FORMS AND Q/I RELATIONSHIP OF POTASSIUM IN IMPORTANT SOIL SERIES OF CENTRAL CAMPUS FARM, RAHURI

By

Miss Nilima Ramrao Bele
B. Sc. (Agri.)

A Thesis Submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI, 413 722 DIST.- AHMEDNAGAR,
Maharashtra State (India)

in Partial Fulfilment of the Requirements for the Degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL CHEMISTRY

DEPARTMENT OF AGRICULTURAL CHEMISTRY & SOIL SCIENCE
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI, DIST- AHMEDNAGAR, M. S. (INDIA)

1993

AFFECTIONATELY DEDICATED
TO MY
BELOVED PARENTS

... Nilima

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DEPARTMENT OF AGRICULTURAL CHEMISTRY & SOIL SCIENCE
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1993

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted by me or any other person to any other University or Institute for a Degree or Diploma

M P K V, Rahuri,
Dated : 30-6-93

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India.

CERTIFICATE

This is to certify that the thesis entitled FORMS AND Q/I RELATIONSHIP OF POTASSIUM IN IMPORTANT SOIL SERIES OF CENTRAL CAMPUS FARM, RAHURI submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri 413 722 (District : Ahmednagar), Maharashtra State, India, for the award of the Degree of MASTER OF SCIENCE (AGRICULTURE) in AGRICULTURAL CHEMISTRY, embodies the results of a piece of bona fide research work carried out by Miss NILIMA RAMRAO BELE under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

M P K V, Rahuri,
Dated : 30-6-93

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Associate Dean,
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(N.K. Umrani)

M P K V, Rahuri,
Dated : 14|7|93

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M P K V, Rahuri,

Dated : 30-6-93

NRBele
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ABSTRACT

FORMS AND Q/I RELATIONSHIP OF POTASSIUM IN IMPORTANT SOIL SERIES OF CENTRAL CAMPUS FARM, RAHURI

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Research Guide	....	Dr. K.R. Sonar
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The studies on forms and Q/I relationship of potassium in six widely spread soil series viz., Nimone, Otur (Vertisol), Sawargaon, Dholwad (Inceptisol), Pargaon and Khanapur (Entisol) of Central Campus Farm, Rahuri were carried out to understand the behaviour of potassium in the surface and subsurface layers of these soils. Neubauer technique experiment was also conducted with wheat as a test crop to evaluate potassium fertility of these soils.

The soils under investigation were alkaline, clayey and clay loam in texture, low to moderately high in organic carbon with high CEC. Lattice K contributed to the bulk of the total K (79.18 %) followed by non-exchangeable K (15 %), exchangeable K (5.57 %) and water soluble K (0.24 %) in all the soil series under study with equilibrium among the different forms as evident from the significant relationships among all the forms of K.

Higher values for AR_o^K , PBC^K, K_L, K_x, K_o and K_p were recorded by Nimone, Otur, Sawargaon and Dholwad soil series in comparison with Pargaon and Khanapur series indicating the

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differential behaviour of potassium in these soils. This may be attributed to the differences in physico-chemical characteristics of these soils. The ΔG values indicated the sufficiency of K and existence of a suitable balance between K and Ca + Mg in these soils.

The results of Neubauer technique showed no variation in dry matter accumulation in wheat. The Nimone, Otur, Sawargaon and Dholwad series recorded higher concentration and uptake of K by wheat cv. HD 2189 (*Triticum aestivum* L.) as compared to Pargaon and Khanapur series indicating the differential K supplying power of the soils.

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Introduction

1. INTRODUCTION

Potassium is a major essential nutrient element and is involved in many physiological and biochemical functions of plant growth and yield formation. Potassium plays a vital role in crops in terms of yield and quality as it is a key element stabilizing more than 60 enzymes and plant metabolism, transpiration, respiration and food transportation in the plants (Rathi and Singh, 1983; Asok Raja et al., 1988 and Jafri et al., 1991).

The most important factor affecting the crop production in any region is the nutrition of a crop based on soil fertility and consumption. The amounts of nutrients removed per hectare by a crop is an indicator of the rate of exhaustion of the soil and the significant role played by a particular nutrient in crop production. For most of the crops, the K requirements are as large as the need for N and in many cases exceeds that of N. This aspect has become important in the context of modern intensive agriculture when growers aim at higher and quality produce of crops per unit area and per unit time (Tandon and Sekhon, 1988). However, the use of potash fertilizer is still lower than nitrogen or phosphorus, which might be due to low response ratio of K which is lower (1 kg K_2O : 5 kg grain) than N (1 kg N : 10 kg grain) or P (1 kg P_2O_5: 7 kg grain). The scanty use of organic manures and relatively lower use of fertilizer potassium may lead to more wide spread deficiency of K in agriculture lands (Khera et al., 1990). Continuous long term intensive cropping with the use of fertilizer N and P without application of K is expected to deplete reserves of potassium in soil.

The potassium content of Indian soils generally varies from 0.5 to 3.0 per cent with an average value of 1.52 per cent (Ray Chaudhuri, 1976). Most of the potassium (90 %) in soil occurs in K bearing primary minerals *viz.*, mica (muscovite and biotite) and feldspars (orthoclase and microcline). Potassium content of soil varies widely depending upon the composition of parent rocks and minerals from which they are formed, the degree of weathering and the climatic condition. It is usually higher in the arid, young alluvial and black clayey soils than in the more weathered red and lateritic soils located in high rainfall areas (Kadrekar and Kibe, 1972).

Potassium dynamics i.e. K concentration of the soil solution, its buffer capacity and changes brought about by fertilizer application have a direct effect on crop yields. Generally, solution K and exchangeable K are considered to be available to plants. But, there are several reports showing that the crops can utilize K from non-exchangeable sources also (Kadrekar and Kibe, 1972; Singh and Ghosh, 1984 and Patil, 1992). If the non-exchangeable K source is utilized for a long term, this may later on create the problem of high K fixation in soil.

Potassium in soils is present in different forms and chemically, all these forms are in reversible equilibrium. On an average, 92 per cent of the total K is present as reserve mineral K, 6.3 per cent as non-exchangeable K, 1.6 per cent as exchangeable and only 0.2 per cent as water soluble K (Tandon and Sekhon, 1988). Potassium in soil is much buffered by reserve K as the proportion of total K held in water soluble and exchangeable forms are relatively very small.

There are a number of instances where crop responds to applied K fertilizer even though it is not predicted by soil tests. This suggests that soil factors can influence the growth of the plant, the ability of the soil to provide a high rate of delivery of K to the roots during the period of its rapid growth, as well as supply of sufficient quantities of K during the growing season. These factors include chemical parameters of soils such as cation exchange capacity (CEC), levels of sub-soil K, K fixation, calcareous nature, texture, leaching and interaction with other nutrients, etc. (Pretty, 1978). The unavailable K tends to become available due to a shift in equilibrium. Clay content in the soil may be considered as a capacity or quantity factor in potassium fixation. Similarly, pH is a strong factor in inducing K fixation in soils (Singh and Pati Ram, 1975). In order to evaluate the K fertility status of soils, both the immediately available and gradually available forms from non-exchangeable sources of K from different soil layers (Sonar, 1984) are to be considered.

Beckett (1964^{a}) following consideration of ratio law (Schofield, 1947) suggested that the intensity (I) of K in soil at equilibrium with its soil solution could best be delivered by ratio $^{a}K/(^{a}Ca + Mg)^{\frac{1}{2}}$. The quantity-intensity parameters of soil K are useful in better understanding of the nature of K equilibrium as well as plant availability of K in a soil. Potassium quantity-intensity relationship (Q/I) plays an important role in predicting K availability to plants as it indicates effects of physico-chemical, and mineralogical properties of soils on the K status and its availability to plants (Adhikari and Ghosh, 1991 and Al Kanani et al., 1991). For crops with very high intensity of cropping, both quantity and intensity parameters of K are important. The quantity-intensity (Q/I) buffer curves measure these parameters and is a better index of K supplying power of soils (Beckett, 1971 and 1972).

Biological methods have also been tried as a technique to assess the availability of soil K. It is studied by taking short duration exhaustive crop in a small quantity of surface soil for a short period. Neubauer technique has been widely used for this purpose.

A thorough knowledge of the behaviour of K in soil helps to determine not only the nutrient supplying ability of soils but also provides an information for long term K fertility management which are vital for the crop production.

At the Central Campus Farm, Rahuri, there are ten soil series out of which six soil series viz., Nimone, Otur (Vertisol), Sawargaon, Dholwad (Inceptisol) and Khanapur, Pargaon (Entisol) occupy the major area of the farm and subjected to intensive cropping. It was, therefore, thought necessary to study the depthwise forms and Q/I relationship of potassium in these six soil series as this information is not available. Depthwise samples were, therefore, obtained from the six soil series and laboratory studies were conducted during the year 1992-93 with the following objectives :

(1) To assess physico-chemical properties of profile samples of the six soil series

(2) To assess the forms of potassium in the soils

(3) To derive Q/I parameters of K in the soils

and

(4) To evaluate K fertility of the soils by conducting a Neubauer technique experiment with wheat (cv. HD 2189) as a test crop.

Review of Literature

2. REVIEW OF LITERATURE

2.1 Forms of Potassium in Soil

Potassium occurs in the soil in various forms viz., water soluble K, exchangeable K, non-exchangeable K, lattice K and total K.

These five forms of K are present in all agricultural soils, though their quantity and relative proportion vary widely. In general, 90 to 98 per cent of total K is in mineral forms, which is relatively inaccessible to a growing crop, 1 to 10 per cent of total K is in the fixed form that is slowly available and 1 to 2 per cent of total K is in the exchangeable + water soluble forms. Out of this 1 to 2 per cent, about 90 per cent may be in exchangeable and 10 per cent in the soil solution forms. However, all these forms are in a dynamic equilibrium (Martin and Sparks, 1985 and Tandon and Sekhon, 1988). Sparks and Huang (1985) presented inter-relationship among the various forms of K in soil (Fig.1)

2.1.1 Water soluble K

Water soluble (soil solution) K is the form taken up directly by plants and microbes and is also subject to leaching (Sparks, 1980). Although water soluble potassium is invariably present in soils, appreciable quantities of this form are not likely to occur except when the soils receive potassic fertilizers or irrigation water of high K content. The distinction between water soluble K and the other form

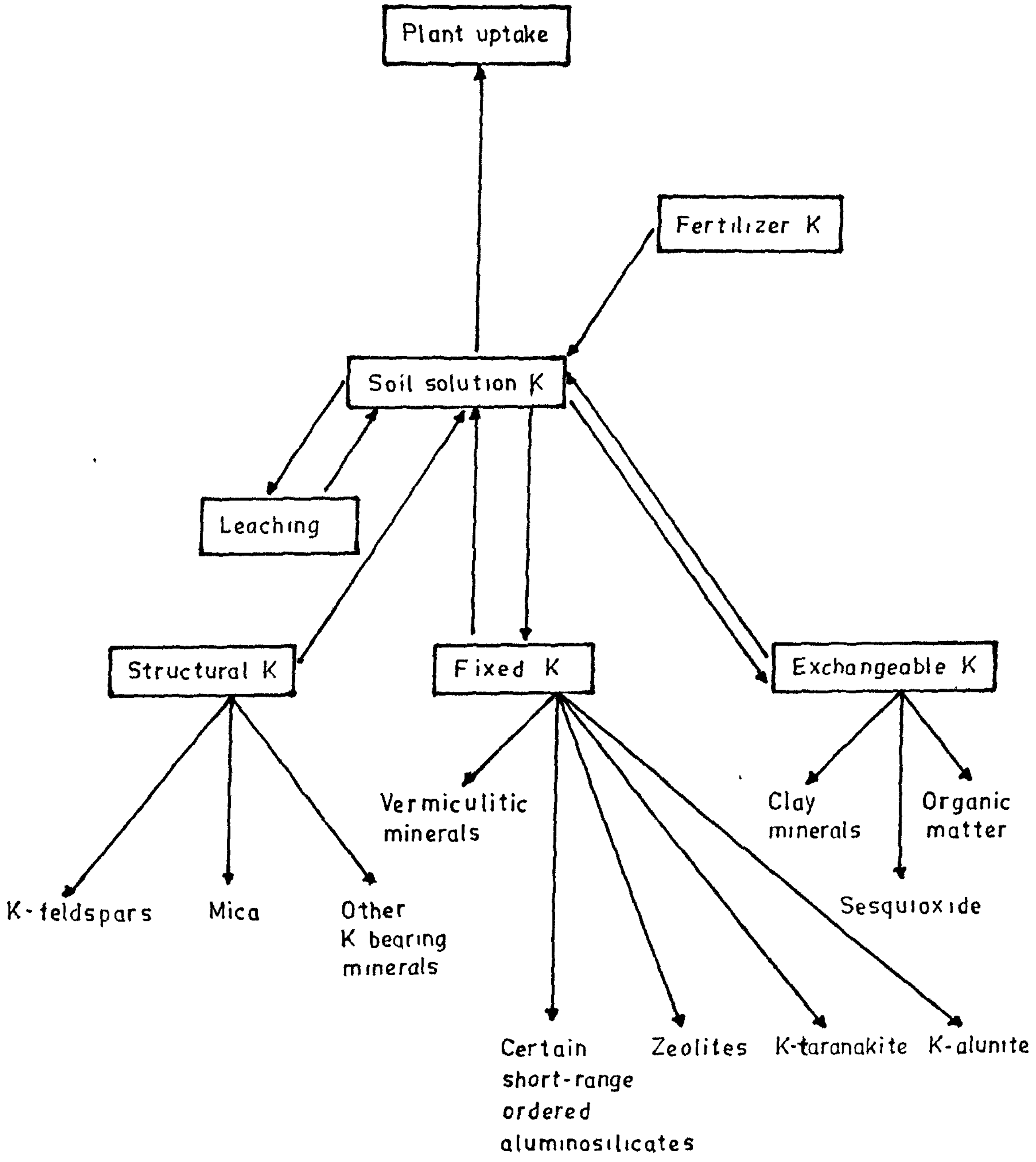

Fig. 1. Inter-relationships of various forms of soil potassium.

is only of an arbitrary nature. For instance, Reitemeir (1946 and 1951) showed that dilution of soil with water increases the soluble potash possibly because of hydrolysis of exchangeable K or by replacement of K with divalent ions or dissolution of K bearing minerals.

The studies on K status of Indian soils by Khera (1955) revealed that exchangeable + water soluble K constituted less than 5 per cent of the HCl soluble K in these soils. In the Punjab soils, Grewal and Kanwar (1966) found that water soluble K accounted for about 1 per cent of the total soil potash. According to Tiwari et al. (1967), the soils of Bihar contained from traces to 0.014 me per cent water soluble K, with a mean value of 0.0073 me per cent. Sedimentary soils were higher in their water soluble K content than that of alluvial soils. The water soluble K constituted only 0.21 per cent of the total K in the soil. After the analysis of soil samples from various zones of Uttar Pradesh, Misra and Shankar (1970) reported that mean water soluble K content of these soils was 0.26 me 100 g^{-1} soil. Mehrotra and Singh (1970) found that the water soluble K contents of Uttar Pradesh soils accounted for about 0.1 per cent of total K.

Kadrekar and Kibe (1972) analysed 55 surface soil samples from different agro-climatic zones of Maharashtra and reported 1 to 18 ppm of water soluble K, with an average of 6 ppm. This fraction constituted less than one per cent of the total K. Medium black soils of Rajasthan have been found to contain on an average 1.7 mg 100 g^{-1} of water soluble K (Bhatnagar et al., 1973). In a study of K status, the water soluble K content of black and red (Vertisol and Alfisol) soils of Bellary varied from 0.7 to 3.2 mg 100 g^{-1} soil (Godse and Gopalkrishnappa, 1976). Chahal et al.(1976) found that water soluble K content varied from 0.5 to 1.8 and 0.8 to 6.3 mg 100 g^{-1} in Ambala and Gurgaon soils, respectively. Maharana et al. (1976) reported water soluble K in old alluvial tracts of Bihar which varied from 0.1 to 0.28 me 100 g^{-1} with the exception of one soil from Belagani black having 1 me 100 g^{-1} water soluble K. Kalbande and Swamynatha (1976) studied the characterization of K in black soils developed on different parent materials in Tungabhadra catchment and revealed that the water soluble K was to the extent of 0.11 per cent of the total K.

Chaudhari and Jain (1979) reported 1 to 1.9 mg 100 g^{-1} with a mean value of 1.4 mg 100 g^{-1} of water soluble K in the soils of different agro-climatic zones of Rajasthan. Ranganathan and Satyanarayana (1980) studied the K status of Karnataka soils and reported that water soluble K ranged from 0.05 to 0.08 me 100 g^{-1} soil. Gajbhiye (1985) reported that the water soluble K ranged from 9 to 20 ppm with a mean of 12 ppm in Inceptisols and 10 to 25 ppm with a mean of 16 ppm in Entisols. Singh and Singh (1986) studied the soils of Garhwal hills and reported that water soluble K ranged from traces to 37 ppm and constituted only 0.014 per cent of the total K. Sharma and Dubey (1988) reported that the surface soil had higher water soluble K ranging from 0.03 to 0.06 and 2.6 to 4.5 per cent of total K and available K, respectively. Pal and Sekhon (1991) studied K status of five alluvial soil series from different geographical regions of India and reported that on an average, water soluble K accounted for 5.6 to 30.6 per cent of NH_4OAc-K which in turn constituted 11.4 to 63 per cent of HNO_3-K. Solankey et al. (1991) reported higher water soluble K content in the Antralia and Panchdaria swell-shrink soil series of Madhya Pradesh.

The soils of different agro-climatic zones of Maharashtra State were fairly high in all the forms of K (Talele et al., 1992^a). Water soluble K in soils of different agro-climatic zones varied from 0.45 mg 100 g^{-1} in zone IB (very high rainfall, non-lateritic basaltic parent material) and IA (very high rainfall, lateritic, laterite parent material) to 1.56 mg 100 g^{-1} in zone IV B (assured rainfall with kharif and rabi cropping, basaltic parent material). Sehgal et al. (1992) studied different forms of K in soil profiles developed on granite, gneiss and basalt occupying relatively low to high physiographic positions, revealed that soils derived from granite gneisses were richer in all the forms of K than soils derived from basalt. Typic chromusterts of granitic gneiss and Typic Pellusterts of basalt, occupying lower physiographic positions, were the richest in water soluble K in their respective groups.

Tiwari and Bansal (1992) studied vertical distribution of forms of K in some soil series of northern Madhya Pradesh. Water soluble K content decreased with depth in Vertisols, while this form increased up to a depth of 135 cm in alluvial soils. The water soluble K content of swell-shrink soils of Maharashtra, ranged from 10 mg kg^{-1} in Sayala series to 15.6 mg kg^{-1} in Barshi series. The mean values of water soluble K for the different agro-climatic zones were 10.6, 13.3, 11.3, 14.6 and 11.4 mg kg^{-1} soil. The water soluble K content constituted 0.12 to 0.39 per cent of the total K with a mean value of 0.23 per cent in the swell-shrink soils of different agro-climatic zones of Maharashtra (Patil, 1992).

2.1.2 Exchangeable K

In Uttar Pradesh soils, the exchangeable K content varied from 0.69 to 0.77 per cent of the total K (Mishra and Shankar, 1970 and Mehrotra and Singh, 1970). According to Misra et al. (1970), the exchangeable K content of Uttar Pradesh soils was 21 mg 100 g^{-1}. Soils from orders like Alfisols, Inceptisols, Mollisols, Ultisols and Oxisols contained exchangeable K varying from 31 to 358 ppm (Oliveira et al. (1971).

Kadrekar and Kibe (1972) analysed 55 soil samples from different agro-climatic zones of Maharashtra State and according to them, the exchangeable K constituted about 2 per cent of the total K in the soils and varied from 31 to 442 ppm with an average of 123.3 ppm. Medium black soils of Rajasthan have been reported to contain on an average exchangeable K to the tune of 10 mg 100 g^{-1} soil (Bhatnagar et al., 1973).

In Karnataka, exchangeable K content of soils varying from 4.5 to 44 mg 100 g^{-1} of soil with a mean value of 21.2 mg 100 g^{-1} has been reported by Godse and Gopalkrishnappa (1976). The exchangeable K content of soil series under Vertisols and associated soils were generally higher than those of Alfisols and related soils. The exchangeable K content of soils from important agro-climatic zones of Gujarat varied from 0.21 to 1.64 me 100 g^{-1} of soil (Mehta, 1976).

Venkatasubbiah et al. (1976) analysed 17 heavy black soils from the West Godawari District (Andhra Pradesh) and reported exchangeable K content to vary from 229 to 498 ppm with a mean of 328 ppm. Kalbande and Swamynatha (1976) found exchangeable K content to account for 2.86 per cent of total K for Tungabhadra catchment. Zende (1978) reported that black soils of Maharashtra contained moderately high to high amounts of available K, whereas exchangeable K in these soils ranged from 5 to 200 mg 100 g^{-1} soil. Ghosh and Varade (1976) reported that sources and levels of potassium did not influence the availability of K as well as exchangeable K in a medium black soil.

Ranganathan and Satyanarayana (1980) reported that the exchangeable K in some soils of Karnataka varied from 0.14 to 0.72 me 100 g^{-1} in the surface layer. Prakashchandra and Singh (1985) reported that exchangeable K in alluvial soils of Western Uttar Pradesh varied from 42 to 175 ppm and constituted on an average 0.67 per cent of the total K. Dhillon et al. (1985) studied the distribution of different forms of K in benchmark soils of Punjab and Haryana, and reported that exchangeable K constituted 0.34 per cent of total K. Brar et al. (1986) reported that high exchangeable K was associated with comparatively low amount of the non-exchangeable fraction. Sharma and Mishra (1986) stated that the exchangeable K ranged between 62.5 to 233.5 ppm which constituted 0.47, 0.54, 0.65 and 0.71 per cent of the total K in loamy sand, sandy loam, loam and clay loam groups, respectively.

Tiwari and Dev (1987) studied the K availability in soils growing wheat and reported that the exchangeable K and HCl-K in these soils ranged from 0.14 to 0.51 and 6.41 to 19.87 mg 100 g^{-1}. They also brought out that available K depends on clay contents, clay mineral composition and fertilizer K addition. Sharma and Dubey (1988) reported that exchangeable K constituted 1 to 2 per cent of the total K in Vertisols. Subba Rao and Sekhon (1988) studied 7 benchmark soil series from the States of Rajasthan (Masitawali), Gujarat (Pithvajal and Mazodar), Maharashtra (Shendvade and Kumbhave 5) and Madhya Pradesh (Sarol and Kamliakheri series). On the basis of available K content, the seven soil series were grouped into three 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. The proportion of non-exchangeable to exchangeable form of K was relatively greater in soils dominated by illite and smectite in comparison to those rich in smectite alone.

Koria et al. (1989) studied the vertical distribution of forms of K in dry farming areas of Saurashtra region in Gujarat and reported that the amount of water soluble, exchangeable, HNO_3 extractable and total K varied from 0.006 to 0.45, 0.06 to 1.05, 0.27 to 5.35 and 6.2 to 23.7 me 100 g^{-1} soil, respectively. Solankey et al. (1991) studied the K status of Antralia and Panchdaria swell-shrink soil series of Madhya Pradesh and reported that the soils of Antralia series (Fulventic Ustochrepts) were high in water soluble, 1 N HNO_3-K, 1 N HCl-K, Total K, labile K and AR_o^K (16, 23, 32, 8, 2 and 18 per cent, respectively). Tiwari and Bansal (1992) studied vertical distribution of forms of K in some soil series of northern Madhya Pradesh and found that exchangeable K content decreased with depth of 135 cm in alluvial soils.

Talele et al. (1992[a]) studied various forms of K in soils of Maharashtra occurring under different agro-climatic zones and found that the exchangeable K varied from 12.03 to 46.8 mg 100 g^{-1} in zone IB (very high rainfall, non-lateritic basaltic parent material) and IV B (assured rainfall with kharif and rabi cropping, basaltic parent material).

The exchangeable K contents of swell-shrink soils of Maharashtra, from different agro-climatic zones ranged from 140 mg kg^{-1} in Kandegaon soil series to 390 mg kg^{-1} in Shendvade soil series. The average exchangeable K in the soils from different agro-climatic zones varied from 170 mg kg^{-1} in zone II (transition zone) to 359 mg kg^{-1} in zone IV A (assured rainfall). The exchangeable K in soils from high rainfall zones (II and V B) had comparatively lower exchangeable K which constituted 2.8 to 8.1 per cent of the total K with a mean value of 4.9 per cent (Patil, 1992).

2.1.3 Non-exchangeable K

When any potassic fertilizer is added to the soil, some of it converted into a form which cannot be extracted with neutral N ammonium acetate. This reversion of applied K is known as potassium fixation which is so characteristic of soils containing predominently illitic type of clays. Such K which forms a part of the clay mineral can be tapped by plant roots through contact exchange. The non-exchangeable K represents a transitional state between the exchangeable K and the lattice K from which it cannot be sharply distinguished.

Oliveira et al. (1971) studied soils from orders Alfisols, Inceptisols, Mollisols, Ultisols and Oxisols and found that the non-exchangeable K content of soils varied from 62 to 652 ppm. The medium black soils of Rajasthan were found to contain on an average 110 mg of non-exchangeable K 100 g^{-1} of soil (Bhatnagar et al., 1973). Godse and Gopalkrishnappa (1976) in their studies on black and red soils of Bellary (Karnataka) found that the non-exchangeable form of K varied from 9.8 to 43.6 mg 100 g^{-1} with the mean value of 27.6 mg. Kalbande and Swamynatha (1976) in their studies on black soils of Tungabhadra catchments found that the non-exchangeable K in different soils accounted for 9.12 per cent of the total K. Choudhari and Jain (1979) reported that the fixed K ranged from 18.4 to 160 mg 100 g^{-1} soil and was influenced by the type of K bearing minerals in the soils of different agro-climatic regions of Rajasthan.

Ranganathan and Satyanarayana (1980) studied the soils of Karnataka and reported fixed K from 250 to 660 ppm which was about 6.6 per cent of the total K. Sahu and Gupta (1982) studied the three broad soil groups of north Bengal and reported that fixed K constituted 1.58 to 6.23; 1.44 to 10.8 and 2.46 to 10.53 per cent of total K for the three soil groups. Distribution of K forms was studied by Singh et al. (1983) in some soils of different agro-climatic regions of Haryana which were under intensive cultivation and the non-exchangeable K was in the range of 175 to 1625 ppm. Brar and Sekhon (1985) studied the soils from northern India, occurring in intensively cultivated alluvial belt. Two villages from each of these areas in Punjab, Haryana and western, central and eastern Uttar Pradesh, where Nabha, Lukhi, Khatki, Akbarpur and Rarha series showed that reserve K did not occur in a similar manner in all the soil series. In Lukhi series, exchangeable as well as reserve K were low, while in Akbarpur series both the forms were high. In soils of Nabha series, high exchangeable K was associated with low reserve K and the reserve relation was observed in the case of khatki and Rarha series.

Gajbhiye (1985) reported that fixed K ranged from 490 to 900 ppm in Inceptisols and 665 to 1140 ppm in Entisols forming 1.28 to 3.08 per cent of total K, while Bandyopadhyay et al. (1985) studied 25 soils from different coastal areas of Orissa and West Bengal ~~were studied~~ for their different fractions of K. The study indicated that the soils were rich in all the forms of K. Dhillon et al. (1985) studied the distribution of various forms of K in some benchmark soils of north, west India and found that boiling 1 N HNO_3 extractable K constituted 7.75 per cent of total K. Prakashchandra and Singh (1985) reported that alluvial soils of western Uttar Pradesh contained 1325 to 1623 ppm of fixed K. Tiwari and Dev (1985) reported that 1 N HNO_3-K ranged from 1.41 to 4.26 me 100 g^{-1} in the wheat growing soils of India.

