AVAILABILITY INDICES OF POTASSIUM IN AN ULTISOL UNDER COLEUS CULTIVATION

By

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THESIS

submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

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DECLARATION

I, Santhosh.C (2004-11-29) hereby declare that the thesis entitled **'Availability indices of potassium in an Ultisol under coleus cultivation'** is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara
17-05-07

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CERTIFICATE

Certified that this thesis, entitled '**Availability indices of potassium in an Ultisol under coleus cultivation**' is a record of research work done independently by **Mr. Santhosh.C** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Santhosh C.

DEDICATED

TO MY

BELOVED PARENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

INTRODUCTION

Potassium is the most abundant cation in plants and is absorbed in large quantities by roots. Potassium absorbed by plants is as high as that of nitrogen for most of the field crops. However the demand for potassium is high for crops such as coconut, banana and tuber crops. It directly or indirectly influences the physiological process such as root growth, water uptake, translocation, transpiration, stomatal behaviour, starch and protein synthesis and enzyme activation. It makes the plant tolerant to drought, resistant to a number of diseases and pest attack besides its positive impact on yield and quality of produce.

Major portion of soil potassium is in fixed or non-exchangeable form and only a small fraction exists as water soluble and exchangeable form. However all these forms are in dynamic equilibrium with one another and hence there is release from non-exchangeable form when solution and exchangeable K is depleted. In the absence of adequate K supply, significant depletion of soil potassium resources occurs. In Kerala, the laterite soil coming under order the Ultisol covers nearly 60 per cent of total area occupying mid lands and mid upland regions. Early works on potassium nutrition in the state relate to the period of 1950-60 which indicated that 88 per cent of the wet land and 93 per cent of dry land of state are low in available potassium due to characteristic clay mineralogy, climatic and topographic factors, soil acidity and low organic matter content (Jose and Devi, 2000). Moreover, the laterite soils are confronted with the problems due to excess aluminium, iron and manganese, with low CEC and exchangeable bases (Seena, 2000).

Exchangeable potassium released from clay minerals and organic matter continually replenishes the potassium depleted in the soil solution and thereby ensuring adequate K nutrition to the crops in many situations. Thus, the availability of potassium to the crops is a function of factors governing the rate of K replenishment, absorption and interaction of applied K and the degree of leaching out of the system.

According to Wiklander (1954) and Scheffer *et al.* (1960) only 1-3 per cent of total K is present in the adsorbed form and the potassium in the soil solution accounts for only a small percentage of the exchangeable fractions. The solution K and exchangeable K are in a state of rapid equilibrium and hence are considered equally available. The level of soil solution K will depend on the equilibrium and kinetic reactions that occur between different forms of soil K, moisture content, and concentration of bivalent ions in solution and exchange phase (Sparks and Haung, 1985). The assessment of K availability in soil is done by using chemical extractants and by chemical kinetic reactions. However the quantity of potassium extracted varies with extractants and the type of soil. For a greater understanding of fertility status of the agricultural soils, Schofield (1947) proposed the ratio law suggesting that the intensity of K may be defined in terms of free energy of exchange between K and Ca. Accordingly, Beckett (1964b) proposed the Quantity-Intensity relationship of potassium as a feasible measure for assessing the K supplying power of the soil. The equilibrium activity ratio obtained from the Quantity-Intensity curve will give a good picture of the availability of K in soil.

Tuber crops play an important role in the maintenance of food security since they serve as starchy, secondary, staple food especially for weaker sections of the population. Potassium deserves special attention in the production of tuber crops due to very high K removal in the harvested produce. In Kerala, area and production of tuber crops according to Nair and Aiyer (1985) was 0.1 million ha and 16.4 million tonnes respectively. Coleus [*Solonostemon rotundifolius* (Poir) J.K. (Morton)] is popularly known as Chinese potato or poor man's potato. It is grown extensively in the homestead gardens of Kerala. Potassium nutrition is essential for the vegetative growth and subsequent tuber formation in coleus as in other tuber crops. Being the above facts as background, a study was conducted in the main campus of College of Horticulture, Vellanikkara with the following objectives

- To find out the effect of applied K on the growth and yield of coleus in laterite soil.
- To find out the optimum level of potassium needed for getting the potential yield of tuber crop, coleus.
- To elucidate the different forms of potassium using different chemical extractants and to assess the feasibility of different extractants as an index for determining the K supplying power of soil.
- To find out the quantity-intensity relationship with the related thermodynamic parameters of potassium availability and the nature of adsorption of potassium in soil under study.

Review of Literature

REVIEW OF LITERATURE

Potassium is a major nutrient present in most soils relatively large quantities up to about 1.9 per cent. It is absorbed by plants in large amounts than any other nutrient except nitrogen. Potassium – soil mineral relationship is of greater significance because of the fact that only a small fraction of the total K is available to the plants. Laterite soils coming under the order Ultisol cover nearly 60 per cent of the total area of Kerala state occupying mid lands and mid uplands. Available literature on the areas pertaining to the current study has been scanned and collated hereunder.

2.1. Potassium in Kerala soils

Satyanarayana and Thomas (1962) had made critical analysis of chemical properties of the coastal laterites in Kerala. They observed that soil is highly acidic, have low CEC due to high content of Kaolinite and the profiles are low in bases. The top soil and intermediate layers are rich in Fe content.

Purushothaman (1964) indicated that the potash content was low in soils containing high amount of organic matter. In soils of Kerala total K_2O content ranges from 0.04 to 0.54 per cent (Praseedom, 1970) whereas the values for many Indian soils range from 0.5 to 3 per cent (Tandon and Sekhon, 1988). The available K of soils ranges from 0.32 per cent of total K (Singh *et al.*, 1983) to 0.69 per cent of total K (Datta and Sastry, 1988).

Venugopal and Koshy (1976) in a study on mineralogy of laterite soils reported that laterite soils of Kerala are low in potassium and the total calcium content of ranged from 0.2 to 2.03 per cent, where as it has very low magnesium content (Hassan, 1977).

Iyer (1979) has reported that the laterite soil in general has a low content of available P and K. Hassan (1977) reported that in upland laterite soils the total K content varied between 0.03 and 0.44 per cent while the available K ranged from 6 to 38 ppm.

From a study on the characters of soils in the command area of Edamalayar project Krishnakumar (1991) observed that the potassium and magnesium contents in the soil are very low. Jacob (1987) in his attempt to characterize the laterite soils from different parent materials in Kerala observed that the total reserves of CaO, MgO, K_2O and P_2O_5 are low and is mainly indicating the minerology of sand fraction dominated by quartz.

Nambiar (1972) reported that the potassium content of laterite soils of Kerala and Tamil Nadu ranged from 0.04 to 0.27 per cent. Sajnanath (2000) and Seena (2000) in their attempt to make an inventory of soils of Vellanikkara campus observed that the available potassium content in the surface layers ranged from 40 to 65 ppm

2.2 Potassium nutrition in tuber crops

From a field experiment conducted at Vellayani, Trivandum, Pillai (1967) reported that tuber yield was increased linearly with K application up to 120 kg ha^{-1} in cassava. However Mohankumar *et al.* (1971) recorded significantly higher number of tubers per plant at 100 kg K_2O ha^{-1}, but better tuber size is observed at higher levels. Application of K beyond this level depressed the tuber yield though the concentration of K in the plant parts increased. Mg uptake and K is positively and significantly correlated with tuber yield of cassava (Mohankumar *et al.*, 1971). But Maglhaes *et al.* (1980) could not find any effect on root number and root weight due to K application. The role of K associated with starch synthesis leading to the promotions of tuber growth through the accelerated translocation of photosynthesis from leaves to tuber (Mukhopadhyay *et al.*, 1993). Potassium application seems to have not much influence on leaf production.

2.2.1. Uptake of potassium by tuber crops

Potassium through its role in synthesis and translocation of carbohydrates has considerable importance in the nutrition of tuber crops. Considerable variation is noticed in the uptake pattern of potassium among the tuber crops. Nair and Mohankumar (1984) found that increase in levels of lime application was instrumental in enhancing K uptake by Sweet potato. Nayar *et al.* (1986) reported that high yielding varieties of cassava absorbed higher amounts of K both under rainfed and irrigated conditions

Kabeerthumma *et al.* (1987) investigated the nutrient uptake and utilization by yam and edible aroids and reported that the K uptake was 107.42 kg for the production of 25.54 t ha^{-1} tubers in Chinese potato and in yams the uptake of K increased progressively with age of plant and the maximum utilization was noticed between 3^{rd} and 5^{th} month. In elephant foot yam maximum K utilization was between 3^{rd} and 5^{th} month and in Chinese potato the peak period of K utilization spreads over a long period, i.e., between 60-120 days after planting.

Nayar and Sadanandan (1992) evaluated the nutrient uptake pattern of cassava intercropped with coconut and reported that the peak demand was at the tuber enlargement phase.

Sreelatha *et al.* (1999) conducted a study on fertilizer recommendation based on soil tests for targeted yield of sweet potato and concluded that for the production of one ton of Sweet potato tubers, 11 kg K_2O is required.

2.2.2. Effect on growth parameters

Ashokan and Sreedharan (1977) recorded the yield increase up to 135 kg K_2O ha^{-1} for the variety H-97 of cassava. Nair (1982) observed an improvement in plant height, stem girth, leaf retention due to higher rates of potassium application in cassava. Ashokan *et al.* (1984) found 60 kg K_2O ha^{-1} as the economic dose for the rainfed sweet potato grown in Trichur tract. Ashokan and Nair (1984) recorded positive response on yield components and yield up to 80 kg ha^{-1} in cassava at Vellanikkara, Thrissur.

Nair and Aiyer (1985) in cassava reported that, though the maximum number of tubers per plant was recorded at 100 kg K_2O ha^{-1} greater size was obtained at 150 kg K_2O ha^{-1}. They also observed the improvement in starch content and quality parameters of starch, viz., amylase content, granule size, viscosity, swelling volume with increase in rates of K application.

Ramanujam and Indira (1987) in their study on the effect of K on yield attributes in cassava observed that the plants that received no potassium were stunted, further increase in plant height, number of leaves produced per plant, accumulation of biomass per plant and crop growth rate was recorded with increase in levels of K_2O up to 200 kg ha^{-1}. Nair and Sadanandan (1987) studied the response to 3 levels of potassium viz., 50. 125, 200 kg K_2O ha^{-1} in red loam soils and recorded yield increase up to highest level of potash application. It has been observed by Oommen (1989) that higher levels of potassium had positive effect on leaf area index, net assimilation rate and crop growth rate recorded at different stages of growth.

Mohankumar and Sadanandan (1989) in study on growth and dry matter accumulation in taro as influenced by the NPK nutrition observed that application of 100 kg K_2O ha^{-1} had significant positive effect on plant height and LAI. In potato dry matter was higher at 75 DAP than at 100 DAP and at maturity, possibly due to complete senescence of plants in the latter case. The same trend was observed for the concentrations and K uptake by shoots. The correlation between K uptake by shoot at 75 DAP and tuber yields at 75 and 100 DAP were found to be significant (Sud and Grewal, 1991).

In contrast with the trend obtained with the shoot, the potato tubers registered considerably higher dry matter, K concentration and K uptake at 100 DAP than at 75 DAP. This may be attributed to the translocation of shoot K to the tuber (Sud and Grewal, 1991).

Nair and Nair (1992) investigated the effect of three levels of (50, 75 and 100 kg K_2O ha^{-1}) potassium on sweet potato and reported that the variations in levels of K had no significant influence on yield components and yield of sweet potato.

2.2.3. Nutrient interaction in tuber crops

Uptake of nutrient particularly cation is seriously influenced by K fertilization. Thus K has been shown to affect the absorption, translocation and distribution of other cations Wild *et al.* (1969), Tiwari *et al.* (1971) and Dijkshoom *et al.* (1974) reported that the uptake of potassium by plant is a function of potassium concentration in soil solution as well as its interrelationship with the uptake of Ca and Mg.

The relationship between K in solid phase and in solution phase of soil plays a key role in determining the ability of soil to supply potassium to plants, which in turn, is influenced by relative abundance of other cations, type and quantity of clay minerals present in soil (Nemeth *et al.*, 1970; Acquaye, 1973).

Devi and Padmaja (1999) reported that in cassava when K content increases with application of K, there is a decrease in the N and P content and the absorption of Ca and Mg in full K treatment was lesser than the other treatments during most of stages and was attributed to the antagonism between K and Ca as well as K and Mg.

Bhandyopadhyay and Goswami (1985), Blanchar and Hosner (1968) and Addiscott (1974) observed that application of Ca and/or magnesium increased the concentration of K^+ in soil solutions. Such a phenomenon is primarily due to replacement of K^+ by Ca^{2+} and/or Mg^{2+} at exchange site, which is also evident from the decreasing tendency of exchangeable K in soil due to application of Ca^{2+} and or Mg^{2+}.

Bhandyopadhyay and Goswami (1988) in a study on dynamics of K with added doses in laterite, alluvial and black soils found that potassium concentration in plant generally increases with added doses of potassium, K concentration in plant was highest in black soils and the lowest in laterite soil although K concentration in soil solution was higher in laterite than the other soils.

2.2.3.1. N and K interactions

Interruptions or inhibitions of nitrate uptake controlled by K^+ results on decreased dry matter production. An adequate supply of K constitutes the key for the efficient utilization of N fertilizers as well as for the operations of photosynthetic system at an optimal ratio (Wicke, 1968). Thus K addition increased the nitrogen uptake by plants (Gupta *et al.*, 1971; Muthuswamy *et al.*, 1974; Menon and Marykutty, 1993). The positive effect of K on the absorption of N may be attributed to the ability of K to reduce fixation of NH_4^+ ions in soil.

In some cases, increased K supply decreased N uptake (Garita and Jarmillo, 1984; Sindhu, 1997). Added K sometime showed no effect on N uptake (Sheela and Aravindakshan, 1990).

2.2.3.2. Potassium and Phosphorous

Increasing concentrations of applied K increased P uptake by plant (Muthuswamy *et al.*, 1974; De Datta and Gomez, 1982; Sindhu, 1997; Sheela and Aravindhakshan, 1990) while a decrease on P uptake by K application was observed by Fageria (1983). Wicke (1968) observed that added K did not affect P uptake.

2.2.3.4. Potassium and Calcium

Increased K supply decreased the uptake of Ca (Harison and Bergman, 1981 and Sindhu, 1997). Absorption of K is stimulated by Ca ions at low concentration and decreased at high concentrations (Fageria, 1983 and Sudhir *et al.*, 1987). While little effect of Ca : Mg on K uptake was reported by Salmon (1964). Antagonistic interaction between K and Ca were also reported by Barber (1986) and Menon and Marykutty (1993).

2.2.3.5. Potassium and Magnesium

Heavy dressing of K decreased the K uptake of Mg (Pushpadas *et al.*, 1976; Wicke, 1968). Since increasing K fertilizers highly significantly decreased the total Mg content of plants and since exchangeable Mg in soil increased the plant Mg content, maintaining a reasonable level of exchangeable soil Mg can affect to some extent the adverse effects of high fertilizer K application on plant Mg concentration (Mc Intosh *et al.*, 1973).

Generally there is decrease in potassium uptake with increase in magnesium concentration. Thus high Mg in solution decreases the concentrations and rate of uptake of K (Landua *et al.*, 1973; Muralidharan, 1992). Increased K supply in soils reduced the supply Mg and uptake by crops.

In some cases, magnesium had no effect on the uptake of K (Subrahmanian *et al.*, 1976, Perumal, 1972). The synergistic effect of magnesium on potassium is mainly on solution concentration rather than uptake, which is dependant on the magnitude of yield (Anathanarayana and Rao, 1979). Synergistic interaction between K and Mg was observed by many workers (Narwal *et al.*, 1985; Sudhir *et al.*, 1987). While lack of response to added K on availability of Mg was reported by Jayaraman (1988) and Menon and Marykutty (1993). Increase in K in tissue with increasing Mg in solution is because of the decreased dry matter production associated with high magnesium in solution. A reduction is magnesium uptake at higher concentration of calcium occurs due to antagonism (Fageria, 1983) and Martin and Page (1965) noticed little evidence of strong Ca-Mg or Mg-Ca antagonism.

2.3. Forms of Potassium and plant availability

Gholston and Hooner (1948) stated that non-exchangeable K should also be considered in assessing the K supplying power of the soil since more than 50 per cent of the K removed by intensive cropping was in non-exchangeable form. Fox and Karcar (1965) reported that non exchangeable K also serves as a source of plant available K.

Thomas (1967).had reported that eleven years of cropping did not deplete the exchangeable K and so also heavy K fertilization did not increase the exchangeable K very much.

Nemeth (1978) reported that for making accurate fertilizer K recommendations in soils intensively cropped over long periods, both exchangeable K and K release from non-exchangeable sources should be taken into consideration

Tabatabai and Hanway (1969) and Krishnakumari *et al* (1984).reported that once the exchangeable K has been removed to some critical level unique for that soil, further growth and uptake of K by the crop may be regulated by the rate of release of non-exchangeable K. Application of higher levels of K increased the concentration of K^+ in soil solution in the soils, more so in case of the laterite soils. (Nemeth *et al,* 1970; Bhandyopadhyay and Goswami 1988).

Nambiar (1972) observed that the values of water soluble K, available K and citric acid soluble K ranged from 0.028 to 0.248, 0.166 to 0.969 and 0.440 to 2.041 Cmol (P^+) kg^{-1} respectively in laterite soils of Kerala and Tamil Nadu.. The labile K is much smaller than exchangeable K indicating that only a smaller fraction of latter is readily replaceable with other cations or available to the plant. (Ghosh and Ghosh , 1976; Ram and Prasad , 1981).

Ramanathan (1978) reported that 1N nitric acid was most suitable extractant for predicting K uptake by plants from soil groups of South India. The correlation coefficient between laboratory estimate of K and K uptake by Neubauer crops were in the order 1N HNO_3 > Non exch. K > 1N NH_4OAC > 0.5 N HCl > 0.01M $CaCl_2$ > water soluble and 0.5 N HCl was the best extractants for K availability. The correlation coefficients obtained between laboratory estimation of K and K uptake by the Neubauer technique were followed the order of 1N NH_4OAC > 0.01 M $CaCl_2$ > 0.5N HCl > water > 6N H_2SO_4 > Morgan's reagent > 9N HNO_3.

Mengel and Wiechens (1979) and Datta and Sastry (1987) reported that non-liable fraction may contribute a significant portion to total K uptake by crop in K depleted soil. Feigenbaum *et al.* (1981) reported that rate of non-exchangeable K release and its mechanism is controlled by nature and amount of clay minerals. Nagarajan (1981) reported that Ammonium acetate, 0.1 N HNO_3 and 0.1 N H_2SO_4 were found to be closely related to uptake whereas ammonium acetate K alone correlated significantly with grain yield.

Singh and Ghosh (1982) observed highly significant correlation of ammonium acetate K with plant K. Ram and Prasad (1983) and Singh and Singh (1992) reported that boiling 1N HNO_3 soluble K recorded the highest value among all the extractants because in addition to exchangeable K some of the non exchangeable K is brought into solution. Rose and Cline (1984) indicated that the amounts of exchangeable K extracted with $BaCl_2$or NaCl were relatively high but were not correlated with K

Bhandyopadhyay and Goswami (1985) in an attempt of characterization of soil K and Q-I relationship of K in some coastal soils observed that all soils registered high content of exchangeable and water soluble K. The ratio between exchangeable K and water soluble K varied between 2.3 to 8.5, the high ratio indicated comparatively stronger bonding energy of K with soil colloids. The ratio between non-exchangeable/exchangeable K in soil remained within a narrow range which varied between 10.3 and 19.9 in case of soils from West Bengal

Chandraprakash and Singh (1985) reported that water soluble K had a significant and positive correlation with exchangeable K, indicating thereby replenishment of water soluble K by exchangeable K that had also significant correlation with fixed, HCl soluble and total K.

Halvin and Westfall (1985) reported that the release of non-exchangeable K was significantly correlated with cumulative K uptake and yield. Husain *et al.* (1986) studied the plant response to K, relation to soil test for K fixation in 30 soils of Lovisiana. They found that there was a high degree of relationship between plant uptake of K and exchangeable K in that soils.

Singh *et al.* (1986) in a study on transformation of applied potassium in relation to it's availability in calcareous soil concluded that the largest fraction of applied K was transformed to non-exchangeable form followed by exchangeable and water soluble form.

Soil solution K, an immediate source of K for plants and micro-organisms, plays a key role in K nutrition of crop plants. In illitic and kaolinitic soils, solution K is a function of EPP (exchangeable potassium percentage). (Brar *et al.*, 1986; Rao and Sekhon, 1990).

Studies conducted by Ravikumar *et al.* (1987) on the forms of potassium in soils of Haryana revealed that the water soluble, exchangeable, HNO_3 soluble and HCl soluble were 6 to 70 ppm, 25 to 528 ppm, 220 to 1170 ppm and 1480 to 3960 ppm respectively. Water soluble K was significantly and positively correlated with exchangeable and available forms of K in Vellayani series (Devi *et al.*, 1990).

It has been argued by Datta and Sastry (1988) that a constant value of total K (solution K plus exchangeable K) extracted for each soil : solution ratio would be expected during desorption, based on the assumption that no K had been released from the non exchangeable form. They also reported that the initial K uptake by plant is solely from exchangeable sources, but once the critical depletion stage had reached, uptake of K is mainly from non exchangeable fraction

Datta and Sastry (1989) in a study on the contribution of different forms of potassium to plant nutrition established a significant contribution of intermediate K towards crop uptake in K depleted soils.

Mercykutty *et al.* (1990) reported that water soluble exchangeable and available K were significantly correlated with fixed K in rubber growing soils of South India. They observed a positive correlation between clay content and total K and also a positive correlation of organic carbon with water soluble, exchangeable, fixed and available K.

