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Response of Potassium Use Efficient Cassava Genotypes under Different Levels of N and K in an Ultisol of Kerala, India

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Abstract

Among the different factors contributing to the production potential of a crop, the genetic potential of the crop in terms of nutrient acquisition, transport and utilization is important with respect to its nutrient use efficiency in reducing the external application of fertilizers. The research work conducted on screening K efficient cassava genotypes resulted in the identification of six genotypes *viz*., Aniyoor, W-19, 7 Sahya-2, 6-6, CR 43-8 and 7 III E3-5 based on their inherent physiological efficiency. These six genotypes were evaluated under different levels of K and N (0, 50, 100, 150 kg ha^{-1}) to standardise the optimum dose of these nutrients for economic yield and also to confirm the N use efficiency potential of the K efficient genotypes. In this regard, observations were taken on nutrient use efficiency (NUE) parameters *viz*., HI, nutrient HI, nutrient uptake ratio, tuber yield and tuber quality. Since leaf and root architecture are the major contributors to NUE, LAI as well as the root parameters were also studied. Correlation among these different parameters were also studied especially to understand the effect of leaf and root characters on yield, NUE parameters including physiological efficiency. The study revealed significant differences among genotypes in the case of LAI and was higher under N than K levels. But, nutrient HI was higher under K. K levels significantly influenced the NUE parameters and K @ 50 kg ha^{-1} had highest impact on these parameters. Though no significant effect of K levels was seen on tuber yield, N @ 150 kg ha^{-1} resulted in significantly the highest tuber yield. The study of different root types in the root system of the crop under controlled conditions and in field over periodic growth intervals of cassava showed that, parameters *viz*., number of tuberous roots, its fresh weight and dry weights as well as root hairs were highest for the selected K efficient genotype Aniyoor. In the case of these genotypes under N levels, the identified genotypes *viz*., W-19 and CR 43-8 possessed larger volume of white roots, root length and diameter. Correlation studies revealed significant positive correlation of tuber yield with LAI, K/N uptake ratio and harvest index. Based on these parameters, the genotype Aniyoor and 7III E3-5 were identified as K efficient and the genotype W-19 and CR43-8 as N efficient.

Key words: Harvest index, nutrient harvest index, nutrient uptake ratio, leaf area index, white roots, tuber yield, cyanogenic glucosides, starch, correlation

Introduction

Root and tuber crops constitute the most important food crops of man after cereals and grain legumes. Among the tropical root tuber crops, cassava (*Manihot esculenta* Crantz) is considered as the most important as regards to its high biological efficiency (250 k cal ha^{-1} day^{-1}), yield potential (25-50 t ha^{-1}), ability to sustain under marginal management conditions, less incidence of pests and diseases and the high extractable starch content and its excellent physico- chemical properties. It is well known that, the potential productivity of a crop is a function of four major components *viz.*, genetic potential of the cultivar, environment under which it is grown, management practices adopted and technology employed to grow the crop.

As regards to the genetic potential of the crop, it is known that, plant species and cultivars within species differ widely in the absorption and utilization of nutrients and such differences are attributed to morphological, physiological and biochemical processes in plants and their interaction with climate, soil, fertilizer, biological and management practices. In this regard, evaluation of the nutrient use efficiency (NUE) potential is useful to differentiate plant species, genotypes and cultivars for their ability to absorb and utilize nutrients for achieving maximum productivity.

NUE of genotype is a new concept as an alternative to reducing or substituting for chemical fertilizers to some extent and it was defined by many researchers so early during 80's and 90's. Graham (1984) defined NUE of a genotype (for each nutrient separately) as its ability to produce high yield in a soil that is limiting in that particular nutrient. According to Blair (1993), nutrient use efficiency is the ability of a genotype/cultivar to acquire nutrients from growth medium and/or to incorporate or utilize them in the production of shoot and root biomass or utilizable plant material. The benefits of using NUE genotypes include reducing the fertilizer inputs, decreasing the rate of nutrient losses and in enhancing the crop yields. According to Baligar et al. (2001), improvement in NUE of plants can be achieved by careful manipulation of plant, soil, fertilizer, biological, environmental factors and best management practices.

Under a research project initiated at ICAR-Central Tuber Crops Research Institute (CTCRI), Kerala, India during 2006 to screen and identify K use efficient genotypes, six K efficient genotypes *viz.,* Aniyoor, W-19, 7 Sahya-2, 6-6, CR 43-8 and 7 III E3-5 were selected based on the inherent physiological efficiency (PE) of the crop after evaluating 83 elite genotypes (Susan John et al., 2020). PE in turn is a function of the total biological yield and total plant uptake of nutrients. Along with the PE, other factors like plant stature, cassava mosaic disease (CMD) tolerance, tuber quality attributes like cyanogen and starch, germination of the setts under moisture stress conditions were also considered.

According to Baligar et al. (2001), NUE is based on three most important efficiencies like uptake efficiency, incorporation efficiency and utilization efficiency. Uptake efficiency is the ability of the genotype to acquire nutrients from soil which are based on root parameters like weight or length of roots as well as the amount of the particular nutrient applied or present in soil. Incorporation efficiency relates to the transport of nutrients to the shoot and leaves and are based on shoot parameters. Utilization efficiency indicates the remobilization from shoot and root to the economic part. The major factors contributing to these efficiencies and finally the NUE is associated with leaf and root characters. In the case of leaf, the leaf area index (LAI) and with respect to root, the different root attributes like root length, root diameter, root hair (white roots) density are important.

Though six K use efficient lines were identified through preliminary screening (Susan John et al., 2020), experiments were further conducted to screen the best one or two lines. Similarly, the N use efficiency of these K use efficient lines were also studied to establish whether these lines are both N and K use efficient. This paper narrates the observations and inferences derived during the conduct of these two experiments for three seasons each with respect to parameters like LAI, root attributes at different growth stages of the crop and their effect on NUE parameters like harvest index (HI), nutrient harvest index (N/K HI), nutrient uptake ratio and finally on yield and quality parameters of the tuber like cyanogenic glucosides (HCN) and starch. Moreover, correlations among these parameters also threw light on the role played by these traits in selecting the most efficient K/N use efficient genotypes.