Shankhayan and Bhardwaj (1987) reported that the average content of non-exchangeable K in some soils of Himachal Pradesh was 272 ppm. Bansal and Jain (1988) studied the forms of K in Vertisols as influenced by long term intensive cropping and fertilizer use and reported significant change in different forms of K after 12 years of intensive rotational cropping. A marked reduction in total and 1 N HNO_3 (boiling) soluble K was observed. Solankey et al. (1988) determined the K status of two swell-shrink soil series of Madhya Pradesh and reported that soils of Baloda series (Typic Chromusterts) contained more 1 N HNO_3 (boiling) extractable K as compared to those of Kamliakheri series (Vertic Ustochrepts).

Subba Rao and Sekhon (1988) subjected seven benchmark soil series from the States of Rajasthan (Masitawali), Gujarat (Pithvajal and Mazodar), Maharashtra (Shendvade and Kumbhave 5) and Madhya Pradesh (Sarol and Kamliakheri) for determination of K status and reported that soils of Masitawali (alluvial) and Shendvade (swell-shrink) were high in non-exchangeable or reserve K (HNO_3 soluble), while all others were low. The proportion of non-exchangeable to exchangeable form of K was relatively greater in soils dominated by illite and illite smectite in comparison to those rich in smectite alone.

Talele et al. (1992^a) studied various forms of K in soils of Maharashtra occurring under different agro-climatic zones showed a large variation. It was found to vary from 268 mg kg^{-1} in Kandegaon soil to 900 mg kg^{-1} in Shendvade soil series with a mean value of 686 mg kg^{-1}. The mean non-exchangeable K content of soils from different agro-climatic zones varied from 450 mg kg^{-1} in zone II (transition zone) to 793 mg kg^{-1} in soils of zone IV A (assured rainfall zone). The non-exchangeable K content constituted about 6.9 to 17.3 per cent of the total K of soils with a mean value of 11.6 per cent (Patil, 1992).

2.1.4 Lattice K

The lattice K is present in the unweathered K bearing primary minerals and is released at an extremely slow rate (Arnon, 1974). Lattice K varied from 2053 to 7509 mg kg^{-1} with a mean value of 5216 mg kg^{-1} in swell-shrink soils of Maharashtra under various agro-climatic zones. Its contribution towards total K was 83 per cent. The highest contribution of lattice K was recorded in Vadgaonamli soil series (89.6 per cent), while its lowest contribution towards total K (74.3 per cent) was recorded in Dholwad soil series (Patil, 1992). The total K content of swell-shrink soils of Maharashtra ranged from 2688 mg kg^{-1} in a soil from Wadgaon series to 8813 mg kg^{-1} in Shendvade soil series. The mean total K ranged from a minimum of 2688 mg kg^{-1} in zone II (transition zone) to a maximum of 7563 mg kg^{-1} in zone IV A (assured rainfall) with a mean value of 6188 mg kg^{-1}.

2.1.5 Total K

Prasad et al. (1967) found that the sand and silt fractions contributed more towards total K content than clay. Misra and Shankar (1970) and Mehrotra and Singh (1970) in their studies on soils of different broad groups of Uttar Pradesh found that the total K content varied from 1.74 to 2.29 per cent. The total K content of important soils of different agro-climatic zones of Maharashtra State varied from 1250 to 20000 ppm with an average value of 6878 ppm (Kadrekar, 1970 and Kadrekar and Kibe, 1972).

Yuan et al. (1976) from their studies on Paleudult soils in lower coastal plain concluded that a total K content varied from 1500 to 2800 kg ha^{-1} in each 15 cm thickness of soil sampled throughout the profile. There is marked variation in total K content of the different soil groups in the State of Tamil Nadu. Total K ranged from 0.05 to 1.32 per cent (Krishnamoorthy et al., 1976). The black soils of Tungabhadra catchment on an average contained 913 mg of total K 100 g^{-1} of soil (Kalbande and Swamynatha, 1976).

Singh and Datta (1986) reported that the total K ranged between 1.96 to 3.84 per cent, with a mean value of 2.7 per cent in the soils of Mizoram. The high value of K may be attributed to the dominance of K bearing minerals. Vijay Kumar et al. (1986) studied the distribution of different forms of K and reported that total K varied from 38.41

to 52.81 me 100 g^{-1} soil. Chamuah (1987) analysed rice soils and observed that the total K content ranged from 1.12 per cent in surface soils to a maximum of 2.4 per cent in subsoils, with a mean value of 1.86 per cent. Total K content increased with depth in all the soil profiles. Sharma and Dubey (1988) studied the K status of Vertisols and associated soils in a toposequence and reported that the total K content in these soils ranged from 1115 to 1355 ppm. Solankey et al. (1988) studied the distribution of different fractions in two swell-shrink soil series of Madhya Pradesh and reported that the mean total K content of Baloda series (Typic Chromusterts) was 20.13 me 100 g^{-1} and that of Kamliakheri series (Vertic Ustochrepts), it was 15.7 me 100 g^{-1} soil.

Sekhon (1990) summarised the total, non-exchangeable and exchangeable K in selected alluvial, black, red and laterite soils. Accordingly, total, non-exchangeable and exchangeable K were low in laterite and some red and acid alluvial soils where kaolinite was the dominant clay mineral and quartz was the dominant mineral in the silt fraction. The total K in black soils ranged from 0.53 to 2.45 per cent. Talele et al. (1992^a) assessed various forms of K in soils of Maharashtra occurring under different agro-climatic zones and revealed that total K ranged from 635 to 1432 mg 100 g^{-1}. Tiwari and Bansal (1992) studied vertical distribution of forms of K in some soil series of northern Madhya Pradesh and no definite distribution pattern of reserve and total K was found in Bagwai series of Vertisols but in Jhadoli series reserve K decreased with depth. In two series of alluvial soils reserve K was the lowest in surface soils and increased with depth up to 150 cm. Reserve K indicated very high positive relationship with exchangeable K in three series.

2.2 Q/I Relationship of Potassium in Soil

A significant contribution was made by Woodruff (1955) who classified the soils on the free energy of exchange for K. Beckett (1964^b) suggested that the linear part of Q/I curve was associated with exchange of K on planner sites and the curved part was due to edge and inter-lattice sites. Buffering capacity values have been used with different interpretations. Beckett (1964^b) and Beckett and Nafady (1967) defined the main potential buffering capacity as the slope of the linear section of the Q/I curve. However, this value could not be calculated with curved relationship. In view of this, Ramamoorthy and Paliwal (1965) determined the equilibrium K activity ratio with a mean value of 0.00308 for wheat, 0.00171 for paddy, 0.0145 for maize and 0.0209 for pearl millet and 0.0282 $(\text{mol L}^{-1})^{\frac{1}{2}}$ for tobacco.

The concept of chemical potential in soil was employed for K by several investigators (Acquaye et al, 1967 & Singh and Jones, 1975). The potash potential indicated the energy status of K in soils (Addiscott, 1970). A comprehensive review on potash potential was presented by Beckett (1972).

The quantity-intensity (Q/I) buffer curves measured these parameters (Beckett, 1971 and 1972). It is a better index of K supplying power of soils to crops. The rate of release of K from non-exchangeable portion decides the adequate supply of K to crops which have high demand for K. Potash potentials ranging from 2500 to 3500 cal $M^{-1}d^{-1}$ were considered adequate for many crops (Singh and Jones, 1975). Higher values were associated with K deficiency, while the lower values were associated with excessive supply of K. Soil with high potash potential responded to K dressings.

Ramakrishnayya and Chatterjee (1976) measured Q/I relation of a large number of soils and recorded low ionic activity ratios in respect of K in black soils dominated by smectite group of clay minerals as compared to the red soils indicating poor availability of K relative to other cations mainly Ca^{2+} and Mg^{2+}. The PBC^{K} values were very high for black soils. According to them, due to high PBC^{K} and low ΔK and AR_{o}^{K} values, the black soils were unfavourable to potash application. Low AR_{e}^{K} values were also reported for black soils by Balasundaram (1977). Sen Gupta and Das (1977) in their studies on K potential and Q/I relationship of soils of West Bengal in relation to their clay mineralogy noted that Q/I relationship was quite distinct for each group of soils. The smectite clays adsorbed more K ions as compared to the illite and kaolinite clays for the same activity ratios. The Q/I relationship in a soil can be used as an index of K supplying power of soil (Chatterjee et al., 1983; Pati Ram and Prasad, 1983^{a}, 1983^{b}; Sen Gupta, 1980).

Equilibration of eleven soils in 0.002 M $CaCl_2$ containing different amounts of KCl gave activity ratios (AR_e^K) which showed a higher degree of correlation with the portion of K uptake derived from the exchangeable form than with the total K uptake by plants (Acquaye and MacLean, 1966). The AR_e^K values together with estimates of the quantities of K released ($-\Delta K_o$) as obtained from equilibration curves were found to be much more indicative of the total K uptake than were the AR_e^K values only. The ratio $-\Delta K_o/AR_e^K$ or potential buffering capacity (PBC^K), showed some relation to the amount of non-exchangeable K which was an important source of K in most of the soils.

Panda (1978) determined K dynamics in Indian laterite soils and results revealed that K_o, AR_e^K, PBC^K, $-\Delta G^0$ ranged from 5.0 to 17.6 X 10^{-2} me 100 g^{-1}, 0.13 X 10^{-3} to 1.4 X 10^{-3} $(ML^{-1})^{\frac{1}{2}}$, 16 to 92 me 100 $g^{-1}/(ML^{-1})^{\frac{1}{2}}$ and -4092 to -2417 cal $M^{-1}d^{-1}$, respectively. Labile K was found to be the best index of K availability.

Bijay Singh et al. (1981) studied Q/I relations of K and response of wheat to potash fertilizer in illitic soils and the results revealed that the activity ratio was more closely correlated with yield response to K fertilizer than exchangeable K and suggested that the latter quantity was not necessarily a good index of K obtained by crops over a period of time or from different soils.

According to Maji and Sen Gupta (1982) activity ratio was in general high in soils having pH in the acid range. It was low in soils having pH above 7.1, all being above K threshold value. Presence of smectite as a major clay mineral constituent of soils was responsible for high K buffering capacity; low soil pH was associated with low K buffering capacity. The value of K_L was low in all soils, but decrease of K intensity by depletion was expected to be quicker in the light textured soils. According to Gupta et al. (1983) the labile form in acid soils of Nagaland as obtained from Q/I relationship, was loosely held K being exchanged by calcium ions from colloidal surfaces. The value of K_L estimated for these soils varied from 0.663 to 0.229 me 100 g^{-1}. The equilibrium activity ratio (AR_o^K) varied from 1.38 X 10^{-3} to 24.90 X 10^{-3} (mol $L^{-1})^{\frac{1}{2}}$. The potential buffering capacity of soils ranging from 5.6 to 19.6 me 100 $g^{-1}/(ML^{-1})^{\frac{1}{2}}$ was responsible to maintain AR_o^K, while K was being removed by plant or by leaching. The change in free energy (ΔG)was found to vary from -2188 to -3902 cal $M^{-1}d^{-1}$.

Rani Perumal and Sonar (1987) reported K availability in soils growing sugarcane and found that K_L values ranged from 0.077 to 0.206 me per cent. The equilibrium activity ratio of K varied from 0.65 to 2.10 $(ML^{-1})^{\frac{1}{2}}$ X 10^{-3}, potential buffering capacity from 38 to 191 me per cent $(ML^{-1})^{\frac{1}{2}}$ and equilibrium chemical potential (ΔGK) ranged from -3200 to -3920 cal $M^{-1}d^{-1}$. Singh et al. (1983) observed that the

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equilibrium activity ratio of K in the range of 4.6 to 11.0 X 10^{-3} (mol $L^{-1})^{\frac{1}{2}}$ for some semi-tropical Indian soils which were several fold higher than the theoretical value of 5 X 10^{-4} (mol $L^{-1})^{\frac{1}{2}}$ as reported by Beckett (1972). Chatterjee et al. (1983) evaluated Q/I relation of soil K and reported that PBC^K values were relatively low in the kaolinite dominated soils.

Subba Rao et al. (1984) assessed the Q/I relationship of potassium in important soil groups of Andhra Pradesh and reported that labile K (K_L) constituted only a fraction of the exchangeable K. In soils with high amount of clay and organic carbon, the content of readily available K, as revealed by equilibrium activity ratio (AR_o^K) and change in the energy (ΔG) values was very small. Bolarin et al. (1984) determined Q/I ratios, equilibrium activity ratios and the size of the labile pool for potassium in 12 soil profiles in south-eastern Spain. The rate of release of easily exchangeable K from the solid phase was greatest in Entisols, intermediate in Inceptisols and smallest in Aridisols,adequate plant nutrition in only half of the profiles and were highest in the saline soils.

Bandyopadhyay et al. (1985) studied Q/I relationship in 25 soils from different coastal areas of Orissa and West Bengal. They reported high K supplying capacity of soils from the potential buffering capacity (PBC^K) and change in free energy (ΔG). Tiwari and Dev (1985) reported that the respective Q/I parameters of AR_o^K , PBC^K and K_L were 2.0 to 6.7 X 10^{-3}

$(ML^{-1})^{½}$, 12.4 to 225 me 100 g^{-1} $(ML^{-1})^{½}$ and 0.07 to 8.65 me 100 g^{-1} for the soils growing wheat in the states of Punjab, Haryana, Uttar Pradesh, Bihar, Madhya Pradesh and Rajasthan.

Dhillon et al. (1986) determined K_L, K_o and K_x values in north-west soils of India which ranged from 0.07 to 0.85, 0.06 to 0.36 and 0.01 to 0.55 me K 100 g^{-1}, respectively. The equilibrium activity ratio of potassium varied from 0.40 to 14.72 x 10^{-3} (mol $L^{-1})^{½}$, potential buffering capacity from 9.6 to 720.0 me 100 g^{-1} (mol $L^{-1})^{½}$ and the free energy of K/(Ca + Mg) exchange ranged from -2.54 to -4.71 K cal $M^{-1}d^{-1}$. Yadav (1986) estimated the Q/I relationship of potassium in five broad groups of sugarcane growing soils, and found that labile K (K_L) constituted 12 to 70 per cent of exchangeable fraction. Calcareous (alluvium) and black soils with higher clay and organic matter content and cation exchange capacity (CEC) had small amount of readily available K as revealed by equilibrium activity ratio (AR_o^K) and change in free energy. In soils low in clay, organic carbon and CEC, the long term potassium supplying power was indicated by poor potential buffering capacity.

Patil and Murthy (1986) studied the Q/I relationship of potassium in some soils of Malaprabha River Valley Project area. According to them, black soils showed a greater affinity for K as indicated by the number of specific adsorptive sites (0.23 me 100 g^{-1} soil) in contrast to red soil (0.07 me 100 g^{-1} soil) which might be due to the selective adsorption of K on the wedge zones of clay present in the black soils. In a study on Q/I relationship in some salt affected soils of Haryana, Tewatia et al. (1987) reported that the equilibrium activity ratio (AR_o^K) and labile potassium (K_L) were used as indices of potassium availability to plants. The AR_o^K and K_L ranged from 1.8×10^{-3} to 5.05×10^{-3} $(mol\ L^{-1})^{\frac{1}{2}}$ and 0.13 to 0.65 me 100 g^{-1} for Typic Ustipsamments and Typic Ustochrepts collected from Mohindergarh and Karnal, respectively. The available K was positively and significantly correlated with K_L ($r = 0.985^{**}$) and AR_o^K ($r = 0.910^{*}$) indicating that both these could be better indices of potassium availability.

The Q/I relations of K in thirty soils of Western Uttar Pradesh were made by Sharma and Mishra (1989). The activity ratio of K (AR_e^K) failed to give an index of the available K status of the soils. However, labile pool (K_L) was found to be more in the heavy soils than in the light textured ones. Potential buffering capacity was also higher in the heavy textured soils than in the light textured soils. This indicated that depletion of K on cropping would be faster in light textured soils than in heavy textured ones. Free energy values showed sufficient level of available potassium reserve in these soils. The Q/I parameters of K were determined in the soils of North-western Rajasthan by Mathure et al.

(1988). Activity ratio (AR_e^K) and PBC^K varied from 0.0018 to 0.0220 $(mol\ L^{-1})^{1/2}$, 25.00 to 93.72 me 100 $g^{-1}/(mol\ L^{-1})^{1/2}$. Potassium uptake by wheat was highly correlated with potential buffering capacity, but showed no relationship with $-\Delta K_o$ and exchangeable K. The PBC^K values served as a useful measurement of the soils K buffering capacity. The Q/I relationships of soil potassium were determined in twelve soil series by Subba Rao and Sekhon (1990). The highest buffer capacity values were recorded in smectite dominant black soils followed by illite alluvial soils, while the lowest values were in kaolinite dominant red and lateritic soils. The reverse was the case for equilibrium activity ratios (AR_o^K) of K. In the smectite and illite clay dominant soils, buffer capacity increased with clay content and cation exchange capacity (CEC) and AR_o^K decreased with clay and CEC. At constant K saturation, AR_o^K was higher in kaolinitic than in the other soils.

Dhillon et al. (1990) studied Q/I relationship of potassium in 15 surface samples of benchmark soil series representing red, black and alluvial soils of India and found that equilibrium activity ratio (AR_e^K) was the highest for sand to loam kaolinitic red soils followed by loamy sand to silty clay illitic alluvial and clay loam to silty loam smectite (beidelitic) black soils. The AR_e^K was significantly correlated ($r = 0.95^{**}$) with water soluble K content of the soils. The magnitudes of labile pool of K(K_L)

and K held on non-specific (ΔK_o) and specific (K_x) sites were higher for black soils than for red and alluvial soils. Potassium held on non-specific sites was significantly correlated with exchangeable K ($r = 0.96^{**}$), CEC ($r = 0.92^{**}$) and clay content ($r = 0.83^{**}$) of the soils. Negative values of standard free energy (ΔG) change indicated that the K/(Ca + Mg) exchange in all the soils was spontaneous.

Maji and Chatterjee (1990) measured Q/I relations of soil K by thermodynamic approach and its modifications in four surface soils of India belonging to plinthustalfs, Haplustalfs, Paleusterts and Vertic Ustochrepts soil taxonomial units. Total labile K (K_L), potential buffering capacity (PBC^K) and free energy ($-\Delta G$) values were found to be more in montmorillonite dominated black soils as compared to the illitic red soils but reverse results were observed in the case of AR_e^K values. Potassium quantity-intensity relationship (Q/I) plays an important role in predicting K availability to plants. These relationships for 19 calcareous soils varying in CEC and mineralogical composition were investigated (Al Kanani et al., 1991). The Q/I plots for these calcareous soils were linear in contrast to curvilinear trends observed in non-calcareous soils. Adhikari and Ghosh (1991) stated that the K status and AR_e^K and PBC^K were greatly influenced by both mineralogy and physico-chemical properties of soils.

Patil and Sonar (1992^a) assessed Q/I parameters of soil potassium in some sugarcane growing swell-shrink soils of Maharashtra and revealed that the values of labile potassium (K_L), activity ratio of K at equilibrium (AR_o^K) and potential buffering capacity (PBC^K) of the soils ranged from 0.50 to 1.0 me 100 g^{-1}, 4.2 to 12.2 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$ and 66 to 166 me 100 g^{-1} $(mol\ L^{-1})^{\frac{1}{2}}$, respectively. While the non-specifically adsorbed potassium (K_x) and potassium held at specific sites (K_o) of the soils ranged from 0.10 to 0.24 and 0.40 to 0.84 me 100 g^{-1}, respectively. The change in free energy for potassium ($-\Delta G$) was found to be in the range of 2641 to 3340 cal $M^{-1}d^{-1}$. Labile K showed positive relationship with CEC ($r = 0.546^{**}$).

The PBC^K of the soils showed non-significant positive correlation with clay ($r = 0.479$), organic carbon ($r = 0.354$) and CEC ($r = 0.340$) and negative so with sand ($r = 0.482$). The soil pH had almost no correlation with Q/I parameters. The AR_o^K was found to have no significant correlation with any of the properties studied. On depletion of 0.8 to 6.1 g kg^{-1} K from five micaceous soils of Punjab by growing 18 crops for two months duration, Q/I isotherms were shifted upward (Mukhopadhyay et al., 1992). It caused an increase of 0.16 to 1.36 (mol kg^{-1}) of sites specific for K. The labile potassium and equilibrium activity ratio decreased on cropping. The increased K preference was equivalent to a chemical potential (ΔF) of 2.65 to 4.37 k J mol^{-1}. Results also suggested interlaminar expansion of micaceous minerals making available more at edge-wedge zones to potassium.

Datta and Joshi (1992) determined the Q/I parameters of potassium in the salt affected soils of Western Rajasthan and found that the AR_{o}^{K} for these soils ranged between 2 to 9×10^{-3} (mol $L^{-1})^{\frac{1}{2}}$. The ranges (me kg^{-1}) observed were : 1.1 to 6.0 for K_L, 0.2 to 3.7 for K_o and 0.6 to 2.5 for K_x. The PBC^K and K potential values (me kg^{-1}) (mol $L^{-1})^{\frac{1}{2}}$ showed wide variation from 62 to 725 and 1.3 to 210, respectively. The $-\Delta G$ values were in the range of 2306 to 5110 cal $M^{-1} d^{-1}$ The distribution of different forms and Q/I parameters of potassium in twelve and ten soil profiles, typical of benchmark soils of Haryana and Vertisol ranging of India, respectively had been investigated by Sharma et al. (1992). Although Vertisols had higher exchangeable K, yet these maintained lower equilibrium activity ratio as compared to remaining soils. Ammonium acetate extractable potassium correlated significantly and positively with equilibrium activity ratios, labile K and potential buffering capacities of the soils.

2.3 Potassium Status by Neubauer Technique Method

Gokhale (1954) modified the Neubauer technique for assessing the available K in soils. In this method, rye seedlings were allowed to grow in a small quantity of soil mixed with pure quartz sand for a period of 17 days. The amount of K extracted by the plant roots is considered to be in an available form (Neubauer value). The Neubauer values were shown by subsequent workers to vary according to the nature of the crop and kind of soil. A value of 17 mg of K_2O is considered as the limiting value at or below which the deficiency may occur in the case of rye seedlings. For Scottish soil 20 mg of K was considered as limiting value by Stewert (1929), while a value of 10 mg was considered as adequate for general crops in the case of Indiana soils by Thornton (1931).

Reuther (1941) found that for all but two samples of orchard soils, the Neubauer values exceeded the values of exchangeable K. Reitemeier et al. (1948) obtained some agreement between exchangeable K and Neubauer values, though all the soils studied by them retained residual exchangeable K, after the Neubauer test was concluded. In Indian soils, Sen et al. (1949) found that available K contents (Neubauer value) varied from 1.38 to 30.36 mg 100 g^{-1} soils with an average of 6.45 mg. They observed a close significant correlation between the exchangeable and the available K content, the correlation coefficient being 0.978^{**}. Grewal and Kanwar (1966) observed that available K_2O (Neubauer value) varied from 8.80 to 27.33 mg 100 g^{-1} soil with a mean value of 17.93 mg in the Punjab soils. The available potash constituted only 0.89 per cent of the total K and it was highly correlated with water soluble and exchangeable K_2O.

2.4 Simple Correlations

2.4.1 Correlations among the forms of K and Q/I parameters of soil

Singh et al. (1985) studied the forms of soil potassium in western part of Haryana and found that the NH_4OAc-K was positively correlated with water soluble form ($r = 0.481^{**}$) 1 N HNO_3 extractable ($r = 0.745^{**}$), concentrated HCl soluble ($r = 0.683^{**}$) and total K ($r = 0.522^{**}$). Singh et al. (1986) studied transformation of applied potassium in relation to its availability in calcareous soil and found that positive and significant correlation of water soluble K with exchangeable K ($r = 0.935^{**}$) and with non-exchangeable K ($r = 0.695^{**}$) were obtained at knee high stage. Chandi and Sidhu (1983) investigated that the PBC^K was positively correlated with K_L, K_o, K_x and showed a negative correlation with AR_o^K, whereas K_L was positively correlated with K_o and K_x values.

In a study on Q/I relationship in some salt affected soils of Haryana, Tewatia et al. (1987) reported that the available K was positively and significantly correlated with K_L ($r = 0.985^{**}$) and AR_o^K ($r = 0.910^{**}$) indicating that both these could be better indices of potassium availability. In a study on potassium status of two swell-shrink soil series of Madhya Pradesh, Solankey et al. (1988) reported that available K (NH_4OAc-K) had positive and significant association with 1 N (boiling) HNO_3 soluble fraction ($r = 0.58^{*}$) in Baloda and with both H_2SO_4-K ($r = 0.52^{*}$) and HNO_3-K ($r = 0.60^{*}$) in

Kamliakheri soils. Total K was not significantly correlated with H_2SO_4 or HNO_3 soluble K in either series. In a study on vertical distribution of forms of potassium in some soil profiles of dry farming areas of Saurashtra region in Gujarat, Koria et al. (1989) reported that the exchangeable K was significantly and positively correlated with K fraction soluble in water ($r = 0.702^{**}$) or 1 N HNO_3 ($r = 0.934^{**}$). Similar type of relationship was found between the latter two ($r = 0.816^{**}$). The total K content was not significantly related with either exchangeable or water soluble and HNO_3 soluble K.

According to Prasad and Rokima (1991), water soluble K, exchangeable K and non-exchangeable K were correlated significantly to each other indicating dynamic equilibrium among these forms of K in soil. The NH_4OAc-K was significantly correlated with water soluble K ($r = 0.70^{**}$ to 0.93^{**}) and with HNO_3-K ($r = 0.36$ to 0.93^{**}) in different soil series (Pal and Sekhon, 1991). In a study on potassium status of Antralia and Panchdaria swell-shrink soil series of Madhya Pradesh, Solankey et al. (1991) reported that available K (1 N NH_4OAc extractable) had positive and significant association with total K in Antralia ($r = 0.51^{*}$) and that in Panchdaria ($r = 0.46$) soils, it was nearer to significant level, though not significant. The total K was significantly and positively correlated with 1 N (Cold) H_2SO_4 soluble K ($r = 0.53^{*}$) in the latter series. The 1N HCl soluble K was positive and significantly correlated with both 1 N (boiling) HNO_3 ($r = 0.60^{**}$) and 1 N (Cold) H_2SO_4-K ($r = 0.65^{**}$) in Antralia and with 1 N (cold) H_2SO_4 extractable K ($r = 0.52^{*}$) in Panchdaria.

Patil (1992) studied dynamics of potassium in swell-shrink soils of Maharashtra and found that non-exchangeable K correlated positively and significantly with lattice K ($r = 0.583^{**}$) and total K ($r = 0.642^{**}$). Lattice K showed highly significant and positive relationship with total K ($r = 0.988^{**}$) showing that major portion of total K was in the lattice form. Patil and Sonar (1992)[a] reported significant positive relationships of equilibrium activity ratio (AR_o^K) with labile K (K_L), potassium held at non-specific sites (K_x) and potassium held at specific sites (K_o) in swell-shrink soils. The AR_o^K showed significant but negative relationship with change in free energy ($-\Delta G$). The AR_o^K showed positive but non-significant relationship with K potential. The AR_o^K showed negative and non-significant relationships with PBC^K indicating the limited dependence of AR_o^K on PBC^K. Labile K (K_L) which is a measure of the exchangeable potassium in soils showed significant positive relationships with K_x, K_o and K_p indicating the conformation of equilibrium among the forms of potassium. Soil potassium potential (K_p) also significantly correlated with potential buffering capacity of the soils indicating the dependence of the K_p of soil to supply K to the crops on the PBC^K of soil.

Tiwari and Bansal (1992) studied vertical distribution of forms of potassium in some soil series of northern Madhya Pradesh and found that significant and positive relationship between total K and 1 N HNO_3 soluble K was observed in Bagwai series. However, in Jhadoli (Gralior), Udenkhera (Morena) series, it was positive but non-significant.

Sehgal et al. (1992) studied different forms of K in six profiles developed on granite, gneiss and basalt occupying relatively low and high physiographic positions, revealed that water soluble, exchangeable, HNO_3 -K soluble and mineral forms were interrelated to one another.