Patiaram and Prasad (1991) established a close relationship between K uptake and non exchangeable K by crops under exhaustive cropping. A fraction of this non exchangeable K known as the 'intermediate K' gets released when soil solution K reaches a critical value known as threshold concentration. The K status and K buffering power of the soil are two contributing factors affecting K desorption in soil solution.

Perumal *et. al.* (1991) in a study on different fractions of potassium with sorghum as a test crop reported that the most important form which had influenced prominently the yield was water soluble K followed by Ex-K (exchangeable) and NE-K (non exchangeable). It is also observed that WS-K (water soluble) and Ex-K were closely related to uptake similar finding was also reported by Ekpete (1972).

Rao and Sekhon (1991) reported a positive correlation between Exchangeable potassium percentage and water soluble K in five soil series from vertisols and vertic ustochrepts belt of India. High order of correlation coefficients were obtained between EPP and water soluble K as compared with those between EPP and saturation.

Sutar *et al.* (1992) studied the forms of K in laterite soils of Maharashtra. The values of water soluble, exchangeable, non exchangeable and total K ranged from 6 to 30, 13 to 23, 76.4 to 374.4 and 2975 to 3256 ppm respectively. Available K measured as water soluble and exchangeable K was higher in lateritic soils (Basumatary and Bordoloi, 1992). Chakravorti (1992) reported that K addition increased the retained K in all Ultisols, Alfisols and Vertisols and the potassium retention power did not change much in most of the cases due to exhaustive cropping.

Kumari and Aiyer (1993) evaluated suitable soil testing methods for available K in the lateritic or red loam soils of Kerala. They reported that neutral normal ammonium acetate, 0.01M $CaCl_2$. Rao *et al.* (1993) and Rao *et al.* (2001) reported that non-exchangeable K is released when the level of solution and exchangeable K are depleted by plant uptake and leaching.

Studies on the forms of K in relation to land form and soil properties of Basaltic terrain revealed that water soluble K was not related to other forms of K. Water soluble K was maximum at the surface which constitute about 1.8 to 17.4 per cent of available K. Exchangeable K accounts for 80 to 98.2 per cent of available (Das *et al.*, 1993).

Rao *et al.* (1993) studied on the non exchangeable K reserves and classified kaolinite dominated soils as low in non exchangeable reserve, and illitic as high K reserve soils. Lateritic and non lateritic soils of the humid region were comparatively low in available potassium. K supply capacity ranged from 98.4 to 310.6 and 136 to 294.7 ppm for lateritic and medium black soils respectively (Patil *et al.*, 1993).

Venketesh and Satyanarayana (1994) in a study on status and distribution of K in Vertisols of North Karnataka reported that among all the forms of potassium, water soluble K constituted lowest of total K. Jyothikumari (1996) reported that 1N NH_4OAC - K, Mathews extractant - K, 0.01 M $CaCl_2$ - K and 1N HNO_3 - K gave significant positive correlation with K uptake by rice as test crop and the highest correlation was obtained with NH_4OAC – K. NH_4OAC – extracted higher amount of potassium from the soils compared to Mathews extractant and 0.01 M $CaCl_2$.

Choudhari and Sanyal (1999) reported that non-exchangeable K content followed the trend Inceptisol > Mollisol > Entisol > Alfisol, meaning that during stress condition, Inceptisol is expected to release K from its non-exchangeable reserve compared to other three and concluded that these soils had an exchangeable K ranging between 624 and 397.8 mg kg^{-1}, all soils in general contained higher amounts of exchangeable K in surface horizons and it decreased with depth. Release of K from organic residues and application of K fertilizer might have the reasons for more amount of exchangeable K in the surface horizons.

2.4. Availability indices of potassium

The amount of nutrient present in the soil solution and change in the concentration that occurs during crop growth should be known for a good interpretation of plant nutrient requirement. Weak extractants remove K only from soil solution while stronger extractants extract large quantities including those from unavailable sources. The correlation between K uptake of plants and K test value is therefore unsatisfactory.

2.4.1. Evaluation of extractants

Tiwari *et al.* (1967) reported that AA-K (Ammonium acetate K) showed highly significant relationship with WS-K which was closely followed by Ex-K. It is evident that WS-K and Ex-K significantly and positively contributed towards the available-K in soil, irrespective of the method of estimation.

Negi *et al.* (1979) observed that potassium soluble in HCl is significantly correlated with fixed K, but not significantly with NH_4OAC. On the contrary, strong as well as weak correlation of exchangeable K with non exchangeable K has been reported by Devi and Aiyer (1974).

Water soluble and dilute $CaCl_2$ extractable K was poorly related to yield and K uptake by pearlmillete (Ramanathan and Krishnamoorthy, 1981). In a comparative study with six extractants Swami and Lal (1970) reported that extraction ability decreases in the order of 1N HNO_3, 1N NH_4OAC, 1.38 N H_2SO_4, 2 per cent acetic acid, Morgan's extractant and water.

In a study on the K extracting efficiency of different methods by estimating the K uptake by ragi seedlings, Nambiar (1972) had ranked those methods as to their suitability for extraction of K in the following order of 1N HNO_3, 6N H_2SO_4, 0.5 N HNO_3 with heating, 1.38 N H_2SO_4, neutral Normal NH_4OAC, 0.5 N HNO_3, with shaking, 1 per cent citric acid, 1 per cent ammonium carbonate, 43.65 per cent sodium acetate and 15 per cent HNO_3.

Ahmed *et al.* (1973) reported that NH_4 OAC and cold H_2SO_4 gave the best estimate of available K and were least influenced by change in the soil properties. The acetic acid extract in general was least effective. Havley (1977) opined that the extraction with $CaCl_2$ solution (0.01 N) would be better method for estimation of available K since it reflected change in free energy and was easy to operate.

Based on a study on the availability indices potassium in the soils of south India, Ramanathan (1978) reported that Normal nitric acid has been found to be most suitable extractant for predicting the K uptake by plants. He arranged the extractant according to their suitability for predicting K available in the order of N HNO_3, non exchangeable K, 1 N NH_4 OAC, 0.5 N HCl, 6N H_2SO_4, 0.01 $CaCl_2$ and water soluble. Grewal and Sharma (1980) reported that soil K extracted with neutral N NH_4OAC or Morgan's extractant was highly correlated with yield and K uptake of potato in acidic brown hill soils of similar region.

Chatterjee and Maji (1984) showed that 0.1 N cold H_2SO_4 and 0.05 M sodium tetraphenayl boron gave high positive significant correlation with dry matter yield of barley. Boiling of 1N HNO_3 extracted more K than other extractants and was found to give no correlations with dry matter production.

Chandraprakash and Singh (1985) in a study on different forms of potassium in alluvial soils of Western Uttar Pradesh found that the values of HCl soluble varied from 2125 to 6625 with mean values of 4181 ppm and it constituted 32.1 per cent of total K. Soils rich in total K possessed abundant quantities of HCl soluble K.

Singh *et al.* (1986) in a study on availability and Q/I relationship of K in some soil series of Hissar reported that the quantity of K extracted from soil by various reagents varied considerably and were significantly correlated among themselves indicating that all these reagents extract K from some group or pools in soil.

Krishnakumari and Khera (1989) in a study on relative efficacy of soil test methods for potassium to measure changes in K status due to uptake in micaceous soils concluded that, efficacy of extractants in this investigation was in the decreasing order of 1 N boiling HNO_3 > Neutral Normal NH_4OAC > Morgan's reagent > 0.01 M $CaCl_2$.

Mongia *et al* (2000) in a study on different forms of potassium in the acidic hill soils of Andamans reported that values of NH_4OAC. K-ranged between 25 and 125 ppm with an average of 66.11 ppm and the values of HNO_3-K ranged between 0.06 and 0.36 per cent with a mean of 0.173 per cent. They also reported that the fixed

K content of the soils varies between 0.02 and 0.18 per cent with an average of 0.06 per cent. This form of K showed almost a similar nature and degree of association with the soil properties as observed in case the of HNO_3 soluble K.

2.4.2. Quantity – Intensity relationship of potassium in soil

Quantity/intensity (Q/I) parameters proposed by Beckett (1964b) have been employed by several workers (Ganeshmurthy and Biswas, 1984; Patra and Khera, 1983; Rao *et al.,* 1984) for describing potassium status of soils in relation to fertilization and K utilization by crops.

Beckett (1964a, b) suggested that the equilibrium activity ratio, $aK/a(Ca+Mg)^{1/2}$ in the soil solution can be used as a measure of K availability. The classical Q/I curves are obtained from these findings and are related to the exchangeable K to obtain the effect of quantity on intensity (Sparks and Liebhardt, 1981).

Woodruff (1955) reported that the free energy change (ΔF) calculated from $AR^{K}o$. $\Delta F = -RT \ln AR^{K}o$ was found to vary between -3.50 and -3.93 K/Cal mol^{-1} and values were higher than the critical value of -4.00 K Cal mol^{-1}. The free energy of exchange, ΔFK, was enhanced markedly with rise in K level in laterite soil however in alluvial and black soils the rate of increase was not so high.

Beckett and Nafady (1967) reported that in K depleted soil, K is associated mainly with edge and interlayer sites and those are desorbed in solution only when the activity ratio or concentration of K is appreciably lowered. This desorption follows a steeper buffering curve in Q/I relationship.

Beckett and Nafady (1968) reported that the linear lower part in the Q/I curves indicate small release of K with drop in AR_eK. AR_oK was not related with any of the soil parameters. None of the soil attributes has significant influence on AR_oK. Correlation of AR_oK with available forms of K are also not significant.

Zandstra and Mackenzie (1968), Beckett and Nafady (1967) reported that the Potential buffering capacity of potassium (PBC^K) was more or less directly related to CEC. PBC^K values vary from 26.66 to 73.07 meg/100 ml. These PBC^K values were related with labile K.

Nemeth *et al.* (1970) reported that Kaolinite being a mineral with a low CEC value - intensity factor may play a more important role as compared to soils with high CEC. Kinetics of K desorption in heterogenous soil systems was shown to conform to first order kinetics and to the parabolic diffusion law (Sivasubrahmanian and Talibudeen (1972).

Continuous application of NPK fertilizers in different combinations under intensive cropping systems has been proved to have variable effects on quantity-intensity parameters.(Patra and Khera, 1983; Ganeshmurthy and Biswas, 1984; Singh *et al.* 1984)

Jardine and Sparks (1984) in a study on the kinetics of exchage pf potassium reported that there is a rapid kinetics of exchange as external planar sites, slow kinetics of exchange on interlattice exchange sites and intermediate kinetics of exchange on interlattice edge sites

Bhandyopadhyay and Goswami (1985) in a study on potassium activity ratio and potassium uptake in three major soils of India found that PBC^K values for alluvial, laterite and black soils are 10.71, 6.89, 38.36 meq/100 g soil $ML^{1/2}$. The respective figures of AR^oK for these soils were found to be 5×10^{-3}, 12.5×10^{-3} and 2.35×10^{-3} $ML^{1/2}$ respectively. Moss and Hondnett (1963) observed that potassium activity ratio of soils was more influenced by the application of K than of Ca and Mg.

Sailakshmiswari *et al.* (1986) on their study on Q/I parameters of potassium in texturally different alluvial soils observed that labile K constituted 29.6 to 48.7 per cent of exchangeable K in different soils indicating that a part of exchangeable K is not subjected to ion-exchange equilibrium described by Q/I relations (Ghosh and Ghosh, 1976; Rao *et al.*, 1984).

Bhandyopadhyay and Goswami (1985) in an attempt to characterize soil K and Q-I relationship of K in some coastal soils observed that potassium buffering capacity was higher because of higher content of exchangeable and non-exchangeable K which were in equilibrium with the intensity factor.

Bhandyopadhyay and Goswami (1988) reported that among laterite, alluvial and black soils, laterite soil had the highest concentration of K in soil solution and the black soil the lowest, while the forms had the lowest concentration of K in exchange phase and the latter the highest.

Singh *et al* (1984) observed higher K intensity with greater amount of added K under mango orchards cropping system of bajra-wheat sequence. Biswas *et al.* (1989) concluded that a balanced fertilization practice with due consideration on the contribution of non-exchangeable K is extremely warranted in order to check any untoward shift in Q/I relation related to K supply.

Swarup and Singh (1989) in a study conducted in sodic soil cropped with rice and wheat continuously for twelve years, concluded that in plots not treated with K, the Q/I curves were continuous but with greater curvature at low activity ratios. At High AR_0K value, the isotherms were approximately linear, whereas at lower values the slope changed.

Noor *et al.* (1993) reported that none of the soil attributes had significant influence on available K. The values of AR_0K in the study were well above minimum AR_0K $(5x10^{-4}$ mol/L$)^{1/2}$ at which crop might respond to K application.

Das *et al.* (1993) in a study on Q/I relationship of K in Balisahi soil series of Orissa found that equilibrium K activity ratio $AR^{o}_{e}K$ is positively correlated with exchangeable K/exchangeable Ca+Mg ratio indicating that soils with high exchangeable K/exchangeable Ca + Mg are able to maintain high K intensity in soil solution.

Bele *et al.* (1994) in a study on Q-I relationship of K in representative soils of Western-Maharastra reported higher values of AR_o^K in the surface layers than at deeper layers whereas the PBC^K values increased with depth.

Choudhari and Sanyal (1999) in a study on the distribution of various forms of K, a lighter soil was found to release K at a faster rate in to the soil solution leading to the higher apparent coefficient than heavier soils. The PBC^K values showed the trend Inceptisol > Entisol > Mollisol > Alfisol suggesting that the Inceptisol would be able to maintain the equilibrium activity ratio (AR^K) of the soil solution K during the times of depletions.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Availability indices of potassium in an Ultisol under coleus cultivation" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University during 2005-06. The experimental site in the main campus was located at 10°31' N latitude and 76°3' N longitude at an attitude of 25 m above mean sea level. The area was left uncropped for several years, Previous to which it was under rubber cultivation. The experimental area has a typical humid tropical climate with an annual rainfall of 266.3cm. The maximum and minimum mean monthly temperatures during the cropping period were 32.8 and 19.3^{0}C respectively.

The materials used and methodology adopted for the study is described in this chapter. Before starting the experiment, surface soil samples were collected and analysed for the basic physico-chemical characteristics and the data is presented in Table 1 .

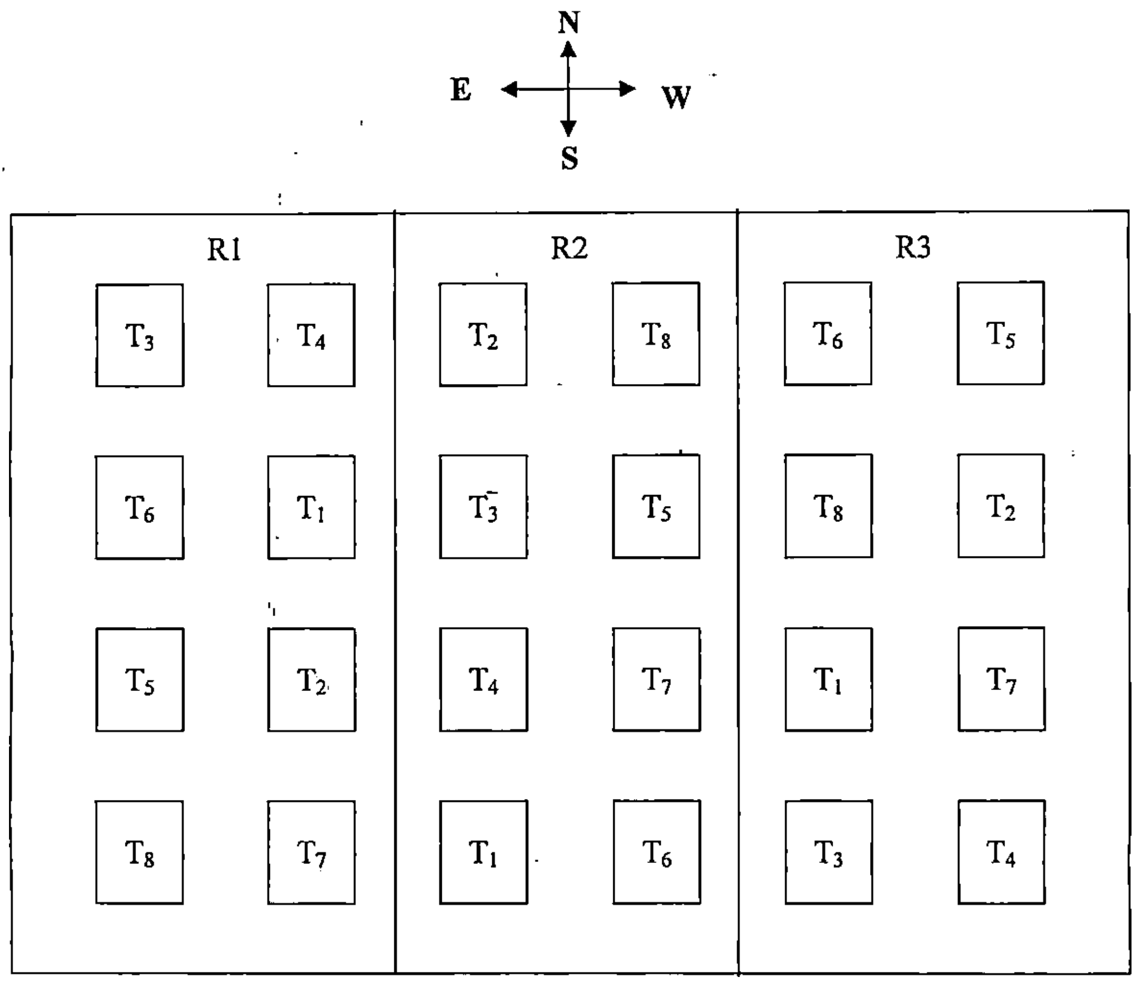
The soil type of the experimental site is laterite which comes under Ultisol belonging to great group Kanhaplustult in Vellanikkara series II. The soil is sandy loam in texture. It was acidic with a pH of 5.3 and an electrical conductivity of 0.46 ds m^{-1}.

The experiment was conducted during the cropping season of 2004 from August to November. The field experiment was laid out in a randomised block design with eight levels of potassium viz., 0 (T_1), 20 (T_2), 40 (T_3), 60 (T_4), 80 (T_5), 100 (T_6), 120 (T_7) and 140 (T_8) kg K_2O ha^{-1} in three replications. The layout of the plot is given in Fig 1. The gross plot area was 7.5 cents with a net plot area of 5.25 cents.

3.1. Field culture

The field was ploughed and harrowed with a tractor and stubbles were removed. The beds of size $4m^2$ were taken. Nitrogenous and phosphatic fertilizers were applied uniformly in all treatments @ 60 and 50 kg ha^{-1} as per Package of Practices Recommendations-Crops (2002) of KAU. Full dose of P and half dose of N

Fig. 1. Layout of the plot



General view of the field

General view of the field

and K were applied as basal. The vine cuttings of coleus variety, Nidhi were planted in September on raised beds with a spacing of 30 x 15 cm.

The gap filling was done within two weeks after planting and weeding was done frequently. Top dressing was done after 45 days of planting. The plots were irrigated immediately after planting and thereafter on a need based manner. Necessary plant protection measures were also under taken during the cropping period. The crop was harvested in December 2005. The tubers were separated on the same day and yield was recorded on fresh and dry basis.

3.1.1. Biometric observations

The following biometric observations on the yield contributing characters such as plant height, tuber yield, number of tubers per plant and tuber girth were recorded during the cropping period.

3.1.1.1. Plant height

The length of shoot was measured at 60 DAP and 100 DAP as the height from ground level to the tip of the top most leaf. The average of five plants was computed and expressed in cm.

3.1.1.2. Days to flowering

The number of days taken from planting till the appearance of first flower opening was recorded as the days to flowering.

3.1.1.3. Days to tuberisation

The number of days taken from planting to the appearance of first tuber was recorded as the days to tuberisation.

3.1.1.4. Tubers per plant

The average number of tubers obtained from the three selected plants was recorded as number of tubers per plant at 60 DAP, 100 DAP and at harvest

3.1.1.5. Girth of tubers

The tuber girth was recorded for the tubers obtained at three stages viz 60 DAP, 100 DAP and at harvest as the average of three tubers selected from each treatment and expressed in centimeters. The length was measured using a cord and a meter scale.

3.1.1.6. Tuber yield per plant

It was recorded for the three stages viz 60 DAP, 100 DAP and at harvest from three randomly selected plants.

3.1.2. Soil analysis

Soil sample collected from the experimental site before laying out the experiment was analysed for electrochemical properties like soil pH and electrical conductivity (Jackson, 1973), organic carbon (Walkley and Black,1934) and particle size analysis by Robinson's international pipette method (Piper, 1966). The following chemical constituents of the soil were analysed as per the standard procedures.

3.1.2.1. Available nitrogen

Available nitrogen in the soil was determined by the alkaline permanganate method proposed by Subbaiah and Asija (1956).

3.1.2.2. Available phosphorus

Available P in the soil samples was determined by extracting with Bray No.1 reagent (Bray and Kurtz, 1945) and estimating colorimetrically by ascorbic acid blue colour method using 'Spectronic-20' (Watanabe and Olsen, 1965).

3.1.2.3. Available potassium

Available K was extracted with neutral-Normal ammonium acetate solution. Potassium content in the extract were determined by flame photometry using ELICO flame photometer (Jackson, 1973).

3.1.2.4. Available Calcium and Magnesium

Available Ca and Mg were determined from the above said ammonium acetate extract using versenate titration method (Jackson, 1973).

