

**Studies on the Pedogenesis and Potassium Supplying
Capacity of the Bench Mark Soils of Kashmir**

thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE
(Soil Science and Water Management)

BY

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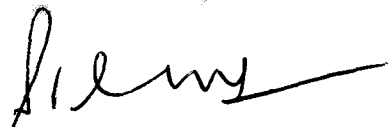
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The assistance and the help received during the course of investigation have been fully acknowledged.

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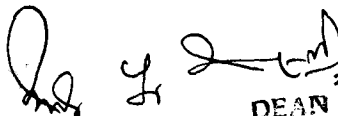
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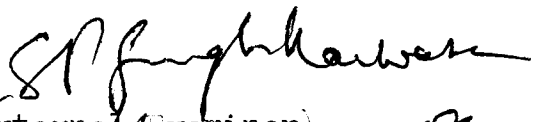
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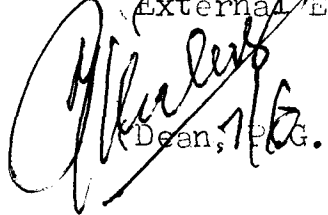

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(Abdul Rashid Talib)

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CHAPTER I

INTRODUCTION

The State of Jammu and Kashmir is mostly a mountainous region of 222,236 square kilometer, with 15.8 per cent of the total area under cultivation and has many valleys of varying dimensions. The State is located in the North Western corner of the Himalayas. The variation in altitude, temperature, precipitation and topography has consequently affected the pedogenic processes particularly in the Kashmir region wherein the effect of climate and vegetation is more pronounced on the soil formation. The resultant effect of these pedogenic processes is the production of primary and secondary minerals, which influence the availability of potassium.

The availability of potassium to plants is related in many ways to the structure and morphology of soil minerals. The large part of potassium in soil minerals, fixation of applied potassium and varied ion selectivity have led research workers to study the relationship between potassium uptake by plants and soil mineralogy for many years (Rich, 1972). It is established that in most soils more than 99.5 per cent of the total K reserves is accounted for by the inorganic forms. So far as the available forms of K are concerned, clay fraction appears to be the most important factor in the soil. The clay not only acts as a store house of nutrients, but other important soil properties like ion exchange equilibria, fixation and diffusion of ions etc., are also controlled by the nature of clay fraction. The properties of the clay fraction obviously depend not only on the dominant

mineral present but also on the whole assemblage of the minerals present in it. It is, therefore, imperative to elucidate the detailed mineralogy of not only the clay fraction but also of the coarse fraction in an attempt to understand the role of a particular soil in supplying potassium to the plants.

Potassium is present in soil in various forms; water soluble, exchangeable, non-exchangeable and inert K held deep in the crystal lattice. All these forms are of varying ability to supply K to the plants and are in dynamic equilibrium with each other. It is important to know the magnitude of different forms of K for a proper appraisal of K-supplying power of the soil. The determination of the K status of soil is usually carried out by extracting the soils with salt solutions, weak or strong acids or buffers of acids and their salts. Depending on their composition these solutions extract the loosely bound K and a variable proportion of more tightly bound K from external and internal surfaces of the soil matrix and the amount extracted more or less approximates with exchangeable K. Exchangeable K is a measure of the quantity which can be relatively easily mobilized as compared to the non-exchangeable K. But no information is obtained as to the rate at which it is mobilized, thus no true evaluation of availability can be made. There are instances where exchangeable K may even be misleading (Grimme, 1976). Beckett (1964) developed the Quantity/Intensity relationship of nutrients with particular reference to K to provide a

scientific basis of nutrient availability concept. From Beckett's recommended experimental procedure one basically obtains a measure of the pool of labile K i.e. quantity factor and also a measure of the intensity at which the soil is capable of supplying the nutrient to the plants.

There is very little information available on this aspect of K-chemistry of soils of Kashmir which are alluvial in nature, predominantly illite (Ghosh and Kapoor, 1982) and are rich in K-status. But with high yielding crop varieties and better fruit plants make a considerable demand on the soil potassium reserves. Therefore, even soils currently sufficient in K-status may begin to show response to K when higher amounts of N and P are applied.

The study of mineralogy in relation to potassium chemistry in assessing the K-availability is likely to throw more light in K-supplying pattern of these soils. In view of such close relationship of mineralogy to general aspect of soil fertility particularly K, the present investigations have been made in soils from various zones of Kashmir with the following objectives:

- a. To characterise the typical soil pedons of Kashmir for their morphological, physico-chemical properties, genesis and their classification into Taxonomic Units of USDA comprehensive system.

- b. To identify primary and clay minerals in the selected soil profiles.
- c. To find out the relationship between different K-fractions, important physico-chemical properties and mineralogy of the soil.
- d. To find out the relationship of soil separates with various forms of K and K-fixing capacity.
- e. To find out the free energy, content of labile K and potential buffering capacity before and after cropping from Q/I ratios and their relationship with K-uptake.

CHAPTER II

REVIEW OF LITERATURE

A brief and pertinent review of literature related to various studies in the purview of present investigation is described below under the following heads:

1. Pedological characteristics
2. Mineralogical studies
3. Potassium supplying capacity

2.1 Pedological characteristics

Very few pedological reports are available on the soils of Kashmir, however, the review as could be available is presented.

The studies of Hoon (1939) revealed that the soils developed under deodar and blue pine in Kashmir valley showed podzol characteristics and those under deodar from Batote range resembled brown earths. Iyer and Dutta (1982) reported that shallow skeletal soils formed from quartzite rock usually support chir pine, while deep moist soils developed on phyllite, shale and schist carried a good stand of blue pine, deodar and spruce in Kulu Himalayas. Raychaudhury and Govinda Rajan (1971) classified soils of Jammu and Kashmir into Alluvial soils, Brown soils and Sub-montane soils. The Sub-montane soils are found in the Sub-Himalayan region and include the whole of Kashmir region. The soils of the valley have resulted from the alluvium deposited by major rivers like Jhelum, Sindh and their tributaries. The soils were classified as Aquept, Ochrept, Aquod, Orthod, Aquent, Ustent and Udent. Talib (1973) while studying the Karewa soils of Kashmir, classified them into Udalfs, Ochrepts and Fluents.

The cold arid soils of Ladakh were classified into Cryorthents (Gawande et al 1979) and Cryoboralfs while temperate soils of Kashmir into Argiudolls, Ochraqualfs, Hapludalfs, and those of Jammu region into Ochraqualfs, Hapludalfs and Haplustalfs (Handoo, 1983).

Soil survey conducted in Pohru catchment of Kashmir by Indian Photointerpretation Institute, Dehradun (Iyer and Dutta, 1982) classified the soils of the catchment into Hapludolls, Argiudolls and Udorthents. They further reported that the soils of the valley are predominantly heavy textured with silty loam to silty clay loam as the predominant texture. This supports the view of Gupta et al (1980) and Handoo (1983).

2.1.1 Physico-chemical properties:

Cation exchange studies are helpful in soil classification and to know the nutrient status of the soil. The cation exchange capacity and exchangeable cations of Kashmir soils, as studied by various workers (Lall, 1959; Gupta et al, 1980 and Handoo, 1983) varied from 20 to 33 me/100g soil. The soils were highly base saturated and exchangeable calcium was the predominant cation and varied from 10.0 to 16.83 me/100g. Exchangeable magnesium and exchangeable potassium varied from 2.25 to 4.0 and 0.33 to 7.16 me/100g soil respectively. Ahmed and Jones (1969) reported that calcium was found to be a dominant cation in calcareous grumusols (derived from lime stone) and exchangeable magnesium in volcanic ash grumusols.

2.2 Mineralogical studies

2.2.1 Petrographic study of sand fraction of soil

The sand fraction contains mainly primary and accessory minerals derived from the parent rocks by the process of weathering. In subsequent stages of soil development the weatherable minerals of this fraction undergo physical comminution and chemical disintegration and supply the reactant component of the soil material for the weathering reaction resulting in the genesis of secondary minerals in the soil. The resistant minerals of this fraction determine the uniformity of parent material down the profile. Thus the mineralogy of sand fraction together with the relative abundance of the various minerals present contributes to the much needed information about the genetic correlation between the rocks and the soil and the effect of weathering process on the disintegration and disappearance of minerals and the formation of new secondary minerals. The work pertaining to this topic is reviewed here in.

Roonwal and Garalapuri (1982) reported that the fine sand fraction of red and red loam soils of Andhra Pradesh and Coimbatore, consisted largely of quartz and feldspar (orthoclase microcline and plagioclase) alongwith other minerals such as hornblende, iron oxide and zircon. The mineralogy of the soils indicate that they are derived from gneissic complex parent material. The heavy mineral crop includes hypersthene augite indicating the influence of charnokite rocks in the area.

The laterite soils are usually reported (Roonwal and Garalapuri, 1982) to be composed of zircon, tourmaline, staurolite, rutile, hornblende, epidote and chlorite as heavy minerals whereas quartz and feldspar is dominant in the light fraction. Das (1977) while studying the red and laterite soils of West Bengal reported that quartz is predominantly high with some feldspars (both plagioclase and orthoclase) in all horizons. He attributed it to excessive leaching under moderate acidic conditions in the tropical region.

Bhargava et al (1973) while studying the Tunga-bhadra catchment soils of Karnataka, used sand mineralogical make up in classifying these soils. The soils of younger origin had more amount of readily weatherable minerals viz. pyroxene and amphiboles whereas the soils which have undergone prolonged weathering were lacking in such minerals and in turn were dominated by zircon, garnet, iron ores and epidote. On the contrary the soils occupying intermediate position with regard to the degree of weathering, contained amphibole in significant amount.

Sehgal (1970) reported that there was regular decrease in hornblende in sand fraction as one proceeds from the aridic through ustic to the udic soil groups in Punjab. Pundeer et al (1974) found rounded garnet and quartz grains with growth structure as well as the heavy mineral suite in some flood plain soils of Punjab on the basis of which they assumed that the parent material of these soils were derived from the reworked Shiwalik formations and attributed low fertility to the lack of easily weatherable minerals.

Roonwal and Garalapuri (1982) report about the Indo-Gangetic alluvial soils that they are filled with material brought by the Himalayan as well as Peninsular rivers. The sand mineralogy of these alluvial soils shows quartz, micas, chlorite and a few feldspars and heavy resistant minerals such as tourmaline, garnet, zircon, apatite, gypsum, calcite, barite and fresh potash feldspars. Muscovite-biotite and chlorite appear to be related to the illite chlorite clays in some low rainfall areas of Northern India.

Dutta (1960) and Gupta et al (1983) report the light fraction of the sand of Kashmir soils was dominated by quartz, orthoclase feldspar, plagioclase, muscovite, mica and heavy fraction contained ilmenite rutile, garnet, zircon and opaque minerals.

2.2.2 Mineralogy of clays:

Mineralogy of clays in a soil reflects the effect of the impact of the forces of weathering in the process of soil development. Clay minerals are the altered products of primary minerals. Determination of the kind and relative amounts of clay minerals is essential to understand more fully such soil physico-chemical properties as cation exchange capacity, potassium reserves and its rate of release. Potential knowledge of soil clay minerals is also required for placing soils with more than 35 per cent clay content into correct family classes according to Soil Taxonomy.

Comprehensive reviews on the nature and distribution of clay minerals in Indian soils is available but the information in respect of mountain soils particularly of Jammu and Kashmir is inadequate. Sehgal and De Coninck (1971) and Sehgal (1974) studied the geographic distribution of clay minerals in soils of different moisture regimes in parts of Punjab and Haryana and reported that the soils were dominantly illitic but some kaolinite and intergrade minerals such as chloritised vermiculite or smectite rather than true chlorite was also present. Their observation regarding chlorite was, however, discounted by Sidhu and Gilkes (1977) who contended that true chlorite was of wider occurrence in the alluvial soils of North-Western India.

Ghosh and Kapoor (1982) reported illite (mica), smectite, chlorite and kaolinite in the fine clay fractions of some semi arid soils of eastern Rajasthan and western Uttar Pradesh. Most of the West Bengal alluvial soils have dominance of smectite (30-60 percent), mica (10-40 per cent) and kaolinite (6-10 per cent) with occasional presence of mixed layer minerals (10-38 per cent) and chlorite (7-18 per cent) as the other associated constituents in clay fractions. Pundeer et al (1978) made quantitative studies on some soil profiles of central Punjab and reported illite (37-66 per cent), kaolinite (10-26 per cent), chlorite (15-18 per cent), vermiculite (4-18 per cent) and smectite (2-13 per cent) in clay fraction.

Kapoor et al (1982) investigated the nature and semi-quantitative distribution of clay mineral constituents of clay and silt fractions of Haryana and Punjab and reported illite

(23-34 per cent), chlorite (10-20 per cent), smectite or chlorotised - smectite (10-40 per cent) and mixed layer minerals of the type illite-chlorite and illite-smectite (15-30 per cent) together with some vermiculite (2-14 per cent) in the clay fraction. Saxena and Singh (1983) reported that illite, chlorite, vermiculite and montmorillonite were present in alluvial soils of Rajasthan. Sahu et al (1983) reported about clay mineralogy of Assam soils that mica, chlorite, and kalinite were predominantly present in these soils besides some mixed layer minerals. From studies on some saline deltaic alluvial soils of coastal West Bengal, Ghosh and Kapoor (1982) reported illite as the dominant mineral (45 per cent) with smectite (25 per cent), vermiculite (10 per cent), chlorite (8 per cent), kaolinite (5 per cent) and mixed layer minerals present rarely. They reported the occurrence of kaolinite and halloysite (34-37 per cent) in association with smectite (18-32 per cent) illite (6-12 per cent) chlorite (4-11 per cent), vermiculite (5 per cent) and inter-stratified minerals (4-12 per cent) in acid sulphate soils of Kerala. The clay mineralogy of some sodic soils of Haryana contained illite (29-35 per cent), smectite (17-20 per cent), vermiculite (4-7 per cent), chlorite (9-11 per cent) and kaolinite was practically absent. Besides mixed layer minerals (15-30 per cent) of the type illite-smectite, illite chlorite, illite-vermiculite and smectite-chlorite were also present. Black soils developed in basalt in Malva plateau were found to contain 70-85 per cent smectite and some red soils from West Bengal revealed the dominance of kaolinite (50-55 per cent) in association with illite (25-35 per cent), smectite (10-15 per cent), chlorite (0-5 per cent) and mixed layer minerals (0-5 per cent).

Laterite soils of West Bengal though dominant in kaolinite (40-60 per cent) contained appreciable quantity of mica (20-29 per cent) together with (4-7 per cent) smectite, (7-20 per cent) mica layer and (4-7 per cent) chlorite in the clay fraction (Ghosh and Ray Chaudhuri, 1974). Kaolinite with occasional presence of halloysite has been found to be the major constituent of the laterite soil clay irrespective of the parent material and location of the pedon in the landscape (Ghosh and Kapoor, 1982).