In a study on various forms of potassium in soils of Maharashtra occurring under different agro-climatic zones. Talele et al. (1992^a) reported that water soluble K was positively and significantly correlated with exchangeable and non-exchangeable forms of K in the soils ($r = 0.434^*$ and 0.378^*). Positive and highly significant correlations were observed between per cent K saturation and $CaCl_2$ extractable K, exchangeable K and total K ($r = 0.810^{**}$, 0.749^{**}, 0.724^{**}, 0.482^{**}). The correlation of exchangeable K with per cent K saturation, non-exchangeable K and total K were also found to be highly significant ($r = 0.712^{**}$, 0.679^{**} and 0.434^*, respectively). Non-exchangeable K in the soil showed a highly positive significant relationship with K saturation ($r = 0.679^{**}$) and total K (0.646^{**}). Similarly, the total K in the soils showed a positive and significant correlation with $CaCl_2$-K, exchangeable K and non-exchangeable K (r = 0.482^{**}, 0.434^{**} 0.646^{**}, respectively).

Prasad (1992) assessed Q/I parameters and their relations with the forms of K in calcareous soil under various cropping systems and reported that the AR_o exhibited negative and significant correlation with $-\Delta G$ (r = 0.984^{**}) and positive and significant correlation with water soluble K (r = 0.422^{*}) and non-exchangeable K (r = 0.800^{**}). Labile K (K_L) was significantly correlated with PBC^K, $-\Delta G$, water soluble K and exchangeable K. Correlations of $-\Delta G$ were negative and significant with water soluble K (r = -0.632^{**}), exchangeable K (r = -0.416^{*}) and non-exchangeable K (r = -0.825^{**}).

Datta and Joshi (1992) determined the Q/I parameters of potassium in the salt affected soils of Western Rajasthan and found that $-\Delta G$ was negatively related with AR_o^K (r = -0.631^{**}). The K potential was significantly related with K_o and PBC^K (r = 0.834^{**}, 0.904^{**}). The K_o was significantly related positively with PBC^K and K potential (r = $0.632^{**}$and 0.834). There was also positive relationship between PBC^K and K potential (r = 0.904^{**}). The AR_o^K was positively related to K_o (r = 0.502) and negatively with $-\Delta G$(r =-0.631^{**}).

2.4.2 Correlations between forms of K and soil properties

Kadrekar and Kibe (1972) studied soil K forms in relation to agro-climatic conditions in Maharashtra and showed that the available form of potash was highly correlated not only with water soluble and exchangeable forms, but also with the fixed and HCl-soluble forms. The clay fractions of the soil was positively correlated with all the forms of potash, but significantly so with HCl-soluble and fixed forms.

Kalbande and Swamynatha (1976) studied characterization of K in black soils developed on different parent materials in Tungabhadra catchment and showed that positive and highly significant correlation was seen between exchangeable and citric acid soluble K and amount of silt, clay ($r = 0.523^{**}$), pH ($r = 0.993^{**}$) and CEC, whereas water soluble K was found to be independent of these soil factors.

According to Koria et al. (1989), the highly significant values of correlation coefficient of the electrical conductivity with water extractable ($r = 0.952^{**}$), exchangeable ($r = 0.714^{**}$) and HNO_3 soluble ($r = 0.825^{**}$) K. The significantly positive association of lime content with the exchangeable K ($r = 0.422^{**}$) and 1 N HNO_3 (boiling) soluble K ($r=0.412^{**}$) in the soil profiles of dry farming areas of Saurashtra region in Gujarat was observed.

Mishra and Srivastava (1991) studied soil profiles of Garhwal Himalayas and showed that water soluble, exchangeable and available K contents were significantly and positively correlated with organic carbon content, electrical conductance and cation exchange capacity of soil. Non-exchangeable soil K failed to show significant relationship with any of the measured soil properties. Lattice K and total K showed significantly negative correlation with clay content and electrical conductance.

Talele et al. (1992^{a}) studied various forms of potassium in soils of Maharashtra occurring under different agro-climatic zones and found that sand fraction of soil was significantly, but negatively correlated with exchangeable and water soluble fractions of K ($r = -0.405^{*}$, $- 0.598^{**}$). However, it was only the relation between silt and non-exchangeable K that was statistically significant ($r=-0.371^{*}$). The clay fraction of the soil was positively and significantly correlated with water soluble and exchangeable K fraction of soil ($r = 0.535^{**}$ and 0.506^{**}, respectively). It was observed that the exchangeable and water soluble forms of K were positively and significantly correlated with exchangeable Ca ($r = 0.511^{**}$, 0.686^{**}), cation exchange capacity ($r = 0.540^{**}$ 0.676^{**}), pH ($r = 0.448^{**}$, 0.726^{**}) and $CaCO_3$ content ($r = 0.361^{**}$, 0.759^{**}) of the soils.

Patil (1992) studied dynamics of potassium in swell-shrink soils of Maharashtra and found that water soluble K showed significant and negative relationship with silt fraction ($r = -0.456^{*}$) and non-significant relationships with other soil properties. Available K showed non-significant, but positive relationship with sand, silt, soil pH, $CaCO_3$, CEC, exchangeable Ca + Mg and negative but non-significant correlation with clay, silt + clay, EC, organic carbon contents in these soils.

Exchangeable K had significant negative relationship with organic carbon ($r = -0.486^{*}$) and positive, but non-significant relationships with sand, silt, pH, $CaCO_3$, CEC and exchangeable Ca + Mg. Non-exchangeable K showed negative but significant relationship with organic carbon ($r = -0.534^{*}$), while it had poor relationships with rest of the soil properties. Lattice K showed significant negative relationships with clay ($r = -0.527^{*}$), organic carbon ($r = -0.486^{*}$) and CEC ($r = -0.484^{*}$). Total K content in these soils showed similar relationships with clay ($r = -0.547^{*}$), organic carbon ($r = -0.502^{*}$) and CEC ($r = -0.477^{*}$).

2.4.3 Correlations between Q/I parameters and soil properties

Pati Ram and Prasad (1981) studied the Q/I parameters of soil K in 30 samples of East Khashi Hills of Meghalaya and found that the clay content showed significant correlation with K_L and AR_o^K, but percentage organic carbon was not correlated with any of the parameters. The PBC values correlated significantly with CEC and Ca + Mg content of the soils, but did not represent the intensity of K availability.

Dhillon et al. (1986) studied the Q/I relationships of potassium in some soils of North-West India and found that AR_e^K was negatively correlated with clay content. The PBC^K was positively correlated with clay content. The K_L

was significantly correlated with clay, silt, HNO_3 extractable K and fixed K. The K held on non-specific sites (K_o) had a positive relationship with exchangeable K, PBC^K, K_L and clay.

Dhillon et al. (1990) studied quantity-intensity (Q/I) relationship of potassium in 15 surface samples of benchmark soil series representing red, black and alluvial soils of India and found that potassium held on non-specific sites was significantly correlated with exchangeable K ($r = 0.96^{**}$), CEC ($r = - 0.92^{**}$) and clay content ($r = 0.83^{**}$) of the soils. Patil and Sonar (1992[a]) studied the Q/I parameters of soil potassium in some sugarcane growing swell-shrink soils of Maharashtra and found that Labile K showed positive correlation with CEC ($r = 0.546^{*}$).

The distribution of different forms and Q/I parameters of potassium in twelve and ten soil profiles, typical benchmark soils of Haryana and Vertisol regions of India, respectively had been investigated by Sharma et al. (1992). Ammonium acetate extractable potassium correlated significantly and positively with equilibrium activity ratios, labile K and potential buffering capacities of the soils. Datta and Joshi (1992) determined the Q/I parameters of potassium in the salt affected soils of Western Rajasthan and found that the PBC^K values were significantly related with CEC and clay ($r = 0.728^{*}$, 0.677^{**}, respectively) and silt ($r = 0.532^{*}$). The K potential was significantly related with CEC ($r=0.68^{**}$) and clay ($r=0.526^{*}$)

Materials and Methods

3. MATERIALS AND METHODS

3.1 Materials

The work reported in this chapter comprises of

(i) Laboratory studies for the determination of physico-chemical properties, fractionation of different forms of potassium; quantity/ intensity (Q/I) parameters of profile samples of six soil series of the Central Campus Farms, Rahuri, and

(ii) Neubauer technique for studying the dry matter accumulation, concentration and uptake of K by wheat for evaluation of potassium fertility of the soils.

3.1.1 Soil

Profile samples of the major soil orders viz., Vertisols (Nimone and Otur series), Inceptisols (Sawargaon and Dholwad series) and Entisols (Khanapur and Pargaon series) were collected at different depths (0-15, 15-30, 30-45 and 45-60 cm for Vertisols and Inceptisols and 0-15 and 15-30 cm for Entisols) for this investigation, the details of which are given in Table 1.

Collection of soil samples : The soil samples (surface and subsurface) of widely occurring six soil series of the Central Campus Farm, Rahuri were collected during the month of April, 1992. A total of 20 soil samples were collected from the six soil series as per the details given in Table 1.

Table 1. The details of the soil profile samples collected

Soil order	Soil series	Classification	Depth of sample (cm)	Block No./ Survey No.
Vertisol	Nimone	Udic Chromusterts	0-15	D - 93
			15-30	
			30-45	
			45-60	
	Otur	Typic Chromusterts	0-15	A - 68
			15-30	
			30-45	
			45-60	
Inceptisol	Sawargaon	Vertic Ustropepts	0-15	B - 51
			15-30	
			30-45	
			45-60	
	Dholwad	Vertic Ustropepts	0-15	D - 71
			15-30	
			30-45	
			45-60	
Entisol	Khanapur	Tropic Ustorthents	0-15	E -113
			15-30	
	Pargaon	Tropic Lithic Ustorthents	0-15	B - 41
			15-30	

As far as possible, the soil samples were collected from the original locations and fields where the soil series were identified by National Bureau of Soil Survey and Land Use Planning, Nagpur. The details of soil samples collected are given as below.

A spot for profile sampling in the field was selected. After removing dry leaves, stubbles, etc. from the surface, 1 x 1 x 0.6 m pit was dug for Vertisols and Inceptisols, while the pits were dug to a depth of 30 cm for Entisols as the depth of the soils was up to 30 cm. Sufficient soil samples were drawn for different depths separately. The samples were preserved in gunny bags which were lined internally with polythene sheets with proper lables. The samples were transported to the laboratory as soon as possible, air-dried in shade, pounded with wooden mortar-pestle and passed through 2 mm sieve discarding small gravel, but not soil crumbs. After sieving, soils were mixed thoroughly and used for further studies.

The description of the six soil profiles are as given below.

Nimone series :

Nimone series includes deep to very deep, somewhat poorly drained soil occurring on nearly level to very gently slopping midland below foot hills and along local drainage lines or in shallow depressions of undulating topography. These are developed on local alluvium and colluvium from surrounding upland situations with shrinking and swelling properties and developing gilgai microrelief and deep and wide vertical cracks during dry period. These soils have dark greyish brown to very dark greyish brown, silty clay to clay, A 1 horizon grading to yellowish brown to dark yellowish brown, clay in C horizon. Lime in fine to medium soft and hard irregularly rounded masses is disseminated throughout the profile, but increasing along depth. They have been classified as deep black soil in India. The Nimone series comprises members of fine, montmorillonitic, isohyperthermic family of Udic Chromusterts.

Otur series :

Otur series includes deep to very deep moderately chained soils occupying on very gently slopping midlands with slope ranging from 1 to 3 per cent on river terraces. These soils are developed on silty basaltic alluvium. The soil profiles have thick, dark brown, silty clay A1 horizon grading to dark yellowish brown, clay loam to silty clay C horizon. Fine to medium lime nodules are spread throughout the profile increasing with depth. Otur series comprises members of fine, montmorillonitic, isohyperthermic family of Typic Chromusterts.

Sawargaon series :

Sawargaon series includes moderately deep to deep imperfectly drained soils occurring on very gently slopping to nearly level midland with smooth gradients ranging from 1 to 3 per cent. The soils are formed on weathered basaltic rock materials. The soils are in deep regolith having dark greyish brown to very dark greyish brown, silty clay to clay, A horizon overlying dark brown to very dark brown clayey B horizon which is underlain by C Ca horizon of massive unconsolidated matrix of weathered basaltic materials mixed with lime. Vertical cracks 0.5 to 1 cm wide extending from 25 to 30 cm deep appear in March and close after the onset of monsoon. These soils have been classified in India as "Medium Black Soil". Sawargaon series comprises members of fine, montmorillonitic, isohyperthermic family of Vertic Ustropepts.

Dholwad series :

Dholwad series includes deep, moderately drained soils developed on coarse river alluvium of weathered basaltic materials. They occur on gently slopping stream terraces and on natural levels with an average slope ranging from 3 to 5 per cent. Dholwad soils are in deep regolith having dark greyish brown to brown, silty clay loam to silty clay, A horizon underlain by dark brown clay to silty clay, B horizon overlying yellowish brown to dark yellowish brown, gravelly C horizon. Medium to large irregularly rounded lime nodules increase with depth. Cracks appear on the surface during summer. Dholwad series comprises members of fine loamy montmorillonitic, isohyperthermic family of Vertic Ustropepts.

Khanapur series :

Khanapur series includes moderately well chained, shallow highly calcareous soils formed on colluvial hill waste and occurs on gently to moderately slopping uplands of foot hills. They have weakly developed light brownish grey to brown, loam to clay loam, A horizon overlying pale brown to yellowish brown and highly calcareous loamy C horizon. The lime nodules are few to many at the surface but increase along the depth. Khanapur series comprises members of fine loamy, mixed, isohyperthermic family of Tropic Ustorthents.

Pargaon series :

Pargaon series includes well drained, shallow, moderately calcareous soils in thin regolith over partly altered jointed basalt and occur on gently to moderately slopping plateau with 3 to 10 per cent

Table 2. Physico-chemical properties of the surface (0-15 cm) soil samples

Soil property	Soil series					
	Nimone	Otur	Sawargaon	Dholwad	Khanapur	Pargaon
<u>Physical properties</u>						
Sand %	19	15	21	26	35	38
Silt %	25	26	23	24	20	25
Clay %	53	56	53	45	38	32
Textural class	Clayey	Clayey	Clayey	Clayey	Clay loam	Clay loam
<u>Chemical properties</u>						
pH (1:2.5)	8.6	8.7	8.5	8.7	8.3	8.6
EC, mS cm^{-1}	0.29	0.58	0.22	0.46	0.17	0.22
Organic carbon, %	0.36	0.48	0.53	0.30	0.46	0.42
$CaCO_3$, %	19.7	15.0	14.2	18.4	6.1	14.2
Water soluble K, mg kg^{-1}	11.5	22.0	6.0	15.0	10.0	7.5
Exchangeable K, mg kg^{-1}	310	340	270	320	132	96
Non-exchangeable K, mg kg^{-1}	540	580	540	840	260	240
Lattice K, mg kg^{-1}	1538	2058	2584	2825	1798	1656
Total K, mg kg^{-1}	2400	3000	3400	4000	2200	2000
K fixing capacity, %	22	27.57	22.79	12.55	11.80	9.01
CEC, me 100 g^{-1}	45.7	55	52.9	44.9	39.6	32.8
Exchangeable Ca, me 100 g^{-1}	38.8	46.8	44.2	26.4	36.8	25.4
Exchangeable Mg, me 100 g^{-1}	5.2	5.6	5.4	4.4	1.0	5.8
Exchangeable Na, me 100 g^{-1}	0.91	1.73	1.56	2.95	0.47	1.34

slope on higher contours. Brown to dark brown, loam to clay loam, A horizon is underlain by massive unconsolidated C horizon over altered consolidated basalt. The structure development is very weak. Lime is found as fine irregular strongly cemented nodules in A horizon. Pargaon series comprises members of fine loamy, mixed isohyperthermic, Lithic Tropic Ustorthents.

The physico-chemical properties of the six soil profiles used for the present investigation are given in Table 2.

3.2 Experimental

3.2.1 Forms of potassium

3.2.1.1 Water soluble K

Water soluble K was determined in the extract of 1:5 soil : water ratio (Richards, 1968).

3.2.1.2 Exchangeable K

Five gram soil was placed in 50 ml centrifuge tube, 25 ml neutral $\underline{N}$ NH_4OAc was added and the tube was shaken for 10 min. Then it was centrifuged (1000 rpm) and the supernatent liquid was decanted into 100 ml volumetric flask. Three additional extractions were made in the same manner. The combined extracts were diluted to 100 ml with neutral $\underline{N}$ NH_4OAc. The solution was mixed and K was determined by flame photometer. If solid particles appear in the extract, filtration was carried out with Whatman No. 1 filter paper before measuring potassium (Knudsen et al., 1982).

3.2.1.3 Non-exchangeable K

Finely ground 2.5 g soil ($\angle 1$ mm) was taken into a 100 ml Erlenmeyer flask, 25 ml 1 N HNO_3 was added and the flask was placed on a ring stand over a gas burner. After boiling the flame was reduced and the suspension was boiled gently for 10 min (when a large number of samples were to be handled, a heating unit may be employed for this purpose). Then the flask was removed, the contents were filtered receiving the filtrate into a 100 ml volumetric flask. The soil was washed four times with 15 ml portion of 0.1 N HNO_3. The solution was cooled, diluted to volume and mixed thoroughly. Potassium was determined with a flame photometer using appropriate K standards made in the same HNO_3 as in the samples (Wood and De Turk, 1941).

3.2.1.4 Total K

Quantity of 0.5 g soil was placed in a platinum crucible, moistened with a few drops of 18 N H_2SO_4. Then 1 ml $HClO_4$ and 5 ml of 43 % HF were added. The crucible was then about 2/3rd covered with lid and placed on a sand bath or an electric hot plate regulated at 200°C to 225°C, after which the acids were evaporated to dryness. The heating rate was regulated so that a total of 3 treatments and evaporations were given. At last, a few drops of H_2SO_4 were added and the mixture was fumed to drive off chlorides. Then the crucible was cooled and 5 ml of 6 N HCl was added. Then suspension was diluted to 20 ml with water in a crucible and boiled gently on a low flame. The residue was soluble in about 5 min. The solution was transferred to a 100 ml volumetric flask and the determination of K was made directly in the HCl medium on a flame photometer (Jackson, 1973).

3.2.1.5 Lattice K

Lattice K was calculated by the difference between total K and sum of water soluble K, exchangeable K and non-exchangeable K.

3.2.2 Quantity-intensity relationship

The Quantity-intensity (Q/I) parameters were determined by the equilibriation method (Beckett, 1964[a]). Eight solutions containing KCl from 0, 5, 10, 20, 40, 60, 80 and 100 ppm K were prepared in 0.02 M $CaCl_2$.

Procedure :

Five g soil was taken into a 100 ml conical flask followed by 50 ml of 0 to 100 ppm graded K solution in 0.02 M $CaCl_2$ (giving 0, 50, 100, 200, 400, 600, 800 and 1000 ppm per gram soil) and shaken for one hour on reciprocating shaker, filtered through Whatman No. 1 filter paper. The filtrate was analysed for K, Ca + Mg and for electrical conductivity for each suspension. The amounts by which the soil gained or lost K in achieving equilibrium with the final solution, + K in me 100 g^{-1} soil was calculated from the difference between the concentration of the initial and final solution. The AR^K (activity ratio of exchangeable K) was calculated from the compound of the final solution. The exchange isotherm between K and (Ca + Mg) is the Q/I relation for soil K.

K : (Ca + Mg) exchange isotherm

Activity ratio of K (AR^K) = $\dfrac{a_K}{\sqrt{a_{(Ca\ +\ Mg)}}}$

The K : (Ca + Mg) exchange isotherm was measured in soil solution which provided an idea about exchange isotherm between K and (Ca + Mg) when it is measured after equilibriation. Only at equilibrium Schofield ratio law is applicable.

<u>What is AR^K</u> ?

$$AR^K = \frac{a_K}{\sqrt{a_{(Ca\ +\ Mg)}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$A = c \times f \text{ (Debye and Huckel)} \quad \ldots\ldots\ldots \quad (2)$$

where,

a = activity, c = concentration (mol L^{-1}),
f = activity coefficient.

So, equation (1) becomes ---

$$AR^K = \frac{K}{\sqrt{c_{Ca\ +\ Mg}}} \times \frac{f_K}{\sqrt{f_{Ca\ +\ Mg}}} \quad \ldots\ldots\ldots \quad (3)$$

where,

c_K = concentration of K (mol L^{-1}),
$c_{Ca\ +\ Mg}$ = concentration of Ca + Mg (mol L^{-1}),
f_K = activity coefficient of K,
$f_{Ca\ +\ Mg}$ = activity coefficient of Ca + Mg

$$f = \frac{az^2 \sqrt{I}}{I + a^B \sqrt{I}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where,

f = activity coefficient,
a = 0.509 constant at 25°C,
I = Ionic strength, mol L^{-1},
a^B = 1.5 constant.

$$I = \frac{\Sigma cz^2}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where,

c = concentration (mol L^{-1}),
z = valency of ion.

Plotting of Q/I graph :

The Q/I relationship was obtained by plotting AR^K on X axis and $\pm \Delta K$ on Y axis. Various parameters of potassium were determined from the Q/I graph as below.

1. Potential buffering capacity of potassium (PBC^K)

   The slope of the linear part of (dQ/dI) is termed as PBC^K or (K_L/AR_O^K) and is a measure of the availability of soil to maintain AR^K as the labile K quantity is changed. The dQ/dI depends mainly upon the CEC of the soil available for K :Ca + Mg exchange. It also depends upon the pH and per cent saturation of CEC by calcium and magnesium.

2. Potassium held at specific sites ($-\Delta K_O$)

   The - ΔK_O was obtained by extrapolating lower linear portion of Q/I graph. Generally, the values of $\Delta K_O (K_O)$ were less than exchangeable K and is a quantity of K in soil.

3. Potassium held at non-specific sites (K_x)

The K_x was the difference between the intercepts of the linear and curved part of 0 activity ratio. The (K_L- ΔK_o) is the amount of K held at such site which was exchangeable in a standard period of 30/60 minutes at 25°C. The PBC^K and K_x are little affected by the addition of K fertilizer or release and fixation likely to be brought about by normal field K dressings or by 5 to 20 years cropping.

4. Labile K (K_L)

The K_L is generally affected by K removal and additions. Generally, values of K_L (not always) in lower than exchangeable K. The K_L measures the total amount of K in the soil which is exchangeable during equilibriation the values of both K_x and K_L depend upon asymptotic extrapolation.

5. Potassium potential (K_p)

The K_p = (- ΔK_o X PBC^K) was proposed by Zandstra and MacKenzie (1968) to define the Q/I relations in a single parameter.

6. Equilibrium activity ratio of potassium (AR_o^K)

Where K was neither gained nor lost (i.e. ΔK_o) or the value of AR^K at K = 0 of linear portion of the curve.

7. Change in free energy (ΔG)

$$\Delta G = RT \ln \frac{a_K}{\sqrt{a_{Ca + Mg}}} \quad .... \quad (6)$$

OR

$$\Delta G = RT \; 2.303 \log \frac{a_K}{\sqrt{a_{Ca + Mg}}} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

where,

R = Gas constant (cal mol^{-1} d^{-1}) i.e. 1.99,
T = absolute temperature (273 + 27 = 300° A),
a_K = activity of potassium (mol L^{-1}),
$a_{(Ca+Mg)}$ = activity of Ca + Mg (mol L^{-1}).

If, $\frac{a_K}{\sqrt{a_{Ca + Mg}}}$ is considered to be AR_o^K, then the relationship is reduced to :

$$\Delta G = RT \; 2.303 \log AR_o^K \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

By putting the value of R and T at 300° A.

$$\Delta G = 1374.89 \log AR_o^K \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

3.2.3 Neubauer technique

Fifty g soil was thoroughly mixed with 150 g of pure quartz sand (16 mesh) and the mixture was uniformly spread over the bottom of Neubauer dish. Fifty well developed and uniform wheat seeds (Triticum aestivum L.) were dibbled to a depth of 1 cm below the surface in a circular manner in order to ensure even spacing. Sixty ml distilled water was added by means of pipette manipulating it over entire surface to effect even wetting of soil in the dish. The dish along with wet soil was weighed daily and evaporational and transpirational losses of water were made up. In all the dishes, 50 seeds were germinated and the seedlings were harvested after 17 days by uprooting with the root system intact. The seedlings were washed with tap water and then with distilled water and moisture removed with blotting paper. The plant samples were then dried in oven at 60°C to constant weight. The dry matter accumulation was recorded. For plant analysis, plants with roots intact were ground with grinding Wiley Mill and used for analysis of potassium. The experiment was conducted in Completely Randomized Block Design with two replications.

3.3 Methods

3.3.1 Soil analysis

Soil samples were analysed by adopting standard methods of analysis as shown in Table 3.

3.3.2 Plant analysis

Wheat plant samples were dried in an oven at 60°C temperature. The dry samples were cut into small pieces with scissor and these homogeneous samples were used for further analysis. The plant samples were digested with 1:1 proportion of conc. H_2SO_4 and 30 per cent H_2C_2 (Parkinson and Allen, 1975).

The K uptake by wheat plants was calculated from the total dry matter accumulated and K concentration in the plants.

3.4 Statistical Analysis

The data on dry matter accumulation, K concentration and K uptake by wheat from Neubauer technique experiment were analysed statistically as described by Cochran and Cox (1957).

Table 3. Analytical methods used for soil analysis

Soil property	Method used	Reference
Particle size distribution	Hydrometer	Bouyoucos (1962)
Soil pH (1:2.5 soil-water ratio)	Potentiometric	Jackson (1973)
Electrical conductivity	Conductometric	Jackson (1973)
$CaCO_3$	Simple titrimetric	El Mahi et al. (1987)
Organic carbon	Walkley and Black	Jackson (1973)
Available K	Neutral $\underline{N}$ NH_4OAc	Hanway and Heidal (1952)
K fixation capacity	Wetting and drying	Jackson (1973)
CEC	Ammonium acetate	Rhoades (1982)
Water soluble K	1:5 soil water extract	Richards (1968)
Exchangeable K	Neutral $\underline{N}$ NH_4OAc	Knudsen et al. (1982)
Non-exchangeable K	Boiling 1 $\underline{N}$ HNO_3	Wood and De Turk (1941)
Total K	Boiling 1 $\underline{N}$ HNO_3	Jackson (1973)

Simple correlation coefficients were also calculated between forms of K, Q/I relationship of K, physico-chemical properties of the soils, dry matter, K uptake and K concentration.

Results and Discussion

4. RESULTS AND DISCUSSION

The results of the investigation have been presented and discussed in this chapter under the following heads.

4.1 The Physico-Chemical Properties of Important Profiles of Soil Series From Central Campus Farm, Rahuri.

4.2 Depthwise Distribution of Forms of Potassium in Important Soil Series of Central Campus Farm, Rahuri.

4.3 Quantity-Intensity Parameters of Important Soil Series of Central Campus Farm, Rahuri.

4.4 Dry Matter Accumulation, Concentration and Uptake of K by Wheat Grown on Different Soils Under Neubauer Technique.

4.5 Correlation Studies.

4.1 The Physico-Chemical Properties of Important Soil Series of Central Campus Farm, Rahuri.

The data on the mechanical composition, pH, EC, organic carbon, $CaCO_3$, CEC, exchangeable bases and available K in the soils are presented in Table 4.

4.1.1 Mechanical composition

It was observed from the data in Table 4 that the average sand contents varied from 14 per cent in Otur series to as high as 38.5 per cent in Khanapur soil series, while silt contents were found to vary from 20 to 25 per cent in Sawargaon soil series to as high as 25.5 per cent in Khanapur soil series.

The clay content ranged from 31 per cent in Khanapur soil series to 59 per cent in Otur soil series. The variation in clay content of soils may be explained on the basis of mineralogical make up of the parent rocks. Talele (1981) and Patil (1992) also concluded that the soils developed from granites showed a greater predominance of coarse fraction and correspondingly low content of clay. The basalt rock contains a higher proportion of readily weatherable minerals like plagioclase feldspar, olivine and pyroxene which give rise to soils having larger proportion of fine fractions. Mechanical composition of the soil series under investigation indicated that Nimone, Otur, Sawargaon and Dholwad soil series had clayey texture, whereas Pargaon and Khanapur soil series had clay loam texture.