3.1.2.5. Cation exchange capacity

The cation exchange capacity was estimated by the method proposed by Hendershot and Duquette (1986). The exchangeable cations (Ca, Mg, Na, K, Al, Fe and Mn) present in exchange sites in soil were replaced by 0.1 M $BaCl_2$ solution and then extracted cations were estimated and expressed in cmol (+) kg^{-1}

3.1.2.6. Available Iron and Manganeese

Iron and manganese in soil were extracted using 0.1 M HCl (Sims and Johnson, 1991). Four grams of soil with 40 ml of 0.1 M HCl was shaken for 5 minutes. It was filtered through Whatman No.1 filter paper and in the filtrate Fe and Mn were determined using an Atomic Absorption spectrophotometer (Perkin Elmer. AAnalyst 400)

Table 1. Physico-chemical properties of soil

Parameter	Value
pH (1:2.5)	5.3
EC (ds m^{-1})	0.48
Sand (%)	46.4
Silt (%)	21.20
Clay (%)	32.40
Particle density (Mg m^{-3})	2.64
Bulk density (Mg m^{-3})	1.34
Porosity (%)	38.3
Percentage base saturation (%)	56.3
Cation exchange capacity (cmol(+) Kg^{-1})	4.8
Organic carbon (%)	1.1
Available nitrogen (kg ha^{-1})	328
Available phosphorus (kg ha^{-1})	35.80
Available potassium (kg ha^{-1})	336
Exchangeable calcium (mg kg^{-1})	305
Exchangeable magnesium (mg kg^{-1})	30
Exchangeable manganese (mg kg^{-1})	99
Exchangeable iron (mg kg^{-1})	20.5
Exchangeable aluminium (mg kg^{-1})	55
Total nitrogen content (%)	0.09
Total phosphorous (%)	0.116
Total potassium (%)	0.32

3.1.2.7. Extractable / Exchangeable Aluminium

Extractable/exchangeable aluminium was determined from the 0.1 M $BaCl_2$ extract prepared as described in 3.1.2.5. Exactly 2 ml of extract was taken in a 25 ml of volumetric flask and the pH was corrected between 2 and 3 using HCl. The volume was then made up to 5 ml. Then 1 ml ascorbic acid was added to it and was heated for ½ hr at 80°C. The solution was then cooled, approximately 1-2 ml of distilled water and 5 ml of aluminium acetate buffer were added for colour development. After 2 hours reading was taken in Systronics at 530 nm (Barnishel and Bertsch, 1982).

3.1.3. Analysis of plant and tuber

Standard procedures referred below were employed to estimate nutrient content of plant and tubers.

Table 2. Methods of analysis of plant parts and tuber.

Sl. No.	Element	Method
1	Nitrogen	Modified Kjeldhal's digestion method (Jackson, 1973)
2	Phosphorous	Vanabdomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3	Potassium	Flame photometry determination (Jackson, 1973)
4	Calcium and magnesium	Versenate titration method (Jackson, 1973)
5	Iron and manganese	Diacid digestion of leaf sample followed by filtration. The filtrate was collected, analysed for Fe, Mn using Perkin-Elmer AAS (Piper, 1966)
6	Aluminium	Aluminon method (Hsu, 1963; Jayman and Sivasubrahmaniam, 1974)

3.1.4. Potassium supplying power of soil

The potassium supplying power of the soil was determined by two ways.

3.1.4.1. Conventional chemical methods

The potassium content of the soil was extracted using different extractants *viz* neutral normal Ammonium acetate (Hanway and Heidal, 1952), modified Morgan's reagent (Blenchet and Peuguad, 1960), Morgan's reagent (Morgan, 1941), 1 N boiling nitric acid (Wood and De Turk, 1941), water (Garley *et al*, 1960), 0.5 M HCl (Piper, 1966) 6N cold suphuric acid (Hunter and Pratt, 1957), 0.01M $CaCl_2$ (Woodruff and Mc Intosch, 1960), and the potassium was estimated using the flame photometer.

3.1.4.2. Q-I relationship

The Quantity-Intensity parameters such as activity ratio (AR_0K) and potential buffering capacity (PBC^K) of soil potassium were measured at two temperatures 25°C and 40^0C following procedures given by Beckett (1964a). Soil samples were equilibrated with 0, 5, 10, 20, 40, 60, 80 and 100 mg L^{-1} of K in 0.01 M $CaCl_2$. Five grams of soil sample was shaken for an hour with 50 ml equilibrating solution, kept overnight at two temperatures 25°C and 40°C. K and Na were determined by flame photometer. Ca, Mg, Fe and Mn by AAS and Al by colorimetry. The activity ratio of K in solution was calculated using the formula

$\mathbf{AR^K = aK / a\,(Ca + Mg)^{1/2}}$ where a = activity in mols L^{-1}

It was also calculated by considering the relative influence of other ions viz. Mn and Al as referred by Seena (2000). The loss or gain of K ($\Delta \pm$ K) in the equilibrated sample was obtained from the difference between the K concenration.of initial and final solutions. The amount of K gained or lost was plotted against activity ratio. The intercept of Q/I curve on the AR^K axis where ΔK_0 gave the soil potassium activity ratio at equilibrium AR^K Specific K (K_0) value was obtained by drawing a tangent from the point on the Q/I curve where $AR_e^K = 0$.

The potential buffering capacity (PBC^K) was determined by dividing labile K (K_L) by AR_e^K. The free energy of K replenishment (ΔF in Calories) was calculated from the following equation.

$-\Delta F = 4.19\ RT\ In\ AR_e^K$. (Woodruff, 1955).

STASTICAL ANALYSIS

The results of various parameters obtained from the experiment were analysed statistically for the test of significance by standard procedures using **MSTATC** package. The correlations between different parameters were also worked out.

4. RESULTS

An experiment was conducted in the Department of Soil Science and Agricultural Chemistry College of Horticulture, Vellanikkara to study the availability indices of potassium in an Ultisol under coleus cultvation. The salient results of the study are presented in this chapter.

4.1. Biometric observations

4.1.1. Plant height

The data on the plant height recorded at the different stages of plant growth viz. 60 DAP and 100 DAP is presented in Table 3. At 60 DAP the height was higher at T_7 and lower at T_3. There was no regular linearity in this parameter with respect to the increased levels of potassium. At the second stage of observation the maximum height of 50.8 cm was recorded at T_2 and the minimum 45.3 cm was recorded at T_1. There was no statistical significant difference among the treatments.

4.1.2. Yield attributes

The data on the yield attributes observed at the 60 DAP are given in Table 4. The data shows that the maximum tuber number (8.6) was obtained at T_5 and the minimum at T_2 (3.0). There was significant difference among the treatments in the effect on tuber number. The tuber girth was maximum at T_6 (5.9 cm) and minimum at T_7 (4.8 cm). But the maximum tuber weight per plant of 42.8 g was recorded at T_5, where as the lowest value of 25.2 g was recorded at T_7. There was no significant difference among the treatments

The data on yield attributes at 100 DAP is presented in Table 5. The maximum tuber number of 9.33 was recorded at T_5 and the minimum of 5.0 was recorded at T_2. There was significant variation among the treatments in their influence on the tuber number. However, T_5 is on par with all other treatments except T_2. The data on the tuber girth showed that it was maximum at T_1 and minimum at T_5. Here, all the treatments were on par with T_1 except the T_5. Mean values of the tuber weight per plant showed that it was maximum at T_4 and minimum at T_2 which is 123.84 and

Results

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76 g respectively. Here the tuber yield varied significantly with respect to the treatments.

The data on the yield attributes and the tuber yield at harvest is presented in the Table 6. The maximum tuber number was recorded at T_7 and minimum at T_1 which was 8.5 and 6.3 respectively. No significant variation among the treatment was observed at this stage. However, with maximum dose of potassium the tuber number got decreased. The tuber girth was maximum at T_1 (8.3 cm) and minimum at T_6 (6.28 cm). There was no significant difference among the treatments in their effect on tuber girth. The maximum tuber weight per plant was registered at T_1 and the minimum was at T_7. However the treatments were not significantly different.

The observations like days to flowering and days to tuberisation were recorded. First flowering was observed 42 days after planting and the first tuberisation was observed 8-10 days after flowering. Almost all the treatments had uniform flowering and tuberisation.

4.1.3. Dry matter yield

The data on total dry matter yield/plant at three stages viz., 60 DAP, 100 DAP and at harvest is presented in Table 7.

At 60 DAP, the maximum dry matter yield per plant was observed for T_6 (53.16 g) followed by T_8 (42.23 g). The minimum value of (30.56 g) was observed for T_5. At 100 DAP, the maximum value of dry matter yield per plant is obtained for T_1 (43.56 g) and the minimum for T_2 (27.26 g). At harvest T_4 recorded the maximum weight (33.93g) and T_2 recorded a minimum of 26.85 g. However there was no significant difference in dry matter yield among the treatments.

4.1.4. Yield at 100 DAP and harvest

The data on the yield recorded at 100 DAP and at harvest is presented in Table 8. At 100 DAP there was significant difference in tuber yield. The maximum yield of 24.15 t ha^{-1} was obtained when potassium was applied @ 60 kg ha^{-1} (T_4) as against the minimum of 18.31 t ha^{-1} in the control. Here, T_4 was superior to all treatments. At harvest the maximum was observed in the same treatment as that at 100 DAP as against the minimum in plot receiving the application of 100 kg K_2O ha^{-1}. However at this stage no significant difference in the yield was observed with respect to the potassium application.

Table 3. Plant height recorded at different stages (cm)

Treatment	60 DAP	100 DAP
T_1	32.60	45.30
T_2	32.40	50.80
T_3	31.06	48.80
T_4	34.30	47.20
T_5	35.30	50.20
T_6	35.86	47.20
T_7	38.20	49.20
T_8	32.66	46.40
CD (0.05)	NS	NS

Table 4. Biometric observations at 60 DAP

Treatment	Tuber Number	Tuber girth (cm)	Tuber weight/plant (g)
T_1	7.0	5.06	32.06
T_2	6.0	5.40	32.06
T_3	3.0	5.80	32.30
T_4	6.3	5.80	36.63
T_5	8.6	5.50	42.80
T_6	5.0	5.90	29.50
T_7	8.3	4.80	25.20
T_8	6.3	5.10	31.96
CD (0.05)	3.442	NS	NS

Table 5. Biometric observations at 100 DAP

Treatment	Tuber Number	Tuber girth (cm)	Tuber weight/plant (g)
T_1	6.67	8.70	93.24
T_2	5.00	7.30	76.00
T_3	8.67	7.73	93.70
T_4	8.68	7.27	123.84
T_5	9.33	6.73	83.53
T_6	9.00	7.67	96.61
T_7	8.30	7.10	92.10
T_8	8.00	7.17	101.60
CD (0.05)	2.932	1.575	20.65

Table 6. Biometric observations at harvest

Treatment	Tuber Number	Tuber girth (cm)	Tuber weight/plant (g)
T_1	6.3	8.30	103.20
T_2	7.9	7.06	91.53
T_3	6.8	7.50	86.00
T_4	7.1	7.03	99.00
T_5	7.6	7.02	91.00
T_6	8.1	6.28	100.30
T_7	8.5	8.12	75.00
T_8	7.4	7.44	94.00
CD (0.05)	NS	NS	NS

Table 7. Dry matter yield/plant in (g)

Treatment	At 60 DAP	At 100 DAP	At harvest
T_1	32.56	43.56	32.76
T_2	33.10	27.26	26.85
T_3	31.10	38.50	30.17
T_4	36.82	34.50	33.93
T_5	30.56	29.61	30.83
T_6	53.16	28.77	29.16
T_7	35.90	33.83	31.73
T_8	42.23	32.33	32.95
CD (0.05)	NS	NS	NS

Table 8. Tuber yield at 100 DAP and at harvest in t ha^{-1}

Treatment	100 DAP	Harvest
T_1	18.31	18.46
T_2	18.79	19.17
T_3	18.59	18.76
T_4	24.15	22.17
T_5	16.29	18.63
T_6	18.84	17.94
T_7	19.91	18.05
T_8	19.83	19.11
CD (0.05)	3.246	NS

4.2. Soil analysis

Soil samples collected at three stages of growth viz. 60 DAP, 100 DAP and after harvest were analysed for available nutrients. The result of analysis is given under.

4.2.1. Available nitrogen

The data on available nitrogen content in soil is presented in Table 9. The content of nitrogen in the soil decreased with crop growth. The maximum available nitrogen content of 766.22 kg ha^{-1} was registered in T_1 followed by T_3 (762.20) and minimum of 713.73 kg ha^{-1} was registered in T_7. However at 100 DAP, the content was decreased and the maximum content of 436.97 kg ha^{-1} was registered at T_7 and the minimum of 400.84 Kg ha^{-1} was registered at T_3. The same trend was repeated at the final stage also. The maximum nitrogen content of 412.89 kg ha^{-1} was registered for T_7 and the minimum of 364.81 Kg ha^{-1} was registered for T_3. The statistical analysis revealed that during first stage the nitrogen content varied significantly with respect to treatment. No significant difference was observed for nitrogen content at the other two stages.

4.2.2. Available phosphorus

The data on available phosphorous content in soil is presented in Table 10. There was no linearity in phosphorus content with crop growth. It shows that available phosphorus was maximum at T_8 and minimum at T_4 which is 41.5 and 33.70 kg ha^{-1} respectively. At 100 DAP, T_3 and T_7 had almost similar value. In general, there was a small increase in the phosphorus status of the soil after three months of planting. At this stage maximum status of P was registered for T_7 (46.43 kg ha^{-1}) and minimum for T_2 (37.36 kg ha^{-1}). At harvest the maximum of 43.15 kg ha^{-1} P was registered for plot where K_2O was applied @ 40 kg ha^{-1} and the minimum value of 34.43 kg ha^{-1} was registered in the soil where K_2O was applied @ 80 kg ha^{-1}.

Statistical analysis revealed that there was no significant variation among the treatments with respect to P status of the soil at all stages of the analysis.

4.2.3. Available potassium

The data on available K status of the soil at three stages of sampling is presented in the Table 11.

The available K content in the soil decreased first and then increased with the crop growth for most of the treatments. The data showed that there was a regular linearity in the K status of the soil at 60 DAP with the increased doses of potassium application and is very well evidenced by the maximum value of 984.67 and 136.67 kg ha^{-1} observed for T_8 and T_1 respectively. The same trend was repeated at the second stage of analysis also. The maximum K content of 744 kg ha^{-1} was registered at T_8 and a minimum of 224 kg ha^{-1} at T_1. At harvest the content was higher than the previous stage and the mean values showed variation from 287 to 866.13 kg ha^{-1}. The statistical analysis showed that the available K status of the soil varied significantly with the levels of potassium applications in the soil in all three stages.

4.2.4. Exchangeable calcium

The mean values of calcium at three different stages of plant growth are presented in Table 12. The data showed that the exchangeable calcium varied between 400 to 423 mg kg^{-1} at the first stage. The exchangeable calcium has been depressed at the second stage. The maximum of 377 mg kg^{-1} was registered at T_7 and the minimum of 313 mg kg^{-1} was registered for T_4. However T_7 was on par with T_8 and T_1.

At harvest the same trend was not repeated. The maximum exchangeable calcium was observed at T_4 (351 mg kg^{-1}) and the minimum of 314 mg kg^{-1} at T_1. The statistical analysis revealed that, only at 100 DAP the calcium content in the soil varied significantly.

Table 9. Available nitrogen content in soil (kg ha^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	766.22	417.72	394.08
T_2	732.73	405.58	391.99
T_3	762.20	400.84	364.81
T_4	732.50	422.31	409.77
T_5	726.50	427.54	408.72
T_6	727.14	406.63	396.17
T_7	713.73	436.97	412.89
T_8	728.12	404.45	394.07
CD (0.05)	24.51	NS	NS

Table 10. Available phosphorus content in soil (kg ha^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	37.07	45.25	35.90
T_2	34.32	37.36	40.59
T_3	38.77	46.08	43.15
T_4	33.70	39.50	38.51
T_5	37.52	38.66	34.43
T_6	36.51	38.44	34.71
T_7	36.01	46.43	41.28
T_8	41.50	37.93	42.95
CD (0.05)	NS	NS	NS

Table.11. Available K content in soil (kg ha^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	130.67	224.00	287.60
T_2	205.33	261.33	425.60
T_3	541.33	298.67	418.06
T_4	578.67	336.00	505.73
T_5	522.67	466.67	597.17
T_6	628.00	597.33	701.87
T_7	672.00	522.67	702.03
T_8	984.67	744.00	866.13
CD (0.05)	130.3	89.02	106.80

Table. 12. Available Ca content in soil (mg kg^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	413	365	314
T_2	413	330	335
T_3	400	326	335
T_4	413	313	351
T_5	413	342	335
T_6	423	354	324
T_7	400	377	324
T_8	406	365	341
CD (0.05)	NS	16.64	NS

Table. 13. Available Mg content in soil (mg kg^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	27.9	35.6	41
T_2	51.9	39.3	47
T_3	40.0	39.3	38
T_4	32.0	49.6	35
T_5	44.0	49.6	44
T_6	51.0	39.3	41
T_7	39.0	49.6	47
T_8	24	35.6	41
CD (0.05)	NS	NS	NS

Table.14. Available Al content in soil (mg kg^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	31.31	62.12	48.64
T_2	33.88	53.27	65.47
T_3	37.85	51.90	56.51
T_4	30.28	45.50	47.60
T_5	26.42	43.24	45.40
T_6	29.14	45.91	48.07
T_7	27.65	35.22	52.93
T_8	32.43	41.87	38.88
CD (0.05)	NS	15.99	11.62

Table. 15. Available Fe content in soil (mg kg^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	23.40	20.30	45.62
T_2	22.53	18.63	44.86
T_3	24.13	15.40	42.70
T_4	23.53	14.83	41.36
T_5	19.73	23.23	52.73
T_6	22.30	20.58	37.73
T_7	21.46	19.06	47.93
T_8	23.80	20.60	49.03
CD (0.05)	NS	5.408	NS

Table. 16. Available Mn content in soil (mg kg^{-1})

Treatments	60 DAP	100 DAP	At harvest
T_1	98.36	99.80	105.20
T_2	97.40	103.0	105.43
T_3	99.53	98.90	103.03
T_4	100.86	100.66	105.83
T_5	102.36	101.13	106.20
T_6	98.26	102.03	104.20
T_7	104.93	101.16	106.60
T_8	96.66	102.66	106.03
CD (0.05)	3.924	NS	NS

4.2.5. Available magnesium

The data on the available magnesium content of the soil recorded at three stages of analysis viz. 60 DAP, 100 DAP and at harvest is presented in the Table 13.

The mean values of exchangeable magnesium at 60 DAP varied from 24 mg kg^{-1} to 51.9 mg kg^{-1}. At 100 DAP the data showed a maximum value of 49.6 mg kg^{-1} for three treatments, i.e., T_4, T_5 and T_7 and the minimum value for T_1 and T_8 (35.6 mg kg^{-1}). At the final stage of analysis, the maximum value of magnesium was observed at T_2 and T_7 and the minimum for T_4. The statistical study revealed that there was no significant variation among treatments with respect to the magnesium content in the soil.

4.2.6. Available micro nutrients and Aluminium

The data on the available nutrients like Al, Fe and Mn is presented in Tables 14, 15 and 16 respectively.

4.2.6.1. Extractable Al

Table 14. showed that the mean values of Al at 60 DAP varied from 26.42 (T_5) to 37.85 (T_3). At the second stage the maximum value of Al 62.12 mg kg^{-1} was observed for T_1 and the minimum of 35.22 mg kg^{-1} for T_7. Here the treatment T_1 was on par with T_2 and T_3.

At harvest the extractable Al was maximum at T_2 and minimum at T_8 which is 65.47 and 38.88 mg kg^{-1} respectively. The data on statistical analysis showed that Al varied significantly only at the second stage.

4.2.6.2. Available Fe

The data in Table 15. shows that available Fe content of soil decreased at 100 DAP and then increased at harvest irrespective of the treatments. At the first stage maximum content of 24.13 mg kg^{-1} was registered at T_3 and the minimum of 19.73 mg kg^{-1} was registered at T_5. At 100 DAP the mean values varied from 14.83 to 23.23 mg kg^{-1} which was at T_4 and T_5 respectively. However T_5 was on par with T_6, T_7, T_8, T_1 and T_2. At the harvest stage the maximum Fe status of soil was registered at T_5 (52.73 mg kg^{-1}) and minimum at T_6 (37.73 mg kg^{-1}). Statistically data was significant only at the second stage.

4.2.6.3. Available Mn

The data on the available Mn in soil is given in Table 16. The Mn content was much higher than Al and Fe contents. The maximum content was found at T_7 and minimum at T_8 at the first stage of analysis. At 100 DAP the maximum Mn status in soil was registered at T_2 (103.00) and the minimum at T_3 (98.90 mg kg^{-1}). The mean values of Mn in soil at the harvest stage varied from 103.03 mg kg^{-1} (T_3) to 106.60 (T_7). It seems that all the treatments have almost same value. The content of Mn in soil increased from planting to harvest. The data on statistical analysis revealed that Mn content in soil significantly varied among treatments only during the first stage. Here T_7 was on par with T_4 and T_5. T_5 was on par with T_6.

4.3. Plant analysis

The plant parts, shoot and tuber collected at different stages of the plant growth viz. 60 DAP, 100 DAP and at harvest were analyzed for the content of major, secondary and micronutrients.

4.3.1. Shoot analysis

The data on total nitrogen, phosphorous and potassium content in shoot is presented in Table 17.

4.3.1.1. Total nitrogen

The nitrogen content of the shoot at 60 DAP was maximum in treatment receiving no potassium and minimum at treatment receiving 140 kg ha^{-1} of K_2O. The maximum value of nitrogen content registered was 1.67 per cent and the minimum was 1.07 per cent. At the second stage the trend was reversed, the maximum nitrogen was found at T_8 and the minimum at T_5 which is 1.6 and 1.24 per cent respectively. At harvest also the maximum content of N was registered at T_8 (1.28 per cent) and the minimum at T_1 (0.95 per cent). The statistical analysis of data shows that nitrogen content of shoot varied significantly among the treatment at all stages of analysis.

