SYNERGISTIC EFFECT OF Na AND K ON YIELD AND NUTRIENT UPTAKE IN COLEUS (*Coleus parviflorus* L.)

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DECLARATION

I hereby declare that this thesis entitled "**Synergistic effect of Na and K on yield and nutrient uptake in Coleus (*Coleus parviflorus* L.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CONTENTS

LIST OF ABBREVIATIONS

@	At the rate of
B:C	Benefit:Cost
Ca	Calcium
CEC	Cation Exchange Capacity
cm	Centimeter
CD	Critical Difference
CTCRI	Central Tuber Crop Research Institute
cv.	Cultivar
$dS\ m^{-1}$	Deci Siemens per meter
EC	Electrical Conductivity
et al.	And others
Fe	Iron
Fig.	Figure
FYM	Farmyard manure
g	Gram
ha	Hectare
HCN	Hydrogen cyanide
HI	Harvest Index
K	Potassium
KAU	Kerala Agricultural University
KCl	Potassium chloride
$kg\ ha^{-1}$	Kilogram per hectare
LAI	Leaf area index
m^2	Square meter
mm	Millimeter
mg	Milligram
Mg	Magnesium
MOP	Muriate of potash
MSL	Mean sea level
N	Nitrogen
Na	Sodium
NaCl	Sodium chloride
P	Phosphorus
POP	Package of Practices
ppm	Parts per million
RLWC	Relative Leaf Water Content
spp.	Species
t	Tonnes
TSS	Total Soluble Solids
%	Per cent
^0C	Degree Celsius

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INTRODUCTION

1. INTRODUCTION

Potassium is one of the major nutrients required for the growth processes of all plants. Its content in plants varies between 1-4 per cent. Even though it is not a structural component, potassium is very essential for the plant growth because of its role in regulating many vital functions like carbon assimilation, enzyme activation, osmotic regulation, translocation of protein and sugars, disease resistance etc. Potassium is also important for improving the quality of fruits by maintaining desirable sugar/acid ratio, ripening of fruits and many other physiological processes.

In tuber crops the main function of K is starch synthesis leading to the promotion of tuber growth through the accelerated translocation of photosynthates from leaves to tubers. Compared to any other element, K plays the key role in the root yield of tuber crops by increasing photosynthetic efficiency. A high level of K increases leaf area duration and suppresses excessive leaf growth resulting in higher root yield (Hahn, 1977).

Coleus (*Solenostemon rotundifolius*, Syn. *Coleus parviflorus*) otherwise known as Chinese potato is supposed to be a native of Central East Africa; but it has adapted well in South East Asia including India and Sri Lanka. It is grown in most of the homestead gardens of Kerala and Tamil Nadu. The plant is a small, herbaceous, bushy annual with succulent stems and aromatic leaves, which attains a height of about 20-30 cm and belongs to the family Labiatae. The duration of the crop is about 5 months. The plant bears a cluster of dark, brownish, heteromorphous tubers, which is used as a vegetable. It has a prostrate or ascending stem, the leaves are thick succulent with aromatic smell.

In India, coleus tubers are used just like potato in curry preparations and are popular for its aromatic flavour. It can be baked like potato or made into chips. Coleus tubers are rich in carbohydrates (18-21 per cent) but low in protein content (1-1.5 per cent) on fresh weight basis. The tubers are also rich in minerals like Ca and Fe and contain certain vitamins including thiamine, riboflavin, niacin and ascorbic acid.

Coleus, being a tuber crop, its K nutrition is very important. Among the tuber crops, coleus has a comparatively high requirement of K than other elements. Considering the quality of tubers, coleus requires a special attention in that it has some medicinal properties besides its culinary value.

Potassium being an important nutrient for tuber crops, a good share of the cultivation expenses accounts for the cost of this nutrient alone. As an imported fertilizer, our country has to expend a major share of its income for K fertilizers. It will be highly economical if any other indigenous material can be used at least as a partial substitute for this costly fertilizer.

In several experiments conducted in the Kerala Agricultural University, it has been proved that Na can be used as a partial substitute for K (Mathew *et al.*, 1984; Prema *et al.*, 1987; George, 1995; Joggy, 1995; Lekshmi, 2000; Sunu, 2001; Sudharmaidevi *et al.*, 2003). Beneficial influence of substitution of K by Na on growth of plant has also been reported by Nair *et al.* (1980) in cassava and Elsie *et al.* (2000) in rubber. Under limited K supply, Na can perform some of the normal functions of K such as maintenance of ionic balance, which is necessary for physiological processes (Tisdale *et al.*, 1992). The beneficial effect of Na has been explained as a sparing action of K through redistribution of K from places of abundance to those of deficiency. Several research works revealed the facts that Na^+ can stimulate K^+ transport by a moderate amount and it is most evident at low levels of K (Box and Schachtman, 2000; Hayes *et al.*, 2001).

Growth stimulation by Na is caused mainly by its effect on cell expansion and on the water balance of the plant. Due to higher supply of sodium to the plants, the leaves become more succulent, thicken and store more water per unit leaf area. Also Na improves the water balance of plants when the water supply is limited. This occurs through stomatal regulation. In this experiment, the plant used (coleus) is a herbaceous succulent plant. Since Na has a role in water economy of the plant, it will favourably influence the growth of coleus plant. Being a tuber crop the requirement of K for tuber growth is very high. Hence this study was undertaken with the following objectives:

1. To find out the synergistic effect of Na and K on the growth and yield of coleus, a tuber crop.
2. If there is such a synergistic interaction, then to find out the optimum levels of these two nutrients to get the maximum yield.
3. To find out the economically most suited nutrient combination giving optimum yield.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Potassium is a very important nutrient for the normal growth and development of all plants. Generally tuber crops have a high requirement of K. Among the important tubers, coleus (*Solenostemon rotundifolius* Syn. *Coleus parviflorus* L.) has the highest requirement of K. According to several studies, tuber development mainly depends on the availability of K (Mayer and Anderson, 1970; Ashokan and Sreedharan, 1977). Similar to K, Na, which is also a univalent cation has shown some beneficial effect on the growth of several plant species (Brownell, 1965). The substitution of K by Na was found to have a favourable influence on plant growth of sweet potato (George, 1995) and cassava (Sudharmaidevi and Padmaja, 1996a). Hence the synergistic effect of Na along with K was investigated by conducting field experiments with coleus. Literature relating to the effect of K and Na on various plant growth and yield parameters of different crops is reviewed in this chapter.

2.1 GROWTH CHARACTERISTICS

2.1.1 Plant Growth

2.1.1.1 Effect of Potassium

In cassava, Pillai (1967) observed significant increase in height with K and Ca application. Potassium application in potato was found to increase the height of the plant (Rajanna *et al.*, 1987). Similar results were obtained by Ashokan *et al.* (1988) and Jimenez (1990) in cassava. But Pushpadas and Aiyer (1976) observed that height of cassava plant decreased with K application. Similar results were observed by Gupta (1992) in potato, Ray *et al.* (1993) in banana and Singh *et al.* (1993) in potato.

In an experiment, Janardan Singh *et al.* (2000) found that better K nutrition resulted in increased plant height and growth in rice and wheat.

Wakeel *et al.* (2002) reported a similar result in maize. But contrary to this, in potato Sobhani *et al.* (2002) noticed that K had minimum effect on plant height. Behura (2001) reported that there was no significant effect on plant height due to the application of K in mango ginger.

2.1.1.2 Effect of Sodium

Besford (1978) noticed that there was no reduction in growth rate in tomato plant when sodium was present up to 2.4 per cent of dry weight. While studying the effect of NaCl in cassava, a concentration of 0-400 ppm NaCl resulted in reduced plant growth and tuber initiation occurred at 2000 ppm and above levels of NaCl (Indira, 1978).

In *Acacia nilotica* plants, Nabil and Coudret (1995) observed that upto 100 m M NaCl concentration, plants were healthy and actively growing. However, the growth decreased as the salinity increased. In a study of substitution of K by Na in sweet potato, it was found that maximum length of vines was produced when, 50 per cent of K was substituted by Na (George, 1995). In another experiment, Sudharmaidevi and Padmaja (1996a) found that the growth in cassava was maximum when 50 per cent K as muriate of potash was replaced with Na of common salt.

Khan *et al.* (1997) developed a negative correlation between the NaCl concentration and relative value of plant height in rice. Karikalan *et al.* (1999) observed that in pigeon pea, the NaCl stress inhibited the root and shoot length of plants. Lekshmi (2000) observed that, in banana cv. Nendran, plant height was maximum at flowering and harvest stages when 50 per cent of K was substituted with Na. But beyond that substitution, plant height decreased.

Sunu (2001) found that when 50 per cent K was substituted by Na, the growth and height of the plant significantly increased in banana cv.

Robusta. Tozlu *et al.* (2004) observed that a linear relationship exists between stem elongation and salt concentration in *Poncirus trifoliata*.

2.1.2 Number of Leaves and Branches

2.1.2.1 Effect of Potassium

Ashokan *et al.* (1988) reported that N and K_2O application increased the number of leaves per plant in cassava. But Pushpadas and Aiyer (1975) found no significant effect between number of leaves and K application in cassava. Similar results were reported by Rajanna *et al.* (1987) and Singh *et al.* (1993) in potato and Ray *et al.* (1993) in banana.

The number of branches in sweet potato was found to increase with K application with a maximum at 100 kg K_2O ha^{-1} (Oommen, 1989). Sudhadevi (1990) in an experiment with 50, 75 and 100 kg K_2O ha^{-1} found that the number of branches was not influenced by different levels of K in sweet potato. Similar result was reported by Nair (1994) in sweet potato.

Increased levels of K resulted in an increasing trend on the total number of leaves and the number of functional leaves in banana cv. Nendran (George, 1994) and cv. Robusta (Parida *et al.*, 1994) respectively. Janardan Singh *et al.* (2000) reported that there was an increase in the number of shoots due to increased application of K in wheat and rice.

2.1.2.2 Effect of Sodium

In coconut palm the number of leaves increased when 50 per cent K was substituted with Na (Prema *et al.*, 1987). A decrease in number of leaves with an increase in NaCl concentration was reported by several research workers (Yaseen *et al.* (1989) in barley, Yang *et al.* (1990) in sorghum, Ibrahim *et al.* (1991) and Mangal *et al.* (1993) in potato, Valia *et al.* (1993) in passion fruit, Nabil and Condret (1995) in *Acacia nilotica*, Sharma (1997) in chick pea and Sharma *et al.* (1997) in sugarcane). George (1995) observed that 50 per cent substitution of K by Na produced more number of leaves in sweet potato. In a study of NaCl nutrition in coconut, it was found that NaCl @ 1kg $tree^{-1}$ $year^{-1}$ along with the recommended dose of NPK significantly increased the number of functional leaves (Devasenapathy *et al.*, 1996).

Rawat and Banerjee (1998) observed that salinity treatment in *Eucalyptus camandulensis* and *Dalbergia sissoo* resulted in significant variation in leaf number, which generally increased at lower salt levels but decreased at higher salt levels.

In banana cv. Nendran, Lekshmi (2000) observed that there was maximum number of leaves when 50 per cent K was substituted with Na of common salt. Sunu (2001) observed that there was no significant increase in the number of leaves due to Na treatment in banana cv. Robusta. Babu and Thirumurugan (2001) reported a reduction in number of leaves in sesame due to increased NaCl concentration.

2.1.3 Leaf Area Index

2.1.3.1 Effect of Potassium

Kulia *et al.* (1992) observed in mustard (*Brassica juncea* L.) that application of N and K increased the leaf area significantly. Chakrabarthy *et al.* (1993) reported that LAI and Leaf Area Duration gradually increased in sweet potato cultivars up to 90 days with enhanced K levels. But Singh *et al.* (1993) found that increase in the levels of K had no significant effect on leaf area per plant in potato. Similar observation was made by White (1993) in rye plant. Janardan Singh *et al.* (2000) reported an increase in the leaf area due to increased K supply in wheat and rice.

2.1.3.2 Effect of Sodium

Maliwal and Paliwal (1979) found that increased salinity resulted in decreased length and width of leaves of carrot and radish. Similar results were obtained by Kayani and Rahman (1988) in maize and Yaseen *et al.* (1989) in barley.

In *Sorghum bicolor* and *Sorghum halepense* as NaCl concentration increased, the leaf area was found to be decreased (Yang *et al.*, 1990). Similar results have been reported by Pezeshki and Pan (1990) in rice, Ibrahim *et al.* (1991) in coleus and Valia *et al.* (1993) in passion fruit.

Nabil and Coudret (1995) observed that at salinity above 100 m M NaCl, the growth of *Acacia nilotica* subspecies decreased. But in cassava 50 per cent substitution of K by Na recorded maximum LAI at all stages of growth of the plant (Sudharmaidevi and Padmaja, 1997). A reduction in the leaf area of chickpea was reported by Sharma (1997) at high levels of salinity. Similar results were reported by Sharma *et al.* (1997) in sugarcane, Pardossi *et al.* (1998) in *Apium graveolens* and Karikalan *et al.* (1999) in pegeon pea.

Lekshmi (2000) reported that maximum LAI was obtained when 50 per cent K was substituted by Na in banana cv. Nendran. A similar result was reported by Sunu (2001) in banana cv. Robusta. Nandini and Subhendu (2002) reported that application of NaCl resulted in decreased total leaf area in mungu bean. Ashrafuzzaman *et al.* (2002) found that the leaf area of maize reduced when salinity increased.

2.1.4 Relative Water Content in Leaves

2.1.4.1 Effect of Potassium

Potassium is essential for regulating the water economy inside the plant cell. Reduction of transpirational water loss through stomatal regulation and improved water use efficiency of plants with application of K was reported by Blanchet *et al.* (1969).

Skogley (1976) has shown that barley plants well supplied with potassium closed their stomata in 5 minutes and reduced transpitational loss of water. Potassium enriched cowpea seedlings showed high relative water content (Sastry, 1982). Application of K has been found to reduce transpirational losses in the crop receiving a restricted water supply (Nelson, 1982).

Prasad *et al.* (2000) noticed that increasing doses of K significantly enhanced the water use efficiency at all moisture levels in mungu bean. This may be due to the favourable effect of K on osmo-regulation of crop under stress.

2.1.4.2 Effect of Sodium

Leaf water content and salinity showed a negative correlation in *Tradescantia albiflora* (Nejad, 1988), in finger millet (Onkwara, 1990) and in rice (Flowers *et al.*, 1991). Ashraf (1989) reported that as salinity increases water content also increases. Decreased transpiration due to the increased stomatal closure is the reason for increasing the water content in plant tissue due to salinity (Ziska and Hutmacher, 1989).

Increase in leaf water potential, with low levels of salinity in barley seedlings was reported by Dhindwal *et al.* (1992). Leaf water potential decreased linearly with increasing salt concentration in *Melilotus indica* reported by Ashraf (1993). Al-Harbi and Burrage (1993) reported that at high salinity levels, plant water uptake and relative water content were significantly reduced in cucumber (*Cucumis sativus*).

In *Lycopersicon pimpinellifolium*, leaf succulence as well as leaf water content of salinized plants increased significantly (Guerrier, 1996). Similarly, in *Apium graveolens*, Pardossi *et al.* (1998) reported an increase in leaf water potential when the plants were treated with 50 m M NaCl.

Sudharmaidevi and Padmaja (1997) reported that when 50 per cent K was substituted by Na, there was a high status of relative water content throughout the growth period of cassava. A similar result was obtained by Sunu (2001) in banana cv. Robusta.

2.1.5 Chlorophyll Content

2.1.5.1 Effect of Potassium

Increased K supply was found to increase the chlorophyll concentration in the leaf of spring wheat (Forster, 1976). But in spring barley, increased K supply decreased the chlorophyll concentration (Votruda and Kase, 1979).

In alfalfa, a linear increase in chlorophyll concentration with increased application of K was reported by Collins and Duke (1981). Patil *et al.* (1987) also reported a positive relationship with chlorophyll content of the leaves of tobacco. In an experiment, Janardan Singh *et al.* (2000) revealed that increased K supply increased the chlorophyll content of leaf in wheat and rice.

2.1.5.2 Effect of Sodium

The stimulative effect of salinity on chlorophyll production was reported by several workers in different plants. In many plants total chlorophyll content was found to increase as a result of increased salinity (Parasher and Varma, 1987; Abdullah and Ahmad, 1990; Dhindwal *et al.*, 1992). But negative response has also been reported by many scientists (Pandey and Saxena, 1987; Ashraf, 1989; Legaz *et al.*, 1993).

Amaranthus tricolor L. developed a high chlorophyll content in the leaves when treated with Na (Ohta *et al.*, 1987). A study by Ando and Oguchi (1990) revealed that chlorophyll content increased because of the involvement of Na in the chlorophyll synthesis.

An experiment conducted by Sudharmaidevi and Padmaja (1997) revealed that chlorophyll content increased with increasing levels of Na substitution in cassava showing the role of Na in the chlorophyll biosynthesis in the plants. But in cluster beans, Garg *et al.* (1997) reported a negative relationship between chlorophyll content and salinity.

In *Eucalyptus camaldulensis* and *Dalbergia sissoo*, Rawat and Banerjee (1998) noticed that at lower levels of salinity there was an increase in chlorophyll concentration but higher salinity reduced its content. In an experiment, Pushpam and Rangaswamy (2000) found that total chlorophyll, chlorophyll a, chlorophyll b and chlorophyll a/chlorophyll b ratio increased with increasing NaCl concentration up to 1 per cent. Babu and Thirumurugan (2001) in sesamum and Sultana *et al.* (2002) in rice reported a reduction in chlorophyll content due to increased salinity.