In general, the distribution of clay in surface and subsoils was more or less the same in Nimone, Otur (Vertisols), Sawargaon and Dholwad (Inceptisols) soil series. Vertisols and associated soils are influenced by pedoturbation process and, therefore, showed more or less uniform distribution of clays throughout the profile. The Pargaon and Khanapur soil series had higher content of sand and silt which reflected in the lower content of clay.

4.1.2 Soil reaction (pH)

The data presented in Table 4 revealed that pH values of the surface and subsurface soils varied from 8.2 to 8.7 with a mean of 8.5. The lowest mean pH of 8.3 was observed in

Pargaon soil series and the highest (8.6) in Sawargaon, Dholwad and Khanapur soil series.

In general, the soils were alkaline in reaction. There was no increasing or decreasing trend in pH with the depth of soils. Alkaline pH of these soils also confirmed the basic nature of parent material. Similar observations were also recorded by Subba Rao and Sekhon (1991) and Sharma and Dubey (1988).

4.1.3 Electrical conductivity

Electrical conductivity of these soil series ranged between 0.16 to 0.98 mS cm^{-1} with an average of 0.34 mS cm^{-1} showing the non-saline characteristics of the soils. The lowest EC of 0.17 mS cm^{-1} was observed in Pargaon soil series, while Dholwad soil series recorded the highest EC of 0.70 mS cm^{-1}.

The increasing trend of EC with depth was observed in Sawargaon and Dholwad (Inceptisols) series. A slight decreasing trend in EC of soil with depth was observed in Nimone and Otur (Vertisols) series, while the EC values were more or less the same with depth in Pargaon and Khanapur soil series. The trends observed in EC may be attributed to the impeded drainage conductions of heavy clay soils and clay loam structure of Pargaon and Khanapur soil series.

The higher EC in lower layers in Sawargaon and Dholwad soil series strongly indicated the salt accumulation in subsoil. These observations are in accordance with those of Adinarayana and Subba Rao (1981) and Arnold and Venkateswarlu (1982)

4.1.4 Organic carbon

Organic carbon content of most of the soils studied was low to moderately high with a mean value of 0.48 per cent. The highest organic carbon content was noticed in Sawargaon soil series (0.78 %), while Dholwad soil series was lowest in organic carbon content (0.30 %). Organic carbon content showed more or less an increasing trend with depth in Nimone, Otur, Sawargaon and Dholwad soil series. However, organic carbon content of surface and subsoil in Pargaon and Khanapur soil series was more or less the same. The differences in management practices and intensity of cropping have contributed for the differential organic carbon content in these soils. The Sawargaon, Nimone, Dholwad and Otur soil series have been put under intensive cropping in comparison with Khanapur and Pargaon soil series.

4.1.5 Calcium carbonate

Most of the soils studied were calcareous (5 to 10 %) to very calcareous (>10 %) in nature (Table 4). The highest $CaCO_3$ content was noticed in Nimone soil series (19.7 %), while the lowest $CaCO_3$ was noticed in Pargaon soil series (5.6%).

In general, $CaCO_3$ content was higher in surface layer of all the soil series which decreased with the depth. Mean $CaCO_3$ content was highest (14.7 %) in Nimone series, while lowest (5.85 %) in Pargaon soil series. The variation in distribution of $CaCO_3$ might be due to variation in rainfall and drainage conditions.

4.1.6 Cation exchange capacity (CEC)

The mean CEC of the 20 soil samples was 44.8 me 100 g^{-1}. The highest CEC of 58.7 me 100 g^{-1} in Otur soil series, whereas the lowest value of 31.8 me 100 g^{-1} in Khanapur soil series was observed. The soils high in clay generally had high CEC content, while Khanapur soil series with a comparatively low clay content had the least CEC. The CEC values were, in general, higher in Otur series followed by Sawargaon and Nimone series than that of Dholwad, Pargaon and the least in Khanapur soil series. The higher CEC values in Otur, Sawargaon and Nimone series might be due to higher content of clay dominated by smectite. It is evident from the data in Table 4 that the CEC values of the soils were in accordance with the clay content. No definite trend of increase or decrease in the CEC was noticed with the depth of the soil series.

4.1.7 Available K

The data on depthwise distribution of available K contents in six profile samples are presented in Table 4.

Mean available K contents of different soil profiles ranged from 87 mg kg^{-1} in Khanapur series to 222 mg kg^{-1} in Dholwad soil series with an overall mean value of 159 mg kg^{-1}. In the surface layer (0-15 cm), the highest available K content was noticed in Otur series (362 mg kg^{-1}) followed by Sawargaon (335 mg kg^{-1}) and Nimone (321 mg kg^{-1}), while the lowest content of available K was observed in Khanapur series (103 mg kg^{-1}). In general, surface soils had appreciably higher amounts of available K, which decreased with the depth of the soil. This may be due to the increased K fixation in subsoil. The higher content of available K in surface soil than that of subsoils might be due to intense weathering and application of potassic fertilizers(Sonar, 1984).

4.1.8 Exchangeable bases

The soil series studied were found to be dominant in calcium content. The mean value was found to be 35.33 me 100 g^{-1} in these soil series. Sawargaon soil series had the highest Ca^{2+} content (44.65 me 100 g^{-1}), while Khanapur soil series had the lowest Ca^{2+} content (27 me 100 g^{-1}). The mean exchangeable Mg^{2+} was also found to be 5 to 18 me 100 g^{-1}. Otur soil series was the highest in mean Mg^{2+} content (12.2 me 100 g^{-1}), while Pargaon soil series had the lowest Mg^{2+} content (1.3 me 100 g^{-1}). The exchangeable Na^{+} was found to vary from 0.45 me 100 g^{-1} in Pargaon soil series to 13.02 me 100 g^{-1} in Dholwad soil series with an overall mean value of 3.33 me 100 g^{-1}. The results showed the dominance of Ca^{2+} on the exchange complex of these soils, the highest being in Sawargaon series (mean 44.65 me 100 g^{-1} soil) followed by Otur (mean 43.4 me 100 g^{-1}) and Nimone (mean 38.25 me 100 g^{-1} soil). This was followed by Mg^{2+} with a range of 1.0 in surface soil of Pargaon series to 18.0 me 100 g^{-1} in 45-60 cm layer of Otur series. The exchangeable Na^+ was comparatively lower in all the soil series except Dholwad series which showed higher proportion in lower layers. However, no specific trend in depthwise distribution of exchangeable bases was observed. The exchangeable potassium status of soils derived from basalt was found to be higher than soils derived from other parent material.

4.1.9 K fixing capacity

The fixation of applied potassium was the highest (28.33 %) in Otur soil series and the lowest (6.25 %) in Khanapur soil series. The mean value was found to be 18.22 per cent in these soil series. In the surface layer (0-15 cm), the highest K fixing capacity was noticed in Otur series (27.57 %) followed by Sawargaon (22.79 %) and Nimone (22.0 %), while the lowest content was observed in Khanapur series (9.01 %). In general, the increasing trend of K fixing capacity with depth was observed in Sawargaon (Inceptisol) series. The decreasing trend of K fixing capacity with depth was observed in Pargaon and Khanapur (Entisols) series, while, K fixing capacity showed more or less an increasing trend with depth in Nimone, Otur and Dholwad soil series. It is evident from the data in Table 4 that K fixing capacity values of the soils were in accordance with the clay content. Similar results were also reported by Chaudhari and Jain (1979) who attributed this to the dominance of vermiculite, illite and montmorillonite minerals to different

Table 4. Physico-chemical properties of important soil series of Central Campus Farm, Rahuri

Soil series	Depth	Mechanical composition				pH	EC	Org.C	$CaCO_3$	CEC	Exch. cations				Avail. K	K fixing capacity
		Sand	Silt	Clay	Texture						Ca	Mg	Na	K		
	cm						mS cm^{-1}	%		me 100 g^{-1}					mg kg^{-1}	%
Nimone	0-15	19	25	53	c	8.6	0.29	0.36	19.7	45.7	38.8	5.2	0.91	0.79	321	22.00
	15-30	19	23	55	c	8.5	0.16	0.47	15.4	45.6	36.4	8.0	0.86	0.29	120	26.35
	30-45	20	22	55	c	8.4	0.17	0.45	14.6	45.1	40.0	4.0	0.80	0.29	116	26.89
	45-60	21	24	52	c	8.3	0.16	0.46	9.2	42.7	37.8	3.8	0.91	0.26	104	20.07
	Mean	19.7	23.5	53.7		8.5	0.20	0.44	14.7	44.8	38.2	5.2	0.84	0.41	165	23.83
Otur	0-15	15	26	56	c	8.7	0.58	0.48	15.0	55.0	46.8	5.6	1.72	0.87	362	27.57
	15-30	15	19	63	c	8.7	0.58	0.71	11.7	63.1	45.6	15.0	2.17	0.34	137	30.05
	30-45	12	29	55	c	8.4	0.25	0.55	11.7	54.4	41.0	10.0	3.52	0.29	117	26.18
	45-60	14	20	62	c	8.2	0.33	0.56	6.0	62.4	40.2	18.0	3.86	0.36	145	29.50
	Mean	14	23.5	59		8.5	0.44	0.58	11.1	58.7	43.4	12.2	2.82	0.47	190	28.33
Sawargaon	0-15	21	23	53	c	8.5	0.22	0.53	14.2	52.9	44.2	5.4	1.56	0.69	276	22.79
	15-30	22	21	54	c	8.5	0.28	0.54	12.0	51.9	46.2	3.6	1.69	0.42	167	25.16
	30-45	22	21	54	c	8.4	0.29	0.56	11.6	51.7	44.4	4.6	2.39	0.31	126	27.88
	45-60	23	16	58	c	8.4	0.59	0.78	6.4	51.4	43.8	5.8	1.47	0.34	136	28.25
	Mean	22	20	55		8.5	0.35	0.60	11.0	52.0	44.6	4.8	1.78	0.44	176	26.02

Table 4 (Contd....)

Soil series	Depth	Mechanical composition				pH	EC	Org.C	$CaCO_3$	CEC	Exch.cations				Avail. K	K fixing capacity
		Sand	Silt	Clay	Texture						Ca	Mg	Na	K		
	cm						mS cm^{-1}	%		me 100 g^{-1}					mg kg^{-1}	%
Dholwad	0-15	26	24	45	c	8.7	0.46	0.30	18.4	44.9	26.4	4.4	2.95	1.15	335	12.55
	15-30	26	24	45	c	8.6	0.45	0.31	17.9	41.0	26.4	1.0	13.04	0.97	189	12.98
	30-45	27	19	50	c	8.5	0.98	0.50	17.8	42.8	20.0	4.2	17.17	0.47	182	17.85
	45-60	27	21	48	c	8.4	0.90	0.47	16.2	40.9	15.6	6.0	18.91	0.47	182	14.10
	Mean	26.5	22	47		8.6	0.70	0.40	17.5	42.4	22.1	3.9	13.02	0.77	222	14.37
Pargaon	0-15	35	20	39	cl	8.3	0.17	0.46	6.1	39.6	36.8	1.0	0.47	0.34	142	11.80
	15-30	36	22	38	cl	8.3	0.16	0.44	5.6	38.6	36.4	1.6	0.42	0.20	84	9.19
	Mean	35.5	21	38.5		8.3	0.17	0.45	5.8	39.1	36.6	1.3	0.45	0.27	113	10.50
Khanapur	0-15	38	25	32	cl	8.6	0.22	0.42	14.2	32.8	25.4	5.8	1.34	0.25	103	9.01
	15-30	39	26	30	cl	8.6	0.19	0.34	14.2	30.8	28.6	1.4	0.69	0.17	71	3.48
	Mean	38.5	25.5	31		8.6	0.21	0.38	14.2	31.8	27.0	3.6	1.02	0.21	87	6.25
Overall mean		25	22.6	47.3		8.5	0.34	0.48	12.4	44.8	35.3	5.18	3.33	0.43	159	18.22

c = Clay, cl = Clay loam.

degrees in these soils. Patil and Sonar (1992^b) reported fixation of 55 to 80 per cent of added K. Talele et al. (1992^b) observed that soils derived from basalt parent material under assured rainfall zone of Maharashtra had higher K fixation capacity.

4.2 Distribution of Various Fractions of Potassium in Soil

4.2.1 Water soluble K

The data on depthwise distribution of water soluble K contents in six soil series are presented in Table 5.

Mean water soluble K contents of different soil series profiles ranged from 4.9 mg kg^{-1} in Sawargaon series to 8.5 mg kg^{-1} in Otur series with an overall mean value of 7.6 mg kg^{-1}. In the surface layer (0-15 cm), the highest water soluble K content was noticed in Otur series (22.0 mg kg^{-1}) followed by Dholwad (15.0 mg kg^{-1}) and Nimone (11.5 mg kg^{-1}), while the lowest water soluble K content was observed in Sawargaon series (6.0 mg kg^{-1}). In general, surface soils had appreciably higher amounts of water soluble K, which decreased with the depth of the soil.

The water soluble K content of the soil contributed to the tune of 0.09 to 0.73 per cent to the total K with a mean value of 0.24 per cent in different soil series indicating its very small contribution.

A higher content of water soluble K in the surface layer of all the soil series is quite likely due to relatively more intense weathering, vegetation, release of labile K from organic residues, application of potassic fertilizers and upward translocation of K from lower depth with capillary rise of ground water. Similar type of distribution of water soluble K was observed in dry farming areas of Saurashtra (Koria et al., 1989), arid tracts of Jodhpur region (Joshi et al., 1988), and different soils of Karnataka (Ranganathan and Satyanarayana, 1980). Talele et al. (1992[a]) and Kadrekar and Kibe (1972) also reported water soluble K contents from 0.05 to 0.19 per cent of total K in the surface soils of different agro-climatic zones of Maharashtra. Singh et al. (1985) and Mishra and Srivastava (1991) also noticed similar observations on water soluble K content in the soils of Western Part of Haryana and Garhwal Himalayas (hill soils), respectively.

4.2.2 Exchangeable K

The data on depthwise distribution of exchangeable K contents in six soil series are presented in Table 5.

Mean exchangeable K contents of different soil series profiles ranged from 81 mg kg^{-1} in Khanapur series to 214 mg kg^{-1} in Dholwad series with an overall mean value of 163.9 mg kg^{-1}. In the surface layer (0-15 cm), the highest exchangeable K content was noticed in Otur series (340 mg kg^{-1} followed by Dholwad (320 mg kg^{-1}) and Nimone (310 mg kg^{-1}), while the lowest content was observed in Khanapur series (96 mg kg^{-1}). In general, surface soils had appreciably higher amounts of exchangeable K, which decreased with the depth of the soil.

The exchangeable K content of soils contributed to the tune of 3.21 to 12.92 per cent to the total K with a mean value of 5.57 per cent in different soil series.

A higher content of exchangeable K in the surface layer of all the soil series is quite likely due to the removal of exchangeable K from the subsoil by plant roots. The addition of K from the surface through plant residues, manures and fertilizers can also result in a preponderance of exchangeable K in surface layers. Similar type of distribution of exchangeable K was observed in soil series of South Kerala (Sudharmai Devi et al., 1990). Talele et al. (1992^a) reported exchangeable K contents from 1.23 to 3.97 per cent of the total K in surface soils of different agro-climatic zones of Maharashtra. In the soils of Maharashtra, the exchangeable K contents varied from 31 to 442 mg kg^{-1} with a mean value of 123 mg kg^{-1} as reported by Kadrekar and Kibe (1972). Singh et al. (1985), Mishra and Srivastava (1991) and Solankey et al. (1988 and 1991) also noticed similar observations on exchangeable K content in soils of Western part of Haryana, Garhwal Himalayas (hill soils) and Antralia and Panchdaria swell-shrink soil series of Madhya Pradesh, respectively.

4.2.3 Non-exchangeable K

The data on depthwise distribution of non-exchangeable K contents in six soil series are presented in Table 5.

Mean non-exchangeable K contents of different soil series profiles ranged from 230 mg kg^{-1} in Pargaon and Khanapur series to 635 mg kg^{-1} in Dholwad series with an overall mean value of 441 mg kg^{-1}. In the surface layer (0-15 cm), the highest non-exchangeable K contents were noticed in Dholwad series (840 mg kg^{-1}) followed by Otur (580 mg kg^{-1}) and Nimone and Sawargaon series (540 mg kg^{-1}), while the lowest content was observed in Khanapur series (240 mg kg^{-1}). In general, surface soils had appreciably higher amounts of non-exchangeable K, which decreased with the depth of the soil.

The non-exchangeable K content of soils contributed to the tune of 9.09 to 24.0 per cent of the total K with a mean value of 15.0 per cent in different soil series. The non-exchangeable K contents were comparatively higher in Dholwad soil series, while the lower values were observed in Pargaon and Khanapur soil series. A higher content of non-exchangeable K in the surface layer of all the soil series is obvious because of more weathering, vegetation, application of K fertilizers, which may result in further potassiation of smectite to illites. Similar type of distribution of non-exchangeable K was observed in South-Eastern Rajasthan (Sehgal et al., 1992) and arid tracts of Jodhpur region (Joshi et al., 1978). Sudharmai Devi et al. (1990) also noticed similar observations on non-exchangeable K content in soil series of South Kerala.

Talele et al. (1992[a]) and Patil (1992) also reported non-exchangeable K contents from 2.06 to 17.3 per cent of the total K in the surface soils of different agro-climatic zones of Maharashtra. However, Dhillon et al. (1985) and Subba Rao and Sekhon (1990) ascribed the lower content of 1 N HNO_3-K in surface soils to the release of non-exchangeable K to compensate the loss of water soluble and exchangeable K due to uptake by crop plants and leaching losses.

4.2.4 Lattice K

The data on depthwise distribution of lattice K contents in six profile samples are presented in Table 5.

Mean lattice or mineral K contents of different soil series profiles ranged from 1494 mg kg^{-1} in Nimone series to 3342 mg kg^{-1} in Dholwad series with an overall mean value of 2327 mg kg^{-1}. The variation in lattice K content could be attributed to the variability in content as well as degree of weathering of K bearing minerals in these soils. In the surface layer (0-15 cm), highest lattice K content was noticed in Dholwad (2825 mg kg^{-1}), while the lowest content was observed in Khanapur series (1656 mg kg^{-1}). In general, the surface soil of Khanapur series had appreciably higher amounts of lattice K which decreased with the depth of soil. In another soil series profiles, no definite trend was evident regarding the depthwise distribution of lattice K.

The lattice K content of the soils contributed 64.08 to 87.09 per cent to the total K with a mean value of 79.18

per cent in different soil series, indicating its very large contribution. The variation in lattice K could be due to the variability in the contents as well as degree of weathering of K bearing minerals in soil. Similar type of distribution of lattice K was observed in Garhwal Himalayas (hill soils) by Mishra and Srivastava (1991). Patil (1992) reported lattice K contents to the extent of 83 per cent of total K followed by non-exchangeable K (12 per cent), exchangeable K (5 per cent) and water soluble K (0.2 per cent), in the surface swell-shrink soils of different agro-climatic zones of Maharashtra.

4.2.5 Total K

The data on depthwise distribution of total K contents in six profile samples are presented in Table 5.

Mean total K contents of different soil series profiles ranged from 1900 mg kg^{-1} in Khanapur series to 4200 mg kg^{-1} in Dholwad series with an overall mean value of 2940 mg kg^{-1} in the surface layer (0-15 cm), the highest total K content was noticed in Dholwad series (4000 mg kg^{-1}) followed by Sawargaon (3400 mg kg^{-1}) and Otur (3000 mg kg^{-1}), while the lowest content was observed in Pargaon and Khanapur series (2000 mg kg^{-1}). In general, surface soils of Nimone (2400 mg kg^{-1}), Pargaon (2200 mg kg^{-1}) and Khanapur (2000 mg kg^{-1}) series had appreciably higher amounts of total K which decreased with the depth of the soil. While in Otur, Sawargaon and Dholwad series, there was no consistent trend in its distribution in the different layers.

Table 5. Forms of potassium of important soil series of Central Campus Farm, Rahuri.

Soil series	Depth	Water soluble K		Exchangeable K		Non-exchangeable K		Lattice K		Total K
	cm	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}
imone	0-15	11.5	0.48	310	12.92	540	22.5	1538	64.08	2400
	15-30	6.4	0.36	114	6.33	360	20.0	1320	73.33	1800
	30-45	4.5	0.23	112	5.60	340	17.0	1543	77.15	2000
	45-60	4.0	0.20	100	5.0	320	16.0	1576	76.88	2000
	Mean	6.6	0.32	159	7.76	390	19.0	1494	72.89	2050
tur	0-15	22.0	0.73	340	11.33	580	19.33	2058	68.50	3000
	15-30	5.5	0.28	132	6.60	480	24.0	1382	69.1	2000
	30-45	3.5	0.11	114	3.56	420	13.13	2662	82.19	3200
	45-60	3.0	0.09	142	4.44	420	13.13	2635	82.34	3200
	Mean	8.5	0.30	182	6.39	475	16.67	2184	76.64	2850
Sawargaon	0-15	6.0	0.18	270	7.94	540	15.88	2584	76.00	3400
	15-30	5.0	0.15	162	4.76	480	14.12	2753	80.97	3400
	30-45	4.5	0.12	122	3.21	460	12.11	3213	84.55	3800
	45-60	4.0	0.11	132	3.67	420	11.67	3044	84.50	3600
	Mean	4.9	0.14	171	4.83	475	13.38	2898	81.65	3550

Table 5 (Contd...)

Soil series	Depth	Water soluble K		Exchangeable K		Non-exchangeable K		Lattice K		Total K
	cm	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}
Dholwad	0-15	15.0	0.38	320	8.00	840	21.00	2825	70.63	4000
	15-30	9.0	0.23	180	4.50	700	17.50	3111	77.78	4000
	30-45	4.50	0.10	178	3.87	500	10.87	3917	85.15	4600
	45-60	4.0	0.10	178	4.24	500	11.90	3518	83.76	4200
	Mean	8.1	0.19	214	5.10	635	15.12	3342	79.59	4200
Pargaon	0-15	10.0	0.45	132	6.00	260	11.82	1798	81.73	2200
	15-30	6.0	0.27	78	3.55	200	9.09	1916	87.09	2200
	Mean	8.0	0.36	105	4.77	230	10.45	1857	84.41	2200
Khanapur	0-15	7.5	0.38	96	4.80	240	12.00	1656	82.80	2000
	15-30	5.0	0.28	66	3.67	220	12.22	1509	83.33	1800
	Mean	6.3	0.33	81	4.26	230	12.11	1582	83.29	1900
Overall mean		7.06	0.24	163.9	5.57	441	15.00	2327	79.18	2940

A wide variation in the total K content of Indian soils was observed by many workers (Kadrekar and Kibe, 1972; Gajbhiye, 1985 and Patil, 1992). The values of total K in soil series under investigation were comparatively low when compared with illitic soils of Punjab (Gajbhiye, 1985). The variation in the content of total K was ascribed to the insufficiency of potash bearing minerals like mica and feldspar. The swell-shrink soils of Maharashtra have smectite as a dominant clay minerals with comparatively less content of illite (Subba Rao and Sekhon, 1988), which could be the reason for low total K content as compared to the soils of other states.

The above results thus, showed that lattice K is the major portion (79.18 %) in the total K content of these soils followed by non-exchangeable K (15 %), exchangeable K (5.57 %) and water soluble K (0.24 %).

4.3 Quantity-Intensity Relationship of K in Soil

The data on Q/I relationship of K in soil are given in Table 6 and graphically shown in Fig. 2 to 14.

The quantity-intensity relationships of K are useful in understanding of the nature of K equilibrium and is a better index of potassium supplying power of soil. The commonly observed form of Q/I relationship consists of two parts, a linear upper part and a curve lower part. The linear part confirms to Gapon type exchange equations and describes

Table 6. Quantity-intensity parameters of important soil series Central Campus Farm, Rahuri

Soil series	Depth	AR^K_o $(ML^{-1})^{\frac{1}{2}}$	K_L	K_x	K_o	K_p	$-\Delta G$ cal.	PBC^K me 100 g^{-1}/
	cm	x 10^{-3}	me 100 g^{-1}		soil		$M^{-1}d^{-1}$	$(ML^{-1})^{\frac{1}{2}}$
Nimone	0-15	20.0	0.88	0.20	0.68	5.43	2335	36
	15-30	6.8	0.40	0.07	0.33	15.64	2984	48
	30-45	8.0	0.40	0.07	0.33	13.20	2883	40
	45-60	6.5	0.39	0.07	0.31	15.02	3007	48
	Mean	10.3	0.52	0.10	0.41	12.32	2802	43
Otur	0-15	20.0	1.25	0.23	1.03	52.53	2335	51
	15-30	6.0	0.60	0.10	0.50	41.66	3054	83
	30-45	5.5	0.43	0.08	0.35	22.27	3106	63
	45-60	6.9	0.53	0.09	0.44	27.93	2975	63
	Mean	9.6	0.70	0.13	0.58	36.10	2867	65
Sawargaon	0-15	12.5	0.85	0.14	0.71	40.61	2662	57
	15-30	9.3	0.68	0.10	0.58	35.74	2796	62
	30-45	5.5	0.45	0.08	0.38	25.56	3106	68
	45-60	4.5	0.55	0.06	0.49	52.81	3226	108
	Mean	8.0	0.63	0.10	0.54	38.68	2947	73.7
Dholwad	0-15	24.3	1.00	0.20	0.80	26.38	2220	32
	15-30	27.5	1.15	0.23	0.93	31.10	2145	33
	30-45	10.0	0.65	0.10	0.55	30.25	2749	55
	45-60	10.5	0.63	0.10	0.53	26.25	2720	50
	Mean	18.1	0.86	0.16	0.70	28.50	2458	42
Pargaon	0-15	12.1	0.70	0.13	0.58	27.32	2635	47
	15-30	6.0	0.35	0.08	0.28	12.60	3054	45
	Mean	9.1	0.53	0.11	0.43	19.96	2844	46
Khanapur	0-15	6.0	0.33	0.06	0.26	11.48	3054	43
	15-30	5.0	0.23	0.06	0.17	5.78	3163	34
	Mean	5.5	0.28	0.06	0.22	8.63	3108	38.5
Overall mean		10.1	0.59	0.13	0.48	24.03	2838	51.46

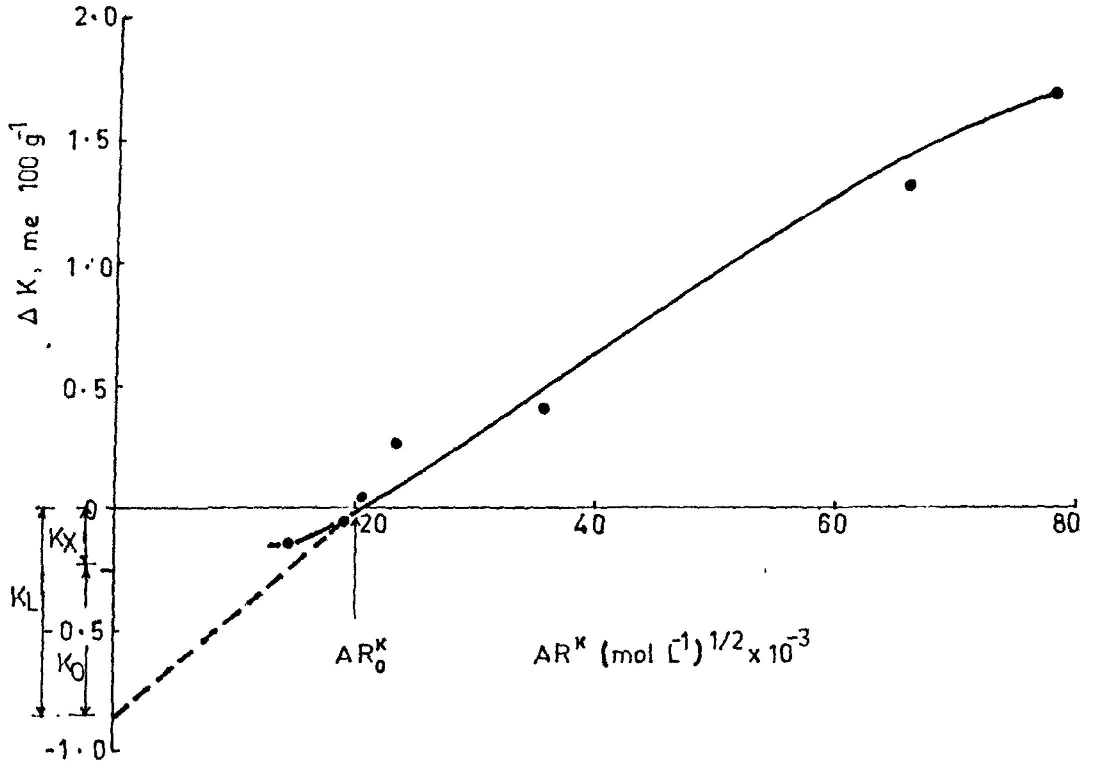

Fig. 2. Quantity-intensity relationship of potassium in Nimone soil series (0-15cm).