4.3.1.2. Total phosphorus

The data on the total phosphorus content in the shoot at 60 DAP showed that the maximum of 0.112 per cent was found at T_8 and the minimum of 0.061 per cent was found at T_7. The phosphorus content increased up to T_3 and then decreased up to T_7 which is minimum. At the second stage the mean values of total P content in the shoot varied from 0.020 per cent to 0.039 per cent which was at T_4 and T_2 respectively. At the final stage of analysis, it has been found that the total P content is maximum at T_8 and minimum value of 0.023 both in T_1 and T_5. The statistical analysis of data showed that P content of shoot varied significantly among the treatment at all stages of analysis.

Table.17. NPK content is shoot

Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	1.67	1.29	0.95	0.080	0.028	0.023	0.96	0.56	0.72
T_2	1.42	1.28	1.10	0.083	0.039	0.025	1.007	0.86	0.89
T_3	1.41	1.32	1.20	0.084	0.033	0.033	0.91	0.82	0.95
T_4	1.49	1.29	1.14	0.070	0.020	0.027	0.93	0.76	1.14
T_5	1.64	1.24	1.05	0.076	0.035	0.023	0.86	0.90	0.69
T_6	1.39	1.32	1.02	0.074	0.029	0.030	0.90	0.88	0.97
T_7	1.16	1.35	1.64	0.061	0.021	0.028	0.92	0.80	0.72
T_8	1.07	1.60	1.28	0.112	0.028	0.035	1.07	1.03	1.18
CD (0.05)	0.35	0.23	0.23	0.02	0.06	0.18	NS	0.10	0.20

Table.18. Calcium and magnesium content in shoot

Treatment	Calcium (%)			Magnesium (%)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	1.31	1.20	1.72	0.42	0.38	0.68
T_2	1.24	1.07	1.58	0.39	0.36	0.53
T_3	1.30	1.39	1.65	0.35	0.36	0.42
T_4	1.26	1.46	1.50	0.39	0.33	0.41
T_5	1.20	1.34	1.63	0.28	0.34	0.57
T_6	1.44	1.25	1.73	0.29	0.37	0.48
T_7	0.97	137	1.39	0.42	0.39	0.33
T_8	1.19	1.38	1.45	0.41	0.33	0.39
CD (0.05)	0.25	0.16	NS	0.08	NS	0.18

Table 19. **Iorn, aluminium and manganese content in shoot**

Treatment	Fe (ppm)			Al (ppm)			Mn (ppm)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	1233	1256	1160	1919	1413	1555	243	293	576
T_2	1323	1246	876	1454	1383	1542	246	293	620
T_3	1043	1146	1306	1507	1151	1356	250	346	540
T_4	1256	1296	920	1215	1548	1473	253	336	573
T_5	1456	1026	1463	1340	1192	1422	276	410	586
T_6	1483	1183	916	1502	1706	1317	246	323	633
T_7	1290	1220	1170	1356	1696	1356	243	346	563
T_8	1593	980	966	1560	1512	1465	256	470	616
CD (0.05)	NS	NS	329.40	199.9	300.40	150.10	NS	113.00	NS

4.3.1.3. Total potassium

The total K content decreased at 100 DAP and then increased slightly at harvest for all treatments. The maximum K content in shoot was 1.07 (T_8) and the minimum was 0.86 (T_5) is at 60 DAP. At 100 DAP the mean values varied from 0.56 to 1.03 which is T_1 and T_8 respectively. At the stage of harvest the maximum total K content of 1.18 per cent was found at T_8 and the minimum of 0.69 per cent at T_5. The data on statistical analysis showed that the total K varied significantly among the treatment both at 100 DAP and at harvest.

4.3.1.4. Calcium and Magnesium

Calcium content was found to slightly increase with crop growth. The data on the calcium and magnesium content in the shoot at different stages of plant sampling is given in Table 18.

At 60 DAP the mean values of total calcium content in shoot varied from 0.97 to 1.44 per cent. A maximum content of 1.46 per cent (T_4) and a minimum value of 1.07 per cent (T_2) were found at 100 DAP. At the final stage, maximum calcium content was registered at T_6 and minimum at T_7 which was 1.73 and 1.39 respectively. The data on statistical analysis revealed that there was significant variation among the treatments at 60 DAP and 100 DAP with respect to the calcium content in shoot. Total magnesium content at 60 DAP showed that maximum value of 0.42 per cent was observed both in T_1 and T_7 and the minimum value of 0.28 per cent at T_5. At 100 DAP, slight decrease was noticed in the content of Mg. The values varied from 0.33 (T_4 and T_8) to 0.39 (T_7). At the harvest stage the treatment which received no potassium registered a maximum value of 0.68 per cent and the treatment with 120 kg K_2O ha^{-1} recorded the minimum of 0.33 per cent at T_7. The magnesium content in shoot was found to be increasing with crop growth. The data on statistical analysis showed that the magnesium content in shoot significantly varied among the treatments at first stage and at harvest.

4.3.1.5. Micronutrients and Aluminium

The data on the total micronutrient content (Fe, Mn) and Aluminium in shoot collected at different stages of plant growth viz. 60 DAP, 100 DAP and at harvest is presented in the Table 19.

Both Mn and Al content in plants increased from planting to harvest however the Fe content in shoot decreased at harvest.

4.3.1.5.1 Iron

The data showed that total Fe content at 60 DAP varied from 1043 (T_3) to 1593 ppm (T_8). At 100 DAP the values ranged from 980 to 1296 ppm. which is at T_8 and T_4 respectively. However at harvest maximum Fe content was found at T_5 (1463 ppm) and minimum at T_2 (876 ppm). The statistical analysis of data showed that the total Fe content varied significantly among the treatments only at the harvest.

4.3.1.5.2. Aluminium

The mean values of total Al content in shoot samples collected at 60 DAP varied from 1215 ppm to 1919 ppm which is at T_4 and T_1 respectively. At 100 DAP the maximum total Al content was found at T_6 (1706 ppm) and the minimum at T_3 (1151 ppm). At harvest it ranged from 1317 to 1555 ppm. The statistical analysis revealed that the Al content varied significantly at all the stages of analysis.

4.3.1.5.3. Manganese

In shoots the content of Mn increased towards harvest. At 60 DAP a maximum of 276 ppm was registered at T_5 and a minimum of 243 ppm was found at T_1 and T_7. The mean values at 100 DAP varied from 293 ppm to 470 ppm. At harvest the maximum content was found at T_6 and the minimum was found at T_3 which is 633 ppm and 540 ppm respectively. The statistical analysis showed that Mn content varied significantly only at second stage of analysis.

4.3.2. Tuber analysis

The tuber was analysed for total N, P, K, Fe, Al and Mn. The data on the total content of nitrogen, phosphorus and potassium in the tuber collected at different crop growth stages is presented in the Table 20.

4.3.2.1. Total nitrogen

On perusal of the data in Table 20.it was observed that the content of nitrogen decreases towards harvest.

At 60 DAP the nitrogen content of tuber was maximum at T_4 (1.69) and minimum at T_3 (1.15 per cent). At 100 DAP the content was maximum at T_5 and minimum at T_8. At harvest maximum value of 1.4 per cent was observed at T_5 and T_6 and the minimum value of 0.87 per cent was found at T_2. On statistical analysis it was observed that the nitrogen content of tuber varied significantly at 100 DAP and harvest.

4.3.2.2. Total phosphorous

At 60 DAP the phosphorus content varied from 0.057 to 0.068 per cent. The maximum phosphorus content of 0.074 per cent at 100 DAP was found at the treatment receiving 120 kg K_2O ha^{-1} (T_7) and the minimum of 0.052 per cent was found at the treatment receiving 80 kg K_2O ha^{-1}.

The mean values of phosphorus content in the tuber at harvest ranged from 0.03 to 0.057 per cent. It was observed that phosphorus content in tuber decreased towards harvest. The statistical analysis revealed that the data is significant only at second stage of analysis.

Table.20. NPK Content in tuber

Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	1.28	1.24	1.14	0.067	0.067	0.039	1.173	1.18	0.76
T_2	1.21	1.31	0.87	0.063	0.067	0.048	1.48	1.20	1.20
T_3	1.15	1.47	0.93	0.064	0.063	0.045	1.90	1.15	1.32
T_4	1.69	1.65	1.30	0.068	0.067	0.039	1.30	1.05	1.16
T_5	1.21	1.71	1.40	0.057	0.052	1.048	1.40	1.11	1.29
T_6	1.21	1.31	1.40	0.057	0.065	0.049	1.30	0.85	1.25
T_7	1.26	1.37	1.20	0.060	0.074	0.057	1.00	1.01	1.48
T_8	1.47	1.23	1.30	0.062	0.065	0.037	1.40	1.22	1.27
CD (0.05)	NS	0.254	0.235	NS	0.18	NS	NS	NS	NS

Table.21. Calcium and magnesium content in tuber

Treatment	Calcium (%)			Magnesium (%)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	0.162	0.159	0.124	0.168	0.087	0.064
T_2	0.168	0.163	0.142	0.133	0.074	0.085
T_3	0.168	0.123	0.112	0.132	0.062	0.094
T_4	0.174	0.138	0.112	0.135	0.090	0.081
T_5	0.174	0.114	0.121	0.137	0.090	0.078
T_6	0.164	0.113	0.124	0:163	0.071	0.088
T_7	0.205	0.117	0.130	0.101	0.071	0.067
T_8	0.174	0.156	0.112	0.143	0.125	0.095
CD (0.05)	NS	0.18	NS	0.06	0.18	NS

Table.22. Iron, aluminium and manganese content in tuber.

Treatment	Fe (ppm)			Al (ppm)			Mn (ppm)		
	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest	60 DAP	100 DAP	At harvest
T_1	2633	986	696	1483	1561	467	216	60	50
T_2	2220	790	880	1606	935	648	156	66	53
T_3	3516	703	736	1690	931	767	163	58	56
T_4	2096	903	856	1450	860	860	120	53	56
T_5	2283	620	790	1535	826	527	136	53	56
T_6	4806	723	560	1939	959	855	200	58	56
T_7	1626	840	583	2016	943	645	246	46	50
T_8	1350	1106	796	1721	1207	571	146	63	56
CD (0.05)	1092	180.40	224.50	244	161.60	118.60	77.71	NS	NS

4.3.2.3. Potassium

The potassium content in the tuber collected at three stages showed no significant difference among the treatments. At 60 DAP the maximum value of 1.90 per cent was found at T_3 and the minimum value of 1.00 per cent at T_7. At second stage the mean values of K content ranged from 0.85 to 1.22 per cent which is at T_6 and T_8 respectively.

At the harvest stage maximum value of 1.48 per cent was found at T_7 and the minimum at T_1. It was noted that at the final stage K content in the tuber increased up to T_6 and then decreased.

4.3.2.4. Calcium and Magnesium

The data on the total calcium and magnesium content in tuber at the three sampling stages is given in the Table 21.

From the data it seems that there was no linearity in the calcium content with the levels of K. The mean values of calcium at 60 DAP ranged from 0.162 to 0.205 per cent. However at the second stages the maximum calcium content was found at T_2 (0.163 per cent) and the minimum at T_6 (0.113 per cent). At the harvest calcium was found to be higher at T_2 (0.142 per cent) and the lowest value obtained was 0.112 per cent at three treatment receiving 40, 60, 140 kg K_2O ha^{-1}. Calcium content in tuber decreased from planting to harvest. The calcium content varied significantly only during the second stage of analysis.

The data on magnesium content on tuber at 60 DAP shows that a maximum value of 0.168 per cent was obtained at T_1 and the minimum is at T_7 (0.101 per cent). At 100 DAP that the total magnesium seemed to be maximum at the treatment receiving highest dose of K and minimum at T_3 which is 0.125 per cent and 0.071per cent respectively. At harvest the mean values ranged from 0.064 to 0.095 per cent. Magnesium content in the tuber decreased from planting towards harvest.
A significant variation of magnesium content among treatment was observed first and second stages of analysis.

4.3.2..5. Micronutrients and Aluminium

The data on the total micronutrient content (Fe, Mn) and aluminium in tuber collected at different stages of plant growth viz. 60 DAP, 100 DAP and at harvest are presented in Table 22.

4.3.2.5.1. Iron

The data on the total Fe, Mn and Al in tuber samples are presented in the table 22. On perusal of the data it was seen that Fe content decreased from 60 DAP towards harvest compared to other stages. Very high content of iron was observed during the initial (first) analysis. At 60 DAP the maximum Fe content was found at T_6 (4806 ppm) and the minimum at T_8 (1350 ppm), it seems that Fe content reduced after the treatment T_6. At 100 DAP Fe content in tuber was found to be decreased than first stage. The maximum value of 1106 ppm was found at T_8 and the minimum of 620 ppm was found at T_5. At the final harvest stage the mean values of total Fe content ranged from 560 (T_6) to 880 ppm T_2. The statistical analysis revealed that Fe content varied significantly among the treatments at all the stages of analysis.

4.3.2.5.2. Aluminium

The Al content was found to be decreased with crop growth. At 60 DAP total Al content in the tuber seemed to be maximum at T_7 and minimum at T_4 which is 2016 ppm and 1450 ppm respectively. At the second stage of sampling a maximum value of 1561 ppm (T_1) and a minimum value of 826 ppm (T_5) was observed. At harvest the mean values ranged from 467 to 860 ppm which is T_1 and T_4 respectively. The aluminium content varied significantly at all the three stages of analysis.

4.3.2.5.3. Manganeese

Similar to Fe and Al, Manganese content also found to be higher during the first stage of analysis and then it decreased with the crop growth. The mean values of total manganese in tuber at 60 DAP ranged from 120 to 246 ppm which is T_4 and T_7 respectively. At 100 DAP the maximum Mn content found was 66 ppm and the minimum found was 46 ppm. At harvest Mn content ranged from 50 to 56 ppm. There was no regular linearity in the Mn content with respect to the levels of K. Moreover, it was observed that variations in the Mn content in tuber between 100 DAP and at harvest was negligible.

4.4. Nutrient uptake

The data on the uptake of nutrients viz. N, P and K at different stages of crop growth i.e. 60 DAP, 100 DAP and at harvest is presented in the Tables 23, 24 and 25 respectively.

4.4.1. Nitrogen uptake

The data showed that at 60 DAP, the maximum N uptake recorded was 238.87 kg ha^{-1} for the treatment receiving 100 kg ha^{-1} of K_2O (T_6) and the minimum was registered at T_8 (149.89 kg ha^{-1}). Nitrogen uptake at 100 DAP showed that the maximum of 214.91 kg ha^{-1} was registered at T_4 and the minimum of 143.43 kg ha^{-1} was registered at T_2. The mean values of N uptake at harvest stage varied from 118.92 to 162.33 kg ha^{-1} which was at T_2 and T_4 respectively. Nitrogen uptake is more at the second stage than the first stage except in T_6. Nitrogen uptake was much less at the harvest stage. The statistical analysis revealed that the treatments varied significantly in their nitrogen uptake.

Table 23. Nitrogen uptake at different stages of crop growth in kg ha^{-1}

Treatment	60 DAP	100 DAP	At harvest
T_1	185.42	211.30	130.33
T_2	165.13	143.43	118.93
T_3	155.94	173.81	130.96
T_4	182.84	214.91	162.33
T_5	170.71	190.83	147.59
T_6	238.87	147.77	151.80
T_7	168.06	193.43	145.80
T_8	149.89	179.29	156.86
CD (0.05)	NS	37.95	NS

Table 24. Phosphorus uptake at different stages of crop growth in kg ha^{-1}

Treatment	60 DAP	100 DAP	At harvest
T_1	9.12	6.51	3.94
T_2	9.37	5.63	3.83
T_3	9.22	7.14	4.61
T_4	11.03	5.83	4.39
T_5	8.49	5.00	4.28
T_6	13.76	5.20	4.48
T_7	8.47	6.70	5.28
T_8	13.83	5.70	4.60
CD (0.05)	3.968	NS	NS

Table 25. Potassium uptake at different stages of crop growth in kg ha^{-1}

Treatment	60 DAP	100 DAP	At harvest
T_1	134	172.00	107.90
T_2	129	126.77	103.88
T_3	160	116.03	127.73
T_4	177	129.00	154.78
T_5	138	116.59	137.62
T_6	261	96.73	128.37
T_7	134	129.13	123.45
T_8	155	142.38	151.00
CD (0.05)	46.18	29.64	NS

4.4.2. Phosphorus uptake

The phosphorus uptake seemed to be reduced with crop growth. The data at 60 DAP showed that the phosphorus uptake was maximum at the treatment receiving highest dose i.e. 140 kg ha^{-1} of K_2O and minimum at T_7 (receiving 120 kg ha^{-1}) which is 13.83 and 8.47 kg ha^{-1} respectively. During the second stage of analysis the mean values of P uptake varied from 5.0 and 7.14 kg ha^{-1}. At harvest the maximum value of 5.28 kg ha^{-1} was registered of T_7 and minimum of 3.83 kg ha^{-1} was registered at T_2. The statistical analysis showed that the P uptake was significant only at the first stage.

4.4.3. Potassium uptake

The maximum potassium uptake of 261 kg ha^{-1} during the first stage of analysis was registered for the treatment receiving 100 kg ha^{-1} K_2O and the minimum of 129 kg ha^{-1} was registered for T_2 (20 kg ha^{-1}). Except in the superior treatment, all other treatments have more or less same K uptake. At 100 DAP maximum K uptake was in the treatment not receiving potassium and minimum was in the treatment receiving 100 kg ha^{-1} K_2O (T_6) which has registered the maximum uptake at the first stage.

At harvest maximum uptake was registered for T_4 and minimum for T_2. It seems potassium uptake was high during the first stage compared to other stage. The statistical analysis showed that the treatments varied significantly with respect to the K uptake at the first and second stage.

4.5. Availability indices of potassium

The amount of potassium extracted with different chemicals is considered as one of the indices of assessing potassium supplying power of the soil. The data on the quantity of potassium extracted with different extractants and their significance is presented hereunder.

4.5.1. Evaluation of extractants.

The details of different extractant and mode of extraction of soil potassium is given in Table 26.

Table 26. Details of conventional chemical methods used for estimating available potassium in soil.

Method used	Chemical composition	Soil to extractant ratio	Mode of extraction
Hanway and Heidal (1952)	1N Ammonium acetate-pH 7.	1 : 5	5 minutes shaking
Morgan (1941)	10 per cent Sodium acetate and 3 per cent acetic acid-pH 4.8	1 : 5	5 minutes shaking
Modified Morgan (Blenchet and Peuguad, 1960)	6 per cent Ammonia solution and 7 per cent acetic acid pH 4.8	1 : 2	1 minutes shaking
Wood and De Turk (1941)	1N Nitric acid	1 : 50	10 minutes boiling
Garley *et al* (1960)	Water	1 : 5	1 hour shaking
Hunter and Pratt (1957)	6N cold sulphuric acid	1 : 10	30 minutes shaking
Woodruff and Mc Intosch (1960)	0.01M $CaCl_2$	1 : 7	Intermittant shaking for 1 hour
Piper (1966)	0.5 M HCl	1 : 10	50 minutes shaking

4.5.1.1. Evaluation of extractants at 60 DAP

The data on the amount of the potassium extracted with different reagents from the soil collected at 60 DAP is presented in Table 27. Water soluble K varied from 42 mg kg^{-1} to 85 mg kg^{-1} which was at T_2 and T_5 respectively. The mean values of ammonium acetate extractable K ranged from 130 to 230. T_7 had maximum NH_4OAC extractable K in the soil. It was found that the ammonium acetate K increased with the levels of K application.

The maximum amount of potassium extracted with Morgan's reagent was at T_8 and the minimum at T_1. There was no regular linearity in the amount of Morgan's reagent-K with the K levels. The mean values of potassium extracted with modified Morgan's reagent varied from 37 to 76. The sulphuric acid soluble K varied from 143 to 332 mg kg^{-1} which is at T_1 and T_5 respectively. The acid extractable K was found to increase up to T_5 and then decreased. The maximum hydrochloric acid soluble K was found at T_8 (268 mg kg^{-1}) and the minimum at T_1 (90 mg kg^{-1}). In general there was an increase in the K extracted with the increased levels of K application.

The mean values of K extractable with 0.01 $CaCl_2$ ranged from 80 to 224. There was an increasing trend in the amount of K extracted from T_1 to T_8. The HNO_3 soluble K recorded maximum value at T_8 (2296 mg kg^{-1}) and the minimum value at T_3 (1210 mg kg^{-1}).

4.5.1.2. Evaluation of extractants at 100 DAP

The data on the amount of potassium extracted with different chemicals from the soil collected at the second stage of plant growth is presented in the Table 28.