Goyal *et al.* (2002) reported that the total chlorophyll content increased with increasing salinity in Indian mustard at all growth stages. Similar result was reported by Kamal *et al.* (2003) in soybean (*Glycim max* L.).

2.2 YIELD AND YIELD ATTRIBUTES

2.2.1 Effect of Potassium

Potassium plays a key role in improving yield and yield attributes. Ashokan and Sreedharan (1977) reported a progressive increase in the tuber yield of cassava up to 112.5 kg level K_2O beyond which there was a significant reduction.

Aiyer and Prabhakumari (1983) found that tuber yield increased with increased application of K_2O up to 100 kg ha^{-1} in cassava. Ashokan *et al.* (1984) reported a quadratic response with respect to tuber yield in sweet potato due to K application. Rajanna *et al.* (1987) noticed a significant yield difference at different levels of K in potato.

Uebel (1992) reported marked yield increase in potatoes at all sites in response to K fertilization. Chakrabarthy *et al.* (1993) noticed that there was a significant increase in the yield of sweet potato with addition of K up to 60 kg ha^{-1}, but higher doses failed to increase the tuber yield.

George (1994) reported a significant high yield of banana cv. Nendran when treated with K at 225 g $plant^{-1}$. Sheela (1995) noticed increased length and weight of fingers with increasing levels of K in tissue cultured banana cv. Nendran. Sindhu (1997) obtained the highest bunch weight and number of fingers per bunch at 450 g K_2O plant^{-1} compared to other lower doses. Janardan Singh *et al.* (2000) reported that yield of wheat was significantly higher with better K nutrition.

Sobhani *et al.* (2002) reported that K application increased the crop yield and biological yield in potato. K has a minimum effect on tuber plant^{-1} but it increased the average tuber weight. Similar result was reported by Saifullah *et al.* (2002) in wheat.

2.2.2 Effect of Sodium

Hamid and Talibudeen (1976) found that yield of barley and sugar beet were increased but that of broad bean was adversely affected by the application of Na. Maliwal and Paliwal (1979) observed that the tap root yield of carrot and radish regularly decreased with increase in salt concentration. Nair *et al.* (1980) recorded higher tuber yield at 200 kg NaCl ha^{-1} out of the 3 levels *viz.*, 200, 400 and 600 kg NaCl ha^{-1} in cassava.

Mathew *et al.* (1984) reported that in coconut, substitution of K_2O by Na_2O to the extent of 50-75 per cent could maintain yield as at 100 per cent K. Prema *et al.* (1987) reported that when K was substituted with Na to the extent of 0-100 per cent, the treatments did not influence the copra weight nut^{-1} significantly.

Quadar (1988) reported that grain yield was adversely affected with increasing levels of sodicity stress in rice. Alam *et al.* (1989) observed that fruit yield of tomato was significantly reduced with increase in salinity levels. Abdullah and Ahmad (1990) reported that salinity reduced the weight of tuber per plant in potato. Tuber yield in potato was found to be inversely related to soil salinity (Mangal *et al.*, 1993).

Higher salinity was found to reduce the yield of crops significantly as reported by Hocking (1993) in sorghum, Garg *et al.* (1997) in Indian mustard, Palaniappan and Yerriswamy (1996) in potato, Lesch *et al.* (1996) in wheat, Sharma *et al.* (1997) in sugarcane and Maliwal (1997) in wheat.

George (1995) observed that all the yield contributing characters like number of tubers $plant^{-1}$, length and girth of tubers were the highest at 50 per cent substitution of K by Na in sweet potato. In cassava, Sudharmaidevi and Padmaja (1996a) reported maximum yield when 50 per cent of the K was substituted by Na as common salt. But, 100 per cent substitution by Na reduced the yield.

Increase in bunch yield of banana cv. Nendran at 50 per cent substitution of K by Na as common salt was reported by Lekshmi (2000). Daniells *et al.* (2001) reported a reduced yield of sorghum (*Sorghum bicolor*) at higher levels of salinity. Sunu (2001) reported increase in yield of banana cv. Robusta at 50 per cent substitution of K by Na. Ghosh *et al.* (2001) reported that salt stress decreased the total and marketable tuber yield due to the decrease in the tuber number per plant and average tuber weight.

Akram *et al.* (2002) found that as the NaCl salinity increased the number of spikelets per spike, number of grains per spikelet and yield $plant^{-1}$ decreased in wheat. Kaya *et al.* (2002) reported that strawberry plants grown at higher levels of NaCl had less fruit yield than those grown in normal nutrient solution. Callu (2003) reported that increased salinity above the threshold for cotton and wheat resulted in a linear decrease in the crop yield.

2.3 DRY MATTER PRODUCTION

2.3.1 Effect of Potassium

Ashokan and Sreedharan (1977) found that dry matter production in cassava (variety H 97) was maximum at 112.5 kg levels of K_2O ha^{-1}. In banana cv. Williams, Turner and Barkus (1980) found that K deficiency resulted in a reduction of 79 per cent in the total dry matter production of fruits. Increased levels of K were found to increase the total dry matter content in banana cv. Palayamkodan (Sheela, 1982).

Sheela *et al.* (1990) reported that increased application of K increased the dry matter production in banana cv. Palayamkodan. Sharma and Ezekiel (1993) noticed that application of K increased the dry matter content in potato. At higher levels of K dry matter content decreased. But in wheat higher levels of K increased the dry matter content (Singh *et al.*, 1993).

Total dry matter production was found to be maximum in the treatment with 600 K_2O $plant^{-1}$ in banana cv. Nendran (George, 1994). Janardan Singh et *al.* (2000) found that increased K supply increased the total dry matter production in wheat and rice.

2.3.2 Effect of Sodium

According to Brownell (1965) dry matter production in *Atriplex vesicaria* increased four times when fertilized with Na. In sugar beet when Na was applied along with other nutrients, plant growth was increased (El-Sheikh *et al.*, 1967). Warcholowa (1971) observed that Na application increased the dry matter yield of roots and the effect was the greatest when K was moderately deficient and also when 50 per cent K_2O and 50 per cent Na_2O were supplied.

An inverse relationship between NaCl concentration and dry matter production was noticed by Chavan and Karadge (1980) in peanut. Khanna and Balaguru (1981b) found that dry weight of shoot, collar and root of wheat increased significantly with the application of Na up to 5 m M^{-1}. A negative response for dry matter yield of shoot and spikes in wheat with increasing salinity was reported by El- Sherbeiny *et al.* (1986).

In an experiment to study the reaction of two pea (*Pisum sativum*) varieties to Na substitution for K, Fakultet and Sad (1988) observed that the dry matter production was the highest when 20 per cent K was substituted with

Na. Ohta *et al.* (1987) recorded the highest fresh weight in *Amaranthus tricolor* when supplied with equal parts of NaCl and KCl.

Figdore *et al.* (1989) reported that plant dry weight was not reduced in tomato plants under low K stress when replaced with Na. But at toxic levels of Na, reduction in plant dry weight was observed.

Abdullah and Ahmad (1990) reported that salinity reduced the shoot growth in potato. Ahmed *et al.* (1993) observed a progressive reduction in the dry matter production with increasing NaCl concentration in *Brachiaria mutica*. Similar results were obtained by Alfocea *et al.* (1996) in tomato, Maliwal (1997) in wheat, Remadevi and Gopalakrishnan (1997) in cowpea, Choudhury *et al.* (1998) in sugarcane and Karikalan *et al.* (1999) in pegeon pea.

Sudharmaidevi and Padmaja (1996a) obtained maximum growth of plants in cassava when 50 per cent K was substituted by Na. But higher levels of Na reduced growth. Similar result was reported by George (1995) in sweet potato, Lekshmi (2000) in banana cv. Nendran and Sunu (2001) in banana cv. Robusta.

Kaya *et al.* (2002) found that strawberry plants grown at higher levels of NaCl produced less dry matter than those grown in normal nutrient solution. Husain *et al.* (2003) reported that the effect of salinity on biomass was less on low Na than on the high Na soil in case of duram wheat.

Boyd and Rogers (2004) observed that chicory (*Cichorium intybus* cv. Puna) produced significantly more dry matter over a range of salinity levels compared to other dairy forage species.

2.4 QUALITY ATTRIBUTES

2.4.1 Influence of Potassium

Pushpadas and Aiyer (1975) reported that application of K increased the starch content of tuber in cassava. Nair *et al.* (1980) found a slight increase in starch content in cassava with increasing levels of K application. In 1984 Nair and Mohan Kumar reported that NPK levels had no significant effect on starch content of sweet potato. In potato Rajanna *et al.* (1987) reported an increase in starch content due to K application. Increasing levels of K, Ca and Mg were found to increase the starch content in cassava tubers (Mohankumar *et al*., 1990).

In 1990, Samra and Quadar reported that K increased the total sugar content in tomato. Sugito and Guritno (1991) reported that combined application of N and P increased the starch content up to 27 per cent in cassava. Potassium application produced tubers with high content of starch and crude protein in potato (Lalitha, 1997). Singh and Verma (2001) reported that increasing levels of K_2O up to 120 kg ha^{-1}markedly increase the carbohydrate content in the bulbs of onion plant. The pungency also increased with increasing K_2O up to 160 kg ha^{-1}.

2.4.2 Effect of Sodium

Nair *et al.* (1980) reported that starch content in the tuber of cassava was not affected by different levels of NaCl. Khanna and Balaguru (1981a) found that Na application increased the TSS in sugar beet. In 1989, Adam and Ho recorded increased sugar content of fruit juice of tomato with increased levels of salinity.

Sudharmaidevi and Padmaja (1996b) observed an increase in the total sugars and reducing sugars with increase in substitution of K by Na as common salt in cassava. Palaniappan and Yerriswami (1996) observed that irrigation with saline water of EC 5 d S m^{-1} adversely affected the quality of banana. At moderate salinity, the glucose and sucrose concentration increased by 1.5 -- 3 times in tomato hybrid (Alfocea *et al.*, 1996). In sugarcane salinity adversely affected the quality of sugarcane by decreasing the sucrose content (Sharma *et al.*, 1997).

Lekshmi (2000) reported that the shelf life of banana cv. Nendran was maximum at 75 per cent substitution of K by Na. Sunu (2001) reported that there was no significant effect on the shelf life of banana cv. Robusta due to application of Na. Sultana *et al.* (2002) reported a reduction in sugar and protein content in the developing grains of rice due to increased salinity.

2.5 NUTRIENT CONTENT AND UPTAKE

2.5.1 Effect of Potassium

Pushpadas *et al.* (1975) found that K application decreased N content of tissue in cassava petiole. Parida *et al.* (1994) reported a significant increase in K content when the dose of K was increased beyond 360 g $plant^{-1}$ in Robusta banana. Pushpadas *et al.* (1976) reported that K content of the petiole tissue increased in cassava with the application of K but N, P and Mg content decreased.

Turner and Barkus (1983) reported an increase in the plant uptake of P and decrease in that of N with increased K supply in banana variety Williams. In potato uptake of K was found to increase with increased rates of K application (Shukla and Singh, 1976; Rajanna *et al.*, 1987). Sheela *et al.* (1990) reported that levels of K had no effect on the uptake of N; uptake of P and K increased with increased levels of K in banana. Mohankumar *et al.* (1990) reported that K application would decrease the absorption of Ca and Mg in cassava.

In banana, increased K fertilization significantly increased the uptake of N and K (Hedge and Srinivas, 1991). A reduction in Ca and Mg contents of rye grass plants with K application was reported by Razmjoo and Kaneko (1993).

Padmaja and Raju (1999) reported that K concentration and uptake increased with increasing K application in sweet potato. Janardan Singh and Singh (2000) reported that there was significant difference in the uptake of N and K due to the increased application of K in rice and wheat. Singh and Verma (2001) found that uptake of N and K increased with increasing levels of K up to 120 kg ha^{-1} in onion. But the uptake of Mg decreased at the highest level of 160 kg ha^{-1} K_2O.

Wakeel *et al.* (2002) reported that there was a synergistic relationship between K application and N uptake in maize. Ranjha *et al.* (2002) reported that increased K application increased the K concentration in wheat plant. K application significantly affected the uptake of N and P in straw as well as grain of wheat (Saifullah *et al.*, 2002).

2.5.2 Effect of Sodium

Huffakar and Wallace (1959) showed that low K level stimulated Na absorption and a high K level decreased its absorption in maize, soybean, *Citrus jambhiri* and *Persea americana*. Increased application of Na decreased the K uptake in coconut (Barrant, 1975).

In peanut, with increase in NaCl concentration, Na accumulated in all plant parts whereas K content decreased in leaf and stem and increased in root (Chavan and Karadge, 1980). Khanna and Balaguru (1981a) reported that Na concentration in all plant parts increased with the application of Na but decreased with an increase in K application in sugar beet.

Increased Na content with increased Na application was reported by Khanna and Balaguru (1981b) in wheat, Hawker and Smith (1982) in cassava, Maliwal (1997) in wheat and Choudhuri *et al.* (1998) in sugarcane. Mathew *et al.* (1984) reported that Na and K contents of leaves were influenced by Na substitution in coconut. Prema *et al.* (1987) reported that substitution of K by Na showed no significant difference in their effect on total N, P and Cl content of leaves where as K and Na contents were significantly influenced by the treatments in coconut.

Ohta *et al.* (1987) noticed that in *Amaranthus tricolor* Na content was increased by Na application but the K uptake was not affected. Abdullah and Ahmad (1990) reported that K content increased at 0.5 per cent salinity and decreased at 1 per cent level in potato. Dhindwal *et al.*

(1992) reported that low levels of salinity stimulated uptake of leaf Ca, Mg and Na in barley seedlings. Sudharmaidevi and Padmaja (1999) observed in cassava that all the treatments, which received Na favoured absorption of Na during early stages. In tuber filling stage, absorption of K was more in treatments where K and Na were applied at 50 per cent levels.

In banana cv. Nendran, maximum uptake of N, P, K and Na were noticed when 50 per cent of K was substituted with Na as common salt (Lekshmi, 2000). Sunu (2001) reported that there was significant increase in the uptake of N, P, K and Na when 50 per cent K was substituted by Na. Kaya *et al.* (2002) reported that Na concentration in plant tissue increased with increased NaCl treatment where as concentration of N and Ca were much lower in high NaCl than in unstressed plants.

Ghosh *et al.* (2001) reported that Na content in stems and tubers markedly increased with increase in salt levels while K content of leaves decreased. But in stems and tubers, it increased with salt stress. The Ca content of leaves and stems decreased but in tubers it increased with salt stress. Parti *et al.* (2002) noticed that in *Brassica juncea*, when salinity increased the N, P and K content of seed and siliqua wall sample decreased. The drop of P content was smaller than that seen with the other two elements. But Na content of the above sample increased with increased salinity. Shareef *et al.* (2002) noticed that increasing salinity levels caused a corresponding increase in upper and lower leaf content of Na, Ca and Mg and simultaneous reduction in K content in these leaves. Also, there was a reduction in K/ Na ratio with increased salinity.

Aktar *et al.* (2003) found that as salinity increased the content of K, Ca, N and decreased that of P in sugarcane. Gulzar *et al.* (2003) reported that shoot Ca^{2+}, Mg^{2+} and K^{+1} concentration remained constant in salinity treatments, while Na^{+} increased and reached greater than 4 mol m^{-3} g^{-1} dry weight in *Aleuropus lagopoides*. Akinci *et al.* (2004) reported when salt concentration increased, leaf Na^+ content increased but K^+ content and K^+/Na^+ ratio decreased in eggplant.

2.6 SOIL PROPERTIES

Different levels of substitution of MOP by common salt did not have any influence on soil pH and EC (Prema *et al.*, 1987). The application of Na had no adverse effect on pH, EC and CEC of the soil (Prema *et al.*, 1992).

In sweet potato, George (1995) reported that there was no significant difference in soil properties like EC and CEC. The soil pH showed a slight increase. There was an increase in soil pH at higher levels of substitution of K by Na in banana cv. Nendran (Lekshmi, 2000). But EC and CEC did not vary significantly in the experiment. Sunu (2001) reported that no significant increase in pH and EC after harvest due to Na treatment in an experiment with banana. Sifola and Postiglione (2002) reported an increased EC of topsoil profile with increased salinity in tobacco.

2.7 SOIL AVAILABLE NUTRIENTS

In 1953 Jordan and Lewis reported that Na salts added to soil increased the available phosphate content. While studying the effect of Na and K, Prema *et al.* (1987) noticed that there was no difference in total N, available P, Na and Cl due to the influence of Na and K treatment in soil. Bhargava *et al.* (1992) found that increased application of K resulted increased amounts of both readily and potentially available forms of K in soil.

George (1995) reported that there was no significance in the available status of K and Na between the treatments under no substitution and full substitution of K by Na in sweet potato. Lekshmi (2000) reported that available N and K were recorded maximum in no substitution treatment and of Na in the treatment with full substitution of K by Na in banana cv. Nendran. But soil available P status was maximum at 50 per cent substitution of K by Na of common salt. Prasad *et al.* (2000) reported that available K in soil after harvest of crop increased with increasing levels of K application in mungu bean.

Sunu (2001) noticed that at harvest the available P, K and Na were significantly high in the treatments where higher doses of K was substituted by Na where as available N did not show any difference due to Na treatment in banana cv. Robusta.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A field experiment to evaluate the "Synergistic effect of Na and K on yield and nutrient uptake in coleus (*Coleus parviflorus* L.)" was carried out from September 2003 to January 2004 at the Instructional farm, College of Agriculture, Vellayani. The details of the experiment site, season and weather conditions, materials used and methods adopted are presented in this chapter.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The Instructional farm, Vellayani is located at 8^0 30' E latitude and at 29 m above MSL.