The clay mineralogy of hill-mountain soils has not been studied much. Clay mineralogy of soil profiles developed on different parent materials in some Himachal Pradesh soils were reported to contain illite, smectite/chlorotised -smectite, chlorite, kaolinite and occasional presence of mixed layer minerals (Sehgal, 1974 and Gupta, 1980).

Clay mineralogical studies of Kashmir soils reveal that illite was the dominant clay mineral besides kaolinite, chlorite, smectite and montmorillonite present in fair amounts (Dutta, 1960; Talib, 1973 and Gupta et al, 1983). Mineralogical variation of alluvial soils reflects the difference of their original materials rather than that of pedogenic processes (Quan Xu Ji, 1983).

Some studies of clay mineralogy in relation to different factors of soil formation such as climate, vegetation and parent material have appeared in literature. The soils developing on granites and pegmatites were rich in kaolinite (Ghosh and Ray Chaudhuri, 1974). While those developed on slates and shales showed the dominance of illite (Kanwar, 1961). According to

Tamhane and Namjoshi (1959) the montmorillonite was the weathering product of limestone and granite - gneiss rocks. Grim (1968) has reported that soils having montmorillonite and kaolinite could be developed from the same parent material under different conditions of climate, time and topography. Tamhane and Karele (1967) also reported that the montmorillonite was the dominant clay mineral under less rainfall conditions, while kaolinite under high rainfall conditions in soil of Maharashtra originated from basalt parent material, while kaolinite was reported to be the predominant clay mineral in soils of humid tropics (Prasad et al, 1969).

2.3 Potassium supplying power of the soils

Potassium supplying power of a soil is defined (Nash, 1971) as the amount of K absorbed by growing plants from soil solution, exchangeable and non-exchangeable forms. Potassium is a major inorganic constituent of plants and its deficiency affects several metabolic processes. Potassium is relatively abundant and widely distributed constituent of the surface rocks of the earth and comprises 2.6 per cent of the lithosphere. Through weathering potassium is set free to the soil which has a K content varying between < 0.1 and > 3 per cent K most frequently about 1 per cent (Schroeder, 1978), thus present in substantial quantities in most of the soils but its availability to plants differs and is related in many ways to the physical chemistry and structure of the soil minerals. Since the various forms of K in the soil exist in a sort of equilibrium with each other, it is imperative to know the magnitude of different forms of potassium for an appraisal of K supplying power of the soil.

The work pertaining to this part is reviewed as under:

2.3.1 Potassium and its distribution

2.3.1.1 Mineralogy of soil potassium

Potassium contained in minerals is found predominantly in primary and secondary crystalline silicates. K feldspar and K-mica, are the two major groups of K-bearing minerals and among the micas, biotite is more abundant than muscovite (Schroeder 1978). Secondary K-bearing minerals, typified by illite and the transitional clay minerals are found in variable quantities. During the process of weathering of K-bearing minerals, K is released. Young-unweathered soils are mainly rich in K-bearing minerals and may release high quantities of K (Mengel and Kirkby, 1980).

The alluvial soils of northern India have been formed from the weathering of the sedimentary rocks of the Himalayas while those of the southern parts of the country from the decomposition of rocks from Peninsular mountains which are mainly composed of crystalline and metamorphic rocks and some igneous and sedimentary rocks (Govinda Rajan and Gopala Rao, 1978 and Wadia, 1960). Most of the alluvial soils have more than 1 per cent K_2O . Weathering and release of K from feldspar is very slow process (Sarma, 1976; Sekhon, 1976). Muscovite, biotite, orthoclase are the principal potash bearing minerals in Punjab soil. The content of these minerals are estimated as 5-30 per cent, 2-15 per cent and 1-5 per cent, respectively. Micas are more susceptible than feldspar to weathering (Rich, 1972; Rasmussen, 1972). Feldspar and micas are mainly present in the sand and silt fractions of

soils. Illite admixture with chlorite is the dominant clay mineral in the alluvial soils of India, (Ghosh and Kapoor, 1982). Vermiculite mixed with illite, vermiculite and chloritized intergrades of vermiculites occur as important constituents (Sehgal and De Coninck, 1971). Of the clay minerals, the illite group (clay mica) is considered to be the only one having a substantial K content (Reitemeier, 1951).

The source of potassium in black soils of India (Sarma, 1976) are mainly orthoclase microcline, muscovite and biotite as they release K on weathering. Quartz, feldspar and micas (muscovite and biotite) are present in varying stages of weathering in red soils. The magnitude of K release from these minerals is in the order biotite > muscovite > orthoclase > microcline (Huang et al 1968).

2.3.1.2 Forms of potassium and their availability

Arnold (1962) reviewed the availability of K to plants and listed four forms that occur:

- i. Water soluble is the quantity of K, at any time dissolved in the soil solution under field moist conditions.
- ii. Exchangeable K is held against negative charges on soil colloids and is replaced with cations of neutral salts in a relatively short period. This form replenishes the water soluble K that is removed by crops.
- iii. Non-exchangeable K but useful K, is held in the outer part of the crystal lattice of clay minerals and this form may be "native soil potassium" or it may have accumulated there. This fraction replenishes the exchangeable K

iv. Inert K is held deep in the crystal lattice. All these forms are of varying ability to supply K to the plants and there exist a dynamic equilibrium among these forms. The basic concept of such equilibrium is that a change in the magnitude of one form will tend to be compensated from another form. Hence study of each form is meaningful and has got its own importance in the K availability evaluation.

Although water soluble K is invariably present appreciable quantities are not likely to occur except by application of soluble potassic fertilizers (Reitemeier, 1951).

Apart from the concept of contact exchange feeding by roots on exchangeable cations, it is presumed that soil K entering roots must be in soluble form. K concentration in the soil solution which when depleted by plant roots via the solution phase from both exchangeable and non-exchangeable form is controlled by K releasing potential of soil minerals (Eagle, 1963).

According to Halsted and Jenny (1959) water soluble K was found to decrease with increasing clay content. Grimme (1976) attached a greater importance to the water soluble form as it constitutes the fraction actually available at a given time and because its concentration affects the uptake role of K by plants.

Application of potassic fertilizers increases the concentration of potassium in soil solution by saturating the inorganic CEC with K (Roy et al 1978) but it is likely to result in fixation of potassium due to shifting of potash equilibria (Wiklander, 1954).

Exchangeable K:

The exchangeable K of a soil is difficult to define theoretically and to determine experimentally for at least three reasons:

- a. the absence of a sharp distinction between soluble and exchangeable fractions.
- b. existence in some soil of difficulty exchangeable K which is not immediately extractable from the usual reagents and;
- c. the dissolution of mineral potassium by exchange extractant (Reitemeier, 1951).

Existence of three different sites has been proposed by Schouwenberg and Schuffelen (1963); planer, edge and inter lattice, each with its specific exchange constant, rapidly exchangeable K occupying the planer and edge inter-lattice (Bolt et al 1963 and Rich, 1964). It has also been reported that a small number of sites are of high preference to K and large number are non-specific to K (Lee, 1973).

Non-exchangeable K:

Bray and De Turk (1939) suggested the importance of micaceous clays as a source of non-exchangeable K used by the plants. They postulated that the micaceous clay represent a reservoir of unavailable K with which the exchangeable K slowly comes to equilibrium. Arnold (1962a) states that the inherent K fertility depends on the K release from the non-exchangeable sources. The release is highest from the soils derived from the basic rocks and lowest from soil derived from the sand stone

(Sobulo, 1973). In the soil its quantity depends on the type of clay minerals and it is normally more in the illite dominant and least in the kaolinite dominant soils (Black, 1968, and Ross, 1972). It has also been demonstrated that a decline in total fertility occurred due to release of K from this form (Mehta, 1976; Singh and Brar, 1977). Ghosh (1964) found a high percentage utilization of non-exchangeable K by plants. The amount of non-exchangeable K repeatedly extracted with NHNO_3 correlated with the K uptake from crops (MacLean, 1961).

The availability of K in soil depends on many factors including the kind of parent material, clay minerals, weathering conditions etc. Correlation of available K in soil with pH, CaCO_3 and organic matter have been found to be positive and significant (Acquaye, 1974). Available K has been reported to range from as low as 0.02 per cent of total K in sandy soils of Tamilnadu (Premanathan and Durairaj, 1966) to 0.5 - 1 per cent in soils of Punjab and Bihar (Grewal and Kanwar, 1966, Tiwari et al 1967) and about 3 per cent of total K in alluvial soils of Rajasthan (Dhawan et al 1968).

The magnitude of other forms of K in alluvial soils also greatly differs from place to place. Grewal and Kanwar (1966) found that Punjab soils contained on an average 1.4 to 2.7 per cent K_2O of which 30 per cent was HCl soluble, 6.1 per cent was in HNO_3 soluble (fixed) and water soluble K was 12.8 ppm. Alluvial soil of Uttar Pradesh are comparatively rich in water soluble and HCl soluble K (Mehrotra et al 1973). Contribution of clay to total K is more in black soils while that of sand and

silt fractions is more in alluvial soils of Madhya Pradesh (Dhawan et al 1968). This suggests that in alluvial soil K bearing minerals are more in the coarser fractions (Ghosh and Ghosh, 1976).

The clay contains 3.03 to 4.13 per cent total K, silt contains 1.78 to 2.77 per cent and fine sand 1.0 to 1.93 per cent total K. The clay contains 1.45 to 2.17 per cent HCl soluble K, silt contained 0.54 to 1.24 per cent and in fine sand HCl soluble K was 0.17 to 0.40 per cent. The clay contains 0.36 to 0.53 per cent fixed K - 1NHNO_3 , silt contains 0.09 to 0.30 per cent and fine sand contains 0.02 to 0.31 per cent. This was reported by Kanwar and Grewal (1966), Lodha and Seth (1970) and Mehrotra et al (1973).

Generally the exchangeable and water soluble K is more in the surface soil than in the sub soil (Chandhuni and Pareek, 1976) This difference is more in coarse textured soils than in fine textured soils. This variation is attributed to (1) relatively more intense weathering of the surface (2) release of soil K from organic residues (3) application of potassic fertilizers and (4) upward movement of soluble K due to capillary rise of water (Chandel et al (1976). Singh and Sekhon (1977) reported that in summer K saturation was maximum in the 0-30 cm layer and minimum in the 180-225 cm layer. It increased in October which was attributed to release of K from illite minerals in 30-225 cm position of the profile during rainy season and subsequent accumulation in layer deeper than 180 cm. It was

further observed that percentage K saturation decreased with the depth in the profile and decrease was irrespective of clay content or CEC of the soil.

The bulk of potassium in Black soils is present in HCl soluble and non-exchangeable forms. Exchangeable K varies from 0.06 me to 4.65 me/100g and the water soluble K forms a very small fraction of the available K. In general, black soils have fairly high content of exchangeable K (Nagarama et al 1976 and Mehta, 1976). Red soils (Verma and Verma, 1968) (Pareek et al 1972) usually have low content of exchangeable and non-exchangeable K which was ascribed to their low clay content and dominant presence of kaolinite in their clay. Grewal and Kanwar (1966) reported total K_2O content in most of Punjab soils was 1925 mg/100g and average total K content in most of the Uttar Pradesh soils was 1940 mg/100g (Mishra and Harishanker, 1970).

The total K content in Maharashtra soils have been observed by Kadrekar and Kibe (1972) to be 688 mg/100g. The total K content in some Himachal Pradesh soils (Gopal Das and Shankhayan, 1979) and Suresh (1979) varied from 1.02 to 2.62 per cent and non-exchangeable K from 145 to 500 ppm. Handoo (1974) observed that the water soluble K varied from 7.60 to 13.80 ppm, exchangeable K from 98 to 283 ppm, non-exchangeable K from 488 to 936 ppm K and total K from 1.40 to 1.54 per cent in some of soils of Kashmir. Of the various laboratory methods, extraction with boiling $1N HNO_3$ correlated better with the continuous cropping technique for the determination of non-exchangeable K uptake by the plants (MacLean and Brydon, 1963). Lack of response to K fertilizer in many soils may be partly

attributed to the greater ability of the soil to release non-exchangeable K (Nash, 1971). The K released from the minerals due to weathering and delivered to the roots must pass through the exchange sites or may reach soil solution directly. According to Grimme (1970) much dependence on the release from the non-exchangeable sites may mean reduction in soil fertility status unless replenished from recycling.

Atage (1973) observed that the amounts of non-exchangeable K extracted from various soil fraction were in the order; clay > silt > sand fraction in Nigerian soils. Munn et al (1976) noted that in four Ohio soils the clay was found to contribute 20-74 per cent, silt 25-56 per cent and sand 3-21 per cent of the total K.

It is found that when potash fertilizer had not been applied to soil, a gradual conversion of non-exchangeable K to the exchangeable form took place during the cropping season, soils fully saturated with calcium with no added K were found to supply plant growth indicating that K was being released from non-exchangeable forms, (Gholstone and Hoover, 1949).

2.3.1.3 K-fixation

Page and Baver (1940) related the fixation to the size of the unhydrated ions. It was postulated that the diameter of K was (2.66 Å), was close to that of size (2.8 Å) of hexagonal oxygen cavity. The fixation is zero with kaolinite, chlorite and micas, slight with montmorillonite variable with illite according to their degree of alteration (K content) and strong

with vermiculite (Duthion, 1968). The phenomenon of potassium fixation i.e. conversion of exchangeable and water soluble K into moderately or slowly available non-exchangeable K is a part of the potassium dynamics in soil.

Movement of water soluble K to exchangeable K is the first step in K fixation and there exists a significant positive correlation between adsorbed and fixed K (Grewal and Kanwar, 1973) and attributed K fixation to illite type of clays (Prasad et al 1967).

A decrease in pH has been found to be associated with the reduction in potassium fixation in some soils of India and Bangladesh, (Bagchi and Ray, 1975; Kade et al 1978 and Karim and Malik, 1957).

The presence of NH_4 ions reduce K-fixation (Sen Gupta et al 1971). Alternate wetting and drying influences considerably the fixed K \rightleftharpoons exchangeable, soluble K reaction in soil. If the exchangeable K is more there is fixation and if it is less there is release (Grewal and Kanwar, 1973). Drying at higher temperature results in an increase in K fixation (Bagchi and Ray 1975) Karim and Malik, 1957). This is because higher temperature favours dehydration and contraction of crystal lattice. The extent of K fixation differs because of the differences in the nature and content of clay besides other factors. It has been reported to be about 57 per cent in soils of Uttar Pradesh, (Pathak and Sharma, 1963), 16-21 per cent in Punjab (Grewal and Kanwar, 1967) and increased with an increase in the amount of applied K

(Ramakrishnayya and Chatterjee, 1976). The K fixing capacity of red soils is less than black and alluvial soils (Ramanathan and Krishnamoorthy, 1976). In most of the Himachal Pradesh soils (Suresh, 1979) K fixing capacity varied from 375 to 650 ppm and attributed it to the presence of illite in these soils.