The mean values of water soluble K ranged from 19 to 56 mg kg^{-1} which is at T_1 and T_8 respectively. The data showed that there was an increasing trend in the amount of water soluble K with increased levels of K application. Similarly the ammonium acetate extractable K was maximum at T_8 (212 mg kg^{-1}) and the minimum at T_4 (121 mg kg^{-1}). T_8 was having exceptionally high amount NH_4OAC extractable K. NH_4OAC was found to be decreased as compared to first stage. The maximum value of 126 mg kg^{-1} (T_8) and the minimum of 53 mg kg^{-1} (T_1) was obtained for Morgan's reagent extractable K. The amount of K showed an increasing trend with levels of K application. A maximum value of 136 mg $kg^{-1}$and a minimum value of 53

Table.27. Quantity of potassium extracted with different extractants at 60 DAP (mg kg^{-1})

Treatment	Water	Ammonium acetate	Morgan's reagent	Modified Morgan's reagent	6N Sulphuric acid	0.5 M HCl	0.01M $CaCl_2$	1N HNO_3
T_1	47	130	125	60	143	90	80	1570
T_2	42	147	146	65	172	127	114	1497
T_3	56	169	146	54	190	132	106	1210
T_4	64	178	126	62	199	185	104	1560
T_5	85	182	240	62	332	253	120	1697
T_6	85	190	176	37	213	139	121	2192
T_7	58	230	246	71	319	255	161	2020
T_8	80	227	254	76	310	268	224	2296

Table.28. Quantity of potassium extracted with different extractants at100 DAP (mg kg^{-1})

Treatment	Water	Ammonium acetate	Morgan's reagent	Modified Morgan's reagent	6N Sulphuric acid	0.5M HCl	0.01M $CaCl_2$	1N HNO_3
T_1	19	124	53	53	119	76	51	1536
T_2	22	122	81	91	152	107	60	1586
T_3	23	137	88	69	151	102	68	1366
T_4	26	121	83	84	155	114	142	1556
T_5	34	163	78	92	175	154	116	1420
T_6	41	160	77	100	218	173	125	1533
T_7	44	157	114	90	224	196	123	1580
T_8	56	212	126	136	258	222	163	1740

Table 29. Quantity of potassium extracted with different extractants at harvest (mg kg^{-1})

Treatment	H_2O	Ammonium Acetate	Morgan's reagent	Modified Morgan,s	6N Sulphuric acid	0.5M HCl	0.01 M $CaCl_2$	1NHNO_3
T_1	23	99	73	56	125	116	93	1216
T_2	37	121	79	57	135	130	126	1440
T_3	29	120	84	66	138	134	127	1448
T_4	44	127	112	80	182	156	196	1283
T_5	49	174	112	117	206	184	188	1291
T_6	64	242	145	134	230	244	251	2200
T_7	45	175	120	127	206	214	210	1323
T_8	69	244	150	138	236	206	219	1380

mg $kg^{-1}$was observed for modified Morgan's reagent extractable K. However no regular linearity was observed for K.

The mean values of sulphuric acid soluble K varied from 119 (T_1) to 258 mg kg^{-1} (T_8). It seems that there was an increasing trend in the amount of H_2SO_4 soluble K with increased levels of K application. The maximum HCl soluble K was found at T_8 (222 mg kg^{-1}) and the minimum at T_1 (76 mg kg^{-1}). As in all other extractants the amount of HCl soluble K increased with the increased levels of K application. The values of $CaCl_2$ extractable K ranged from 51 to 163 mg kg^{-1}which is at T_1 and T_8 respectively. However, there was no regular linearity from T_1 to T_8. The HNO_3 soluble K ranged from 1366 to 1740 mg kg^{-1}. On comparison of extractants it was observed that HNO_3 soluble K was the highest in all treatments.

4.5.1.3. Evaluation of extractants at harvest

The data on the quantity of K extracted with different extractants from the soil collected at harvest of the crop is presented in the Table 29.

The water soluble K ranged from 23 to 69 mg kg^{-1} which is at T_1 and T_8 respectively. However, there was no regular linearity among the treatment with respect to the water soluble K. The maximum amount of ammonium acetate extractable K was found at T_8 and minimum at T_1. The data shows that the NH_4OAC-K increased up to T_6 and then decreased and again increased. The maximum amount of K extracted with Morgan's reagent was found at T_8 and the minimum at T_1 which is 150 mg kg^{-1} and 73 mg kg^{-1}respectively.

The maximum amount 138 mg kg^{-1} (T_8) and minimum of 56 mg kg^{-1} of K was found (T_1) for modified Morgan's reagent. The mean values of H_2SO_4 soluble K ranged from 125 to 236 mg kg^{-1}. It seems that H_2SO_4 soluble K increased with the level of K application. The maximum HCl-soluble-K was found at T_6 (244 mg kg^{-1}) and minimum at T_1 (116 mg kg^{-1}). The data shows that there was an increasing trend in the amount of HCl-soluble-K up to T_6 and then decreased. The higher value of 251 mg $kg^{-1}$and the minimum value of 93 mg kg^{-1} was obtained from $CaCl_2$ extractable-K which is at T_6 and T_1 respectively. The mean values of boiling 1N HNO_3-soluble-K ranged from 1216 to 2200 mg kg^{-1}. The maximum was obtained for T_6 and minimum for T_1. On perusal of the three tables it was observed that water soluble and HNO_3 soluble K in soil decreased from planting to harvesting. Exchangeable K seems to be more or less the same.

4.5.2. Quantity - Intensity relationship of Potassium

The values of Q/I parameters estimated at two different temperatures viz. 25 and 40°C is presented in the Table 30.

Table 29. Quantity-Intensity parameters at two temperatures

Parameters	At 25°C	At 40°C
AR_o^eK x 10^{-3} (mol L^{-1}) $^{0.5}$	1.5	2.4
K_L cmol(+) kg^{-1}	0.23	0.30
PBC^K cmol kg^{-1}/(mol L^{-1})$^{0.5}$	53.3	47.5
Δ F Kcal mol^{-1} $degree^{-1}$	-1.82	-2.279

The equilibrium activity ratio was higher at 40°C than that at 25°C. At 40°C AR_o^eK is 2.4 x 10^{-3} (mol L^{-1}) $^{0.5}$. The labile K was found to increase with the increase in temperature by recording a lower value of 0.23 cmol (+) kg^{-1} and higher value of 0.30 cmol (+) kg^{-1} at 40°C. The values of Δ F was found to decrease with the rise in temperature. Δ F estimated at 25°C is -1.82 Kcal mol^{-1} degree and at 40°C -2.279 kcal mol^{-1} $degree^{-1}$. The potential buffering capacity (PBC^K) recorded a value of 53.3 and 47.5 cmol kg^{-1} / (mL^{-1}) $^{0.5}$ x 10^{-3} at 25 and 40°C respectively indicating that PBC^K decreased with the rise in temperature.

4.5.3. Adsorption isotherms

An attempt has been made to fit the quantity intensity curve on standard chemical adsortption isotherms viz. Freundlich and Langmuir adsorption isotherm and it has been observed that Q-I in the present study followed only Freundlich isotherm.

4.6. Correlation studies

4.6.1. Correlation between available nutrients.

The result of simple correlation studies conducted between available nutrients at 60 DAP, 100 DAP and at harvest are given in the Tables 31, 32 and 33 respectively.

At 60 DAP availability of nitrogen was negatively correlated with available K as indicated by the significant negative correlation coefficient of (-0.468*) and it was also negatively influenced by the magnesium and manganese content in the soil. Availability of nitrogen was found to be influenced by P, Fe and calcium positively. However, aluminium was positively correlated with nitrogen availability. Availability of P was negatively influenced by the magnesium and manganese content of soil. The availability of the potassium was negatively influenced by the concentration of all the exchangeable cations considered for the analysis.

The correlation between available nutrients at 100 DAP shows that the exchangeable Al, exchangeable Mn were negatively correlated with nitrogen availability in the soil, whereas the available P, available K and exchangeable cations like Ca and Mg were positively correlated with nitrogen availability. A significant positive correlation (r = 0.468*) observed between available N and exchangeable Mg. With respect to the available phosphorus, exchangeable cations like Ca, Mg and Al are positively correlated. However Mn was found be correlated significantly and negatively with P. At this stage Ca and Fe have a positive influence on available potassium in soil.

At harvest a significant positive correlation was observed between nitrogen and potassium and also with calcium. Available P was found to be significantly correlated with available Mn. Even though it was not significant the correlation was found to be positive with K. At harvest even though Ca and Mg were found to be negatively correlated with available K it was not significant.

4.6.2. Simple correlation of yield attributes with potassium extracted with different reagents.

Simple correlation of yield attributes with extractable potassium by different reagents were worked out at all stages of analysis.

4.6.2.1. Correlations at 60 DAP

Correlation coefficients obtained between yield attributes and extracted K at 60 DAP is presented in the Table 34.

Number of tubers showed positive correlation with the potassium extracted with all the extractants. However significant correlation was observed only with H_2SO_4 ($r = 0.337$), and with HCl ($r = 0.330$).Positive correlation was noted in the case of tuber girth with K extracted with all extractants. However significant correlation was found only with 0.01 M $CaCl_2$ ($r = 0.279$). K content in shoot was positively correlated ($r = 0.248$) with tuber girth. Tuber yield per plant had weak and positive correlation with K extracted with all reagents.

4.6.2.2. Correlations coefficients of yield attributes with potassium at 100 DAP

Correlation coefficients obtained between yield attributes and extracted K is presented in the Table 35.

Number of tubers per plant had positive correlation with potassium extracted with different chemicals. However positive correlation ($r = 0.291$) was obtained both with H_2SO_4 and HCl. Girth of tuber had positive correlation with available K, and the potassium extracted with different chemicals. However high degree of correlation was obtained with Morgan's reagent ($r = 0.424$) followed by

HCl. Tuber yield was found to be negatively correlated the K content in the shoot. Tuber yield had weak positive correlations with K extracted by different chemicals. However high degree of correlation was obtained only with $CaCl_2$ (r = 0.320).

4.6.2.3. Correlation coefficient of yield attributes with potassium at harvest

Correlation coefficients obtained between yield attributes and extracted K at harvest is presented in the Table 36.

Number of tubers per plant showed positive correlation with potassium extracted with different reagents. Higher correlation coefficient (r = 0.373) was obtained for 6N H_2SO_4 followed by water. The tuber girth had a negative correlation with K extracted. But it showed positive correlation with available K. The correlation between tuber yield and K extracted with different chemicals are found to be positive, but not significant.

Table 31. Correlation between available nutrients at 60 DAP

	Available N	Available P	Available K
Available N	1.00		
Available P	0.166	1.00	
Available K	-0.468*	0.059	1.00
Ca	0.109	0.086	-0.103
Mg	-0.027	-0.379	-0.148
Exchangeble Al	0.303	0.071	-0.100
Fe	0.256	0.228	-0.017
Mn	-0.142	-0.102	-0.037

Table 32. Correlation between available nutrients and K uptake at 100 DAP

	Available N	Available P	Available K
Available N	1.00		
Available P	0.089	1.00	
Available K	0.018	-0.154	1.00
Ca	0.025	0.082	0.345
Mg	0.468*	0.108	-0.003
Exchangeable Al	-0.218	0.246	-0.533*
Fe	0.065	-0.124	0.283
Mn	-0.149	-0.328	-0.329

* significant at 5per cent level

Table 33. Correlation between available nutrients and K uptake at harvest

	Available N	Available P	Available K
Available N	1.00		
Available P	-0.092	1.00	
Available K	0.421*	0.190	1.00
Ca	0.441*	-0.070	-0.109
Mg	0.098	-0.053	-0.183
Exchangeble Al	-0.278	-0.139	0.070
Fe	0.121	0.342	-0.023
Mn	-0.036	0.355	-0.155

Table 34. Correlation between extractable K, yield attributes at 60 DAP

	Tuber No.	Tuber girth	Tuber yield/plant
Water soluble K	0.172	0.126	0.200
Ammonium acetate K	0.054	0.061	0.092
Sulphuric acid	0.337	0.203	0.053
Morgan's reagent	0.294	0.175	0.040
Modified Morgan's reagent	0.253	0.185	0.092
HCl	0.330	0.185	0.042
$CaCl_2$	0.037	0.279	0.154
HNO_3	0.191	0.170	0.100
K in shoot	-0.249	0.248	0.144

* significant at 5 per cent level
** significant at 1 per cent level

Table 35. Correlation between extractable K, yield attributes at 100 DAP

	Tuber No. per plant	Tuber girth	Tuber yield/plant
Water soluble K	0.183	0.209	0.076
Ammonium acetate K	0.023	0.222	0.160
Sulphuric acid	0.291	0.138	0.068
Morgan's reagent	0.123	0.424*	0.085
Modified Morgan's reagent	0.013	0.156	0.040
HCl	0.291	0.256	0.077
$CaCl_2$	0.101	0.171	0.320
HNO_3	0.130	0.164	0.038
K in shoot	0.181	0.084	-0.065

Table 36. Correlation between extractable K, yield attributes at harvest

	Tuber No. per plant	Tuber girth	Tuber yield/plant
Water soluble K	0.331	-0.350	0.020
Ammonium acetate K	0.282	-0.289	0.100
Sulphuric acid	0.373	-0.271	0.085
Morgan's reagent	0.130	-0.105	0.100
Modified Morgan's reagent	0.237	-0.153	0.150
HCl	0.300	-0.214	0.159
$CaCl_2$	0.286	-0.199	0.104
HNO_3	0.095	-0.292	0.049
K in shoot	-0.119	-0.204	0.182

* significant at 5 per cent level
** significant at 1per cent level

4.6.3. Correlation between potassium content in plant and extractable K

Simple correlation coefficients were worked out between potassium content in different part of plant and K uptake with potassium extracted with different extractants at 60 DAP, 100 DAP and at harvest. The data is presented in the Tables 36, 37 and 38 respectively.

K content in the tuber showed positive correlation with the potassium extracted with all chemicals except nitric acid. However the coefficients obtained were not significant. The same results holds good for the K content in the shoot also. However significant correlation (r = 0.358) was observed only with water soluble potassium. Positive correlations were observed for total K content in the whole plant with potassium extracted with all the extractants. There also only water soluble potassium was significant. With respect to the potassium uptake by plants highly significant positive correlation was observed only with water soluble potassium. Here also potassium extracted with all chemicals had positive correlation.

At 100 DAP, the K content in tuber showed positive correlation with potassium extracted with different extractants. Higher correlation was observed with 6N H_2SO_4 soluble K (0.224). K content in the shoot had significant positive correlation with potassium extracted with all extractants. Higher correlation value (r = 0.706) was observed with 0.5 M HCl followed by NH_4OAC (r = 0.692). Total K content in the plant showed positive correlation with the K extractable with all chemicals. Here the same correlation coefficient (r = 0.314) was obtained both for NH_4OAC and 0.5M HCl. Total K content showed almost similar correlation with 0.01M $CaCl_2$ and 6N H_2SO_4. The same result holds good for total K uptake with K extracted with all extractants. Very weak correlation (0.009) is observed for 1N HNO_3. Here high correlation was obtained only for 0.01M $CaCl_2$.

K content in the tuber showed positive correlation with the potassium extracted with all extractants. Higher correlation (r = 0.301) was obtained for 0.01M $CaCl_2$ and the weak correlation was obtained with 1N HNO_3. Potassium content in the shoot had positive correlation with K extracted by all extractants. However significant correlation was observed 0.01 M $CaCl_2$. The same results holds good for correlation between total K content in the plant and extractable K. Highly significant positive correlation were observed with most of the reagents. Higher correlation (r = 0.521*) was observed with 0.01M $CaCl_2$ followed by 6N H_2SO_4 (r = 0.519*).

Table 37. Correlation between K content in plant and extractable potassium with different reagents at 60 DAP

Extractant	K content in tuber	K content in shoot	Total K in whole plant	K uptake by whole plant
NH_4OAC	0.105	0.301	0.210	0.215
Water	0.109	0.358	0.253	0.390
Sulphuric acid	0.068	0.129	0.073	0.135
0.5M HCl	0.059	0.108	0.670	0.166
Morgan's reagent	0.009	0.065	0.310	0.092
Modified Morgan's reagent	0.011	0.034	0.200	0.294
1N HNO_3	-0.001	-0.008	0.003	0.101
0.01M $CaCl_2$	0.113	0.134	0.129	0.158

Table 38. Correlation between K content in plant and extractable potassium with different reagents at 100 DAP

Extractant	K content in tuber	K content in shoot	Total K in whole plant	K uptake by whole plant
NH_4OAC	0.145	0.692**	0.314	0.204
Water	0.098	0.667**	0.201	0.089
Sulphuric acid	0.224	0.683**	0.303	0.132
0.5M HCl	0.219	0.706**	0.314	0.121
Morgan's reagent	0.089	0.613**	0.291	0.114
Modified Morgan's reagent	0.045	0.661**	0.234	0.101
1N HNO_3	0.092	0.332	0.193	0.009
0.01M $CaCl_2$	0.153	0.531*	0.301	0.214

* significant at 5 per cent level
** significant at 1 per cent level

Table 39. Correlation between K content in plant and extractable potassium with different reagents at harvest

Extractant	K content in tuber	K content in shoot	Total K in whole plant	K uptake by whole plant
NH_4OAC	0.181	0.179	0.132	0.356
Water	0.101	0.068	0.053	0.227
Sulphuric acid	0.213	0.204	0.198	0.519*
0.5M HCl	0.031	0.191	0.141	0.221
Morgan's reagent	0.193	0.164	0.168	0.394
Modified Morgan's reagent	0.121	0.114	0.092	0.412*
1N HNO_3	0.004	0.098	0.073	0.008
0.01M $CaCl_2$	0.301	0.285	0.293	0.521*

* significant at 5 per cent level
** significant at 1 per cent level

Discussion

5. DISCUSSION

An experiment was conducted in the Department of Soil Science and Agricultural Chemistry to study the availability indices of potassium in Ultisol under coleus cultivation. The salient results of the study are discussed in this chapter.

5.1.Biometric observations.

5.1.1. Plant height and yield attributes

The height of plant observed at three stages of growth have shown no linearity with the levels of potassium. Even though no influence was noticed at initial stages, K applied at the levels of 100 kg ha^{-1} had given the maximum height at three months after planting. However, at the levels above 100 kg K_2O the height seems to be reduced. This shows that heavier dose of K did not further influence the vegetative growth of tuber crops. Similar findings were reported by Nair and Aiyer (1985) on plant height in cassava with higher levels of K applications.

Both the tuber number and tuber girth got increased with the levels of K. Significant effect was noticed for the number of tubers per plant both at initial stages and three months after planting. However the tuber girth was increased significantly only at 3 MAP (months after planting). The maximum number of tubers per plant was observed with 80 kg of K both at 60 DAP and 100 DAP. Nearly 40 per cent increase in the tuber number was found with medium levels of K compared with the plots with no potassium. With regard to tuber girth the highest was in the treatment with 100 kg K_2O ha^{-1}. Even though tuber girth of 8.7 cm is noticed in the control at this stage, the highest yield recorded was in the plot with 60 kg K_2O. Thus it is evident that tuber number is more significant than the tuber size as far as the final yield is concerned. Similar results were reported by Mohankumar *et al* (1987) on the tuber yield in cassava. Even though the size was decreased by 17 per cent over the control, the yield got increased to about 33 per cent in plot where K is applied @ 60 kg K_2O ha^{-1}.

The tuber weight per plant was increased with the levels of potassium both at 60 DAP and 100 DAP. However it was significant only at second stage of observation. At 60 DAP the tuber weight was maximum for 80 kg K_2O ha^{-1} followed by 60 kg K_2O ha^{-1}. However at the second stage maximum yield was recorded in the plots with 60 kg K_2O rather than with 80 kg K_2O ha^{-1} as in the initial stage where the tuber formation just started. This yield increase with 60 kg K_2O might be attributed to the slight difference in the tuber size as compared to plots with 80 kg K_2O ha^{-1}. At the harvest stage none of the parameters are significantly influenced by the levels of K. Only tuber number per plant varied slightly with levels of K. Even though the size of tuber and yield per plant was highest for the plots without any addition of K, it did not vary significantly. Random sampling might be the reason for the higher tuber weight recorded in the control. Further the maximum utilization of K by the crop would occur during 60-100 days of plant growth. Kabeerthumma *et al.* (1987) have reported that the peak period of K utilization spreads between 60-120 days after planting. This is corroborated by the significant effect observed for K on the tuber yield recorded at 100 DAP.

The soil of experimental site contains high amount of available K as evidenced by the basic analytical data before laying out the experiment. Since potassium is an element subject to luxury consumption by certain crops especially tuber crops which respond well to the same, have the tendency to remove whatever the nutrient that is available over and above the requirement. This was well reflected by the higher size of tubers observed in the plots without potassium application. The increase in the number of tubers noted in the plots where K was applied during the period 60-100 DAP might be due to the efficient utilization of potassium taken up by the plants at this periods of growth. This is line with the report of Kabeerthumma *et al.* (1987) on the vegetative growth and tuber yield in cassava.

The treatment has no effect on dry matter production. All the treatments have recorded almost the same dry matter yield. However the maximum dry matter yield was observed for the plot without potassium applications. This could be

Tuber yield per plant

Tuber yield per plant

attributed to the highest availability of all nutrients in the experimental soil other than potassium in soil.

5.1.2. Yield at two stages

The yield recorded at two stages of growth showed that K has a significant influence on the tuber yield only at three months after planting. The maximum yield recorded was 24.15 t ha^{-1} at 60 kg K_2O application. However when the crop was harvested after another 20 days of growth, significant yield difference was not observed. The maximum yield recorded was in the same treatment as that observed at 100 DAP. Earlier studies on coleus have reported that it takes 3 ½ - 4 months to attain the maximum productive stage. Since this crop is photosensitive in nature, planting should be carried out during early August so as to harvest by November itself. Due to some technical problems the planting was delayed by three weeks even then the tuberisation might have over by November itself. Further there was not much difference in plant characteristics such as tuber number, size of tuber and tuber yield per plant between these two stages ie. 100 DAP and at harvest Thus it is confirmed that even though the planting was delayed the productive stage was over by three months period itself.

The high temperature, highest sunshine hours and heavy wind ("vrischika kattu") prevailed in the period caused the dryness of soil and these might have lead to the excess evaporation of water from tuber and plant parts which in turn reduced the tuber yield. Thus in the present study it can be concluded that yield recorded at 100 DAP, could be taken as the potential yield of the crop. Based on this view K applied @ 60 kg ha^{-1} can be taken as the requirement of the crop. Earlier studies have shown that in tuber crops the N: K ratio should be 1:1 to 1:1.3 for getting the maximum yield potential. The present result is in conformity with the findings of Rajendran *et al* (1976). Thus it can be concluded that 60 kg K_2O ha^{-1} is found to be the best dose for coleus in soils like laterite.