3.1.2. Soil

The soil of the experimental site belongs to the family of Loamy Skeletal Kaolinitic Isohyperthermic Rhodic Haplustult.

The physical and chemical characteristic of the soil where the experiment was conducted are given in Table 1.

3.2 SEASON

The experiment was conducted during the period September 2003 to January 2004.

3.3 WEATHER CONDITIONS

The mean rainfall of the location during the cropping season was 693.0 mm. The mean maximum and minimum temperature of the location during the cropping season were 32.2^0 C and 20.7^0 C respectively. Monthly distribution of rainfall and temperature, which prevailed during the cropping period is depicted in Fig 1.

Table 1 Physical and Chemical properties of soil of the experiment

1.Mechanical composition	
Sand (per cent)	79.8
Silt (per cent)	11.6
Clay (per cent)	8.1
2. Texture	Sandy Loam
3. pH	5.6
4.EC (dS m^{-1})	0.012
5. Organic Carbon (per cent)	0.64
6. Available N (kg ha^{-1})	301
7. Available P (kg ha^{-1})	89.6
8. Available K (kg ha^{-1})	235.2
9. Available Na (kg ha^{-1})	73.9
10. Exchangeable Ca (c mol kg^{-1})	1.4
11. Exchangeable Mg (c mol kg^{-1})	0.4

3.4 MATERIALS

3.4.1 Planting Material and Variety

The planting material of the coleus variety Sreedhara was obtained from the Instructional Farm, Vellayani. Sreedhara is a high yielding variety of coleus released from CTCRI, Sreekariyam.

3.4.2 Manures and Fertilizers

Cattle manure was applied @ 10 t ha^{-1}. Nitrogen and phosphorus were applied as per the Package of Practices, Kerala Agricultural University. Potassium and common salt were applied as per the treatments.

3.5 METHODS

3.5.1 Design and Layout of Experiment

Design	-	Randomised Block Design
Variety	-	Sreedhara
Replication	-	3
Treatments	-	9
Plot size	-	3.3 x 2.1 m^2
Spacing	-	30 cm x 30 cm

3.5.2 Treatments

N P K recommendations for coleus according to POP is 60 : 60 : 100 kg ha^{-1}.

T_1 - No K, No Na (control)

T_2 - 50 per cent K as MOP.

T_3 - 100 per cent K as MOP

T_4 - 50 per cent K as MOP plus 50 per cent Na as common salt.

T_5 - 50 per cent K as MOP plus 75 per cent Na as common salt.

T_6 - 50 per cent K as MOP plus 100 per cent Na as common salt.

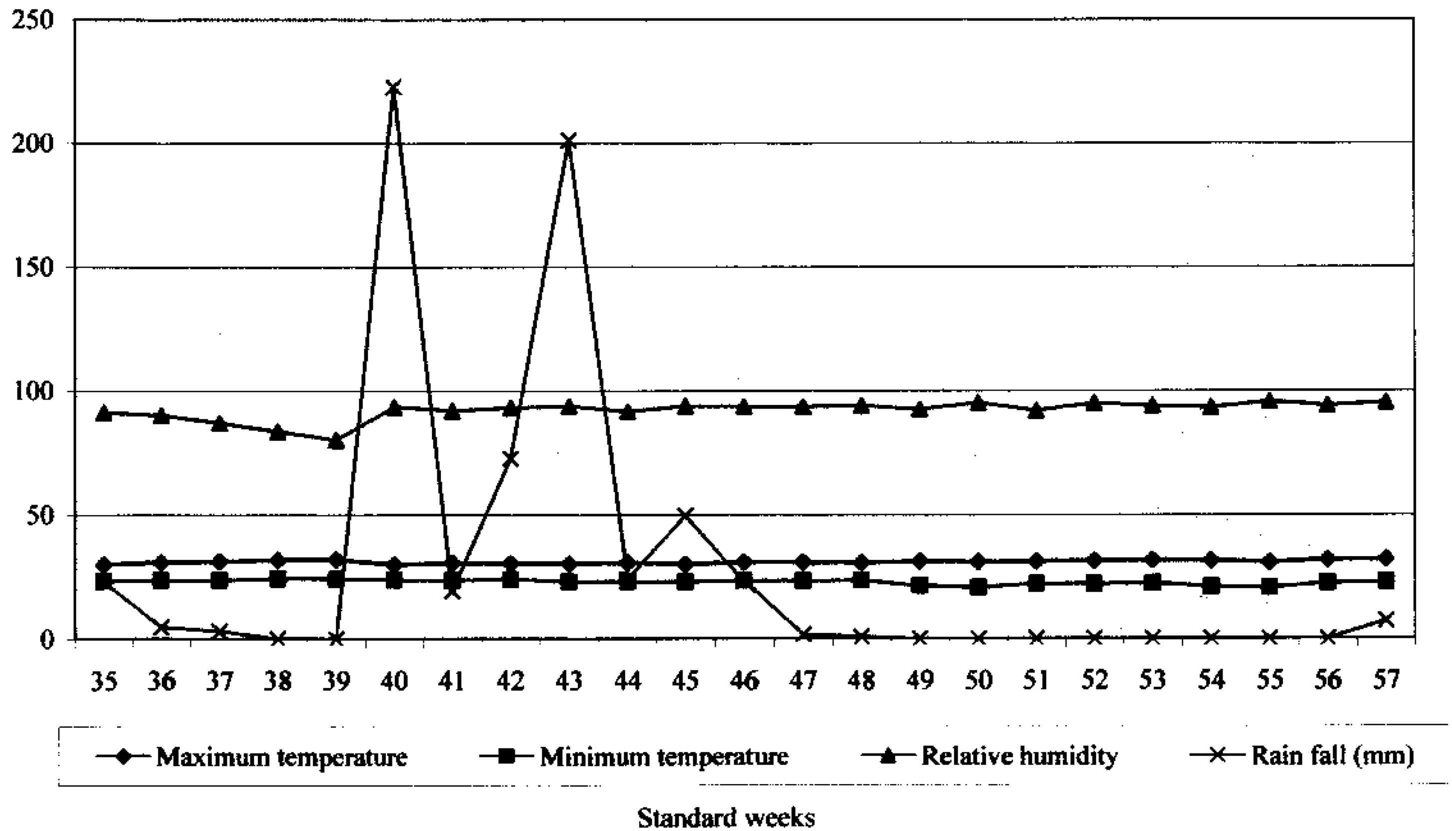


Fig 1. Weather parameters during field experiment

T_7 - 100 per cent K as MOP plus 50 per cent Na as common salt.

T_8 - 100 per cent K as MOP plus 75 per cent Na as common salt.

T_9 - 100 per cent K as MOP plus 100 per cent Na as common salt.

Sodium content in common salt is 39.30 per cent.

The lay out plan of the experiment is given in Fig 2.

3.6 BIOMETRIC OBSERVATIONS

The following observations of the plant under different treatments were recorded at two months after planting. Observations were taken from plants. selected from each plots.

3.6.2 Plant Spread

Plant spread was measured by taking the diameter of spread of the selected plants in each plot.

3.6.2 Number of Branches per Plant

The total number of branches produced by the selected plant in each plot was counted.

3.6.3 Number of Functional Leaves

The total number of functional leaves in the selected plant was counted.

3.7 PHYSIOLOGICAL CHARACTERS

The following parameters were recorded at two months after planting.

3.7.1 Leaf Area Index

Leaf Area Index was calculated as described by Watson, 1952.

$$L.A.I = \frac{\text{Leaf area plant}^{-1}}{\text{Land area plant}^{-1}}$$

3.7.2 Chlorophyll Content

Chlorophyll estimation was done in samples from first mature leaves of selected plant from each plot by colorimetric method as suggested by Arnon (1949).

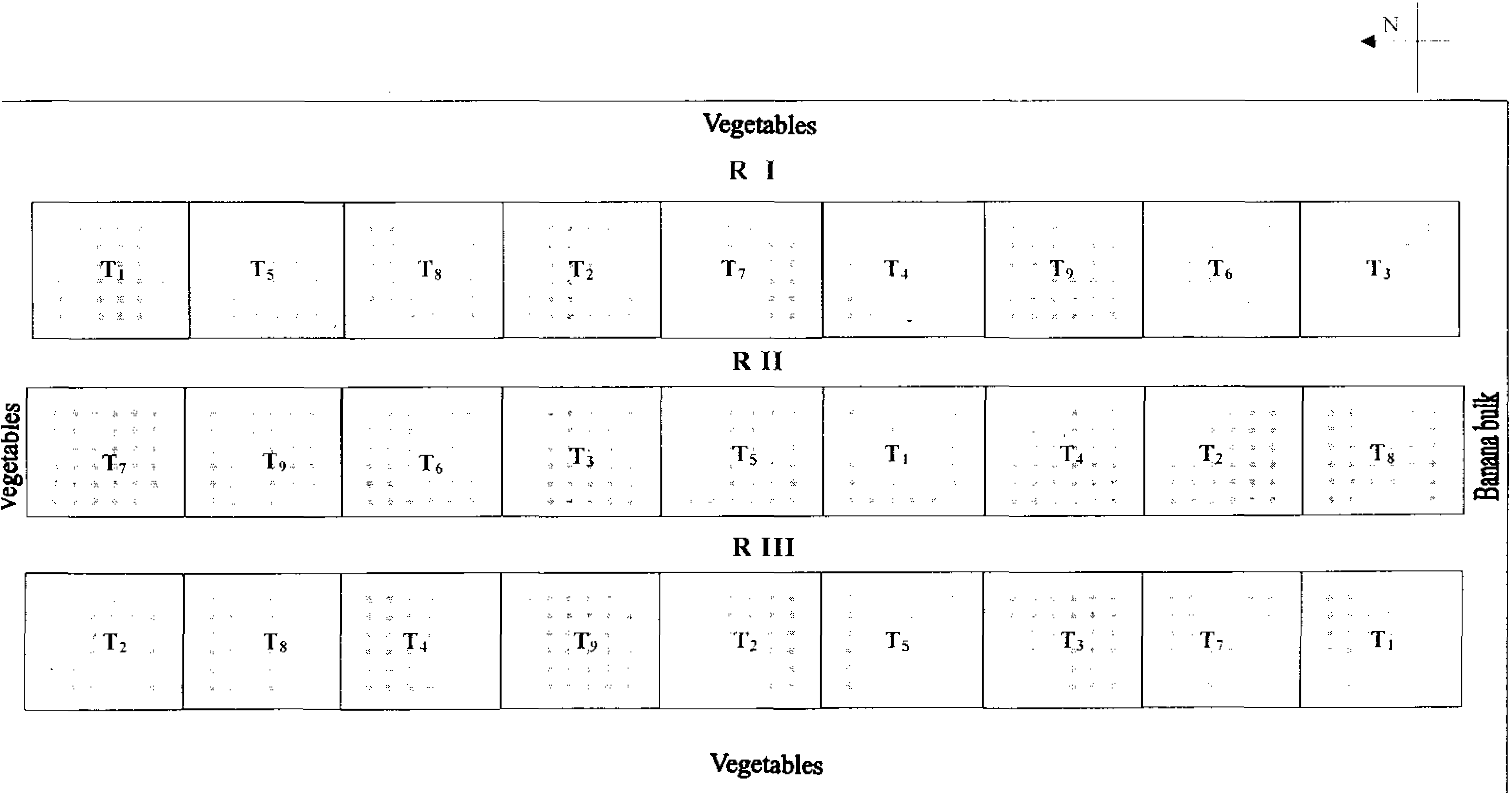


Fig. 2 Layout plan of the experiment

3.7.3 Relative Water Content in Leaves

Leaf samples from selected plants were taken and relative water content in leaves was determined by the method proposed by Weatherly (1950) which was modified by Slatyer and Barrs (1965).

$$RLWC = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Turgid weight} - \text{Oven dry weight}} \times 100$$

3.8 YIELD COMPONENTS

The following parameters were recorded at harvest.

3.8.1 Number of Tubers per Plant

Number of tubers of selected plants in each plot was counted.

3.8.2 Weight of Tubers per Plant

Weight of tubers of selected plant in each plot was taken.

3.8.3 Tuber Index

Tuber Index was calculated as the number of tubers required to get 1kg tuber weight. Tuber Index for each plot was calculated.

3.9 QUALITY ATTRIBUTES

3.9.1 Keeping Quality

The duration of time from harvest to the development of visual symptoms of rotting and damage of the tubers was recorded to determine the storage life or the keeping quality of the tubers at room temperature.

3.9.2 Cooking Quality

The cooking quality of tuber was assessed by a taste panel and scores were given as per the procedure described by Prema *et al.* (1975).

3.9.3 Starch Content

Starch content of the tuber from each plot was estimated as per the procedure described by Chopra and Kanwar (1976).

3.10 PLANT ANALYSIS

After harvest the leaf, stem, tuber and roots were separately analysed for the contents of N, P, K, Na, Ca and Mg.

Nitrogen was estimated by modified Kjeldahl method after digestion with concentrated sulphuric acid (Jackson, 1973). Determination of P, K, Na, Ca and Mg were done after digestion with nitric-perchloric acid mixture in the ratio 9:4 (Jackson, 1973). P was estimated by the vanadomolybdic yellow colour method in a spectrophotometer (Systronics Model 169) (Jackson, 1973). Na and K were estimated using the flame photometer (Elico Model CL 22 D). Ca and Mg were estimated by versenate method (Jackson, 1973).

3.11 UPTAKE OF NUTRIENTS

Uptake of N, P, K, Na, Ca and Mg were calculated from their contents in the plant parts multiplied by the respective dry weight.

3.12 TOTAL DRY MATTER

Weight of the plants after drying in hot air oven 70^0 C for 48 h was found out.

3.13 SOIL ANALYSIS

Soil samples from each plot were analysed for pH, EC, Organic carbon, available N, P, K, Na, Ca and Mg. The procedures followed are given in Table 2.

3.14 ECONOMIC ANALYSIS

The economics of cultivation was worked out considering the cost of cultivation and income derived from the plant. It was calculated as per the norms and rates fixed by the Instructional Farm, College of Agriculture, Vellayani.

$$\text{Benefit:Cost ratio} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

Table 2 Analytical methods followed in Soil Analysis

Parameter Studied	Method of estimation	Instrument used	Reference
PH	Direct reading	pH meter	Jackson (1973)
EC	Direct reading	EC meter	Jackson (1973)
Organic Carbon	Walkley- Black rapid titration	Titration	Jackson (1973)
Available N	Alkaline permanganate method	Titration	Subbiah and Asija (1956)
Available P	Molybdenum-blue colour method (Bray extraction method)	Klett-Summerson Colorimeter	Jackson (1973)
Available K	Direct reading (NN ammonium acetate extraction)	Flame photometer	Jackson (1973)
Available Na	Direct reading (NN ammonium acetate extraction)	Flame photometer	Jackson (1973)
Exchangeable Ca	Versenate-Titration method	Titration	Jackson (1973)
Exchangeable Mg	Versenate-Titration method	Titration	Jackson (1973)

3.15 STATISTICAL ANALYSIS

Statistical methods of analysis such as analysis of variance and correlation studies were carried out to find out the relationship between variables and to draw definite conclusions.

RESULTS

4. RESULTS

An experiment entitled "Synergistic effect of Na and K on yield and nutrient uptake in coleus (*Coleus parviflorus* L.)" was carried out in the College of Agriculture, Vellayani, during 2003 –2004 with Sreedhara variety of coleus. Beneficial effect of Na on growth and yield of plants have been reported by several scientists (Jain *et al.*, 1988; Quadar, 1992). In various experiments conducted in the College of Agriculture, Vellayani on substitution of K of muriate of potash by Na of common salt, it was found that when, fifty per cent of K was replaced by Na, the uptake of all major and secondary nutrients except Mg was increased. The substituted plants showed higher vigour of growth and gave higher yields when compared with non-substituted plants. This increase in vigour is attributed to the synergistic effect of Na and K on the mineral absorption of plant. Hence the aim of the experiment was to study the effect of substitution of K by Na and their interaction on the growth and nutrient uptake of coleus. The important results obtained are presented below:

4.1 GROWTH CHARACTERISTICS

4.1.1 Plant Spread

The mean values of plant spread for the different treatments at two months after planting are presented in Table 3. There was significant difference in the plant spread due to treatments.

Highest plant spread was observed in the treatment T_4 (50 per cent K as MOP plus 50 per cent Na as common salt) and the lowest in T_1 (control). Plant spread at 50 per cent K and 50 per cent Na was significantly higher than 100 per cent K (T_3) but on par with treatments T_6 and T_7. The treatments T_1, T_2 and T_3 did not differ significantly in this parameter and were on par with treatments T_8 and T_9.

Table 3. Growth characteristics as affected by application of K and Na in different proportions

Treatments	Plant spread (cm)	Number of branches	Number of leaves
T_1 (No K, No Na)	81.6	25	339
T_2 (50 % K alone)	86.6	32	431
T_3 (100 % K alone)	87.6	33	518
T_4 (50 % K + 50 % Na)	114.3	38	760
T_5 (50 % K + 75 % Na)	90.0	32	773
T_6 (50 % K + 100 % Na)	109.3	40	793
T_7 (100 % K + 50 % Na)	104.3	41	844
T_8 (100 % K + 75 % Na)	86.3	34	757
T_9 (100 % K + 100 % Na)	83.3	29	878
CD (0.05 level)	17.29	NS	246.91

4.1.2 Number of Branches

Number of branches per plant was recorded two months after planting. The mean values are given in Table 3.

