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Influence of NUE genotypes on yield and nutrient use efficiency (NUE) parameters in the selection of K use efficient cassava genotypes

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Abstract

It is known that chemical fertilizers are one of the expensive inputs used by farmers to achieve desired crop yields along with improvement in soil fertility. But the recovery of applied inorganic fertilizers or the use efficiency of nutrients by plants is low in many soils due to various reasons and hence there exists a need to increase the nutrient use efficiency (NUE). Among the primary nutrients, K is considered as the 'key nutrient' for tuber crops due to its effect both on tuber yield and tuber quality. Hence, at ICAR- CTCRI, experiments were initiated since 2008 to screen K use efficient genotypes in cassava to reduce the use of chemical K fertilizers which in turn are fully imported. In this respect, detailed experiments for three seasons were conducted with six genotypes *viz.,* Aniyoor, W-19, 7 Sahya-3, 6-6, CR 43-8 and 7III E3-5 selected from the preliminary screening of 83 elite genotypes at four levels of K viz., (0, 50, 100, 150 kg K_2O ha^{-1}) in a split plot design. This paper describes the independent effect of genotypes, years and interaction effect of genotypes over years on tuber yield and nutrient use efficiency parameters which in turn was used in the selection of most K efficient genotypes. The data generated on these parameters for the three years was statistically analysed using Genstat and seen significant independent effect of genotypes on tuber yield during first and third years, K uptake ratio (KUR) during the second and third years and percent K utilization for biomass (% KUB) during the third year. Pooled effect of genot over years was significant for tuber yield, utilization efficiency (UE), harvest index (HI), % K utilization for tuber (% KUT), K efficiency ratio (KER), K harvest index (KHI), K uptake ratio (KUR) and % K utilization for biomass (% KUB). Years imparted significant effect in the case of agro physiological efficiency (APE) and % KUB during the three years. The overall effect of years was significant for agronomic efficiency (AE), APE, KUR % KUB. The interaction effect of genotypes and years of experimentation was significant for tuber yield, KER, KUR and % KUB. Based on the studied parameters, Aniyoor and 7 III E3-5 was selected as K efficient.

Keywords: Nutrient use efficiency, Cassava genotypes, Potassium uptake, Harvest index, Physiological efficiency

Introduction

Expansion of productive agriculture land for sustainable crop production in the coming years can be difficult under the existing global environmental repercussions affecting the crop performance with respect to its growth and yield. In such a scenario of limited availability of productive land for enhanced productivity to meet the food demand of the burgeoning world population, among

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the different avenues available, exploiting the intrinsic potential of the plants to dissolve, take up and utilize the available nutrients present in the soil is one of the best options. In this regard, the inherent crop character for proper and optimum utilization of the soil nutrients for better crop yield otherwise referred to as 'Nutrient Use Efficiency (NUE)' needs to be characterised by computing the different parameters associated with it. These parameters are directly linked to the uptake and utilization efficiency which in turn can improve or enhance the nutrient use efficiency and is indirectly a reflection of the amount and availability of nutrients in the soil. In the determination of the efficiency by which plants use nutrients to produce biomass and or grain, there exists the conjoint effect of both plant intrinsic factors and environmental factors. Though NUE is the common term used in this regard, there are several indices to characterize the same (Dobermann, 2005) like agronomic efficiency, physiological efficiency, agro-physiological efficiency. In addition, being the uptake and utilization of the nutrients are the two pathways governing the ultimate NUE, there are many parameters related to these processes which can be determined for arriving at the NUE of a crop precisely. The ultimate benefit of exploiting this plant unique intrinsic character is saving of chemical fertilizers for crop nutrition. In the present day agriculture, there is increased demand for fertilizer nutrients to meet the global demand for food. However, there are limitations in the availability of fertilizer resources and there is growing public concern related to nutrient use side effects. This notion too has led to focus on the identification of specific NUE genotypes of different crops without sacrificing the present productivity of the crop.

