. 1990. Physiology of cereals for mineral nutrient uptake, use, and efficiency. In: Crops as enhancers of nutrient use (Eds.), V.C. Baligar, and R.R. Duncan, Academic Presss, San Diego, California, pp. 131-209.

Craswell, E.T. and Velk, P.L.G. 1979. Fate of fertilizer nitrogen applied to wetland rice. In: IRRI (Ed.), Nitrogen and Rice IRRI, Los Banos, Philippines, pp. 175-192.

CTCRI, 1983a. Three Decades of Research. ICAR- Central Tuber Crops Research Institute, Thiruvananthapuram, p. 1-81.

Duncan, R.R. and Baligar, V.C. 1990. Genetics, breeding and physiological mechanisms of nutrient uptake and use efficiency: An overview. In: V.C. Baligar, and R.R. Duncan (Eds.), Crops as enhancers of nutrient use. Academic Press Inc., San Diego, CA, pp. 3-35.

De Wit, C.T. 1992. Resource use efficiency in agriculture, *Agric. Syst.*, **40**: 125-151.

Dobermann, A. 2007. Nutrient use efficiency: Measurement and management. Paper presented at the IFA International Workshop on Fertilizer Best Management Practices, Brussels, Belgium, 7-9 March, 2007, pp. 1-28.

Fageria, N.K. and Baligar, V.C. 1994. Screening crop genotypes for mineral stresses. In: J.W. Maranville, V.C. Baligar, R.R. Duncan and J.M. Yohe (Eds.), Adaptation of plants to soil stress, University of Nebraska, INTSORMIL-USAID, Lincil, NE, pp. 152-159.

Fageria, N.K. and Baligar, V.C. 2003. Methodology for evaluation of lowland rice genotypes for nitrogen use efficiency. *J. Plant Nutr.*, 26: 1315-1333.

Fageria, N.K., Baligar, V.C. and Clark, R.B. 2006. Physiology of Crop Production, The Haworth Press, New York.

Fageria, N.K., Baligar, V.C. and Li, Y.C. 2008. The role of nutrient use efficient plants in improving crop tields in the twenty first century. *J. Plant Nutr.*, **31**: 1121-1157.

Gerloff, G.C. 1977. Plant efficiency in the use of nitrogen, phosphorus, potassium. In: M.J. Wright (Ed.), Plant adaptation to mineral stress in problem soils, Cornell University Press, Ithaca, New York, pp. 161-173.

Graham, R.D. 1984. Breeding for nutritional characteristics in cereals. In: P.B. Tinker and A. Lauchi (Eds.), Advances in Plant Nutrition, Vol.1, Praeger Publisher, New York, pp. 57-102.

Metwally, T.F., Gewaily, E.E. and Naeem, S.S. 2011. Nitrogen response curve and nitrogen use efficiency of Egyptian hybrid rice. *Journal of Agricultural Research Kafer El- Sheikh University*, **37**(1): 73-84.

Omondi, J.O., Lazarovitch, N., Rachmilevitch, S., Boahen, S., Ntawuruhunga, P., Sokolowski, E. And Yermiyahu, U. 2018. Nutrient use efficiency and harvest index of cassava decline as fertigation solution concentration increases. *Journal of Plant Nutrition and Soil Science*, 1-11.

Rengel, Z. And Damon, P.M. 2008. Crops and genotypes differ in efficiency of potassium uptake and use. *Plant Physiol.*, **133**: 624-636.

Samal, D., Kovar, J.L., Steingrobe, B., Sadana, U.S., Bhadoria, P.S. and Classen, N. 2010. Potassium uptake efficiency and dynamics in the rhizosphere of maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and sugar beet (*Beeta vulgaris* L.) evaluated with a mechanistic model. *Plant and Soil*, **332**:105-121.

Susan John, K., Sreekumar, J., Sheela, M.N., Shanida Beegum, S.U., Sanket.J. More and Suja, G. 2020a. Pre evaluation of cassava (*Manihot esculenta* Crantz) germplasm for genotypic variation in the identification of K efficient genotypes through different statistical tools. *Physiol. Mol. Biol. Plants,* https://doi.org/10.1007/s12298-020-00867-2.

Susan John, K., Sreekumar, J., Shanida Beegum, S.U., Sanket J. More, Sheela, M.N. and Suja, G. 2020b. *J. Root Crops,* **46**(2): 41-53.

Susan John, K. and Sheela, M.N. 2024. Influence of NUE genotypes on yield and nutrient use efficiency parameters in the selection of K use efficient cassava genotypes. *Journal of Root Crops,* **50**(2): 8-16

White, P.J. and Bell, M.J. 2017. The genetics of potassium uptake and utilization in plants. In: T.S. Murrel and Mikkelsen, R.L.(Eds.). Proceedings for the Frontiers of Potassium Science Conference, 25-27 January 2017, Peachtree Corners, International Plant Nutrition Institute, Rome, pp. 46-65.

White, P.J. 2013. Improving potassium acquisition and utilization by crop plants. *Journal of Plant Nutrition and Soil Science*, **176**: 305-316.

White, P.J., Bowen, H.C., Broadley, M.R., El-Serehy, H.A., Neugebauer, K., Taylor, A., Thompson, J.A. and Wright, G. 2017. Evolutionary origins of abnormally large shoot sodium accumulation in non saline environments within the caryophyllales. *New Phytol.*, **214**: 231-249.

White, P.J. Bradshaw, J.E., Dale, M.F.B., Ramsay, G., Hammond, J.P. and Broadley, M.R. 2009. Relationships between yield and mineral concentrations in potato tubers. *Hortic. Sci.*, **44**: 6-11.