The other part of the dynamic equilibrium is the release of K from non-exchangeable or fixed fraction. Plants are able to take more K from the soil than is present in water soluble and exchangeable forms, indicating that K is released from non-exchangeable sources for use by crop plants. Alluvial soils contain much higher amount of fixed K than soluble and exchangeable forms (Mehrotra and Singh, 1970). Sachdeva (1975) observed that non-exchangeable K contributed towards the crop requirements at high yield levels in medium K-soils and the contribution of soil available K towards crop removal was an elastic one, varying widely with yield levels.

Clay minerals, addition of K fertilizers, soil reaction, free lime, alternate wetting and drying and organic carbon are some of the factors affecting K fixing capacity of soil. Application of ammonium sulphate significantly decreased the availability of potassium. Superphosphate behaved similarly when applied in large amounts (Patil et al, 1976). Potassium fixation not only protects soil K against leaching but it also renders it more difficultly available to plants (Mitra et al 1958).

2.3.1.4 Potassium uptake:

Ahenkorah (1970) using perennial grasses in pot experiments found that the release of non-exchangeable K varied from 5 to 1200 kg/h. Mehta (1976), however, found the release from 250 to 480 kg/h. Kadrekar and Kibe (1972) found that 36 to 80 per cent of the total K uptake came from the non-exchangeable fractions. A wheat and a maize crop grown in succession remove about 150 to 200 kg/h/yr and at such a rate of removal the total potassium may last only about 200 to 300 years provided all of it is susceptible to adsorption by crops. But a portion of K removed by crops is returned to it in the form of organic manures and plant residues (Sekhon, 1976). Six successive crops of bajra removed 654 kg K/h out of which the non-exchangeable K contributed 81 per cent of the total K taken up by the crops (Mehta and Shah, 1956).

Potassium release characteristics of soils have been computed. The cumulative K release during the successive extractions with 0.01 N HCl has been found to be positively correlated with K uptake by a ragi crop (Ramanathan, 1975).

The K-content in 40-days old wheat plant was 2.96 per cent and uptake of K was significantly higher in barley at 40 days after sowing but lower at 100 day after sowing than wheat. Increasing rate of N increased the total K-uptake (Sandil, 1979). K-uptake is rapid in early stage of growth, during the time of peak uptake rate, K is taken up at a rate of 2.0 to 3.3 kg/h/day by wheat and 3.1 to 6.0 kg/h/day by maize. Maximum K uptake is reached some time before maximum dry matter production and K

content decreases as the grain matures. Wheat takes 70-75 per cent of its K need by anthesis with 40-60 per cent during tillering and ear initiation (Rejado, 1978).

Goswami et al (1976) observed differences in the magnitude of crop response to fertilizer potassium between various soil groups. Laterites, red and black soils are generally the most responsive to K and observed that rice tended to respond to potassium more than wheat.

Albrecht (1940) has observed that the plants which are notably high in carbohydrate production and low in protein production have a higher K and Ca requirement than leguminous plants that are mostly high in protein. The K content was higher in the beginning of plant growth and decreased with an increase in the age of plant. A wheat plant of 35 days old had 5.36 per cent K (Singh and Singh, 1981) whereas in leaf it varied from 3.09 to 4.66 per cent (Lodha et al 1969). Young seedlings take up K very rapidly and 2 to 6 per cent K in corn plants 15 cm high was observed. Higher levels of potassium ensure adequate crop uptake of K under conditions of low soil temperature and reduced frost damage. Grewal and Sharma (1978) recorded a marked effect of potassium in mitigating frost injury to potato.

2.3.1.5 Physico-chemical approaches:

No single chemical extractant can be recommended for all types of soil for predicting the K-availability to plants. K estimated by the chemical extraction method serves as a workable index to what is available for the plant at the time of estimation. It does not indicate the changes in availability

of K from the soil or with what intensity it is available for the plant as K depletion from the soil occurs either due to crop removal or due to leaching. Thus to obtain a clear picture of K-supplying power of the soil (Beckett, 1964b) introduced Quantity/Intensity relations.

Activity ratio: The availability of a nutrient can best be described by the total amount that would be available for the crop during its growth i.e. the total labile pool or quantity factor and the intensity with which it would be available. The quantity factor (ΔK) and the intensity factor (AR^k) proposed by Beckett (1964) give a better picture of the potassium supplying power of a soil than available K or ionic activity ratio of potassium. He has proposed Activity ratio of potassium (AR^k) i.e. $\frac{a_k}{\sqrt{a(Ca+Mg)}}$ as the intensity factor. This technique consists of equilibrating the soil with a known graded AR^k solution having different amount of K. The activity ratio of the solution to which the soil neither gains nor releases K is taken as the equilibrium activity ratio of potassium (AR_e^k) in the soil. From the composition of the equilibrium solution the K lost or gained by the soil ($\pm \Delta K$) is computed and a plot of $\pm \Delta K$ and AR^k of the equilibrium solution is made. The curve obtained fully describes the Q/I changes in the soil. The potential buffering capacity (PBC) (Beckett, 1964) combines in one parameter the Quantity - Intensity factor. The concept of PBC^k is also useful for predicting the ability of the soil to supply K for sustained crop production.

Some workers (Beckett, 1964a; Tinkar, 1964a) pointed out that the activity of K alone might not give a good correlation but the ratio of the activity of K to the activity of other cations should give a better information of K availability. The activity ratio (AR) gives a satisfactory measure of the chemical potential of labile K in soil provided the soils are not of wide calcium status. Beckett (1964c) again has shown that the AR is constant over a variation in the Ca and Mg content of the soil. The AR may be same for two soils although the absolute K content of the soil are different and thus the decisive effect of K concentration upon K uptake will not be taken into account.

According to Beckett (1964b) the following five facts are to be considered while AR is used as a measure of K availability.

- i. The AR provides a measure of K availability at the time of measurement, it will vary with prolonged activity.
- ii. The AR will not give a measure of K status while comparing soils with wide Ca status.
- iii. If the uptake is regulated by mainly one antagonistic ion like Mg the $\frac{a_K}{a_{Mg}}$ may indicate about the K-availability.
- iv. The AR will not give a good measure of K-availability if the soil is of low charge density.
- v. Soils with high Na or Al will vary in the AR.

Role of Al, Fe and Mn in influencing the AR was also studied by different workers. Thus Tinker (1964a) included Al ion in the calculation of AR for Nigerian soils in which Al

was the main exchangeable cation - $\frac{ak}{\sqrt[3]{a \text{Ca+Mg} + Pa \frac{1}{3} Al}}$. Singh and Talibudeen (1969) suggested to use only $\frac{ak}{\sqrt[3]{a Al}}$ for calculating the activity.

Randhawa and Pasricha (1976) found a better relationship with K content when they considered Fe and Mn also in the AR calculations. While measuring the Activity Ratio of some Ghanaian soils to know the intensity of K, Acquaye et al (1967) observed that it was related to the amount of exchangeable K extracted by $NH_4 OAc$ and particularly to the uptake of K by oats. Moss (1967) found activity ratio to be related with exchangeable and non-exchangeable soil K. Acquaye and MacLean (1966) observed that the ratio - $\Delta K^o / AR_e^k$ or FBC^k showed some relationship to the amount of non-exchangeable K which was an important source of K in most of the soils. Nafady and Lamm (1972) observed decrease of equilibrium activity ratio to occur unless the rate of mobilization from difficultly exchangeable K was high enough to sustain the loss.

Numerous studies have been made on Q/I relationship as a parameter for potassium nutrition of plants. Good correlations have been obtained either between the activity ratio or ΔF (change in free energy) and concentration or uptake of K by plants (Tinker, 1964; Addiscot, 1970; Woodruff, 1955 and Talibudeen, 1974). But in most of the cases activity ratio have been observed to be inadequate to describe availability of K to plants (Bandyopadhyay, 1976; Blanchar and Hossner, 1968 and Addiscot, 1974).

Ghosh and Ghosh (1976) have reported the value of AR_0^k varying from 4.0×10^{-3} to $24. \times 10^{-3}$ (moles/L) $^{\frac{1}{2}}$ for soils of Nagaland.

The value of AR_0^k as reported by other workers are 0.0005 to 0.009 for some Ghanaian soils (Acquaye, 1973) and 0.0041 to 0.017 in some soils of Himachal Pradesh (Suresh, 1979).

Ramakrishnayya and Chatterjee (1976) found AR_e^k to be high (1.8 to 20.8 M/L) $^{\frac{1}{2}} \times 10^{-3}$ in red soils dominated by kaolinite clay and low (1.0 to 1.8 (M/L) 0.5×10^{-3}) in black soils dominated by smectite group of clay minerals. The value of AR_0^k of Delhi and Pondicherry were 5×10^{-3} and 2.35×10^{-3} M/L $^{\frac{1}{2}}$, respectively (Bandyopadhyay, 1976).

The plant uptake of K has been found to be positively correlated with AR_0^k (Ghosh and Ghosh, 1976) and hence sometimes it is taken as a good index of K availability. The ability of K in the soil solution partly depends on the release of K from the fixed form and partly on the rate of K diffusion into the soil solution. Tinker (1964a) while investigating acid soils of Africa found that the slope of Q/I curve was much lower than the English soil. This showed that the tropical soils were less buffered against the K depletion. Q/I relationship was found to be similar for most of the soils except in cases where CEC was low (Beckett, 1964c; Talibudeen and Dev, 1968a).

Depending on the soil type both the parameters Quantity and Intensity fall to a minimum in soils being intensively cropped after which the pool serves as the vehicle by which K from

interlattice sites becomes available to the plants (Le Roux and Sumner, 1968). However, in any one season the response of plant to K will depend mainly on the value of the pool of labile K at the beginning of that season. Ghosh and Ghosh (1976) observed no extra advantage in describing K availability in terms of Q/I relationship. Similar conclusions were also drawn by Bandhyopadhyay (1976) while working on red, black and alluvial soils of India.

The slope of the Q/I curve is known as potential buffering capacity (PBC^k) which indicates the capacity of the soil to replenish supply of K to soil solution. In alluvial soils, PBC^k is dependent on the quantity and type of clay minerals (Sen Gupta and Das, 1977; Bandhyopadhyay, 1976) and organic matter in soil (Chatterjee, 1976).

Numerous studies have been made on Q/I relationship as a parameter for potassium nutrition of plants. Good correlations have been obtained either between the activity ratio or F (change in free energy) and the concentration or uptake of K by plants (Tinker, 1964; Addiscot, 1970; Talibudeen, 1974).

Ramamoorthy and Paliwal (1965) found a good correlation between K response in rice and KAR in Indian soils. Soils having high PBC^k and low K and AR_e^k values are not responsive to K.

Ghosh and Ghosh (1976) reported that labile pool K^o had high correlation with K uptake by plants. Narayanan Nambiar as quoted by Ramanathan and Krishnamoorthy (1978) found that the red soils had low PBC^k value than the black soils and AR_e^k was

highly correlated to water soluble K and exchangeable K. Ramakrishnayya and Chatterjee (1976) found that the AR_e^k and R^o value were higher and PBC^k values lower in red soils than black soils. Therefore red soils are more likely to respond to K application. Sen Gupta and Das (1975) determined PBC^k of some soils of West Bengal and Assam from Q/I relationship and observed that smectite dominant soils have high PBC^k followed by illite and kaolinite dominant soils. Panda (1978) quoted that PBC^k values ranged from 15.9 to 67.6 for laterite soils of Tamilnadu, whereas for Orissa soils it was 35.7 and for laterite soils of Kerala it was 46 to 129.0 ($me/100g$)^{M/L^{1/2}}.

Le Roux and Sumner (1969) found a high correlation between PBC^k and CEC of the soil and Fernandez et al (1975) observed a close relation between PBC^k and labile K. Bradfield (1972) found a good correlation between various parameters of Q/I curve and plant growth characteristics. The total labile K content (KL) has been found to be more in the soil rich in organic matter as compared to those poor in organic matter content. It appears that KL value is also governed by the organic matter content. It is further supported by the fact that the correlation coefficients between KL value and uptake of K and dry matter yield of the plant is significant. The PBC^k and LBC^k value have been found to be low in the hilly soils (Maji, 1980). Arnold, (1962) reported that the free energy ($-\Delta F$) values above 4000 cal/mole is the deficiency level of K. The correlation coefficient between ΔF and uptake of K and dry matter yield of the whole plant are found to be highly negative and significant at 1 per cent level. In Delhi soils the free energy was above

-2000 cal/eq (Bandhyopadhy, 1976). PBC^k (me/100g) $(M/L)^{-\frac{1}{2}}$ as reported by different workers are 4.7 - 180 for some Tobacco growing soils in India (Ramakrishnayya and Chatterjee, 1976), 6.2 to 15.8 for soils of Nagaland (Ghosh and Ghosh, 1976), 17.46 to 305.88 for soils of Ghana (Acquaye, 1973), 17-111 for uncropped Canadian soils (Acquaye, and MacLean, 1966) and 18-67 in some Himachal Pradesh soils (Suresh, 1979). PBC^k values in black soil was found to be more (85.5 to 135.0 me/100g) - M/L - 0.5 when compared to red soils (4.7 to 20.6) Ramakrishnayya and Chatterjee 1976) and in Nagaland soils (Ghosh and Ghosh, 1976), it was in the range of 6.2 to 15.8 me/100g (M/L) 0.5.

Rao (1977) reported that PBC^k values varied from 1.18 to 13.71 me/100g $(M/L)^{\frac{1}{2}}$ and were relatively low in the kaolinite dominant soils. The activity ratio in soil solution was found to be a function of concentration of K in soil solution, the exchangeable K content of the soil and percentage K solution. This observation supported the findings that AR_K of soil was closely related with concentration of K in the saturation extract (Acquaye, 1973) exchangeable K content (Le Roux and Sumner, 1968). Koch et al (1970) while working on Oxisols have shown that pool of labile K is a good index of the amount available to corn. It is superior as a criterion to both the equilibrium activity ratio and exchangeable K.

Moss (1967) observed that AR_K (initial K activity ratio) value was well correlated with K uptake and labile K was a useful index of ultimate K uptake over a growing season and

Mackenzie (1968) while working on Quibic soils reported that crop growth did not change the PBC^k of two selected soils which indicated that quantity/intensity relation regulated the release of K although the activity ratio was greatly reduced. Le Roux and Sumner (1968) observed that Q/I studies on soil samples taken after various periods of plant growth could illustrate how the pool of labile K and equilibrium activity ratio decreased as increasing amounts of K were taken up by the plants.

The literature reviewed in this section is evident that Quantity/Intensity relationships have been employed to obtain a clear picture of soil K availability. At present such information is altogether lacking for the soils of Kashmir.