Highest number of branches was recorded for the treatments T_7 (100 per cent K plus 50 per cent Na) and T_6 (50 per cent K plus 100 per cent Na), followed by T_4 (50 per cent K plus 50 per cent Na).

The minimum number of branches was recorded for the treatment T_1 (control) followed by T_9 (100 per cent K plus 100 per cent Na). The treatments T_4, T_6 and T_8 recorded higher number of branches compared to T_3 (100 per cent K alone).

4.1.3 Number of Functional Leaves

The mean values for the number of functional leaves per plant are presented in Table 3.

The highest number of functional leaves per plant was recorded in treatment T_9 and the lowest value in the treatment T_1 (control). T_9 was found to be significantly higher than T_1, T_2 and T_3. The treatments T_5, T_6 and T_7 also recorded significantly higher values than T_1, T_2 and T_3. All the treatments, which were given Na recorded higher number of functional leaves.

4.1.4 Leaf Area Index

The mean values of Leaf Area Index are given in Table 4. The values showed significant difference between treatments. The highest value of LAI was recorded for the treatment T_8 (100 per cent K plus 75 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na). The Na treated plots showed significantly higher values of Leaf Area Index compared to the other plots. The lowest value was recorded for the treatment T_1 (control). The treatments T_1, T_2 and T_3 were on par. The highest value of LAI recorded is 5.63 for T_8 (100 per cent K plus 75 per cent Na) and the lowest value recorded is 2.79 for T_1 (control).

Table 4. Physiological Characters as affected by application of K and Na in different proportions

Treatments	LAI	Chlorophyll content (mg g^{-1})	RLWC (%)
T_1 (No K, No Na)	2.79	0.36	81.0
T_2 (50 % K alone)	3.13	0.36	82.0
T_3 (100 % K alone)	3.20	0.34	81.0
T_4 (50 % K + 50 % Na)	5.49	0.44	83.6
T_5 (50 % K + 75 % Na)	5.45	0.49	94.0
T_6 (50 % K + 100 % Na)	5.25	0.44	88.0
T_7 (100 % K + 50 % Na)	5.54	0.44	87.3
T_8 (100 % K + 75 % Na)	5.63	0.33	86.7
T_9 (100 % K + 100 % Na)	5.34	0.32	86.3
CD (0.05 level)	0.62	NS	3.08

4.1.5 Chlorophyll Content

The mean values of chlorophyll content of different treatments are presented in Table 4. There was no significant difference between the treatments in the leaf chlorophyll content. The highest value was recorded for the treatment T_5 (50 per cent K plus 75 per cent Na). The treatments T_4 (50 per cent K plus 50 per cent Na), T_6 (50 per cent K plus 100 per cent Na) and T_7 (100 per cent K plus 50 per cent Na) recorded the same value of chlorophyll content. The lowest value was recorded for T_9 (100 per cent K plus 100 per cent Na).

4.1.6 Relative Leaf Water Content

The relative water content of leaves at two months after planting is presented in Table 4. There was significant difference between treatments in relative leaf water content values. It was found that in Na treated plants, there was an increase in the relative water content compared to the K alone treated plants. The highest value of RLWC was registered by treatment T_5 (50 per cent K plus 75 per cent Na) followed by T_6 (50 per cent K plus 100 per cent Na). The lowest value of RLWC was recorded for the treatment T_1 (control) and T_3 (100 per cent K alone). The highest value was 94 per cent and the lowest value was 81 per cent. The RLWC value of T_5 was significantly different from the values of other treatments. T_1, T_2 and T_3 recorded lower values and found to be on par.

4.2 YIELD AND YIELD ATTRIBUTES

Yield and yield attributes were recorded at harvest and the mean values are recorded in Table 5. There was no significant difference in the yield or yield attributes due to application of treatments.

4.2.1 Number of Tubers

Number of tubers was counted from the selected plants in each plot and the mean values recorded in Table 5. The highest number of tubers was obtained from the treatment T_8 (100 per cent K plus 75 per cent Na) followed by T_6 (50 per cent K plus 100 per cent Na). The lowest number of

Table 5. Yield components as affected by application of K and Na in different proportions

Treatments	Number of tuber	Weight of tuber g $plant^{-1}$	Tuber Index	Yield of tuber ($t\ ha^{-1}$)
T_1 (No K, No Na)	33.6	260.0	188.33	6.13
T_2 (50 % K alone)	47.3	243.3	175.00	7.30
T_3 (100 % K alone)	49.6	326.6	195.00	10.07
T_4 (50 % K + 50 % Na)	57.0	416.6	154.67	11.60
T_5 (50 % K + 75 % Na)	58.6	406.6	145.67	10.73
T_6 (50 % K + 100 % Na)	62.3	400.0	120.00	11.03
T_7 (100 % K + 50 % Na)	50.0	343.3	119.00	11.10
T_8 (100 % K + 75 %Na)	70.6	296.6	126.00	8.85
T_9 (100 % K + 100 % Na)	45.3	343.3	135.00	8.80
CD (0.05 level)	NS	NS	NS	NS

tubers was obtained from T_1 (control). Na treated plants in general recorded higher number of tubers compared to the K treated plots.

4.2.2 Weight of Tuber

Weight of tuber at the time of harvest was recorded and the mean values are presented in Table 5. T_4 (50 per cent K plus 50 per cent Na) recorded the highest value of weight of tuber from a single plant, followed by T_5 (50 per cent K plus 75 per cent Na). The lowest value was recorded for the treatment T_2 (50 per cent K alone) followed by T_1 (control). The highest value recorded was 416.6 g plant^{-1} and the lowest value recorded was 243.3 g plant^{-1}.

4.2.3 Tuber Index

The tuber index was calculated from the number of tubers and weight of tubers and the mean values were recorded. The data are presented in Table 6. T_3 (100 per cent K alone) was found to have the highest tuber index followed by T_1 (control). There was no significant difference between the treatments as far as Tuber Index is concerned.

4.2.4 Yield of Tuber

Tuber yield did not vary significantly due to treatments. The highest value was recorded for the treatment T_4 (50 per cent K plus 50 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na). The lowest value recorded for T_1 (control). T_8 (100 per cent K plus 75 per cent Na) and T_9 (100 per cent K plus 100 per cent Na) recorded lower values compared to T_3 (100 per cent K alone).

4.3 QUALITY ATTRIBUTES

4.3.1 Starch Content

Starch content was estimated at the time of harvest using fresh tubers. The mean values were recorded and presented in the Table 6a. There was significant variation between treatments in the content of starch.

Table 6a. Quality attributes affected by application of K and Na in different proportions

Treatments	Starch content (%)	Storage period in days
T_1 (No K, No Na)	19.95	44
T_2 (50 % K alone)	20.99	52
T_3 (100 % K alone)	20.87	75
T_4 (50 % K + 50 % Na)	23.13	83
T_5 (50 % K + 75 % Na)	18.33	85
T_6 (50 % K + 100 % Na)	18.37	86
T_7 (100 % K + 50 % Na)	17.93	88
T_8 (100 % K + 75 % Na)	23.30	89
T_9 (100 % K + 100 % Na)	16.93	92
CD (0.05 level)	3.83	10.46

Table 6b. Scores obtained on organoleptic tests

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Score obtained based on overall acceptability	1.5	3.4	4	3.5	4	2.5	3.5	3.6	1

T_8 (100 per cent K plus 75 per cent Na) recorded the highest starch content of 23.3 per cent followed by T_4 (50 per cent K plus 50 per cent Na) as 23.13 per cent. The lowest value was recorded for T_9 (100 per cent K plus 100 per cent Na) with a value of 16.9 per cent. T_8 was found to be on par with T_2 (50 per cent K alone), T_3 (100 per cent K alone) and T_1 (control).

4.3.2 Keeping Quality

Wide variation could not be obtained in keeping quality as a result of application of treatments. The tubers from treatment with no K or no Na (T_1) had the shortest shelf life. They started sprouting 45 days after harvest. Treatment T_2 (50 per cent K alone) showed slight sprouting with storage, where as the others could be stored for three months without sprouting. Treatment T_9 (100 per cent K plus 100 per cent Na) showed the highest shelf life (Table 6a).

4.3.3 Cooking Quality

Organoleptic tests were conducted and it was found that T_3 (100 per cent K alone) and T_5 (50 per cent K plus 75 per cent) were good in taste, appearance and texture. T_8, T_6, T_4 and T_2 were comparatively better than the remaining treatments. When overall acceptability was taken in to consideration, T_3 (100 per cent K alone), T_4 (50 per cent K plus 50 per cent Na) and T_5 (50 per cent K plus 75 per cent Na) were comparable (Table 6b).

4.4 DRY MATTER PRODUCTION

Dry matter production values are presented in Table 7. The values showed significant difference between treatments. The treatment T_4 (50 per cent K plus 50 per cent Na) recorded significantly higher dry matter production compared to all other treatments. T_1 (control) recorded the lowest value and was on par with treatments T_2, T_3, T_8 and T_9. At low and high levels of K along with high levels of Na showed a decrease in the dry matter production when compared with others.

Table 7. Dry matter production as affected by application of K and Na in different proportions (kg ha^{-1})

Treatments	Tuber dry matter production	Aerial dry matter production	Total dry matter production
T_1 (No K, No Na)	1000.0	1927.6	2927.6
T_2 (50 % K alone)	1133.3	2042.1	3175.4
T_3 (100 % K alone)	1066.6	2070.9	3137.4
T_4 (50 % K + 50 % Na)	1533.3	2482.0	4015.3
T_5 (50 % K + 75 % Na)	1400.0	2158.6	3558.6
T_6 (50 % K + 100 % Na)	1413.3	2004.2	3417.5
T_7 (100 % K + 50 % Na)	1306.6	2210.1	3516.7
T_8 (100 % K + 75 % Na)	1213.3	1788.2	2991.5
T_9 (100 % K + 100 % Na)	1360.0	2027.0	3387.0
CD (0.05 level)	188.6	111.5	423.8

Table 8. Nitrogen content in the plant parts as affected by application of K and Na in different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	1.22	0.45	0.54	0.71
T_2 (50 % K alone)	1.14	0.46	0.56	0.75
T_3 (100 % K alone)	1.36	0.56	0.99	0.94
T_4 (50 % K + 50 % Na)	1.29	0.73	0.94	1.0
T_5 (50 % K + 75 % Na)	1.38	0.65	0.69	1.09
T_6 (50 % K + 100 % Na)	1.41	0.68	0.64	0.98
T_7 (100 % K + 50 % Na)	1.57	0.92	1.42	1.08
T_8 (100 % K + 75 % Na)	1.29	0.77	0.94	0.99
T_9 (100 % K + 100 % Na)	1.13	0.93	0.74	0.33
CD (0.05 level)	NS	0.290	0.387	NS

followed by T_3 (100 per cent K alone), which did not differ significantly from the values obtained for T_4 and T_8. The treatment receiving K alone (T_1 and T_2) recorded lowest values and were significantly inferior to the Na treated plants.

4.6 PHOSPHORUS CONTENT IN PLANT PARTS

Phosphorus content of the plant parts are presented in Table 9.

4.6.1 Phosphorus in Leaf

The content of P in the leaves did not show any significant difference between treatments. T_2 (50 per cent K alone) recorded the highest value of leaf P content. The lowest value was recorded for the treatment T_9 (100 per cent K plus 100 per cent Na). The treatments receiving K alone (T_2 and T_3) recorded higher values than the treatments receiving Na along with K.

4.6.2 Phosphorus in Stem

Phosphorus content in stem did not show any significant variation due to treatments. The highest value of stem P was recorded for T_7 (100 per cent K plus 50 per cent Na) and T_8 (100 per cent K plus 75 per cent Na). The lowest values of stem P were recorded for T_1 (control) and T_2 (50 per cent K alone).

4.6.3 Phosphorus in Tuber

Tuber P content did not show significant variation due to treatments. The highest value of tuber P was recorded for the treatment T_6 (50 per cent K plus 100 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na) and T_9 (100 per cent K plus100 per cent Na). The lowest value was recorded for T_1 (control).

4.6.4 Phosphorus in Root

The P content of root varied significantly due to treatments. The highest value of root P was recorded for T_3 (100 per cent K alone) followed

Table 9. Phosphorus content in the plant parts as affected by application of K and Na in different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	0.29	0.13	0.24	0.15
T_2 (50 % K alone)	0.37	0.17	0.31	0.17
T_3 (100 % K alone)	0.32	0.20	0.31	0.32
T_4 (50 % K + 50 % Na)	0.24	0.18	0.25	0.23
T_5 (50 % K + 75 % Na)	0.25	0.22	0.26	0.14
T_6 (50 % K + 100 % Na)	0.26	0.19	0.36	0.18
T_7 (100 % K + 50 % Na)	0.29	0.23	0.33	0.31
T_8 (100 % K + 75 % Na)	0.27	0.23	0.30	0.30
T_9 (100 % K + 100 % Na)	0.22	0.19	0.32	0.31
CD (0.05 level)	NS	NS	NS	9.294

by T_7 (100 per cent K plus 50 per cent Na) and T_9 (100 per cent K plus 100 per cent Na). The lowest value of root P was recorded for T_5 (50 per cent K plus 75 per cent Na) followed by T_1 (control).

4.7 POTASSIUM CONTENT IN PLANT PARTS

The mean values of K content in plant parts are presented in Table 10.

4.7.1 Potassium in Leaf

The K content of leaves showed significant difference between treatments. The highest value of K content in leaves was recorded for T_8 (100 per cent K plus 75 per cent Na) followed by T_9 (100 per cent K plus 100 per cent Na). The lowest value of leaf K content was recorded for the treatment T_1 (control) and T_2 (50 per cent K alone). But T_1, T_2 and T_3 were found to be on par. The treatments receiving Na along with K showed higher leaf K values.

4.7.2 Potassium in Stem

Stem K content did not show any significant variation due to treatments. T_9 (100 per cent K plus 100 per cent Na) recorded the highest value of stem K content followed by T_6 (50 per cent K plus 100 per cent Na) and T_4 (50 per cent K plus 50 per cent Na). The lowest value was recorded for T_1 (control).

4.7.3 Potassium in Tuber

Potassium in tuber showed significant difference due to treatments. Treatments with higher levels of either K or Na registered high values of tuber K content. The highest value of tuber K was recorded for T_6 (50 per cent K plus 100 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na) and T_3 (100 per cent K alone). The lowest value was recorded for T_1 (control).

4.7.4 Potassium in Root

The content of root K did not show any significant difference due to treatments. The mean values are presented in Table 10. The highest value of

Table 10. Potassium content in the plant parts as affected by application of K and Na in different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	1.09	2.00	1.38	1.15
T_2 (50 % K alone)	1.09	2.75	1.45	1.48
T_3 (100 % K alone)	1.52	4.51	2.03	3.38
T_4 (50 % K + 50 % Na)	1.79	4.64	1.72	2.29
T_5 (50 % K + 75 % Na)	1.85	4.11	1.93	2.45
T_6 (50 % K + 100 % Na)	1.51	4.95	2.43	2.15
T_7 (100 % K + 50 % Na)	1.69	3.01	2.04	3.79
T_8 (100 % K + 75 % Na)	2.15	4.17	1.84	2.63
T_9 (100 % K + 100 % Na)	1.88	5.09	1.88	1.90
CD (0.05 level)	0.64	NS	0.49	NS

root Na was recorded for T_7 (100 per cent K plus 50 per cent Na), which was on par with T_3 (100 per cent K alone). The lowest value was recorded for the treatment T_1 (control) and T_2 (50 per cent K alone).

4.8 SODIUM CONTENT IN PLANT PARTS

The mean values of Na content in plant parts are presented in Table 11.

4.8.1 Sodium in Leaf

The leaf Na content did not show any significant difference between the treatments. T_9 (100 per cent K plus 100 per cent Na) recorded the highest value of leaf Na content. It was found to be on par with T_3 (100 per cent K alone). The lowest value was recorded for T_2 (50 per cent K alone). The leaf Na content in T_3 (100 per cent K alone) was higher than all other treatments except T_9 (100 per cent K plus 100 per cent Na).

4.8.2 Sodium in Stem

The content of Na in stem did not vary significantly due to treatments. The highest value of stem Na was recorded for T_9 (100 per cent K plus 100 per cent Na) followed by T_4 (50 per cent K plus 50 per cent Na). The lowest value of stem Na was recorded for T_2 (50 per cent K alone).

4.8.3 Sodium in Tuber

Sodium in the tuber did not show any significant difference due to treatments. The highest value of tuber Na content was recorded for T_5 (50 per cent K plus 75 per cent Na). The lowest value of Na content of tuber was recorded in the treatment T_2 (50 per cent K alone). All the treatments, which received Na along K contained higher concentration of K in tuber.

4.8.4 Sodium in Root

The Na content of root did not show any significant variation due to treatments. Highest value of root Na was recorded for the treatment T_5 (50 per cent K plus 75 per cent Na) and T_6 (50 per cent K plus 100 per cent Na). The lowest value of root Na content was recorded for T_1 (control).

Table 11. Sodium content in the plant parts as affected by application of K and Na in different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	0.21	0.56	0.23	0.35
T_2 (50 % K alone)	0.19	0.35	0.19	0.44
T_3 (100 % K alone)	0.53	0.45	0.33	0.56
T_4 (50 % K + 50 % Na)	0.32	0.59	0.36	0.37
T_5 (50 % K + 75 % Na)	0.41	0.40	0.41	0.77
T_6 (50 % K + 100 % Na)	0.20	0.37	0.32	0.75
T_7 (100 % K + 50 % Na)	0.40	0.44	0.4	0.61
T_8 (100 % K + 75 % Na)	0.25	0.49	0.36	0.40
T_9 (100 % K + 100 % Na)	0.85	0.61	0.35	0.56
CD (0.05 level)	NS	NS	NS	NS

4.9 CALCIUM CONTENT IN PLANT PARTS

Calcium content in plant parts is presented in Table 12.

