INTER-RELATIONSHIP OF POTASSIUM WITH OTHER SOIL FERTILITY PARAMETERS IN TWO MAJOR WETLAND RICE SOILS OF KERALA

By

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THESIS
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1997

DECLARATION

I hereby declare that this thesis entitled **"Inter-relationship of potassium with other soil fertility parameters in two major wetland rice soils of Kerala"** 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 to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani,
2-7-1997.

NAVEEN LENO

CERTIFICATE

Certified that this thesis entitled **"Inter-relationship of potassium with other soil fertility parameters in two major wetland rice soils of Kerala"** is a record of research work done independently by **Mr. Naveen Leno** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Potassium, atomic number 19 and mass number 39.1, is an element not found in the free state in nature but first obtained in elemental form by Humphry Davy in 1807. It is one of the earliest plant nutrients recognised by Justus von Liebig (1840), who proved its essentiality for the growth and development of plants. Being a constituent of soil forming minerals like feldspars and micas its occurrence is wide spread.

However, being an alkali metal of high solubility it is found to be a limiting plant nutrient in the soils of humid tropical areas. Under high precipitation and temperature existing in these regions, the soils are subjected to intense weathering and leaching with the result that arable soils of the tropics become extremely deficient in this nutrient. It is doubtful whether there is any other element which acclaims as much importance as that of K because of its involvement in more than 60 enzymatic reactions within the plant. Though there are claims that sodium can substitute some of the functions of potassium, it is yet to be proved and accepted by the scientific community.

With respect to K requirement different crop species vary differently. So also the occurrence of different forms and amounts of K in soils also show high variability. This is true with respect to upland soils and wetland soils because of the inter - relationships of potassium with other soil constituents like organic matter, clay minerals, macro and micro nutrients as well the physical, physico - chemical, chemical and hydrological phenomena of the soil environment.

Reports from the different rice research stations in Kerala have revealed that there exists a high variability in the response of fertiliser 'K' with respect to rice yields. Though there is differential response in different high yielding varieties it is seen that with the same variety there exists marked variation in yield in different wetland soil groups of the State.

Recent studies on the natural and man made wetlands of Kerala have shown that the spatial and temporal variability in the physico - chemical and mineralogical characteristics are highly significant. Proper assessment of potassium availability is a pre - requisite for soil fertility evaluation, correct interpretation and appropriate use of fertiliser

The present study is an attempt to unveil the inter - relationship of potassium with other soil fertility parameters and the response of applied potassium as reflected by the changes in its availability in two major wetland rice soils namely, lateritic alluvium of Pattambi (brown hydromorphic) and *Onattukara* sandy soils (greyish *Onattukara*) of Kayamkulam.

REVIEW OF LITERATURE

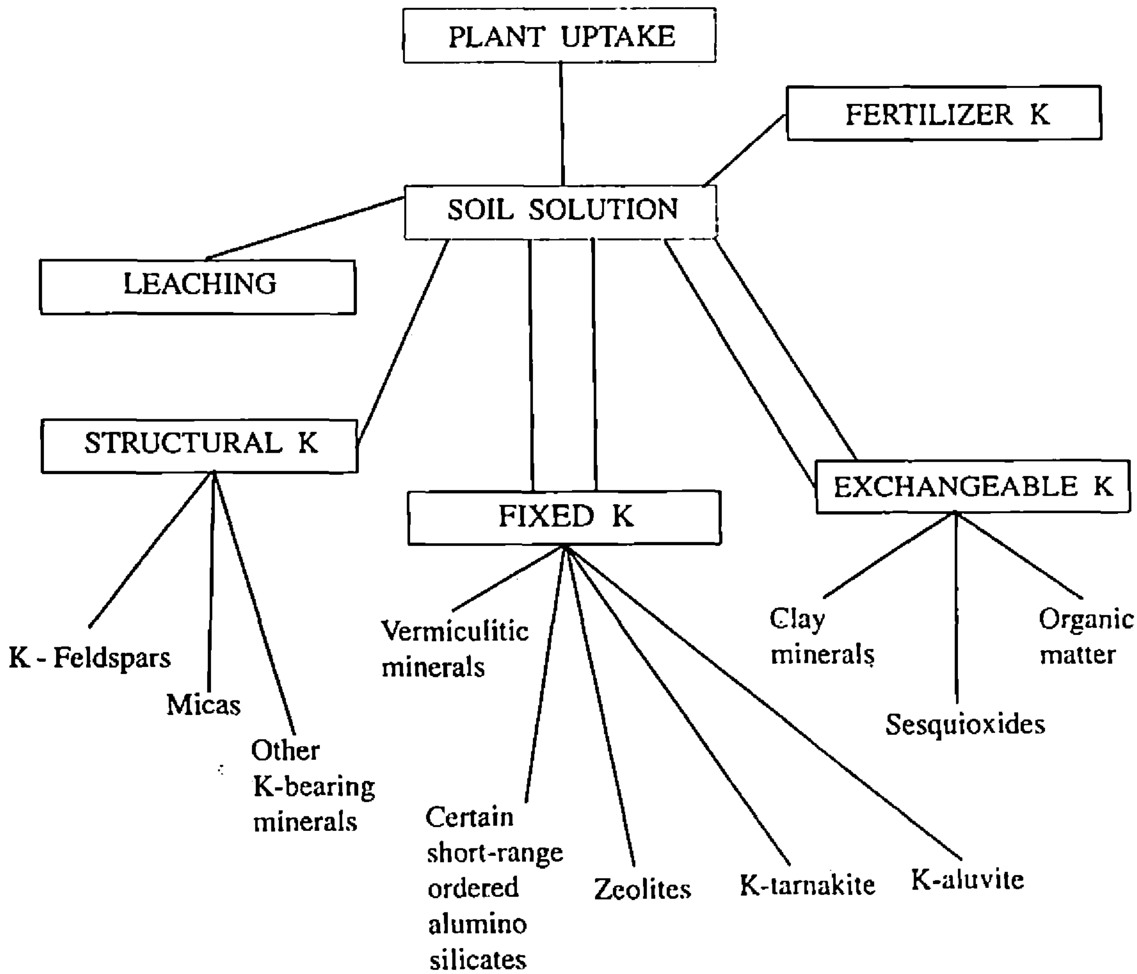
REVIEW OF LITERATURE

Although an immense array of literature about soil potassium is available, information regarding the intricate dynamics of native and added potassium in soils is rather meagre. An attempt to present the salient gleanings of the same is the sole objective of this treatise.

2.1. Forms of soil potassium

The forms of K in soil in the order of their availability to plants and microbes are soluble, exchangeable, non -exchangeable and mineral. Dynamic equilibrial reactions exist between the phases of soil K. The availability to plants depend on the amount and relative mobility of the different forms, including the factors dictating the rate of replenishment of depleted immediately available forms by reserve supplies.

Castro *et al.* (1972) investigated the different forms of potassium in the various soil types of Brazil. The total, exchangeable and non - exchangeable K in quartz sand was 1.0-6.0 g kg^{-1}, 0.50-1.10 mmol kg^{-1}, 1.10-2.50 mmol kg^{-1} respectively, red - yellow latosol 1.0 - 28.8 g kg^{-1}, 0.50 - 6.20, 1.00 - 9.60 mmol kg^{-1}, Typic Tropudalf 1.3 - 20.4 g kg^{-1}, 0.40 - 7.80, 1.00 - 16.00 mmol kg^{-1}.



Inter-relationship of various forms of soil K (Sparks and Huang, 1985)

Zhue-Wei-he *et al.* (1980) reported that the available K, slowly available K (HNO_3) and total K in the paddy soils of Guangdong province was 8.3 - 498 ppm, 23 - 1010 ppm and 0.25 - 3.15% respectively.

The exchangeable and non-exchangeable K content of Imo State, Nigeria was 0.03 to 0.19 meq 100 g^{-1} and 0 to 0.46 meq 100 g respectively. (Unamba-Oparah, 1985).

Total and assimilable K (sum of soluble and exchangeable fractions) status of 0.12-0.39% and 11.11-45.24 mg 100 g^{-1} was observed by Daoud and Cadi (1987).

In the coastal plain sands of Nigeria, total, exchangeable, difficultly exchangeable and HNO_3 exchangeable K ranged between 2.56 and 16.15, 0.01 and 0.18, 0.06 and 0.29, 0.10 and 0.45 me 100 g^{-1} respectively. (Ano, 1991).

Verma *et al.* (1968) studied the status of available potassium in different soils of Madhya Pradesh. The available potassium varied from 0.064-4.65 me 100 g^{-1}. Alluvial soils contained 0.67 me of available K whereas it was 1.2 me in medium black soils.

Mehrotra and Singh (1970) reported that the surface soil samples obtained from different broad soil groups of U.P. contained on an average 61.95, 31.06, 6.19, 0.69 and 0.10 per cent of total K as lattice K, HCl soluble K, fixed K, exchangeable K and water soluble K.

The black soils of the Tungabhadra catchment contained 913 mg total K_2O 100 g^{-1} soil, of which 9.12% was HNO_3 soluble, 2.86% exchangeable and 0.11% water soluble. (Kalbande and Swamynatha, 1976).

Water soluble, exchangeable, available and boiling 1 N HNO_3 extractable K constitute 0-06, 0.34, 0.40 and 7.55 per cent of total K respectively in the benchmark soils of Punjab and Himachal Pradesh. (Dhillon *et al.*, 1985).

Brar *et al.*, 1986 found that soils of Nedumangad (laterite), Vijayapura and Tyamagondalu (red) series were low and those of Noyyal were very high in both available and reserve potassium.

The distribution of various forms of potassium in different alluvial zones of West Bengal was examined by Tarafdar and Mukhopadhyay (1986). The water soluble exchangeable, labile, non-exchangeable and total K contents were 0.032, 0.213, 0.247, 2.85 and 27.08 me 100 g^{-1} respectively.

6-70 ppm of water soluble 28-520 ppm exchangeable, 220-1179 ppm HNO_3 soluble, 1480-3960 ppm HCl soluble and 1.12-2.40 per cent total K was reported in the soils of central Haryana (Ravi Kumar, *et al.*, 1987).

Sahu and Gupta (1988) reported that the water soluble, exchangeable, fixed, HCl soluble and lattice K ranged from 0.02 to 0.18, 0.04 to 0.42, 2.19 to 23.45, 5.75 to 24.07 and 18.48 to 68.63 meq 100 g^{-1} respectively and total K from 0.81 - 2.87% in some soils under forest cover in West Bengal.

Water soluble K contributed to 0.03 - 0.06% of the total K and 2.6 - 4.5% of the available K, whereas exchangeable K constituted 1.1 - 2.0% of the total K in a toposequence in the Malwa plateau. The fixed and lattice K ranged from 14.8 - 20.7% and 78.6 to 86.8% of total K (Sharma and Dubey, 1988).

On the basis of available K content, Subba Rao and Sekhon (1988) grouped seven soil series from western India into 3 categories viz. Kumbhave - 5 (lateritic) as low to just medium, Mazodar (arid) medium to marginally high and the remaining five (occurring in alluvial and swell-shrink soil regions) as high. Soils of Masitawali (alluvial) and Shendvada (swell-shrink) were high in non - exchangeable or reserve (HNO_3 soluble) K.

The amount of water soluble, exchangeable HNO_3, extractable and total potassium varied from 0.006 to 0.450, 0.06 to 1.05, 0.27 to 5.35 and 6.2 to 23.7 me 100 g^{-1} in the dry farming areas of Saurashtra in Gujarat. (Koria, *et al.*, 1989).

In the alfisols of West Bengal, 0.002 to 0.028, 0.06 to 0.34, 0.06 to 0.37, 0.39 to 2.41 and 6.91 to 17.46 me 100 g^{-1} were the recorded values of water soluble, exchangeable, available, non - exchangeable and total potassium. (Pal and Mukhopadhyay, 1990).

Pal and Sekhon (1991) analysed the potassium status of five alluvial soil series from different geographical regions of India. Water soluble K ranged between 9.9 - 4.2 mg kg^{-1}, 21.1 - 11.7 mg kg^{-1}, 75.5 - 35.2 mg kg^{-1}, 29.1 - 31.9 mg kg^{-1} and 10.9 - 2.7 mg kg^{-1} in the Lidder, Bagru, Purakkad, Chandole and Kalathur series respectively. 1N NH_4O Ac extractable K ranged between 49 - 22 mg kg^{-1}, 94 - 37 mg kg^{-1}, 245 - 77 mg kg^{-1}, 424 - 234 mg kg^{-1} and 193 - 38 mg kg^{-1}, whereas the HNO_3 extractable K ranged between 430 - 74 mg kg^{-1}, 246 - 64 mg kg^{-1}, 386 - 60 mg kg^{-1}, 1030 - 565 mg kg^{-1} and 893 - 102 mg kg^{-1} respectively in the five series.

The amount of water soluble, exchangeable, available, non - exchangeable, lattice and total soil K varied from 5.5 to 27.5, 54.5 to 216.2, 62.5 to 243.7, 537 to 1156 ppm, 0.97 to 1.49 and 1.05 - 1.60 per cent respectively, as revealed by the investigations of Mishra and Srivastava (1991) in the soils of Garhwal Himalayas.

Trivedi and Verma (1991) reported that the U.P. soils contained 0.11 - 2.12% total K, 291.5 - 1293.0 ppm non-exchangeable K, 17.3 - 165.3 ppm exchangeable K and 1.0 - 42.6 ppm water soluble K.

The water soluble, exchangeable, non-exchangeable, lattice and total K in different lateritic soils of Phondagat soil series in south Konkan ranged from 0.6 to 30.0, 13.9 to 231.0, 76.4 to 373.4, 2975 to 5625 and 3250 to 6250 ppm, respectively (Sutar *et al.*, 1992).

Variations of 0.45 mg 100 g^{-1} to 1.56 mg g^{-1} in water soluble K, 12.03 to 46.80 mg 100 g^{-1} in exchangeable K, 14.6 to 137.9 mg 100 g^{-1} in non - exchangeable K and 635 to 1432 mg 100 g^{-1} in total K have been observed by Talele *et al.* (1992) in soils of Maharashtra occurring under different agro - climatic zones.

Water soluble and exchangeable K content decreased with depth in vertisols while these forms increased up to a depth of 135 cm in alluvial soils in some soil series of northern Madhya Pradesh (Tiwari and Bansal, 1992).

Soils of Nainital tarai contained total potassium ranging from 1.58 to 3.00 per cent, water soluble potassium ranging from 6.6 to 99.0 mg kg^{-1}, exchangeable potassium ranging from 53.85 to 216.20 mg kg^{-1}, non - exchangeable potassium ranging from 533. 0 to 1023.0 mg kg^{-1} (Singh *et al.*, 1993). In ten established soil series of western Uttar Pradesh, water - soluble, exchangeable, available, non - exchangeable, lattice and total K varied from 1.09 - 60.38, 15.51 - 221.12, 23.51 - 252.69, 185.48 - 2104.84, 5920 - 23720 and 6250 - 25000 mg kg^{-1} respectively. (Dixit *et al.*, 1993).