CHAPTER III

MATERIALS AND METHODS

The present investigation was aimed at studying the pedogenesis, mineralogical built up and potassium chemistry of the soils from various zones of Kashmir. Fourteen soil pedons as shown their locations in Fig.1 were exposed and 60 soil samples based on heterogeneity of the profile were collected from these zones. Bulk surface samples were also collected from these spots for green house studies.

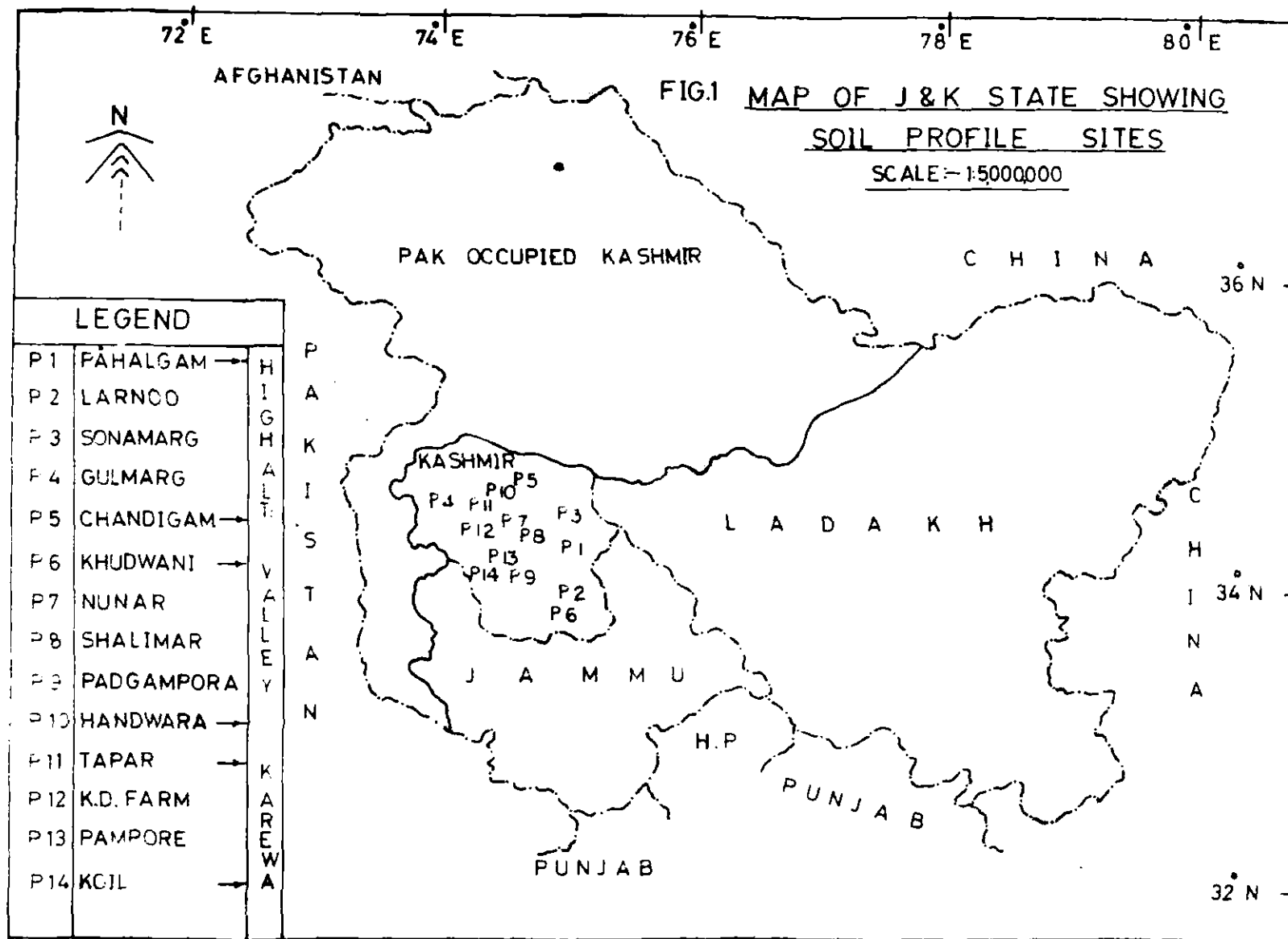
Description of the morphological features of these pedons is given in appendix I. A brief description of the area and the procedures followed for analytical work are given below:

3.1 General description of the area

The state of Jammu and Kashmir, comprising the extreme western sector of the Himalayas, occupies almost a central position in the continent of Asia. It lies in the extreme north of the Indian Union and extends from $32^{\circ} 17'$ to $37^{\circ} 05'$ N latitude and from $72^{\circ} 40'$ to $80^{\circ} 30'$ E longitude. The total geographical area of the state is 2,22,236 sq km and has a population of 59,54,010 (India 1982). It has high mountains with many snow covered peaks. The altitude ranges between 213 and 7012 meters.

3.1.1 Physiography

On the basis of Physiographic features, the state has been divided into four major zones:



a. Outer plains region

This region represents a fringe of level land in continuation of plains of the Punjab approaching from Gurdaspur and extends to Akhner through Sarba and Kathua. The region is bordered by a low and sparsely wooded hilly country and is stretched with numerous gullies. The average altitude is about 350 m above mean sea level.

b. Outer hilly region

This region is comprised of two parts (a) Eastern division belonging to outermost hills between rivers Ravi and Chenab. These hills rise from the plains and continue till they attain a height of about 680 m above mean sea level. (b) the Western division starts from Chenab or the north of the plains. These hills are thickly wooded beyond Akhner and Reasi.

c. The middle mountain (Pir Panjal) range

This region is located between the outer hills and the higher mountain ranges of Punjab. The region starts from Buschli and runs along north of Ramnagar, Reasi and Rajouri and takes a north-western dissection towards Muzaffarabad. Northern boundary of the region is made up of two lofty mountain ranges, one coming from South east end at Kishtwar while the other is the Panjal ridge which overlooks as well as guards the Kashmir valley. The space is occupied by mass of mountains cut into by ravines or divided by narrow valleys. The valley of Kashmir stretches 150 km from South east to north-west, having an average elevation of 1700 meters and a width of 80 km. The valley is enclosed

by a ring of mountains the Pir Panjal in the south and the great Himalayas in the north. Besides, small valleys i.e. Kishtwar, Bhaderwah are also located in this region.

d. The inner mountains

This is the zone of highest elevation. The mountains begin to appear to the north of the Pir-Panjal range and rise above the snow line into peaks of perpetual snow. There are many peaks in the north Kashmir range, an off-shoot of Zaskar range forming the north-eastern border of the valley, which is 4600 to 7000 meters high. Beyond this range, there is a high level plateau desert, Ladakh, utterly devoid of any kind of vegetation. The altitude further rises till the mighty Karakoram range attains the height of 8600 m. The topography is rugged and the population sparse.

3.1.2 Climate

The climate of the state varies from Arctic cold in Ladakh to tropical heat of the sub-montane and semi-mountainous tracts of Jammu. Kashmir valley is, however, free from extremes and has a temperate and salubrious climate. During winter the temperature in the valley sometimes goes below the freezing point. Much snow falls at the higher altitude. The mean daily temperature is lowest in January and highest in June or July. The total precipitation is received during two periods, the cold season from December to April and the south-west monsoon period from June to September. The average rainfall in the state varies from 170 cm in the South-West to 8 cm in the North-East. In the valley of Kashmir, this average varies from 76 cm to 38 cm and is about 114 cm in

Jammu district (Table 1). Normal mean daily maximum and minimum temperature is 19.83°C and 6.3°C respectively.

Table 1: The climatic features of the various zones of Jammu and Kashmir (Mean values).

Zone/Region	Annual Temp (°C)	Annual rainfall (mm)	Annual PET (mm)	Climatic Index	
				Thermal	Hydric
1. Subtropical (Jammu plains)	24.5	1460	1976	Mega-thermic	Dry Humid
2. Subtropical temperate transition (Jammu hilly region Doda, Poonch, Udhampur)	20.0	1171	1732	Mesothermic	Dry Humid
3. Temperate (Kashmir Valley)	13.9	721	1453	Micro-thermic	Dry
4. Cryosic-arid (Ladakh)	3.9	72	512	Cryosic	Arid

Source : Indian Meteorological Department Srinagar.

The cold season precipitation from December to March is due to storms which advance from Iran and Baluchistan. In the valley of Kashmir, this is the major precipitation of the year. April and May also receive the rainfall. The distribution of rainfall viz.a.viz the profile sites is given in Table 2 and temperature data as recorded at Srinagar in Table 3.

3.1.3 Geology

The state is one of the best geologically explored parts of the Himalayas and contains within a small geographical

Table 2: Rainfall pattern at different places in Kashmir (mm)

Location	Normal rainfall	1976		1977		1978		1979	
		No. of rainy days	Total rainfall	No. of rainy days	Total rainfall	No. of rainy days	Total rainfall	No. of rainy days	Total rainfall
Srinagar (Shalimar*)	658.9	50	541.5	43	500.2	43	529.6	42	535.5
Ganderbal (Nunar)	642.3	68	762.2	47	562.2	57	695.9	50	742.9
Sonamarg	1815.4	-	-	50	437.0	75	871.5	78	736.2
Budgam (K.D. Farm)	584.9	58	865.5	40	421.3	42	530.5	59	493.0
Anantnag (Khudwani)	663.0	51	916.0	40	336.2	50	420.0	43	493.0
Fahalgam (Larnoo)	-	109	1235.0	104	1488.1	106	1752.0	68	1166.2
Handwara	1062.0	68	1070.9	57	769.2	79	1195.4	25	340.0
Gulmarg	-	57	1006.8	67	998.3	60	985.1	66	1082.1
Sogam (Chandigam)	-	80	1290.2	74	1000.6	78	1105.1	66	945.0
Pulwama (Koil, Pampore, Padgampora)	611.2	23	178.1	20	129.1	36	404.4	34	285.9
Baramulla (Tapar)	955.3	56	632.9	45	413.5	36	286.4	56	438.9

* The words in the brackets indicate nearest profile locations.

Source: Statistical Digest Directorate of Statistics and Evaluation
J&K Government, Srinagar.

Table 3: Mean maximum and mean minimum temperature at Srinagar.
Unit: Degrees Centigrade

Month	Unit		1976	1977	1978	1979
January	Mean	Minimum	2.09	1.5	2.0	2.8
	Mean	Maximum	8.5	6.4	5.8	6.8
February	Mean	Minimum	1.2	1.8	0.3	0.0
	Mean	Maximum	6.6	10.2	8.2	9.5
March	Mean	Minimum	2.1	0.7	3.0	2.4
	Mean	Maximum	12.6	19.5	12.1	13.3
April	Mean	Minimum	6.0	9.2	7.2	9.2
	Mean	Maximum	20.0	19.7	21.2	22.9
May	Mean	Minimum	9.6	10.6	11.7	9.4
	Mean	Maximum	26.0	23.8	27.5	21.9
June	Mean	Minimum	12.9	15.6	17.1	14.9
	Mean	Maximum	29.1	29.6	32.5	30.2
July	Mean	Minimum	17.7	19.8	19.3	18.7
	Mean	Maximum	37.7	31.3	29.6	32.4
August	Mean	Minimum	14.8	17.7	18.5	16.8
	Mean	Maximum	30.6	29.8	30.5	10.6
September	Mean	Minimum	11.5	13.2	5.1	11.1
	Mean	Maximum	27.1	28.0	28.4	26.6
October	Mean	Minimum	6.6	7.5	2.3	6.9
	Mean	Maximum	21.0	23.0	26.6	24.1
November	Mean	Minimum	0.6	3.1	2.3	3.6
	Mean	Maximum	15.6	16.1	12.7	14.2
December	Mean	Minimum	1.8	8.7	2.8	0.1
	Mean	Maximum	9.2	6.5	11.4	7.9

Source : Meteorological Centre Srinagar.

compass one of the finest developments of stratified rocks. The crystalline metamorphic rocks, gneisses and schists occupy very large areas in Kashmir to the north of outer Himalayas. The gneisses are not all of Archaen age but are of intrusive origin, which have invaded rocks at various geological periods (Wadia 1961). The sedimentary pre-Cambrian rocks consisting of slates, phyllites and schists are interbedded with zinc stones and flaggy quartzites. Fossiliferous Paleozoic rocks of Kashmir occupy elongated allipse shaped patches in the north of alluvial part of the Kashmir valley, stretching from North-West to the South-East and of the Kashmir sedimentary basin (Ray Chaudhuri et al 1963). Rocks of the Panjal volcanic series mainly found on the north eastern slopes of Pir Panjal and on the other side of the Jhelum, consist of Pyroclastic slates, conglomerates and agglomeratic products. The Triassic system is represented by a series of light blue lime stone, slates, sand-stones and dolomites.

The valley of Kashmir is an alluvium filled basin, a large part of which is of recent formation by the river Jhelum (Wadia 1961). More than half of its area is occupied by distinctly older alluvium, which forms flat mounds or platforms sloping away from the high mountains that border the valley on all sides. These deposits locally known as Karewas are Pleistocene or post Pliocene deposits and are composed of fine silty clays with sand and bouldery gravel. These have been held to be the surviving remnants of deposits of a lake which once filled the valley basin.

3.1.4 Natural Vegetation

The state forms a transitional region of diverse physical features between weak monsoon zone of the Punjab and cold dry (arid) zone of Tibet, thus the vegetation of the state is of diverse nature, varying from scrub forests to coniferous forests. The main vegetation in the outer plains and outer hills is comprised of Kiker (Acacia arabica); flame trees (Butea frondosa); Phulai (Acacia modesta); Cacti (Cacti spp.); Sanatha (Lidonia viscosa); Brankar (Adhatoda vasica); Sarkanda (Saccharum spontaneum); Khair (Acacia catechu).

The chir pine (Pinus roxburghii) occupies the zone in between 750 m to 1200 m altitude. This is followed in succession by Deodar zone, Kail (Pinus excelsia) and Deodar mixed zone, Kail and Fir (Abies alba) mixed zone, Fir zone and Birch (Betula) zone. This covers altitudinal zone upto 3352 m. Oak (Quercus) Pahu (Parietia) grow in between 1675 m and 2750 m altitude. Medicinal plant herbs such as Colchicum, cphpedra, Pedophyllum, Atropa acuminata, Sausuria lappa grow in between 1525 m to 4260 m in the state.

3.1.5 Agriculture

The economy of the state is largely agrarian. Rice, maize and wheat are the main principal crops. Besides, Barley, Bajra, Jowar and Gram are also cultivated in some parts. The net area under cultivation in 1980-81 was 714000 hectares and formed 15.8 per cent of the total area. The state harvested a record of over 12 lakh tonnes in 1978-79 and it was targetted at 13.70 lakh tonnes for 1980-81. Production of fruit touched 5 lakh tonnes during 1980-81.