4.9.1 Calcium in Leaf

The Ca content in leaves showed significant difference between the treatments. T_4 (50 per cent K plus 50 per cent Na) recorded the highest value of leaf Ca content of 3.48 per cent followed by T_5 (50 per cent K plus 75 per cent Na) with value 3.25 per cent. The lowest value of leaf Ca was recorded for T_1 (control). T_4, T_5 and T_7 showed significant difference from T_1 and T_2.

4.9.2 Calcium in Stem

Calcium content in stem did not show significant variation due to treatments. T_4 (50 per cent K plus 50 per cent Na) recorded the highest value of stem Ca content followed by T_5 (50 per cent K plus 75 per cent Na). The lowest value of stem Ca content was recorded for T_2 (50 per cent K alone). All the treatments receiving Na recorded higher values of stem Ca than the treatments receiving K alone.

4.9.3 Calcium in Tuber

Calcium content of tuber was found to be significantly different between treatments. The mean values are presented in Table 12. The highest value of tuber Ca was recorded for the treatment T_7 (100 per cent K plus 50 per cent Na) followed by T_6 (50 per cent K plus 100 per cent Na). The lowest value was recorded for the treatment T_2 (50 per cent K alone) and T_1 (control). All the Na treated plants were found to have significantly higher content of Ca than the K alone treated plots.

4.9.4 Calcium in Root

Root Ca content was found to be significantly varying due to treatments. The mean values are presented in Table 12. The highest value of root Ca was recorded by T_6 (50 per cent K plus 100 per cent Na) and this

Table 12. Calcium content of plant parts as affected by application of K and Na in different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	2.38	1.91	0.16	1.24
T_2 (50 % K alone)	2.52	1.49	0.21	1.22
T_3 (100 % K alone)	2.86	1.55	0.21	1.44
T_4 (50 % K + 50 % Na)	3.48	2.51	0.37	2.37
T_5 (50 % K + 75 % Na)	3.25	2.24	0.32	1.68
T_6 (50 % K + 100 % Na)	3.09	1.76	0.44	3.37
T_7 (100 % K + 50 % Na)	3.20	2.08	0.45	1.65
T_8 (100 % K + 75 % Na)	2.51	2.08	0.41	1.12
T_9 (100 % K + 100 % Na)	2.83	2.15	0.40	1.49
CD (0.05 level)	0.665	NS	0.171	0.983

was significantly superior to other treatments. The lowest value of root Ca was recorded for T_8 (100 per cent K plus 75 per cent Na) followed by T_2 (50 per cent K alone). T_4 and T_5 were found to be on par.

4.10 MAGNESIUM CONTENT OF PLANT PARTS

The Mg content of plant parts is presented in Table 13.

4.10.1 Magnesium Content in Leaf

The leaf Mg content showed significant difference between the treatments. Sodium treated plants showed higher values of Mg content than the untreated plants. The highest value of Mg content was recorded for T_7 (100 per cent K plus 50 per cent Na) followed by T_8 (100 per cent K plus 75 per cent Na) and T_9 (100 per cent K plus 100 per cent Na). T_7 and T_8 showed significant variation when compared to T_1 (control) and T_2 (50 per cent K alone). The lowest value of leaf Mg content was recorded by T_1 (control).

4.10.2 Magnesium Content in Stem

The stem Mg content showed significant difference due to treatments. The Na treated plants recorded a higher value of Mg compared to the K alone treated plants. The highest value of stem Mg content was recorded for T_9 (100 per cent K plus 100 per cent Na), which was significantly higher compared to all other treatments. The next higher values were recorded for T_4 (50 per cent K plus 50 per cent Na) and T_8 (100 per cent K plus 75 per cent Na), which were found to be on par. T_4 was also found to be significantly higher than T_1 (control), T_2 (50 per cent K alone) and T_3 (100 per cent K alone). The lowest value of stem Mg was recorded for the treatment T_2 (50 per cent K alone).

4.10.3 Magnesium Content in Tuber

Magnesium content of tuber was found to be significantly different between treatments. The highest value of Mg content of tuber was recorded by T_7 (100 per cent K plus 50 per cent Na) followed by T_6 (50 per cent K

Table13. Magnesium content in the plant parts as affected by application of K and Na different proportions (%)

Treatments	Leaf	Stem	Tuber	Root
T_1 (No K, No Na)	0.16	0.27	0.11	0.21
T_2 (50 % K alone)	0.21	0.16	0.16	0.27
T_3 (100 % K alone)	0.27	0.27	0.16	0.16
T_4 (50 % K + 50 % Na)	0.32	1.01	0.37	0.43
T_5 (50 % K + 75 % Na)	0.43	0.51	0.32	0.69
T_6 (50 % K + 100 % Na)	0.43	0.61	0.51	0.64
T_7 (100 % K + 50 % Na)	0.69	0.85	0.53	0.64
T_8 (100 % K + 75 % Na)	0.61	0.91	0.45	0.75
T_9 (100 % K + 100 % Na)	0.45	1.60	0.43	0.59
CD (0.05 level)	0.206	0.150	0.132	0.189

plus 100 per cent Na) and T_8 (100 per cent K plus 75 per cent Na). The lowest value of tuber Mg content was recorded by T_1 (control). All the Na treated plants showed a significantly high content of tuber Mg compared to the plants treated with K alone.

4.10.4 Magnesium Content in Root

Magnesium content of root varied significantly due to treatments. The mean values are presented in Table 13. The highest value of root Mg content was recorded for the treatment T_8 (100 per cent K plus 75 per cent Na) followed by T_5 (50 per cent K plus 75 per cent Na). The lowest value of root Mg was recorded for T_3 (100 per cent K alone) followed by T_1 (control) and T_2 (50 per cent K alone). All the treatments, which included Na were found to have high content of root Mg compared to K treated plots.

4.11 NUTRIENT UPTAKE BY AERIAL PLANT PARTS

The uptake by leaf and stem were summed up to get the total uptake by aerial parts. There was significant variation in the uptake of N, K, Ca and Mg by aerial plant parts due to treatments. The mean values are presented in Table 14.

4.11.1 Nitrogen

The uptake of N by aerial plant parts showed significant variation due to treatments. The highest value of N uptake by aerial plant parts was recorded by the treatment T_7 (100 per cent K plus 50 per cent Na) followed by T_4 (50 per cent K plus 50 per cent Na) and T_5 (50 per cent K plus 75 per cent Na), but they were found to be on par. The lowest value was recorded for the treatment T_1 (control) followed by T_2 (50 per cent K alone).

4.11.2 Phosphorus

Phosphorus uptake by aerial plant parts did not show significant difference between treatments. T_7 (100 per cent K plus 50 per cent Na) recorded highest value of P uptake. The lowest value was recorded by the treatment T_1 (control).

Table 14. Uptake of nutrients by aerial plant parts as affected by application of K and Na in different proportions (kg ha^{-1})

Treatments	N	P	K	Na	Ca	Mg
T_1 (No K, No Na)	15.31	3.76	30.71	7.49	41.14	4.18
T_2 (50 % K alone)	15.91	5.38	40.57	5.55	40.27	3.80
T_3 (100 % K alone)	20.27	5.42	59.77	10.29	46.11	6.14
T_4 (50 % K + 50 % Na)	23.62	5.21	86.99	11.92	72.19	18.46
T_5 (50 % K + 75 % Na)	21.35	5.09	64.82	8.89	58.81	10.22
T_6 (50 % K + 100 % Na)	19.62	4.42	73.11	6.01	46.06	10.76
T_7 (100 % K + 50 % Na)	27.05	5.62	51.40	9.5	56.79	17.31
T_8 (100 % K + 75 % Na)	18.34	4.45	55.71	6.79	41.06	13.72
T_9 (100 % K + 100 % Na)	19.64	3.96	75.44	14.37	45.99	22.57
CD (0.05 level)	6.87	NS	28.35	NS	14.84	3.33

4.11.3 Potassium

Uptake of K by aerial plant parts was found to be significantly different due to treatments. Sodium treated plants showed higher values of K uptake than the K treated plants. The highest value of K uptake was recorded by T_4 (50 per cent K plus 50 per cent Na) followed by T_9 (100 per cent K plus 100 per cent Na). But they were found to be on par. The lowest value was for T_1 (control) and it was significantly lower to all treatments except T_2, T_7 and T_8.

4.11.4 Sodium

Sodium uptake by aerial plant parts did not show any significant difference between treatments. T_9 (100 per cent K plus 100 per cent Na) recorded the highest value of Na uptake followed by T_4 (50 per cent K plus 50 per cent Na). The lowest value of Na uptake was recorded by T_2 (50 per cent K alone).

4.11.5 Calcium

Uptake of Ca by aerial plant parts was found to be significantly varying due to treatments. The highest value was recorded by T_4 (50 per cent K plus 50 per cent Na) followed by T_5 (50 per cent K plus 75 per cent Na) and T_7 (100 per cent K plus 50 per cent Na). T_2 (50 per cent K alone) recorded the lowest value of Ca uptake. T_4 and T_5 were having significantly higher values than others, but they were found to be on par.

4.11.6 Magnesium

Magnesium uptake by aerial plant parts showed significant variation due to treatments. Sodium treated plots showed significantly higher values of Mg uptake than the K alone treated plots. T_9 (100 per cent K plus 100 per cent Na) recorded the highest value of Mg uptake by aerial plant parts followed by T_4 (50 per cent K plus 50 per cent Na). The lowest value was recorded by T_2 (50 per cent K alone) followed by T_1 (control).

4.12 NUTRIENT UPTAKE BY TUBER

Uptake of nutrients except Na by tuber was found to vary significantly due to treatments. The mean values are presented in Table 15.

4.12.1 Nitrogen

The N uptake by tuber was significantly different due to treatments. T_6 (50 per cent K plus 100 per cent Na) registered the highest value of uptake of nitrogen by tuber followed by T_4 (50 per cent K plus 50 per cent Na). The lowest value of nitrogen uptake by tuber was recorded by T_1 (control) followed by T_3 (100 per cent K alone).

4.12.2 Phosphorus

The uptake of P was influenced significantly by treatments. The Na treated plots recorded higher values of P uptake by tuber than the untreated plots. The highest value of uptake of P by tuber was recorded by T_6 (50 per cent K plus 100 per cent Na) followed by T_9 (100 per cent K plus 100 per cent Na) and T_7 (100 per cent K plus 50 per cent Na). But they were found to be on par. T_1 (control) recorded the lowest value of uptake of P by tuber.

4.12.3 Potassium

Potassium uptake by the tuber was found to vary significantly due to treatments. Sodium treated plots showed higher values of uptake of K compared to the K treated plots. T_6 (50 per cent K plus 100 per cent Na) recorded the highest value of K uptake by tuber, followed by T_5 (50 per cent K plus 75 per cent Na) and T_7 (100 per cent K plus 50 per cent Na). The lowest value was recorded by T_1 (control) followed by T_2 (50 per cent K alone) and T_3 (100 per cent K alone).

4.12.4 Sodium

The uptake of Na by tuber did not show any significant difference due to treatments. Highest value of uptake of Na by tuber was recorded by the treatment T_5 (50 per cent K plus 75 per cent Na) followed by T_4 (50 per cent

Table 15. Uptake of nutrients by tuber as affected by application of K and Na in different proportions (kg ha^{-1})

Treatments	N	P	K	Na	Ca	Mg
T_1 (No K, No Na)	7.25	2.35	13.95	2.35	1.6	1.17
T_2 (50 % K alone)	8.39	3.5	16.36	2.08	2.45	1.81
T_3 (100 % K alone)	7.77	3.25	21.44	3.55	2.24	1.71
T_4 (50 % K + 50 % Na)	14.36	3.75	25.93	5.47	5.76	5.76
T_5 (50 % K + 75 % Na)	13.71	3.72	26.67	5.95	4.48	4.59
T_6 (50 % K + 100 % Na)	15.26	5.04	33.97	4.23	6.18	7.09
T_7 (100 % K + 50 % Na)	12.75	4.25	26.56	5.43	6.72	7.02
T_8 (100 % K + 75 % Na)	14.11	3.68	22.31	4.41	4.94	5.48
T_9 (100 % K + 100 % Na)	13.52	4.34	25.62	4.65	5.41	5.78
CD (0.05 level)	3.74	1.12	6.99	NS	2.37	1.89

K plus 50 per cent Na). The lowest value was recorded by T_2 (50 per cent K alone) followed by T_1 (control) and T_3 (100 per cent K alone)

4.12.5 Calcium

Uptake of Ca by tuber was found to be significantly different between treatments. Treatments with Na showed higher values of Ca uptake by tuber than the K treated plots. T_7 (100 per cent K plus 50 per cent Na) recorded the highest value of calcium uptake by tuber and it was followed by T_6 (50 per cent K plus 100 per cent Na) and T_4 (50 per cent K plus 50 per cent Na). But they were on par. The lowest value was recorded by T_1 (control) followed by T_3 (100 per cent K alone).

4.12.6 Magnesium

Magnesium uptake was found to be significantly different between treatments. T_6 (50 per cent K plus 100 per cent Na) recorded the highest value of Mg uptake by tuber followed by T_7 (100 per cent K plus 50 per cent Na). The lowest value of Mg uptake by tuber was recorded by T_1 (control) followed by T_3 (100 per cent K alone). The Na applied plants were having significantly high values compared to the K treated plants.

4.13 SOIL ANALYSIS

4.13.1 pH

Soil pH after the harvest was recorded and presented in Table 16. The values did not show any significant difference between treatments.

4.13.2 Electrical Conductivity

Electrical Conductivity (EC) values recorded after harvest are presented in Table 16. The values varied significantly due to treatments. T_7 (100 per cent K plus 50 per cent Na) recorded the highest value of EC where as T_4 (50 per cent K plus 50 per cent Na) recorded the lowest value of EC.

4.13.3 Organic Carbon

Organic carbon values are presented in Table 17. The values did not show any significant difference due to treatments. The treatment T_8 (50 per

Table 16. pH and EC as affected by application of K and Na in different proportions

Treatments	pH	EC (d S m^{-1})
T_1 (No K, No Na)	5.4	0.007
T_2 (50 % K alone)	5.4	0.007
T_3 (100 % K alone)	5.3	0.009
T_4 (50 % K + 50 % Na)	5.6	0.007
T_5 (50 % K + 75 % Na)	5.5	0.007
T_6 (50 % K + 100 % Na)	5.3	0.008
T_7 (100 % K + 50 % Na)	5.7	0.015
T_8 (100 % K + 75 % Na)	5.4	0.011
T_9 (100 % K + 100 % Na)	5.5	0.009
CD (0.05 level)	NS	0.003

Table 17. Organic carbon (%) as affected by application of K and Na in different proportions

Treatments	Organic carbon content
T_1 (No K, No Na)	0.55
T_2 (50 % K alone)	0.59
T_3 (100 % K alone)	0.71
T_4 (50 % K + 50 % Na)	0.73
T_5 (50 % K + 75 % Na)	0.67
T_6 (50 % K + 100 % Na)	0.72
T_7 (100 % K + 50 % Na)	0.64
T_8 (100 % K + 75 % Na)	0.84
T_9 (100 % K + 100 % Na)	0.75
CD (0.05 level)	NS

cent K plus 75 per cent Na) recorded the highest value of organic carbon content as 0.84 per cent and the lowest value of organic carbon was recorded for the treatment T_1 (control) as 0.55 per cent. T_1 (control) and T_2 (50 per cent K alone) showed the lowest value of organic carbon content.

4.13.4 Available Nitrogen

The values of available N at harvest are presented in Table 18. Even though the amount of N applied were the same, the treatments showed significant difference in the available N status of soil. The highest value was recorded for the treatment T_6 (50 per cent K plus 100 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na) where as the lowest value of available N was recorded for the treatment T_8 (100 per cent K plus 75 per cent Na).

4.13.5 Available Phosphorus

Soil available P values are presented in Table 18. The values showed significant difference between treatments. The highest value of available P was recorded in the treatment T_3 (100 per cent K alone) followed by T_5 (50 per cent K plus 75 per cent Na). The lowest value was recorded for the treatment T_7 (100 per cent K plus 50 per cent Na).

4.13.6 Available Potassium

Soil available K values are presented in Table 18. The values differed significantly between treatments at harvest. The highest value was recorded for the treatment T_9 (100 per cent K plus 100 per cent Na) followed by T_8 (100 per cent K plus 75 per cent Na). The lowest value was recorded for the treatment T_1 (control). Other Na treated plots recorded higher values of available K compared to the treatment T_3 (100 per cent K alone).

4.13.7 Available Sodium

The values of available Na are presented in Table 18. The values did not show any significant variation due to treatments. The highest value was

Table 18. Soil nutrient content as affected by application of K and Na in different proportions

Treatments	Available Nitrogen (kg ha^{-1})	Available Phosphorus (kg ha^{-1})	Available Potassium (kg ha^{-1})	Available Sodium (kg ha^{-1})	Exchangeable Calcium (c mol kg^{-1})	Exchangeable Magnesium (c mol kg^{-1})
T_1	261.0	95.6	126.8	226.5	1.9	0.65
T_2	328.3	101.1	186.6	255.8	1.9	0.41
T_3	259.8	152.8	174.8	223.1	2.1	0.70
T_4	266.0	124.2	180.4	231.4	1.8	0.62
T_5	319.3	145.1	148.7	219.5	1.8	1.10
T_6	369.0	103.4	180.5	224.4	1.7	0.87
T_7	351.6	53.7	208.6	229.9	1.6	1.10
T_8	241.3	129.4	211.3	238.8	2.8	0.31
T_9	323.2	107.9	238.4	205.7	2.2	0.61
CD (0.05 level)	84.49	33.47	48.12	NS	0.27	0.51

recorded for the treatment T_2 (50 per cent K alone) and the lowest value was for the treatment T_9 (100 per cent K plus 100 per cent Na).