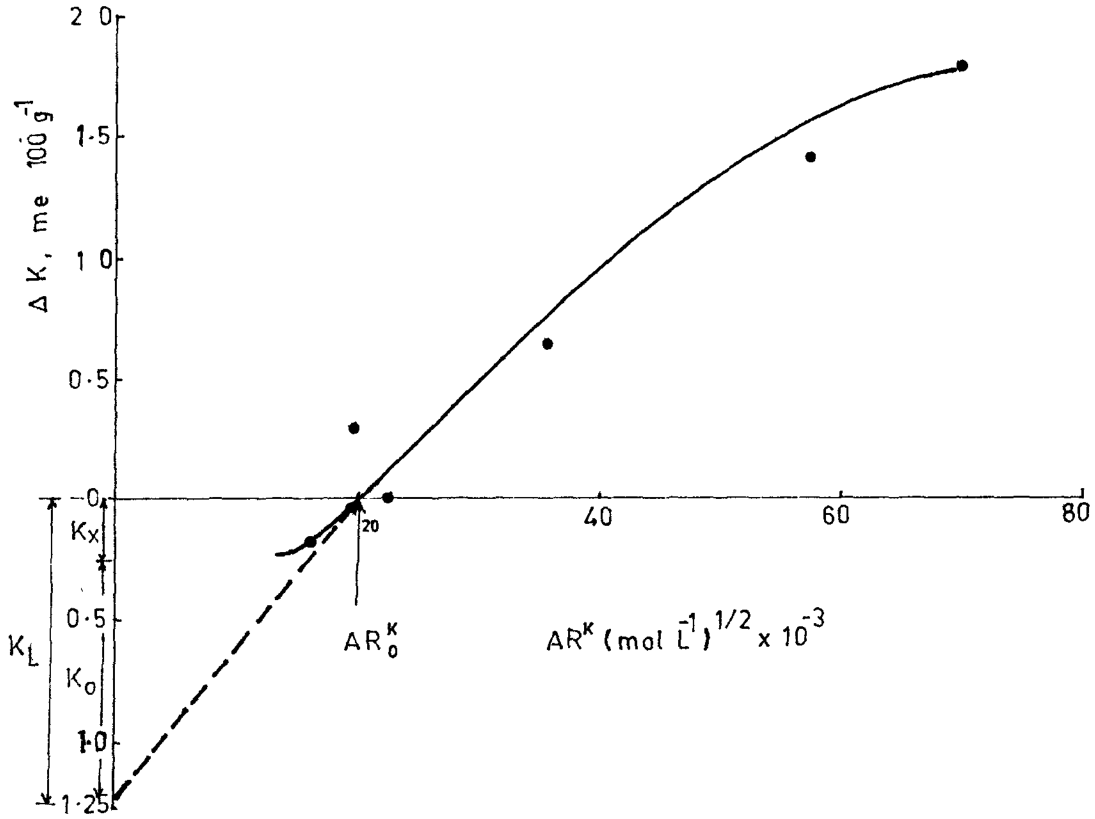

Fig.3. Quantity-intensity relationship of potassium in Otur soil series (0-15cm).

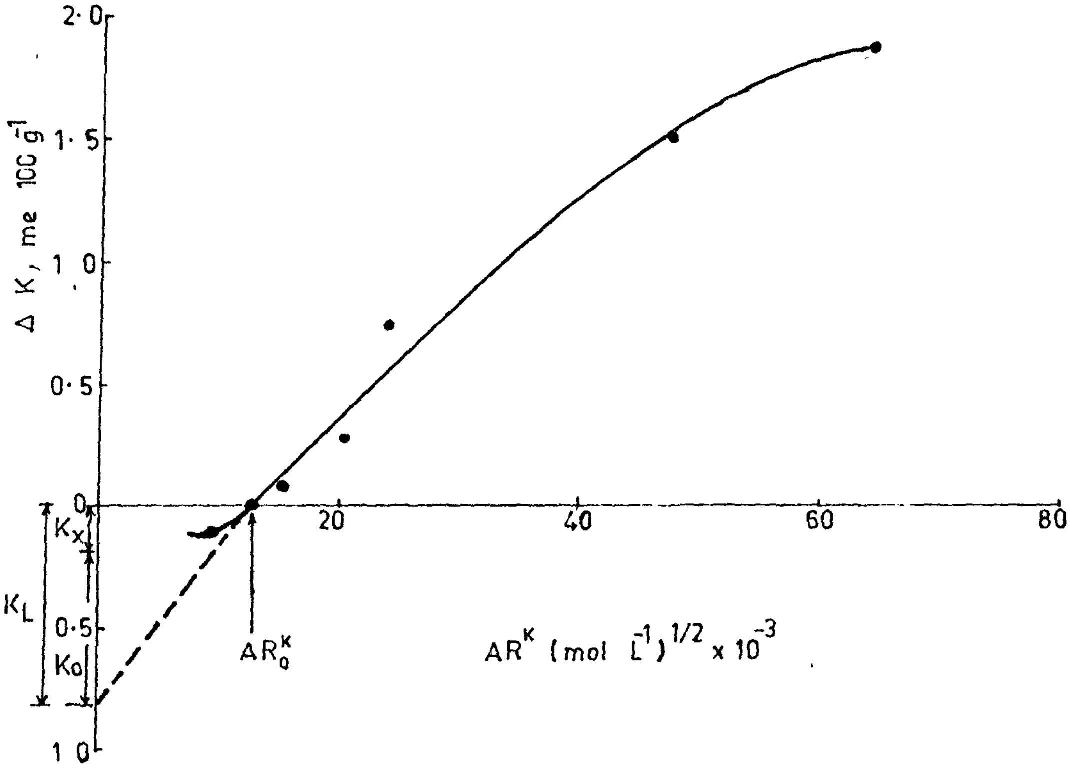

Fig.4. Quantity-intensity relationship of potassium in Sawargaon soil series (0-15 cm).

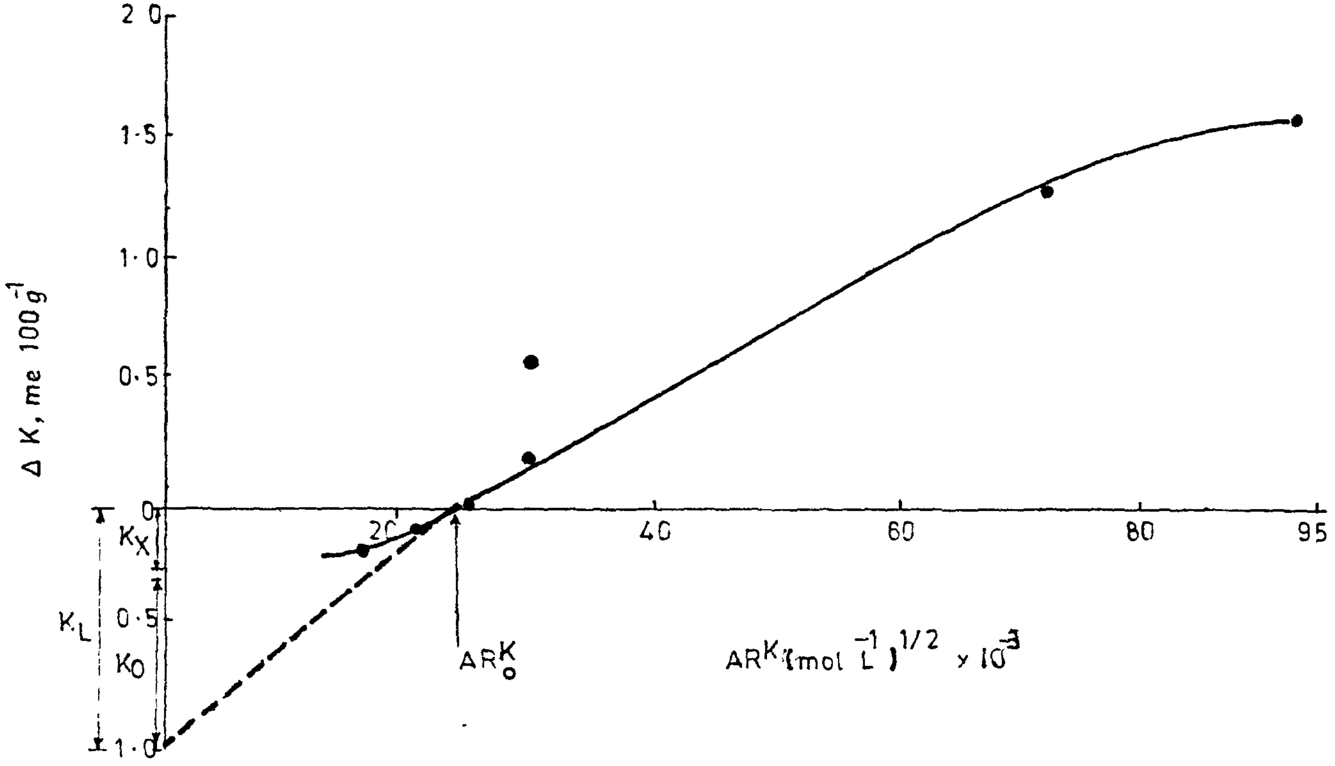

Fig. 5. Quantity-itensity relationship of potassium in Dholwad soil series (0-15 cm).

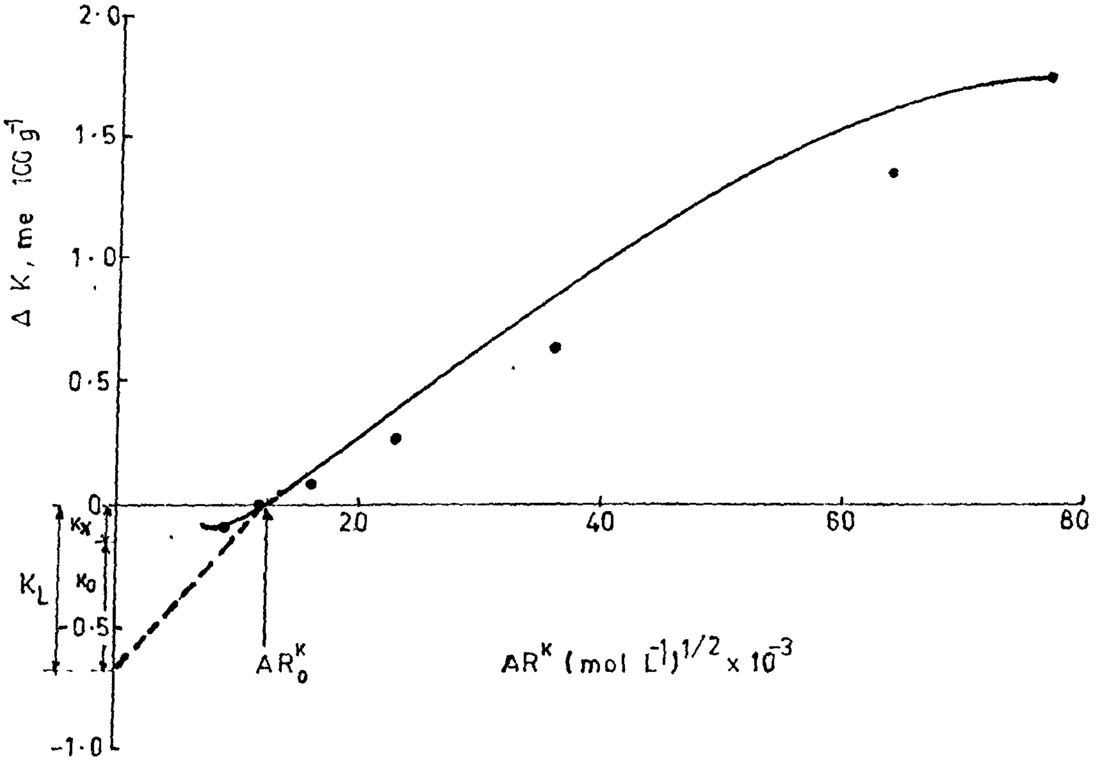

Fig. 6. Quantity- intensity relationship of potassium in Pargaon soil series (0-15 cm).

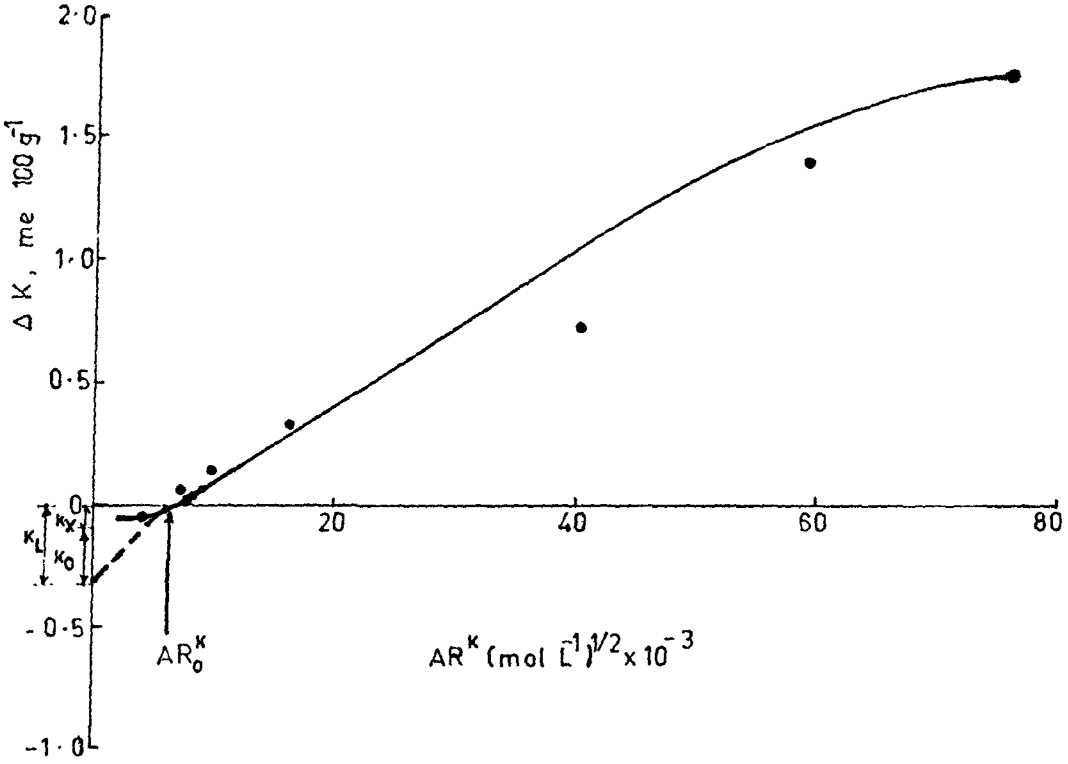

Fig.7. Quantity-intensity relationship of potassium in Khanapur soil series (0-15 cm).

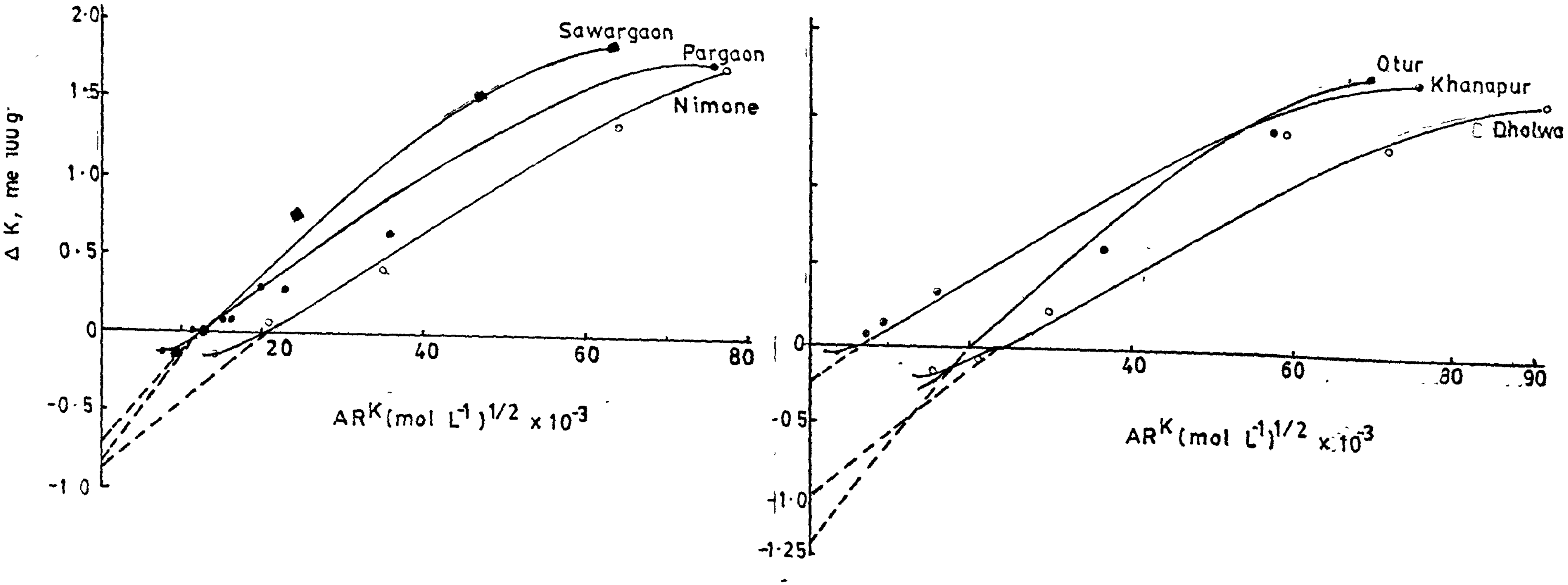

Fig. 8. Quantity-intensity relationship of potassium in different soil series (0-15 cm).

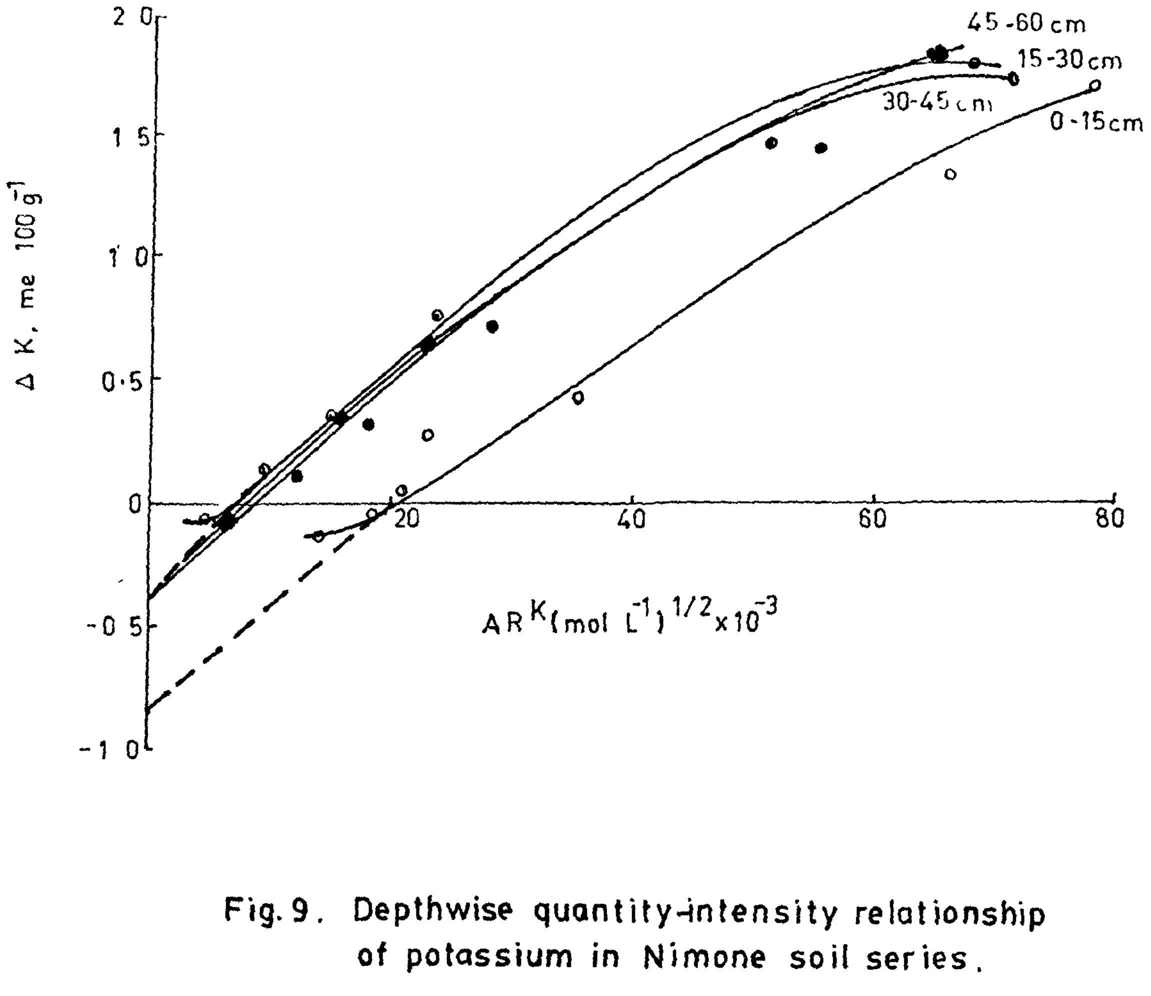

Fig. 9. Depthwise quantity-intensity relationship of potassium in Nimone soil series.

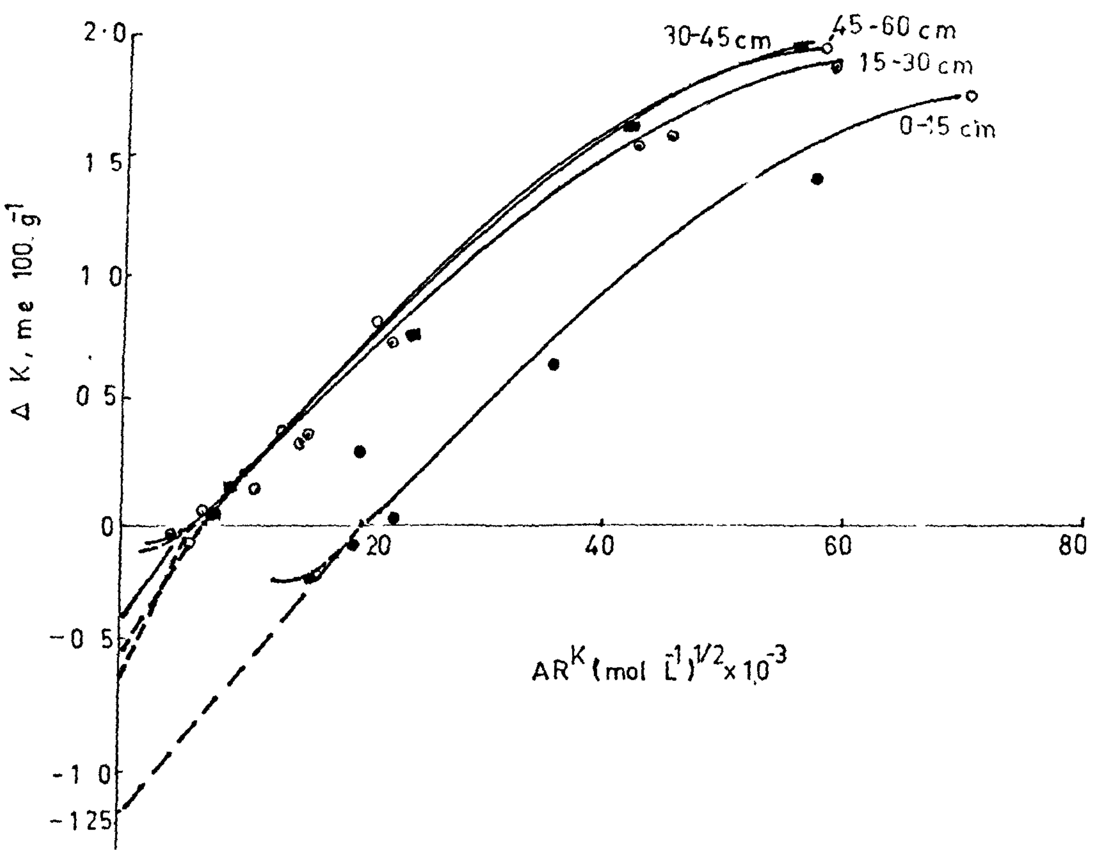

Fig. 10. Depthwise quantity-intensity relationship of potassium in Otur soil series.

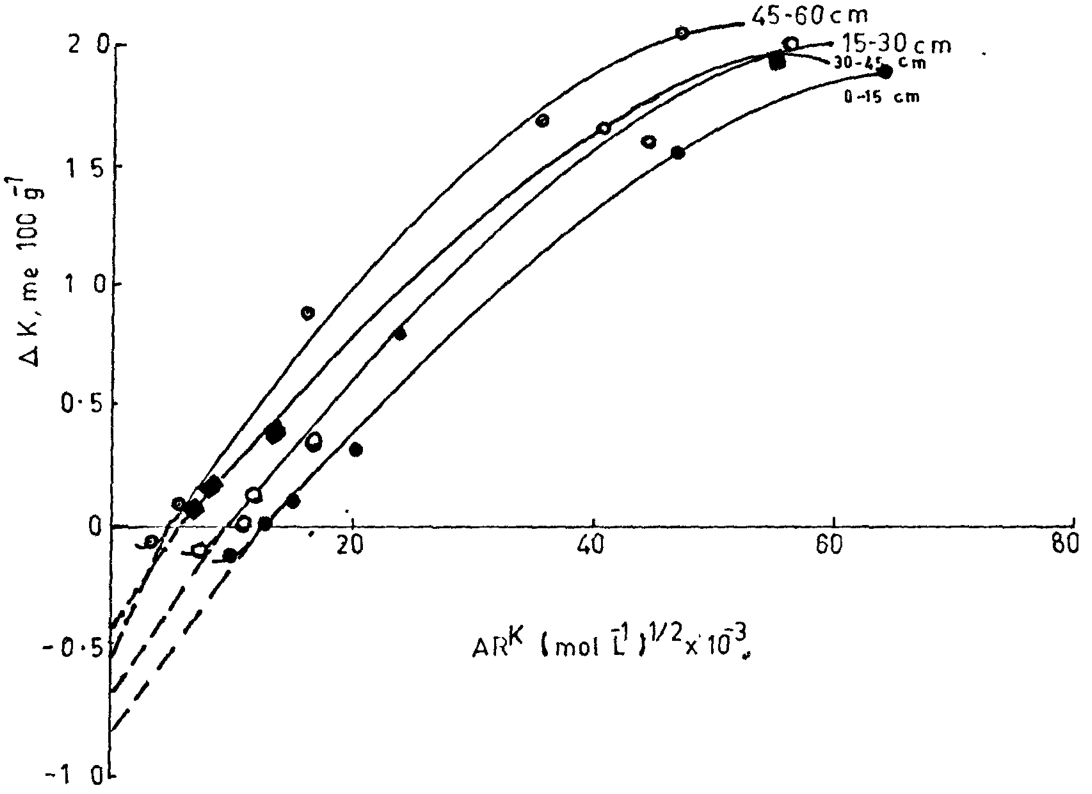

Fig. 11. Depthwise quantity-intensity relationship of potassium in Sawargaon soil series.