Among the tropical tuber crops, cassava (*Manihot esculenta* Crantz) is regarded as the most important with respect to its biological efficiency, area under cultivation, climate resilience, biotic and abiotic stress tolerance and diversified uses especially for industries. The high biological efficiency of cassava manifested in terms of high yield underscore the extraction of voluminous quantum of soil nutrients which needs to be replenished for maintaining sustainable tuber yield. Among the primary nutrients, potassium (K) is considered as the 'key nutrient' for cassava owing to its role in affecting both yield and quality. As the source of K *viz.,* muriate of potash (MoP), the commonly used K fertilizer is an imported one and K is very essential for cassava, we have initiated research on identification of K use efficient cassava genotypes from the available germplasm of ICAR- CTCRI. This paper deals with the different NUE parameters computed to screen the K use efficient cassava genotypes from the selected genotypes after preliminary screening based on physiological efficiency.

Materials and Methods

A total of 83 elite genotypes were screened initially and found out the best six genotypes primarily based on physiological efficiency (Susan John et al*.,* 2020a, 2020b) coupled with ideal crop biometric characters, tuber yield, tuber quality and tolerance to cassava mosaic disease (CMD). The six genotypes similarly identified were Aniyoor, W-19, 7 Sahya-3, 6-6, CR 43-8 and 7III E3-5. From these genotypes, the selection of better K use efficient lines was done by computing the important NUE parameters and tuber yield. In this regard, experiments were conducted for three seasons in a split plot design with six genotypes as above as main plot treatments and four levels of K (K_2O @ 0, 50, 100, 150 kg ha^{-1}) as sub plot treatments with two replications. The major observations made were on leaf, stem and tuber yield, initial and post harvest soil K, plant K (leaf, stem and tuber K). In the case of soil K, the soil after extraction with neutral normal ammonium acetate was read in flame photometer (Systronics) and the plant K was estimated by using the same equipment following triacid digestion using nitric acid: perchloric acid: sulphuric acid 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. The NUE parameters computed were agronomic efficiency, physiologic efficiency, agro-physiological efficiency, apparent recovery efficiency, utilization efficiency, harvest index, K utilization ratio (K utilization for tuber), K uptake ratio, K utilization for biomass, and K harvest index. These were calculated as per the following formulae (Dobermann, 2007; Fageria et al*.*, 2008):

$$\text{Agronomic efficiency} = \frac{\text{Tuber produced (kg)}}{\text{K applied (kg)}} \quad \text{… Eqn. (1)}$$

$$\text{Physiological efficiency} = \frac{\text{Plant biomass produced (kg)}}{\text{K uptake (kg)}} \quad \text{… Eqn. (2)}$$

$$\text{Agro-physiological efficiency} = \frac{\text{Tuber produced (kg)}}{\text{K uptake (kg)}} \quad \text{… Eqn. (3)}$$

$$\text{Apparent recovery efficiency} = \frac{\text{Total plant K uptake (kg)}}{\text{K applied (kg)}} \quad \text{… Eqn. (4)}$$

$$\text{Utilization efficiency} = \frac{\text{Plant biomass produced (kg)}}{\text{K applied (kg)}} \quad \text{… Eqn. (5)}$$

$$\text{Harvest index} = \frac{\text{Tuber yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \quad \text{… Eqn. (6)}$$

$$\text{Percent K utilization for tuber} = \frac{\text{Tuber produced (g)}}{\text{Plant K (g)}} \quad \text{… Eqn. (7)}$$

$$\text{K uptake ratio} = \frac{\text{K plant (g)}}{\text{K soil (g)}} \quad \text{… Eqn. (8)}$$

$$\text{K utilization for biomass} = \frac{\text{Plant biomass produced (g)}}{\text{K in plant biomass (mg)}} \quad \text{… Eqn. (9)}$$

$$\text{K harvest index} = \frac{\text{Tuber yield (t ha}^{-1}\text{)} \times \text{Tuber K (\%)}}{\text{(Stem + leaf) yield} \times \text{K \% (Stem + leaf)} + \text{Tuber yield} \times \text{Tuber K\%}} \quad \text{… Eqn. (10)}$$

The data generated on the above parameters during the three seasons and the pooled analysis of the three seasons was statistically analysed using Genstat Discovery Edition. A correlation of the above NUE parameters with tuber yield also was undertaken using the above programme.

Results and Discussion

The results primarily comprised of the effect of genotypes alone during the three years as well the combined (pooled) effect over three years on tuber yield, and NUE parameters.