3.1.6 Soils

The broad groups of the soils in the Kashmir are:

- i) High altitude soils:- These are located within an altitude of 1800 to 2500 m stretching from Karewa from one end and bordering forests on the other. These are heavy textured soils, pH generally ranges from 6.0 to 6.5 and are of good fertility.
- ii. Valley basin:- These have resulted from alluvium deposited from major rivers like Jhelum, Indus and their tributaries. These lie at an altitude of about 1500 to 1600 m. Most of these soils are poorly drained.
- iii. Karewa soils:- This group include severely eroded to moderately eroded big table lands protruding out of the mountains and usually bordering slopes of mountains. These are lacustrine deposits, located within an altitude of 1650 to 1800 m and are relatively less fertile than the high altitude soils.

3.2 Methods of soil analysis

3.2.1 Collection of soil samples

Soil profiles were exposed at fourteen different representative sites in different zones of the Kashmir valley i.e. 5 profiles in high altitude zone; 5 profiles in valley basin and 4 profiles in Karewa zone in order to represent the major soil groups found in the region. In all 60 soil samples from these profiles were collected, after studying the morphological features following standard procedures (U.S.D.A. Manual Handbook No. 18). Fourteen bulk soil samples were

also collected from these places for green house studies. The soil samples collected were processed and stored in polythene bags. The samples were then used for various types of studies to achieve the objectives already outlined. The procedures followed are described as under :

3.2.2 Laboratory studies

3.2.2.1 Mechanical analysis

Mechanical analysis of the soil samples was carried out by following the International Pipette method as outlined by piper(1966). The texture of the samples was computed from the textural diagram of the USDA (Soil Taxonomy 1975).

3.2.2.2 Physico-chemical analysis

- i. Soil reaction:- The pH of the soil was determined in 1:2.5 soil water suspension with the help of expanded systronics pH meter .
- ii. Calcium carbonate:- It was determined by Rapid titration method using normal HCl as described by Piper(1966).
- iii. Organic carbon:- Organic carbon was estimated by wet digestion method of Walkley and Black using potassium dichromate and sulphuric acid as given by Piper(1966).
- iv. Total nitrogen:- Estimation of total nitrogen was made by following the Kjeldahl's method as described by Jackson(1967).
- v. Available phosphorus:- The available phosphorus was extracted by Olsen's extractant(0.5 M NaHCO_3 at pH 8.5) and colour was developed by ammonium molybdate and stannous

chloride. The percentage transmittance was measured with the help of spectronic-20 spectrophotometer at 660 mu wave length (Olsen et al (1954).

vi. Available potassium: The available potassium was extracted with 1N NH_4OAc (pH 7.0) and determination was carried out with the help of EEC flame photometer (Jackson 1967).

vii. Cation exchange capacity (CEC) and exchangeable cations: CEC was determined by Schollenberger's method of leaching the soil with normal NH_4OAc and determining ammonical nitrogen by distillation (Piper 1966). The exchangeable calcium and magnesium were determined by versenate method from NH_4OAc extract with EDTA titration method using ammonium purpurate and erichrome black (T) indicators as described by Black (1965). Potassium was estimated from NH_4OAc extract flame photometrically using systronics flame photometer.

3.2.2.3 Potassium determination

The soil samples and the fractions of selected soil samples were analysed for different forms of K as per the procedure:

1. Total K: It was estimated by digesting the soil with HF and HClO_4 as outlined by Jackson (1967).
2. Fixed K (1NHNO_3 soluble K): Estimation was carried out by using boiling 1NHNO_3 as described by Hunter and Pratt (1957).
3. HCl soluble K: HCl soluble K was estimated by treating the soil samples with conc. HCl as given by Piper(1967)

4. Water soluble potassium:- It was determined from 1:5 soil water suspension after shaking the suspension for two hours and allowing them to stand 16 hours.

5. Potassium fixing capacity:- K-fixing capacity of the surface samples was done as outlined by Jackson(1967). The estimation of potassium in all these cases was made with flame photometer.

6. Plant analysis:- Plant samples were digested with tri-acid mixture and then analysed for their K content as given by Jackson(1967).

3.2.2.4 Mineralogical analysis

The investigations related to mineralogical properties of the soil comprised of determining primary and clay minerals in fine sand and clay fractions. The methods used for the studies are described as under :

1. Separation of fine sand silt and clay fractions:- For separation of fine sand silt and clay fractions, the method outlined by Black(1966 Part I) was followed. Enough air dried 2 mm soil sample of the selected profiles was taken so as to get about 8-10 grams of clay. The soil was treated with sodium acetate buffer solution (pH 5.0) for removing CaCO_3 and other salts. Organic matter was destroyed by the use of 30 per cent H_2O_2 and free iron oxides were removed by sodium bicarbonate - citrate - dithionite (Mehra and Jackson 1960). The disaggregation was achieved by using NaOH (0.1 N) as dispersing agent. The various separates were collected as outlined by Piper(1966).

2. Analysis of fine sand fractions

The light and heavy fractions of sand were separated using bromoform with specific gravity of 2.87. The amount of both the fractions was then calculated on the basis of the amount of total sand taken. For identification of primary minerals the slides of each fractions (light and heavy) were made by placing few grains on the surface of the glass slide followed by addition of a drop of distilled water. The slide was then dried on hot plate and thereafter canada balsam was added to cover sand grains. The slide was warmed taking care that no air bubble remained between the cover slip and the slide. the presence of different primary minerals was then identified in the prepared slide with the help of Nikon (Tokyo) Microscope.

3.2.2.5 Analysis of clay fraction

Clay samples were subjected to

- i. Physico-chemical analysis.
- ii. X-ray diffraction

1. Physico-chemical analysis

This comprised of determining CEC, Si, Al, Fe and K. For this purpose H saturated clay samples were used. CEC was determined by saturating the H clays with N NH₄O Ac solution (Piper 1966). Silica was determined calorimetrically in an extract prepared by fusing the clays with sodium carbonate (Piper 1966). Fe was estimated in Atomic Absorption Spectrophotometer from HF extract of the clays and Al was determined calorimetrically from HF extract using Aluminon as the colouring agent. (Hardwitz 1975 in AOAC book).

ii. X-Ray diffraction analysis

A part of the separated clay sample was saturated with Magnesium and another part with potassium using N-MgCl₂ and N-KCl respectively. The third part of the clay was mounted without any treatment (Black 1965 Part I). The excess salts (Chloride ions) were removed by 3-4 washings with alcohol and alcohol + acetone mixtures. These salt free clay samples were then oriented on glass micro-slides from a water suspension at room temperature and X-ray diffraction patterns were obtained using Philips X-ray Diffractometer with Cu - K radiation, (Goniometer scanning speed of 2 degrees 2 θ /minute, voltage 240 kV and amperage of 20 mA).

The magnesium saturated samples were glycolated and K saturated samples were heated to 350°C. The sequence followed for X-ray diffraction in respect of slides was done as follows:

- a. Untreated
- b. Magnesium saturated
- c. Mg glycolated
- d. K saturated and
- e. K saturated and heated

Interpretation of X-ray diffractograms

The identification of clay minerals by X-Ray Diffraction technique is based on the reflection of X-Ray by the characteristic atomic lattice planes within the mineral crystal. For the identification of clay minerals species, the diffraction maxima obtained were compared with the standard d values (Å) characteristics for each mineral species (Brown 1961).

3.2.3 Green house studies

The bulk soil samples collected from the various places for the uptake studies and to find their relation with Q/I parameters, were processed and plastic pots of 1.5 kg capacity were filled with one kg soil. Wheat (VL 421) as a test crop was grown in the pots in green house. Some quantity of sand was mixed with soil to provide proper drainage and aeration. The pots were arranged in different blocks and rearranged within each block during the course of experiment. The design of the experiment followed was completely randomized with three replications for each soil. A basal dose of 120 ppm Nitrogen (half before sowing and half after one month of sowing) and 60 ppm P was applied in the form of urea and DAP respectively. The K treatments consisted of control, 200 and 400 ppm K in the form of muriate of potash. The dose of K was fixed after determining the K-fixing capacity of these soils. The seed was treated with captan in 1:3000 ratio before sowing in order to protect the crop from any fungal attack. Eight seeds were sown per container and after emergence the plants were thinned to three in each pot. The pots were frequently watered to maintain them at approximately field capacity level and were frequently weeded. After 60 days (half interval of maximum flowering) the plants from each pot were taken out along with roots. They were washed with tap water, distilled water and dilute HCl to remove all the adhering material and were then sun dried. The material was subsequently dried at 65°C, weighed, ground and preserved for subsequent analysis. Soil samples were also taken from each pot for laboratory analysis.

Various treatment combination are :

Soils = 14
Replications = 3
Treatments = KC, K₂₀₀ and K₄₀₀ ppm
Total number of pots = 126

3.2.4 Quantity/intensity relationship

Quantity/Intensity relationship of soils were estimated by the method given by Beckett(1964 a,b) using the following modifications:

Two gram portions of soil samples were shaken with 50 ml aliquot of solutions of KCl (10^{-4} to 10^{-3} M) and CaCl₂ (2.7×10^{-3} M) in 100 ml conical flasks for 1 hour. The flasks were then allowed to stand overnight at 25°C for equilibration. Next day the equilibrated solution was filtered and K was determined in the filtrate flame photometrically and Ca and Mg by complexometric titration with EDTA according to procedure of Barrows and Simpson(1962).

The activity ratio (AR_e^k) was calculated using the Debye - Huckel equation and the free energy determined by using Gibb's free energy equation. (Maren and Prutton 1965). The equations used:

$$\frac{a_k}{a(Ca+Mg)} = \frac{c_k}{c(Ca + Mg)} \times \frac{f_k}{f(Ca + Mg)}$$

where a = activity (moles/L)
c = Concentration (moles/L)
f = Activity coefficient

The Q/I relationship was found by plotting K against the concentration values of the activity ratio (AR_c^R) where sorption and desorption rates are equal (K=0), was obtained by the interpolation of the Q/I curve to cut the X-axis. The distance between the two points where K=0 and where the curvilinear part of the Q/I curve on extrapolation meets the $AR_c^K = 0$ line was taken as a measure of labile K (K_L). The potential buffering capacity was calculated as the linear slope of the Q/I. The free energy change (ΔF) was calculated by following the relation as :

$$F = -RT \ln \frac{a/k}{\sqrt{aCa}} = -2.303 RT (\frac{1}{2}P_{ca} - PK) \text{ cal/mole}$$

3.2.5 Statistical analysis

The data was analysed statistically as outlined by Chandel (1958). Simple and multiple correlations were worked out for different variables of relevance in the study (Spiegel 1961).

CHAPTER IV

EXPERIMENTAL FINDINGS

The experimental results pertaining to the study of pedogenesis, mineralogy and potassium chemistry of soils collected from various zones of Kashmir are presented under the following heads:

1. Physico - chemical characteristics of soil
2. Mineralogy
3. Potassium chemistry
- 4.1 Physico-chemical properties of soil
- 4.1.1 Mechanical composition

The data on the mechanical composition of the soil is presented in Table 4. The particle size distribution in various soil profiles in respect of coarse sand showed a slight variation in the three zones. The coarse sand fraction varied from 0.22 to 3.45, 0.16 to 2.22 and 0.10 to 1.52 percent in high altitude zone, valley basin and kerewa soils respectively. The values for weighted average of this fraction varied from 0.38 to 2.25, 0.38 to 1.08 and 0.13 to 0.97 per cent in high altitude zone, valley basin and Karewa soils respectively. The distribution of coarse sand in the soil profiles in all the three zones was by and large erratic and was slightly more in high altitude soils than in the soils of the other two zones. The fine sand fraction varied from 7.15 to 27.10, 14.76 to 33.15 and 11.85 to 24.08 per cent in high altitude, valley basin and Karewa soils

Table 4: Mechanical composition of soils from different zones of Kashmir

(per cent on air dry basis)							
Location	Depth (cm)	Horizon	Coarse Sand	Fine Sand	Silt	Clay	Texture
1	2	3	4	5	6	7	8
High Altitude soils							
Pahalgam	0-15	Ap	1.25	23.52	47.85	27.65	Clay loam
	15-35	B1	1.47	23.05	46.45	28.05	Clay loam
	35-50	B21	0.35	14.05	50.45	35.03	Silty clay loam
	50-125	B22t	0.22	12.50	48.50	38.51	Silty clay loam
	125-150	B221t	0.32	11.85	40.84	45.20	Silty clay
Weighted average			0.52	15.03	47.08	36.79	Silty clay loam
Larnoo	0-18	Ap	0.40	19.65	41.08	39.50	Silty clay loam
	18-70	B1	0.30	15.45	40.84	43.45	Silty clay
	70-120	B21t	0.75	8.25	42.04	48.44	Silty clay
	120-150	B22t	0.80	7.15	41.05	50.25	Silty clay
Weighted average			0.56	12.89	42.37	42.82	Silty clay
Sonamarg	0-20	Ap	0.57	24.01	36.42	38.75	Clay loam
	20-60	B1	0.52	23.56	36.89	39.15	Clay loam
	60-90	B21t	0.33	17.14	40.26	42.10	Silty clay
	90-128	B22t	0.24	8.62	40.19	50.12	Silty clay
	128-150	B23t	0.27	7.53	40.56	51.48	Silty clay
Weighted average			0.38	15.20	39.87	44.27	Silty clay
Gulmarg	0-20	Ap	1.05	18.42	51.21	26.05	Silty loam
	20-50	B1	1.21	21.40	50.48	27.52	Silty loam
	50-90	B21t	1.84	17.01	48.16	34.72	Silty clay loam
	90-150	B22t	3.45	14.26	46.23	35.12	Silty clay loam
Weighted average			2.25	16.97	48.25	32.28	Silty clay loam
Chandigarh	0-17	Ap	2.45	18.12	50.12	28.21	Silt loam
	17-60	B21t	2.61	16.42	51.25	29.42	Silt loam
	60-90	B22t	2.17	16.86	45.31	35.21	Silty clay loam
	90-150	B221t	1.56	27.21	32.18	38.42	Clay loam
Weighted average			2.08	21.01	42.30	34.04	Clay loam
Valley basin soils							
Khuᳵwani	0-20	Ap	0.16	26.85	51.85	20.10	Silt loam
	20-40	B1	0.42	33.15	35.70	29.85	Clay loam
	40-70	B21t	2.52	22.28	41.35	33.70	Clay loam
	70-120	B22t	1.05	17.92	40.85	40.45	Silty clay loam
	120-150	B23t	0.75	18.25	42.05	38.52	Silty clay loam
Weighted average			1.08	22.07	41.97	34.58	Clay loam
Nunar	0-20	Ap	1.45	28.42	40.28	29.50	Clay loam
	20-40	B21t	1.05	27.56	39.17	32.42	Clay loam
	40-75	B211t	0.65	18.08	43.40	36.28	Silty clay loam
	75-150	B22t	0.58	19.21	41.21	39.10	Silty clay loam
Weighted average			0.77	21.28	41.32	35.77	Clay loam

contd.....