Mishra *et al.* (1993) reported that the saline - alkali soils of Chambal command area contained 5.0 to 19.5, 125.5 to 228.0, 135.0 to 245.0, 567.0 to 1122.0 ppm, 1.02 - 1.26 and 1.10 - 1.35 per cent of water soluble, exchangeable, available, non - exchangeable, lattice and total soil K.

0.017 to 0.037, 0.09 to 0.53, 0.12 to 0.62, 0.98 to 18.32, 1.9 to 18.78, 26.93 to 64.83 and 36.41 to 73.58 me 100 g^{-1} of water soluble, exchangeable, available, non - exchangeable, HNO_3 soluble, structural and total potassium have been observed by Singh and Tripathi (1993) in ten predominantly illitic soils of Himachal Pradesh.

Water soluble, exchangeable, non exchangeable, lattice and total potassium in the swell-shrink soils of Maharashtra ranged between 10 to 16, 140 to 390, 268 to 900, mg kg^{-1} and 0.21 to 0.75, 0.27 to 0.88 per cent respectively. (Patil and Sonar, 1993)

Dhillon and Dhillon (1994) studied the different forms of potassium in three major soil groups of India. Alluvial soils were richer in 1 N (4.47 cmol kg^{-1}) HNO_3 extractable K followed by black and red soils. Total K content was highest in red soils (46.41 cmol kg^{-1}) followed by alluvial and black soils. Red soils contained the largest amount of water soluble K (0.06 cmol kg^{-1}) and black soils contained the largest amount of exchangeable K (0.68 cmol kg^{-1}).

The total potassium in black and red soils of South India ranged between 1.02 and 4.08 per cent (Sharma and Sekhon, 1994).

In the central alluvial region of Uttar Pradesh, water soluble, exchangeable and HNO_3 soluble K varied from 0.95 to 0.078, 0.11 to 1.68, 2.25 to 7.87 me 100 g^{-1} (Tiwari and Nigam, 1994).

Water soluble, exchangeable and fixed K varied from 14.0 to 30.0, 50 to 200, 720 to 1920 ppm in the soils of Agra. (Singh *et al.*, 1995).

A poor total potash content of 0.10% was observed in 69 per cent of the area of Trichur and Talappalli taluks (Anonymous 1938) and 85% of the area was poor in total potash in Mukundapuram taluk (Sankara Menon, 1942).

88 per cent of the wetland soils of Kerala State are rated as low in available potash, the deficiency being marked in laterite soils and the coastal sandy tracts. (Britto Mutunayagam, 1961).

Sreedevi (1972) studied the potassium status of five major acid rice soil groups of kerala viz. *Kole, Kari, Kayal, Karapadom* and low level laterites (LLL). The magnitude of exchangeable potassium was in the order *Kari* > *Karapadom* > *Kayal* > *Kole* > LLL, difficultly exchangeable potassium *Kayal* > LLL > *Kole* > *Karapadom* > *Kari*.

The water soluble, available, HNO_3 soluble and total K in the red and laterite soils of Trivandrum were found to be 1.53 - 7.16 mel^{-1}, 9.0 - 32.0 cg kg^{-1}, 10.0 - 58.0 cg kg^{-1} and 1200 - 1290 ppm (Prabhakumari, 1981), while that of Vellayani sandy clay was 0.358 - 2.353 mel^{-1} 2.00 - 10.80 cg kg^{-1} 3.20 to 13.20 cg kg^{-1} and 0.083 - 0.167 per cent (Valsaji, 1989).

The water soluble, exchangeable, available, lattice and total K of Vellayani series varied from 5.2 to 18.9, 10.8 to 72.0, 18.8 to 82.5, 61.8

to 437.0, 115 to 513 ppm whereas that of Neyyattinkara series varied from 2.8 to 26.8, 18.5 - 89.9, 21.3 - 100, 136 - 432, 186 - 591 ppm. (Devi, *et al.*, 1990).

2.2. Interaction with physico - chemical parameters

2.2.1 Sand

Chaudhari and Pareek (1976) obtained no significant relationship of total potassium with the sand and silt fraction in Rajasthan soils.

Singh *et al.* (1989) reported significant negative relationship of exchangeable and available forms of K with the sand fraction in the Chotanagpur region. However, water soluble and total K were correlated significantly with the sand fraction.

Though fixed and HNO_3 K were significantly and positively correlated with sand, available K behaved inversely in the soils of south Andamans (Mongia and Bandopadhyay, 1991).

None of the K fractions seemed to have a significant relationship with sand in the Garhwal Himalayas. (Mishra and Srivastava, 1991).

All but lattice K fraction of inceptisols, which had a positive relationship, and exchangeable K fraction of alfisol were negatively and significantly correlated with the fine sand fraction. Though related negatively, correlations were not significant in all the other K fractions in alfisol as revealed by investigations of Basumatary and Bordoloi (1992) in Assam. With regard to coarse sand, all fractions in both soils were negatively correlated.

Das *et al.* (1993) found that there was a marked negative relationship of the non exchangeable, lattice and total K with the sand fraction in the basaltic terrain.

In the soil series of western Uttar Pradesh, a similar behaviour was observed between the available, exchangeable, non exchangeable lattice and total potassium with the sand fraction (Dixit *et al.*, 1993).

Dhillon and Dhillon (1994) opined that the per cent contribution of sand to total K was highest in red soils followed by micaceous alluvial and black soils.

The water soluble K showed positive correlation with sand in Bangladesh soils (Sirajul Islam, 1994)

2.2.2. Silt

Brar and Sekhon (1987) concluded that the HNO_3 K increased with the silt content in five benchmark soil series in north India.

Singh *et al.* (1989) observed a similar trend with exchangeable K and a reverse trend with water soluble and total K.

The exchangeable, available, non - exchangeable and total K were reported to be closely associated with the silt content in the entisols of West Bengal (Pal and Mukhopadhyay, 1992).

Dixit *et al.* (1993) noticed a positive significant relationship of K fractions except water soluble with the silt content in the soils of western U.P.

Sirajul Islam *et al.* (1994) found a decreasing trend in the available and water soluble fractions with increasing silt contents.

2.2.3. Clay

Ranganathan and Sathyanarayana (1980), Mishra and Srivastava (1991) have reported significant negative relationship of lattice and total K with clay.

Significant negative correlation of total K with clay have been reported by Koria *et al.* (1981), Singh *et al.* (1989), Dhillon *et al.* (1994).

Though Brar and Sekhon (1987), Srinivas and Seshaiah (1993), Sirajul Islam *et al.* (1994) and Tiwari and Nigam (1994) observed significant positive correlations of HNO_3 K with clay, Ano (1991) and Mongia and Bandopadhyay (1991) obtained negative correlations.

Devi *et al.* (1990) observed significant positive correlations of lattice and total K with clay in the Neyyattinkara and Vellayani soil series.

Mongia (1991), Dixit *et al.* (1993), Dhillon *et al.* (1994) and Sirajul Islam *et al.* (1994) observed significant positive correlations of available K with clay.

A close association of water soluble, exchangeable, non - exchangeable, lattice and total K with the clay content was reported by Basumatary and Bordoloi (1992).

Pal and Mukhopadhyay (1992) noticed a positive relationship of exchangeable available, non - exchangeable and total K with clay.

2.2.4. pH

Mehlich (1943) measured the extent of winter leaching of exchangeable K from plots of Creedmoor sandy loam in which the pH ranged from 4.4 to 7.5; with increasing pH, the percentage loss of exchangeable K by leaching decreased.

Raychaudhuri *et al.* (1960) observed that available K generally decreases with decreasing pH in the case of alluvial sandy soil (Rajasthan) and laterite soil (Kerala).

The available K was significantly and positively related to pH (Rajakkannu *et al.*, 1970, Agboola and Corey, 1973, Sirajul Islam *et al.*, 1994). However, non - significant or negative relationship of available K with pH have also been reported. (Sarkunan, 1973; Mongia *et al.*, 1991).

Devi *et al.* (1990) reported a significant positive relationship between laterite K and soil pH.

Positive correlations of HNO_3 K with pH were reported by Mongia *et al.* (1991).

In Nedumangad series, the soils with high acidity recorded lower amounts of both water soluble and exchangeable K contents than soils with low acidity. In soils with appreciable amounts of organic carbon and pH greater than 5.5, the influence of pH on available K status is negligible (Subba Rao and Sekhon, 1991).

Trivedi and Verma (1991) observed that the exchangeable and total K increased with an increase in pH.

Total K was found to be negatively correlated with soil pH. (Basumatary and Bordoloi, 1992). Non - significant or negative correlation was observed between pH and water soluble, exchangeable, non - exchangeable and lattice K fractions.

Dixit *et al.* (1993) obtained a close relation of water soluble, available, exchangeable, lattice and total K with pH.

2.2.5. EC

Sarkunan *et al.* (1973) opined that there was no significant relation between available K and EC. However, Mishra and Srivastava (1991), Dixit *et al.* (1993), Dhillon *et al.* (1994) obtained significant correlations between available K and EC.

Koria (1989) reported that the water soluble, exchangeable and HNO_3 K fractions were closely related to EC.

Mishra and Srivastava (1991) obtained negative relationship of lattice and total K with EC.

2.2.6. Organic Carbon

Significant positive relationship between different forms of K and organic carbon content of the soil was observed by many scientists. Brar and Sekhon (1987) obtained a positive correlation with exchangeable K, Mishra and Srivastava (1991) with water soluble, exchangeable and available forms of K, Trivedi and Verma (1991) with exchangeable and total K, Basumatary and Bordoloi (1992) with water soluble, non - exchangeable, lattice and total K, Sreenivas and Seshaiah (1993) with HNO_3 extractable and available forms, Dhillon *et al.* (1994) with HNO_3 - K and Sirajul *et al.* (1994) with available and HNO_3 extractable forms.

Mongia (1991) obtained a negative trend of HNO_3 and fixed forms with organic carbon. Mishra and Srivastava (1991) also obtained similar trends with lattice and total K.

Greater potassium solubility was observed in soils with higher organic carbon compared to lower organic carbon ones as in Kharbona and Nedumangad (Subba Rao and Sekhon, 1991).

2.2.7. CEC

In the dunal soils of Rajasthan, Dutta and Joshi (1989) obtained a close correlation of HNO_3 extractable and fixed K with the CEC. Similar conclusions were also made by Singh *et al.* (1989) for available and exchangeable forms of K, Mishra and Srivastava (1991) for water soluble, exchangeable and available forms, Pal and Mukhopadhyay (1992) for exchangeable available, non - exchangeable and total K, Dixit *et al.* (1993) for non - exchangeable, lattice and total K, Vandana and Nigam (1994) for water soluble, exchangeable and HNO_3 extractable forms.

However, Singh *et al.* (1989) observed a significant negative correlation of water soluble and total K with CEC. Mishra and Srivastava (1991) for lattice and total K, Dhillon *et al.* (1994) for total K.

2.2.8. ECEC

Analyses of 119 surface soil samples from the State of Sao Paulo, Brazil showed that K occupied 2.5 and 5.0% of the effective CEC respectively for clay and sandy soils (Anon, 1960).

The difference between total and effective CEC indicates exchange sites in a given soil that can be filled by cations such as K^+, Ca^{2+} and Mg^{2+} (Malavolta, 1985).

2.2.9. Active iron

Ponnamperuma (1965) observed a slight increase in exchangeable

K after submergence, this increase being highest in strongly acid latosolic soils rich in active Fe.

2.2.10. Base Saturation

Basumatary and Bordoloi (1992) concluded that there exists a significant positive relationship of water soluble, exchangeable, non exchangeable, lattice and total K with the base saturation of alluvial soils and of all but non exchangeable fraction of K with the base saturation of laterite soils of Assam.

2.2.11. Calcium and Magnesium

Although the proportion of exchangeable K to exchangeable Ca and Mg is normally very small, K tends to control the availability of cations to many plants. (Reitmeier, 1951).

Varghese and Money (1965) opined that calcium tended to increase available potash in soil.

Omar and Kobbia (1966) observed a one way competition, with the uptake of Mg being reduced by an increase uptake of Mg being reduced by an increase in nutrient K, whereas K absorption was hardly affected by the presence of nutrient Mg even at high levels.

Koria *et al.* (1989) ascribes the significantly positive association of lime content with exchangeable and 1 N HNO_3 soluble K to the role of

$CaCO_3$ in promoting the opening up of edges of clay mineral pockets thus releasing previously trapped or lattice potassium.

Agboola and Corey (1973) found that there is an antagonism for exchangeable Mg, Ca with K.

Kabeerathuma and Bidappa (1975) concluded that liming enhanced the fixation of potassium in acid sulphate soils of Kerala.

Trivedi and Verma (1991) obtained a positive correlation of total and exchangeable K with CaO and MgO.

Vijayalakshmi and Mathan (1991) concluded that there was an antagonistic effect between K and Mg in the soil.

Talele *et al.* (1992) observed that the exchangeable and water soluble forms of K were positively and significantly correlated with exchangeable calcium.

Dixit *et al.* (1993) reported a close relationship of available, exchangeable, non exchangeable, lattice and total K both with exchangeable calcium and magnesium whereas water soluble fraction exhibited an inverse relationship in both cases. Varghese & Jose (1994) observed a negative relationship between available K and Mg in the acid rice soils of Kerala.

2.2.12. Sodium

A positive and significant relationship of water soluble K with exchangeable sodium, a positive but not significant relation with available, exchangeable, lattice and total K and a negative correlation with non exchangeable K was reported by Dixit *et al.* (1993).

Srivastava and Srivastava (1993) opined that adsorption of Na is preferred over K by illitic clays with increase in ESP of Natraqualfs.

2.2.13. Available N and P

Edwards (1968) reported that absorption rates of P from solution were independent of solution K^+ levels.

Available K was significantly correlated with available N in black, red and alluvial soils of Tamil Nadu as observed by Rajakannu *et al.* (1970).

Sarkunan *et al.* (1973) concluded that available K status increased with the N content in soils. Available P was negatively correlated with available K.

The phosphate ion is capable of neutralising positive charges of Fe hydroxides in the clay fraction generating electronegative sites that can be occupied by K^+ ions (Uchara and Gilman, 1981).

According to Chakravorti (1989) application of K tended to increase the nitrogen content in grain and total N uptake by the crop while the concentration of P was little affected.

2.2.14. Exchange Acidity

A negative correlation between exchangeable acidity and percentage potassium saturation of exchangeable complex in Nedumangad series was reported by Subba Rao and Sekhon (1991).

2.2.15. Exchangeable aluminium

Exchangeable Al^{3+}, which in acid tropical and subtropical soils can be present in higher concentration than other cations, competes with K^+ for the non - specific sites of exchange as shown by Tinker (1964) in Nigeria and by Sivasubramanian and Talibudeen (1972) in Sri Lanka.

2.2.16. Chloride and Sulphate

Evangelou (1986) reported that the type of anion SO_4^{2-} or Cl^- had an effect on the equilibrium concentration ratio for K^+ (CR^{ko}) and the labile K^+ (CE_x K^o).