5.2. Soil analysis

5.2.1. Available nitrogen

At 60 DAP the maximum available nitrogen content of 766.22 kg ha^{-1} was recorded in the control plot. Even though there was significant effect for the treatment on the content of nitrogen there was not much difference between the treatments with 80 and 140 kg K_2O ha^{-1}. The initial high value recorded might be due to the high fertility status of the soil, and the fact that the organic manures and nitrogenous fertilizers were applied uniformly in all plots irrespective of treatments. At 100 DAP the nitrogen content in soil was decreased by 50 percent which indicates the uptake of nitrogen by the crop during the vegetative growth stage. At harvest all the treatments recorded almost the same nitrogen content. However, the highest value was recorded in plots with 80 kg K_2O ha^{-1}. It can be concluded from these results that, nitrogen content in the soil decreases with the crop growth and it is in conformity with the reports of Rani (2000) in cassava. Both K and N are found to be complimentary to each other, each enabling the release of one another.

5.2.2. Available phosphorus

Phosphorus content is soil recorded at 60 DAP was the lowest and thereafter it increased. At 60 DAP the available phosphorus status of the soil ranged from 33.70 kg ha^{-1} for the treatment with 60 kg K_2O ha^{-1} to 41.50 kg ha^{-1} with the application of 140 kg K_2O ha^{-1}. However at 100 DAP the content of P in the soil decreased with the increased levels of applied K. This is well supported by the negative correlation observed between available K and available P. The lowest value was recorded in the plot with 140 kg K_2O ha^{-1}. This could be attributed to the increased absorption and utilization of P along with the excess removal of K during the initial growth and establishment of the crop. Phosphorus nutrition is highly essential in the initial establishment stage rather than in productive stage (Mengel and Kirkby, 1984). This is very well evidenced by the increased P content in soil recorded at harvest compared to the previous stages. However, in all the three stages the treatment has no significant effect on soil phosphorus.

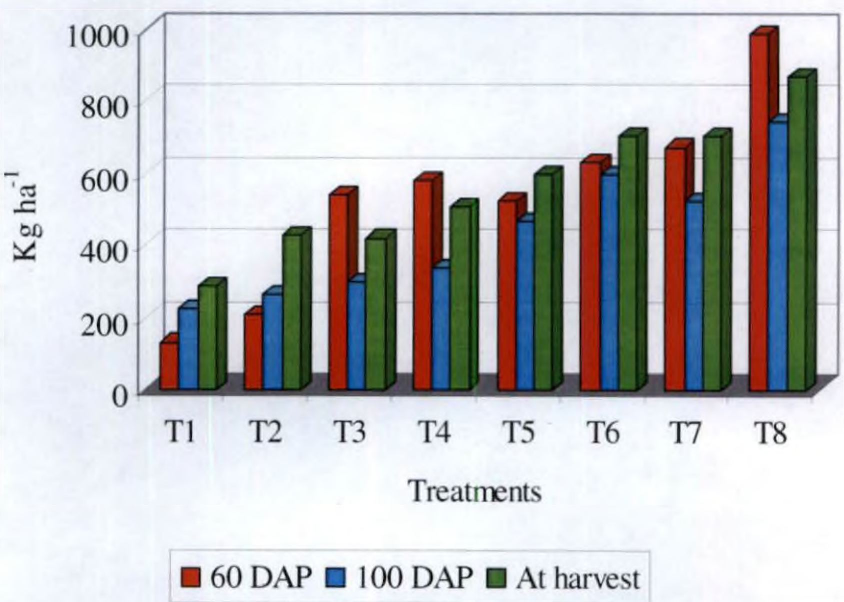
5.2.3. Available potassium

Observations noted on available potassium status of the soil clearly indicated the increase in its availability with the applied dose. There is a regular linear increase in the available K status of the soil from planting to harvest. At 60 DAP a maximum value of 984.67 kg ha^{-1} was noted in the plot with 140 kg K_2O application as against 130.67 kg ha^{-1} noted in the treatment without potassium application. The minimum value observed for the control could be attributed to the maximum absorption of K over and above the requirement by the present crop during the initial stage which is well reflected in the increased dry matter yield. In the second stage also, the maximum value was observed at the highest K application and there was about 33 percent increase over the control. In soil, solution K will depend upon equilibrium and kinetic reaction that occur between different forms of soil K, moisture content, and the concentration of divalent ions in the exchange phase (Sparks and Haung, 1985). The higher K content observed for the treatment might be due to the release of K from the native soil source i.e., release of K from nonexchangeable form or transfer of K from solution to exchangeable form. Similar results were reported by Krishnakumari *et al* (1984) and Gholston andHooner (1948).

5.2.4. Available calcium in soil

Exchangeable calcium content in the soil was found to decrease at the later stages of the crop growth. The treatment had no significant effect on the calcium in the initial stages of the crop growth. But it was significant at 100 DAP with a maximum value of 477 mg kg^{-1} for the treatment with 120 kg K_2O and minimum of 313 mg kg^{-1} for the treatment with 80 kg K_2O application. Thus at higher levels of potassium application more of calcium is released in the available form while at lower concentrations less of calcium will be released. This could be attributed to the

Fig.2. Available K content in soil



antagonistic effect of mono and divalent cations present in the soil. It was also due to the attainment of dynamic equilibrium between the different forms of potassium. Similar results were reported by Fageria (1983) and Sindhu (1997) in soils of rice field.

5.2.5. Available magnesium in soil

Exchangeable magnesium content of soil increased from planting to harvest. A maximum value of 49.66 mg kg^{-1} was recorded for both the treatments receiving 60 and 80 kg K_2O application at 60 DAP. Further the value got decreased with higher doses of K. This might be attributed to the antagonistic effect of K^+ on the release of Mg in soil. This is well evidenced by the negative correlation between Mg and K in soil. The treatments had no significant effect on the content of exchangeable Mg in the soil. However higher values were obtained at 3 months after planting. This is due to the increased uptake of Mg by the standing crop during the early stages of crop growth.

5.2.6. Available aluminium

Potassium had significant effect on the available Al content of the soil both at 100 DAP and at harvest and the variation was more pronounced at 100 DAP. This could be attributed to the preferential absorption of K^+ by the standing crop over Al during the crop growth between 60 and 100 days. At 100 DAP a maximum value of 62.12 mg kg^{-1} was recorded in the plot where no potassium has applied. Further a linear decrease in this content was observed with the levels of K. This might be due to the antagonistic effect of potassium on Al release in soil (Singh and Pathak, 2002). This is well reflected in significant positive correlation observed between Al and K. Higher concentration of K causes the release of adsorbed Al and that will increase its availability.

5.2.7. Iron

At 60 DAP, there was no response in the Fe content with the K application. However it had a significant effect at 100 DAP. A maximum value of 23.23 mg kg^{-1} was recorded for the treatment with 80 kg ha^{-1} thereafter it got reduced. This might be due to the increased demand for Fe during the vegetative growth of crop where it is needed as Co factor for many of the enzymes in plants. Potassium was found to influence the Fe content in soil to a particular level as it is evidenced by the positive correlation between Fe and K. At harvest the content was increased by two times irrespective of the treatment. The increase could be attributed to the increased solubilisation as well as the increased content in root exudates.

5.2.8. Available manganese

Potassium had significant effect on available Mn content in soil. The maximum value was recorded for the plot where K was applied @ 120 kg ha^{-1} followed by 80 kg K_2O application. Mn content was found to be decreased at only higher doses of K as evidenced by the lower content of Mn at 140 kg K_2O application than the control. The Mn content in the soil had greater influence on the availability of K. In laterite soil the content of Mn is high and it has significant influence in the availability of K (Seena, 2000). Since the experimental soil contained high quantity of manganese as compared to Fe and Al, large quantity of K is needed to suppress the effect of Mn and it is evidenced by the reduced content of Mn with 140 kg K_2O ha^{-1} which is reflected by the negative correlation between Mn and K. The same trend was observed at later stages of crop growth, though the effect was not significant.

5.3 Shoot Analysis

5.3.1. Total nitrogen

The nitrogen content in the plant at the initial stages of growth was highest for the treatment where no K was applied. At 60 DAP the maximum value recorded was 1.67 per cent as against 1.07 per cent noted in the treatment with maximum K application. The available N content of the soil under study before laying out the experiment was higher. Moreover the organic manures and nitrogenous fertilizers were uniformly applied in all plots irrespective of the treatment. At initial stages plants normally utilize the available forms of nutrients in the soil. At this stage there will not be any interaction with other nutrients either in antagonistic or synergestic form. But on ageing, the trend was reversed and the maximum content was recorded in those plots with higher doses of K application both at 100 DAP and at harvest as supported by the positive correlation between N and K at the later stages. At this stage applied K seems to have some synergestic effect on N availability. This agrees with the findings of Singh and Singh (1979). Thus during the crop growth the availability of K was found to increase with the levels of K and the effect of K was highly significant on total nitrogen content at all stages. The increased availability of N may be due to the suppressing effect of K on N fixation (ammoniacal form) in soil. Similar results were reported in cassava by Rani (2000) on nitrogen content in soil with the application of potassium.

5.3.2. Total phosphorus

At 60 DAP the phosphorus content in the plant recorded a maximum value of 0.112 per cent in the treatment which received maximum K application. The phosphorus content in the plant was highest during the initial stages (Mengel and Kirkby, 1984) and than that at 100 DAP and at harvest. The phosphorus was utilized to the maximum extent in the initial stages of the plant growth. At this stage the effect of applied K was well reflected in the P content. The highest content of P at 60 DAP is expected from the favourable effect of applied K on the absorption and utilization of P as evidenced by the positive correlation between P and K in soil. Thereafter even though the effect was significant, the content of phosphorus is much less. The results obtained are in confirmation with the findings of Rani (2000) in Cassava.

5.3.3. Total Potassium

The data on the total potassium content showed that the K content in the plant increased with doses of K application. At all the three stages the maximum content was recorded in the treatment with 140 kg K_2O ha^{-1} and the content varied significantly among the treatments with levels of K application. This could be due to the excess absorption of K by the crop and its utilization for tuberisation. This is in close similarity with the reports of Kabeerthumma *et al* (1987) in aroids. Even though the highest absorption was noticed in the treatment with 140 kg K_2O ha^{-1}, it had not reflected in the final yield as indicated by the insignificant positive correlation between K content in shoot and tuber yield. Luxury consumption may be the reason for the excess absorption and its accumulation in plants parts as reported by Rajendran *et al.* (1976) and Mohankumar *et al.* (1987) in cassava. The content progressively increased with advancement of plant growth starting from planting up to 100 DAP. Thus maximum absorption and utilization spread over 60-100 DAP. This result is in close conformity with the findings of Kabeerthumma *et al* (1987) on the content and utilization of K by Chinese potato.

5.3.4. Calcium and magnesium

Calcium content in the plant showed an increasing trend towards crop growth up to three months. Afterwards it got reduced. However the value observed at this stage was higher than the initial values. With respect to the influence of K, calcium content decreased with the levels of K applied. At 100 DAP the maximum content of 1.46 per cent was noticed in the plot with 80 kg K_2O ha^{-1} whereas at harvest highest was recorded in the treatment receiving 100 kg K_2O application. At all stages

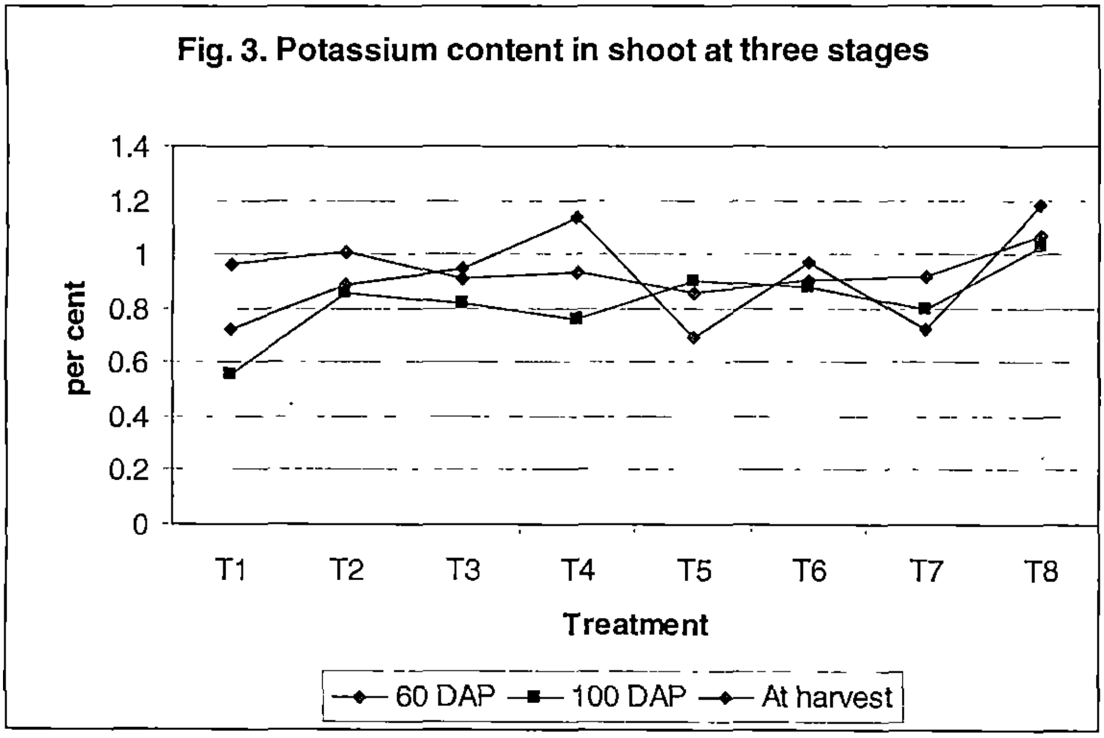


Fig. 3. Potassium content in shoot at three stages
1.4
1.2
1
0.8
0.6
0.4
0.2
0
per cent
T1
T2
T3
T4
T5
T6
T7
T8
Treatment
60 DAP
100 DAP
At harvest

slight increase in Ca content was noticed up to 100 kg K_2O ha^{-1}. Thereafter it got decreased. Thus lower concentration of K has some beneficial effect on the absorption of Ca (Fageria, 1983 and Sudhir *et al.*, 1987). At higher concentrations, due to antagonistic effect K will suppress the absorption of Ca. as reported by Menon and Marykutty (1993) on the availability of Ca in laterite soils of Kerala.

Like calcium, the content of magnesium in the plant first decreased and then increased with the crop growth. Even though maximum content was recorded in the treatment receiving 120 kg K_2O ha^{-1} both at 60 DAP and 100 DAP as indicated by the negative correlation between Mg and K. At harvest the trend was reversed by recording the maximum in the treatment where no K was applied. At lower concentrations K has synergestic effect on Mg and increased its absorption (Fajeria, 1987; Sudhir *et al.*, 1987 and Narwal *et al.*, 1985). However, at high concentration K has an antagonistic effect on divalent cations like Ca and Mg (Singh and Patak, 2002). Among these two Ca is preferred over Mg and that might be the reason for increased content of Ca over Mg. High content of Mg noted early at a 60 DAP might be attributed to the greatest demand of the growing crop for this element.

5.3.5. Iron

The Fe content in the plant was significant only at harvest stage. The maximum of 1463 ppm was recorded in the plot where K was applied @ 80 kg ha^{-1}. Fe content was much less in the plot where K was applied @ 140 kg ha^{-1}. During the crop growth it was observed that the absorption of Fe was higher in the initial stages and later on it decreased. This might be attributed to the translocation of nutrients from the plants parts to the produce. An inducing effect was observed for the absorption of Fe by the K applied. Maximum absorption and utilization occurs during the early stages of crop growth as the element is necessary for the physiological activities of the growing plant. This might be the reason for the reduced content of Fe in the second stage of observation. Potassium has the capacity to reduce the element to the ferrous from the ferric form thereby accelerating the uptake of the Fe in moist condition

(Sahrawat, 2003). This may the reason for the excess uptake and accumulation over and above the requirement at the later stages of growth.

5.3.6. Aluminium

At all stages of the crop K has significantly reduced the content of Al. This could be attributed to the antagonistic effect of K on Al. Both at 60 DAP and at harvest the highest value was observed for the treatment where no K has been applied. At 60 DAP the Al content decreased in the plant and at harvest it increased but less than that of initial stage. At 60 DAP Al recorded a maximum value of 1919 ppm and it got reduced to 1706 and 1555 ppm at 3 months after planting and at harvest respectively. The soil contains excess of exchangeable Al and there is chance for excess absorption over and above the requirement. And this might be reason for the increased content noticed in the plant parts at later stages.

5.3.7. Manganese

The content of manganese of the plant was significant only at 3 MAP. The manganese content recorded lower values at initial stages in comparison to other two stages. However in shoot there was a gradual increase in the content irrespective of K levels towards crop growth. Even though the soil contained excess of Mn and Fe, during early stages of growth the plant has the tendency to absorb preferably Fe rather than Mn and this causes reduction in the absorption of Mn in initial stage and in turn resulted in its less content in plant. Maximum content was recorded at harvest. At 100 DAP, the maximum content was observed in treatment with 140 kg K_2O application and the minimum in control. This could be due to stimulating effect of K on the release of Mn in the available form by way of reduction Mn^{4+} to Mn^{2+} (Sahrawat, 2003).

Even though the plant contained lower amounts of micronutrients and Al, plant has absorbed large quantities of the element. The absorption of micronutrient by plants is affected by many complex factors viz., environmental factors, which include temperature, moisture and the plant factors like absorption behaviour of plant and nature of root system etc. The highest quantity of Fe, Al and Mn observed in all the plots might be due to the particular reducing habits of roots and also the composition of root exudates.

5.4. Tuber analysis

5.4.1. Total nitrogen

Potassium has a significant effect on nitrogen content of tuber both at 100 DAP and at harvest and not at 60 DAP. In early stages of growth plants absorb nitrogen from the native soil source as the soil itself supplies ample amount of N. Further nitrogenous fertilizers and FYM were applied uniformly irrespective of treatment. This might be the reason for the lack of response to the applied levels of K at early 60 days of growth. The maximum value of 1.71 per cent was obtained for treatment with 80 kg K_2O ha^{-1} followed by 1.68 per cent at 60 kg K_2O ha^{-1}. The lowest value was observed at the highest level of K. At harvest all treatments recorded lower values of N than that in previous stages. Here also the maximum of 1.40 per cent was observed for the same treatment which received 80 kg K_2O application. The increased availability of nitrogen with adequate supply of K might be due to the reducing effect of K on the nitrogen fixation (Rani, 2000). The lack of response at higher levels of K might be due to some physiological imbalance between the various elements within the plant.

5.4.2. Total phosphorous

Phosphorous content in the tuber was significantly reduced at three months after planting with the levels of K application. However the highest value of 0.074 per cent was observed for the treatment with 120 kg K_2O ha^{-1}. It could be due to some other factors rather than potassium since all the treatments have a reducing tendency on the content of P. Even though the content of phosphorus was not significantly different both at 60 DAP and at harvest the control plot recorded the maximum value. The highest content of P observed both in tuber and shoot at the initial stages of crop growth thus confirms the need of P along with K for the initial plant establishment (Mengel and Kirkby, 1984).

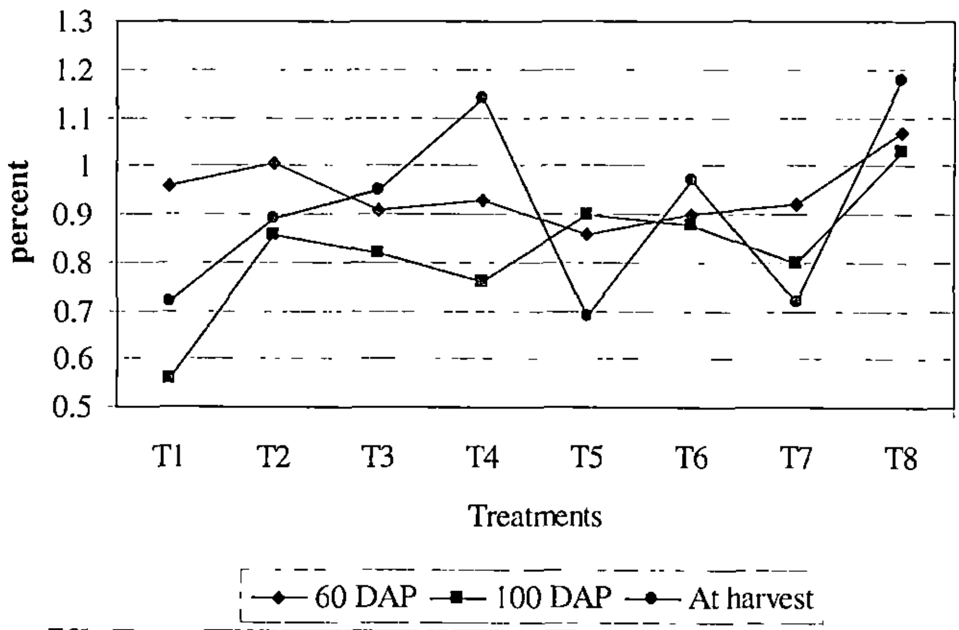
5.4.3. Total potassium

The applied K had no significant effect on K content in the tuber unlike in the shoot. On ageing K content got reduced in all the treatments. The soils of experimental site are high in available K. For the tuber crops K is needed for vegetative growth as well as for the formation of tuber. Further its translocation from shoot to tuber is limited. Thus it emphasizes the need for fertilization in the early stages of growth.

5.4.4. Calcium and magnesium

Potassium had significantly reduced the content of Ca and Mg in the tuber at three months after palnting. Both of these elements got reduced during the crop growth. The content of magnesium was minimum at harvest irrespective of the level of K. The calcium content had a minimum value of 0.113 per cent in the treatment receiving the application of 100 kg K_2O and the maximum value of 0.159 per cent was recorded in the control. In the case of Mg the minimum value of 0.071 per cent was noted in the same treatment as against 0.087 per cent for the control. The reduction in the absorption of these divalent cations might be due to antagonistic effect of K as evidenced by their negative correlations with K. This is in line with these reports of Fageria (1983) and Sindhu (1997). However slight increase in the content of both these elements was observed in treatments where K was applied in excess i.e.above 100 kg ha^{-1}. This could be attributed to the preferential adsorption of K in situations of its higher availability over Ca^{2+} and Mg^{2+} in the soil colloids and releasing Ca^{2+} to the soil solution.