Materials and Methods

The experiments (1) identifying K use efficient genotypes (2) evaluation of the N efficiency potential of the selected K efficient genotypes were conducted at the block V of ICAR-CTCRI farm which is a typical laterite soil (Ultisol). The soil is acidic with a pH of 4.5-5.5, medium to high organic carbon (0.5-0.75%) and low available N, K and very high available P varying as 120-160, 100-150 and 30-70 kg ha^{-1} respectively. The experiments with the selected six genotypes *viz.,* Aniyoor, W-19, 7 Sahya-2, 6-6, CR 43-8 and 7 III E3-5 were conducted during 2009-2012 with different levels of K *viz.,* 0,50,100, 150 kg ha^{-1} as sub plot treatments in a split plot design. Similarly, from 2013-2016, the N efficiency potential of the above six K efficient genotypes were studied under four levels of N *viz.,* 0,50,100, 150 kg ha^{-1} with the same design as in the previous experiment. The levels of K and N were based on the recommended package of practices (PoP) of NPK for cassava for Kerala as 100:50:100 kg ha^{-1}. Hence, fixed an omission of N or K treatment (0 K/N) and a suboptimal (50 kg K/N) and super optimal level (150 kg K/N) treatments. The plot size was 4.5× 4.5 m spaced at 0.9×0.9m accommodating 25 plants with 16 boarder and 9 inner plants which were used for sampling at periodic intervals. Apart from giving K as treatments in the K experiment, N and P were applied as per PoP and in the case of N experiment, P and K were applied as per PoP and N at different levels as treatments. The crop was cultivated under rainfed condition with rainfall during the crop season ranging from 1750- 3000 mm and irrigation was not given at any point of time as the crop received sufficient rainfall during all its critical growth stages.

Observations were taken on leaf characters particularly LAI. Apart from this, harvest index (HI), K harvest index (KHI), K uptake ratio (KupR), tuber quality attributes like cyanogenic glucosides (HCN) and starch and tuber yield were recorded. Since root architecture was regarded as one of the most important attributes contributing to NUE, the root characters of these six genotypes were studied elaborately by planting them both under fibre glass pots and big cement tanks of $1m^3$ volume with a media having sand, soil and farm yard manure in equal proportion to isolate and extract the roots easily without disruption. Observations on root parameters like length, diameter, fresh weight, dry weight of tuberous, non tuberous, tuber linked roots and root hairs were recorded at periodic intervals from 2 months after planting (MAP) to harvest at 10MAP. The root length and root diameter of these roots were determined by measuring the length using a 30 cm scale and diameter using a screw gauge and expressed in centimetres. The white roots responsible for nutrient and water absorption seen at the tip of these feeding roots assessed for their fresh weight and dry weights.

In the case of LAI, during 3,6 and 9MAP, from the two labelled representative plants, three leaves each representing the bottom, middle and top portion of the plant were plucked and the leaf area was measured using the leaf area meter (LICOR). The mean of this value was multiplied by the mean number of retained leaves at that intervals and divided by the land area (90 × 90 cm) to get the LAI. In the calculation of HI, destructive sampling was made at these intervals, determined the leaf, stem and tuber fresh weight per plant along with dry matter percentage (DMP) in these samples by keeping 50 g each of these samples for drying. From the DMP, the dry weight of leaf, stem and tuber per plant was determined and converted on per hectare basis. From these data, HI was calculated by dividing the tuber yield with total biological yield (tuber+leaf+stem) on dry matter basis (Watson, 1947).

In order to determine KHI as per Soon (1992), the K content of leaf, stem and tuber during these intervals were determined (Piper, 1970) from the samples kept for determining the dry matter percentage. From the dry matter yield of leaf, stem and tuber and its respective K percentage, the KHI was computed following the formula:

$$KHI = \frac{\text{Tuber dry matter yield (kg plant}^{-1}\text{)} \times \text{tuber K (\%)}}{\text{Leaf dry matter yield (kg plant}^{-1}\text{)} \times \text{leaf K (\%)} + \text{stem dry matter yield (kg plant}^{-1}\text{)} \times \text{stem K (\%)} + \text{tuber dry matter yield (kg plant}^{-1}\text{)} \times \text{tuber K (\%)}}$$

The K uptake ratio (KUpR) was determined as below as per Soon (1992):

$$\text{K uptake ratio} = \frac{\text{Leaf dry matter yield (kg plant}^{-1}\text{)} \times \text{leaf K (\%)} + \text{stem dry matter yield (kg plant}^{-1}\text{)} \times \text{stem K (\%)} + \text{tuber dry matter yield (kg plant}^{-1}\text{)} \times \text{tuber K (\%)}}{\text{Total soil available K (kg plant}^{-1}\text{)}}$$

In addition to the data on plant dry matter yield *viz.,* leaf, stem and tuber and their respective K contents (%), the soil available K (kg $plant^{-1}$) was determined by adding the soil available K before the start of the experiment and that added through fertilizer. Necessary conversion too did to convert the fertilizer K_2O to K as the plant K is in K. In this regard, the per hectare total soil available K was converted to per plant K (g $plant^{-1}$) by dividing with the number of plants per hectare (12345).

As regards to tuber quality parameters, cyanogenic glucosides (HCN) was determined in the fresh tubers immediately after harvest (Indira and Sinha, 1969) and starch in the dry tuber (Chopra and Kanwar, 1976) and expressed on fresh weight basis. In addition to the tuber yield recorded at tri monthly intervals, the same was recorded at harvest (9-10 months after planting). The average per plant yield of the inner plants was converted on per hectare basis.

In the case of N trial with K efficient genotypes under field situation, the same observations as in the case of K level experiment were conducted and the root observations too were made under field situations.

Based on the observations made in two experiments, the response of the same genotypes under different levels of two different nutrients like N and K with respect to the aforementioned parameters and the interrelationship among these parameters including the effect of root and leaf characters on nutrient use efficiency parameters *viz.,* HI, KHI, K uptake ratio and finally on tuber yield and tuber quality were analysed. The multiple comparisons of the means were carried out using Duncan's Multiple Range Test (DMRT) (Duncan, 1955). All the analysis were carried out using GENSTAT and SAS 9.3 (SAS, 2011).

Results and Discussion

The results of the study on the parameters indicated above under the influence of different levels of K and N are discussed below:

a. Leaf Area Index (LAI)

The effect of genotypes, K and N levels and their interactions and a comparison between N and K levels for the same genotypes are described as follows.

K efficient genotypes at different K levels

The LAI as influenced by K efficient genotypes at different intervals viz., 3,6 and 9 months after planting (MAP) are presented in Table 1.