2.3. Inter-relationship of K fractions

The water soluble K had low correlation with fixed and medium correlation with lattice K, whereas correlation of this form were of a higher order with exchangeable and total K in the soil groups of U.P. Exchangeable K had low positive correlation with fixed, lattice and total K and lattice K showed a high correlation with total K content. (Mehrotra and Singh, 1970).

Singh and Singh (1986) obtained significant positive correlation with exchangeable and fixed K, indicating that water soluble K is directly replenished from these forms.

According to Singh *et al.* (1989) total and water soluble K were significantly correlated with other forms excluding water soluble and total.

Devi *et al.* (1990) reported that water soluble K was significantly and positively correlated to the exchangeable and available forms of potassium.

Maji and Chatterjee (1990) concluded that the availability of K from non - exchangeable sources was higher from smectite dominant black soils as compared to that from the illitic red soils.

A high rate of release from exchangeable to water soluble K as well as from non - exchangeable to exchangeable K were observed in the bench mark soils of central Punjab (Bhangu and Sidhu, 1990).

Singh *et al.* (1990) opined that there was positive and significant relationship between ammonium acetate - K and HNO_3 - K in the surface soils of Delhi.

In the Nigerian coastal sands, difficultly exchangeable K correlated positively and significantly with exchangeable K. (Ano, 1991).

Mishra and Srivastava (1991) noted that water soluble and exchangeable K were positively correlated but the relationship between exchangeable and non exchangeable K was not significant in the soils of Garhwal Himalayas.

Soils of Purakkad contained high water soluble and ammonium acetate K in association with low HNO_3 - K with the result that the crop growing in this soil may not require K fertilisation because of its constant renewal with sea water. (Pal and Sekhon, 1991).

Tiwari and Bansal (1992) found that exchangeable and water soluble K were interrelated with each other in the soils of northern Madhya Pradesh.

Sidhu and Bhangu (1993) concluded that correlation between water soluble and exchangeable K was highly significant in acidic and ustic zone soils and non - significant in udic moisture regime in Punjab.

Singh *et al.* (1993) noticed that the exchangeable K was highly correlated with available, non-exchangeable and total K in the mollisols of Nainital tarai.

In the soils of Himachal Pradesh Singh and Tripathi (1993) observed that the available K had positive and significant correlation with exchangeable K. Total K correlated highly with structural K whereas its relationship with other forms of K was not significant. Non - exchangeable K had positive and significant relationship with HNO_3 soluble K in the soils.

Dhanorkar *et al.* (1994), Venkatesh and Sathyanarayana (1994) have reported that all forms of K were intercorrelated indicating the existence of a dynamic equilibrium among them.

Tiwari and Nigam (1994) reported that the degree of correlation between water soluble K and exchangeable K was generally of high order.

2.4. Transformation of K fractions on submergence

Incubation under wet condition of seven latosols and seven andosols from Costa Rica favoured fixation of exchangeable K. (Martinii and Suarez, 1977).

Verma and Verma (1971) studied the potassium fixation in soils of Madhya Pradesh after equilibriation with potassium for 3 days with 5 me 100 g^{-1} of soil. The average K fixing capacities were 0.48 0.69, 0.71, 0.72, 0.78 and 1.13 me 100 g^{-1} soil for alluvial, mixed red, yellow and deep black soil respectively.

Datta and Sastry (1985) concluded that with the incorporation of water, available K changed with time depending primarily on the mineralogy of the clay fraction and also on potassium level and nature and intensity of moisture treatment.

Chakravorti *et al.* (1988) observed that under submerged condition, very little of soil K was converted into boiling 1N HNO_3 extractable form.

Prakash and Singh (1989) studied the fate of applied K to soils of varying texture after incubating for 90 days. They found that the exchangeable K content of both the soils increased with increasing levels of K and decreased with passage of time. Similarly the amounts of K fixed increased with levels and passage of time.

Chakravorti and Patnaik (1990) found that the release of non exchangeable K was more from the alluvial and red soils than from lateritic and black soils.

A linear increase in water soluble, exchangeable and non exchangeable K content was obtained after a 25 week incubation with K (0 to 250 mg K kg^{-1}) in 10 soil orders of the continental U.S. and Puerto Rico (Sharpley, 1990).

Singh and Singh (1992) reported that the dynamics of available and fixed potassium in mollisols showed that with the advancement of time, both these forms showed a steady increase upto two weeks and then a sharp increase at the end of the third week. After the fourth week, there was a sudden decrease which stablized after the fifth week.

Jessymol (1993) concluded that at the end of the three month incubation period, there was a remarkable increase in all the three fractions of K viz., water soluble ammonium acetate extractable and nitric acid soluble forms for all soils although slight fluctuations were noticed throughout the incubation period. The relationship of the different forms of K and the relative proportion of each in the soil varied with the clay content and mineralogical composition.

Joseph *et al.* (1993) observed that the exchangeable K content on incubation increased up to the 60^{th} day, maintained the same level until the 75^{th} day and then decreased. The water soluble and Morgan extractable K had higher values on the 15^{th} day of incubation and decreased thereafter.

Saleh and Khalid (1993), after incubation of 1/6, 4, 8, 12, 20, 36, 52 days, with and without K additions, found that both native and applied K concentration in soil solution decreased with time.

Talele *et al.* (1993) performed incubation studies which revealed that the exchangeable K fraction increased with increase in amount of K added, whereas it decreased with the period of incubation. In non exchangeable K, percent increase in the fraction decreased with increase in level of K added and increased with increase in the time of incubation. A large portion of added K is converted into non exchangeable form during the period of 30 days.

Verma *et al.* (1994) opined that the water soluble and exchangeable K were increased and non exchangeable and residual K were decreased upon water logging.

Srinivasa Rao and Khera (1995) reported 19 per cent reduction in exchangeable K in two months of equilibration over two hours of equilibration in illitic alluvial soils.

MATERIALS AND METHODS

MATERIALS AND METHODS

Investigations on the inter-relationship of K with other soil fertility parameters and the transformation of applied potassium under submergence were made on two major wetland rice soils of Kerala viz., lateritic alluvium of Pattambi (brown hydromorphic) and *Onattukara* sandy soils (greyish *Onattukara*) of Kayamkulam. According to the U.S. Soil Taxonomy (1975), the classification of soils of the two sites are as follows :

1. Pattambi RARS - Man made wetland (lateritic alluvium) Fine, Kaolinitic, Isohyperthermic, Aeric Kandiaqult

2. Kayamkulam RRS - Man made wetland (*Onattukara* sandy soil) Sandy, Mixed, Isohyperthermic, Ustic Quartzipsamment.

The climatological data regarding the mean monthly temperature, rainfall and evaporation were collected from the two research stations.

The climatic data (mean over a period of 10 and 40 years respectively) and the basic soil data of the typifying pedons of Pattambi and Kayamkulam are given in Tables 1 and 2.

Table 1. Climatic data

Pattambi RARS

Altitude 25M | Latitude 10° 48'N | Longitude 76° 12'E

	Period (years)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Precipitation (mm)	10	1	3	16	90	170	577	677	424	208	265	262	3	2696
2. EP (mm)	10	195	185	220	195	171	135	112	115	135	118	132	164	1877
3. T mean (°C)	10	26.5	27.9	29.9	29.9	28.8	26.5	25.5	25.9	26.8	27.7	27.1	26.7	27.4
4. T max (°C)	10	33.2	34.9	36.6	35.4	33.3	30.2	28.4	29.1	30.6	31.4	31.9	32.9	32.3
5. T min (°C)	10	19.7	20.9	23.2	24.4	24.2	22.8	22.5	22.7	23.0	23.9	22.3	21.0	22.6

Kayamkulam RRS

Altitude 3M | Latitude 9° 30'N | Longitude 76° 20'E

	Period (years)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Precipitation (mm)	40	20	18	47	135	282	465	447	235	235	298	115	50	2347
2. EP (mm)	40	142	130	152	158	164	143	129	127	141	144	138	142	1710
3. T mean (°C)	40	26.8	27.9	28.9	28.7	28.7	26.8	26.9	26.9	27.0	27.1	26.9	26.6	27.4
4. T max (°C)	40	32.9	33.8	34.3	34.3	32.9	30.2	30.6	30.6	30.6	30.8	31.5	32.1	32.5
5. T min (°C)	40	20.6	22.0	23.4	23.1	24.5	23.3	23.1	23.1	23.3	23.3	22.3	21.0	22.7

Table 2. Basic soil data of typifying pedons

1. Pattambi

Texture	Ap Clay	B1 Clay	B2t Clay	C1 Clay	C2 Clay	C3 Clay
pH (water)	5.4	5.3	5.3	5.4	5.4	5.6
pH (KCl)	4.9	5.0	5.1	5.0	5.1	5.3
EC (d SM^{-1})	0.05	0.60	0.01	0.05	0.10	0.10
Organic cabon (%)	1.12	0.81	0.50	0.21	0.20	0.10
Organic matter (%)	1.93	1.39	0.86	0.36	0.34	0.17
CEC cmol (p+) kg^{-1}	9.47	8.96	7.32	5.21	5.0	4.33
ECEC cmol (p+) kg^{-1}	8.59	6.86	6.86	3.41	2.49	1.30
Base saturation (%)	43.8	38.3	46.0	38.8	36.2	36.3
Exchangeable H me 100 g^{-1}	0.69	0.47	0.29	0.49	0.67	0.53
Exchangeable Al me 100 g^{-1}	0.21	0.41	0.40	0.91	1.21	1.11
Total N (%)	0.142	0.10	0.061	0.026	0.028	0.017
Exchangeable K me 100 g^{-1}	1.81	2.34	2.12	2.27	2.11	2.02
Exchangeable Ca me 100 g^{-1}	1.93	1.94	1.57	1.07	1.01	1.12
Exchangeable Mg me 100 g^{-1}	0.48	0.36	0.39	0.33	0.30	0.28
Exchangeable Na me 100 g^{-1}	0.48	0.93	0.01	0.11	0.20	0.43

Contd...

(Table 2. Contd...)

2. Kayamkulam

Texture	Ap Loamy fine sand	C1 Loamy fine sand	Cg1 Loamy fine sand	Cg2 Loamy fine sand
pH (water)	5.0	5.7	6.4	5.6
pH (KCl)	4.3	4.7	5.9	4.5
EC (d SM^{-1})	0.07	0.02	0.02	0.03
Organic cabon (%)	0.69	0.11	0.07	0.22
Organic matter (%)	1.19	0.19	0.12	0.38
CEC cmol (p+) kg^{-1}	3.2	2.1	1.8	2.9
ECEC cmol (p+) kg^{-1}	1.3	1.1	0.7	0.8
Base saturation (%)	25	67	89	55
Exchangeable H me 100 g^{-1}	0.3	0.3	0.1	0.1
Exchangeable Al me 100 g^{-1}	0.2	0.1	0.1	0.1
Total N (%)	0.06	0.01	0.00	0.01
Exchangeable K me 100 g^{-1}	0.0	0.0	0.0	0.0
Exchangeable Ca me 100 g^{-1}	0.6	1.0	1.0	1.0
Exchangeable Mg me 100 g^{-1}	0.0	0.3	0.3	0.3
Exchangeable Na me 100 g^{-1}	0.2	0.1	0.3	0.3

3.1. Collection of soil samples

Surface soil samples (0-20 cm) were collected from ten locations for each of the two representative sites selected. Apart from this, profile samples were also collected from RARS, Pattambi and RRS, Kayamkulam. The locations selected for each representative site were as follows:

Lateritic alluvium of Pattambi

1. RARS, Pattambi
2. Koppam
3. Muthuthala
4. Perumudiyur
5. Kodumunda
6. Njangathri
7. Maruthur
8. Ongalloor
9. Vadanakkurishy
10. Karakkadu

Onattukara **sandy soils of Kayamkulam**

1. RRS, Kayamkulam
2. Keerikkadu
3. Kareelakulangara
4. Mavelikkara
5. Chettikulangara

6. Ochira
7. Muthukulam
8. Bharanikavu
9. Kattaanam
10. Kattachira

3.2. Laboratory investigations

The wetland soil samples were air dried, powdered and sieved through a 2 mm IS sieve and stored in air tight plastic bottles. These sieved soil material was subjected to physical and chemical evaluations. A portion of the fresh sample was kept separately in wet condition for specific determination.

3.2.1. Mechanical analysis

The mechanical composition of the soil samples were determined by International Pipette Method (Jackson, 1973).

3.2.2. Chemical analysis

3.2.2.1. pH

The pH of the fresh and air dried soil samples were determined in water (1:1 soil and water and 1:2.5 soil and water), 1 M KCl (1:2.5 soil and KCl) and $CaCl_2$ 0.01M (1:2 soil and $CaCl_2$) using 'Perkin Elmer' pH meter (Jackson, 1973, USDA- SCS Anon, 1984).

3.2.2.2. Electrical conductivity

The electrical conductivity of the 1:2:5 soil water extract was read using an 'Elico' conductivity bridge. Jackson (1973).

3.2.2.3. Organic carbon

Organic carbon and organic matter were determined by modified Walkley and Black wet digestion method. (Jackson, 1973).

3.2.2.4 Exchangeable acidity

Determined volumetrically by titration of 1M KCl extract with 0.025 M NaOH, Page (1982).

3.2.2.5. Exchangeable hydrogen and aluminium

The exchangeable aluminium and hydrogen were estimated in the 1 M KCl extract (Black,1965).

3.2.2.6. CEC and ECEC

Cation exchange capacity was determined by neutral 1 N NH_4OAC leachate method as described by Jackson (1973). Effective CEC was derived by adding sum of bases (CEC) and exchangeable acidity (USDA - SCS Anon, 1984).

3.2.2.7. Base saturation and exchangeable bases

Exchangeable bases and base saturation were calculated on the basis of total CEC as suggested by Jackson (1973).

3.2.2.8. Active iron

The sample was shaken with a complexing acid ammonium oxalate solution dissolving the active compounds of iron which are determined in the extract by AAS (USDA, SCS, 1972).

3.2.2.9 Available nitrogen

Available nitrogen was estimated by alkaline potassium permanganate method. (Subbiah and Asija, 1956).

3.2.2.10. Available phosphorus

Bray No. 1 method was employed for the estimation of available phosphorus (Jackson, 1973).

3.2.2.11. Chloride

Volumetric determination of chloride was done as suggested by Black (1965).

3.2.2.12. Sulphate

Turbidimetric determination as described by Chesnin and Yien (1951).

3.2.2.13. Forms of potassium

The following laboratory procedures were used to determine the different forms of potassium.

3.2.2.13.1. Water soluble K

Water soluble K was estimated by extraction with distilled water.

Ten grams of soil was treated with 50 ml of distilled water, shaken for 1 hour and filtered. Potassium was determined by flame photometry (Jackson, 1973).

3.2.2.13.2. Available K

Available K was estimated by extraction with Neutral 1 N NH_4OAC in the ratio 1:5 for 5 minutes. In the filtered extract, K was determined by flame photometry (Jackson, 1973).

3.2.2.13.3. Exchangeable K

This was computed as the difference between available K and water soluble K.