4.13.8 Exchangeable Calcium

The exchangeable Ca content in the soil after harvest is presented in Table 18. The values showed significant difference between the treatments. The highest value was recorded for the treatment T_8 (100 per cent K plus 75 per cent Na) followed by T_9 (100 per cent K plus 100 per cent Na). The lowest value recorded for T_7 (100 per cent K plus 50 per cent Na). T_1, T_2 and T_3 were found to be on par.

4.13.9 Exchangeable Magnesium

The values of exchangeable Mg are shown in Table 18. The values varied significantly due to treatments. T_5 (50 per cent K plus 75 per cent Na) and T_7 (100 per cent K plus 50 per cent Na) recorded the highest value of exchangeable Mg. The lowest value was recorded for T_1 (control). T_6 and T_7 were found to be significantly different from T_1 and T_2. T_1, T_2 and T_3 were found to be on par.

4.14 ECONOMIC ANALYSIS

Benefit : cost ratio was not found to vary significantly due to treatments. The mean values are presented in Table19.

The highest B:C ratio was recorded by the treatment T_4 (50 per cent K plus 50 per cent Na) followed by T_7 (100 per cent K plus 50 per cent Na). The lowest return was obtained from T_1 (control) with B: C ratio 0.85 followed by T_2 (50 per cent K alone) as 1.02.

4.15 CORRELATION STUDIES

The correlation of various parameters to yield was studied. Dry matter production and uptake of Ca showed significant positive correlation to yield with values 0.6007** and 0.5949**. However the uptake of all the nutrients under study were positively correlated with yield. The

Table 19. B : C ratio as affected by application of K and Na in different proportions

Treatments	B: C ratio
T_1 (No K, No Na)	0.85
T_2 (50 % K alone)	1.02
T_3 (100 % K alone)	1.40
T_4 (50 % K + 50 % Na)	1.65
T_5 (50 % K + 75 % Na)	1.49
T_6 (50 % K + 100 % Na)	1.51
T_7 (100 % K + 50 % Na)	1.54
T_8 (100 % K + 75 % Na)	1.23
T_9 (100 % K + 100 % Na)	1.22
CD (0.05 level)	NS

physiological characters like chlorophyll content showed positive correlation with yield.

Dry matter production showed significant positive correlation with uptake of N, Ca and Mg, chlorophyll content and LAI. Uptake of P, K and Na showed positive correlation with dry matter production (Table 20).

Table 20. Correlation of different parameters to yield

	Yield of tuber	DMP	N uptake	K uptake	Na uptake	P uptake	Ca uptake	Mg uptake	Chlorophyll content	Number of leaves	LAI
Yield of tuber	1.0000										
DMP	0.6007	1.0000									
N uptake	0.3223	0.6352	1.0000								
K uptake	0.0907	0.3168	0.3498	1.0000							
Na uptake	0.3741	0.2123	0.1941	0.2722	1.0000						
P uptake	0.1529	0.3361	0.5532	0.0334	0.0539	1.0000					
Ca uptake	0.5949	0.7768	0.5506	0.2019	0.3623	0.4006	1.0000				
Mg uptake	0.2910	0.4047	0.4709	0.4971	0.4571	0.0154	0.4467	1.0000			
Chlorophyll content	0.2377	0.4963	0.3388	0.0171	0.0405	0.3368	0.5650	0.0934	1.0000		
Number of leaves	0.3198	0.2756	0.3717	0.5093	0.2734	-0.0391	0.2254	0.6856	˜0.0700	1.0000	
LAI	0.3476	0.4688	0.4630	0.4964	0.2247	0.0559	0.3798	0.7666	0.1975	0.8955	1.0000

DISCUSSION

5. DISCUSSION

An investigation entitled "Synergistic effect of Na and K on yield and nutrient uptake in coleus (*Coleus parviflorus* L.)" was carried out in the College of Agriculture, Vellayani during 2003-2004 to elucidate the effect of K:Na interactions on the growth and yield of coleus plant. Sreedhara variety was taken up as the test crop. The results obtained from the above experiment are discussed in this chapter.

5.1 GROWTH CHARACTERISTICS

The growth characteristics like plant spread, number of functional leaves and number of branches showed significant variation due to treatments.

The plant spread was the highest in the treatment where K and Na were given in 50:50 proportions. Number of branches and number of functional leaves produced when the plants were given a combination of 100:50 either Na or K were similar and on par. This means that as far as growth characteristics are concerned, it is better to apply the two univalent ions in a more economic ratio of 50:50. Prema *et al.* (1992) recorded maximum number of leaves when K and Na were supplied at 50:50 combinations. The lower values on branches and number of functional leaves in the treatments, where K alone was given show that K could not produce a specific effect on plant spread or number of leaves and branches. Behura (2001) also reported that K had no effect on plant height and number of leaves in mango ginger. It was noticed that treatments without K and Na recorded a lower number of functional leaves. This revealed that Na at even its higher or lower concentration along with high or low dose of K influenced the production of functional leaves.

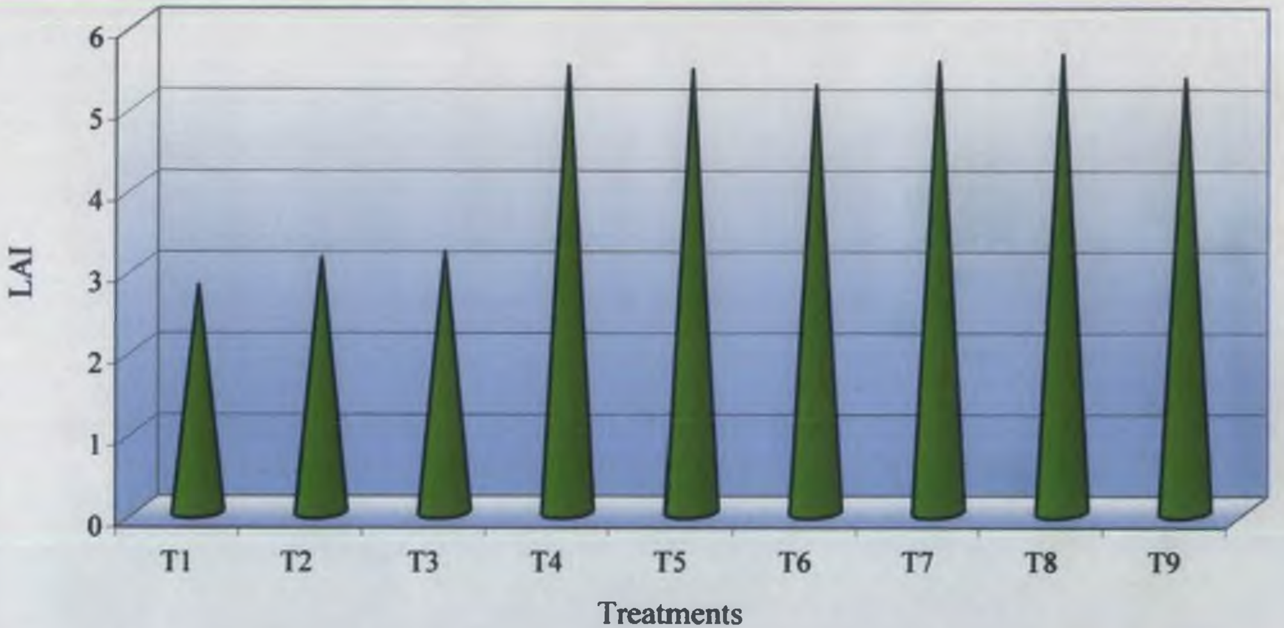
Plate 1. Overall view of the experimental plot

Plate 2. Effects of treatments T_3 and T_4 on plant growth

Plate 3. Effect of treatments T_5, T_6 and T_7 on plant growth

The values of LAI also showed significant difference due to treatments. Here also the Na with K treated plots showed significantly higher values compared to plots treated with only K (Fig.3). The LAI is a very important growth factor especially for tuber crops, which influences the overall growth and production of tubers. In cassava, Williams and Ghazali (1969) had reported that a high LAI predetermines a high tuber yield since the development of leaf canopy precedes tuber growth. LAI is a factor contributing to photosynthetic efficiency by providing more area for interception of solar energy. Devasenapathy *et al.* (1996) reported a similar behaviour of the plant when NaCl nutrition along with recommended dose of NPK was given for coconut. Sudharmaidevi and Padmaja (1997) reported that the LAI of cassava was significantly higher when Na and K were given at 50:50 proportions in comparison to application of K alone

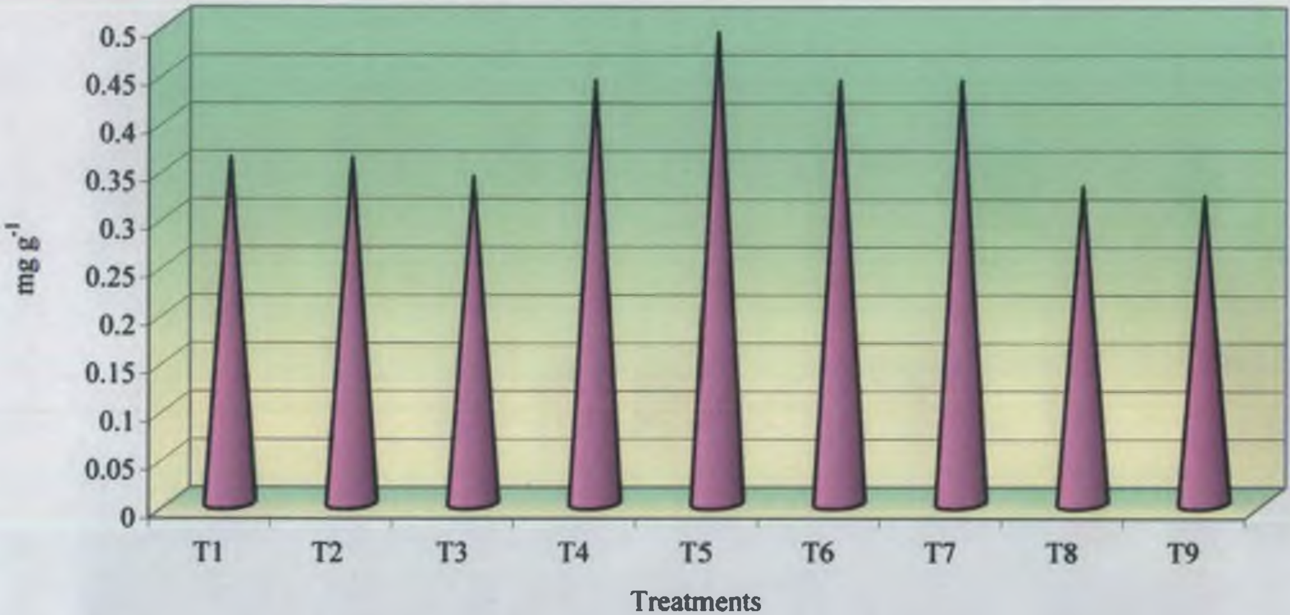
The chlorophyll concentration in the leaves of a plant is a direct indication of its photosynthetic efficiency. Hence this parameter assumes much importance, when the growth attributes are taken into consideration. In the present study, it was noticed that the chlorophyll content increased in treatments with 50 per cent K along with varying levels of Na (Fig.4). Treatments, which received K alone recorded lower values of chlorophyll content. This shows that Na also has a deciding role in the chlorophyll biosynthesis and the effect of Na was more pronounced when K was at its lower concentration. According to Ando and Oguchi (1990), Na is found to increase the chlorophyll content of C_4 plants. Sudharmaidevi and Padmaja (1997) also reported higher amounts of total chlorophyll content when Na and K were given in 50:50 combination or lower doses. 100 per cent K along with 100 per cent Na resulted in a lower amount of total chlorophyll content. This may be due to the high doses of Na along with full dose of K exerting an adverse effect on chlorophyll synthesis.



T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)

T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 3. Leaf area index as influenced by treatments



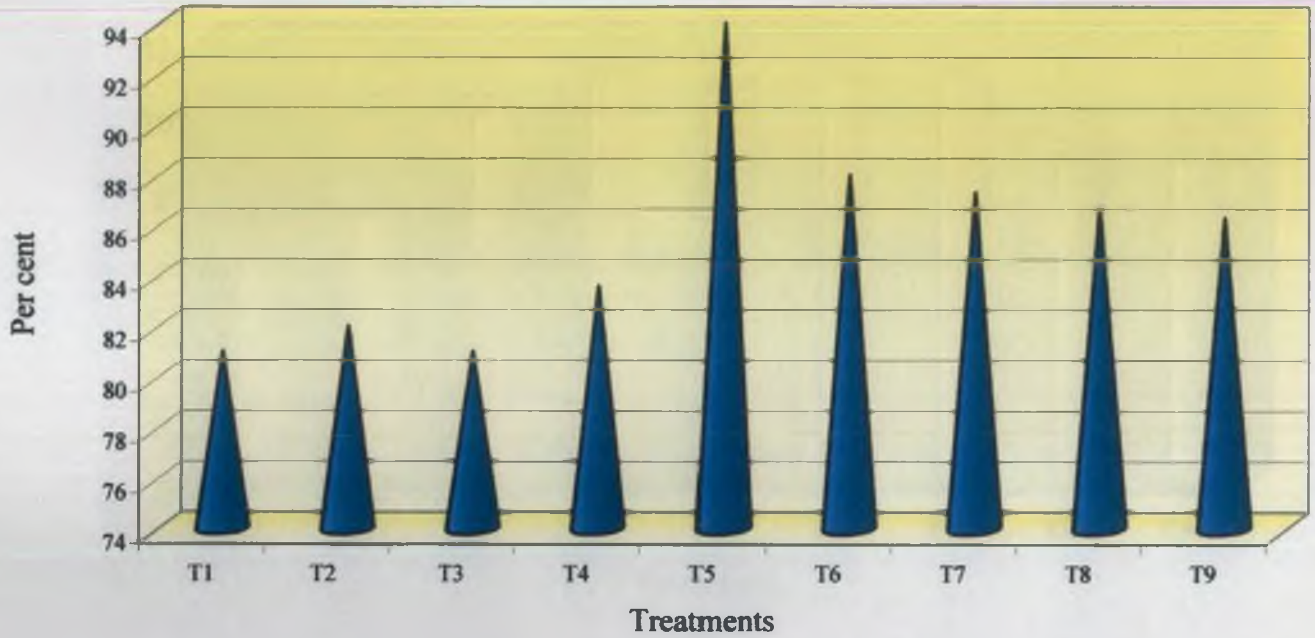
T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 4. Chlorophyll content as influenced by treatments

Coleus being a semi succulent plant, stores more water in aerial parts. It requires a reasonably good, evenly distributed rainfall and cannot withstand drought conditions. Treatments showed significant difference in terms of RLWC (Fig.5). Na with K treated plants showed an increase in the RLWC compared to the K alone treated plants. Ashraf (1989) reported that as salinity increases the water content of plant also increases. Here the medium and high levels of Na along with low levels of K showed high RLWC. This showed that the effect of Na in controlling the maintenance of leaf water potential is effective only at low levels of K. Sudharmaidevi and Padmaja (1997) reported an increase in relative leaf water content in cassava due to the substitution of K by Na at 50 per cent level. Sunu (2001) also reported similar results in banana cv. Robusta. A high relative leaf water content is due to the result of reduction in leaf transpiration rate. Na^+ and Cl^- ions accumulate mainly in the vacuole rather than the cytoplasm (Greenway and Munns, 1980), with their accumulation therefore being conductive to osmotic adjustment and turgor maintenance. Therefore it can be thought that these plants with a high RLWC may be more efficient than others in withstanding drought.

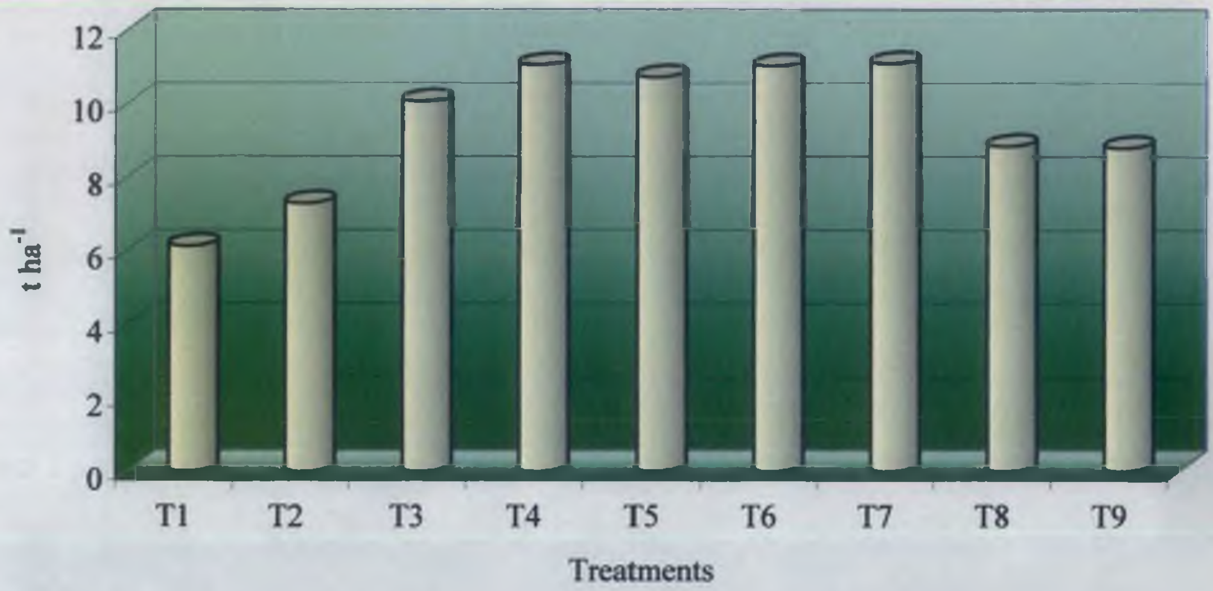
5.2 YIELD AND YIELD ATTRIBUTES

Yield and yield attributes did not show any significant difference due to the treatments. But in general Na with K treated plants showed better performance in terms of yield and yield attributes than the K alone treated plants (Fig.6). The highest yield was recorded when Na and K were given in 50:50 combination. This can be attributed to the synergistic interaction of Na and K leading to stimulation in the growth parameters, which were evident from a higher value for number of functional leaves, Leaf Area Index and chlorophyll content. The rate of nutrient uptake was also higher, which ultimately lead to a higher tuber yield. In the plants treated with K alone, such a synergistic effect could not occur, which resulted in lower growth rate and tuber yield. The top growth is predisposing to tuber yield.