Fig. 4. Potassium content in tuber at three stages



5.4.5. Iron

The iron content in the tuber varied significantly with the levels of K applied at all stages of growth. Initial absorption of Fe was high and it gradually decreased on ageing. At 2 MAP the maximum content of Fe was noted in T_6 which was much higher than that at all other treatments. The exceptionally high value recorded may be due to some other factors and not due to the sole effect of K. At 3 MAP the maximum Fe content was observed in the plots with 140 kg K_2O ha^{-1} and the value recorded was 1160 ppm. The effect of K is well projected at the second stage of observations as the maximum content was observed at 140 kg ha^{-1}. However the reduced content of Fe noted at harvest might be due to the lesser demand of Fe at productive stage. K has a beneficial effect on release of Fe to an available form. This is because K increases the reducing power at the root zone so that the ferric got reduced to ferrous form. Moreover the particular root system may also have reducing effect and also the root exudates might have reduced the ferric to ferrous forms (Sahrawat (2003) and Malewar (2005). The reduced content of Fe at harvest might also be due to lesser demand of Fe at the productive stage.

5.4.6. Aluminium

The content of Al in the tuber was influenced significantly by the levels of K at all stages. Similar to Fe content Al also decreased towards the harvest of the crop. The soil contains excess of exchangeable Al and hence more of K is needed to suppress its availability. This might be attributed to the increased absorption up to 120 kg ha^{-1}. The maximum value recorded was 2016 ppm at 100 kg K_2O ha^{-1} and beyond this level it got reduced. This is contradictory to the findings of Singh and Pathak (2002). The excess of exchangeable Al observed in the soil might be one of the reason for the higher absorption and accumulation in shoot and tuber at initial stages. At 3 MAP and at harvest the control plot recorded the maximum values. This could be due to the antagonistic effect.

5.4.7. Manganese

Potassium had significant influence on the content of manganese in the tuber only at initial stages and the maximum value was recorded in treatment with 20 kg K_2O. Both at 3 MAP and at harvest the content was reduced by 33 per cent and there was not much variation between two stages and there was no significant variation with respect to the levels of K. The higher content noticed at the initial stages might be attributed to the greater demand of Mn for better biochemical reaction which is expected to occur during the intial phases of growth as Mn is acting as a Co- factor for many of enzymes in the plant system.

5.5. Nutrient uptake.

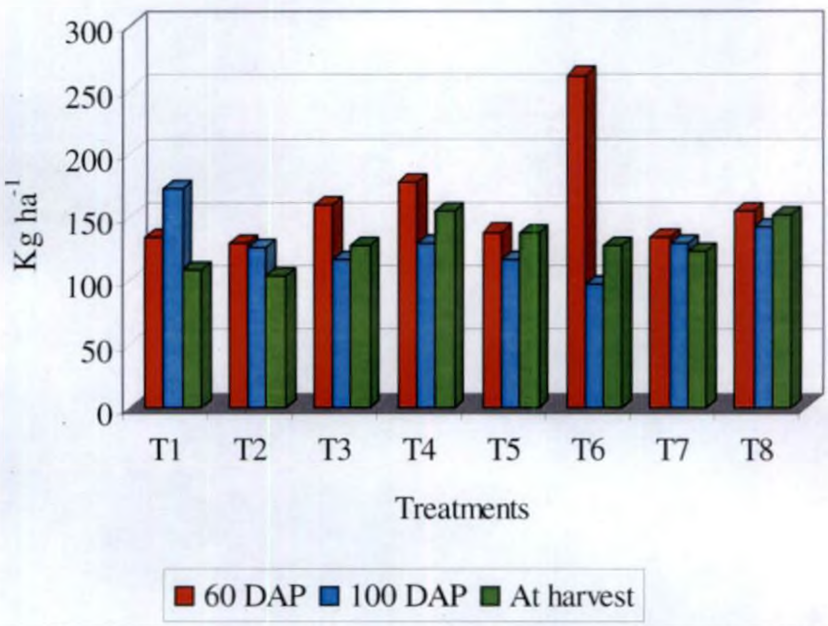
5.5.1. Nitrogen uptake

The uptake of nitrogen was significantly influenced by potassium at 3 MAP. The maximum N uptake was registered at 60 kg K_2O application and it got reduced beyond this level of K. The high concentration of K has an antagonistic effect on the availability of N (Garita and Jarmillo, (1984) and Sindhu, (1997)). This might be the reason for the reduced uptake of N when K was applied above 60 kg K_2O ha^{-1}. Even though the content of N both in shoot and tuber was significant both at 60 DAP and at harvest the K had no significant effect on the uptake of N.

5.5.2. Phosphorus uptake

Significant effect of K on P uptake was noticed only at initial stages of growth i.e., up to 2 MAP. At this stage maximum uptake was observed with 140 kg K_2O application. The higher uptake of P with highest level of applied K might be due to the stimulating effect of K on P (Muthuswamy *et al.*, 1974; De Datta and Gomez, 1982; Sheela and Aravindakshan, 1990; Sindhu, 1997). As the crop grows the content got reduced and no significant effect was noticed at later stages. This may be

Fig. 5. Potassium uptake



attributed to the greater demand for the element P for the initial growth and establishment of the crop (Mengel and Kirkby, 1984). Further the P absorption seems to be negligible.

5.5.3. Potassium uptake

Significant effect on K uptake was noticed at all stages except at harvest. The demand for almost all tuber crops including Chinese potato spreads over a period of three months. But the non significant effect of treatments on K uptake noticed at harvest might be attributed to the low dry matter yield recorded as well as the less utilization of K at the advanced stages of crop.

5.6. Availability indices of potassium

5.6.1. Extraction of potassium with chemical reagents.

The quantity of potassium estimated with different extractants at three critical stages of plant growth is depicted in Fig 6 to 13. At 60 DAP, the water soluble K varied from 42 to 85 mg kg^{-1} and there was a linear increase with the increased doses of potassium. The NH_4OAC extractable K ranged from 130 to 230 mg kg^{-1}. The NH_4OAC extractable includes exchangeable as well as water soluble K and it is considered as the immediately available form because it is loosely held in the colloidal complex in soil (Rao *et al.*, 2001). It is considered as a fair index of available K in soils (Rao and Sekhon, 1990).

At three months after planting with low doses of K and for the control water soluble K had decreased but with doses beyond 80 kg ha^{-1} slight increase was observed with a maximum value of 44 mg kg^{-1} in the treatment with 140 kg K_2O ha^{-1}. At 100 DAP the quantity of potassium extracted with all reagents recorded lower values than that in the first stage, indicating that the absorption by plants is maximum at this stage (60-100 days). Morgan's reagent extractable K is also available K which

Fig.6. Quantity of K exctracted in T_1 by different reagents at three stages

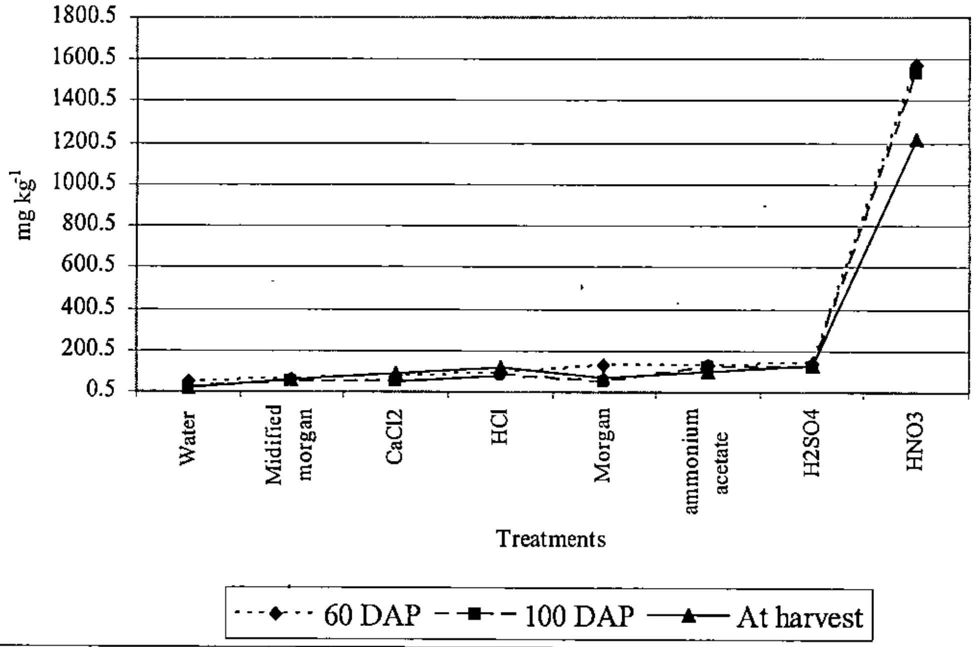


Fig.7. Quantity of K exctracted in T_2 by different reagents at three stages

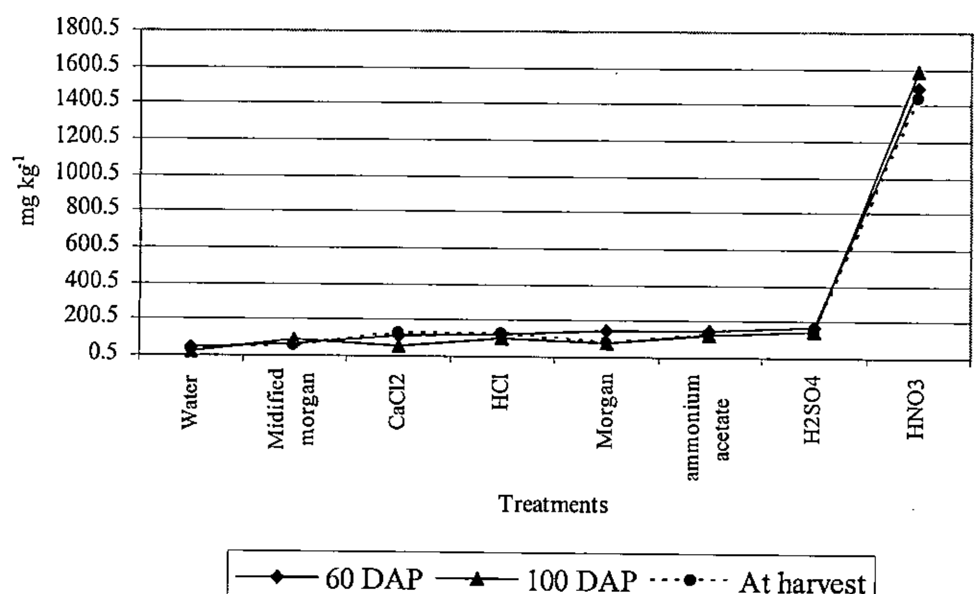


Fig.8. Quantity of K exctracted in T_3 by different reagents at three stages

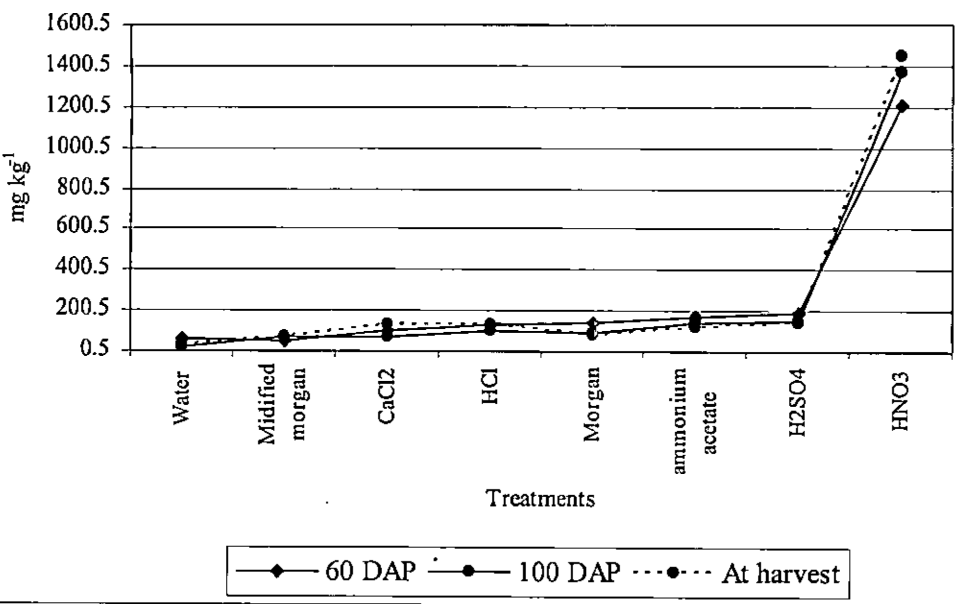


Fig.9. Quantity of K exctracted in T_4 by different reagents at three stages

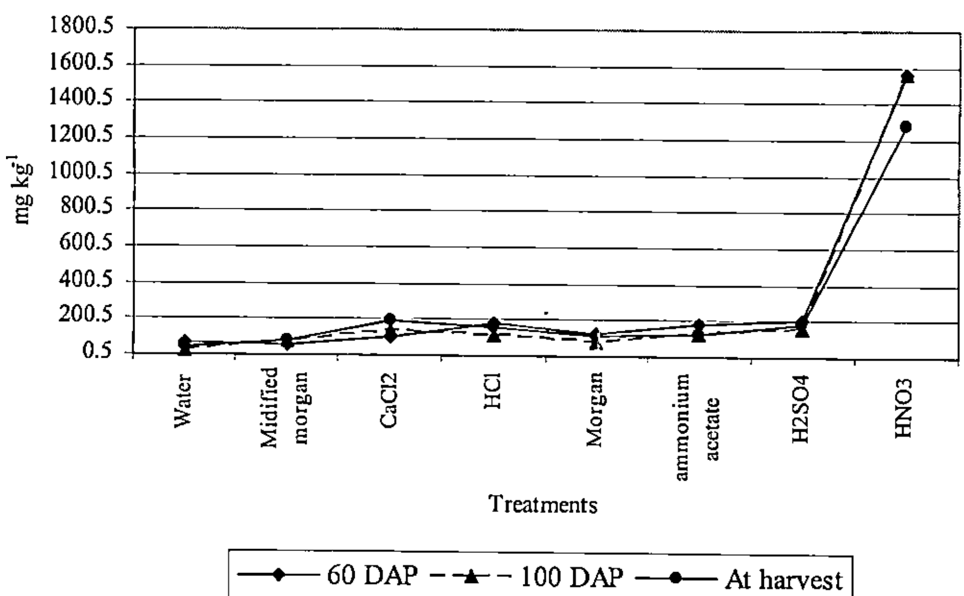


Fig.10. Quantity of K exctracted in T_5 by different reagents at three stages

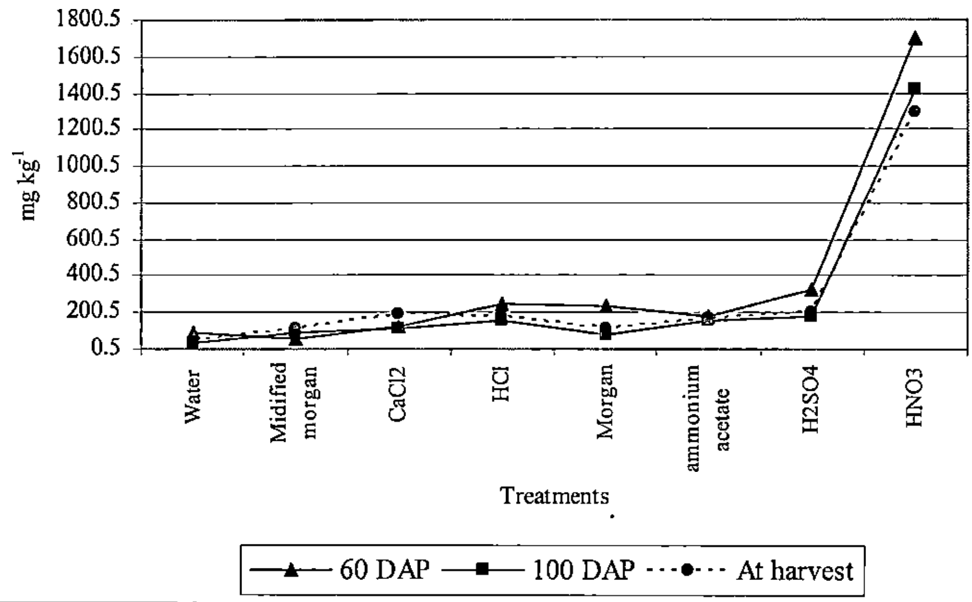


Fig.11. Quantity of K exctracted in T_6 by different reagents at three stages

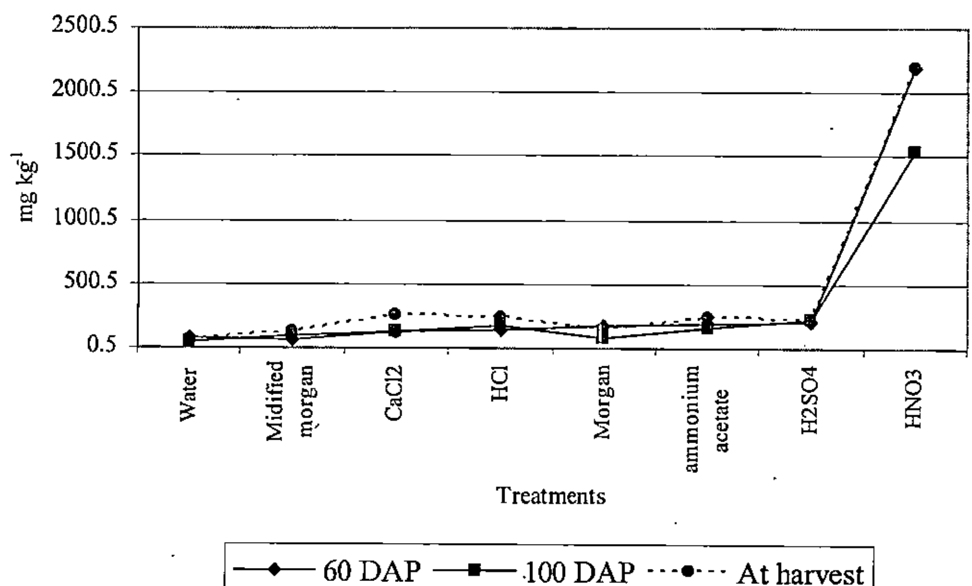


Fig.12. Quantity of K exctracted in T_7 by different reagents at three stages

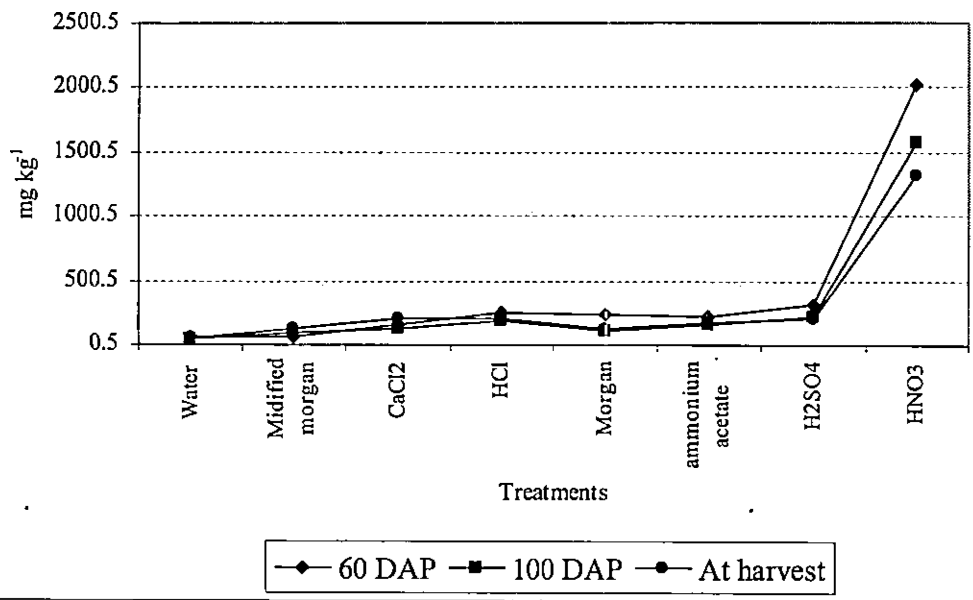
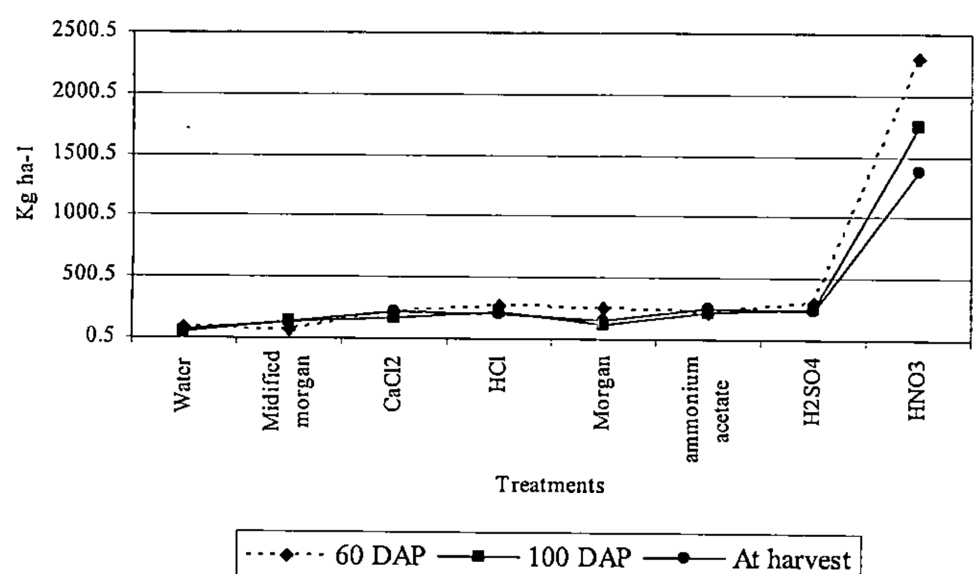


Fig.13.Quantity of potassium extracted in T_8 by different reagents at three stages



is loosely held in soil colloidal complex. Morgan's reagent extractable K was found to be increasing with the levels of potassium application. At 60 DAP the maximum of 254 mg kg^{-1} was recorded at 140 kg K_2O ha^{-1} as against the 125 mg kg^{-1} in the control.. At three months after planting all the treatments recorded lower values than that at the other two stages.