3.2.2.13.4. HNO_3 extractable K

Finely ground soil (2.5g) was taken in an Erlenmeyer flask and 1.0 N HNO_3 (25 ml) was added. The contents were boiled for ten minutes, cooled, filtered and made up to 100 ml in a volumetric flask by subsequent washing with 0.1 N HNO_3. Potassium was determined by flame photometry (Wood and De turck, 1941).

3.2.2.13.5. Non-exchangeable / fixed K

It was estimated by subtracting available K from HNO_3 - K.

3.2.2.13.6. Total K

Finely ground soil (0.1 g) taken in a platinum crucible was digested with 5 ml HF and 0.5 ml $HCLO_4$ on a hot plate. The contents were then evaporated to dryness in a sand bath at 200 - 225°c. It was cooled and 5 ml of 6 N HCl and 5 ml of water was added. Then the solution was gently boiled over a hot plate and the residue was completely dissolved. It was cooled and transferred to a 100 ml volumetric flask and made up to volume. Potassium was determined by flame photometry (Pratt, 1965)

3.2.2.13.7. Lattice K

The lattice K was calculated as the sum of 1 N HNO_3 (boiling) and extractable K deducted from the total soil K.

3.3. Laboratory incubation experiment

A laboratory incubation experiment was carried out for finding out the transformations of different forms of potassium under submergence in the rice soils. Surface soil samples collected from RARS, Pattambi and the RRS, Kayamkulam were used for the experiment done at two levels of applied K - 0 and 45 kg K_2O ha^{-1}, each with three replications.

Soil samples equivalent to 500 g of oven dry soil were taken in plastic containers from the bulk sample maintained in field condition. These samples were then flooded with water so as to maintain a standing level of 5 cm. Potassium was applied in the form of potassium chloride as per the treatment levels. The soil in each container was stirred with a thick glass rod to ensure uniform mixing. The buckets were then placed for incubation for a period of two months at room temperature on a level surface in the laboratory. Wet soil samples were drawn from each incubation bucket at intervals of 0,10,15,20,30,40,50 and 60 days. These samples were analysed for the various potassium fractions as per standard analytical procedures.

3.4. Statistical analysis of the data

Statistical analysis was carried out by adopting the standard methods described by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of the study conducted to investigate the inter-relationships of the different K fractions with the physico-chemical and fertility parameters of two major wetland rice soils of Kerala and the data on the transformation of native as well as applied potash as influenced by a flooded water regime in these soils are presented and discussed here under.

4.1. Laboratory analyses of soils

Soil samples collected from the different locations were subjected to physico-chemical analysis and the data obtained are presented in Tables 3-8.

4.1.1. Mechanical analysis

Significant statistical differences were observed with regard to the coarse sand and clay fractions of Pattambi and Kayamkulam soils. While coarse sand was the predominant fraction of the latter (77.16 %), clay fraction was predominant in the former (49.0 %). The fine sand and silt content of both soils did not show statistically significant differences. The textural class of Pattambi was clay and that of Kayamkulam was loamy sand.

Table 3. Mechanical composition of surface soils

	Pattambi	Kayamukulam	't' value
Coarse sand %	32.15	77.16	6.65**
Fine sand %	10.26	10.65	0.14
Silt %	8.25	4.25	1.56
Clay %	49.0	11.75	11.82**
Textural Class	Clay	Loamy Sand	

Table 4. Values of pH (water), pH (KCl), pH (Ca Cl_2),wet pH, EC, chloride and sulphate of surface samples

	Pattambi	Kayamkulam	't'values
pH of dry soil (water) (1:1)	5.3	4.9	2.37*
pH (water) (1:25)	5.4	5.0	2.11*
pH (KCl)	4.6	4.4	0.93
pH (Ca Cl_2)	4.8	4.5	1.21
Field pH (wet soil)	5.8	5.3	2.70*
EC	0.04	0.01	1.52
Chloride (ppm)	4.5	2.5	2.85*
Sulphate (ppm)	12.5	5.9	1.7

4.1.2. Soil reaction (pH), EC, chloride and sulphate

All the soils studied were acidic in reaction and the increase in soil pH was of the order pH (KCl) < pH ($CaCl_2$) < pH (water) (1:1) < pH (1:2.5) < wet pH. The lowest value of 4.4 pH (KCl) was recorded in Kayamkulam soils and the maximum value of 5.8 pH (field wet) in Pattambi soils. Statistical analysis revealed significant differences in pH (water) (1:1) and (1:2.5) and wet pH among both the soils.

Though the chloride contents of both the soils were significantly different, with regard to EC and sulphate, the two soils did not show marked difference.

Low pH observed in Kayamkulam soils may be due to high leaching losses of bases owing to sandy texture when compared to Pattambi soils. The order of increase in pH determined using various extractants in the present study is in accordance with the reports of Unnikrishnan (1993). Low chloride contents observed in the Kayamkulam soils may be due to the high leaching loss, which is inherent to sandy textured soils.

4.1.3. Organic matter, active iron, CEC, ECEC, exchangeable Al and H

Statistically significant differences were observed in the contents of organic matter, active iron, CEC and ECEC, between the two soils. The respective contents of these in Pattambi and Kayamkulam soils were 1.76 and 0.81 %, 0.302 and 0.120 %, 5.05 and 3.32 cmol kg^{-1} and 2.45

and 1.56 cmol kg^{-1}. However both the soils were not statistically different with respect to exchange acidity, exchangeable Al and exchangeable H.

High content of organic matter in Pattambi soils as compared to Kayamkulam soils can be attributed to the inherently high content of native organic matter characteristic of Pattambi soils. High active iron, CEC and ECEC observed in Pattambi soils compared to Kayamkulam soils may be due to the high organic matter and clay content associated with the former. Positive relation between active iron and organic matter (Pisharody, 1965) and CEC and organic matter (Agboola and Corey, 1973) were also reported.

4.1.4. Available N, P_2O_5 and K_2O

Only the P_2O_5 content of the two soils showed a significant difference. The values recorded were 49 and 121 kg ha^{-1} for Pattambi and Kayamkulam soils respectively. Though not statistically significant N and K_2O contents were higher in Pattambi soils.

Significantly high P content observed in Kayamkulam soils as compared to Pattambi soils may be due to the low P fixing capacity of these soils resulting from low clay content. The residual P accumulated through continuous rice cultivation with addition of phosphorus fertilisers coupled with low P fixing capacity of the soil might have resulted in the abnormally high P content in Kayamkulam soils. Though not statistically significant, high N and K content associated with Pattambi soil may be due to the high organic matter and CEC observed in these soils.

Table 5. Content of organic matter, active iron, CEC, ECEC, exchangeable Al and H of surface soil samples.

	Pattambi	Kayamkulam	't' value
Organic matter %	1.76	0.81	3.06^{**}
Active iron %	0.302	0.120	3.66^{**}
CEC cmol (p+) kg^{-1}	5.05	3.32	2.50^{*}
ECEC cmol (p+) kg^{-1}	2.45	1.56	5.10^{**}
Exchange acidity cmol (p+) kg^{-1}	0.44	0.36	0.71
Exchangeable Al cmol (p+) kg^{-1}	0.25	0.19	1.44
Exchangeable H cmol (p+) kg^{-1}	0.19	0.17	0.27

Table 6. Available nutrients in the surface samples

	Pattambi	Kayamkulam	't' Value
N kg ha^{-1}	341	282	091
P_2O_5 kg ha^{-1}	49	121	8.83^{**}
K_2O kg ha^{-1}	161	137	1.24

4.1.5. Base saturation and exchangeable cations

Percentage base saturation, exchangeable Na and K were not statistically different in the soils. However, exchangeable Ca, Mg and sum of bases were of a greater degree in Pattambi soils as compared to Kayamkulam soils.

High total bases especially Ca and Mg in Pattambi soils compared to Kayamkulam soils is due to the high CEC associated with Pattambi soils. It is further proven by the fact that though the base saturation percentage was not significant, the total base content of these two soils exhibited statistically significant difference.

Table 7. Base saturation and exchangeable cations in the surface samples

	Pattambi	Kayamkulam	't' Value
Base saturation %	43.09	36.82	1.28
Exch. Ca cmol kg^{-1}	1.006	0.5035	3.768**
Exch. Mg cmol kg^{-1}	0.4935	0.2481	4.4746**
Exch. Na cmol kg^{-1}	0.4165	0.3700	1.0124
Exch. K cmol kg^{-1}	0.0878	0.0784	0.6773
Sum of bases cmol kg^{-1}	2.0038	1.2000	4.2142**

Table 8. Potassium fractions in the surface soil samples of Pattambi and Kayamkulam

	Pattambi mg kg^{-1}	Kayamkulam mg kg^{-1}	't' Value
Total K	3250	2440	2.3*
Water soluble K	15.4	11.8	2.1
Exchangeable K	34.3	30.6	0.7
Available K	49.7	42.4	1.2
HNO_3-K	329.1	160.8	2.9**
Fixed K	279.4	117.6	2.9**
Lattice K	2920.9	2279.2	2.1

4.1.6. Fractions of K

Pattambi and Kayamkulam soils were markedly different with respect to their contents of total, HNO_3 soluble and fixed forms of K, the values recorded being 3250 and 2440, 329.1 and 160.8, 279.4 and 117.6 mg kg^{-1} respectively. Water soluble, exchangeable, available and lattice K contents did not show much variation between these two soils.

The above results showed that Pattambi soils contained high amounts of total as well as all forms of potassium when compared to Kayamkulam soils. This can be attributed to the fine textured nature, high organic matter and CEC of Pattambi soils compared to Kayamkulam soils. Significant positive correlations of different forms of K with these fractions viz., total K with organic matter, CEC and clay (Singh and Datta, 1986), HNO_3 K with clay (Brar and Shekhon, 1987), with CEC (Datta and Joshi, 1989), with organic matter (Dhillon *et al.*, 1994), exchangeable K with clay and organic matter (Brar and Shekhon, 1987), with CEC (Pal and Mukhopadhyay, 1992), available K with clay and organic matter (Mongia and Bandyopadhyay, 1991), with CEC (Pal and Mukhopadhyay, 1992), water soluble K with clay, organic matter and CEC (Basumatary and Bordoloi, 1992) have been reported.

4.2. Inter-relationships of physico-chemical parameters with K fractions

4.2.1. Pattambi soils

4.2.1.1. Total K

Of the various physico-chemical parameters, exchangeable Ca and Mg were found to be positively and significantly correlated with total K ($r = 0.6350^*$ and 0.6993^*). Insignificant but positive correlations were obtained with fine sand, silt, clay, pH (water), pH (KCl), pH ($CaCl_2$), wet pH, EC, chloride, sulphate, CEC, ECEC, available K_2O and sum of bases. Negative correlations of total K were noticed with coarse sand, organic matter, active iron, exchange acidity, exchangeable Al, exchangeable H, available N, available P_2O_5, base saturation and exchangeable Na. However, these were not statistically significant.

Table 9. Correlation of K fractions with physico chemical parameters of Pattambi soil

		Total K	WSK	Exch K	Avail K	HNO_3 K	Fixed K	Lattice K
1.	Coarse sand	-0.1278	-0.7488**	-0.3600	-0.5750	-0.1806	-0.1379	-0.1172
2.	Fine Sand	0.1612	0.0714	-0.0294	-0.0021	0.1244	0.1313	0.1668
3.	Silt	0.0481	0.2102	0.1890	0.2399	0.1103	0.0938	0.0363
4.	Clay	0.0719	0.7915**	0.3929	0.6188	0.1125	0.0626	0.0639
5.	pH (w) (1:1)	0.5826	-0.5083	0.0555	-0.1225	0.5028	0.5385	0.5931
6.	pH (w) (1:2.5)	0.5632	-0.5227	0.0275	-0.1525	0.4856	0.5232	0.5734
7.	pH (KCl)	0.5202	-0.5528	-0.0743	-0.2536	0.4080	0.4509	0.5371
8.	pH ($CaCl_2$)	0.5450	-0.5631	-0.0170	-0.2059	0.4353	0.4752	0.5612
9.	pH (wet)	0.6239	-0.4651	0.1002	-0.0681	0.5335	0.5658	0.6360
10.	EC	0.0090	-0.5500	-0.2604	-0.4186	-0.0048	0.0323	0.0115
11.	Chloride	0.1263	0.2807	-0.1346	-0.0249	0.1295	0.1381	0.1248
12.	Sulphate	0.5088	-0.4821	-0.2120	-0.3524	0.4196	0.4719	0.5215
13.	OM	-0.0404	-0.2406	-0.6226	0.6372*	-0.2123	-0.1656	-0.0085
14.	Active iron	-0.1123	0.0161	-0.6310*	-0.6487*	-0.1976	-0.1581	-0.0958
15.	CEC	0.4726	-0.2748	-0.0775	-0.1620	0.3602	0.3925	0.4898
16.	ECEC	0.5479	-0.2656	0.3439	0.2170	0.5030	0.5079	0.5525
17.	Exch. acidity	-0.3060	0.3194	0.0687	0.1696	-0.2823	-0.3118	-0.3081
18.	Exch. Al.	-0.1989	0.3821	0.0573	0.1806	-0.1563	-0.1806	-0.2052
19.	Exch. H.	-0.4500	0.1582	0.0785	0.1236	-0.4638	0.4981	-0.4442
20.	Avail. N.	-0.5728	0.4275	-0.0267	0.1210	-0.4763	-0.5104	-0.5864
21.	Avail. P_2O_5	0.2205	0.6075	-0.0558	0.1562	-0.1429	-0.1639	-0.2332
22.	Avail. K_2O	0.4473	0.4718	0.9413**	1.0000	0.5761	0.5148	0.4203
23.	Base Saturation	-0.1073	-0.0747	0.1154	0.0774	-0.0655	-0.0758	-0.1142
24.	Exch. Ca	0.6350*	-0.4554	0.2163	0.0388	0.5496	0.5730	0.6461
25.	Exch. Mg	0.3993*	-0.4174	0.3301	0.1532	0.7006*	0.7213*	0.6940*
26.	Exch. Na	-0.4067	0.3123	-0.3629	-0.2182	-0.3791	-0.3781	-0.4089
27.	Exch. K	0.4820	0.1465	1.0000	0.9422**	0.5981	0.5430	0.4571
28.	Sum of bases	0.6307	-0.3965	0.2530	0.0915	0.5800	0.6002	0.6355*

Significant positive correlation between total K and exchangeable Ca and Mg observed in the present study is in accordance with the reports of Dixit *et al.* (1993). Positive correlations of total K with clay and CEC (Dixit *et al.*, 1993) were also reported.

4.2.1.2. Water soluble K

It was observed that water soluble K had significantly positive correlation with clay ($r = 0.7915^{**}$) whereas it had significant negative correlation with the coarse sand fraction ($r = -0.7488^{**}$). Though fine sand, silt, chloride, active iron, exchange acidity, exchangeable Al, exchangeable H, available N, available P_2O_5, available K_2O and exchangeable Na were positively correlated with the water soluble form of K and pH determined with different solutions, sulphate, organic matter, CEC, ECEC, base saturation, exchangeable Ca and Mg and sum of bases were negatively correlated with the water soluble fraction of K, none of these were statistically significant.