Table 1. Influence of genotypes on LAI at different intervals at different K levels

	Leaf Area Index			
Genotypes	3 MAP	6 MAP	9 MAP	Mean (G)
Aniyoor	3.38	5.48	3.57	4.14
W-19	5.12	8.98	4.65	6.25
7 Sahya-2	0.90	2.43	2.09	1.81
6-6	2.27	3.95	2.68	2.97
CR43-8	3.77	5.70	5.86	5.11
7 III E3-5	2.15	3.21	2.00	2.45
CD(0.05)	2.282	3.526	2.441	2.75
Mean (Interval)	2.93	4.96	3.47	3.79

The data indicated an increase in LAI at 6MAP and then decreased towards harvest at 9MAP in the case of all genotypes. Among the genotypes, W-19 had the highest LAI at 3 MAP (5.12) and 6 MAP (8.98) which was on par with Aniyoor (3.38) and CR 43-8 (5.48) during these intervals. At 9MAP, genotype CR 43-8 had the highest LAI (5.86) on par with the genotype Aniyoor (3.57) and W-19 (4.65). The mean LAI of the six genotypes indicated the highest LAI with W-19 (6.25) on par with Aniyoor (4.14) and CR 43-8 (5.11) (Table 1). According to Adekunle et al., (2014) and IITA (2003), LAI is a function of the number and size of leaves and it usually peaks at 3–6 MAP in the tropics depending on variety and environmental factors.Genotypic variation with respect to plant canopy and architecture was reported by many scientists (Fageria et al., 2006; Baligar et al., 2001).

As regards to the different levels of K on LAI, at 3,6 and 9MAP, the highest LAI was recorded at K @ 100, 150 and 0 though the effect was insignificant at different levels of K during the three intervals. Moreover, the mean of LAI at three intervals at the four levels of K did not show any significant difference. However, K @100 and 150 kg ha^{-1} has resulted in the highest LAI (3.99) where the average of the LAI at three intervals was 3.79 (Table 2). Biratu et al., (2018) studied the effect of INM including mineral fertilizers on LAI at two sites of Africa and did not find any significant effect of mineral fertilizers at one site on LAI whereas the INM could increase the canopy diameter and hence LAI in the other site.

Table 2. Influence of levels of K on LAI

K Levels	Leaf Area Index			
(kg ha^{-1})	3 MAP	6 MAP	9 MAP	Mean
K0	3.04	4.63	3.90	3.86
K50	2.32	4.33	3.29	3.31
K100	3.44	4.86	3.68	3.99
K150	2.93	6.02	3.03	3.99
Mean (K Levels)	2.93	4.96	3.47	3.79
CD (0.05)	NS	NS	NS	NS

K efficient genotypes at different N levels

The LAI was significantly affected by the genotypes during the three intervals at four different levels of N *viz.,* 0, 50, 100 and 150 kg ha^{-1}. Genotype CR 43-8 had the highest LAI at 3 MAP (7.76) and 9 MAP (11.62) on par with W-19 (11.75) and CR 43-8 (10.96) at 6 MAP. Genotypes *viz.*, Aniyoor, 7 Sahya 2, CR 43-8 showed an increase of LAI from 3 MAP to 6 MAP and to 9 MAP. Among the genotypes, CR 43-8 had the highest LAI (10.11) on par with W-19 (9.54) (Table 3). In potato, Jahan et al., (2014) reported steady increase in LAI up to 60 DAP which then declined.

Table 3. Influence of genotypes on LAI at different intervals at different N levels

Genotypes	Leaf Area Index			
	3 MAP	6 MAP	9 MAP	Mean
Aniyoor	3.10	4.86	6.04	4.67
W-19	6.75	11.75	10.12	9.54
7 Sahya-2	4.53	5.80	6.02	5.45
6-6	4.54	4.07	3.55	4.05
CR 43-8	7.76	10.96	11.62	10.11
7 III E3-5	4.26	2.91	3.76	3.64
CD(0.05)	2.718	3.770	4.882	3.79
Mean (Interval)	4.81	6.30	6.57	5.89

As regards to the effect of different N levels on K efficient genotypes, there was no significant effect of N levels on LAI between 3 and 9 MAP . Though not significant, N @ 150 kg ha^{-1}resulted in the highest LAI (7.01) among the four levels during 3, 6 and 9 MAP. The mean LAI under different N levels was 6.24. Plants without N had higher LAI (5.96) over N@ 50 kg ha^{-1} (5.81). At N @ 50 and 100 kg ha^{-1}, there was an increase in LAI between 3 and MAP (Table 4). Biswas (2011) reported increase in LAI with mineral fertilizers compared to absolute control without any nutrient application either through fertilizers or manures.

Table 4. Effect of levels of N on LAI

N Levels	Leaf Area Index			
(kg ha^{-1})	3MAP	6MAP	9MAP	Mean
N0	4.55	6.81	6.52	5.96
N50	5.08	6.04	6.31	5.81
N100	5.00	6.50	7.07	6.19
N150	5.99	7.55	7.50	7.01
Mean (N Levels)	5.155	6.725	6.85	6.24
CD(0.05)	NS	NS	NS	NS

Comparison of LAI of K efficient genotypes under K and N levels

A comparison of the LAI of the six K efficient genotypes at the four levels of K (0, 50, 100, 150 kg ha^{-1}) and at the same levels of N is depicted in Fig.1. It is clear from the figure that, for the same genotypes, the LAI is higher under N compared to K at all levels and at all intervals.

Fig. 2 depicts the genotypic variation in LAI under different levels of K and N. The mean values of LAI of the six genotypes under different K and N levels clearly indicated higher LAI for all genotypes under N over K. Among the genotypes, CR 43-8 had the highest LAI on par with W-19 (Fig. 2).

For the same K efficient genotypes under same levels of K and N, the LAI was higher under N at all the four levels. El-Sharkawy (2004) found high LAI mostly from high nitrogen fertilizer application.

Nutrient use efficiency (NUE) parameters

1. Harvest Index, Nutrient Harvest Index and Nutrient Uptake Ratio

As regards to the three NUE parameters, *viz.,* harvest index (HI), nutrient (K and N) harvest index (K and N) HI and nutrient (K and N) uptake ratio, among the six genotypes under different K and N levels, significant effect was seen only with nutrient uptake ratio under different levels of K.