Tuber yield

Genotypes imparted significant effect during first and third seasons as well as in the pooled analysis. Though, the independent effect of years was not significant, the interaction effect of genotypes and years was significant (Table 1). During the first year, the tuber yield was highest for 7 III E3-5 and was on par with CR 43-8 and 7 Sahya 3. Aniyoor recorded the lowest tuber yield on par with W-19 and 6-6. During the second season, significant effect of genotypes was not seen on tuber yield. During the third season, 7 Sahya-3 caused significantly the lowest tuber yield followed by 6-6 which was on par with 7 III E3-5 whereas W-19 resulted in the highest tuber yield on par with Aniyoor, CR 43-8 and 7 III E3-5. The mean over the three seasons too was significant with CR 43-8 recorded the highest tuber yield on par with 7 III E3-5 and Aniyoor. 6-6 registered the lowest tuber yield on par with 7 Sahya 3 and W-19. As regards to the interaction effect of genotypes over years, 7 III E3-5 during the first year resulted in significantly higher yield on par with all genotypes during the first year and all genotypes except 6-6 during the second year. The drastic variation in tuber yield noticed under these genotypes corroborates to the reports of Baligar et al., (2001) and Graham (1984) that genetic and physiological components of plants have profound effects on their abilities to absorb and utilize nutrients under various environmental and ecological conditions thereby directly affecting the NUE which in turn have a direct bearing on the yield of plants. Baligar et al., (1990) too reiterated the genetic variability as the most critical parameter governing nutrient uptake and hence NUE and incidentally the yield.

Nutrient use efficiency parameters

Though the parameters as described above were determined, the NUE genotypes imparted significant effect only on the parameters as below:

1. Agronomic Efficiency (AE)

The years imparted significant effect on AE and there was no significant effect of genotypes and interaction of years and genotypes on AE. The AE was significantly highest during the first year and the AE during the second year was on par with the third year (Fig. 1). According to Liang et al., (2022) agronomic efficiency can vary over years depending on factors like quality and quantity of plant residues in the soil and types of fertilizer applied. Dhillon et al., (2019) stated that the agronomic efficiency of potassium in cereal crops has varied over the years and is closely tied to the amount of fertilizer used.

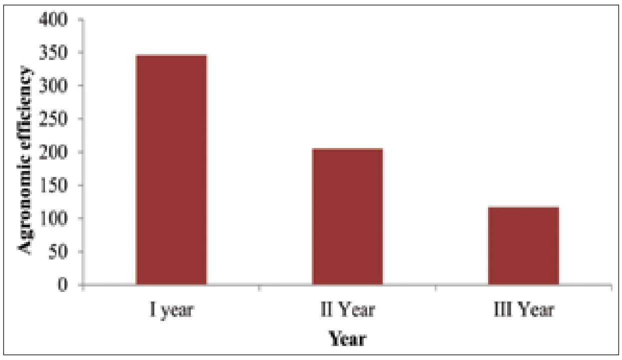

Fig. 1. Agronomic efficiency (kg tuber produced per kg K applied) of NUE genotypes during three years

Table 1. Effect of NUE genotypes on tuber yield over three years

Year (Y)	Genotypes (G)						
	Aniyoor	W-19	7 Sahya-2	6-6	CR 43-8	7 III E3-5	Mean Y
1	34.76	36.03	44.52	40.35	47.88	49.92	42.24
2	45.33	36.20	40.51	32.19	43.02	43.10	40.06
3	25.84	26.96	10.19	18.33	24.77	22.51	21.43
Mean (G)	35.31	33.06	31.74	30.29	38.56	38.51	
CD(0.05) (G) I year	6.77						
CD (0.05) (G) II Year	NS						
CD (0.05) (G) III Year	5.995						
CD (0.05) (G) Pooled	3.420						
CD (0.05) (Y)	NS						
CD (0.05 (G×Y)	16.660						

2. Apparent Recovery Efficiency (ARE)

The effect of NUE genotypes on ARE was significant only during the third year of experimentation. The effect of years as well as the interaction effect of genotypes over years too was not significant. W-19 caused significantly higher ARE on par with Aniyoor and all other genotypes behaved similar (Fig. 2). The genotypic effect on ARE might be due to the difference in the quantity of nutrients absorbed per unit of nutrient applied as well as due to the synergistic and antagonistic effect of nutrients on NUE among various plant species as well as within cultivars of the same species as per the findings of Fageria and Baligar (2003).