Significant positive correlations between water soluble K and clay reported by Basumatary and Bordoloi (1992) also support the results of the present study. Significant negative correlation between water soluble K and coarse sand may be due to the very low CEC associated with coarse sand.

4.2.1.3. Exchangeable K

Even though positive relationships of the exchangeable K fractions existed with silt, clay, pH (water) - 1:1 and 1:2.5, wet pH, ECEC, exchange acidity, exchangeable Al and H, available K_2O, base saturation, exchangeable Ca and Mg and sum of bases, appreciable correlation was observed only with available K_2O ($r = 0.9413^{**}$) content of the soil.

Coarse and fine sand fractions, pH (KCl and $CaCl_2$), EC, chloride, sulphate, organic matter, active iron, CEC, available N, available P_2O_5 and exchangeable Na content bore a negative relationship with this fraction. However the correlation with active iron ($r = -0.6319^{*}$) alone was statistically high.

Among all the soil parameters a negative significant correlation of exchangeable K existed with active iron. However this is contrary to the observations of Ponnamperuma (1965).

4.2.1.4. Available K

There existed a significant positive relationship of available K with the organic matter ($r = 0.6372^{*}$) and significant negative correlation with active iron ($r = -0.6487^{*}$) content.

Negative but insignificant relationships were noticed with coarse and fine sand fractions, pH with different media, EC, chloride, sulphate, CEC and exchangeable Na.

It is also evident that the silt and clay fractions, ECEC, exchange acidity, exchangeable Al and H, available N, available P_2O_5, available K_2O, base saturation, exchangeable Ca and Mg and sum of bases were positively but insignificantly correlated with the available K fraction.

Significant positive correlation of available K with organic carbon content may be due to the high exchange capacity of organic matter, which can hold and exchange more K compared to soils with low CEC. This result is supported by the reports of Mishra and Srivastava (1991) and Sirajul *et al.* (1991). Negative correlation of available K with active iron may be due to the negative effect of active iron on exchangeable K which constitute the major part of available K.

4.2.1.5. HNO_3 - K

Exchangeable Mg had a positive significant correlation with the HNO_3 soluble K fraction ($r = 0.7006^*$). Though to a lesser extent, soil separates with the exception of the coarse sand fraction, pH with different solutions, chloride, sulphate, CEC, ECEC, available K_2O, exchangeable Ca and sum of bases also had a positive association with this fraction.

A negative insignificant relationship of HNO_3-K with coarse sand, EC, organic matter, active iron, exchange acidity, exchangeable Al and H, available N, available P_2O_5, base saturation and exchangeable Na was also observed.

Dominance of exchangeable Mg and Ca in the exchange complex will convert the exchangeable K into difficultly exchangeable K ie., HNO_3-K, which results in a positive interaction by exchanging Ca and Mg with HNO_3-K as reported by Koria *et al.* (1989). The positive significant correlation of HNO_3-K with exchangeable Mg obtained in the present study is in conformity with the above observation.

4.2.1.6. Fixed K

The fixed K fraction too had a positive significant relation with exchangeable Mg (r = 0.7213*). Though positive, correlations with fine sand, silt, clay, pH (water), pH (KCl), pH ($CaCl_2$), wet pH, EC, chloride, sulphate, CEC, ECEC, available K_2O, exchangeable Ca and sum of bases were not significant. Similar insignificant negative relationships of fixed K were evidenced with coarse sand, organic matter, active iron, exchange acidity, exchangeable Al and H, available N, P_2O_5, base saturation and exchangeable Na.

The significant positive correlation of exchangeable Mg with fixed K was due to the dominance of exchangeable Mg in the exchange complex as explained in the case of HNO_3-K.

4.2.1.7. Lattice K

The lattice K fraction of Pattambi soil was observed to have a significant positive association with wet pH (r = 0.6360*), exchangeable Ca (r = 0.6461*), exchangeable Mg (r = 0.6940*) and sum of bases (r = 0.6355*). Correlations of lattice K with fine sand, silt, clay, dry pH, EC, chloride, sulphate, CEC, ECEC and available K_2O were positive and insignificant whereas that with coarse sand, organic matter, active iron, exchange acidity, exchangeable Al and H, available N, P_2O_5, base saturation and exchangeable Na were negative but insignificant.

Positive correlation between pH and lattice K observed in the present study was in conformity with the results of Devi *et al.* (1990). Positive significant correlation between CEC and lattice K, that too in lateritic soils reported by Basumatary and Bordoloi (1992) explains the positive correlation of lattice K with exchangeable Ca and Mg observed in the present investigation.

4.2.2. Kayamkulam soil

4.2.2.1. Total K

Significant positive relationship of total K existed with organic matter ($r = 0.6405^{*}$), CEC ($r = 0.6841^{*}$), ECEC ($r = 0.7825^{**}$). Though not appreciable, a close association of this fraction with fine sand, silt, clay, wet pH, available N and P_2O_5, chloride, active iron, exchange acidity, exchangeable Al and H, available K_2O, exchangeable Ca, Mg and Na and sum of bases was observed. Similar insignificant but negative association of total K with the coarse sand fraction, dry pH in water (1:1 and 1:2.5), KCl and $CaCl_2$, EC, sulphate and base saturation was also evidenced.

Significant positive relationship of total K with other soil fertility parameters have been reported by many workers; Basumatary and Bordoloi

(1992) and Trivedi and Varma (1991) (total K with organic matter), Pal and Mughopadhyaya, 1992 and Basumatary and Bordoloi, 1992 (total K with CEC and ECEC).

4.2.2.2. Water soluble K

Statistical analysis revealed positive significant influences of organic matter ($r = 0.8159^{**}$), active iron content ($r = 0.6963^{*}$), CEC ($r = 0.8519^{**}$), ECEC ($r = 0.8687^{**}$) and exchangeable H ($r = 0.7355^{*}$). However positive insignificant relationships were observed with fine sand, silt, clay, EC, sulphate, exchange acidity, exchangeable Al, available N, available K_2O, available P_2O_5, exchangeable Ca, Mg and Na and sum of bases.

Negative significant association of coarse sand ($r = -0.6554^{*}$) and insignificant associations of pH (water - 1:1 and 1:2.5), pH (KCl), pH ($CaCl_2$), wet pH, chloride and base saturation with the water soluble fraction of K were obtained in these soils.

Since water soluble K is in dynamic equilibrium with exchangeable K, fertility parameters like organic matter, CEC, ECEC, active iron which affect exchangeable K, will have its influence on water soluble K also. Positive correlations of water soluble K with organic matter, CEC, ECEC and active iron were reported by Basumatary and Bordoloi (1992), Ponnamperuma (1965), Mishra and Srivastava (1991) and Vandana and Nigam (1994). Significant negative correlation of sand with water soluble K is obviously due to its low exchange capacity.

Table 10. Correlation of K fraction with physico chemical parameters of Kayamkulam soils

		Total K	WSK	Erch. K	Avail. K	HNO_3K	Fixed K	Lattice K
1.	Coarse sand	-0.4967	-0.6554*	0.1088	-0.0542	-0.7025*	0.6883*	-0.4446
2.	Fine sand	0.4322	0.5835	-0.3936	-0.2364	0.6514*	0.6705*	0.3789
3.	Silt	0.5666	0.5818	-0.0774	0.0665	0.7024*	0.6909*	0.5268
4.	Clay	0.4347	0.5518	0.1384	0.2662	0.6180	0.5839	0.3884
5.	pH (w) 1:1	-0.0500	-0.2636	0.5204	0.4354	-0.0961	-0.1512	-0.0397
6.	pH (w) 1:2.5	-0.1059	-0.2577	0.5715	0.4859	-0.1769	-0.2427	-0.0894
7.	pH (Kcl)	-0.1355	-0.3917	0.5389	0.4222	-0.2692	-0.3210	-0.1058
8.	pH ($CaCl_2$)	-0.0612	-0.3786	0.5640	0.4495	-0.2018	-0.2567	-0.0318
9.	pH (wet)	0.0699	-0.1262	0.5834	0.5291	-0.0060	-0.0743	0.0835
10.	EC	-0.4413	0.0985	-0.2026	-0.1706	-0.4255	-0.4119	-0.4345
11.	Chloride	0.0187	-0.1251	-0.0446	-0.0730	-0.1389	-0.1407	-0.0497
12.	Sulphate	-0.0752	0.2609	-0.3729	-0.2946	0.0038	0.0457	-0.0892
13.	Org. Matter	0.6405*	0.8159**	-0.1379	0.0651	0.8011**	-0.7795**	0.5941
14.	Active iron	0.4214	0.6963*	0.0250	0.1924	0.5222	0.4756	0.3919
15.	CEC	0.6841*	0.8519**	-0.1016	0.1087	0.8308**	0.8037**	0.6395*
16.	ECEC	0.7825**	0.8687**	-0.0230	0.1882	0.9182**	0.8889**	0.7380*
17.	Exch. acidity	0.4792	0.6165	-0.0230	0.1882	0.9182**	0.8889**	0.7380*
18.	Exch. Al.	0.4272	0.4980	-0.2950	-0.1626	0.4444	0.4591	0.4142
19.	Exch. H.	0.5246	0.7355*	-0.2142	-0.0275	0.6104	0.6024	0.4957
20.	Avail. N	0.5025	0.5812	-0.2272	-0.0771	0.6282	0.8378**	0.5794
21.	Avail. P_2O_5	0.6236	0.6162	0.2629	0.4497	0.5660	0.5908	0.5365
22.	Avail. K_2O	0.2524	0.2806	0.9716**	1.0000	0.0470	-0.0883	0.2877
23.	Base Saturation	-0.3007	-0.5447	0.3561	0.2098	-0.3335	-0.3414	-0.2874
24.	Exch. Ca.	0.3117	0.2624	0.1383	0.1963	0.4655	0.4470	0.2741
25.	Exch. Mg.	0.1019	0.2346	-0.7829**	-0.6943*	0.4541	0.5524	0.0295
26.	Exch. Na.	0.6183	0.5584	0.4657	0.5820	0.5619	0.4807	0.6157
27.	Exch. K.	0.0968	0.0458	1.0000	0.9704**	-0.1447	-0.2738	0.1427
28.	Sum of bases	0.4943	0.4643	0.2365	0.3393	0.6030	0.5616	0.4616

4.2.2.3. Exchangeable K

Of the various physico-chemical parameters studied, statistically significant positive and negative correlations of total K were noticed only with available K_2O ($r = 0.9716^*$) and exchangeable Mg ($r = -0.7829^{**}$) respectively.

While coarse sand and clay fractions, pH (water - 1:1 and 1:2.5), pH (KCl), pH ($CaCl_2$), wet pH, active iron content, available P_2O_5, base saturation, exchangeable Ca and Na and sum of bases were found to bear a positive association with the exchangeable fraction of K, fine sand and silt fractions, EC, chloride, sulphate, organic matter, CEC, ECEC, exchange acidity, exchangeable H and Al and available N were negatively correlated.

The existence of a dynamic equilibrium between exchangeable K and available K explains the significant positive correlation between these two parameters observed in the present investigation. Negative correlation between exchangeable Mg and exchangeable K observed in the present study can be explained by the fact that high Mg in the exchange complex is consequent to replacement of other cations including exchangeable K from the exchange complex, thus resulting in a low content of exchangeable K. This observation is in concordance with the results of Agboola and Corey (1973).

4.2.2.4. Available K

Although positive correlations of the available K fraction were observed with silt, clay, pH (water - 1:1 and 1:2.5), pH (KCl), pH ($CaCl_2$), wet pH, organic matter, active iron, CEC, ECEC, available P_2O_5, base saturation, exchangeable Ca and Na and sum of bases, none of these bore statistical significance.

While a considerably high negative correlation existed between available K and exchangeable Mg ($r = -0.6943^*$), it did not assume statistically significant proportions with coarse sand and fine sand separates, EC, chloride, sulphate, exchange acidity, exchangeable Al and H and available N.

Since fertility parameters like organic matter, CEC, ECEC, active iron mainly determine the available K, the non-significant effect observed in the present study may be due to the significant effect of these parameters on exchangeable K and water soluble K, which together constitute the plant available K fraction. Significant negative effects of exchangeable Mg on available K can be attributed to its effect on exchangeable K as explained in the case of exchangeable K. Low exchangeable K in turn leads to low content of available K fraction in the soil solution.

4.2.2.5. HNO_3 - K

Fine sand ($r = 0.6514^*$), silt ($r = 0.7024^*$), organic matter ($r = 0.8011^{**}$), CEC ($r = 0.8308^{**}$) and ECEC ($r = 0.9182^{**}$) were positively and significantly correlated to nitric acid extractable fraction of K. Though positive, the relationships with clay content, sulphate, active iron, exchange acidity, exchangeable Al and H, available N, P_2O_5 and K_2O, exchangeable Ca, Mg and Na and sum of bases could not be rated as statistically significant.

Though a significant negative association existed between HNO_3-K and the coarse sand fraction ($r = -0.7025^{*}$), negative but insignificant correlations with pH water - 1:1 and 1:2.5, pH (KCl), pH ($CaCl_2$), wet pH, EC, chloride and base saturation were obtained.

Positive significant correlations of HNO_3-K with silt was obtained by Brar and Shekhon (1987), with sand by Mongia and Bandopadhyaya (1991), with CEC and ECEC by Datta and Joshy (1989), with organic matter by Dhillon *et al.* (1994) and Sirajul *et al.* (1994) confirming the results obtained in this regard where in the HNO_3-K fraction was found to be positively correlated with sand, silt, organic matter, CEC and ECEC.

4.2.2.6. Fixed K

Statistical analysis revealed that the fixed K fraction was closely associated with fine sand ($r = 0.6705^{*}$), silt ($r = 0.6909^{*}$), CEC ($r = 0.8037^{**}$), ECEC ($r = 0.8889^{**}$) and available N ($r = 0.8378^{**}$). However, insignificant positive correlations existed with clay, sulphate, active iron, exchange acidity, exchangeable Al and H, available P_2O_5, exchangeable Ca, Mg and Na and sum of bases.

Though a significant negative relationship was noticed between fixed K and organic matter (r = -0.7795*), fixed K and the coarse sand fraction (r = -0.6883*), correlations with pH (water - 1:1 and 1:2.5), pH (KCl), pH ($CaCl_2$), wet pH, EC, chloride, available K_2O and base saturation were negative but lacked statistical significance.

Significant positive relationships of fixed K with fine sand, silt, CEC, ECEC obtained in the present study are in congruence with the reports of Datta and Joshi (1989) and Mongia and Bandopadhyaya (1991).

Significant negative correlations obtained with organic matter and fixed K appears to be consequent to the high exchange capacity and organic matter content which hold most of the potassium in their exchange sites thus preventing fixation. This result is in accordance with that of Mongia and Bandopadhyaya (1991).

2.2.7. Lattice K

A close association of the lattice K fraction with CEC (r = 0.6395*), ECEC (r = 0.7380*) was noticed. Fine sand, silt and clay separates, wet pH, organic matter, active iron, exchange acidity, exchangeable Al and H, available N, P_2O_5 and K_2O, exchangeable Ca, Mg and Na and sum of bases were however insignificantly correlated with lattice K.