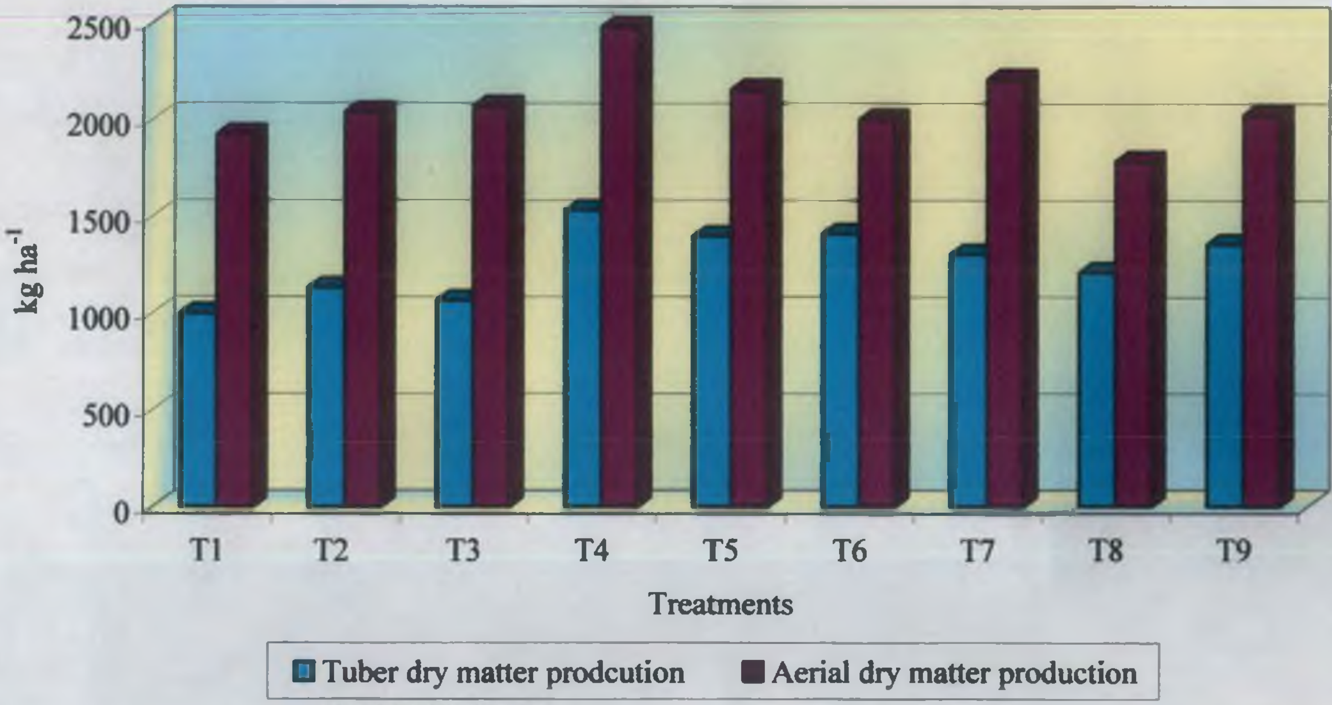
T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig. 5. Relative leaf water content as influenced by treatments



T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 6. Yield of tuber as influenced by treatments



T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 7. Tuber and aerial dry matter production as influenced by treatments

the ultimate yield depending on the inherent harvest index (HI) of the plant. A high yielder therefore would have a high photosynthetic capacity and partitioning priority in favour of the storage tubers (Okeke *et al.*, 1979). Therefore it would appear that the key to high yield is the efficiency of partitioning of photosynthates to the sink site. Hence from the results obtained in this study, it is reasonable to think that plants receiving Na plus K in 50:50 combinations have a high partitioning efficiency. The lower yield of plants supplied with obtained in 100 per cent K is explained by the poor partitioning efficiency of such plants. Many research workers have made similar reports in different crops (Sudharmaidevi and Padmaja (1999) in cassava, Lekshmi (2000) in banana cv. Nendran and Sunu (2001) in banana cv. Robusta).

5.3 DRY MATTER PRODUCTION

Dry matter production showed significant difference between treatments. The 50:50 combination of K and Na resulted in the highest value of dry matter production (Fig.7). Treatments with 100 per cent Na along with different levels of K resulted in a lower levels of dry matter production. This shows that a high level of Na can cause reduction in growth and hence dry matter production. But the low and medium levels of Na along with different levels of K registered the higher rate of production of dry matter. Along with Na, K even at low levels could give better growth and produced more number of leaves and branches indicating the synergistic effect of Na and K on plant functions, which gave the better performance in terms of growth characteristics and thus in dry matter production.

Being a tuber crop, the tuber yield also contributes a portion of the dry matter. The Na treated plants produced comparatively better yield than the untreated plots. This revealed that for the tuber growth and development Na could play a key role along with K. But the high concentration of Na always resulted in an adverse effect. However it can be concluded that Na has some beneficial role in the uptake and growth, and herce the dry matter production when it is applied along with K even in the low concentration. Sunu (2001) reported a higher dry matter production in banana cv. Robusta when 50 per cent of K was replaced with Na of common salt.

5.4. QUALITY PARAMETERS

The characteristic flavour of coleus tuber is due to the presence of essential oil, mainly composed of phenolics. Tubers are rich in carbohydrates, minerals and essential aminoacids. Among the quality parameters, starch content of the tuber, which is the most important constituent as far as cooking quality is concerned, showed significant variation due to treatments. 100 per cent K and 50 per cent K along with medium and low levels of Na gave high starch content. But the high doses of Na and K resulted in the least content of starch revealing the adverse effect of high concentrations on starch synthesis. The 50:50 combination yielded tubers with a high starch content. Sudharmaidevi and Padmaja (1996b) also reported a stimulation in production of starch in cassava tubers, when 50 per cent of K was replaced with Na of common salt.

Cooking quality of the tuber showed different trends, but those with high levels of K gave better results in terms of taste and appearance. The full doses of Na and K resulted in the least acceptability compared to the other Na treated ones. The overall acceptability of tubers from the treatment receiving K and Na in equal proportion was comparable to those receiving K alone. This shows that the same quality can be obtained at a lesser cost if the 50 :50 combination is adopted. Sunu (2001) recorded that maximum fruit quality in banana cv. Robusta resulted when 100 per cent K alone was given.

Keeping quality of the tubers did not show wide variation due to treatments. But tubers from the plot receiving K and Na in 100:100 proportion exhibited the longest storage life. This shows that in addition to K, Na is also having a role in extending the keeping quality of coleus tubers. The influence of Na on the keeping quality of cassava tubers has been reported by Sudharmaidevi and Padmaja (1996b). The reason attributed for long shelf life of cassava tubers was the high levels of phenols and HCN in the rind of such tubers.

5.5 NUTRIENT CONTENT AND UPTAKE

It is known that plant growth is the result of inter- related utilization of different elements concerned in nutrition. Accordingly the concept of cation balance presents a situation where the addition of an element may cause positive or negative growth effects depending on the relative concentration of other elements. Hence in the present investigation, the concentration of each nutrient element was separately determined in different parts such as leaf, stem, root and tuber of the plant

Nitrogen content in the different plant parts showed variation between treatments; the highest content being recorded in leaves in all the treatments. All the plants, which received Na in addition to K, recorded higher values of N content than those receiving K alone. This shows that Na has a key role in N absorption in coleus. The highest values of N absorption were registered by plants from treatment T_7 (100 per cent K plus 50 per cent Na). Here, 47 per cent was retained in absorbing roots and stem, the rest being translocated to leaves and tubers. But in the treatment T_4, which recorded the highest tuber yield, only 42 per cent was retained in roots and stem, the rest being utilized in leaves and tubers.

The coleus tubers are known to contain moderately high amounts of proteins. All the tubers from plots receiving Na along with K registered higher per cent of N content in comparison to those receiving K alone. This shows that the tubers from the combined treatments are nutritionally more rich. The high content of N in the leaves of the treatments T_4, T_5, T_6 and T_7 coincides well with the high content chlorophyll noticed in these plants. All these facts prove that a synergistic effect of K and Na was exerted in coleus in improving N use efficiency of plants.

The treatments had little influence on the P content of plants. The combination treatments receiving varying levels of Na along with 100 per cent K recorded high values of total P in comparison to treatments with varying levels of Na with 50 per cent K. In the treatments where K alone was applied, the P content was higher than this. But the lower yields recorded in the treatments, which were given full K with or without Na, compared to the treatments supplied with varying levels of Na with 50 per cent K, indicate that the P absorbed was not fully utilized. At the same time Na and K at 50:50 proportion was the most efficient combination in utilizing P indicating a synergistic effect at this combination in terms of P use efficiency.

Potassium,.which is known as the quality nutrient is having a special importance in tuber crops because of its specific functions in starch synthesis, translocation of sugars to the tuber *etc*. It is very interesting to note that in all the treatments receiving Na, the K uptake was high. When the different parts were separately analyzed, the leaf content of K was considerably higher in Na plus K treatments, when compared to K alone treatments. Even then the plants receiving 100 per cent K recorded lower values of leaf K than Na plus K treated plants (Fig.8 to11). This indicates that Na has a very important role in K absorption. Elsie *et al.* (2000), studying the substitution of K by Na in rubber, reported that K uptake increased in substituted treatments. Evidence for increase in K uptake in presence of Na had also given by Box and Schachtman (2000) in wheat.

These reports and the present findings point to the existence of such mechanisms, which become active in presence of Na for absorption of K (Fig.12). In the tuber also, the contents in these treatments were higher. This might have directly contributed to the good quality and extended storage life of tubers. The stem also contained higher amounts K in these treatments. This might have helped in a higher rate of translocation of sugars to the tubers, for further conversion to starch and protein.

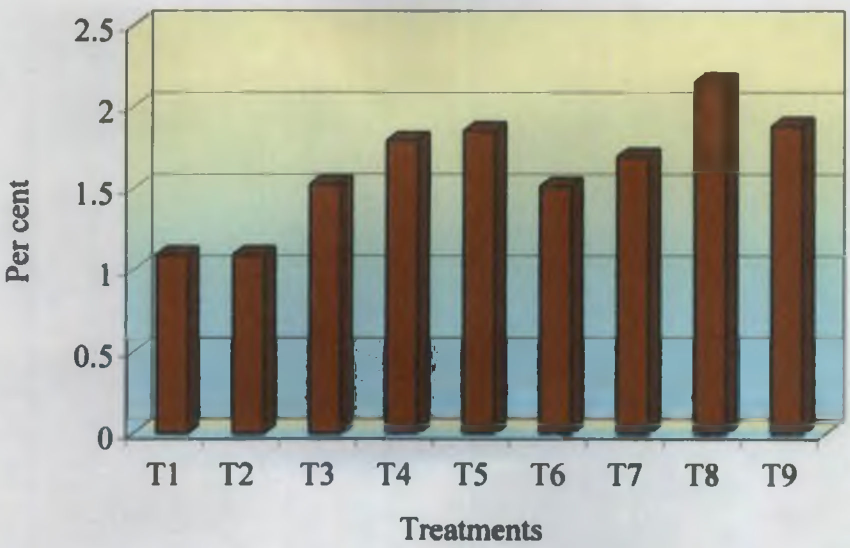


Fig 8. Potassium content of leaf as influenced by treatments

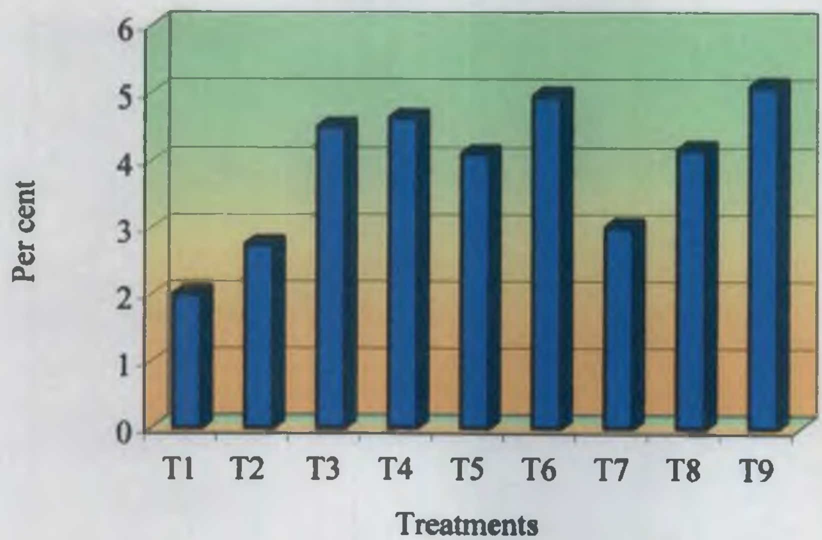


Fig 9. Potassium content of stem as influenced by treatments

T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

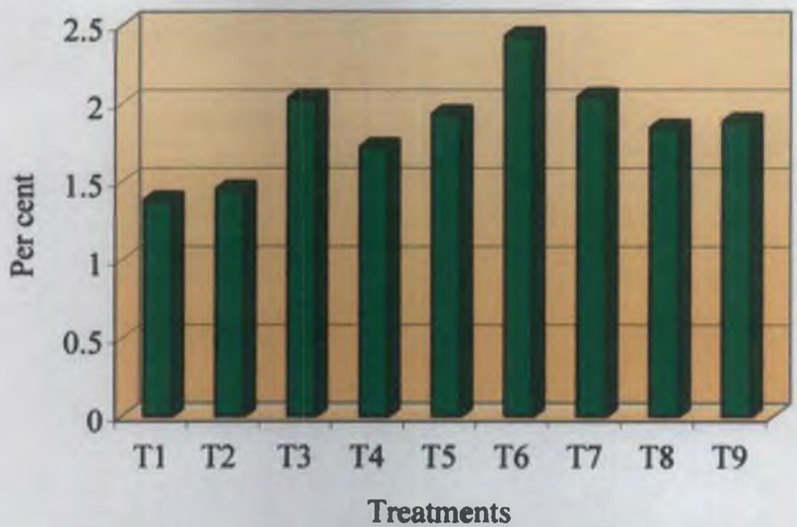


Fig 10. Potassium conent of tuber as influeced by treatments

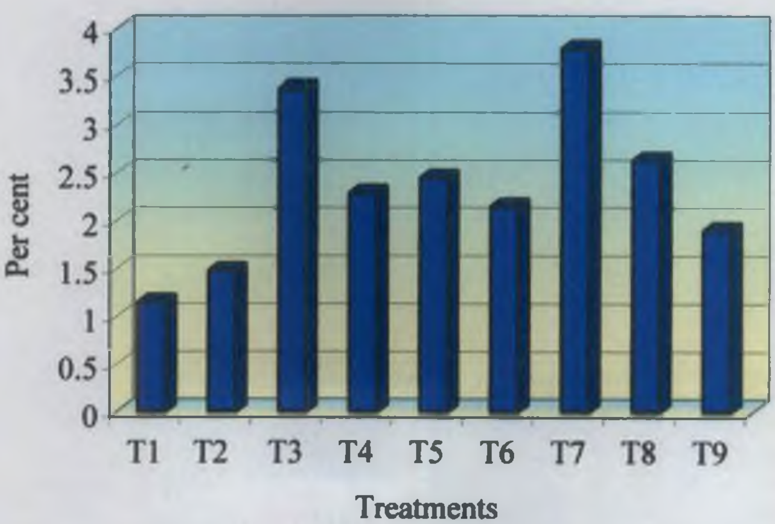


Fig 11. Potassium content of root as influenced by treatments

T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

These findings suggest that the K use efficiency increased several folds by adopting combined application of K and Na at 50:50 proportions. In contrast to the uptake pattern of K, leaf content of Na was the highest in full K treated plots.