1	2	3	4	5	6	7	8
Shalinar	0-15	Ap	0.45	26.42	52.28	22.51	Silt loam
	15-45	B21t	0.75	28.25	41.41	29.32	Clay loam
	45-90	B21t	0.85	18.26	42.81	37.28	Silty clay loam
	90-150	B22t	0.60	14.76	41.25	43.41	Silty clay
	Weighted average			0.69	19.67	42.85	36.92
Padanpora	0-17	Ap	0.70	25.81	52.21	21.58	Silt loam
	17-85	B1	0.62	19.21	46.42	32.42	Silty clay loam
	85-110	B2	0.27	18.85	45.61	34.51	Silty clay loam
	Weighted average			0.55	20.04	47.13	31.21
Handwara	0-17	Ap	0.35	16.52	60.58	22.58	Silt loam
	17-35	B1	0.78	18.42	57.21	22.20	Silt loam
	35-85	B2	0.34	17.97	54.22	26.81	Silt loam
	85-150	B21	0.31	16.91	51.72	32.27	Silty clay loam
	Weighted average			0.38	17.40	54.21	28.14
Karewa soils							
Tapar	0-15	Ap	1.52	22.45	46.91	28.00	Clay loam
	15-35	B1	1.08	17.26	48.21	32.42	Silty clay loam
	35-60	B21t	1.25	15.86	45.38	36.32	Silty clay loam
	60-90	B22t	0.91	18.20	40.45	40.01	Silty clay loam
	90-150	B23t	0.72	11.85	41.38	45.20	Silt clay
	Weighted average			0.97	15.56	43.32	39.25
K.L.Farm	0-16	Ap	0.27	24.08	54.48	24.26	Silt loam
	16-31	B1	0.19	22.56	52.01	24.18	Silt loam
	31-47	B21t	0.12	21.48	47.02	31.48	Clay loam
	47-97	B211t	0.10	15.28	42.85	39.89	Silty clay loam
	97-150	B22t	0.10	11.88	40.41	36.48	Silty clay
	Weighted average			0.13	16.40	44.58	37.65
Pansore	0-20	Ap	0.40	20.51	51.58	26.41	Silt loam
	20-60	B21t	0.39	20.42	50.40	29.38	Silt loam
	60-85	B211t	0.10	17.82	42.16	39.42	Silty clay loam
	85-150	B22t	0.10	14.42	40.28	44.18	Silty clay
	Weighted average			0.21	17.39	44.80	37.07
Kail	0-20	Ap	0.85	22.81	51.18	23.81	Silt loam
	20-50	B1	0.62	21.85	50.42	25.21	Silt loam
	50-85	B21t	0.48	18.65	45.12	34.80	Silty clay loam
	85-150	B22t	0.51	17.16	42.26	38.08	Silty clay loam
	Weighted average			0.57	19.19	45.74	33.27

respectively. The weighted average value varied from 11.89 to 21.01, 17.40 to 22.07, 15.56 to 19.19 per cent in soils of high altitude, valley basin and Kerewa zone respectively. The maximum content of 27.21 per cent of fine sand was observed in Chandigarh soil profile (90-150 cm) and the lowest value of 7.15 per cent in the Larnoo (120-190 cm) soil profile. The distribution of fine sand fraction did not show much variation though it was slightly more in the soils from valley basin.

The amount of silt varied from 32.18 to 51.25 per cent and the weighted average values varied from 38.87 to 48.25 per cent in soil samples from high altitude zone. In the valley basin it varied from 35.70 to 60.58 per cent and the weighted average values ranged from 41.32 to 54.21 per cent. In case of Kerewa soils, silt varied from 40.28 to 54.48 per cent and the weighted average values ranged from 43.32 to 45.74 per cent. The soils from the valley basin had a higher content of silt and a maximum of 60.58 per cent was observed in the Handwara (0-17 cm), while the minimum of 35.70 per cent was observed in Khuowani soil profile (20-40 cm). There was an inconsistent trend in the amount of silt fraction with an increase in the depth of the soil profile.

The clay fraction varied from 26.05 to 51.48, 20.10 to 43.41 and 20.26 to 46.48 per cent in soil samples from high altitude zone, valley basin and Kerewa soils, respectively.

The corresponding values for weighted averages ranged from 32.28 to 44.27, 28.14 to 36.92, and 33.27 to 39.25 per cent in these soils. The clay fraction was comparatively more in the profiles from high altitude zone with 51.48 per cent as maximum in Sonamarg profile (128-150 cm) than in the soils of other zones. In general the clay content increased remarkably with an increase in the depth in all the soil profiles.

The predominant texture of the soils in high altitude zone ranged between silty clay loam and silty clay, in the valley basin and Karewa soil profiles between silt loam and silty clay loam, showing thereby that the soils in all the three zones are heavy textured with more finer particles in the high altitude soils.

4.1.2 Chemical properties

The data on various chemical properties are presented in Table 5.

i. Soil reaction:- A perusal of the data indicates a slight variation in pH of soils in the three zones. The pH ranged from 6.20 to 7.80 in the high altitude soils and values for weighted average varied from 6.38 to 7.60. The pH value of the soils from valley basin and Karewa zone varied from 7.3 to 8.5 and 7.4 to 8.2 respectively. Their corresponding weighted average values varied from 7.40 to 8.37 and 7.64 to 8.18.

ii. Calcium carbonate:- The calcium carbonate (CaCO_3) content showed a variation from 1.0 to 3.5 , 0.5 to 10.5 and 1.5 to 12.0 per cent in the soils of high altitude, valley basin and Karewa zone respectively. The weighted averages in the soils of respective zone ranged from 1.36 to 2.54, 0.85 to 4.86 and 2.31 to 8.73 per cent. The soils of the three zones are generally calcareous and the Karewa soils in particular had higher content of CaCO_3 than those of other two zones.

iii. Organic carbon :- The organic carbon content varied from 0.81 to 4.44, 0.80 to 1.98 and 0.22 to 1.86 per cent in the high altitude, valley basin and Karewa soils respectively. The corresponding weighted average values in these zones ranged from 1.37 to 2.89, 1.10 to 1.54 and 0.47 to 1.00 per cent. A highest content of 4.44 per cent organic carbon was recorded in Gulmarg soil profile (0-20 cm) and the lowest (0-22 ~~per cent~~ %) in Pampore (85-150 cm). The surface horizons of all the profiles contained comparatively high organic carbon content which decreased down the profile. High altitude soils had comparatively higher content of organic carbon and the Karewa soils had the lowest.

iv. Total nitrogen:- Total nitrogen was higher in the high altitude soils than the soils of valley basin and Karewa zone. The contents of total nitrogen varied from 0.05 to 0.24, 0.05 to 0.16 and 0.02 to 0.12 per cent in the high altitude zone, valley basin and Karewa soils respectively.

Table 5: Chemical composition of soils from different zones of Kashmir.

Location	Depth (cm)	pH (1:2.5)	CaCO ₃ (%)	Organic Carbon (%)	Total N (%)	Available Kg/h)	
						P ₂ O ₅	K ₂ O
1	2	3	4	5	6	7	8
High Altitude soils							
Paha lgam	0-15	6.8	2.0	2.31	0.18	30.8	323
	15-35	6.6	1.5	1.91	0.14	25.7	280
	35-50	7.0	2.5	1.65	0.12	25.7	291
	50-125	6.9	2.0	1.12	0.06	23.1	281
	125-150	7.1	1.5	0.99	0.05	15.4	261
Weighted average		6.9	1.8	1.37	0.09	23.2	285
Larnoo	0-18	6.4	1.2	2.34	0.18	25.7	296
	18-70	6.8	1.5	1.95	0.12	23.1	283
	70-120	7.1	1.5	0.98	0.07	15.4	291
	120-150	7.3	1.0	0.81	0.06	14.1	275
Weighted average		6.9	1.4	1.44	0.10	19.0	285
Sonamarg	0-20	6.9	3.5	3.93	0.20	25.7	296
	20-60	6.7	2.5	3.69	0.19	15.4	229
	60-90	6.7	2.0	1.86	0.12	14.1	215
	90-128	6.9	2.0	1.52	0.09	23.1	283
	128-150	7.0	1.5	1.47	0.01	15.4	242
Weighted average		6.8	2.2	2.48	0.14	18.5	251
Gulmarg	0-20	6.4	2.5	4.44	0.24	38.5	323
	20-50	6.4	2.0	3.60	0.21	30.8	296
	50-90	6.2	1.5	3.42	0.19	23.1	312
	90-150	6.5	2.0	1.68	0.12	20.5	258
Weighted average		6.3	1.9	2.89	0.18	25.7	289
Cha ndigam	0-17	7.7	2.0	2.55	0.20	25.7	310
	17-60	7.5	2.5	1.75	0.14	23.1	229
	60-90	7.8	3.0	1.42	0.13	15.4	269
	90-150	7.7	2.5	1.06	0.09	23.1	256
Weighted average		7.6	2.5	1.50	0.12	21.9	257
Valley basin soils							
Khudwani	0-20	7.4	2.0	1.92	0.16	30.8	256
	20-40	7.3	1.5	1.20	0.10	25.7	237
	40-70	7.4	1.5	1.14	0.09	23.1	215
	70-120	7.4	1.0	0.86	0.07	15.4	175
	120-150	7.5	1.0	0.80	0.06	15.4	210
Weighted average		7.4	1.3	1.09	0.09	20.4	209
Nunar	0-20	7.9	10.5	1.92	0.16	26.7	215
	20-40	7.8	8.0	1.74	0.13	18.0	202
	40-75	7.7	6.0	1.11	0.09	14.1	188
	75-150	7.7	2.0	0.96	0.07	20.5	256
Weighted average		7.7	4.8	1.22	0.09	19.4	227

Contd.....

1	2	3	4	5	6	7	8
Shelimar	0-15	7.5	0.5	1.98	0.14	23.1	275
	15-45	7.4	1.5	1.65	0.12	18.0	283
	45-90	7.4	1.0	1.28	0.09	15.4	256
	90-150	7.4	0.5	1.20	0.08	15.4	221
	Weighted average	7.4	0.8	1.39	0.10	16.7	249
Padgampora	0-17	8.5	5.5	1.81	0.12	15.4	242
	17-85	8.4	5.0	1.62	0.10	15.4	229
	85-110	8.2	4.0	1.44	0.09	18.0	256
	Weighted average	8.3	4.8	1.54	0.10	16.0	237
Handwara	0-17	7.5	2.0	1.44	0.10	25.7	229
	17-35	7.7	1.5	1.23	0.10	23.1	188
	35-85	7.8	2.0	1.20	0.09	15.4	173
	85-150	8.0	2.0	0.90	0.05	14.1	242
	Weighted average	7.8	1.94	1.10	0.08	16.9	211
Karewa soils							
Tapar	0-15	7.5	2.0	1.86	0.12	30.8	229
	15-35	7.4	2.5	0.92	0.09	25.7	202
	35-60	7.6	3.5	0.82	0.07	18.0	188
	60-90	7.6	3.0	0.68	0.06	18.0	215
	90-150	7.8	1.5	0.50	0.04	25.7	256
	Weighted average	7.6	2.3	0.78	0.06	23.4	226
K. D. Farm	0-16	7.6	1.5	1.74	0.10	25.7	283
	16-31	7.6	1.5	1.08	0.08	25.7	256
	31-47	7.8	3.5	1.01	0.07	23.1	220
	47-97	7.8	6.0	0.89	0.06	15.4	237
	97-150	7.8	8.0	0.87	0.05	15.4	242
	Weighted average	7.7	5.5	1.00	0.06	18.3	244
Pampore	0-20	7.6	3.5	0.89	0.06	28.2	256
	20-60	7.8	6.5	0.66	0.05	23.1	229
	60-85	7.7	8.0	0.39	0.03	15.4	188
	85-150	8.0	12.0	0.22	0.02	14.1	167
	Weighted average	7.8	8.7	0.45	0.04	18.6	199
Koil	0-20	8.1	4.0	0.91	0.05	19.2	215
	20-50	8.2	3.7	0.68	0.04	15.4	202
	50-85	8.2	8.5	0.45	0.03	15.4	175
	85-150	8.2	8.0	0.26	0.02	14.1	188
	Weighted average	8.10	6.7	0.47	0.03	15.3	191

The corresponding weighted average values ranged from 0.09 to 0.18, 0.08 to 0.10 and 0.03 to 0.06 per cent. The soils in these zones differed in respect of the nitrogen content. The distribution of nitrogen in the soil profiles of the three zones depicted a decreasing trend with an increase in the depth of the profile, the surface layers containing comparatively higher nitrogen content.

v. Available phosphorus:- The available phosphorus (P_2O_5) content varied from 14.1 to 38.5, 14.1 to 30.8 and 14.1 to 28.2 kg/h in high altitude valley basin and Karewa soils respectively. The values for weighted averages ranged from 18.5 to 25.7, 16.0 to 20.4 and 15.3 to 23.4 kg/h in high altitude zone, valley basin and Karewa soils respectively. The surface horizons had invariably higher content of P_2O_5 which showed generally decreasing trend down the profile. The fertility status of the soil in respect of the available P_2O_5 may be rated as medium.

vi. Available potash:- The contents of available potash (K_2O) varied from 215 to 323, 173 to 283 and 167 to 283 kg/h in the high altitude, valley basin and Karewa soils respectively. The corresponding weighted average values ranged from 251 to 285, 209 to 249 and 191 to 244 kg/h. The high altitude soils contain relatively higher amount of available K_2O . The higher K_2O content of 323 kg/h was observed in the surface soils of Bahalgam and Gulmarg falling in the high altitude zone. The fertility status of available K_2O may be rated as medium to high.

4.13 Cation exchange capacity and exchangeable cations

The results for cation exchange capacity (CEC) and exchangeable cations are presented in Table 6.

It is observed from the data that CEC varied from 21.08 to 30.80 me/100g in the high altitude soils and the weighted average values varied from 22.49 to 28.98 me/100 g. The CEC in the valley basin ranged from 15.30 to 22.95 me/100g and their weighted average values ranged from 15.80 to 22.31 me/100g whereas in the Karewa soils it varied from 14.50 to 23.50 me/100g and the value for weighted average ranged from 15.01 to 20.14 me/100g. The highest value of CEC (30.80 me/100g) was recorded in Gulmarg profile (0-20 cm) which had higher content of organic carbon and a fairly good amount of clay. The lowest value of 14.50 me/100g was observed in the sub-soil of Koil profile (50-150 cm). The high altitude soils exhibited a higher value of CEC than the soils from remaining zones, the Karewa soils had the lowest cation exchange capacity. The lower horizons indicated generally higher CEC because of the tendency of the clay particles to increase with the increase in depth.