Coarse sand, pH (water - 1:1 and 1:2.5), pH (KCl), pH ($CaCl_2$), EC, chloride, sulphate and base saturation were seen to bear negative but insignificant correlation with lattice K.

The positive significant association of lattice K with CEC and ECEC obtained in the study is in line with that obtained by Basumatary and Bordoloi (1992).

4.3. Inter correlation of K fractions

4.3.1. Pattambi soils

4.3.1.1. Total K

It was found that the total K was positively and significantly correlated with HNO_3-K($r = 0.9666^{**}$), fixed K ($r = 0.9738^{**}$) and lattice K ($r = 0.9989^{**}$).

In the light of the fact that 98 % of the total K is constituted by HNO_3-K, fixed K and lattice K fractions, the high positive correlation of total K with these fractions obtained in the study is well explained. Similar results were also reported by Mehrotra and Singh (1970), Ranganathan and Sathyanarayana (1980), Sirajul Islam *et al.* (1994) and Basumatary and Bordoloi (1992).

4.3.1.2. Water soluble K

No significant correlation of this fraction with other forms were observed in the soils of Pattambi.

Table 11. Intercorrelation of K fractions of Pattambi and Kayamkulam soils

	Total K	WSK	Exch.K	Avail K	HNO_3 K	Fixed K	Lattice K
Total K		0.0652	0.4814	0.4522	0.9666**	0.9738**	0.9989**
WSK	0.6711*	KAYAMKULAM	0.1465	0.4395	0.1379	0.1029	0.0514
Exch K	0.0964	0.0456		0.9422**	0.5979	0.5427	0.4570
Avail.K	0.2550	0.2858	0.9703**		0.5804	0.5193	0.4253
HNO_3 K	0.9053**	0.7835**	-0.1450	0.0505	PATTAMBI	0.9973**	0.9535**
Fixed K	0.8693**	0.7356*	-0.2742	-0.0849	0.9905**		0.9624**
Lattice K.	0.9964**	0.6336*	0.1423	0.2900	0.8662**	0.8257**	

4.3.1.3. Exchangeable K

There was a highly positive relation between exchangeable K and available K ($r = 0.9422^{**}$).

Exchangeable K and available K fractions were positively intercorrelated, reiterating the existence of a dynamic equilibrium between these two forms of potassium. Similar observations were also recorded by Dhanorkar *et al.* (1994), Singh *et al.* (1993), Singh and Tripathi (1993).

4.3.1.4. Available K

Other than with the exchangeable fraction, there did not exist any significant relation between available K and other forms of K.

Though not statistically significant, positive relations of all potassium fractions with the available K fraction was noticed, which is of primary concern as far as plant nutrition is concerned.

4.3.1.5. HNO_3 - K

The HNO_3-K seemed to maintain a highly positive correlation with fixed K ($r = 0.9973^{**}$) and lattice K ($r = 0.9535^{**}$).

Significant positive correlations of HNO_3-K with lattice and fixed K obtained in the study are in accordance with the reports of Dhanorkar *et al.* (1994).

4.3.1.6. Fixed K

The fixed K fraction was highly correlated with lattice K ($r = 0.9624^{**}$).

Significantly positive intercorrelations of fixed K with lattice K recorded by Dhanorkar *et al.* (1994) support the observation of the present study.

4.3.2. Kayamkulam soils

4.3.2.1. Total K

The total K seemed to bear a highly positive correlation with water soluble ($r = 0.6711^{*}$), HNO_3 soluble ($r = 0.9053^{**}$), fixed ($r = 0.8693^{**}$) and lattice ($r = 0.9964^{**}$) fractions of K.

Positive significant relationships of total K with water soluble K, HNO_3-K, fixed K and lattice K recorded in the present study is in line with the reports of Dhanorkar *et al.* (1994), Mehrothra and Singh (1970), Ranganathan and Sathyanarayana (1980), Sirajul Islam *et al.* (1994) and Basumatary and Bordoloi (1992).

4.3.2.2. Water soluble K

A positive and significant association of water soluble K with HNO_3-K ($r = 0.7835^{**}$), fixed K ($r = 0.7356^{*}$) and lattice K ($r = 0.6336^{*}$) was observed in the soils of Kayamkulam.

Unlike in Pattambi soils, significant positive correlations of water soluble K with HNO_3, fixed and lattice forms of K observed in Kayamkulam soils can be attributed to a delicate equilibrium between these fractions of K owing to the inherently low buffering capacity of these soils. Studies conducted by Venkatesh and Sathyanarayana (1994), Dhanorkar *et al.* (1994) also yielded similar correlations.

4.3.2.3. Exchangeable K

The exchangeable K fraction was observed to be closely related to the available form of K ($r = 0.9703^{**}$).

Similar trends of correlation of exchangeable K with other K fractions were observed in Pattambi soils also.

4.3.2.4. Available K

None of the K fractions seemed to maintain a significant correlation with available K except the exchangeable fraction.

Correlations obtained by Dhanorkar *et al.* (1994) is in firm support of the significant positive relationship of exchangeable K with available K, revealed in the present investigation.

4.3.2.5. HNO_3 - K

Statistical analysis revealed that HNO_3-K was positively and significantly related to fixed ($r = 0.905^{**}$) and lattice ($r = 0.8662^{**}$) forms of K.

As far as correlations of HNO_3 K with different forms of K are concerned, the results obtained in Kayamkulam soils were similar to that of Pattambi soils.

4.3.2.6. Fixed K

There existed a significant and positive correlation of fixed K with the lattice K fraction ($r = 0.8257^{**}$).

Correlation effects of different fractions of K on fixed K in these soils was in uniformity with that of Pattambi soils.

4.4. Laboratory incubation experiment

A laboratory incubation study was carried out to monitor the dynamics of native as well as applied K in the two representative soil types as influenced by a flooded moisture regime. Potassium was applied in the form of potassium chloride (A.G.) so that the rate of applied potash was 45 kg K_2O ha^{-1}.

The soils were maintained under submergence for a period of 60 days. Soil samples were drawn at intervals of 0, 10, 15, 20. 30. 40, 50 and 60 days and analysed for water soluble, exchangeable, available. nitric acid soluble, fixed and lattice bound fractions of potassium. The results obtained are detailed below :

4.4.1. Water soluble potassium

The data on the content of water soluble forms of potassium at different periods of submergence of the two soils is presented in Table 12.

Table 12. Changes in water soluble K (mg kg^{-1}) under different periods of submergence (days)

Location:	Pattambi			Kayamkulam		
Levels of K (kg K_2O ha^{-1}) / Days	0	45	Mean	0	45	Mean
0	15.4	47.5	31.5	11.8	51.4	31.6
10	15.1	42.6	28.9	11.7	48.2	29.7
15	15.3	39.4	27.4	11.8	47.5	29.7
20	15.8	38.3	27.1	11.9	44.7	28.3
30	16.4	33.5	25.0	12.1	41.5	26.8
40	16.8	29.6	23.2	12.62	39.6	26.1
50	17.3	26.5	21.9	12.70	37.5	25.1
60	17.7	24.8	21.3	12.82	36.0	24.4
Mean	16.2	35.3		12.19	43.3	
CD Treatments	2.8			2.5		
CD Interaction	6.6			7.5		

In Pattambi soils, the mean values of water soluble K differed significantly with and without added K. The mean water soluble K content at zero level of added K was 16.2 mg kg^{-1} whereas that at 45 kg ha^{-1} of added K_2O was 35.3 mg kg^{-1}. With advancement in submergence, though the mean water soluble K content recorded a gradual decrease from 31.5 to 21.3 mg kg^{-1} no statistical significance was observed. Water soluble K at both levels of K behaved contrastly on submergence. At zero level, water soluble K showed a gradual increase from 15.4 to 17.7 mg kg^{-1} at the end of 60 days of submergence. But this increase was not statistically significant. However, at 45 kg ha^{-1} of added K_2O, water soluble fraction showed a drastic significant decrease from 47.5 to 24.8 mg kg^{-1}. With respect to the initial value, statistical significance of water soluble K was observed from the 15^{th} day of submergence onwards.

In Kayamkulam soils the mean water soluble K fractions differed significantly with and without added K. At zero level of K the mean water soluble K content was 12.2 whereas that at 45 kg ha^{-1} of added K_2O was 43.3 mg kg^{-1}. No significant difference in water soluble K levels due to submergence was observed. At zero level of added K, a slight increase was noticed in water soluble K on submergence which was not substantial. At added levels of K, statistically significant decrease of water soluble K from 51.4 to 36.0 mg kg^{-1} was recorded, the statistically significant decrease commencing on the 20^{th} day of submergence.

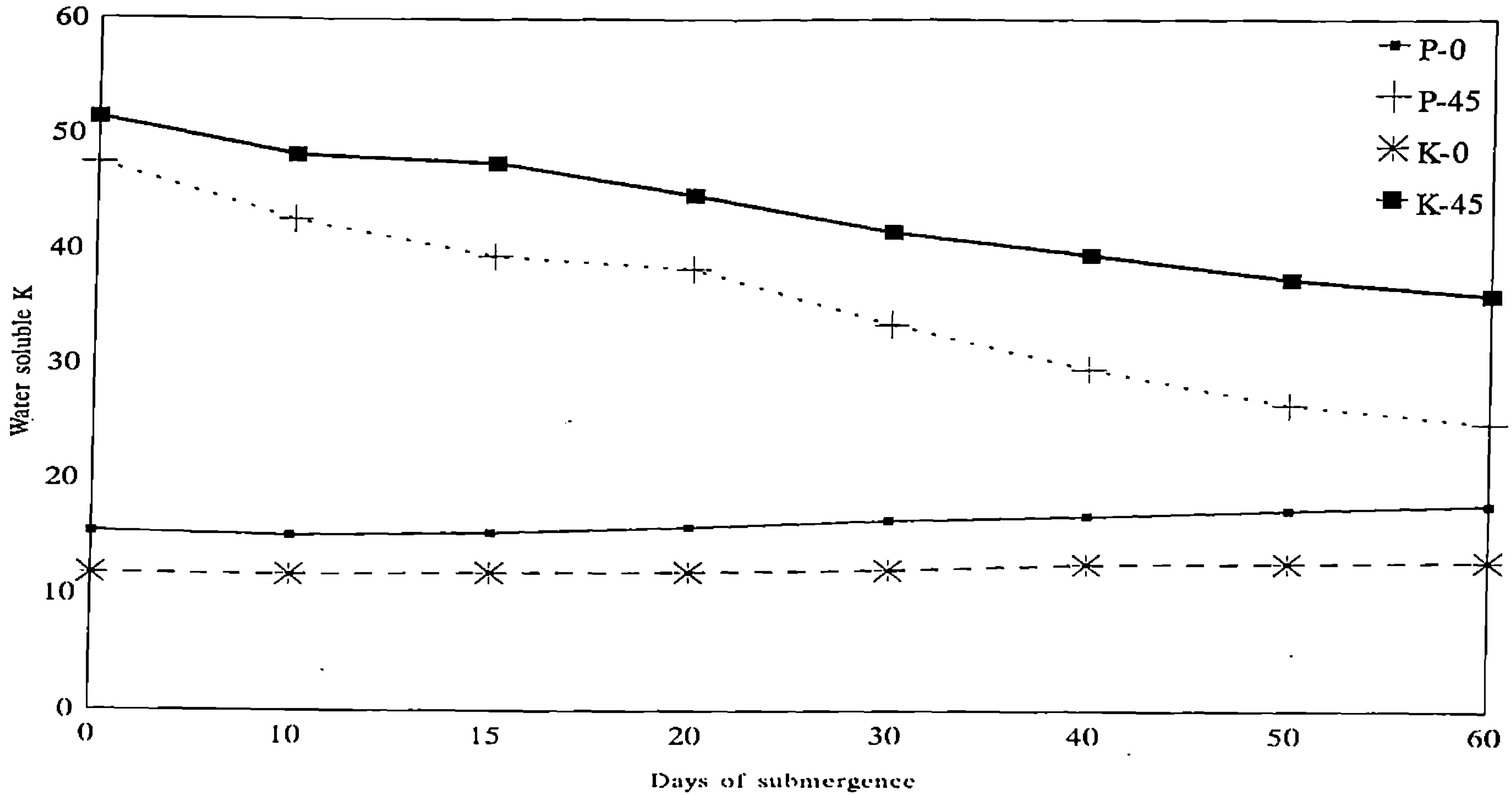


Fig. 1. Changes in water soluble K (mg kg^{-1}) under different periods of submergence (days)

The significant increase in the water soluble fractions in both soil types due to addition of fertilizer potassium is quite obvious. At zero levels of added K, the gradual increase of water soluble fraction observed in both the soils may be explained by the formation of free cations, consequent to reduction processes set in by submergence, which substitute the exchangeable K from the exchange sites, ultimately leading to an increase in water soluble K content of soil solution.

At added levels of potassium in both soils, submergence had a depressing effect on the water soluble fraction. This may be due to the conversion of water soluble form to the exchangeable form. However, the magnitude of this depressing effect in both the soils are note worthy. At all periods of observations, Kayamkulam soils recorded higher values of water soluble K compared to Pattambi soils. This may be attributed to the high exchange capacity resulting from high organic matter and clay content associated with Pattambi soils which retained more of the added K in the exchange sites rather than in solution as compared to Kayamkulam soils.

4.4.2. Exchangeable potassium

The data relating to the changes in the exchangeable K fraction under different periods of submergence in both the soils are presented in Table 13.

Table 13. Changes in exchangeable K (mg kg^{-1}) under different periods of submergence (days)

Location:	Pattambi			Kayamkulam		
Levels of K (kg K_2O ha^{-1}) / Days	0	45	Mean	0	45	Mean
0	34.3	47.3	40.8	30.64	36.03	33.33
10	34.4	52.3	43.4	30.52	39.23	34.87
15	34.5	54.8	44.7	30.6	39.8	35.2
20	33.9	55.7	44.8	30.6	42.3	36.5
30	33.3	58.5	45.9	30.4	45.2	37.8
40	33.4	60.0	46.7	30.1	47.3	38.7
50	33.0	62.1	47.6	29.8	49.5	39.7
60	33.2	62.8	48.0	29.2	51.0	40.1
Mean	33.8	56.7		30.2	43.8	
CD Treatments	4.2			3.6		
Intervals	5.2			...		
Interaction	11.8			7.8		

The data revealed in Pattambi soils a statistically significant increase in exchangeable K fraction due to addition of fertilizer K. The mean exchangeable K fraction with and without added K was 56.7 and 33.8 mg kg^{-1} respectively. On submergence this fraction of K gradually increased from 40.8 to 48.0 mg kg^{-1}, the statistical significance being exhibited from the 40^{th} day of submergence, when compared with the initial value.

Contrasting trends of the exchangeable K fraction at both levels of added K upon submergence were observed. At zero level though the exchangeable K fraction was statistically not significant, it exhibited a decreasing trend with the advancement of submergence. However at added levels of K, this fraction exhibited a progressive increase from 47.3 to 62.8 mg kg^{-1}, which was statistically significant after 40 days of incubation.