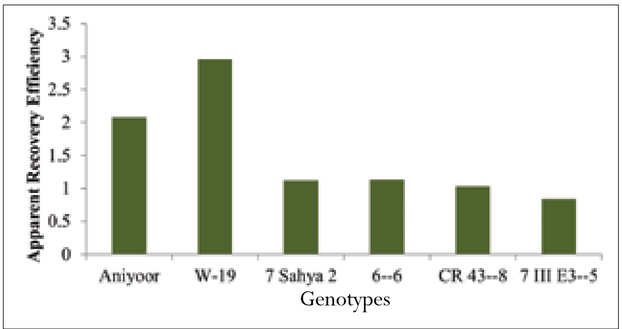

Fig. 2. Apparent Recovery Efficiency (total plant K uptake per kg K applied) of NUE genotypes during the third year

3. Agro Physiological Efficiency (APE)

As in the case of AE, APE also was significantly different during the three years of experimentation with first year resulted in significantly the highest APE and APE of the second and third years were on par (Fig. 3). Metwally et al., (2011) reported that, APE can vary over years and is affected by factors such as genotypes, fertilizer levels and the interaction between the two.

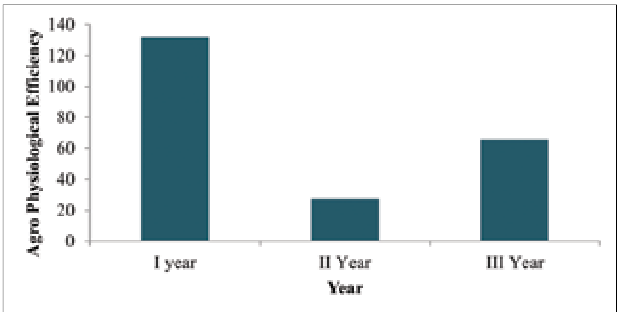

Fig. 3. Agro Physiological Efficiency (kg tuber produced per kg total plant K uptake) of NUE genotypes during the third year

4. Physiological Efficiency (PE)

The NUE genotypes/years/the interaction effect of both did not significantly affect the PE during all the three years of experimentation.

5. Utilization efficiency (UE)

Though there was no significant effect of genotypes during individual years on UE. The pooled analysis of the three years indicated significant effect on UE. Years as well as the interaction effect of genotypes over years also were not significant. All genotypes except Aniyoor and 6-6 were significantly inferior in UE and others were on par with 7III E3-5 which in turn registered the highest UE followed by CR43-8 (Fig. 4). UE being the product of PE and ARE, the various factors affecting the two may contribute to the genotypic differences. However, several workers (Baligar and Fageria, 1997, Duncan and Baligar, 1990) reported the unique plant as well as climate factors in affecting the nutrient acquisition, nutrient movement in the root, nutrient accumulation and remobilization in shoot and nutrient utilization for growth as the primary factors.

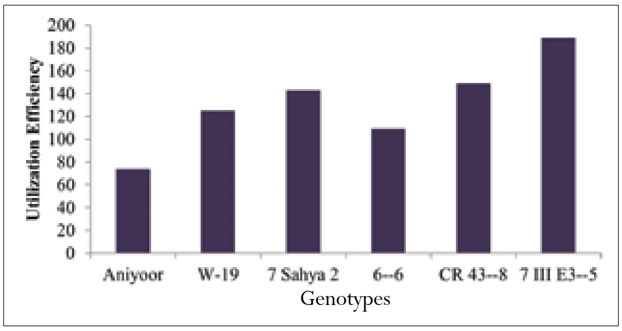

Fig. 4. Utilization Efficiency (kg plant biomass produced per kg K applied) of NUE genotypes (Mean over 3 years)

6. Harvest Index (HI)

The effect of genotypes on HI was found significant only in the pooled analysis and the independent effect of genotypes, years as well as the interaction effect of both were not significant. The overall effect of genotypes in the pooled analysis indicated, W-19 had the lowest HI on par with CR43-8 and Aniyoor had significantly the highest HI and 7 III E3-5 recorded higher HI on par with 7 Sahya-2 and 6-6 (Fig. 5). The data highlighted the significance of genotypes in affecting the HI which involves the total biomass yield and is the sum of the