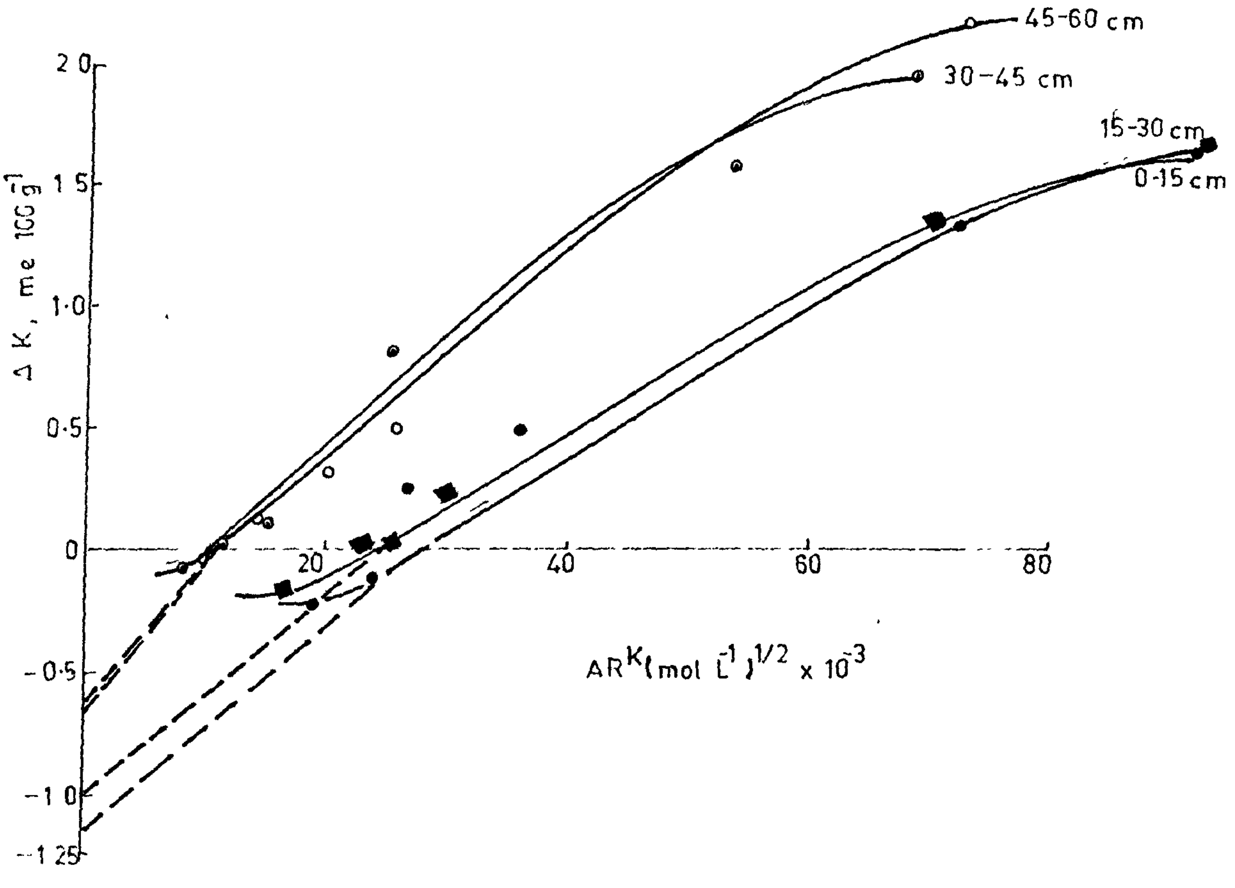

Fig. 12. Depthwise quantity-intensity relationship of potassium in Dholwad soil series.

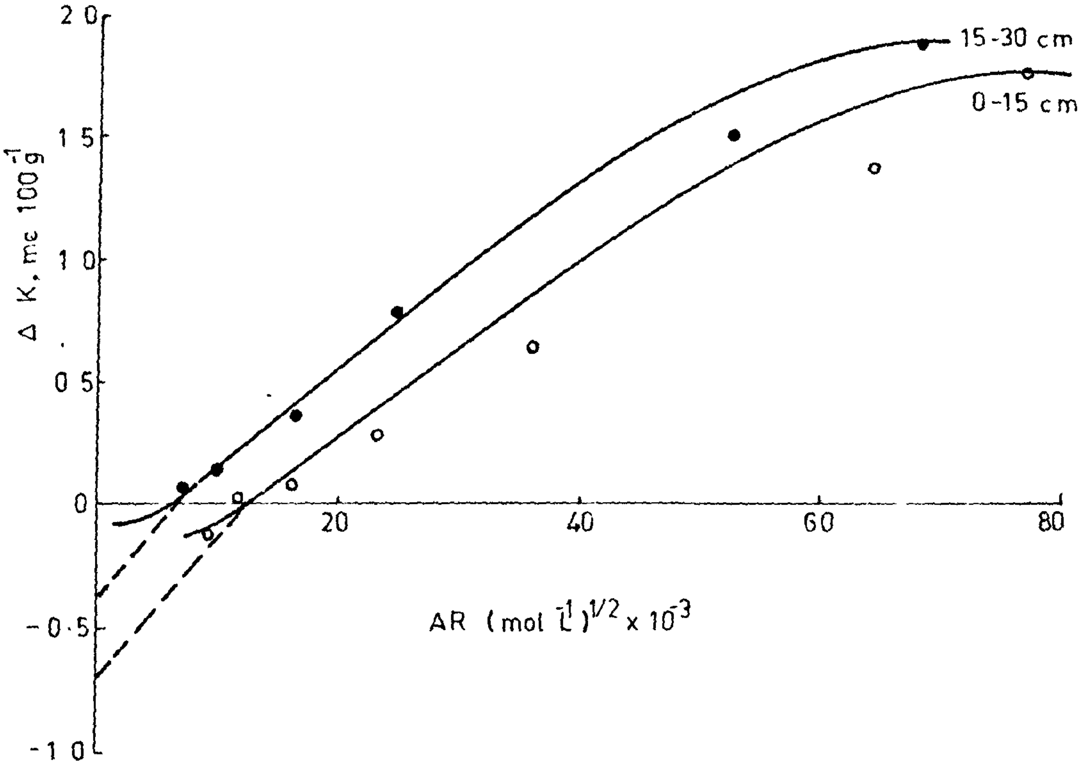

Fig. 13. Depthwise quantity-intensity relationship of potassium in pargaon soil series.

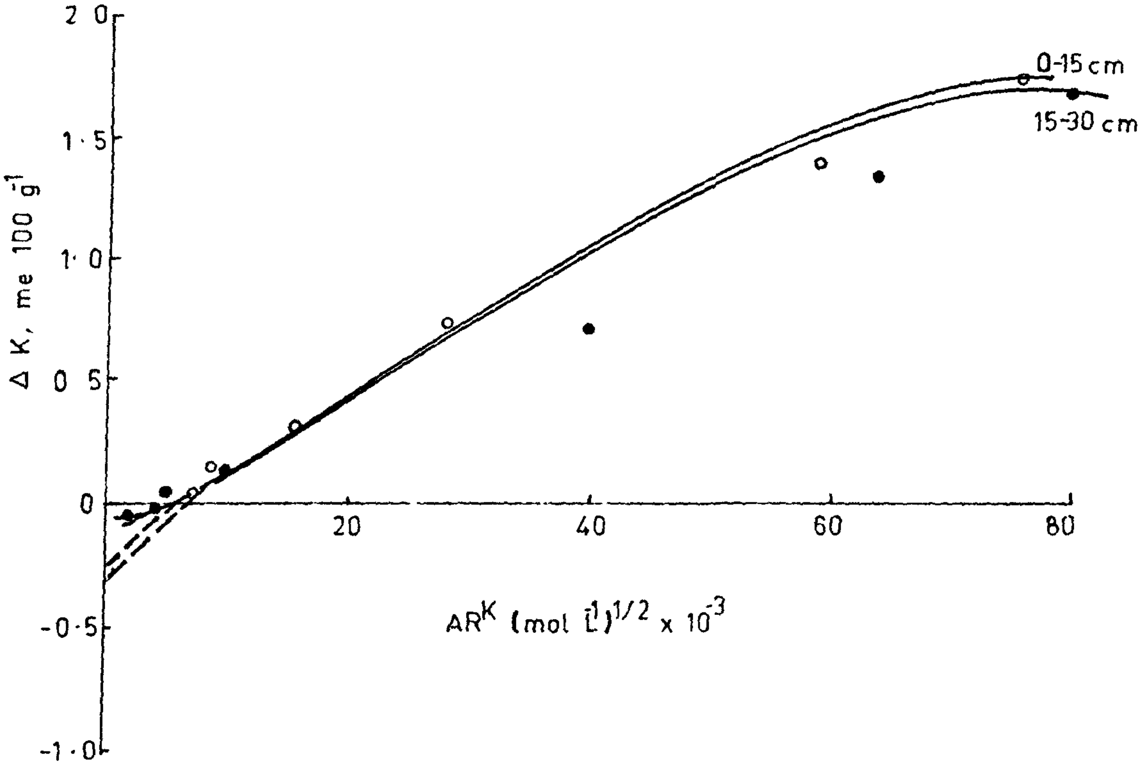

Fig. 14. Depthwise quantity-intensity relationship of potassium in Khanapur soil series.

the rapid non-specific exchange on planner surface of clay minerals (Beckett and Nafady, 1967). The curved part conforms to exchange at sites in the interlayer space of clay minerals. Several workers (Woodruff, 1955; Beckett, 1964^a) suggested that the ability of a soil to provide K to crops and to maintain the supply against depletion is regulated at least in part by the form of its K : (Ca + Mg) exchange isotherms. It is, therefore, useful to look for the relationships between soil properties measured in routine analysis and the Q/I parameters.

The Q/I relationships of soil potassium were determined by following the Beckett (1964^b) technique. From the Q/I curve obtained (Fig. 2 to 14) labile K i.e. the quantity factor (K_L), equilibrium activity ratio of potassium i.e. the intensity factor (AR_o^K), potential buffering capacity of potassium (PBC^K) which is a measure of the availability of soil to maintain activity ratio of K (AR^K) as the labile K quantity is changed, non-specifically adsorbed K (K_x) and K held at specific sites (K_o) were computed and the data on depthwise Q/I parameters in the six soil profile samples are presented in Table 6 and Appendices 1 to 20.

It could be seen from the data presented in Tables 4 and 6 that these soils have different quantities of available K (NH_4OAc-K) and showed wide variation in Q/I parameters indicating the dynamic behaviour of K in soils.

Mean depthwise potassium activity ratio of different soil series ranged from 5.5 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$ in Khanapur series to 18.1 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$ in Dholwad series with an overall mean value of 10.1 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$ indicating a wide variation in intensity of potassium in soil solution at equilibrium. In the surface layer (0-15 cm), the highest AR_{o}^{K} value was noticed in Dholwad series [24.3 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$] followed by Nimone [20.0 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$] and Sawargaon [12.5 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$], while the lowest value was observed in Khanapur series [6.0 $(ML^{-1})^{\frac{1}{2}} \times 10^{-3}$]. This variation in AR_{o}^{K} values might be due to the differences in the clay content of these soils. However, Subba Rao et al. (1984) reported that the black soils having relatively greater amounts of clay and CEC, registered the lowest AR_{o}^{K} values. The Nimone, Otur, Sawargaon and Dholwad soil series had higher clay content and CEC and proportionately gave higher values of AR_{o}^{K} in comparison with Pargaon and Khanapur soil series. Higher values of AR_{o}^{K} in soils may be due to higher ionic strength of K^{+} in comparison to Ca^{2+} and Mg^{2+} ions in the soil solution. The lower values of AR_{o}^{K} in soils might be due to their higher cation retention power, which implies that only a small amount of K would remain in soil solution of these soils. Similar observations were reported by Ghosh and Ghosh (1976), Gupta et al. (1983) and Sharma and Mishra (1989).

Mean PBC^{K} values of different soil series profiles ranged from 38.5 me 100 $g^{-1}/(ML^{-1})^{\frac{1}{2}}$ in Khanapur series to

73.05 me 100 $g^{-1}/(ML^{-1})^{1/2}$ in Sawargaon series with an overall mean value of 51.46 me 100 $g^{-1}/(ML^{-1})^{1/2}$. In the surface layer (0-15 cm), the highest PBC^K value was noticed in Sawargaon series [57 me 100 $g^{-1}/(ML^{-1})^{1/2}$] followed by Otur [51 me 100 $g^{-1}/(ML^{-1})^{1/2}$] and Pargaon [47 me 100 $g^{-1}/(ML^{-1})^{1/2}$], while the lowest value was observed in Dholwad series [32 me 100 $g^{-1}/(ML^{-1})^{1/2}$]. Patil and Sonar (1992^a) reported that the high PBC^K values are indicative of soils less susceptible to changes due to plant uptake and/or depletion. The highest PBC^K value in black soil suggests its higher potential to replenish K in soil solution (Beckett, 1964^b).

Soils with high content of clay and organic carbon, showed higher PBC^K values. Similar type of results were observed in East Khashi Hills of Meghalaya (Pati Ram and Prasad, 1981), representative soils of Andhra Pradesh (Subba Rao et al., 1984), sugarcane growing soils (Yadav, 1986). A wide variation in PBC^K values observed in this study might be largely due to variation in the clay content. Low PBC^K values of soils suggested that the crops grown on these soils respond to potassic fertilizers. It may be inferred that light textured and highly leached soils with inherently low K content would not meet the long term K needs of crops.

Mean labile potassium contents of different soil series profiles ranged from 0.28 me 100 g^{-1} in Khanapur series to 0.86 me 100 g^{-1} in Dholwad series with an overall mean value of 0.59 me 100 g^{-1}. In the surface layer (0-15 cm), the highest K_L values were noticed in Dholwad series (1.00 me 100 g^{-1}) followed by Nimone (0.88 me 100 g^{-1}) and Sawargaon (0.85 me 100 g^{-1}) series, while the lowest values were observed in Khanapur series (0.33 me 100 g^{-1}). Tiwari and Dev (1985) also noticed similar observations in the soils of different states. Labile potassium in soils was almost equal to the exchangeable K. However, Subba Rao et al.(1984) and Pati Ram and Prasad (1981) reported that labile K was much smaller than that of exchangeable K, indicating that only a fraction of the latter is readily replaceable with other cations or available to plant. Labile K (K_L) values represent the amount of potassium which is capable on ion exchange during the period of equilibration period between soil solids and soil solution.

The differences in K_L values in the soil series may be due to variation in the nature and quantity of adsorbed potassium. Soils rich in clay content showed higher K_L values than light textured soils. Higher amounts of exchangeable K might have contributed greater value of labile K in these soils.

Mean values for the potassium held at non-specific sites (K_x) of different soil series profiles ranged from 0.06 me 100 g^{-1} in Khanapur to 0.16 me 100 g^{-1} in Dholwad soil series with an overall mean value of 0.13 me 100 g^{-1}. In the surface layer (0-15 cm), the highest K_x value of 0.23 me 100 g^{-1} was noticed in Otur series followed by Nimone and Dholwad series (0.20 me 100 g^{-1}), while the lowest content was observed in Khanapur series (0.06 me 100 g^{-1}).

Higher K_x values indicate higher exchange surface offering a selective or specific binding for potassium and not for Ca and Mg. It is evident from the data given in Table 6 that heavy soils have higher amount of K_x than the light textured ones. The differences in K_x values among the soils may be due to variation in clay and organic matter content. Patil and Sonar (1992^a) reported K_x values of 0.10 to 0.24 me 100 g^{-1} in Vertisols of Maharashtra. The K_x is the content of exchangeable K associated with specific sites.

The K_o values obtained by extrapolating lower linear portion of Q/I graph is the amount of K held at specific sites and mean K_o values of different soil series profiles ranged from 0.22 me 100 g^{-1} in Khanapur series to 0.70 me 100 g^{-1} in Dholwad soil series with an overall mean value of 0.48 me 100 g^{-1}. In the surface layer (0-15 cm), the highest K_o content was noticed in Otur series (1.03 me 100 g^{-1}) followed by Dholwad (0.80 me 100 g^{-1}) and Sawargaon (0.71 me 100 g^{-1}) and Nimone series (0.68 me 100 g^{-1}). The results thus indicated that K_o values were higher in heavy textured soils than in the light textured ones. The reason for the differences in the K_o values might be due to the nature and quantity of clay minerals present in soil. These results are in agreement with those reported by Patil and Sonar (1992^a) who observed K_o values from 0.40 to 0.80 me 100 g^{-1} in Vertisols of Maharashtra.

The potassium potential (K_p) proposed by Zandstra and Mackenzie (1968) to define Q/I relation (both quantity and intensity) in a single parameter. The mean K_p values of different soil series profiles ranged from 8.63 me 100 g^{-1} in Khanapur series to 38.68 me 100 g^{-1} in Sawargaon series with an overall mean values of 24.03 me 100 g^{-1}. In the surface layer (0-15 cm), the highest K_p values were noticed in Otur series (52.53 me 100 g^{-1}) followed by Sawargaon (40.61 me 100 g^{-1}) and Pargaon (27.32 me 100 g^{-1}), while the lowest values were observed in Nimone series (5.43 me 100 g^{-1}).

Mean energies of replacement ($-\Delta G$ cal $Mol^{-1}d^{-1}$) of Potassium ~~magnesium~~ in different soil series profiles ranged from 2458 cal $M^{-1}d^{-1}$ in Dholwad series to 3108 cal $M^{-1}d^{-1}$ in Khanapur series with an overall mean value of -2838 cal $M^{-1}d^{-1}$. In the surface layer (0-15 cm), the highest value of ΔG was noticed in Khanapur series (-3054 cal M^{-1} d^{-1}) followed by Sawargaon(-2662 cal $M^{-1}d^{-1}$) and Pargaon (-2635 cal $M^{-1}d^{-1}$), while the lowest value was observed in Dholwad series (-2220 cal $M^{-1}d^{-1}$) indicating a suitable balance between exchangeable Ca, Mg and K in these soils. Similar observations were reported by Patil and Sonar (1992a) in the Vertisols of Maharashtra who observed $-\Delta G$ value from 2641 to 3240 cal $M^{-1}d^{-1}$. The $-\Delta G$ values in these soils indicate that there is optimum level of K in soil. According to Woodruff (1955) the $-\Delta G$ values below -3500 cal $M^{-1}d^{-1}$ indicate K deficiency, the values above -2000 cal $M^{-1}d^{-1}$ indicate excess of K and might show Ca deficiency in plant.

From these Q/I parameters inference can be drawn that though these soils have adequate level of available K its peculiar behaviour in the period of actual crop growth may be responsible for the response to application of K fertilizers. These observations are in conformity with those reported by Bandyopadhyay et al. (1985), Subba Rao and Sekhon (1990), Solankey et al. (1991) and Patil and Sonar (1992^a).

4.4 Dry Matter Accumulation, K Concentration and Uptake by Wheat Grown on Different Soils Under Neubauer Technique

The data on depthwise production of dry matter yield of wheat in six soil series are presented in Table 7.

Mean dry matter yield of wheat (<u>Triticum aestivum</u> L.) in different soil series profiles ranged from 1.24 g pot^{-1} in Khanapur series to 1.27 g pot^{-1} in Nimone series with an overall mean value of 1.25 g pot^{-1}. In the surface layer (0-15 cm) the highest dry matter yield of wheat was noticed in Dholwad series (1.28 g pot^{-1}) followed by Sawargaon and Khanapur (1.27 g pot^{-1}) and Nimone series (1.26 g pot^{-1}), while the least dry matter yield was observed in Dholwad series (1.21 g pot^{-1}). The results showed that there was no much variation in dry matter yield of wheat grown on different

Table 7. Dry matter accumulation, K concentration and K uptake by wheat grown on different soils under Neubauer technique

Soil series	Depth (cm)	Dry matter yield (g pot^{-1})	K concentration (%)	K uptake (mg pot^{-1})
Nimone	0-15	1.26	0.738	9.24
	15-30	1.24	0.288	3.61
	30-45	1.30	0.338	4.39
	45-60	1.26	0.213	2.66
	Mean	1.27	0.407	4.98
Otur	0-15	1.24	0.613	7.62
	15-30	1.24	0.363	4.51
	30-45	1.27	0.213	2.71
	45-60	1.24	0.263	3.29
	Mean	1.25	0.363	4.53
Sawargaon	0-15	1.27	0.638	8.11
	15-30	1.24	0.413	5.09
	30-45	1.25	0.213	2.66
	45-60	1.22	0.088	1.07
	Mean	1.25	0.338	4.23
Dholwad	0-15	1.28	0.588	7.50
	15-30	1.21	0.313	3.80
	30-45	1.28	0.263	3.38
	45-60	1.22	0.413	5.01
	Mean	1.25	0.394	4.92
Pargaon	0-15	1.23	0.488	5.96
	15-30	1.29	0.413	5.32
	Mean	1.26	0.451	5.64
Khanapur	0-15	1.27	0.263	3.35
	15-30	1.20	0.163	1.92
	Mean	1.24	0.213	2.63
Overall mean		1.25	0.364	4.56

soil series as well as within the profile of each soil series. In general, the soils rich in available K showed higher dry matter accumulation in wheat plants than the soils with lower available K content. No variation could be seen in dry matter accumulation of wheat probably due to sufficient nutrients in the seed and soil for normal growth of seedling during the period of 17 days. These might be differences in dry matter accumulation of wheat if grown until maturity.

The data on depthwise distribution of concentration of K in wheat plants grown on six soil series are presented in Table 7.

Potassium concentration in wheat plants grown on different soil series revealed that in all the soil series, marginal differences in the K contents of the crop were observed. Mean K concentration of different soil series profiles ranged from 0.213 per cent in Khanapur series to 0.451 per cent in Pargaon series with an overall mean value of 0.364 per cent. Wheat plants grown in surface layer (0-15 cm) of Nimone series showed the highest K concentration (0.738 %) followed by plants grown on Sawargaon (0.638 %) and Otur (0.613 %), while the lowest concentration was observed in plants grown on Khanapur series (0.263 %).

In general, the potassium contents in the plants from the soils which were high in available K levels maintained high K concentration in the plants. Similar type of distribution of K content was observed by Patil (1992) in the case of lucerne. It could be seen from the results in Table 7 that the soils with high content of available K resulted in high concentration of potassium in wheat plants.

The data on depthwise distribution of K uptake in wheat plants grown on six soil series are presented in Table 7.

Mean K uptake by wheat plants grown on different soil series profiles ranged from 2.63 mg pot^{-1} in Khanapur series to 5.64 mg pot^{-1} in Pargaon series with an overall mean value of 4.56 mg pot^{-1}. When wheat was grown on the surface layer (0-15 cm), the highest K uptake was noticed in Nimone series (9.24 mg pot^{-1}) followed by Sawargaon (8.11 mg pot^{-1}) and Otur (7.62 mg pot^{-1}), while the lowest uptake of K was observed in plants grown on Khanapur series (3.35 mg pot^{-1}). It is evident from the data in Table 7 that heavy textured soils resulted in increasing the K uptake by wheat than that of light texture ones.

4.5 Correlation Studies

The interrelationship among different forms of K, Q/I parameters of K, dry matter yield and K uptake by wheat and physico-chemical properties of the soils were studied in order to understand the relationship among the different factors which contribute for K fertility.

4.5.1 Relationship between different forms of potassium in soil

The relationships between the forms of K were worked out and the data are given in Table 8.

Table 8. Correlation coefficient (r) among the forms of potassium in soil

Form of potassium	Form of potassium			
	Exchangeable K	Non-exchangeable K	Lattice K	Total K
Water soluble K	0.750^{**}	0.464^{*}	- 0.201	0.015
Exchangeable K	-	0.788^{**}	0.177	0.413
Non-exchangeable K	-	-	0.493^{*}	0.682^{**}
Lattice K			-	0.958^{**}
Total K				-

Scrutiny of the data revealed that the water soluble K in these soils correlated positively and significantly with exchangeable ($r = 0.750^{**}$) and non-exchangeable K ($r = 0.464^{*}$). The exchangeable K showed positive and significant relationship with non-exchangeable K ($r = 0.788^{**}$) indicating the dynamic equilibrium of these forms in the soils. The data further revealed that the non-exchangeable K showed significant relationship with lattice K ($r = 0.493^{*}$) and total K ($r = 0.682^{**}$). This indicates that there exists an equilibrium between these forms of K.

Lattice K showed significant relationship with total K ($r = 0.958^{**}$) showing that the major portion of total K and non-exchangeable K was in the lattice form. These findings are in conformity with the results reported by Ranganathan and

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Satyanarayana (1980). This suggests that there is a dynamic equilibrium between these forms of soil. Chahal et al. (1976) observed that the water soluble, exchangeable, non-exchangeable and HCl soluble K were significantly interrelated with each other.

These positive and significant associations among the forms of K were indicative of existence of dynamic equilibrium between some forms of potassium. On the other hand, poor degree of correlations of water soluble and exchangeable K with lattice and total K was probably due to lack of sufficient K bearing minerals and less intense weathering in pedogenic environment of these soils might not have brought a larger fraction of K into exchangeable and water soluble forms.

4.5.2 Correlation between forms of potassium and Q/I parameters of soil

The data on correlation coefficients between forms of potassium and Q/I parameters of soil profiles of Central Campus Farm, Rahuri are presented in Table 9.

Water soluble K showed significant positive relationship with AR_0^K, K_L, K_0 ($r = 0.726^{**}$, 0.748^{**}, 0.582^{**}, respectively). It showed significant but negative relationship with change in free energy ($r = -0.723^{**}$). Prasad (1992) reported significant relationship between water soluble K and AR_0^K, K_L. Bhangu and Sidhu (1992) also reported significant relationship between water soluble K and K_L.

Table 9. Correlation coefficient (r) between forms of K and Q/I parameters of soil

Form of potassium	Q/I parameter						
	AR_o^K	K_L	K_x	K_o	K_p	$-\Delta G$	PBC^K
Water soluble K	0.726^{**}	0.748^{**}	0.374	0.582^{**}	0.243	-0.723^{**}	- 0.361
Exchangeable K	0.780^{**}	0.869^{**}	0.532^{**}	0.613^{**}	0.379	-0.815^{**}	- 0.191
Non-exchangeable K	0.779^{**}	0.816^{**}	0.246	0.708^{**}	0.453^{*}	-0.745^{**}	- 0.061
Lattice K	0.143	0.286	-0.175	0.437	0.493^{*}	- 0.143	0.339
Total K	0.373	0.482^{*}	-0.056	0.560^{**}	0.495^{*}	- 0.369	0.193

Exchangeable K showed significant positive relationship with AR_o^K, K_L, K_x and K_o (r = 0.780^{**}, 0.869^{**}, 0.532^{**} and 0.613^{**}, respectively). It showed significant but negative relationship with change in free energy (r = -0.815^{**}). Sharma et al. (1982) reported significant relationship of exchangeable K with AR_o^K and K_L. Prasad (1992), Bhangu and Sidhu (1992) also reported significant relationship between exchangeable K and K_L. Non-exchangeable K showed significant positive relationship with AR_o^K, K_L, K_o and K_p (r = 0.779^{**}, 0.816^{**}, 0.708^{**} and 0.453^{*} , respectively). It showed significant but negative relationship with change in free energy (r = -0.745^{**}). Prasad (1992), and Bhangu and Sidhu (1992) also reported significant relationship between non-exchangeable K and AR_o^K, K_L.

Lattice K showed significant positive relationship with K potential (r = 0.493^{*}). Total K showed significant positive relationship with K_L, and K_p (r = 0.482^{*}, 0.560^{**}, 0.495^{**}, respectively). Bhangu and Sidhu (1992) reported significant relationship between total K and K_L. Patil and Sonar (1992^a) also reported significant relationship between exchangeable K and AR_o^K and K_x as well as between non-exchangeable K and AR_o^K in Vertisols of Maharashtra.

4.5.3 Correlation coefficients among the Q/I parameters of the soils

The correlations among the various Q/I parameters of the soils are presented in Table 10.