In Kayamkulam soils, significant difference in the exchangeable K fraction was observed at both levels of added K, the mean values being 30.2 and 43.8 mg kg^{-1} at 0 and 45 kg ha^{-1} of K_2O respectively. On submergence, though an increasing trend in the mean exchangeable K fraction was observed, it was not statistically significant.

Though the exchangeable K fraction without fertilizer K addition showed a decreasing trend during the incubation, unlike in Pattambi soils, it did not exhibit any statistical significance. However at added K levels the increase in exchangeable K content from 36.0 to 51.0 mg kg^{-1} was statistically significant after one month of incubation.

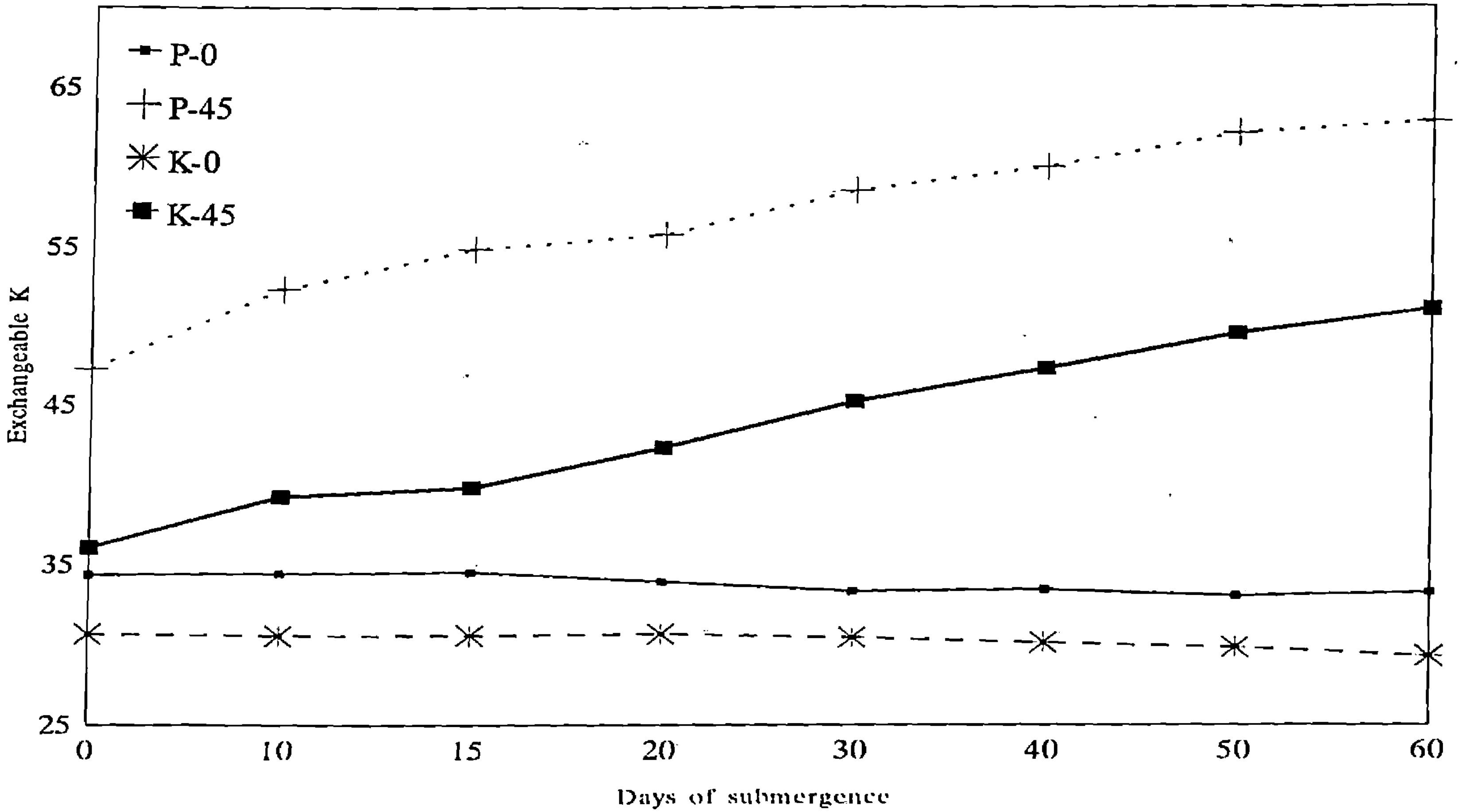


Fig. 2. Changes in exchangeable K (mg kg^{-1}) under different periods of submergence (days)

The addition of fertilizer potassium has resulted in the increased exchangeable K content in both soils, thus supporting the existence of a dynamic equilibrium between different forms of K, especially water soluble and exchangeable K. This observation is in concurrence with the reports of Mishra and Shankar (1971).

The significant increase in exchangeable K observed in Pattambi soils upon submergence is due to the conversion of water soluble form to exchangeable form at a higher magnitude as compared to Kayamkulam soils owing to its high exchange capacity. The reason for the decreasing trend in exchangeable K at zero levels of K in both soils is as explained in the case of water soluble K at this dose of K. The increase in exchangeable K on submergence observed in both soil at higher dose of K is due to the conversion of available form to exchangeable form. The higher magnitude of this increase in Pattambi soils is relevant from the potassium nutrient management point of view. Added K is seen retained in the exchange complex, thus not only preventing leaching loss of added potassium from the soil but also extending the availability of potassium for a longer period due to the existence of the dynamic equilibrium between exchangeable and water soluble forms.

4.4.3. Available potassium

The dynamics of available K as revealed by the incubation study given in Table 14 revealed that in Pattambi soils the mean available K content was significantly high (92.0 mg kg^{-1}) at 45 kg K_2O ha^{-1} compared to zero level of K (50.0 mg kg^{-1}). Though the mean available K content decreased on submergence it did not bear any statistical significance. With respect to the different K levels, a slight increase was observed in the available K content at zero level and a slight decrease at 45 kg K_2O ha^{-1}. However both these effects were insignificant.

Table 14. Changes in available K (mg kg -1) under different periods of submergence (days)

Location:	Pattambi			Kayamkulam		
Levels of K (kg K_2O ha^{-1}) / Days	0	45	Mean	0	45	Mean
0	49.7	94.75	72.25	42.4	87.4	65.0
10	49.5	94.9	72.2	42.2	87.4	64.8
15	49.8	94.2	72.0	42.4	87.3	64.9
20	49.7	94.0	71.9	42.6	87.0	64.8
30	49.7	92.0	70.9	42.5	86.7	64.6
40	50.2	89.6	69.9	42.7	86.9	64.8
50	50.3	88.6	69.5	42.5	87.1	64.7
60	50.9	87.6	69.3	42.1	87.0	64.5
Mean	50.0	92.0		42.4	87.1	
CD Treatments	3.5			5.8		

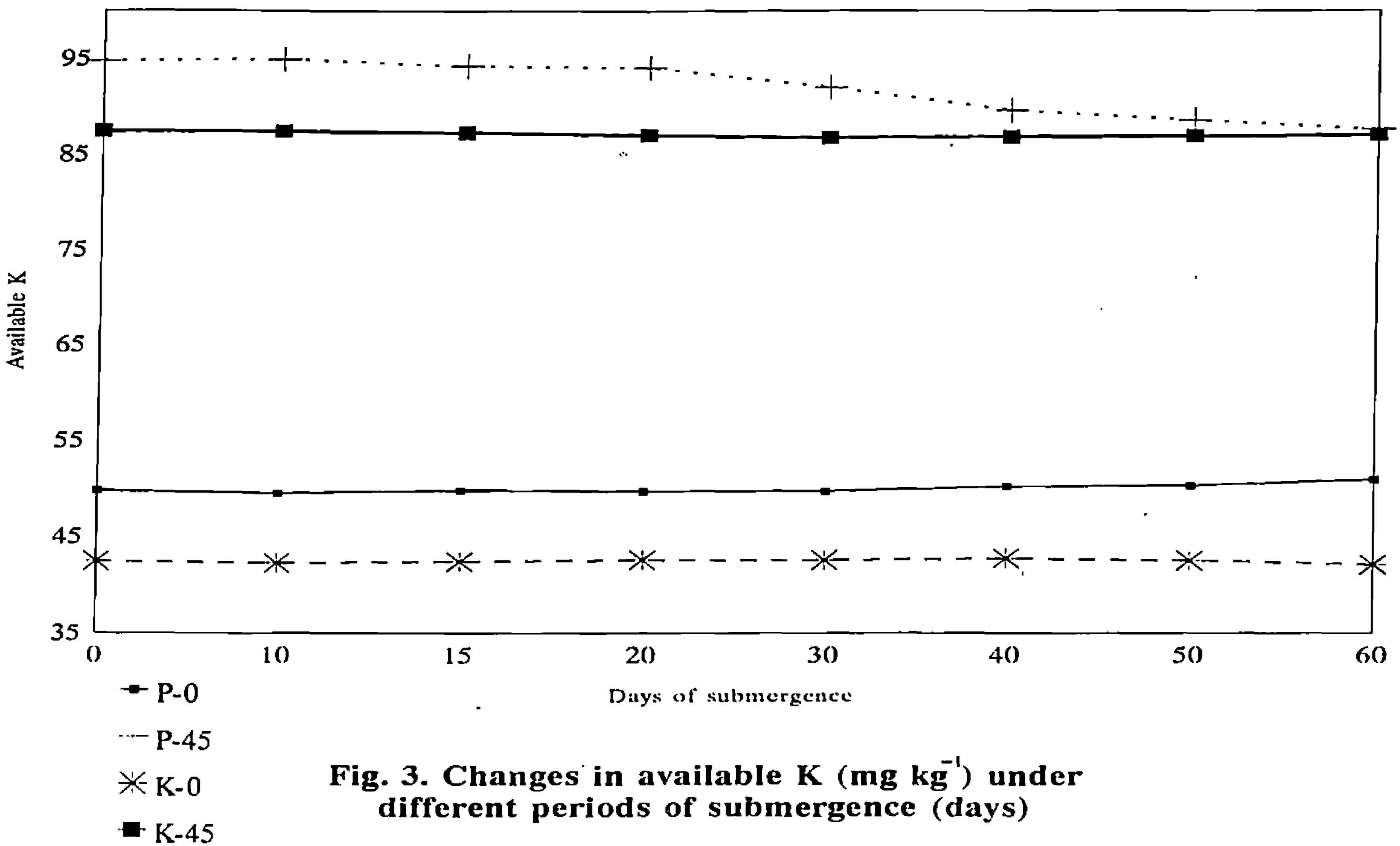


Fig. 3. Changes in available K (mg kg^{-1}) under different periods of submergence (days)

As evident in Table 14, in Kayamkulam soils the available K content with and without added potassium differed significantly. At zero level the mean available K content recorded was 42.4 mg kg^{-1} and 87.1 mg kg^{-1} at 45 kg K_2O ha^{-1}. The mean available K content maintained more or less a static nature throughout the incubation period. A similar trend was noticed with available K contents all through the incubation period at both levels of K.

The increased values of available K recorded for the higher level of K addition is self explanatory. Among the soil types compared, with respect to available K on submergence, Pattambi soils alone exhibited notable changes. The increase in available K with submergence at zero level is as explained in the case of water soluble K. At added levels of K, there occurred a decrease in this fraction of K with submergence which can be attributed to potassium fixation in this soil, which is not noticed in Kayamkulam soils.

4.4.4. HNO_3 - K

The quantitative changes in the nitric acid soluble fraction of K at different periodical intervals of incubation, with and without applied potash are detailed in Table 15.

A close scrutiny of the data revealed that in Pattambi soils a significant increase in the HNO_3 K due to K addition existed. The mean values recorded were 330.8 and 376.5 mg kg^{-1} at zero and 45 kg ha^{-1} of K_2O

respectively. The mean HNO_3 K content increased from 351.7 to 357.3 mg kg^{-1} as a result of submergence. However a statistically significant increase was observed only after two months of submergence. Even though increase in HNO_3 K was observed at both K levels, neither of them bore statistical significance.

Table 15. Changes in HNO_3- K (mg kg -1) under different periods of submergence (days)

Location:		Pattambi			Kayamkulam	
Levels of K ($kg\ K_2O\ ha^{-1}$) / Days	0	45	Mean	0	45	Mean
0	329.1	374.3	351.7	160.8	204.5	182.7
10	328.4	374.5	351.5	160.9	204.6	182.8
15	329.0	374.7	351.8	160.9	204.5	182.7
20	331.0	375.0	353.0	161.2	204.9	183.1
30	331.2	376.4	353.8	161.4	204.1	182.7
40	331.5	377.1	354.3	161.8	204.1	183.0
50	332.2	379.2	355.7	162.1	203.9	183.0
60	333.6	380.4	357.1	162.2	204.8	183.5
Mean	330.8	376.5		161.4	204.4	
CD Treatments	4.4			5.2		
Interval	4.5					

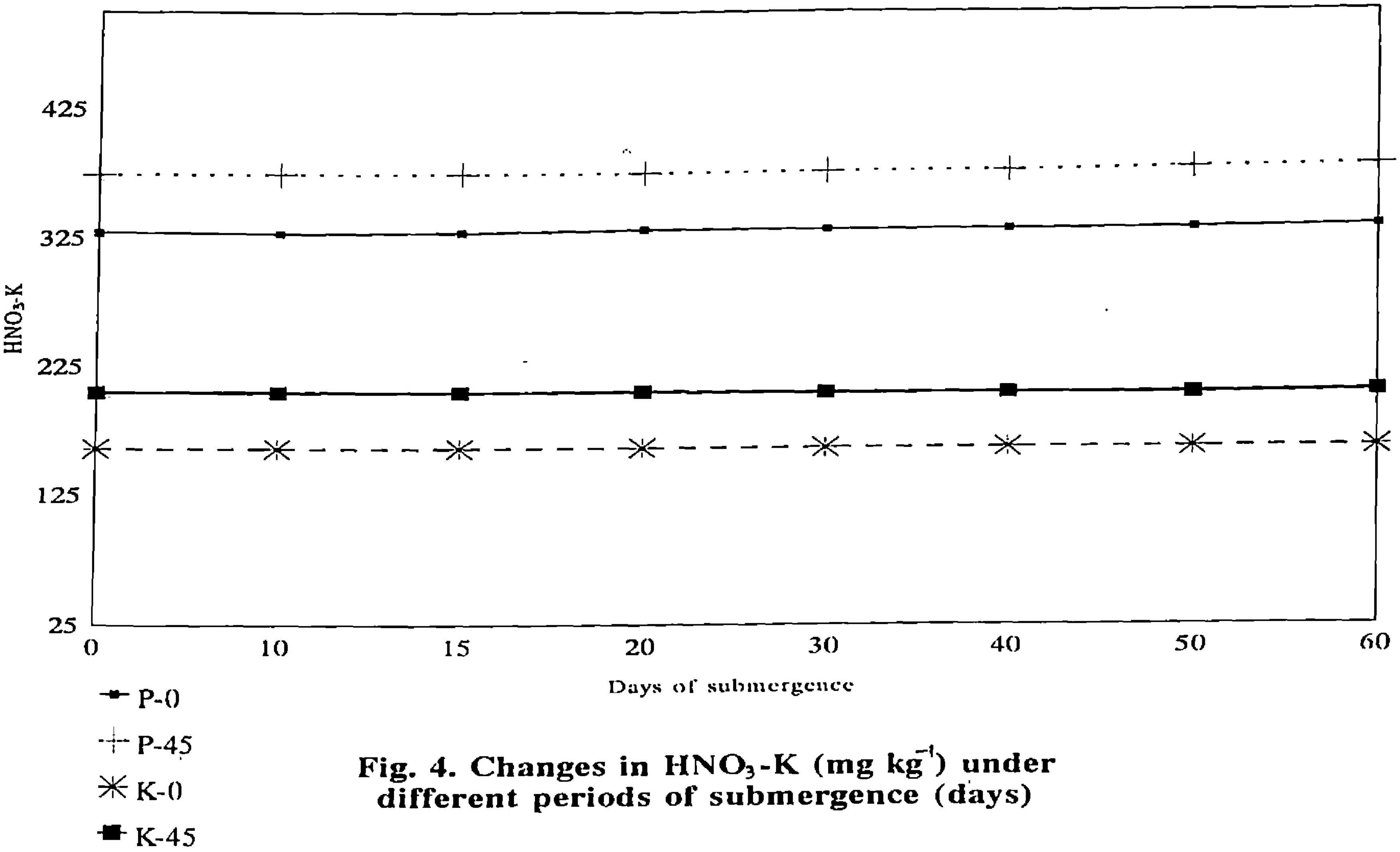


Fig. 4. Changes in HNO_3-K (mg kg^{-1}) under different periods of submergence (days)

In Kayamkulam soils, the mean HNO_3 K fraction at 45 kg K_2O ha^{-1} (204.4 mg kg^{-1}) was significantly higher than that without added K (161.4 mg kg^{-1}). The changes in HNO_3 K fraction on submergence at both levels of added K were meagre.