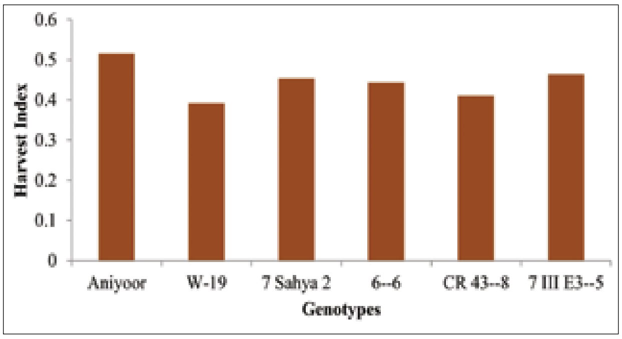

Fig. 5. Harvest Index (kg plant biomass produced per kg tuber of NUE genotypes (Mean over 3 years)

yield of the different plant parts and is governed by the availability, acquisition, transport and utilization for the formation and development of the different plant parts. Omondi et al. (2018) got similar results of decreased HI in cassava with increased levels of fertigation solution. Similar findings in rice were reported in Egyptian hybrid rice (Metwally et al. 2011).

7. Percent K utilization for tuber (% KUT)

In the case of % KUT, significant effect of genotypes was seen in the pooled analysis. Aniyoor performed significantly highest followed by 7 III E3-5 which in turn was on par with all other genotypes except W-19 (Fig. 6). This finding conforms to the report of White and Bell (2017) that there exists difference among plant species in their ability to utilize K physiologically for vegetative and reproductive growth. No significant independent effect of genotypes, years and interaction effect of genotypes and years was seen on % K utilization for tuber.

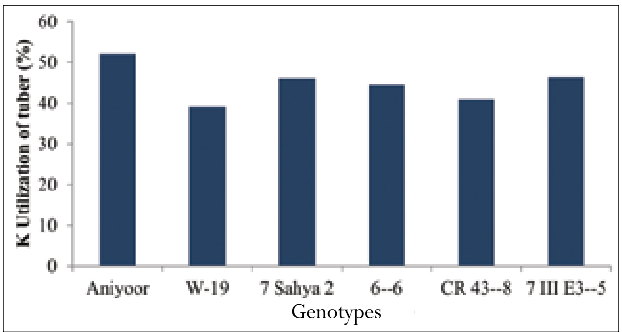

Fig. 6. Percentage K Utilization for Tuber (g tuber produced per g plant K) of NUE genotypes (Mean over 3 years)

8. K Efficiency Ratio (KER)

Though there was no significant effect of genotypes independently during the three years as well as the independent years on KER, the overall effect of genotypes over the three years as well as the interaction effect of years and genotypes was significant. Among the genotypes, the KER was significantly higher for Aniyoor which was on par with 7 Sahya-3, 6-6 and 7III E3-5. W-19 recorded the least KER on par with CR 43-8. As regards to the interaction effect of genotypes over years, it was found that, W-19 during the first season had the lowest KER on par with all other genotypes during the same season, W-19, 6-6 and 7III E3-5 during second season and all genotypes during the third season. Aniyoor during the second season had the highest KER on par with 7III E3-5 during the first season, 7 Sahya-3, CR43-8, 7III E3-5 during the second season, Aniyoor, 6-6 and 7III E3-5 during the third season (Table 2). This finding adheres to the reports of White (2013) that, plant species differ in their ability to utilize the K they have acquired for growth and yield. In this regard, White (2013) and White and Bell (2017) found that, there is variation among genotypes, plant species and K supply in affecting the K uptake, transport and utilization finally causing variation in their efficiencies.