The content of exchangeable calcium was found to be unevenly distributed in the soils of three regions. It varied from 11.85 to 18.95, 8.03 to 14.90 and 7.95 to 14.98 me/100g soil in the high altitude, valley basin and Karewa soils respectively. The corresponding values of weighted average varied from 12.50 to 15.95, 8.87 to 13.04 and 8.38 to 12.48 me/100 g soil. The highest value of

Table 6- Cation exchange capacity (CEC) and exchangeable cations of soils from different zones of Kashmir.
(me/100g)

Location	Depth (cm)	CEC	Exchangeable		
			Ca	Mg	K
1	2	3	4	5	6
High Altitude soils					
Pahalgam	0-15	22.50	14.60	5.39	0.81
	15-35	21.08	12.95	4.85	0.62
	35-50	22.40	13.81	5.62	0.71
	50-125	25.52	16.48	5.62	0.85
	125-150	27.21	16.92	6.41	0.91
Weighted average		24.59	15.52	5.62	0.81
Larnoo	0-18	21.08	14.64	6.07	0.53
	18-70	22.45	14.64	6.41	0.49
	70-120	23.08	15.30	7.01	0.42
	120-150	22.46	16.01	5.21	0.48
Weighted average		22.49	15.13	6.32	0.46
Sonamarg	0-20	23.30	12.45	8.02	0.43
	20-60	22.58	12.45	7.95	0.42
	60-90	21.50	11.85	7.08	0.28
	90-120	23.48	12.05	8.41	0.28
	120-150	24.01	13.71	8.82	0.39
Weighted average		22.92	12.50	8.05	0.36
Gulmarg	0-20	30.80	18.95	9.91	0.81
	20-50	28.15	17.46	9.45	0.72
	50-90	29.80	17.46	9.45	0.62
	90-150	28.25	13.24	9.85	0.72
Weighted average		28.98	15.95	9.51	0.70
Chandigam	0-17	25.00	15.42	7.85	0.35
	17-60	23.50	13.18	8.01	0.32
	60-90	24.50	15.72	8.01	0.30
	90-150	24.00	15.90	7.35	0.30
Weighted average		24.07	15.02	7.72	0.31
Valley basin soils					
Khudwani	0-20	20.28	14.55	4.50	0.26
	20-40	19.46	14.90	4.01	0.31
	40-70	17.50	12.42	4.36	0.21
	70-105	16.89	11.85	3.85	0.28
	105-150	20.50	12.91	6.82	0.17
Weighted average		18.89	13.04	4.95	0.23

contd.....

1	2	3	4	5	6
Nunari	0-20	18.90	10.58	6.45	0.30
	20-40	19.58	12.41	6.05	0.33
	40-75	20.41	11.90	7.42	0.35
	75-150	20.41	12.05	7.12	0.41
	Weighted average	20.09	11.86	6.95	0.37
Sholimar	0-15	20.50	12.46	7.01	0.35
	15-45	21.00	11.95	7.45	0.42
	45-90	22.95	11.95	8.05	0.37
	90-150	22.95	12.08	7.45	0.43
	Weighted average	22.31	12.05	7.58	0.40
Podgampora	0-17	16.75	9.56	5.82	0.39
	17-85	15.75	9.01	5.82	0.35
	85-110	15.30	8.03	6.05	0.41
	Weighted average	15.80	8.87	5.87	0.36
Handwara	0-17	20.30	11.08	7.81	0.25
	17-35	21.85	11.95	6.12	0.21
	35-85	22.35	12.11	6.72	0.35
	85-150	18.85	13.31	5.73	0.41
	Weighted average	20.54	12.49	6.34	0.34
Karewa soils					
Tapar	0-15	19.52	12.55	5.21	0.51
	15-35	18.42	10.81	6.44	0.41
	35-60	21.85	13.81	5.85	0.33
	60-90	20.42	12.98	6.41	0.45
	90-150	20.02	12.23	6.41	0.32
	Weighted average	20.14	12.48	6.20	0.38
K.D. Farm	0-16	19.70	12.46	6.02	0.62
	16-31	18.08	10.81	6.15	0.59
	31-47	19.70	10.45	6.15	0.50
	47-97	19.70	11.53	6.45	0.58
	97-150	20.30	12.05	5.62	0.42
	Weighted average	19.75	11.62	6.04	0.52
Pompore	0-20	23.50	14.98	6.12	0.55
	20-60	19.00	12.05	5.81	0.51
	60-85	20.85	12.81	6.48	0.61
	85-150	19.00	11.75	6.12	0.42
	Weighted average	19.90	12.43	6.09	0.49
Koil	0-20	15.00	8.56	4.58	0.29
	20-50	16.75	9.01	5.81	0.28
	50-85	14.50	8.56	5.01	0.21
	85-150	14.50	7.95	4.05	0.21
	Weighted average	15.01	8.38	4.69	0.23

18.95 me/100g was observed in Gulmarg soil, (0-20 cm) and the lowest value of 7.95 me/100g was found in the Koil profile (85-150 cm). The exchangeable Ca was the dominant cation present in all the three zones and high altitude soils had comparatively higher content of exchangeable Ca. The exchangeable Mg content ranged from 4.85 to 9.91, 3.85 to 8.05 and 4.05 to 6.48 me/100g in the high altitude zone, valley basin and Karewa soils respectively. The corresponding values for weighted averages ranged from 5.62 to 9.51, 3.85 to 8.05 and 4.05 to 6.48 me/100g soil. The amount of exchangeable Mg was higher in the high altitude soils than in the soils from other two zones. The Gulmarg profile contained the higher content of exchangeable Mg with its weighted average value as 9.51 me/100g. The distribution of exchangeable Mg was erratic in almost all the soil profiles.

The contents of exchangeable K ranged from 0.28 to 0.91, 0.17 to 0.43 and 0.21 to 0.62 me/100g in high altitude, valley basin and Karewa soils respectively, and their corresponding values of weighted average ranged from 0.31 to 0.81, 0.23 to 0.40 and 0.23 to 0.52 me/100g. The highest content (0.81 me/100g) was observed in Pahalgam (0-15 cm) and the lowest (0.21 me/100g) was recorded in Khudwani, Handwara and Koil profile samples. The exchangeable K was higher in high altitude soil and the valley soils had the lowest. Exchangeable Ca was found to be the dominant cation followed by Mg and K in the soils studied.

4.2 Mineralogical studies

Mineralogical composition of the selected soil samples was studied for primary and clay minerals and the results are presented in Table 7.

4.2.1 Sand Mineralogy:- The fine sand fraction of the soils contained 96 to 98 per cent light minerals and 2 to 4 per cent heavy minerals. Generally the percentage of heavier minerals was found to be slightly more in lower horizons. The important features of these minerals as observed under microscope are described below :

1. Quartz:- The fine sand fraction from high altitude zone contained quartz as the dominant light mineral constituting 55 to 63 per cent, the valley basin soils contained 45 to 55 per cent and the Karewa soils 43 to 55 per cent. Petrographic study revealed that quartz grains were heavily stained and were sub rounded to sub-angular shaped with stained inclusions. Fresh rounded grains of quartz were observed in Larnoo and Pahalgam soil. The Gulmarg soil had relatively higher content of quartz. The Gulmarg soil had relatively higher content of quartz. The sample from Koil and Pampore had lower content of quartz.
- ii. Feldspar:- Feldspars (orthoclase and plagioclase) were observed to be rectangular to platy in shape and light grey to yellowish coloured. The plagioclase grains were irregular to platy and of different colours. The contents of feldspar varied from 18 to 24 per cent, 15 to 20 per cent

Table 7: Mineralogical composition of fine sand fraction of soils from different zones of Kashmir.

Location/ Depth (Cm)	Light minerals	Heavy minerals
1	2	3
High altitude soils		
Pahalgam (0-15)	Quartz (60) feldspar (20) Muscovite (10) kaolin (5)	Opaque minerals (25) biotite(9) zircon (8) chlorite (6) augite (5) ilmenite (5) tourmaline (4).
Larnoo (0-18)	Quartz (63) feldspar (22) muscovite (8) kaolin (4)	Opaque minerals (25) biotite(10) zircon (9) chlorite (6) augite (6) garnet (5) hornblende (5)
Sonamarg (0-20)	Quartz (60) feldspar (21) muscovite (10) kaolin (5)	Opaque minerals (25) biotite(10) chlorite (8) zircon (7) hornblende (5) magnetite (3)
Gulmarg (0-20)	Quartz (63) feldspar (24) muscovite (7) kaolin (4)	Opaque minerals (25) biotite(10) tourmaline (7) zircon (6) magnetite (4) garnet (4) augite (4).
Gulmarg (90-150)	Quartz (62) feldspar (21) muscovite (7) kaolin (3)	Opaque minerals (24) zircon (10) biotite (8) chlorite (6) tourmaline (8) ilmenite (5) Rutile (5).
Chandigam (0-17)	Quartz (55) plageofeldspar (18) muscovite (8) kaolin (4)	Opaque minerals (25) biotite(10) chlorite (8) tourmaline (8) augite (6).
Valley basin soils		
Khudwani (0-20)	Quartz (55) altered plagioclase and orthoclase (20) muscovite (7) kaolin (4).	Opaque minerals (20) biotite(11) chlorite (7) tourmaline (6) ilmenite (5) zircon (5).
Nunar (0-20)	Quartz (55) feldspar (19) muscovite (8) kaolin (4)	Opaque minerals (21) biotite (10) chlorite (8) ilmenite (5) hornblende (3) zircon (3).
Nunar (75-150)	Quartz (53) feldspar (15) muscovite (7) kaolin (2).	Opaque minerals (20) biotite(11) chlorite (7) garnet (5) zircon (4) hornblende (2).
Shalimar (0-15)	Quartz (55) feldspar (18) muscovite (8) kaolin (2)	Opaque minerals (20) biotite(11) chlorite (7) tourmaline (6) augite (5) garnet (5).

contd....

Table contd...

1	2	3
Fadgampora (0-17)	Quartz (45) feldspar (18) muscovite (7) kaolin (5)	Opaque minerals (20) biotite(12) tourmaline (7) chlorite (7) augite (5) hornblende (3).
Handwara (0-17)	Quartz (50) feldspar (20) muscovite (7) kaolin (5)	Opaque minerals (18) biotite(13) chlorite (8) augite (6) garnet (4) ilmenite (4).
<u>Karewa soils</u>		
Tapar (0-15)	Quartz (55) feldspar (21) muscovite (10) kaolin (5)	Opaque minerals (16) biotite(10) chlorite (6) augite (5) ilmenite (4) hornblende (2).
K.D. Farm (0-16)	Quartz (51) feldspar (19) muscovite (8) kaolin (6)	Opaque minerals (16) biotite(10) chlorite (6) augite (6) zircon (6) hornblende (2).
Pampore (0-20)	Quartz (45) feldspar (18) muscovite (8) kaolin (7).	Opaque minerals (17) biotite(8) ilmenite (6) augite (5) chlorite (5) zircon (4).
Pampore (85-150)	Quartz (50) feldspar (15) muscovite (10) kaolin (8)	Opaque minerals (16) biotite (9) augite (6) garnet (5) chlorite (5) hornblende (3).
Koil (0-20)	Quartz (43) feldspar (14) muscovite (10) kaolin (7).	Opaque minerals (15) biotite(8) chlorite (5) augite (4) ilmenite (4) magnetite (2).

(Figures in brackets indicate approximate percentage).

and from 14 to 21 per cent in high altitude soil, valley basin and Karewa soils respectively. Larnoo and Gulmarg samples in the high altitude zone had relatively higher content and the Koil sample from Karewa zone had the lowest content of feldspar.

iii. Muscovite:- Muscovite mica grains were present as thin platy flakes and were mostly coloured. The distribution of muscovite was more or less uniform in all the soils under investigation and varied from 7 to 10 per cent. The other light minerals present include kaolin and microcline which were found in varying proportion in these soils.

Amongst the heavy minerals, biotite showing light brown to dark brown with cleaved flakes was present in all the zones. It exhibited red stains in valley basin samples which could possibly be due to the oxidation of Fe^{++} . Its content varied from 8 to 13 per cent in all these soils. Augite and hornblende present, were dark black to dark green in colour and had irregular to prismatic shape. They contributed 5 to 15 per cent the heavy mineral present in these samples. Chlorite grains were present to the tune of 5-8 per cent and were coloured and rounded. The other heavy minerals included garnet, ilmenite, magnetite, tourmaline and zircon. The content of opaque minerals was slightly higher in all the soils and varied from 15 to 25 per cent.

4.2 Clay mineralogy

Clay minerals were identified on the basis of chemical analysis and X-Ray diffraction.

4.2.2.1 Physico-chemical analysis:- The data (Table 8) indicates that CEC of high altitude soil clays varied from 36.42 to 44.81 in valley basin from 28.36 to 36.42 and in Karewa soil clays from 26.40 to 36.48 me/100g. The CEC was more for the high altitude soil clays than in the valley basin and Karewa clays. The Pahalgam sample had the highest CEC (44.81 me/100g) and Koil sample had the lowest (26.40 me/100g). The CEC of soil clays of these soils tended to approach those of illite and chlorite which have the CEC within this range.

The silica content (SiO_2) varied from 42.48 to 46.52, 41.60 to 44.80 and 41.46 to 46.52 per cent in soil clays from high altitude zone, valley basin and Karewa soils respectively. The silica content did not exhibit any marked variation in these soils. The Fe_2O_3 content varied from 11.92 to 14.42, 12.62 to 16.25 and 11.94 to 18.42 per cent in high altitude, valley basin and Karewa soil clays respectively. The higher content of 18.42 per cent was recorded in the K. D. Farm and the lowest (11.92 per cent) in Larnoo soil clays. The Al_2O_3 content varied from 20.26 to 22.42, 21.48 to 24.48 and 22.60 to 25.83 per cent in the soil clays of high altitude zone, valley basin and Karewa zone respectively. The K_2O content varied from 3.36 to 5.76, 3.35 to 5.52 and 3.83 to 6.48 per cent in high

Table 3: Physico-chemical Analysis of clay (2u) samples of soils from different zones of Kashmir.