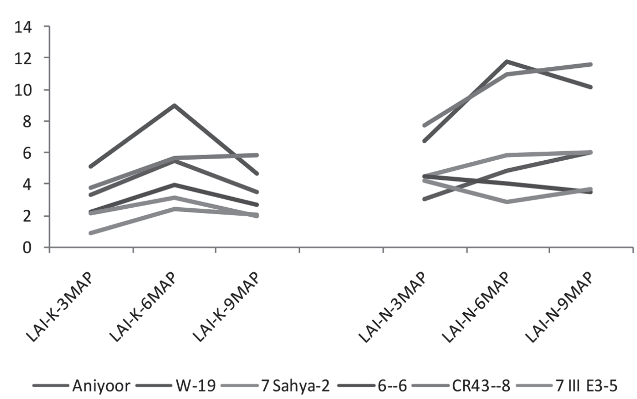


Fig.1. LAI of K efficient genotypes at different K and N levels at different growth period

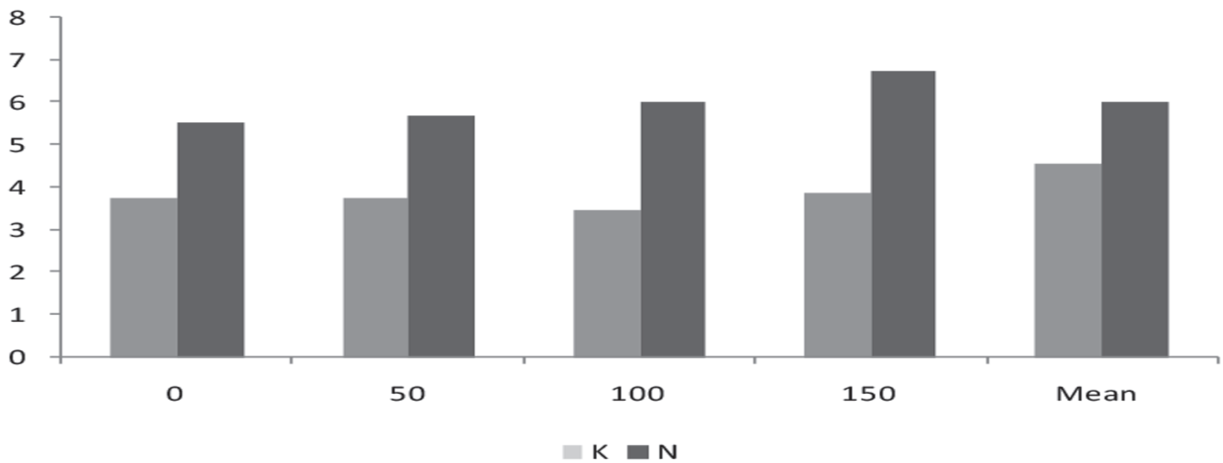
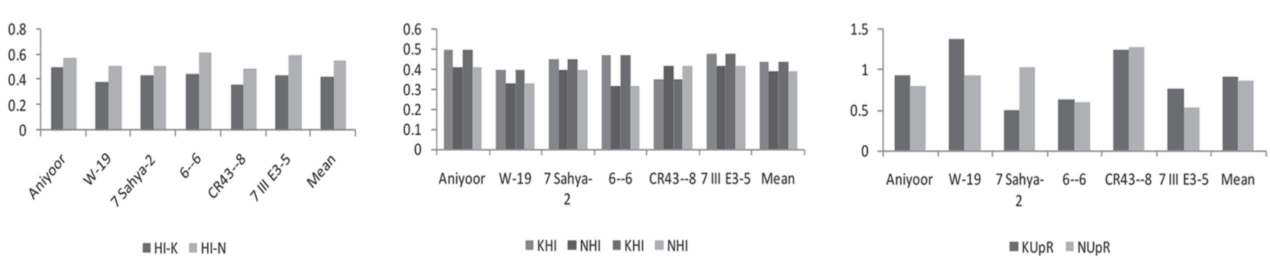


Fig. 2. LAI of K efficient genotypes under different K and N levels

The HI was found higher under N (Fig. 3), whereas the nutrient (K and N) HI was high with K. Among the genotypes, Aniyoor showed the highest HI and KHI under K levels. In the case of HI under different N levels, genotype 6-6 had the highest and CR43-8 and 7 III E3-5 had the highest NHI. Rengel and Paul (2008) reported genotypic differences in K efficiency uptake and utilization for major economically important plants. Karim et al., (2020) found significant variation among cassava genotypes with respect to HI. In Durum wheat, Desai and Bhatia (1978) found significant variation among cultivars on NHI. According to Isfan (1993), among the NUE parameters, N, P, K harvest indices is the most important as this will determine the capability of the genotypes to use the nutrient input more efficiently. As regards to the N or K uptake ratio, under different levels of K, genotype W-19 had the highest (1.38) on par with CR 43-8 (1.25). In the case of N uptake ratio, genotype CR 43-8 had the highest (1.28). Several reports indicated genetic variability among genotypes of the same species for macro and micronutrient use (Clark, 1990., Fageria and Baligar, 2005; Hillel and Rosenzweig, 2005).

As regards to the influence of different levels of K and N in the K efficient genotypes with respect to the NUE parameters, it is seen that, K levels alone produced significant effect on HI, KHI and K uptake ratio. HI was highest without K but was on par with K at 50 and 100 kg ha^{-1}. Similarly, KHI and K uptake ratio were highest for K_0, but was on par with K @50 kg ha^{-1}. Gwathmey et al., (2009) reported that, cultivar differences in K utilization efficiency may be more apparent under K limiting conditions. In the case of HI, under different levels of N, these were higher than under K levels but not significant. An increase in HI was seen with increase in N levels from 0 to 150 kg ha^{-1}. The same trend was seen in the case of N HI and N uptake ratio, but the values are lower than under different K levels (Table 5). The variation among genotypes under different levels of N and K can be attributed to the difference in the efficiency of acquisition, transport and utilization of nutrients among genotypes and cultivars (Baligar et al., 2001).Though the HI, K HI and K uptake ratio was found decreased with increasing levels of K, the respective parameters increased with increasing levels of N.



a. Harvest Index b. K and N Harvest Index c. K and N uptake ratio

Fig. 3. Effect of genotypes on HI, nutrient HI and nutrient uptake ratio under K and N levels

Table 5. NUE parameters as affected by different levels of K and N

K/N levels (kg ha^{-1})	HI		K/N HI		K/N/UpR	
	K	N	K	N	K	N
0	0.461	0.52	0.49	0.35	1.072	0.74
50	0.458	0.55	0.46	0.37	0.920	0.80
100	0.426	0.58	0.43	0.40	0.850	0.85
150	0.367	0.64	0.38	0.42	0.799	1.07
Mean (K or N Levels)	0.428	0.552	0.428	0.39	0.910	0.863
CD(0.05)	0.061	NS	0.059	NS	0.217	NS

Liang et al. (2020) while screening N use efficient cassava genotypes for low N soils of China reported that, even with different genotypes, N levels and season are responsible for variation in yield and the N uptake efficiency is the most important factor affecting yield which in turn vary with genotypes and N levels.