9. K Harvest Index (KHI)

Genotypes imparted significant effect on KHI only in the pooled analysis. The pooled analysis data of the three years indicated significant effect with Aniyoor recording

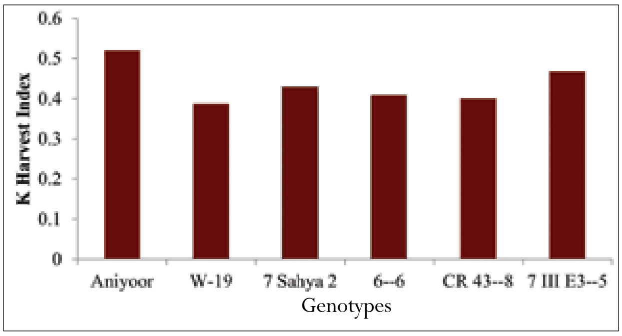

Fig.7. Effect of genotypes on K Harvest Index

Table 2. K Efficiency Ratio of the NUE genotypes over three years

Year (Y)	Genotypes (G)						
	Aniyoor	W-19	7 Sahya-2	6--6	CR 43-8	7 III E3--5	Mean Y
1	0.43	0.354	0.403	0.401	0.363	0.537	0.415
2	0.763	0.484	0.662	0.514	0.668	0.527	0.603
3	0.545	0.408	0.432	0.576	0.390	0.565	0.486
Mean (G)	0.579	0.415	0.499	0.497	0.474	0.543	
CD(0.05) (G) I year	NS						
CD (0.05) (G) II Year	NS						
CD (0.05) (G) III Year	NS						
CD (0.05) (G) Pooled	0.083						
CD (0.05) (Y)	NS						
CD (0.05 (G×Y)	0.240						

the highest on par with 7 Sahya-3 and 7 III E3-5. W-19 had the least KHI on par with 7 Sahya-3, 6-6 and CR 43-8 (Fig. 7). No significant effect of genotypes independently during the three years as well as years independently was seen on KER. Liu et al., (2022) reported genetic variation in KHI of 437 wheat varieties in China which in turn was accounted due to variation in grain, straw and glume uptake of K, shoot and grain utilization efficiencies.

10. K Uptake Ratio (KUR)

Genotypes imparted significance during the second and third seasons and in the pooled analysis. During the second year, W-19 caused significantly higher KUR on par with 7 III E3-5, 7 Sahya -2 and Aniyoor. In the third season also W-19 resulted in significantly higher KUR on par with CR 43-8. The pooled analysis data too indicated the same trend as in the third year. A significant effect of years too was seen with first year resulting in significantly highest KUR followed by second year which was on par with third year. As regards to the interaction effect of genotypes over years, 7 Sahya -2 during the first year caused significantly higher KUR on par with all genotypes except 7 III E3-5 during the first year, W-19 during the second year and W-19 and CR 43-8 during the third year (Table 3). In the present study, the differences noticed among genotypes, can be justified as per the findings of White (2013) and White et al., (2017) indicating 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).

11. % K Utilization for Biomass (% KUB)

Genotypes imparted significant effect during third season and in pooled analysis and seasons imparted significant effect in the pooled analysis. There was significant interaction effect of genotypes and years too. As regards to the effect of genotypes on % KUB, 7III E3-5 had the highest on par with Aniyoor, 6-6 and CR43-8 while W-19 had the least. In the case of the effect of seasons, it is seen that, second season had the highest on par with third season and first season recorded significantly the least %KUB. As regards to the interaction effect of genotypes over years, Aniyoor during the first season had the lowest on par with all other genotypes during the first season and W-19 and 7 Sahya-2 during the third season. CR 43-8 during the second season had the highest % KUB on par with Aniyoor and 7 Sahya-2 during the second season and 6-6 and 7 III E3-5 during the third season (Table 4). White et al., (2021) justified the variation among genotypes on % KUB was as due differences in K use efficiency of plant species which is the product of uptake and utilization efficiencies.

Table 3. K Uptake Ratio of the NUE genotypes over three years

Years (Y)	Genotypes (G)						
	Aniyoor	W-19	7 Sahya-2	6--6	CR 43-8	7 III E3--5	Mean Y
1	1.189	1.264	1.399	1.144	1.384	1.050	1.238
2	0.982	1.176	0.983	0.714	0.835	1.085	0.963
3	0.933	1.376	0.502	0.635	1.245	0.770	0.910
Mean (G)	1.035	1.272	0.961	0.831	1.154	0.969	
CD(0.05) (G) I year	NS						
CD (0.05) (G) II Year	0.234						
CD (0.05) (G) III Year	0.355						
CD (0.05) (G) Pooled	0.163						
CD (0.05) (Y)	0.062						
CD (0.05 (G×Y)	0.259						