Table 10. Correlation coefficient (r) among the Q/I parameters of soil

Q/I Parameter	Q/I Parameter					
	K_L	K_x	K_o	K_p	$-\Delta G$	PBC^K
AR_o^K	0.898^{**}	0.491^{*}	0.673^{**}	0.166	-0.977^{**}	-0.500^{**}
K_L	-	0.447^{*}	0.848^{**}	0.544^{**}	-0.902^{**}	-0.159
K_x		-	-0.074	-0.166	-0.514^{**}	-0.246
K_o			-	0.748^{**}	-0.671^{**}	0.014
K_p				-	-0.162	0.655^{**}
$-\Delta G$					-	0.528^{**}
PBC^K						-

It was observed that equilibrium activity ratio of K (AR_o^K) showed significant positive relationships with K_L ($r = 0.898^{**}$), K_x ($r = 0.491^{*}$) and K_o ($r = 0.673^{**}$). This indicates the existence of equilibrium among the various forms of soil potassium estimated by Q/I parameters. The AR_o^K showed significant but negative relationship with change in free energy ($r = -0.977^{**}$) and PBC^K ($r = -0.500^{*}$) indicating the dependence of potassium exchange on Ca + Mg. The AR_o^K showed positive but non-significant relationship with K_p indicating that availability of K in soil solution was independent of soil K potential.

The K_L which is a measure of the exchangeable K in soils showed significant positive relationship with K_x, K_o

and K_p ($r = 0.447^{*}$, $r = 0.848^{**}$ and $r = 0.544^{**}$, respectively) indicating the conformation of equilibrium among the forms of potassium. The K_L and K_x values showed significant but negative relationship with $-\Delta G$ ($r = -0.902^{**}$ and -0.514^{**} respectively). The K_o value showed positive relationship with K_p ($r = 0.748^{**}$) but negative relationship with $-\Delta G$ ($r=-0.671^{**}$).

Soil potassium potential (K_p) also significantly correlated with potential buffering capacity ($r = 0.655^{**}$) of the soils indicating the dependence of the K_p of soil to supply K to the crops on the PBC^K of soil. Similar type of relationships among the Q/I parameters was also reported by Dhillon et al. (1986, 1990) and Patil and Sonar (1992^a). The change in free energy ($-\Delta G$) was also significantly related with PBC^K ($r = 0.528^{**}$) of the soils which implies that replenishment of soil solution K is mainly regulated by K held on the planer surface sites. Similar type of relationships was also reported by Dhillon et al. (1990).

4.5.4 Relationship between forms of potassium and physico-chemical properties of the soils

The correlation coefficients(r) between the forms of potassium and soil physico-chemical properties were worked out and the data are presented in Table 11.

From the data presented in Table 11, it would be seen that soil pH showed positive and significant relationship with water soluble K ($r = 0.618^{**}$), exchangeable K ($r = 0.572^{**}$) and non-exchangeable K ($r = 0.573^{**}$). These results are

Table 11. Correlation coefficient between physico-chemical characteristics and forms of potassium in soil

Soil property	Forms of potassium				
	Water soluble K	Exchangeable K	Non-exchangeable K	Lattice K	Total K
Sand	-0.034	-0.333	-0.419	-0.106	-0.157
Silt	0.353	0.182	0.047	-0.376	-0.248
Clay	-0.101	0.246	0.360	0.214	0.216
pH	0.618**	0.572**	0.573**	-0.063	0.076
EC	0.085	0.327	0.473*	0.715**	0.689**
Organic carbon	-0.396	-0.234	-0.155	0.248	0.084
$CaCO_3$	-0.121	0.004	0.130	0.209	0.166
CEC	-0.010	0.272	0.361	0.215	0.210
Available K	0.774**	1.000**	0.780**	0.159	0.397
Exchangeable Ca	0.061	0.076	-0.490*	-0.260	-0.259
Exchangeable Mg	-0.221	-0.022	0.074	0.022	-0.037
Exchangeable Na	-0.152	0.110	0.372	0.745**	0.703**
Exchangeable K	0.709**	0.890**	0.905**	0.262	0.502**
K fixing capacity	-0.103	0.150	0.209	0.106	0.092

comparable with the findings of Talele et al. (1992^a) and Dhillon et al. (1985). The electrical conductivity showed positive relationship with non-exchangeable K ($r = 0.473^*$), lattice K ($r = 0.715^{**}$) and total K ($r = 0.689^{**}$). Available K showed positive relationship with water soluble K ($r = 0.774^{**}$) and exchangeable K ($r = 1.00^{**}$) because water soluble and exchangeable forms of K together constitute the available form of K in soils. A significant positive relationship was observed between available K and nonexchangeable K ($r = 0.780^{**}$), which could be easily explained in view of the dynamic equilibrium existing between the water soluble, exchangeable and non-exchangeable forms of K (Sudharmai Devi et al., 1990).

Exchangeable Ca showed negative relationship with non-exchangeable K ($r = -0.490^*$), while exchangeable Na showed positive relationships with lattice K ($r = 0.745^{**}$) and total K ($r = 0.703^{**}$). Exchangeable K showed positive and significant correlation with water soluble, exchangeable, non-exchangeable and total K ($r = 0.709^{**}$, 0.890^{**}, 0.905^{**} and 0.502^{**}, respectively).

4.5.5 Correlation between physico-chemical properties and Q/I parameters of soils

The data on correlation coefficients between physico-chemical properties and Q/I parameters of soils are presented in Table 12.

Table 12. Correlation coefficients (r) between physico-chemical characteristics and Q/I parameters of soil

Soil property	Q/I parameter						
	AR_o^K	K_L	K_x	K_o	K_p	$-\Delta G$	PBC^K
Sand	-0.062	-0.275	-0.199	-0.206	-0.396	0.074	-0.389
Silt	0.274	0.087	0.227	-0.064	-0.439	-0.234	-0.615**
Clay	0.061	0.208	0.118	0.191	0.518**	0.035	0.591**
pH	0.549**	0.551**	0.278	0.409	0.224	-0.503**	-0.174
EC	0.208	0.374	0.002	0.426	0.503**	-0.237	0.280
Organic carbon	-0.580**	-0.220	-0.264	-0.032	0.617**	0.575**	0.974**
$CaCO_3$	0.178	0.148	0.433	-0.041	-0.055	-0.218	-0.034
CEC	-0.059	0.256	0.035	0.289	0.620**	0.049	0.627**
Available K	0.788**	0.875**	0.529**	0.621**	0.377	-0.821	-0.203
Exchangeable Ca	-0.188	0.061	0.120	0.041	0.383	0.193	0.493*
Exchangeable Mg	-0.295	-0.117	-0.074	-0.085	0.227	0.290	0.464*
Exchangeable Na	0.258	-0.251	0.022	0.317	0.143	-0.293	-0.084
Exchangeable K	0.948**	0.920**	0.415	0.726**	0.325	-0.921**	-0.324
K fixing capacity	-0.188	0.095	0.080	0.098	0.482*	0.631**	-0.103

Silt fraction of soil showed negative relationship with PBC^K, while clay showed positive relationship with K_p ($r = 0.518^{**}$) and PBC^K ($r = 0.591^{**}$). The sand fraction did not show significant relationship with Q/I parameters. Patil and Sonar (1992[a]), Datta and Joshi (1992) and Dhillon et al. (1986) reported significant relation between clay and PBC^K, while Datta and Joshi (1992) reported significant relation between clay and K_p. Soil pH showed significant relationship with AR_o^K and K_L ($r = 0.549^{**}$, 0.551^{**}, respectively). It showed significant but negative relationship with $-\Delta G$ ($r = -0.503^{**}$). Electrical conductivity showed positive relationship with K_p ($r = 0.503^{**}$). Organic carbon showed negative relationship with AR_o^K ($r = -0.580^{**}$), but positive relationship with K_p, change in free energy and PBC^K ($r = 0.617^{**}$, 0.575^{**} and 0.974^{**}, respectively). Datta and Joshi (1990 and 1992) also reported significant relationship between CEC and K_p. Pati Ram and Prasad (1981) and Datta and Joshi (1992) have reported significant relationship between CEC and PBC^K of the soils. Available K content of soils showed significant relationship with AR_o^K, K_L, and K_o ($r = 0.788^{**}$, 0.875^{**}, 0.529^{**} and 0.621^{**}, respectively) indicating that these could be better indices of potassium availability. Patil (1992) also reported significant relationship between available K and AR_o^K, available K and K_x in Vertisols of Maharashtra. Tewatia et al. (1987) reported significant relationship between available K and AR_o^K, available K and K_L. Exchangeable Ca and Mg showed positive correlations with PBC^K ($r = 0.493^*$ and 0.464^*, respectively), but did not represent the intensity of K availability. Dhillon et al. (1986) reported significant relationship between Ca+Mg and PBC^K in alluvial soils. Exchangeable K showed positive significant relationship with AR_o^K, K_L, K_o ($r = 0.948^{**}$, 0.920^{**} and 0.726^{**}, respectively). It showed significant but negative relationship with change in free energy ($r = -0.921^{**}$). The K fixing capacity showed significant positive relationship with K potential and change in free energy ($r = 0.482^*$ and 0.631^{**}, respectively).

4.5.6 Correlation between physico-chemical properties of soil with dry matter yield, K concentration and K uptake by wheat

The data on correlation coefficients between physico-chemical properties and dry matter yield, K concentration and K uptake are given in Table 13.

Almost all the properties of the soils under investigation showed non-significant correlation with dry matter yield, K concentration and K uptake by wheat plants except available K which showed significant positive relationships with K concentration and K uptake ($r = 0.670^{**}$ and 0.659^{**}, respectively) and exchangeable K showed significant positive relationship with K concentration and K uptake ($r = 0.606^{**}$ and 0.600^{**}, respectively).

None of the soil properties were significantly correlated with dry matter yield of wheat due to no variation in dry matter accumulation in wheat grown on different soil series under Neubauer technique.

Table 13. Correlation coefficients (r) between physico-chemical characteristics of soils and dry matter yield, K concentration and K uptake by wheat

Soil property	Dry matter yield of wheat	K concentration in wheat plant	K uptake by wheat
Sand	-0.104	-0.113	-0.115
Silt	0.138	0.217	0.219
Clay	0.066	0.032	0.034
pH	-0.131	0.357	0.352
EC	-0.182	-0.004	-0.012
Organic carbon	-0.090	-0.354	-0.353
$CaCO_3$	-0.082	0.214	0.205
CEC	-0.032	0.063	0.062
Available K	-0.133	0.670**	0.659**
Exchangeable Ca	0.043	0.114	0.116
Exchangeable Mg	-0.110	-0.193	-0.195
Exchangeable Na	0.068	0.061	0.060
Exchangeable K	-0.085	0.606**	0.600**
K fixing capacity	0.107	-0.032	0.028

4.5.7 Correlation between forms of potassium and Q/I parameters of soil and dry matter yield, K concentration and K uptake by wheat

The data on correlation coefficients between forms of potassium, Q/I parameters of soil and dry matter yield, K concentration and K uptake are presented in Table 14.

Table 14. Correlation coefficient (r) between Q/I parameters and forms of potassium in soil with dry matter yield, K concentration and K uptake by wheat

Forms of potassium	Q/I parameter		
	Dry matter yield of wheat	K concentration in wheat	K uptake by wheat
AR_o^K	-0.000	0.688^{**}	0.682^{**}
K_L	-0.061	0.715^{**}	0.706^{**}
K_x	0.152	0.709^{**}	0.707^{**}
K_o	-0.107	0.412	0.406
K_p	-0.218	0.108	0.101
$-\Delta G$	-0.027	-0.759^{**}	-0.752^{**}
PBC^K	-0.182	-0.395	-0.396
Water soluble K	-0.173	0.559^{**}	0.546^{**}
Exchangeable K	-0.128	0.667^{**}	0.656^{**}
Non-exchangeable K	-0.138	0.379	0.373
Lattice K	-0.123	-0.107	-0.106
Total K	-0.062	0.037	0.035

The AR_o^K showed positive relationship with K concentration and K uptake by wheat ($r = 0.688^{**}$ and 0.682^{**}, respectively). The K_L showed positive relationship with K concentration and K uptake ($r = 0.715^{**}$ and 0.706^{**}, respectively), while K_X showed positive relationship with K concentration and K uptake by wheat ($r = 0.709^{**}$ and 0.707^{**}, respectively). Change in free energy showed negative relationship with K concentration and K uptake by wheat ($r = -0.759^{**}$ and -0.752^{**} respectively). Pati Ram and Prasad (1981) reported that all the measured parameters except PBC^K of soil correlated positively and significantly with dry matter yield and K uptake.

Water soluble K content of soils showed positive relationship with K concentration and K uptake ($r = 0.559^{**}$ and 0.546^{**}, respectively), while exchangeable K showed significantly positive relationship with K concentration and K uptake by wheat ($r = 0.667^{**}$ and 0.656^{**}, respectively). Positive and highly significant correlations between various plant indices and forms of K in soil suggesting a good availability of plant utilizable potassium in these soils. Sharma and Sekhon (1991) reported that ammonium acetate extractable and nitric acid soluble potassium correlated positively with plant K concentration.

Summary and Conclusions

5. SUMMARY AND CONCLUSIONS

Laboratory and potted studies were conducted on depthwise distribution of forms of potassium and Q/I relationships of potassium in six soil series viz., Nimone, Otur (Vertisols), Sawargaon, Dholwad (Inceptisol), Pargaon and Khanapur (Entisol) of Central Campus Farm, Rahuri during the year 1992-93 at Mahatma Phule Krishi Vidyapeeth, Rahuri (India). Because of no differentiation of horizons, the soil samples were obtained to a depth of 0-15, 15-30, 30-45 and 45-60 cm for Vertisol and Inceptisol, and 0-15 and 15-30 cm depth for Entisol orders. Physico-chemical properties, forms of K and Q/I relationship of K in these soils were determined. Neubauer technique experiment was also conducted with wheat cv. HD 2189 (Triticum aestivum L.) as a test crop to assess the potassium status of these soils. The important findings and the conclusions drawn are summarized as below :

(1) Nimone, Otur (Vertisol), Sawargaon and Dholwad (Inceptisol) soil series were clayey in texture, whereas Pargaon and Khanapur (Entisol) soil series were clay loam. All the soil series were alkaline in reaction (pH 8), low to moderately high in organic carbon and calcareous in nature. The CEC of soil series ranged from 31.8 to 58.7 me 100 g^{-1}. The Ca^{2+} was dominated the exchange complex and all the soil series were high in available K content.

(2) Lattice K contributed bulk of the total K (79.18 %) followed by non-exchangeable K (15 %), exchangeable K (5.57 %) and water soluble K (0.24 %) in all the series under study with equilibrium among the different forms of K.

(3) Soils rich in clay and higher CEC (Nimone, Otur, Sawargaon and Dholwad) showed higher AR_o^K, PBC^K, K_L, K_x, K_o, K_p

and ΔG values than that of soils with lower clay and CEC (Pargaon and Khanapur).

(4) The water soluble K significantly correlated with exchangeable K, non-exchangeable K ($r = 0.750^{**}$, and 0.464^{*}, respectively). Exchangeable K significantly correlated with non-exchangeable K ($r = 0.788^{**}$ and non-exchangeable K showed relationships with lattice K and total K ($r = 0.493^{*}$ and 0.682^{**}, respectively), while lattice K significantly correlated with total K ($r = 0.958^{**}$). The significant relationships among the forms of K indicated the existence of equilibrium among the K forms. Poor relationships with some of the soil properties might be due to the narrow range of variations in the soil properties.

(5) Poor relationships of Q/I parameters with exchangeable Ca^{2+} and Mg^{2+} and particularly the $-\Delta G$ indicated that there was an existence of a suitable balance between K and exchangeable Ca, Mg in these soil series.

Thus, the study revealed that in addition to physico-chemical properties and K fertility evaluation by different forms of potassium may not bring the differential behaviour of K for its availability to growing crop. However, the studies on Q/I relationship brought out the differential behaviour of potassium inspite of similar or close differences in characters and K forms in these soils, which may be utilized for further studies on long term K fertility evaluation and K fertilizer management in these or similar types of other soils.

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6. LITERATURE CITED

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* Originals not seen.

Appendices

DETAILS OF COLUMNS

Col. No.	Particular
1.	K added, ppm
2.	K, mol L^{-1}
3.	K, me 100 g^{-1}
4.	Observed K, ppm
5.	K, me 100 g^{-1}
6.	CK, mol L^{-1}
7.	ΔK, me 100 g^{-1}
8.	Ca + Mg, me L^{-1}
9.	Ca + Mg, mol L^{-1}
10.	$\sqrt{Ca + Mg}$, mol L^{-1}
11.	$\frac{CK}{\sqrt{Ca + Mg}}$
12.	EC, dS m^{-1}
13.	mol L^{-1}
14.	PfK
15.	fK
16.	$Pf_{Ca + Mg}$
17.	$f_{Ca + Mg}$
18.	$\sqrt{f_{Ca + Mg}}$
19.	$\frac{fK}{\sqrt{f_{Ca + Mg}}}$
20.	$ARK = \frac{CK}{\sqrt{Ca + Mg}} \times \frac{fK}{\sqrt{f_{Ca+Mg}}}$

Appendix-1. Calculations of Q/I parameters in soil (Nimone, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	64	0.164	1.64×10^{-3}	-0.164	35.8	0.0179	0.1337
5	1.28×10^{-4}	0.128	78	0.200	2.00×10^{-3}	0.071	33.6	0.0169	0.1296
10	2.56×10^{-4}	0.258	88	0.225	2.25×10^{-3}	0.030	34.2	0.0171	0.1307
20	5.13×10^{-4}	0.513	100	0.256	2.56×10^{-3}	0.256	35.4	0.0177	0.1330
40	1.03×10^{-3}	0.103	150	0.384	3.84×10^{-3}	0.641	34.4	0.0172	0.1311
80	2.05×10^{-3}	0.205	288.33	0.726	7.26×10^{-3}	1.324	35.2	0.0176	0.1326
100	2.56×10^{-3}	0.256	333.33	0.854	8.55×10^{-3}	1.709	35.8	0.0179	0.1337

11	12	13	14	15	16	17	18	19	20
0.0122	3.115	0.0467	0.0824	0.827	0.3296	0.468	0.6842	1.2087	14.75×10^{-3}
0.0154	3.168	0.0475	0.0830	0.826	0.332	0.466	0.6823	1.2106	18.64×10^{-3}
0.0172	3.168	0.0475	0.0830	0.826	0.332	0.466	0.6823	1.2106	20.80×10^{-3}
0.0192	3.168	0.0475	0.0830	0.826	0.332	0.466	0.6823	1.2106	23.20×10^{-3}
0.0292	3.326	0.0498	0.0847	0.823	0.339	0.458	0.6770	1.2156	35.50×10^{-3}
0.0543	3.432	0.0514	0.0858	0.821	0.3432	0.454	0.674	1.2180	66.10×10^{-3}
0.0639	3.432	0.0514	0.0858	0.821	0.3432	0.454	0.674	1.218	77.80×10^{-3}

Appendix-2. Calculation of Q/I parameters in soil (Nimone, 15-30)

1	2	3	4	5	6	7	8	9	10
0	0	0	21	0.0538	5.384×10^{-4}	-0.053	34.2	0.0171	0.1307
5	1.28×10^{-4}	0.128	29	0.0743	7.435×10^{-4}	0.054	34.0	0.0170	0.1303
10	2.56×10^{-4}	0.258	40	0.1025	1.025×10^{-3}	0.153	35.2	0.0176	0.1326
20	5.13×10^{-4}	0.513	64	0.1641	1.640×10^{-3}	0.348	35.0	0.0175	0.1322
40	1.03×10^{-3}	0.103	100	0.2564	2.564×10^{-3}	0.769	35.6	0.0178	0.1334
80	2.05×10^{-3}	0.205	216.6	0.5555	5.555×10^{-3}	1.495	34.8	0.0174	0.1319
100	2.56×10^{-3}	0.256	283.3	0.7264	7.264×10^{-3}	1.837	35.4	0.0177	0.1330

11	12	13	14	15	16	17	18	19	20
4.12×10^{-3}	3.274	0.0491	0.0844	0.823	0.338	0.4596	0.678	1.2138	4.99×10^{-3}
5.71×10^{-3}	3.284	0.0492	0.0844	0.823	0.338	0.4596	0.678	1.2138	6.93×10^{-3}
7.73×10^{-3}	3.231	0.0494	0.0841	0.824	0.336	0.461	0.679	1.2135	9.38×10^{-3}
0.0124	3.273	0.0491	0.0844	0.823	0.338	0.4596	0.678	1.2138	15.05×10^{-3}
0.0192	3.316	0.0497	0.0846	0.823	0.3384	0.459	0.677	1.2156	23.3×10^{-3}
0.0421	3.295	0.0494	0.0846	0.823	0.3384	0.459	0.677	1.2156	51.17×10^{-3}
0.0546	3.443	0.0516	0.0861	0.820	0.3444	0.452	0.673	1.2184	66.5×10^{-3}

Appendix-3. Calculation of Q/I parameters in soil (Nimone, 30-45 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	26	0.0666	6.67×10^{-4}	-0.0666	34.6	0.0173	0.1315
5	1.28×10^{-4}	0.128	36	0.0923	9.23×10^{-4}	0.035	32.4	0.0162	0.1272
10	2.56×10^{-4}	0.258	50	0.1282	1.28×10^{-3}	0.128	33.2	0.0166	0.1288
20	5.13×10^{-4}	0.513	74	0.1897	1.89×10^{-3}	0.323	33.4	0.0167	0.1292
40	1.03×10^{-3}	0.103	116.66	0.2991	2.99×10^{-3}	0.7265	33.6	0.0166	0.1290
80	2.05×10^{-3}	0.205	233.33	0.5982	5.98×10^{-3}	1.453	34.8	0.0174	0.1319
100	2.56×10^{-3}	0.256	300	0.7692	7.69×10^{-3}	1.7948	35	0.0175	0.1322

11	12	13	14	15	16	17	18	19	20
5.07×10^{-3}	3.157	0.0474	0.0835	0.825	0.334	0.463	0.681	1.2114	6.141×10^{-3}
7.26×10^{-3}	3.020	0.0453	0.0821	0.828	0.3284	0.4694	0.685	1.2087	8.770×10^{-3}
9.95×10^{-3}	3.274	0.0491	0.0847	0.823	0.3388	0.458	0.677	1.216	12.09×10^{-3}
0.01468	3.199	0.0479	0.0839	0.824	0.3356	0.462	0.6795	1.2127	17.80×10^{-3}
0.02318	3.062	0.0459	0.0825	0.827	0.33	0.468	0.684	1.2091	28.03×10^{-3}
0.04536	3.295	0.0494	0.0848	0.823	0.3392	0.457	0.676	1.2174	55.22×10^{-3}
0.05818	3.295	0.0494	0.0848	0.823	0.3392	0.457	0.676	1.2174	70.83×10^{-3}

Appendix-4. Calculations of Q/I parameters in soil (Nimone, 45-60 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	20	0.051	5.128×10^{-4}	-0.0512	33.8	0.0338	0.1300
5	1.28×10^{-4}	0.128	28	0.072	7.179×10^{-4}	0.0564	34.8	0.0348	0.1319
10	2.56×10^{-4}	0.258	40	0.103	1.026×10^{-3}	0.1538	34.6	0.0346	0.1315
20	5.13×10^{-4}	0.513	66	0.169	1.692×10^{-3}	0.3435	34.4	0.0344	0.1311
40	1.03×10^{-3}	0.103	100	0.256	2.564×10^{-3}	0.7692	34.2	0.0342	0.1307
80	2.05×10^{-3}	0.205	216.66	0.556	5.555×10^{-3}	1.4957	34.8	0.0348	0.1319
100	2.56×10^{-3}	0.256	283.33	0.726	7.265×10^{-3}	1.8376	36.2	0.0362	0.1345

11	12	13	14	15	16	17	18	19	20
3.945×10^{-3}	3.1876	0.0478	0.0838	0.825	0.3352	0.462	0.6798	1.2135	4.79×10^{-3}
5.443×10^{-3}	3.2845	0.0492	0.0847	0.828	0.3388	0.458	0.677	1.2153	6.62×10^{-3}
7.802×10^{-3}	3.3383	0.0500	0.0852	0.821	0.3408	0.456	0.675	1.2175	9.49×10^{-3}
0.0129	3.3383	0.0500	0.0852	0.821	0.3408	0.456	0.675	1.2175	15.71×10^{-3}
0.0196	3.3922	0.0509	0.0857	0.821	0.3428	0.454	0.674	1.2179	23.80×10^{-3}
0.0421	3.4460	0.0517	0.0864	0.819	0.3456	0.451	0.672	1.2196	51.30×10^{-3}
0.0540	3.1768	0.0477	0.0837	0.825	0.3349	0.462	0.680	1.213	64.48×10^{-3}

Appendix-5. Calculations of Q/I parameters in soil (Otur, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	73	0.187	1.8717×10^{-3}	-0.1870	38	0.038	0.1378
5	1.28×10^{-4}	0.128	82	0.210	2.1026×10^{-3}	-0.0820	34	0.034	0.1303
10	2.56×10^{-4}	0.258	94	0.241	2.4102×10^{-3}	0.0153	33.8	0.038	0.1300
20	5.13×10^{-4}	0.513	83.33	0.214	2.1370×10^{-3}	0.2991	34.6	0.0346	0.1315
40	1.03×10^{-3}	0.103	150	0.385	3.8460×10^{-3}	0.6410	34.6	0.0346	0.1315
80	2.05×10^{-3}	0.205	250	0.641	6.4100×10^{-3}	1.4102	37.2	0.0372	0.1363
100	2.56×10^{-3}	0.256	300	0.769	7.6920×10^{-3}	1.7948	36.2	0.0362	0.1345

11	12	13	14	15	16	17	18	19	20
0.01358	3.3922	0.0509	0.0857	0.8210	0.3428	0.4540	0.674	1.2179	16.54×10^{-3}
0.01613	3.3922	0.0509	0.0857	0.8210	0.3428	0.4540	0.674	1.2179	19.64×10^{-3}
0.01854	3.3922	0.0509	0.0857	0.8210	0.3428	0.4540	0.674	1.2179	22.57×10^{-3}
0.01624	3.4460	0.0517	0.0864	0.8195	0.3456	0.4520	0.672	1.2196	19.81×10^{-3}
0.02924	3.4999	0.0524	0.0867	0.8190	0.3469	0.4498	0.6702	1.2212	35.71×10^{-3}
0.04703	3.5537	0.0533	0.0872	0.8180	0.3491	0.448	0.669	1.2230	57.51×10^{-3}
0.05719	3.6076	0.0541	0.0877	0.8171	0.3508	0.446	0.668	1.2232	69.96×10^{-3}

Appendix-6 : Calculations of Q/I parameters in soil (Otur, 15-30 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	21	0.054	5.385×10^{-4}	-0.0538	34.8	0.0348	0.1319
5	1.28×10^{-4}	0.128	30	0.077	7.692×10^{-4}	0.0512	33.4	0.0334	0.1292
10	2.56×10^{-4}	0.258	41	0.105	1.0513×10^{-3}	0.1512	34.8	0.0348	0.1319
20	5.13×10^{-4}	0.513	62	0.159	1.589×10^{-3}	0.3538	34.6	0.0346	0.1315
40	1.03×10^{-3}	0.103	100	0.256	2.564×10^{-3}	0.7692	34.6	0.0346	0.1315
80	2.05×10^{-3}	0.205	183.33	0.470	4.700×10^{-3}	1.5812	34.6	0.0346	0.1334
100	2.56×10^{-3}	0.256	250	0.640	6.410×10^{-3}	1.9230	36.2	0.0362	0.1345