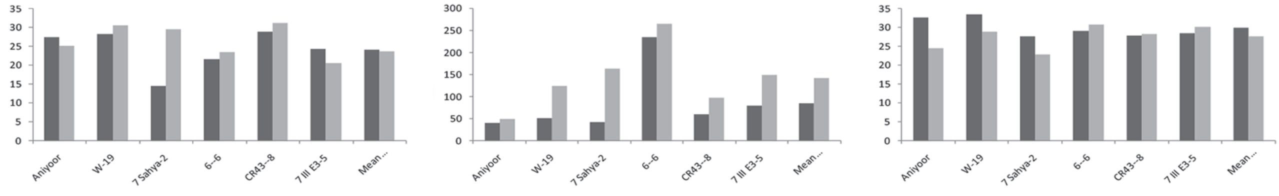
Tuber yield and tuber quality of the genotypes under different levels of K and N

The tuber yield and cyanogenic glucoside content of the cassava tubers of the different genotypes were significantly influenced under different levels of K and N. Genotype CR 43-8 had the highest tuber yield both under K (28.79 t ha^{-1}) and N (31.105 t ha^{-1}) and was on par with genotypes *viz.,*Aniyoor and W-19 under different K levels and with genotypes *viz.,*W-19 and 7 Sahya -2 under different levels of N (Fig.4a).

The cyanogenic glucosides content was low under K with Aniyoor having the lowest (40.4 ppm) and on par with all genotypes except genotype 6-6. Under N levels too, Aniyoor had the lowest (50.1 ppm) and on par with genotype CR 43-8 (98.4 ppm) (Fig.4b). Although starch content was not significantly affected under different K and N levels, genotype W-19 had the highest starch content under different K levels (33.27%), and the genotype 6-6 under different N levels (30.58%) (Fig. 4c). Siva et al. (2014) in Brazil observed significant variation among cassava genotypes with respect to different morphological, agronomic, physiological and biochemical parameters including tuber yield and starch content. The variation in starch content in the different genotypes is in agreement with the findings of Ceballos et al. (2004) and Benesi et al. (2008).

Different K levels did not have any significant effect on tuber yield of the K efficient genotypes. However, K @ 100 kg ha^{-1} resulted in the highest tuber yield (26.20 t ha^{-1}). Under different N levels, N @150 kg ha^{-1} resulted in significantly the highest tuber yield (33.45 t ha^{-1}). El-Sharkawy and Cadavid (2000) studied genetic variation among cassava genotypes under different levels of K and reported K efficient genotypes had high K adaptation indices, high K use efficiency and biomass production under low K levels.

Although the cyanogenic glucoside content of the tubers were not affected by K levels,the lowest (81.2 ppm) was recorded at K @ 50 kg ha^{-1}. Endris (1977) found that, the cyanogenic glucoside content of cassava roots were significantly reduced by potassium application. In the case of different N levels, the lowest HCN (114.3 ppm) was recorded at N @150 kg ha^{-1} which was on par with N @100 kg ha^{-1}(125.9 ppm).This is in agreement with the findings of Rolinda et al. (2008) that, application of N or K fertilizer did not significantly affect the cyanide content. The starch content of the genotypes were not significantly influenced under different K and N levels. However, K@ 100 kg ha^{-1} and N @ 50 kg ha^{-1} resulted in the highest starch content in cassava tubers to the tune of 31.22 and 28.61% respectively (Table 6). Susan John et al. (2007) reported low cyanogen and comparatively high starch with high K and low N application in cassava.



a. Tuber yield (t ha^{-1}) b. Cyanogenic glucosides (ppm) c. Starch (%)

Fig. 4. Variation among genotypes on tuber yield and tuber quality attributes under levels of K and N

Table 6. Effect of levels of K and N on tuber yield and tuber quality attributes

K or N levels (kg ha^{-1})	Tuber Yield(t ha^{-1})		HCN (ppm)		Starch (% FW basis)	
	K	N	K	N	K	N
0	22.89	20.039	84.8	174.1	30.63	27.23
50	23.23	23.839	81.2	152.2	28.80	28.61
100	26.20	29.240	86.8	125.9	31.22	28.02
150	24.11	33.448	87.0	114.3	28.28	25.98
Mean (K or N Levels)	24.11	24.64	84.95	141.6	29.73	27.46
CD(0.05)	NS	2.108	NS	33.46	NS	NS

Root characters of the K efficient genotypes under controlled conditions

The mean of the characters over period of time as well the changes over growth stages are presented below. There are several reports indicating the significance of root systems in the water and nutrient uptake of important agronomic crops (Lynch, 1995, 2013; Borch et al., 1999; Postma and Lynch, 2012; York et al., 2013; Paez Garcia et al., 2015).

Fibre glass pots

As regards to nontuberous roots, except genotype W-19, all genotypes had more or less the same number, length, diameter, fresh weight and dry weight with genotypes *viz.,*H 1687, 6-6, CR 43-8 showing the maximum values. Tuber linked roots were the thick root stalk like structures attached to the tip of the tuber which is supposed to have role in nourishing the tuber in tuber bulking. Compared to the check variety H 1687 and genotype W-19, all genotypes except 7IIIE3-5, possessed almost the same fresh weight of non tuberous roots. The same trend was seen for its dry weight too (Table 7a). The results conforms to the reports of El-Sharkawy (2003) that, there exists genetic differences in root traits throughout the production cycle.

The mean number of tubers was found higher for genotypes *viz.,*Aniyoor and 7III E 3-5 which in turn was more compared to the check variety. Fresh weight and dry weight of the tuberous roots also followed the same trend with genotypes *viz.,* Aniyoor and 7 III E3-5 registering the highest. As regards to root hairs, the genotype, H 1687 followed by genotype CR 43-8 and 6-6 had the highest fresh weight of white roots and the same trend was seen in the case of their dry weights too (Table 7b). Subere et al. (2009) also indicated variation in length of adventitious roots of 28 cassava germplasm collection when grwon in pots.