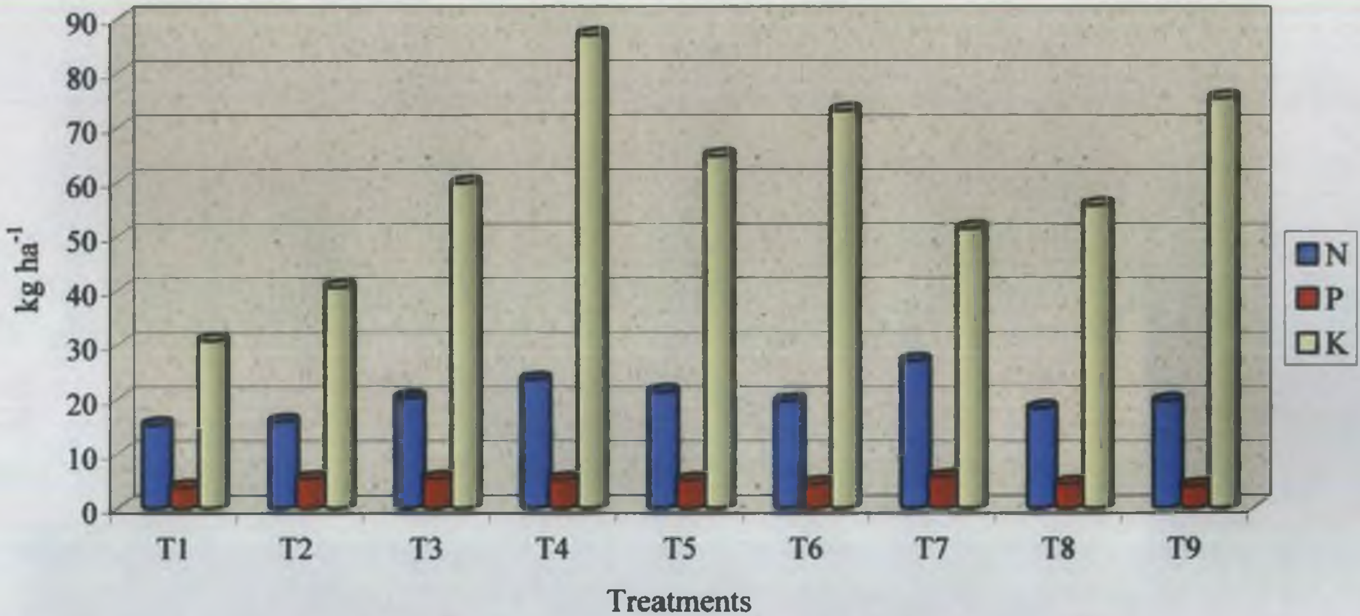
As far as the secondary nutrients are concerned, there was significant difference in the Ca content of plants. In all the Na treated plants, there was a considerable increase in the Ca content. The low Ca content in the K alone treated plots may be due to the antagonistic effect of K on the absorption of Ca at the absorption sites as reported by Singh and Verma (2001) in onion. The increase in Ca content in the Na treated plants is a desirable trait since it improves the quality of tubers in coleus. The Mg content also followed the same trend as that of Ca (Fig.13). A similar result was reported earlier by Shareef *et al.* (2002) in wheat.

5.6 CHANGE IN PHYSICAL AND CHEMICAL PROPERTIES OF SOIL DUE TO SODIUM AND POTASSIUM TREATMENTS

The analyses of the soil sample after harvest showed different trends due to treatments. There was no influence on the pH as a result of application of treatments. The EC values recorded were very low so as to cause any effect on crop growth. This shows that use of Na at these levels is safe and beneficial for growth of plants. Organic carbon status of the soil did not show much difference due to treatments.

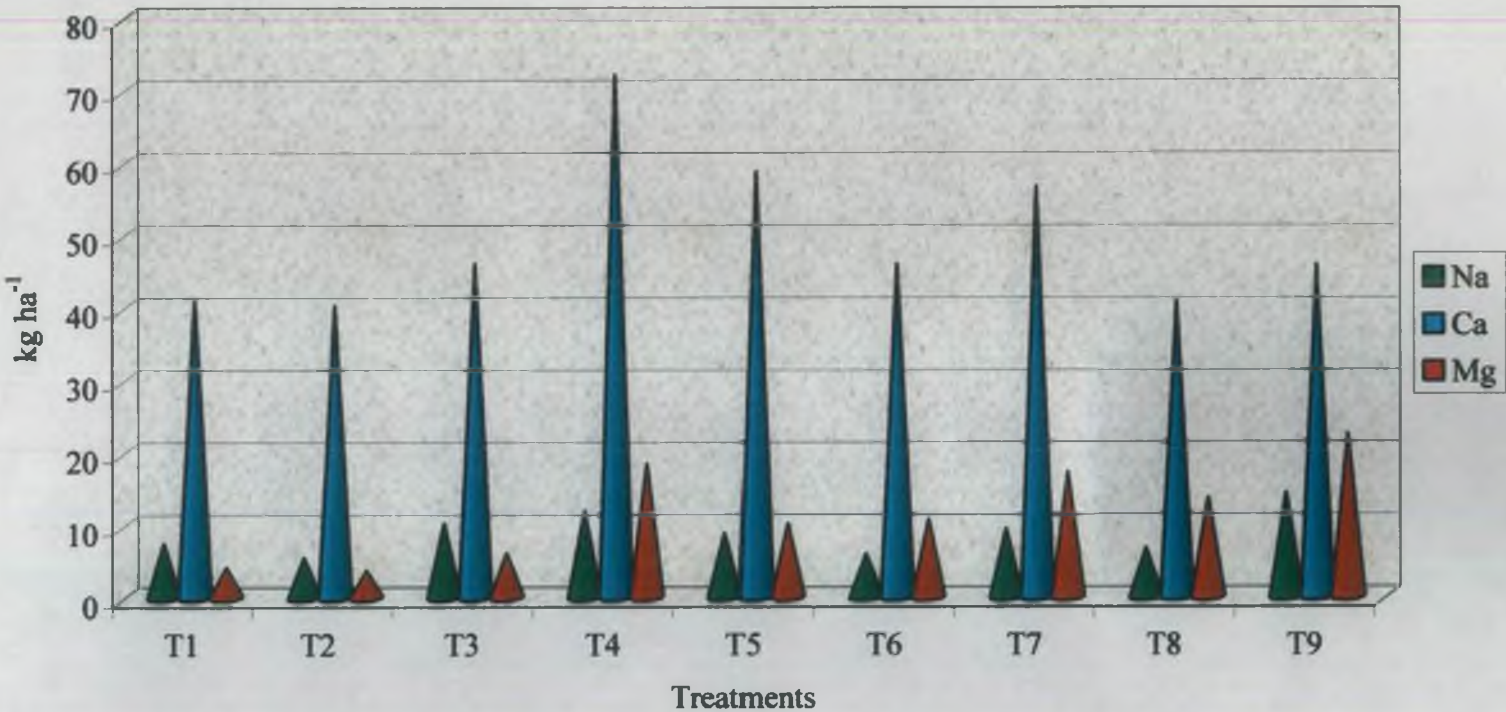
The soil available N was higher in the combination treatments compared to the K alone treatments. The higher content of N in plant parts of combination treatments support this finding. But the available P content was the highest in the K alone treated plots because of the less crop removal. The high content of P, which was recorded in the plant parts of K treated plants give ample proof for the increased availability in that treatment.

The soil available K was also higher in the combination treatments, following the same pattern of uptake of K by plants. The values on



T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 12. Uptake of N, P and K as influenced by treatments



T_1 (No K, No Na)
T_2 (50 % K alone)
T_3 (100 % K alone)
T_4 (50 % K + 50 % Na)
T_5 (50 % K + 75 % Na)
T_6 (50 % K + 100 % Na)
T_7 (100 % K + 50 % Na)
T_8 (100 % K + 75 % Na)
T_9 (100 % K + 100 % Na)

Fig 13. Uptake of Na, Ca and Mg as influenced by treatments

available Na did not show any significant difference due to treatments. But contrary to the uptake pattern, the availability of Ca in soil was higher in all the plots, which received 100 per cent K. This justifies the view that an antagonism exists between K and Ca at the absorption sites. This also points to the fact that for increased Ca uptake and therefore increased Ca efficiency, it is better to apply Na along with K.

The pattern of Mg availability was slightly different from that of Ca. The availability and uptake were more in treatments, which received varying levels of Na with 50 per cent of K. Sudharmaidevi and Padmaja (1999) also reported that Mg availability increased, when Na was also included as treatment.

5.7 CORRELATION STUDIES

Tuber yield was found to be positively and significantly correlated with the total dry matter production. This is expected because canopy growth is a determining factor in tuber production. Here in this study, the tuber growth followed the pattern of canopy growth and therefore the treatments, which produced more quantity of dry matter also produced more tubers.

The dry matter production in turn, was positively and significantly correlated to the LAI, chlorophyll and uptake of N, Ca and Mg. All these factors are directly influencing the growth of plants. The tuber yield had positive and significant correlation with Ca uptake. Coleus tubers have a high content of Ca in the tuber composition. The strong correlation is evident from the uptake pattern of Ca by plant parts.

Tuber yield also had a positive correlation with all the major nutrients. It had a stronger correlation with Na uptake than with K uptake. This leads to the conclusion that Na had more influence in the final tuber yield than K in coleus.

5.8 ECONOMIC ANALYSIS

When the B:C ratio was analyzed, it was clear that the treatment T_4 (50 per cent K plus 50 per cent Na) had the highest return per rupee invested. It was evident from Table 19 that all the treatments which received different levels of Na with 50 per cent K were more economic than the treatment, which received K alone. Hence it can be recommended to the farmers because, for a lesser investment he can get a better income.

SUMMARY

6. SUMMARY

An investigation entitled "Synergistic effect of Na and K on yield and nutrient uptake in coleus (*Coleus parviflorus* L.)" was carried out in College of Agriculture, Vellayani from September 2003 to January 2004 to study the synergistic effect of Na along with K on the growth and yield of coleus crop. Common salt and Muriate of Potash were taken respectively as the sources of Na and K. The experimental crop was coleus, variety Sreedhara, released from CTCRI, Sreekariyam. The treatments included are 50 and 100 per cent of the recommended doses of K alone and in combination with 50, 75 and 100 per cent of Na of common salt to equalize the same amount of recommended doses of K. The experiment was conducted in Randomized Block Design.

The important results of the study are summarized below:

1. The different growth characters like plant spread, number of leaves and leaf area index (LAI) showed significant difference due to treatments. The values of the above parameters were significantly higher in treatments receiving Na at different levels along with 50 per cent K, showing that combined application of K and Na exerts a beneficial influence on the growth of coleus plants.

2. The chlorophyll content even though did not show significant difference between treatments. However, increased Na application along with 50 per cent K showed an increase in chlorophyll content, indicating the role of Na in chlorophyll biosynthesis.

3. The RLWC, which is a very important factor as far as coleus plants are concerned, showed significant variation due to treatments. Sodium with K treated plants showed an increase in RLWC compared to the K alone treated plants. This shows that Na has an important role in

8. Starch content of tubers showed significant variation due to treatments. The highest starch content was in the treatment T_8 (100 per cent K plus 75 per cent Na). The treatment T_9 (100 per cent K plus 100 per cent Na) was found to contain the lowest starch content. This shows that tubers with a higher quality can be produced at a lesser cost by adopting combined application of K and Na.

9. Nitrogen, P and Na content of tuber did not show significant difference due to treatments. But K, Ca and Mg content of tubers showed significant difference due to treatments. Though the content of N and P did not show any significant difference due to treatments, uptake of nutrients by tuber was found to increase in the Na and K treated plants compared to K alone treated plants. Fifty per cent K along with different levels of Na was found to have higher uptake of nutrients than the others. This shows that Na has a stimulative effect on uptake of nutrients.

10. Uptake of nutrients like N, K, Ca and Mg by aerial plant parts showed significant difference due to treatments. The Na plus K treated plants showed higher values of uptake of nutrients. Uptake of Na and P by aerial plant parts did not show any variation due to treatments. The 100:100 combinations of Na and K showed higher uptake of Na by aerial plant parts. But it was found to be on par with the treatment with 100 per cent K alone.

11. Soil pH after harvest did not show any significant difference due to treatments. Na treated plots showed only slight increase in pH but they were on par with Na untreated plots.

12. Electrical conductivity values after harvest showed significant difference due to treatments. The 50:50 combinations of Na and K showed the lowest EC value. This showed that use of Na at these levels is safe and beneficial for growth of plants.

13. In the case of available nutrient status of soil, N, P, K, Ca and Mg content of soil after harvest showed significant variation due to treatments. Even though the N and P applied in all plots were same, the available status of these nutrients after harvest varied significantly. The available Na after harvest did not show any significant variation due to treatments. The higher uptake values of nutrients support the higher availability in soil.

14. Dry matter production, uptake of N, P, K, Na, Ca and Mg, chlorophyll content and LAI showed positive correlation with yield of tuber. The dry matter production and uptake of Ca showed significant positive correlation with yield of tuber.

15. LAI showed significant positive correlation with dry matter production, uptake of N, K and Mg. The dry matter production in turn, was positively and significantly correlated to the LAI, chlorophyll and uptake of N, Ca and Mg. All these factors are directly influencing the growth of plants.

16. Maximum B: C ratio was recorded for the treatment with 50:50 combinations of Na and K, making it clear that this combination is the most economic one.

From the findings in the present study, it can be concluded that a combination of 50 per cent K and 50 per cent Na is optimum for getting the maximum yield, with improved quality and nutritionally rich tubers. The high B:C ratio makes it an economically feasible practice which can be recommended to farmer

Future lines of Work

Based on the results obtained in this experiment, the following aspects need to be studied in a detailed manner.

1. The synergistic influence of Na on the uptake and functioning of K in plants.
2. The mechanism of action of Na in improving the quality and shelf life of tubers.
3. Physical, chemical and biological properties of soil due to the continuous application of Na.

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7. REFERENCES

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* Original not seen

APPENDIX

APPENDIX - I

Weather parameters during the cropping period (September 2003 to January 2004)

Standard week	Maximum temperature (^0C)	Minimum temperature (^0C)	Relative humidity (%)	Rain fall(mm) (Monthly total)
35	30.1	23.4	91.3	23.1
36	30.8	23.7	90.2	4.6
37	31.3	23.6	87.1	3.1
38	31.8	24.3	83.6	0.0
39	32.2	24.3	80.3	0.0
40	29.9	23.8	93.6	222.8
41	30.6	23.5	92.1	19.2
42	30.5	24.0	93.2	72.8
43	30.2	23.0	93.9	201.1
44	30.6	23.0	91.7	24.0
45	30.0	22.9	93.9	49.7
46	30.9	23.5	93.7	23.2
47	30.9	23.4	93.6	1.7
48	30.7	23.5	94.0	0.8
49	31.3	21.3	92.6	0.0
50	31.0	20.7	95.1	0.0
51	31.1	22.1	92.0	0.0
52	31.4	22.1	95.0	0.0
53	31.7	22.3	94.0	0.0
54	31.5	20.9	93.3	0.0
55	30.8	20.5	95.6	0.0
56	31.8	22.3	94.1	0.0
57	32.0	22.9	95.3	7.2

SYNERGISTIC EFFECT OF Na AND K ON YIELD AND NUTRIENT UPTAKE IN COLEUS (*Coleus parviflorus* L.)

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Abstract of the
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ABSTRACT

A field experiment was carried out in College of Agriculture, Vellayani during September 2003 to January 2004 to study the "Synergistic effect of Na and K on yield and nutrient uptake in coleus (*Coleus parviflorus* L.)". The treatments included were 50 and 100 per cent of the recommended dose of K alone and in combination with 50, 75 and 100 per cent of Na of common salt to equalize the same amount of recommended dose of K. The experiment was conducted in Randomized Block Design.

The plant growth characteristics like plant spread, number of functional leaves and LAI showed significant variation due to treatments. The highest values for these parameters were registered by K and Na at 50:50 proportions, showing the synergistic interaction of the two elements at this combination. Leaf water content varied significantly due to treatments. The 50 per cent K plus 75 per cent Na treated plants showed highest value of RLWC. Even though the chlorophyll content did not show significant difference between treatments, it increased with Na application along with 50 per cent K, revealing a role of Na in chlorophyll biosynthesis

Tuber yield did not show any significant difference due to treatments. Even then the 50:50 combinations of Na and K treatment gave the highest tuber yield followed by 100 per cent K plus 50 per cent Na treated plants. The yield attributes like number of tubers, weight of tubers and tuber index did not vary significantly.

Among the quality attributes, starch content varied significantly due to treatments. The treatment with 100 per cent K plus 75 per cent Na gave the highest value of starch followed by the 50:50 combinations of Na and K. The cooking quality of treatments T_3 (100 per cent K alone), T_4 (50 per cent K plus 50 per cent Na) and T_5 (50 per cent K plus 75 per cent Na) were

similar. The shelf life of 100 per cent K plus 100 per cent Na treated tubers were found to be the highest.

There was an increase in the content of N, K, Ca and Mg in the plants when Na was also supplied as treatment. Consequently the uptake of nutrients increased with the application of different levels of Na along with 50 per cent K. This shows that Na has a stimulative effect on uptake of nutrients. Application of Na did not affect any soil properties like pH, EC and organic carbon. The available nutrients like N, P, Ca and Mg increased in Na treated plots

Yield of tuber was positively and significantly correlated with the dry matter production and uptake of Ca. Yield was positively correlated with the uptake of all nutrients under study.

From the above points, it can be concluded that a combination of 50 per cent K and 50 per cent Na is optimum for getting the maximum yield. From the present study it also became evident that the efficiency of nutrient uptake increased at this combination. By adopting this practice, it was seen that the quality of coleus tubers improved and they became nutritionally more rich. This practice was found to be economically more feasible. Considering all these aspects, this fertilizer practice can be recommended to the farmers for getting a higher profit. From this investigation we can clearly establish a synergistic interaction of the two monovalent nutrient ions, K and Na on the growth and yield of coleus.