Table 4. Percentage K utilization for biomass of the NUE genotypes over three years

Years (Y)	Genotypes (G)						
	Aniyoor	W-19	7 Sahya-2	6-6	CR 43-8	7 III E3-5	Mean Y
1	92.6	99.8	95.1	93.9	90.7	105.5	96.3
2	126.9	112.6	126.3	116.3	140.6	114.7	122.9
3	108.9	103.5	96.5	126.7	110.1	131.2	112.8
Mean (G)	109.5	105.3	106.0	112.3	113.8	117.1	
CD(0.05) (G) I year	NS						
CD (0.05) (G) II Year	NS						
CD (0.05) (G) III Year	11.64						
CD (0.05) (G) Pooled	8.00						
CD (0.05) (Y)	15.01						
CD (0.05 (G×Y)	14.74						

Table 8. Correlation of NUE parameters with tuber yield during the three seasons and over three years (combined)

Season	Tuber yield										
	% KUT	HI	KER	KHI	KUR	% KUB	APE	AE	ARE	PE	UE
I	0.963*	0.963*	0.904	0.928	0.388	-0.966*	0.594	0.251	0.459	0.935	0.506
II	0.649	0.670	0.726	0.762	0.299	0.542	-0.878*	-0.564	-0.181	0.090	0.116
III	-0.213	-0.213	-0.029	-0.217	0.839*	0.194	-0.180	-0.384	0.530	0.084	0.416
Pooled	0.043	0.070	0.270	0.216	0.346	0.641	0.055	0.092	0.118	0.309	0.482

CR 43-8 during the first year had the lowest on par with Moreover, all genotypes (except 7 III E3-5) during the first season and W-19 and 7 Sahya-3 during the third season, the percent K utilization for biomass was significantly higher during the second year which was on par with the third year and the effect was significantly lowest during the first year. These findings conforms 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.

Correlation studies

Correlation was done between tuber yield and NUE parameters during the three seasons independently and also with the three years combined. During the first season, significant positive correlation at 5% level was seen between tuber yield and % KUT (r^2 = 0.963*), HI (r^2 = 0.963*) and significant negative correlation of tuber yield with % KUB (r^2 = -0.966*). During the second season, significant negative correlation (r^2 = -878*) between tuber yield and APE was seen. In the third year, significant positive correlation of tuber yield was seen with KUR (r^2 =0.839*). The pooled data of the three years did not show either significant positive or negative correlation of tuber yield with any of the NUE parameters (Table 8). Liu et al., (2022) tried to establish relationship among the different K use efficiency parameters in wheat like the one we have done in this study and reported significant positive correlation of K HI with wheat yield, grain K concentration and grain K uptake.

Conclusion

Among the major nutrients, K is considered as very significant as regards to its role in enhancing crop productivity, improving crop produce quality, managing both biotic and abiotic stresses. This is particularly true especially for tuber crops as K is considered as the 'key nutrient' for this group of crops. The present study was focussed on computing the various potassium use efficiency parameters of some elite genotypes of cassava under four different levels of K to select the best K use efficient genotypes. The study revealed that, the different K use efficiency parameters like agronomic K use efficiency, K uptake efficiency and K utilization efficiency are interrelated which in turn depend on yield, K available to the crop, and the crop K content per unit K available. It is seen that, there is considerable genetic variation between and within genotypes in these parameters which is primarily due to the ability of the root system to exploit the soil volume effectively, to manipulate the rhizosphere to release non exchangeable K from the soil and the ability to take up K at low rhizosphere K concentrations. In the present study, it is seen that, genotypes *viz.,* Aniyoor and 7III E3-5 was found having better K use efficiency parameters under low (K_2O @ 0 and 50 kg ha^{-1}) levels of K due to their greatest K utilization efficiency in redistributing K from older to younger tissues to maintain growth and photosynthesis. Since there is sufficient heritable variation in the K uptake and utilization efficiencies among genotypes and was found higher under low levels of K with K use efficient genotypes, efforts need to be evolved to develop crops with higher K use efficiency. Moreover, as there exists strong interactions between genotypes and environment, of genotypes with greater K use efficiency may be developed by combining genetic and agronomic strategies to make better use of K fertilizers in agriculture to reduce fertilizer costs, protect the environment and slow down the exhaustion of non renewable resources.

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