The increase in HNO_3 K associated with addition of K observed in both soils is quite obvious since HNO_3 K comprises of both available as well as fixed form of K. Even though the changes in HNO_3 K on submergence were non-significant, in Pattambi soils the increases were of higher degree especially at higher levels of added K. This may be due to fixation of K associated with these soils. Increase in HNO_3 K associated with the period of incubation obtained in the present study is supported by the reports of Jessymol, S. (1993).

4.4.5. Fixed potassium

The influence of flooded condition on the behaviour of fixed form of K, with and without applied potash, would be comprehensive with the aid of Table 16.

The data revealed that in Pattambi soil, the increase of fixed K fraction from 280.8 mg kg^{-1} at zero level to 283.5 mg kg^{-1} at 45 kg K_2O ha^{-1} was significant. The mean values of fixed K over different period of submergence were also statistically significant which varied from 275.3 mg kg^{-1} to 287.9 mg kg^{-1}. The effect of submergence was pronounced only at higher levels of K where an increase from 279.6 mg kg^{-1} to 293.1 mg kg^{-1} was recorded.

Table 16. Changes in fixed K (mg kg -1) under different periods of submergence (days)

Location:	Pattambi			Kayamkulam		
Levels of K ($kg\ K_2O\ ha^{-1}$) / Days	0	45	Mean	0	45	Mean
0	279.4	279.6	279.5	118.4	117.1	117.7
10	278.9	271.6	275.3	118.7	117.2	118.0
15	279.2	281.0	279.8	118.5	117.2	117.9
20	281.3	281.0	281.1	118.6	117.9	118.2
30	281.5	284.4	283.0	118.9	117.3	118.1
40	281.3	287.5	284.4	118.8	117.3	118.1
50	281.9	290.6	286.3	119.6	117.0	118.3
60	282.7	293.1	287.9	120.1	117.8	119.0
Mean	280.8	283.5		118.9	117.4	
CD Treatment	2.2					
Interval	4.5					
Interaction	7.5					

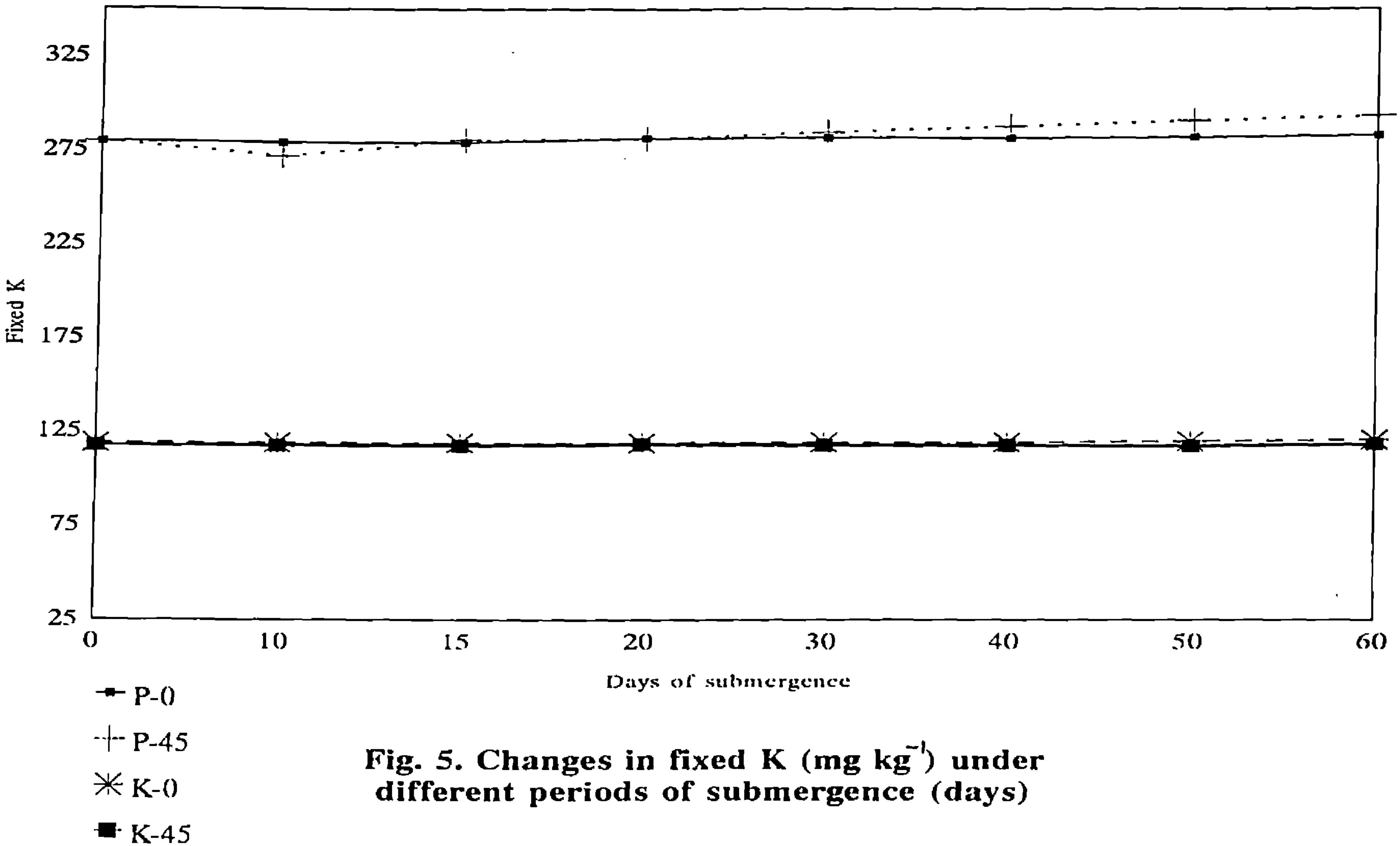


Fig. 5. Changes in fixed K (mg kg^{-1}) under different periods of submergence (days)

In Kayamkulam soils, neither the K levels nor the period of incubation had any influence on K fixation. The increase in fixed K levels and incubation period observed in this study also supported the results of Prakash and Singh (1989).

The above results clearly indicated that potassium fixation is a problem in Pattambi soils, especially at higher levels of K applied. This may be the constraining factor for the low response to added K in Pattambi soils. Hence K fixation should be taken into consideration as a factor in the formulation of potassium management strategies for cost-effective utilisation of this vital input.

Table 17. Changes in lattice K (mg kg^{-1}) under different periods of submergence (days)

Location:	Pattambi			Kayamkulam		
Levels of K (kg K_2O ha^{-1}) / Days	0	45	Mean	0	45	Mean
0	2920.9	2960.7	2940.8	2279.2	2275.5	2277.3
10	2921.6	3013.2	2967.4	2279.1	2275.4	2277.3
15	2921.0	3015.0	2968.0	2279.1	2275.5	2277.3
20	2919.0	3015.1	2967.1	2278.9	2275.1	2277.0
30	2918.8	3015.4	2967.1	2278.6	2276.0	2277.3
40	2918.5	3015.5	2967.0	2278.5	2275.9	2277.2
50	2917.8	3015.5	2966.7	2277.9	2276.1	2277.0
60	2916.4	3015.0	2965.7	2277.8	2275.2	2276.5
Mean	2919.3	3008.2		2278.6	2275.6	

4.4.6. Lattice potassium

The dynamics of lattice K as revealed by the incubation study is presented in Table 17.

Even though a slight enhancement of lattice K fraction consequent to K addition was observed, the changes were statistically insignificant in both the soils. Due to submergence at zero levels of K there was a slight decrease and at 45 kg level a slight increase was noticed with respect to lattice K fraction irrespective of the soil types studied. However these changes did not bear any statistical significance.

This indicates that with neither the added K nor with the period of submergence, a change could be brought about in the clay mineral lattice which accommodates the lattice K fraction.

SUMMARY AND CONCLUSION

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An investigation was conducted at the College of Agriculture, Vellayani during 1994-95 to study the inter-relationship of potassium with other soil fertility parameters, the various forms of potassium and their transformation under submergence. Form ten locations each, of the two representative sites, surface samples were collected to study the physico chemical parameters, fractionation of potassium and the dynamics of these fractions under submergence with and without added potassium.

Soil types selected for the study were having high variation in physico - chemical properties. The lateritic alluvium of Pattambi was clayey, high in chloride, organic matter, active iron, CEC, ECEC, exchangeable Ca, Mg, and sum of bases and was low with respect to coarse sand and available P_2O_5 contents and was less acidic.

The *Onattukara* sandy soil of Kayamkulam was loamy sand with a high content of coarse sand fraction, more acidic, high in P_2O_5 content and low in clay, chloride, organic matter, active iron, CEC, ECEC, exchangeable Ca, Mg and sum of bases.

Fractionation studies revealed that Pattambi soils had a higher content of total K, HNO_3K and fixed K as compared to that of Kayamkulam soils. However, the water soluble, exchangeable and available forms of K did not exhibit marked variation.

Significant positive correlation of total K with exchangeable Ca and Mg in Pattambi soils and with organic matter, CEC and ECEC in Kayamkulam soils were obtained.

While water soluble K fraction of Pattambi soils had positive correlation with clay content, it was negatively correlated with the coarse sand fraction. The significant negative correlation of sand with water soluble K obtained in Kayamkulam soils is due to its low exchange capacity.

The high positive correlation of exchangeable K with the available K fraction in both the soil types is an ample proof for the existence of a dynamic equilibrium between the two fractions.

The exchangeable and available fractions of K in Pattambi soils was found to have a negative correlation with active iron which was contrary to earlier observations.

The non significant influence of soil pH on the available K status of Pattambi soils, which had appreciable pH and organic matter as compared to Kayamkulam soils, leads to the conclusion that management of organic matter in tropical soils rich in kaolinite is important to maintain the available K status for sustainable farming.

The CEC of the soil and the organic matter content are responsible for retaining potassium in their exchange sites thus preventing fixation.

The poor degree of correlation of water soluble, exchangeable and available forms of K with total K in Pattambi soils was probably due to lack of intense weathering of potash bearing minerals in these soils that might have brought a larger fraction of K into exchangeable and water soluble forms. The major portion of the soil potassium was in the lattice form and hence the lattice K was positively and significantly correlated to total K.

The increase in available potassium with advancement of incubation period is ascribed to the addition of potassium, reflecting the amount of potassium adsorbed on the soil and the soil solution, suggesting forward direction of the equilibrium. The decrease observed with added K suggest diffusion of potassium in the internal surfaces of the soil clays.

Potassium fixation was found to be a constraint in Pattambi soils especially for added K, which should hence form an inevitable criterion which should be given due consideration while formulating potassium management strategies.

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* Originals not seen

INTER-RELATIONSHIP OF POTASSIUM WITH OTHER SOIL FERTILITY PARAMETERS IN TWO MAJOR WETLAND RICE SOILS OF KERALA

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ABSTRACT OF A THESIS
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ABSTRACT

A study was done at the College of Agriculture, Vellayani during 1994-95 to quantify the different forms of potassium and to investigate the inter-relationships of these forms with other soil fertility parameters. Soil samples were collected from ten locations each, of the two major wet land rice soils of Kerala selected for the study viz., lateritic alluvium of Pattambi (brown hydromorphic) and *Onattukara* sandy soil (greyish *Onattukara*) of Kayamkulam. Incubation studies were also carried in both soil types, with and without applied potash, for a period of two months.

The study revealed that considerable variation existed in the physico-chemical properties of the two soils. The lateritic alluvium of Pattambi was clayey, high in chloride, organic matter, active iron, CEC, ECEC, exchangeable Ca, Mg and sum of bases and was low with respect to coarse sand and available phosphorus contents and was less acidic as compared to the *Onattukara* sandy soils of Kayamkulam. The latter was loamy sand in texture with a high content of coarse sand fraction, more acidic, high in phosphorus content and low in clay, chloride, organic matter, active iron, CEC, ECEC, exchangeable Ca, Mg and sum of bases in comparison to the former.

Fractionation studies revealed that the Pattambi soils had a higher content of total K, HNO_3K and fixed K as compared to that of Kayamkulam soils.

The high positive correlation of exchangeable K with the available K fraction in both the soil types justifies the existence of a dynamic equilibrium between the two fractions.

The negative correlation of exchangeable and available fractions of K with active iron observed in Pattambi soils was contrary to earlier observations in this regard.

Though comparatively high in organic matter, the effect of soil reactión on the available K status was not considerable in Pattambi soils as compared to Kayamkulam soils. This led to the conclusion that management of organic matter in tropical soils is important to maintain the available K status for sustainable farming.

The positive inter correlation obtained between lattice K and total K indicated that the major portion of soil potassium existed in the lattice form. The positive and significant association of other forms of potassium was indicative of the existence of a dynamic equilibrium between these forms of K.

Potassium fixation was found to be a constraint in Pattambi soils especially with the addition of potassic fertilisers. Hence this should be given due consideration while formulating cost-effective and efficient potassium management strategies since the major chunk of potassic fertilisers are imported in our country.