Cement tanks (Lysimeter structures)

The six K efficient genotypes were planted in big cement tanks and observations on root attributes were taken at periodic intervals. The mean of these characters over period of time are presented in Table 8. Here, observations were mainly taken on tuber forming roots,

Table 7a. Root characters of the K use efficient genotypes under fibre glass pot studies (Mean)

Genotypes	Non tuberous roots					Tuber linked roots	
	Number	Length (cm)	Diameter (cm)	Fresh weight (g)	Dry weight (g)	Fresh weight (g)	Dry weight (g)
Aniyoor	17	38.33	2.00	13.51	2.47	6.86	1.63
CR43-8	20	34.00	2.67	20.66	3.53	6.39	1.14
7III E3-5	22	36.00	2.00	16.54	3.02	10.39	2.06
H1687	27	37.33	2.33	21.09	3.31	3.56	0.77
6-6	24	50.00	2.67	21.18	3.13	6.77	1.06
W-19	13	34.43	1.33	10.06	1.48	3.44	0.61

Table 7b. Root characters of the K use efficient genotypes under fibre glass pot studies (Mean)

Genotypes	Tuberous roots			White roots	
	Number	Fresh weight (g)	Dry weight (g)	Fresh weight (g)	Dry weight (g)
Aniyoor	14.33	189.89	21.48	56.53	8.35
CR43-8	8.33	167.68	12.61	82.61	13.86
7III E3-5	12.67	181.63	17.48	69.22	11.68
H1687	3.33	44.76	4.58	83.94	12.50
6-6	4.00	44.16	3.78	79.26	13.75
W-19	5.67	115.60	10.73	50.64	7.89

root hairs and non tuberous roots. In the case of tuber forming roots, the tuber number was maximum with the genotype Aniyoor and it was on par with the check variety (H 1687). Genotype Aniyoor followed by genotypes W-19 and 6-6 had the highest fresh tuber weight and the dry weight was also high with these genotypes compared to variety H 1687. The tuber dry matter percentage also followed the same trend. Kengkanna et al. (2019) observed larger phenotypic variation of root traits in cassava.

The fresh weight of white roots was highest with the variety H 1687 followed by genotypes *viz.,*Aniyoor and 6-6 and the same trend was noticed for their dry weights too. Genotypes *viz.,*CR 43-8 and 6-6 possessed the highest number of nontuberous roots and their fresh weight also was higher with genotypes CR 43-8, 6-6 and H 1687 and hence their dry weights too.

Root characters of the K efficient genotypes under different levels of N

The root characters studied included white roots fresh weight, its dry weight, root length and root diameter at 3 MAP and 6 MAP. The influence of genotypes on these parameters were not significant. The comparison of the six NUE efficient genotypes with the popular hybrid variety H 1687 indicated that the genotype W-19 had higher white root fresh weight at 3 MAP whereas all genotypes except 7 III E3-5 had high white root fresh weight at 6 MAP. Genotypes Aniyoor and W-19 had more root length at 3 MAP whereas genotypes Aniyoor, 6-6, CR 43-8 and 7 III E3-5 with higher root length at 6 MAP. Genotypes 6-6 and 7 III E3-5 had more root diameter at 3MAP and Aniyoor had higher root diameter at 6 MAP (Table 9). Adu et al. (2018) studied root system architecture (RSA) in cassava genotypes with high water and nutrient use efficiency and found that, root diameter and root branching density are important parameters. El-Sharkawy (2003) reported phenotypic differences in root traits in the cassava germplasm. The decrease in root traits especially in root diameter from 3 MAP to 6 MAP as seen in the present study is associated with tuber bulking as reported by Izumi et al. (1999).

As regards to the influence of levels of N on the above characters, it is seen that, there is no significant effect. However, the white roots fresh weight at 3 and 6MAP were higher without N and N @150 kg ha^{-1} respectively. The white root dry weights at these intervals was found highest under N @ 50 and 100 kg ha^{-1} respectively. Root

Table 8. Root characters of the K use efficient genotypes grown under cement tanks (Mean)

Genotypes	Tuber forming roots			White roots			Non tuberous roots		
	Number	Fresh weight (g)	Dry weight (g)	Number	Fresh weight (g)	Dry weight (g)	Number	Fresh weight (g)	Dry weight (g)
Aniyoor	21.5	4378	1380	26.6	35.41	3.58	18	20.67	7.19
CR43-8	12.5	3484	833	18.7	15.51	1.13	27	36.45	7.53
7III E3-5	16.75	3235	1010	24.6	20.97	2.15	18	21.34	5.27
H1687	21.5	3818	1180	24.0	55.13	10.78	22	29.09	8.86
6-6	18.25	4077	1365	25.0	24.92	3.15	23	29.77	6.86
W-19	15	4355	1437	29.3	8.93	0.93	15	10.78	2.84

Table 9. Effect of genotypes under different levels of N on root characters

Genotypes	White roots				Root length		Root diameter	
	Fresh weight (g $plant^{-1}$)		Dry weight (g $plant^{-1}$)		cm			
	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP
Aniyoor	2.91	15.9	0.507	2.77	20.25	27.1	7.34	1.68
W-19	5.64	16.5	1.367	4.00	21.49	21.1	7.14	1.55
H 1687	4.79	11.1	0.893	2.07	18.87	21.4	7.54	1.58
6-6	3.02	15.2	0.636	3.20	18.66	22.2	9.93	1.25
CR 43-8	2.30	15.0	0.708	4.62	17.54	29.1	7.48	1.26
7 III E3-5	1.13	10.6	0.212	1.99	18.37	22.2	9.28	1.28
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Mean (Interval)	3.30	14.05	0.72	3.11	19.20	23.85	8.12	1.43

Table 10. Effect of levels of N on root characters

	White roots				Root length		Root diameter	
N levels	Fresh weight (g $plant^{-1}$)		Dry weight (g $plant^{-1}$)		cm			
(kg ha^{-1})	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP
N0	3.74	13.9	0.759	2.82	19.30	27.4	7.28	1.56
N50	3.42	12.0	0.861	3.02	18.54	21.5	8.42	1.39
N100	3.43	15.0	0.839	3.67	19.84	23.0	8.36	1.30
N150	2.61	15.3	0.498	2.92	19.11	23.5	8.40	1.48
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Mean (Interval)	3.3	14.05	0.74	3.11	19.20	23.85	3.3	1.43

length was highest at N @ 100 kg ha^{-1} and without N respectively at 3 and 6 MAP. The root diameter was highest with N @ 50 kg ha^{-1} and without N at 3 and 6 MAP respectively (Table 10). Sumner (1990) found that, the enhanced uptake of nutrients can be due to improved root surface area and activity resulting in an overall increase in root and shoot growth. The genotypic variation in nutrient uptake and utilization among K efficient genotypes is associated with better root geometry, ability of plants to take up sufficient nutrients from lower or subsoil, plant's ability to solubilize nutrients in the rhizhosphere, better transport, distribution and utilization within plants and balanced source sink relationships.