On comparison of the values with extractant NH_4OAC, sodium acetate is found to be less efficient and this is confirmation with the findings of Mariam (1986). In respect of the requirement of K by the growing crop, maximum utilization was during the growth after 60 days as indicated by maximum value in the second stage. The quantity of K extracted by NH_4OAC-pH 4.5 was less than that extracted by NH_4OAC-pH 7. At 60 DAP the maximum value observed was 76 mg kg^{-1} as against the 60 mg kg^{-1} for the plots with no K application. In the second and third stage the K extracted was found to be less up to 100 kg K_2O application. The reduction in value obtained was not to same tune as that estimated with 1N NH_4OAC-pH 7.

The amount of K extracted with 6 N cold H_2SO_4 represents the strongly held forms of K in soil. The acid releases a certain portion of non-exchangeable K due to the degradation of primary and secondary minerals other than exchangeable forms of K as indicated by the higher value obtained than that extracted with NH_4OAC. At all three stages H_2SO_4 extractable K was also found to increase with the levels of K application. At 60 DAP the maximum of 510 mg kg^{-1} was recorded in the treatments with 140 kg K_2O and the minimum of 143 mg kg^{-1} in the control plot. On comparison of the values at all the three stages it was seen that acid extractable K is less at the second stage compared to the other two stages. It was also observed that there is not much difference between the K extracted at higher doses at later two stages. This can be attributed to the lesser absorption of K from the excess that is applied.

The K extracted with 0.5 M HCl represents the slowly available K in the soil. The HCl extractable K is less than K extracted by H_2SO_4. The maximum value of HCl extractable K was recorded in the treatment with 140 kg K_2O ha^{-1} and the minimum in the control. Here also the extractable K had lower values than the other two stages. Potassium extracted with 0.01 M $CaCl_2$ represents the exchangeable K like the NH_4OAC pH-7. The maximum value of $CaCl_2$ extractable K was recorded at two months after planting. Here also the maximum value of 254 mg kg^{-1} was recorded in the treatment where K was applied @ 140 kg ha^{-1} as against the minimum value of 125 mg kg^{-1} in the control plot. On comparison of the data at three stages it was observed that K extracted is much less at the second stage. It also emphasizes the fact that maximum utilization of K is between 60 and 100 DAP.

Boiling with 1N HNO_3 releases K from non exchangeable reserves. This method is used to represent the fixed K by taking into account the water soluble and the exchangeable K. 1N HNO_3 extracted the higher amounts at all the three stages. At the productive stage slowly available potassium is of greater use as is evidenced by positive significant correlation recorded for HNO_3 followed by HCl and Morgan's reagent (Nambiar, 1972 and Grewal and Sharma, 1980).

Tuber girth and tuber yield were positively correlated with the K extracted by all reagents however significant correlation is noticed only with $CaCl_2$ (Havley, 1977). No significant correlation was observed between tuber yield and K extracted as K is only one of the factors that affect the tuber yield. At 100 DAP, H_2SO_4 and HCl extractable K were significantly correlated with tuber number, however tuber girth is significantly correlated with H_2O soluble K, Ammonium acetate etc. Maximum value was observed for Morgan's reagent, which shows that for the development of tuber the translocation of K from shoot to tuber occurs during the stages of growth. Hence the tuber yield per plant also seems to be positively correlated with K extracted by all reagents. At harvest, the slowly available K gives maximum correlation with the tuber number, tuber girth and tuber yield as it is indicated by the highest correlation obtained for H_2SO_4 ($r = 0.373$). This is in line with the report of Chatterjee and Maji (1984) and Nambiar (1972) and Ahmmed *et al* (1973). This shows that at later stages of growth when H_2O soluble and exchangeable K is exhausted, non exchangeable K is the major source from the plant.

Correlation studies taken up between the K content in the tuber, shoot and plant with K extracted by all the extractants, except 1N HNO_3 clearly indicated that at early stages the plant would absorb the available K of the soil reserve. This was very well indicated from the positive correlation obtained for all the extractant except 1N HNO_3. Further the uptake of K by whole plant had highly significant correlation with water soluble K as well as the modified Morgan's reagent suggesting that K in soil solution has a significant effect on the growth of plant. This result agrees with the findings of Rao and Sekhon, (1990) ., Brar *et al.*, (1986) and Perumal *et al* (1991).

Three months after planting the water soluble K got exhausted and the exchangeable K might be the sole source of K for the plants. This is well indicated by the positive correlation obtained between K content in the different plant parts with the K extracted by all extractants. However significant positive correlations were obtained only with K content in shoot and with total K in the whole plants.

On comparing K content in the plant parts, shoot K had highly significant correlation with all extractants except in 1N HNO_3. The significant effect noticed for 6N H_2SO_4 and HCl exhibit the release of even non exchangeable K in situations where exchangeable K is exhausted. Earlier reports also confirm these findings (Krishnakumari *et al.*, 1984, Gholston and Hooner, 1948, Datta and Sastry, 1987).

Even though positive correlation was observed between the K extracted by all reagents and K uptake it was not significant. As the dry matter yield was not affected by the levels of K as seen in the result, that might be attributed to the lack of significant correlation at 100 DAP. At harvest also the K extracted by all extractants was found to be positively correlated with K content in shoot, tuber and K uptake. However maximum correlation was obtained for 0.1M $CaCl_2$. In situations where easily available form of K got exhausted, the divalent ions, like Ca^{2+} have the greater replacing capacity. This is well projected by the significant positive correlation between K extracted by $CaCl_2$ and K uptake, K content in the whole plant.

5.6.2. Quantity- Intensity parameters of potassium

The intensity factor is a measure of K in soil solution that is immediately available for the absorption by plant root, since K^+ absorption is influenced by the activity of other ions. The quantity factor is a measure of the capacity of the soil to maintain a level of K in soil over a long period. The buffering capacity indicates how the potassium level in soil solution (intensity) varies with the amount of labile form of this element. Usually the Q/I curves describing the exchange of K with other cations, between solution and soil phase is constructed by plotting the change in K i.e. amount of K adsorbed or desorbed (ΔK) against activity ratio (AR). As the soil of the experiment site contained high amounts of exchangeable Mn, and Al than Mg the activity ratio is calculated by considering these cations also. It has been found that when Mn^{2+} was accounted along with Ca and Mg^{2+}, the relative activity of K got reduced. With this idea in mind the conventional activity ratio aK/a (Ca + Mg) ½ was modified as AK/a (Ca+Mg+Mn)½.. Fig. 13 and 14 represents the Q-I curve for potassium at two temperatures.

The AR_0^eK of soil estimated at 25°C and 40°C are 1.5 and 2.4 $(mol\ L^{-1})^{0.5}$ x 10^{-3} respectively which means that the soil is in high K category which was revealed from initial analysis of soil. In general soils with high content of labile K will have higher AR_0^eK. The low value of AR_0^eK at 25°C may be due to lower ionic strength of K in comparison to other cations which leads to the release small amount of K in to solutions. This is in line with reports of Lamm and Nafady (1971), Rao *et al.* (1982) and Roy *et al.* (1991).

The K_L values estimated at 25 and 40°C were 0.23 and 0.30 cmol(+) kg^{-1} respectively. These values are lower than exchangeable K (0.35 cmol(+) kg^{-1}) indicating that only a fraction (67 per cent) of the exchangeable K is readily replaceable with other cations meaning that only 67 per cent of K in capable of ion exchange during the period of equilibriation between soil solids and soil solution.

Fig 13. Quantity-Intensity curve of K at 25°C

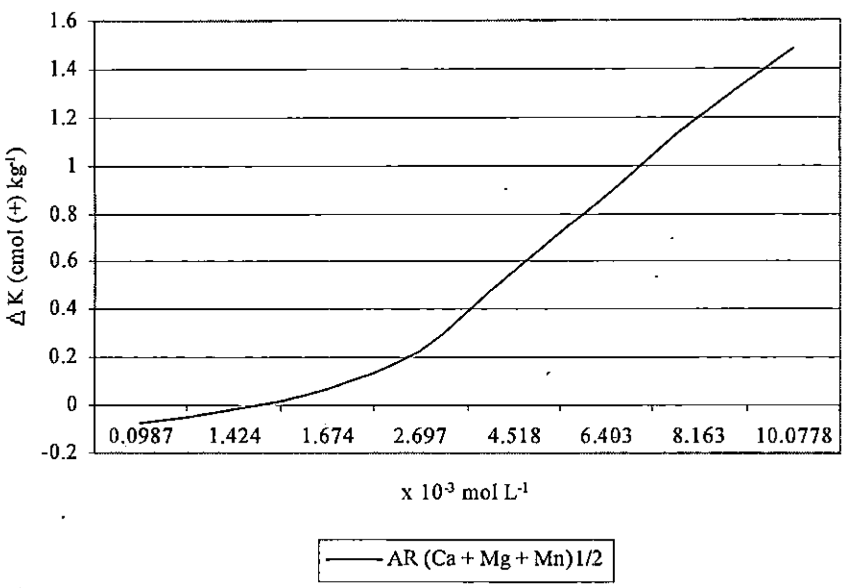
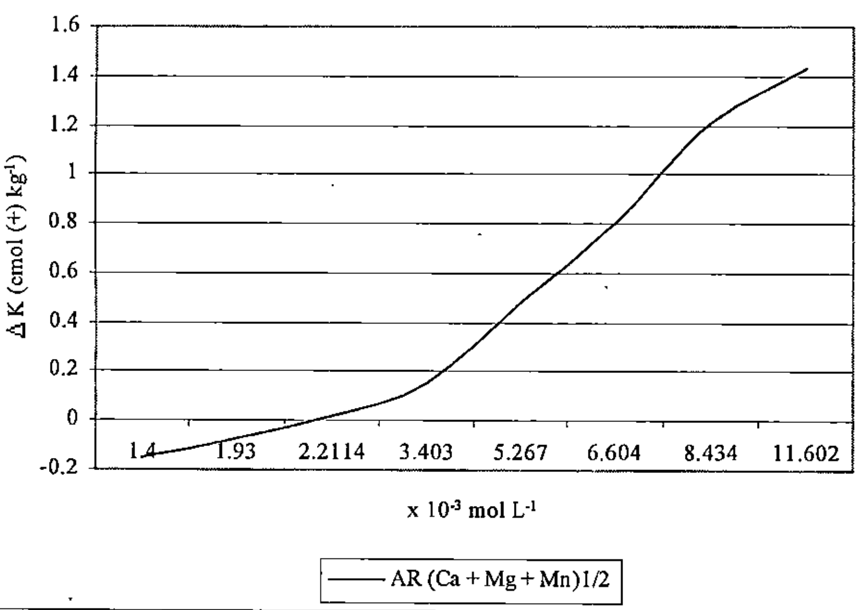


Fig. 14. Quantity-Intensity curve of K at 40°C



This is in close similarity with the reports of Rao *et al.* (1984) and Sharma and Mishra (1989). It was also noted that at 40°C labile K had increased indicating that there will be an increase in K availability at an increased soil temperatures.

The potential buffering capacity (PBC^K) estimated at two different temperatures were 53.3 and 47.5 cmol(+) kg^{-1}/ (mol L^{-1}) $^{0.5}$ respectively. The high content of native soil K may be the reason for appreciable PBC^K of the soil in present study. Thus is in conformity with the reports of Pal and Rao (1997).

The value of ΔF estimated at 25 and 40°C are -1.82 and -2.279 kcal mol^{-1} $degree^{-1}$ respectively. According to Woodruff (1955) classification the soil under study belongs to the category of soils with an ample supply of K. At 40°C the ΔF was reduced which means that the adsorption is exothermic in nature which in turn means that the free energy of exchange is low at high temperature, indicating that the adsorption is spontaneous at higher temperature. The practical significance is that there will be more K desorptions to the soil solutions in summer months when the soil temperature comes to about 35°C and more K availability to the plants than in winter months.

5.7. Adsorption Isotherm

An adsorption isotherm is a curve relating the concentrations of a solute on the surface of an adsorbant to the concentration of the solute in the liquid with which it is in contact. There are basically two well established types of isotherms, the Langmuir and Freundlich adsorption isotherms.

In the present study an attempt has been made to check whether the Q-I isotherm follow the above said classical isotherms and it has been observed that the positive adsorption Q-I curve follows only the Freundlich adsorption isotherm. This is in line with the report of Das *et al* (1993). Freundlich adsorption isotherm is one of the most widely used adsorption equation to describe the experimental data on adsorption of ionic or molecular species. Mathematically it is expressed by equation

$$\mathbf{X = KC^n}$$

where x is the amount adsorbed per unit surface of adsorbent and C is the equilibrium concentration of adsorbate. K and n are constants whose values are determined experimentally. The linear form of the equation is

$$\mathbf{\log x = \log K + n \log C}$$

Here x is the amount of potassium adsorbed by soil (c mol(+) kg^{-1}), C is the equilibrium concentration (mol L^{-1}), K (c mol(+) kg^{-1}) and n (mol L^{-1}) are constants. K is the amount of potassium adsorbed in mg kg^{-1} of soil when the equilibrium concentration of potassium is one ppm. The n and K values were determined from the slope and intercept of regression equation.

The equations for the curves are

at 40°C

$$\log x = -2.118 + 2.63 \log C \; (R^2 = 0.922^{**})$$

at 25°C

$$\log x = -1.165 + 1.672 \log C \; (R^2 = 0.970^{**})$$

The highly positive correlation between log x and log C indicates that K adsorption in the experimental soil obeys Freundlich adsorption isotherm at both the temperatures.

Summary

SUMMARY

A field experiment was carried out in the main campus of College of Horticulture, Kerala Agricultural University, Vellanikkara to study the availability indices of potassium in an Ultisol under the coleus cultivation. The experiment was laid out in a randomized block design with eight treatments and three replications. The treatments consisted of eight different levels of potassium. All other crop management practices were done uniformly in all plots as per the recommendation of KAU.

The growth characters such as plant height, number of tubers, tuber girth and tuber weight per plant were recorded at three stages viz., 60 DAP, 100 DAP and at harvest. The soil, shoot and tuber were analysed for the various nutrients at these three stages. The quantity of potassium extractable by various reagents was also estimated at these three stages. The Q/I parameters were estimated for the soil under study and the thermodynamic parameters related to K supplying power of soil were worked out.

- Tuber number was significantly increased with potassium application and the maximum number of tubers was observed in the treatment which received the application of 60 kg K_2O ha^{-1}.
- The tuber yield was increased significantly with the levels of K and the maximum tuber yield was recorded with the application of 60 kg K_2O ha^{-1}.
- The tuber girth, was not significantly affected with the graded doses of potassium.
- The application of 60 kg K_2O ha^{-1} registered maximum number of medium sized tubers.
- Significant difference in the increase of dry matter production was not observed with the increased levels of potassium.
- At the early stages, the availability of nitrogen decreased with increased levels of available potassium in soil. However, significant difference in soil N with respect to available K was not observed.

- Available phosphorus was not significantly varied with the various levels of K application.
- Available K in the soil increased with the levels of K application and it got reduced towards the harvest irrespective of the treatment.
- The available calcium content of the soils was influenced by potassium application only two months after planting.
- The magnesium content of the soil was not significantly influenced by potassium application at any of the three stages of analysis.
- The maximum available Al of 62.12 mg kg^{-1} was recorded in the treatment where the K was not applied and available Al was found to reduce with increased levels of potassium application.
- The maximum Fe content of 49.03 mg kg^{-1} was recorded in the plot with 140 kg K_2O ha^{-1} and the significant increase in the Fe content with the levels of K application was observed only at 100 DAP.
- Mn content in the soil was found to increase with the levels of K. However the significant difference in the available Mn was observed only at the initial stages of growth i.e., at 60 DAP.
- At 2 MAP the maximum nitrogen content of 1.67 per cent in shoot was observed in the control plot and it was found to reduce with the levels of potassium. A reduction in the nitrogen content in the shoot was observed towards harvest of the crop.
- The phosphorus in the shoot was found to increase with the levels of potassium in the initial stages of growth.
- Significant difference in the potassium content of shoot was observed only at 100 DAP. However regular linearity in the potassium content in shoot was observed with the levels of potassium.
- The calcium content in the shoot was found to reduce with the levels of K and the maximum of 1.31 per cent was registered in the control plot and at harvest it was 1.72 per cent.
- The aluminium content in the shoot significantly differed with the levels of available potassium at the initial stages of growth. The maximum content of Al

was observed in the control plot. Unlike Mn the aluminium and Fe absorption was found to reduce towards harvest.

- The total nitrogen and P content in the tuber was found to reduce towards harvest and the significant difference in the nitrogen content was noticed at 3 MAP and at harvest.
- The different levels of potassium application did not significantly influence the potassium content in tuber at any of the three stages.
- The calcium and magnesium content in tuber was significantly affected by the potassium application only at 100 DAP.
- Fe and Al contents in the tuber were significantly differed with respect to the potassium application at all stages of analysis and it was found to reduce from planting towards harvest.
- The Mn content in the tuber was high at the initial stages of growth and the significant difference was noticed only at this stage.
- The ratio of 1:1 was recorded for nitrogen and K uptake at 60 kg K_2O ha^{-1} where highest tuber yield was recorded.
- At all stages of analysis the quantity of K extracted with all reagents increased with the levels of potassium application in the soil.
- The water soluble, exchangeable and non-exchangeable potassium were reduced from initial stages towards harvest indicating the crop utilization and the presence of dynamic equilibrium between the various forms of potassium.
- Correlation studies conducted between yield attributes and quantity of K extracted revealed positive correlation between tuber yield and tuber number with water soluble and exchangeable K.
- Simple correlation coefficients were worked out between the potassium extracted with various reagents at 100 DAP with potassium content in the tuber, shoot and total K uptake. The study exhibited the existence of significant positive correlation between K content in plant and the quantity of K extracted. The suitability of reagents to assess K supplying power as judged from the correlation studies were in the order of $NH_4OAC \geq 0.5M\ HCl > 6N\ H_2SO_4 > 0.01M\ CaCl_2$ at 100 DAP.

- Correlation coefficient ratios between the total K uptake and quantity of K extracted at harvest followed the order 0.01M $CaCl_2$ > 6N H_2SO_4 > modified Morgan's reagent > Morgan's reagents > NH_4OAC.
- The quantity-intensity parameters estimated at temperatures viz. 25^0C and 40^0C showed that the desorption of potassium is more at higher temperature indicating the higher availability of K in summer season.
- The labile pool of potassium constituted only a fraction of exchangeable K indicating that all exchangeable K is not immediately available to the plants.
- The potassium adsorption of soil under study followed the Freundlich adsorption isotherm both at 25°C and 40°C.

The present investigation revealed a significant influence of potassium on the number of tubers and then to yield of coleus up to 60 kg K_2O ha^{-1} in soil under study. At the active stage, ammonium acetate and at later stage $CaCl_2$ were found to be the best extractants for assessing the K availability in soil. The adsorption of potassium in soil followed Freundlich isotherm and its release is higher during summer seasons as compared to other. However, elaborate field experiments are to be carried out in other areas of coleus cultivation to confirm the results obtained.

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AVAILABILITY INDICES OF POTASSIUM IN AN ULTISOL UNDER COLEUS CULTIVATION

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A field experiment was carried out in the main campus of College of Horticulture, Kerala Agricultural University, Vellanikkara to study the availability indices of potassium in an Ultisol under the coleus cultivation. The experiment was laid out in a randomized block design with eight treatments and three replications. The treatments consisted of eight different levels of potassium. All other crop management practices were done uniformly in all plots as per the recommendation of KAU. Observations on biometric parameters as well as yield attributes were recorded during the cropping period. The soil, shoot and tuber were analysed for the various nutrients. The quantity of potassium extractable by various reagents was also estimated at these three stages. The Q/I parameters were estimated for the soil under study and the thermodynamic parameters related to K supplying power of soil were worked out.

Tuber number and tuber yield were significantly influenced by the potassium application up to 60 kg K_2O ha^{-1}. The size of the tuber was not significantly affected with potassium application. Available potassium status that increased linearly with the levels of K did not affect the availability of P where as availability of N increased during the active growth stage of the coleus. Available potassium increased significantly with the levels of K application. Availability of exchangeable Al and Mn in soil got reduced with the increased levels of K. Even though the nitrogen and potassium content in shoot increased with the levels of K application at active stages of crop growth it had not reflected in the final yield. Calcium and aluminium absorption were found to reduce with increase in available K. Nitrogen and phosphorous content in the tuber reduced towards the harvest of crop. Calcium and magnesium content in tuber was influenced by K application where as K content in tuber was not increased with the levels of K.

At all stages of analysis the quantity of K extracted with all reagents increased with the levels of potassium application in the soil. The water soluble, exchangeable and non-exchangeable potassium were reduced from initial stages

towards harvest indicating the crop utilization and the presence of dynamic equilibrium between the various forms of potassium. Correlation studies conducted between yield attributes and quantity of K extracted revealed positive correlation between tuber yields and tuber number with water soluble and exchangeable K. The quantity-intensity parameters estimated at temperatures viz. 25°C and 40°C showed that the desorption of potassium is more at higher temperature indicating the higher availability of K in summer season. The potassium adsorption of soil under study followed the Freundlich adsorption isotherm both at 25°C and 40°C.