11	12	13	14	15	16	17	18	19	20
4.08×10^{-3}	3.4460	0.0517	0.0864	0.8195	0.3456	0.4512	0.6717	1.2201	4.98×10^{-3}
5.95×10^{-3}	3.3922	0.0509	0.0857	0.8209	0.3428	0.4541	0.6739	1.2181	7.25×10^{-3}
7.97×10^{-3}	3.3922	0.0509	0.0857	0.8209	0.3428	0.4521	0.6739	1.2181	9.79×10^{-3}
0.01208	3.3922	0.0509	0.0857	0.8209	0.3428	0.4521	0.4521	1.2181	14.73×10^{-3}
0.01949	3.4660	0.0517	0.0864	0.8195	0.3456	0.4521	0.6712	1.2201	23.79×10^{-3}
0.03523	3.4999	0.0524	0.0867	0.8190	0.3469	0.4498	0.6707	1.2212	43.02×10^{-3}
0.0476	3.6076	0.0541	0.0877	0.8171	0.3508	0.4458	0.6677	1.2238	58.32×10^{-3}

Appendix-7. Calculations of Q/I parameters in soil (Otur, 30-45 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	19	0.049	4.88×10^{-4}	-0.0487	32.4	0.0324	0.1272
5	1.28×10^{-4}	0.128	26	0.067	6.67×10^{-4}	0.06153	31.0	0.0310	0.1244
10	2.56×10^{-4}	0.258	37	0.095	9.49×10^{-4}	0.1615	32.6	0.0326	0.1276
20	5.13×10^{-4}	0.513	57	0.146	1.46×10^{-3}	0.3666	33.2	0.0332	0.1288
40	1.03×10^{-3}	0.103	100	0.256	2.56×10^{-3}	0.7692	34.0	0.0340	0.1303
80	2.05×10^{-3}	0.205	183.33	0.470	4.70×10^{-3}	1.5812	31.6	0.0316	0.1256
100	2.56×10^{-3}	0.256	233.33	0.598	5.98×10^{-3}	1.9658	34.0	0.0340	0.1303

11	12	13	14	15	16	17	18	19	20
3.83×10^{-3}	3.4922	0.0524	0.0867	0.819	0.346	0.4498	0.671	1.2206	4.67×10^{-3}
5.36×10^{-3}	3.3845	0.0507	0.0856	0.821	0.343	0.454	0.674	1.218	6.53×10^{-3}
7.44×10^{-3}	3.5566	0.0533	0.0872	0.818	0.3491	0.448	0.669	1.223	9.09×10^{-3}
0.01135	3.6139	0.0542	0.0878	0.817	0.3513	0.445	0.667	1.225	13.89×10^{-3}
0.0197	3.4419	0.0516	0.0862	0.8199	0.3448	0.452	0.672	1.220	24.00×10^{-3}
0.0374	3.4992	0.0524	0.0868	0.8188	0.3472	0.449	0.671	1.220	45.66×10^{-3}
0.0459	3.4992	0.0524	0.0868	0.8188	0.3472	0.449	0.671	1.220	56.00×10^{-3}

Appendix-8. Calculations of Q/I parameters in soil (Otur, 45-60 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	24	0.062	6.1538×10^{-4}	-0.0615	33.2	0.0332	0.1288
5	1.28×10^{-4}	0.128	30	0.077	7.6923×10^{-4}	0.0512	31.4	0.0314	0.1252
10	2.56×10^{-4}	0.258	43	0.110	1.1025×10^{-3}	0.1461	31.8	0.0318	0.1261
20	5.13×10^{-4}	0.513	63	0.162	1.6154×10^{-3}	0.3512	32.8	0.0328	0.1281
40	1.03×10^{-3}	0.103	83.33	0.214	2.1366×10^{-3}	0.8119	31.8	0.0318	0.1261
80	2.05×10^{-3}	0.205	166.66	0.427	4.2733×10^{-3}	1.6239	32.0	0.0320	0.1265
100	2.56×10^{-3}	0.256	233.33	0.598	5.9828×10^{-3}	1.9658	32.0	0.0320	0.1265

11	12	13	14	15	16	17	18	19	20
4.78×10^{-3}	3.4992	0.0524	0.0868	0.8188	0.3472	0.4495	0.6705	1.2212	5.84×10^{-3}
6.14×10^{-3}	3.4992	0.0524	0.0868	0.8188	0.3472	0.4495	0.6705	1.2212	7.50×10^{-3}
8.74×10^{-3}	3.4992	0.0524	0.0868	0.8188	0.3472	0.4495	0.6705	1.2212	10.67×10^{-3}
0.01261	3.5566	0.053	0.0873	0.8178	0.3493	0.4470	0.6688	1.2229	15.43×10^{-3}
0.01694	3.5566	0.053	0.0873	0.8178	0.3493	0.447	0.6688	1.2229	20.70×10^{-3}
0.0342	3.3271	0.049	0.0852	0.8219	0.3406	0.456	0.6756	1.2166	41.62×10^{-3}
0.0473	3.6139	0.054	0.0878	0.8169	0.3513	0.445	0.667	1.2248	57.92×10^{-3}

Appendix-9 Calculations of Q/I parameters in soil (Sawargaon, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	45	0.115	1.15×10^{-3}	-0.115	36.2	0.0362	0.1345
5	1.28×10^{-4}	0.128	53	0.136	1.36×10^{-3}	-0.0769	33.2	0.0332	0.1288
10	2.56×10^{-4}	0.258	66	0.169	1.69×10^{-3}	0.0872	36.2	0.0362	0.1345
20	5.13×10^{-4}	0.513	84	0.215	2.15×10^{-3}	0.297	33.8	0.0338	0.1300
40	1.03×0^{-3}	0.103	100	0.256	2.56×10^{-3}	0.769	34.2	0.0342	0.1307
80	2.05×10^{-3}	0.205	200	0.513	5.13×10^{-3}	1.538	35.6	0.0356	0.1334
100	2.56×10^{-3}	0.256	266.66	0.684	6.84×10^{-3}	1.880	34.0	0.0340	0.1303

11	12	13	14	15	16	17	18	19	20
8.55×10^{-3}	3.385	0.050	0.0858	0.8207	0.3433	0.4536	0.6735	1.2186	10.42×10^{-3}
0.01055	3.269	0.049	0.0846	0.8230	0.3384	0.4587	0.6773	1.2151	12.82×10^{-3}
0.0125	3.385	0.050	0.0858	0.8207	0.3433	0.4536	0.6735	1.2186	15.23×10^{-3}
0.0165	3.327	0.049	0.0853	0.8216	0.3414	0.4556	0.6749	1.2174	20.08×10^{-3}
0.0196	3.556	0.053	0.0873	0.8178	0.3493	0.4474	0.6688	1.2229	23.96×10^{-3}
0.0384	3.499	0.052	0.0868	0.8188	0.3472	0.4495	0.6705	1.2212	46.89×10^{-3}
0.0524	3.557	0.053	0.0873	0.8179	0.3493	0.4475	0.6688	1.2229	64.08×10^{-3}

Append. 10 : Calculations of Q/I parameters in soil (Sawargaon, 15-30 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	33	0.085	8.46×10^{-4}	-0.0846	34.6	0.0346	0.1315
5	1.28×10^{-4}	0.128	46	0.118	1.18×10^{-3}	0.0103	32.0	0.0320	0.1265
10	2.56×10^{-4}	0.258	47	0.121	1.21×10^{-3}	0.1360	32.6	0.0326	0.1276
20	5.13×10^{-4}	0.513	6[illegible]	0.174	1.74×10^{-3}	0.3380	31.8	0.0318	0.1261
40	1.03×10^{-3}	0.103	100	0.256	2.56×10^{-3}	0.769	33.8	0.0338	0.1300
80	2.05×10^{-3}	0.205	183.33	0.470	4.70×10^{-3}	1.581	33.8	0.0338	0.1300
100	2.56×10^{-3}	0.256	233.33	0.598	5.98×10^{-3}	1.966	34.0	0.0340	0.1304

11	12	13	14	15	16	17	18	19	20
6.43×10^{-3}	3.257	0.0489	0.0844	0.823	0.3378	0.4594	0.6777	1.2149	7.818×10^{-3}
9.32×10^{-3}	3.369	0.0500	0.0857	0.829	0.3428	0.4542	0.6739	1.2181	11.35×10^{-3}
9.44×10^{-3}	3.368	0.0500	0.0860	0.821	0.3428	0.4542	0.6739	1.2181	11.50×10^{-3}
0.01383	3.424	0.0513	0.0860	0.821	0.3435	0.4534	0.6734	1.2189	16.85×10^{-3}
0.0197	3.2027	0.0480	0.0839	0.824	0.3359	0.4614	0.6793	1.2135	23.90×10^{-3}
0.0362	3.3132	0.0496	0.0850	0.822	0.3397	0.4574	0.6763	1.2161	44.02×10^{-3}
0.0459	3.3680	0.0500	0.0860	0.822	0.3428	0.4542	0.6739	1.2161	55.82×10^{-3}

Appendix-11. Calculations of Q/I parameters in soil (Sawargaon, 30-45 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	19	0.049	4.87×10^{-4}	-0.049	36.4	0.0364	0.1349
5	1.28×10^{-4}	0.128	25	0.064	6.41×10^{-4}	0.064	32.2	0.0322	0.1259
10	2.56×10^{-4}	0.258	34	0.087	8.72×10^{-4}	0.169	31.8	0.0318	0.1261
20	5.13×10^{-4}	0.513	54	0.138	1.39×10^{-4}	0.374	31.8	0.0318	0.1261
40	1.03×10^{-3}	0.103	96	0.246	2.46×10^{-3}	0.779	31.6	0.0316	0.1257
80	2.05×10^{-3}	0.205	166.66	0.427	4.27×10^{-3}	1.624	34.0	0.0340	0.1304
100	2.56×10^{-3}	0.256	233.33	0.598	5.98×10^{-3}	1.965	33.2	0.0332	0.1288

11	12	13	14	15	16	17	18	19	20
3.61×10^{-3}	3.368	0.050	0.0856	0.8209	0.3428	0.4542	0.6739	1.2181	4.399×10^{-3}
5.05×10^{-3}	3.3132	0.0496	0.0849	0.8224	0.3397	0.4574	0.6763	1.2166	6.142×10^{-3}
6.91×10^{-3}	3.2027	0.0480	0.0839	0.8243	0.3359	0.4614	0.6793	1.2134	8.389×10^{-3}
0.01098	3.257	0.0489	0.0844	0.8233	0.3378	0.4594	0.6777	1.2149	13.34×10^{-3}
0.01958	3.257	0.0489	0.0844	0.8233	0.3378	0.4594	0.6777	1.2149	23.78×10^{-3}
0.03276	3.368	0.0500	0.0849	0.8224	0.3397	0.4574	0.6763	1.2160	39.83×10^{-3}
0.04645	3.2028	0.0480	0.0839	0.8243	0.3359	0.4614	0.6793	1.2134	56.36×10^{-3}

Appendix-12. Calculations of Q/I parameters in soil (Sawargaon, 45-60 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	18	0.046	4.62×10^{-4}	-0.046	35.8	0.0358	0.1338
5	1.28×10^{-4}	0.128	22	0.056	5.64×10^{-4}	0.0717	33.0	0.033	0.1285
10	2.56×10^{-4}	0.258	34	0.087	8.72×10^{-4}	0.169	33.4	0.0334	0.1292
20	5.13×10^{-4}	0.513	56	0.144	1.44×10^{-3}	0.369	32.8	0.0328	0.1281
40	1.03×10^{-3}	0.103	66.66	0.171	1.71×10^{-3}	0.855	32.8	0.0328	0.1281
80	2.05×10^{-3}	0.205	150	0.385	3.85×10^{-3}	1.667	34.4	0.0344	0.1311
100	2.56×10^{-3}	0.256	200	0.513	5.13×10^{-3}	2.051	34.4	0.0344	0.1311

11	12	13	14	15	16	17	18	19	20
3.45×10^{-3}	3.424	0.0513	0.0858	0.8207	0.3435	0.4534	0.6733	1.2189	4.20×10^{-3}
4.39×10^{-3}	3.20276	0.0480	0.0839	0.8243	0.3359	0.4614	0.6792	1.2136	5.33×10^{-3}
6.75×10^{-3}	3.257	0.0489	0.0844	0.8233	0.3378	0.4594	0.6777	1.2149	8.20×10^{-3}
0.01121	3.3132	0.0496	0.0849	0.8224	0.3397	0.4574	0.6763	1.2160	13.63×10^{-3}
0.0133	3.20276	0.0480	0.0839	0.8243	0.3359	0.4614	0.6792	1.2136	16.14×10^{-3}
0.0293	3.478	0.0521	0.0866	0.8192	0.3464	0.4504	0.6711	1.2207	35.76×10^{-3}
0.0391	3.4236	0.0513	0.0861	0.8201	0.3443	0.4525	0.6727	1.2192	47.60×10^{-3}

Appendix-13. Calculations of Q/I parameters in soil (Dholwad, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	66.66	0.171	1.709×10^{-3}	-0.171	32.0	0.032	0.1264
5	1.28×10^{-4}	0.128	83.33	0.214	2.137×10^{-3}	-0.085	29.6	0.0296	0.1223
10	2.56×10^{-4}	0.258	99.00	0.254	2.538×10^{-3}	0.0025	29.2	0.0292	0.1208
20	5.13×10^{-4}	0.513	116.66	0.299	2.99×10^{-3}	0.2136	29.4	0.0294	0.1212
40	1.03×10^{-3}	0.103	166.66	0.427	2.991×10^{-3}	0.598	29.8	0.0298	0.1221
80	2.05×10^{-3}	0.205	283.33	0.726	7.265×10^{-3}	1.328	30.2	0.0302	0.1229
100	2.56×10^{-3}	0.256	360.66	0.925	9.248×10^{-3}	1.639	30.2	0.0302	0.1229

11	12	13	14	15	16	17	18	19	20
0.01352	3.478	0.0521	0.0866	0.8192	0.3464	0.4504	0.6711	1.2207	16.50×10^{-3}
0.01747	3.2027	0.0480	0.0839	0.8243	0.3359	0.4614	0.6792	1.2135	21.20×10^{-3}
0.021009	3.257	0.0489	0.0844	0.8233	0.3358	0.4594	0.6777	1.2149	25.53×10^{-3}
0.02467	3.257	0.0489	0.0844	0.8233	0.3378	0.4594	0.6777	1.2149	29.97×10^{-3}
0.02449	3.3132	0.0496	0.0849	0.8224	0.3397	0.4574	0.6763	1.2160	29.78×10^{-3}
0.05911	3.368	0.050	0.0856	0.8209	0.3427	0.4541	0.6739	1.2181	72.00×10^{-3}
0.07525	3.5341	0.0530	0.0871	0.8182	0.3489	0.4483	0.6695	1.2222	91.97×10^{-3}

Appendix-14. Calculations of Q/I parameters in soil (Dholwad, 15-30 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	79	0.203	2.026×10^{-3}	-0.2025	35	0.035	0.1323
5	1.28×10^{-4}	0.128	88	0.226	2.256×10^{-3}	-0.097	25.8	0.0258	0.1136
10	2.56×10^{-4}	0.258	88.33	0.226	2.137×10^{-3}	0.043	24	0.024	0.1095
20	5.13×10^{-4}	0.513	100	0.256	2.564×10^{-3}	0.2564	27.8	0.0278	0.1179
40	1.03×10^{-3}	0.103	150	0.385	3.846×10^{-3}	0.641	26.4	0.0264	0.1179
80	2.05×10^{-3}	0.205	266.66	0.684	6.837×10^{-3}	1.368	27	0.027	0.1162
100	2.56×10^{-3}	0.256	350	0.897	8.974×10^{-3}	1.667	29	0.029	0.1204

11	12	13	14	15	16	17	18	19	20
0.01531	4.204	0.0631	0.0930	0.8071	0.3720	0.4246	0.6516	1.2388	18.96×10^{-3}
0.01986	3.513	0.0527	0.0868	0.8186	0.3475	0.4492	0.6702	1.2215	23.90×10^{-3}
0.01952	3.628	0.0544	0.0879	0.8167	0.3518	0.4448	0.6669	1.2247	24.25×10^{-3}
0.02175	3.455	0.0518	0.0863	0.8197	0.3453	0.4515	0.6719	1.2200	26.54×10^{-3}
0.0335	3.455	0.0518	0.0863	0.8198	0.3453	0.4515	0.6719	1.2201	40.87×10^{-3}
0.0568	3.570	0.0536	0.0874	0.8177	0.3497	0.4469	0.6685	1.2232	69.47×10^{-3}
0.0745	3.743	0.0561	0.0889	0.8148	0.3559	0.4406	0.6638	1.2276	91.45×10^{-3}

Appendix-15. Calculations of Q/I parameters in soil (Dholwad, 30-45 cm)

1	2	3	4	5	6 6	7	8	9	10
0	0	0	30	0.077	7.69×10^{-4}	-0.077	29	0.029	0.1204
5	1.28×10^{-4}	0.128	36	0.092	9.23×10^{-4}	0.0359	22	0.022	0.1049
10	2.56×10^{-4}	0.258	49	0.126	1.26×10^{-3}	0.131	22	0.022	0.1049
20	5.13×10^{-4}	0.513	66	0.169	1.69×10^{-3}	0.3436	22.2	0.0222	0.1054
40	1.03×10^{-3}	0.103	83.33	0.214	2.14×10^{-3}	0.812	23	0.023	0.1072
80	2.05×10^{-3}	0.205	183.33	0.470	4.70×10^{-3}	1.5812	23.4	0.0234	0.1082
100	2.56×10^{-3}	0.256	233.33	0.598	5.98×10^{-3}	1.966	23.4	0.0234	0.1082

11	12	13	14	15	16	17	18	19	20
6.39×10^{-3}	4.14612	0.0622	0.0946	0.8043	0.3785	0.4183	0.6467	1.2434	7.95×10^{-3}
8.79×10^{-3}	3.339	0.0501	0.0853	0.8216	0.3412	0.4558	0.6752	1.2170	10.71×10^{-3}
0.01198	3.339	0.0501	0.0853	0.8216	0.3412	0.4558	0.6752	1.2170	14.58×10^{-3}
0.0161	3.513	0.0527	0.0869	0.8186	0.3475	0.4492	0.6703	1.2214	19.66×10^{-3}
0.01993	3.4551	0.0518	0.0363	0.8198	0.3453	0.4515	0.6719	1.2200	24.32×10^{-3}
0.0434	3.4551	0.0518	0.0863	0.8198	0.3453	0.4515	0.6719	1.2200	52.95×10^{-3}
0.0553	3.513	0.0527	0.0869	0.8186	0.3475	0.4493	0.6703	1.2214	67.54×10^{-3}

Appendix-16. Calculations of Q/I parameters in soil (Dholwad, 45-60 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	32	0.082	8.21×10^{-4}	-0.0820	28.8	0.0288	0.12
5	1.28×10^{-4}	0.128	37	0.095	9.49×10^{-4}	0.0333	21.2	0.0212	0.1029
10	2.56×10^{-4}	0.258	46	0.118	1.18×10^{-3}	0.1385	21.2	0.0212	0.1029
20	5.13×10^{-4}	0.513	67	0.172	1.72×10^{-3}	0.3410	22.0	0.022	0.1049
40	1.03×10^{-3}	0.103	83.33	0.214	2.14×10^{-3}	0.8119	22.0	0.022	0.1049
80	2.05×10^{-3}	0.205	183.33	0.470	4.70×10^{-3}	1.5812	23.2	0.0232	0.1077
100	2.56×10^{-3}	0.256	250	0.641	6.41×10^{-3}	1.923	23.6	0.0236	0.1086

11	12	13	14	15	16	17	18	19	20
6.84×10^{-3}	4.204	0.0631	0.09302	0.8072	0.3720	0.4246	0.6516	1.2388	8.47×10^{-3}
9.22×10^{-3}	3.3975	0.0509	0.0859	0.8209	0.3435	0.4534	0.6736	1.2184	11.23×10^{-3}
0.01145	3.4551	0.0518	0.0863	0.8197	0.3453	0.4515	0.6719	1.2201	13.97×10^{-3}
0.01637	3.5703	0.0536	0.0874	0.8177	0.3497	0.4469	0.6685	1.2232	20.02×10^{-3}
0.02037	3.5703	0.0536	0.0874	0.8177	0.3497	0.4469	0.6685	1.2232	24.92×10^{-3}
0.0436	3.6278	0.0544	0.0879	0.8167	0.3518	0.4448	0.6669	1.2247	53.39×10^{-3}
0.05902	3.7430	0.0561	0.0889	0.8149	0.3559	0.4406	0.6638	1.2276	72.45×10^{-3}

Appendix-17. Calculations of Q/I parameters in soil (Pargaon, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	39	0.100	1.00×10^{-3}	-0.100	33.2	0.0332	0.1288
5	1.28×10^{-4}	0.128	49	0.126	1.26×10^{-3}	0.0025	33.2	0.0332	0.1288
10	2.56×10^{-4}	0.258	65	0.167	1.67×10^{-3}	0.0897	32.4	0.0324	0.1272
20	5.13×10^{-4}	0.513	94	0.241	2.41×10^{-3}	0.272	32.8	0.0328	0.1281
40	1.03×10^{-3}	0.103	150	0.385	3.85×10^{-3}	0.641	33.8	0.0338	0.13
80	2.05×10^{-3}	0.205	266.66	0.684	6.84×10^{-3}	1.368	34.2	0.0342	0.1308
100	2.56×10^{-3}	0.256	316.66	0.812	8.12×10^{-3}	1.752	33.6	0.0336	0.1296

11	12	13	14	15	16	17	18	19	20
7.76×10^{-3}	3.295	0.049	0.0849	0.8224	0.3396	0.4575	0.6763	1.21607	9.44×10^{-3}
9.75×10^{-3}	3.353	0.050	0.0854	0.8214	0.3419	0.4550	0.6746	1.2177	11.87×10^{-3}
0.013105	3.526	0.053	0.0869	0.8186	0.3479	0.4488	0.6699	1.2220	16.02×10^{-3}
0.01881	3.410	0.051	0.0859	0.8205	0.3439	0.4530	0.6730	1.2192	22.93×10^{-3}
0.0296	3.468	0.052	0.0864	0.8195	0.3458	0.4510	0.6715	1.2205	36.13×10^{-3}
0.0523	3.584	0.054	0.0874	0.8177	0.3499	0.4467	0.6684	1.2234	63.98×10^{-3}
0.0626	3.642	0.055	0.0880	0.8166	0.3521	0.4455	0.6667	1.2248	76.67×10^{-3}

Appendix-18. Calculations of Q/I parameters in soil (Pargaon, 15-30

1	2	3	4	5	6	7	8	9	10
0	0	0	19	0.049	4.87×10^{-4}	-0.0487	33.0	0.033	0.1285
5	1.28×10^{-4}	0.128	27	0.069	6.92×10^{-4}	0.0589	32.8	0.0328	0.1281
10	2.56×10^{-4}	0.258	40	0.103	1.026×10^{-3}	0.1538	34.6	0.0346	0.1315
20	5.13×10^{-4}	0.513	65	0.167	1.667×10^{-3}	0.346	33.6	0.0336	0.1296
40	1.03×10^{-3}	0.103	100	0.256	2.564×10^{-3}	0.769	33.4	0.0334	0.1292
80	2.05×10^{-3}	0.205	216.66	0.556	5.555×10^{-3}	1.496	34.4	0.0344	0.1311
100	2.56×10^{-3}	0.256	283.33	0.726	7.265×10^{-3}	1.838	34.6	0.0346	0.1315

11	12	13	14	15	16	17	18	19	20
3.79×10^{-3}	2.659	0.0398	0.07821	0.8352	0.31284	0.4865	0.6975	1.1974	4.54×10^{-3}
5.40×10^{-3}	3.410	0.051	0.0859	0.8205	0.3439	0.4530	0.6730	1.2191	6.59×10^{-3}
7.79×10^{-3}	3.410	0.051	0.0859	0.8205	0.3439	0.4530	0.6730	1.2191	9.51×10^{-3}
0.01286	3.410	0.051	0.0859	0.8205	0.3439	0.4530	0.6730	1.2191	15.68×10^{-3}
0.0198	3.468	0.052	0.0864	0.8195	0.3458	0.4510	0.6715	1.2205	24.17×10^{-3}
0.0424	3.526	0.053	0.0869	0.8187	0.3479	0.4488	0.6699	1.2219	51.81×10^{-3}
0.0552	3.584	0.054	0.0874	0.8177	0.3499	0.4467	0.6684	1.2233	67.53×10^{-3}

Appendix-19. Calculations of Q/I parameters in soil (Khanapur, 0-15 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	17	0.044	4.36×10^{-4}	-0.0436	33.0	0.033	0.1284
5	1.28×10^{-4}	0.128	29	0.074	7.44×10^{-4}	0.0538	33.0	0.033	0.1284
10	2.56×10^{-4}	0.258	41	0.105	1.05×10^{-3}	0.1513	33.2	0.0332	0.1288
20	5.13×10^{-4}	0.513	66	0.169	1.69×10^{-3}	0.344	33.2	0.0332	0.1288
40	1.03×10^{-3}	0.103	116.66	0.299	4.27×10^{-3}	0.7265	33.8	0.338	0.1300
80	2.05×10^{-3}	0.205	250	0.641	6.41×10^{-3}	1.4103	34.2	0.342	0.1308
100	2.56×10^{-3}	0.256	316.66	0.812	8.12×10^{-3}	1.752	34.2	0.342	0.1308

11	12	13	14	15	16	17	18	19	20
3.39×10^{-3}	3.410	0.051	0.0859	0.8205	0.3439	0.453	0.673	1.219	4.14×10^{-3}
5.79×10^{-3}	3.355	0.050	0.085	0.8214	0.3419	0.455	0.675	1.218	7.05×10^{-3}
8.16×10^{-3}	3.295	0.049	0.0849	0.8224	0.3396	0.457	0.676	1.216	9.93×10^{-3}
0.01314	3.353	0.050	0.0854	0.8215	0.3419	0.455	0.675	1.218	16.00×10^{-3}
0.0329	3.468	0.052	0.0864	0.8196	0.3458	0.451	0.672	1.221	40.16×10^{-3}
0.0490	2.890	0.043	0.0806	0.8306	0.3227	0.476	0.689	1.204	59.01×10^{-3}
0.0621	3.468	0.052	0.0864	0.8196	0.3458	0.450	0.672	1.221	75.79×10^{-3}

Appendix-20. Calculations of Q/I parameters in soil (Khanapur, 15-30 cm)

1	2	3	4	5	6	7	8	9	10
0	0	0	11	0.028	2.82×10^{-4}	-0.0282	34.6	0.0346	0.1315
5	1.28×10^{-4}	0.128	22	0.056	5.64×10^{-4}	0.0718	33.0	0.0330	0.1284
10	2.56×10^{-4}	0.258	36	0.092	9.23×10^{-4}	0.1641	32.8	0.0328	0.1281
20	5.13×10^{-4}	0.513	65	0.167	1.67×10^{-3}	0.3462	33.2	0.0332	0.1288
40	1.03×10^{-3}	0.103	116.66	0.299	2.99×10^{-3}	0.7270	33.0	0.0330	0.1284
80	2.05×10^{-3}	0.205	266.66	0.684	6.84×10^{-3}	1.368	34.4	0.0344	0.1311
100	2.56×10^{-3}	0.256	333.33	0.855	8.55×10^{-3}	1.709	34.2	0.0342	0.1308

11	12	13	14	15	16	17	18	19	20
2.15×10^{-3}	3.295	0.049	0.0849	0.8224	0.3396	0.4575	0.6763	1.216	2.61×10^{-3}
4.39×10^{-3}	3.237	0.049	0.0841	0.8239	0.3367	0.4605	0.6786	1.214	5.33×10^{-3}
7.21×10^{-3}	3.237	0.049	0.0841	0.8239	0.3367	0.4605	0.6786	1.214	8.75×10^{-3}
0.0129	3.295	0.049	0.0849	0.8224	0.3396	0.4575	0.6763	1.216	15.68×10^{-3}
0.0233	3.353	0.050	0.0854	0.8215	0.3419	0.4550	0.6746	1.218	28.36×10^{-3}
0.0522	3.353	0.050	0.0854	0.8215	0.3419	0.4550	0.6746	1.218	63.56×10^{-3}
0.0653	3.468	0.052	0.0864	0.8195	0.3458	0.4510	0.6715	1.221	79.70×10^{-3}

Vita

8. VITA

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