Correlation among the different parameters studied

The interrelationship among the different parameters especially LAI, nutrient use efficiency parameters like HI, nutrient harvest index, nutrient uptake ratio and root characters and their influence on tuber yield as well as the influence of LAI and root characters on NUE parameters and tuber yield was worked out following Pearson correlation. In all these cases, significance was found by comparing the correlation value of the associated two parameters from the correlation matrix table with the critical value from the table of significance for correlation with respect to the number of samples (n). The correlation matrix for K genotypes is given in Table 11a&b.

K efficient genotypes

From the matrix table, significant positive correlation was seen for LAI with tuber yield (r=0.834**) and K uptake ratio (r= 0.969**). Similarly, tuber yield with K uptake ratio (r= 0.870**), harvest index with K harvest index (r=0.943**)(Table 11a). Karim et al., (2020) reported significant positive correlation between harvest index and root yield per plant as well as leaf characters with root yield per plant.

K Levels

Significant positive correlation was derived for HI with KHI (r=0.966**) and HCN (r=0.962**), K uptake ratio and HCN (r=0.978**)(Table 11b). Babu Rao et al., (2017) reported similar correlation while investigating the interrelationship of yield related characters and the extent of their contribution in tuber yield for the direct selection of genotypes.

N efficient genotypes

There was significant positive correlation for LAI with tuber yield (r=0.871**) and root hair dry weight at 6 MAP (r=0.858**), tuber yield with N uptake ratio (r=0.923**), HCN with root diameter at 3 MAP (r=0.847**), root hair fresh weight at 3 MAP with root hair dry weight at 6 MAP (r=930**), root hair dry weight at 6 MAP with LAI (r=0.858**). Similarly significant negative correlation was seen for LAI with HI (r=-0.848**), tuber yield with HI (r=-0. 935**), HI with N uptake ratio (-0. 931**) (Table 11c). Liang et al., (2020) reported the correlation of N uptake efficiency and yield in the screening of N use efficient cassava genotypes.

N levels

Significant positive correlation was derived between LAI and N uptake ratio (r=0.959**), tuber yield with HI (r=0.979**) and NHI (r=0.999**), HI with NHI (r= 0.973**), N uptake ratio with HI (r=0.984**), HCN with root hair fresh weight at 6 MAP (r=0.998), root hair dry weight at 3 MAP with starch (r=0.964**). Significant negative correlation was seen for HI with root hair fresh weight at 3 MAP (r=-0. 961**), N uptake ratio with root hair fresh weight at 3MAP (r=-0.988**) (Table 11d). Kundy et al., (2014) made similar studies in cassava using correlation and path analysis

Conclusion

In the present study, the N use efficiency potential of the six K efficient genotypes was evaluated based on LAI, fresh and dry weight of root mass, root traits, tuber yield and HCN content of tubers. In this process, the K and N use efficiency of the K efficient genotypes was evaluated under four levels of K and four levels of N. Since the nutrient use efficiency is basically linked to plant architecture specifically leaf and root geometry, observation was taken on leaf area index (LAI) at 3, 6

Table 11a.Correlation matrix table for K efficient genotypes

	LAI	TY	HI	KHI	KUpR	HCN	Starch
LAI	1.000	0.834**	-0.523	-0.617	0.969**	-0.471	0.648
TY	0.834**	1.000	-0.307	-0.361	0.870**	-0.555	0.549
HI	-0.523	-0.307	1.000	0.943**	-0.621	0.0256	0.214
KHI	-0.617	-0.361	0.943**	1.000	-0.674	0.163	0.159
KUpR	0.969**	0.870**	-0.621	-0.674	1.000	-0.553	0.537
HCN	-0.471	-0.555	0.026	0.163	-0.553	1.000	-0.406
Starch	0.648	0.549	0.214	0.159	0.537	-0.406	1.000

Table 11b. Correlation matrix table for K levels

	LAI	TY	HI	KHI	KUpR	HCN	Starch
LAI	1.000	-0.797	0.562	0.509	0.432	0.596	-0.465
TY	-0.797	1.000	-0.364	-0.476	-0.627	-0.683	0.449
HI	0.562	-0.364	1.000	0.966**	0.807	0.879	0.471
KHI	0.509	-0.476	0.966**	1.000	0.932	0.962**	0.495
KUpR	0.432	-0.627	0.807	0.932	1.000	0.978	0.413
HCN	0.596	-0.683	0.879	0.962**	0.978**	1.000	0.313
Starch	-0.465	0.449	0.471	0.495	0.413	0.313	1.000

Table 11 c. Correlation matrix table for N genotypes

	LAI	TY	HI	NHI	NUpR	HCN	Starch	RHFW3	RHDW3	RHFW6	RHDW6	RL3	RL6	RR3	RR6
LAI	1.00	0.871**	-0.848**	-0.070	0.810	-0.391	0.048	0.406	0.684	0.488	0.858**	0.152	0.332	-0.657	0.004
TY	0.871**	1.000	-0.935**	-0.073	0.923**	-0.443	-0.366	0.662	0.795	0.376	0.644	0.186	0.223	-0.779	0.289
HI	-0.848**	-0.935**	1.000	-0.201	-0.931**	0.651	0.399	-0.514	-0.652	-0.105	-0.500	-0.068	-0.224	0.810	-0.252
NHI	-0.070	-0.073	-0.210	1.000	0.271	-0.622	-0.420	-0.551	--0.571	-0.506	-0.270	-0.478	0.553	-0.273	0.055
NUpR	0.810	0.923**	-0.931**	0.271	1.000	-0.522	-0.432	0.356	0.501	0.216	0.594	-0.122	0.495	-0.755	0.168
HCN	-0.391	-0.443	0.651	-0.622	-0.522	1.000	0.614	-0.211	-0.199	0.132	0.029	-0.274	-0.251	0.847**	-0.609
Starch	0.048	-0.366	0.399	-0.420	-0.432	0.614	1.00	-0.382	-0.147	0.169	0.337	-0.166	-0.140	0.644	-0.789
RHFW3	0.406	0.662	-0.514	-0.551	0.356	-0.211	-0.382	1.000	0.930**	0.326	0.180	0.685	-0.450	-0.539	0.603
RHDW3	0.684	0.795	-0.652	-0.571	0.501	-0.200	-0.147	0.930**	1.000	0.470	0.494	0.607	-0.301	-0.567	0.385
RHFW6	0.488	0.376	-0.105	-0.506	0.216	0.132	0.169	0.326	0.470	1.000	0.750	0.507	0.356	-0.312	0.191
RHDW6	0.858**	0.644	-0.500	-0.270	0.593	0.029	0.337	0.180	0.494	0.750	1.000	0.053	0.485	-0.340	-0.238
RL3	0.152	0.186	-0.068	-0.478	-0.122	-0.274	-0.166	0.685	0.607	0.507	0.053	1.000	-0.353	-0.446	0.726
RL6	0.332	0.223	-0.224	0.553	0.495	-0.251	-0.140	-0.450	-0.301	0.356	0.485	-0.354	1.000	-0.336	-0.072
RR3	-0.657	-0.779	0.810	-0.273	-0.755	0.847**	0.644	-0.539	-0.567	-0.312	-0.340	-0.446	-0.336	1.000	-0.701
RR6	0.004	0.289	-0.252	0.055	0.168	-0.609	-0.789	0.603	0.385	0.191	-0.238	0.726	-0.072	-0.701	1.000

Table 11 d. Correlation matrix table for N levels

	LAI	TY	HI	NHI	NUpR	HCN	Starch	RHFW3	RHDW3	RHFW6	RHDW6	RL3	RL6	RR3	RR6
LAI	1.000	0.861	0.924	0.851	0.959**	0.727	-0.875	-0.918	-0.929	0.767	-0.088	0.179	-0.052	0.346	0.143
TY	0.862	1.000	0.979**	0.999**	0.928	0.635	-0.513	-0.888	-0.628	0.670	0.343	0.236	-0.482	0.733	-0.374
HI	0.924	0.979**	1.000	0.973**	0.984**	0.591	-0.626	-0.961**	-0.754	0.634	0.146	0.101	-0.423	0.678	-0.204
NHI	0.851	0.999**	0.973**	1.000	0.917	0.642	-0.496	-0.874	-0.609	0.675	0.370	0.257	-0.486	0.737	-0.396
NUpR	0.959**	0.927	0.984**	0.917	1.000	0.564	-0.729	-0.988**	-0.852	0.611	-0.032	0.010	-0.322	0.579	-0.030
HCN	0.727	0.635	0.591	0.642	0.564	1.000	-0.684	-0.433	-0.572	0.998**	0.332	0.799	0.295	0.004	-0.008
Starch	-0.875	-0.513	-0.626	-0.496	-0.729	-0.684	1.000	-0.686	-0.964**	-0.715	0.426	-0.159	-0.405	0.136	-0.581
RHFW3	-0.918	-0.888	-0.961**	-0.874	-0.988**	-0.433	0.686	1.000	0.839	-0.485	0.118	0.142	0.387	-0.613	0.006
RHDW3	-0.929	-0.628	-0.754	-0.609	-0.852	-0.572	0.964**	0.839	1.000	-0.615	0.443	0.027	-0.172	-0.085	-0.486
RHFW6	0.767	0.670	0.634	0.675	0.611	0.998**	-0.715	-0.485	-0.615	1.000	0.304	0.763	0.270	0.036	0.003
RHDW6	-0.088	0.343	0.146	0.370	-0.032	0.332	0.426	0.118	0.443	0.304	1.000	0.657	-0.424	0.464	-0.900
RL3	0.179	0.236	0.101	0.257	0.010	0.799	-0.159	0.142	0.027	0.763	0.657	1.000	0.344	-0.171	-0.267
RL6	-0.052	-0.482	-0.423	-0.486	-0.322	0.295	-0.405	0.387	-0.172	0.270	-0.424	0.344	1.000	-0.949	0.765
RR3	0.346	0.733	0.678	0.737	0.579	0.004	0.136	-0.613	-0.085	0.036	‘0.464	-0.171	-0.949	1.000	-0.737
RR6	0.143	-0.374	-0.204	-0.396	-0.03	-0.008	-0.581	0.006	-0.486	0.003	-0.900	-0.267	0.765	-0.737	1.000

and 9 MAP and root characters like root length, root diameter, white root fresh weight and white root dry weight at 3 and 6 MAP, NUE parameters like harvest index, nutrient (K or N) harvest index, nutrient uptake ratio, tuber yield and tuber quality parameters. These were studied under the influence of genotypes and levels of K and N. Moreover, the association among these parameters too was studied by working out the correlation to understand the linkage of these parameters in affecting ultimately the tuber yield and tuber quality.

As regards to the selected six K efficient genotypes, the LAI was highest at 6 MAP both under K and N levels. Among the genotypes, W-19 had the highest on par with Aniyoor and CR 43-8 under different levels of K. Under different levels of N, CR 43-8 had the highest LAI on par with W-19. However, both K and N levels did not influence the LAI. A comparison of the LAI under K and N levels showed higher LAI under all N levels and at all the three intervals between 3 and 9 MAP. As regards to the NUE parameters of the genotypes, HI was higher under N and nutrient HI under K. Under K levels, genotype Aniyoor had higher HI and KHI and under different N levels, 6-6 had the highest HI and the genotypes *viz.,* CR 43-8 and 7 III E3-5 had the highest NHI. K uptake ratio was highest with genotype W-19 and N uptake ratio with the genotype CR 43-8. K levels produced significant effect on NUE parameters with the highest in plants without K which was on par with K @50 and 100 kg ha^{-1}. K and N levels significantly affected tuber yield with genotype CR 43-8 having the highest tuber yield both under K and N levels and was on par with genotypes Aniyoor and W-19 under K levels and W-19 and 7 Sahya 2 under N levels. Under both K and N levels, genotype Aniyoor had the lowest cyanogen content. Starch was highest with the genotype W-19 under K levels and genotype 6-6 under N levels. Though K levels did not significantly affect the tuber yield, N @ 150 kg ha^{-1} resulted in significantly the highest tuber yield. Cyanogenic glucoside (HCN) was not affected by K levels but N @150 kg ha^{-1} resulted in the lowest HCN on par with N @100 kg ha^{-1}. Starch content was not affected either by K or N levels. Root characters were not affected either by genotypes or N levels. The correlation worked out with respect to genotypes, K and N levels clearly indicated the association /linkage of all parameters especially NUE with tuber yield and tuber quality in the case of genotypes under different K levels. Similarly, the significant association of NUE with LAI and root characters was seen for the six K efficient genotypes under different N levels. Hence, these observations too contributed in delineating the genotypes *viz.,* Aniyoor and 7III E3-5 as K efficient. The genotype Aniyoor was released as the first K efficient cassava variety in 2015 by name 'Sree Pavithra'. Similarly genotypes *viz.,* W-19 and CR 43-8 were identified as N efficient.

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