Location	CEC me/100g	SiO ₂ (%) ²	Fe ₂ O ₃ (%) ³	Al ₂ O ₃ (%) ⁵	R ₂ O ₃ (%) ⁶	K ₂ O (%) ⁷	MOLAR RATIOS		
							SiO ₂ /R ₂ O ₃ ⁸	SiO ₂ /Al ₂ O ₃ ⁹	Al ₂ O ₃ /K ₂ O ¹⁰
1	2	3	4	5	6	7	8	9	10
<u>High Altitude soils</u>									
Pahalgam (0-15)	44.81	42.48	13.08	21.85	34.93	5.28	2.6	3.3	3.9
Larnoo (0-18)	40.42	44.20	11.92	22.42	34.34	3.84	2.5	3.3	5.5
Sonamarg (0-20)	38.90	43.08	14.42	22.42	36.84	5.76	2.3	3.2	3.6
Gulmarg (0-20)	42.52	46.52	13.90	21.40	35.30	4.56	2.6	3.7	4.3
Gulmarg (90-150)	38.46	46.52	13.90	20.26	34.16	3.36	2.7	3.9	3.5
Chandigam (0-17)	36.42	44.58	13.08	20.80	33.88	3.84	2.6	3.7	5.0
<u>Valley basin soils</u>									
Khudwani (0-20)	30.46	43.08	12.62	24.48	37.10	5.52	2.2	3.0	4.0
Nunar (0-20)	32.38	41.66	15.80	23.96	39.76	4.42	2.9	2.8	5.0
Nunar (75-150)	30.82	43.60	16.25	23.42	39.67	3.84	2.1	3.0	6.0
Shalimar (0-15)	36.42	44.80	14.80	22.82	37.61	3.35	2.4	3.4	6.3
Padgampora (0-17)	28.36	44.50	14.05	21.48	35.51	3.84	2.5	3.5	5.2

Contd.....

Table contd....

1	2	3	4	5	6	7	8	9	10
Handwara (0-17)	34.90	43.82	12.95	22.26	35.21	3.36	2.4	3.3	6.0
	<u>Karewa soils</u>								
Tapar, (0-15)	32.60	46.52	11.94	25.26	37.18	5.36	2.1	3.1	4.3
K.D. Farm (0-16)	34.42	43.50	18.42	24.80	43.22	3.88	2.0	3.0	6.0
Pampore (0-20)	36.43	41.46	15.42	24.03	39.45	4.12	2.0	2.9	5.3
Pampore (85-150)	34.21	42.90	15.60	25.88	41.48	5.28	2.0	2.8	4.6
Koil (0-20)	26.40	42.64	15.60	22.60	38.20	4.32	2.2	3.2	5.0

Figures in brackets indicate depth in cm..

altitude, valley basin and karowa soil clays, respectively. The samples from the lower horizon revealed lesser K_2O content in case of Gulmarg and Nunar but the trend was reverse in Pampore.

4.2.2 Molar ratios:

The molar ratios of $SiO_2 : R_2O_3$, $SiO_2 : Al_2O_3$ and $Al_2O_3 : K_2O$ were computed from the clay analysis data and are presented in Table 8.

Silica - sesquioxide ratio ($SiO_2 : R_2O_3$): Silica and sesquioxide constituted the major portion of soil fabric. The ratio varied from 2.3 to 2.7 in the high altitude soil clays, from 2.1 to 2.9 in valley basin clays and from 2.0 to 2.2 in clays from karowa zone. The silica and sesquioxide ratio ranged between 2 to 3 in the soils studied which suggested the presence of illite and chlorite minerals.

Silica: alumina ratio ($SiO_2 : Al_2O_3$): The silica alumina ratio varied from 3.2 to 3.9, 2.8 to 3.5 and 2.8 to 3.2 in the soil clays of high altitude, valley basin and karowa zone, respectively. Higher values of SiO_2/Al_2O_3 ratio (3.9) was observed in high altitude soil clays (Gulmarg). The silica - alumina ratio indicate the possible presence of illite and chlorite.

Alumina - potassium ratios ($Al_2O_3 : K_2O$): The alumina - potassium ratios varied from 3.5 to 5.5, 4.0 to 6.0 and 3.7 to 6.0 in high altitude, valley basin

and Karewa soil clays respectively. The higher value of 6.0 as exhibited by the samples from Nunar, Shalimar, Handwara and K.D.Farm may be attributed to the higher content of finer particles which make up about 80 per cent of the soil fabric in these soils. The clay samples, by and large contained fairly higher content of K_2O . The presence of illite is thus inferred in these samples.

4.2.2.3 X-ray diffraction:- The important d-spacings of different clay minerals obtained from x-ray diffractogramme of clay samples are presented in Tables 9, 10 and 11. The diffraction pattern of these clay samples are shown in Fig. 2.

The soil clays from high altitude zone showed a strong reflection at 10.04 to $10.52A^\circ$ in Mg saturated samples. The glycolated samples showed the basal reflection at 10.04 to $10.39A^\circ$. Upon heating the samples the spacings did not expand but reflection became more intense. The higher order peaks of these reflections occur at 5.0 to 5.21 and 3.32 to $3.45 A^\circ$ d-spacings. This suggests the presence of mica (illite) as the dominant clay mineral. The $10A^\circ$ peak in case of Pahalgam, Larnoo and Gulmarg samples showed asymmetrical broadening towards low 2θ angles, suggesting the presence of degraded nature of illite in these samples. Glycolation failed to exhibit any expansion of $14 A^\circ$ thereby ruling out the presence of expanding minerals. The collapse

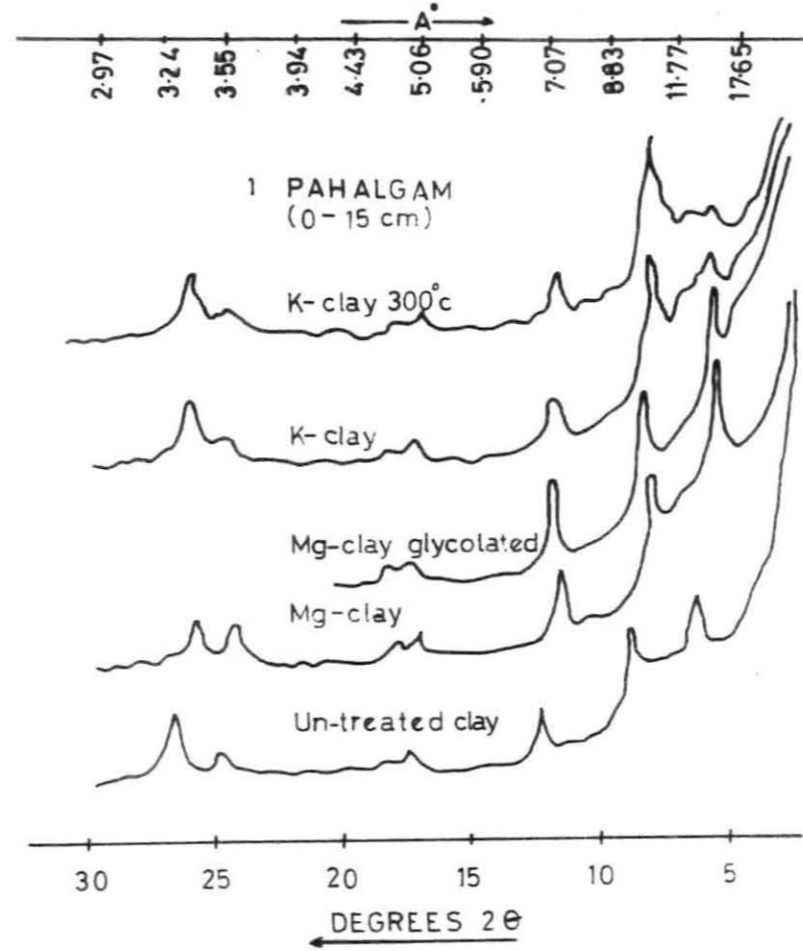
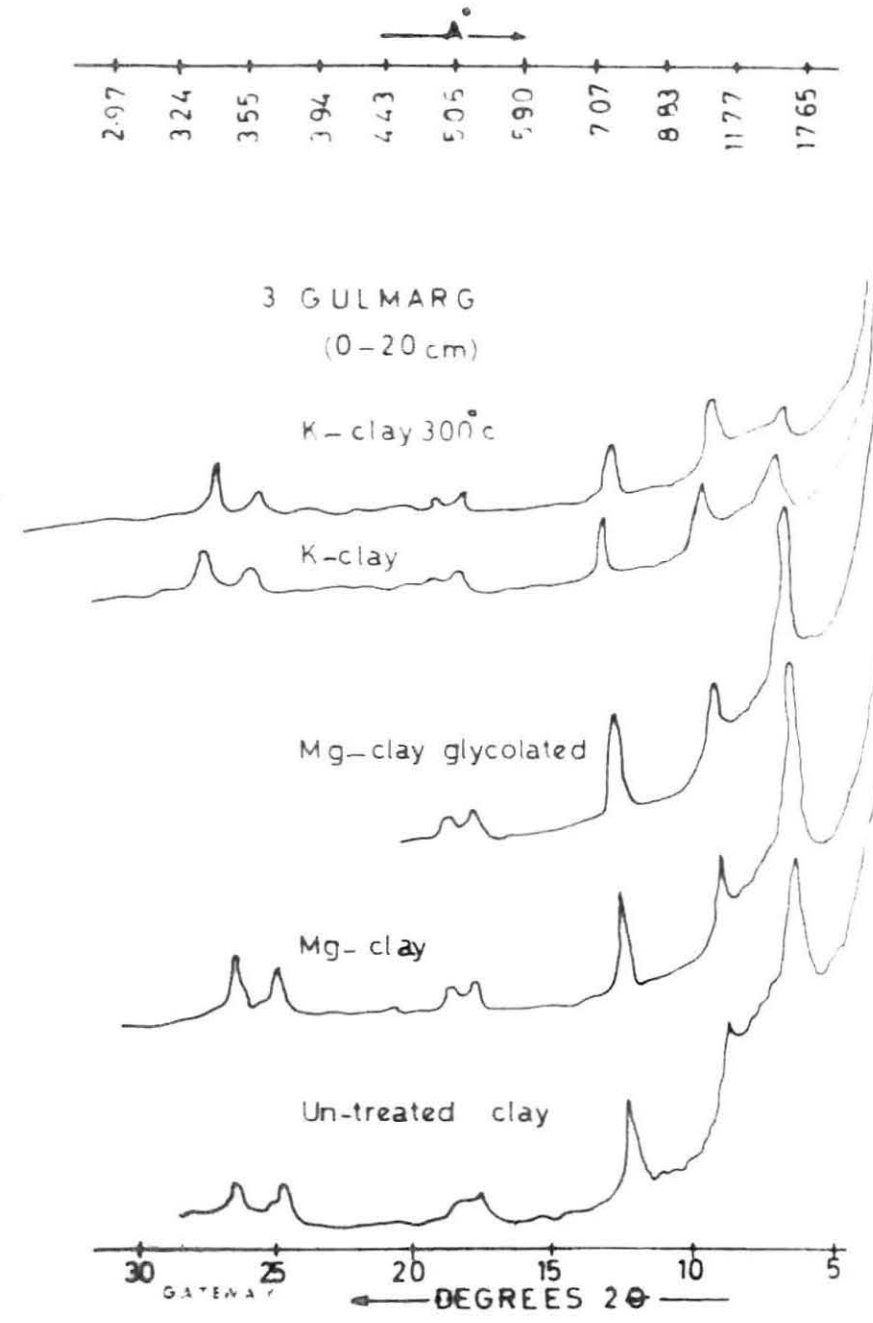
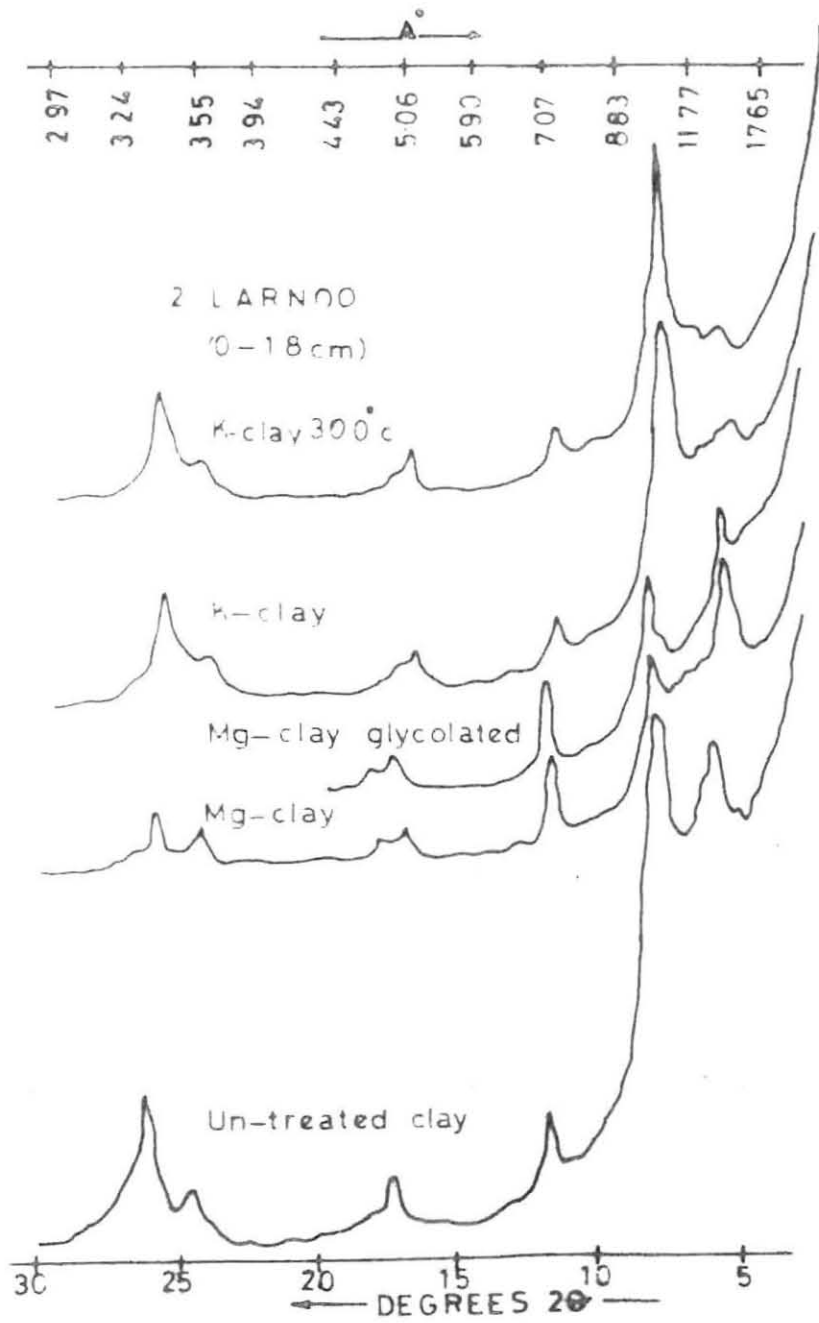
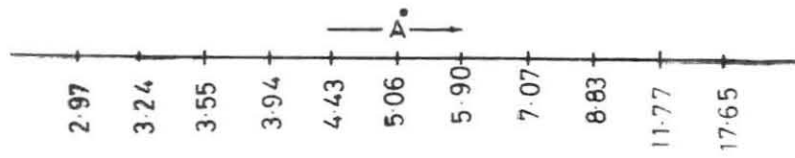
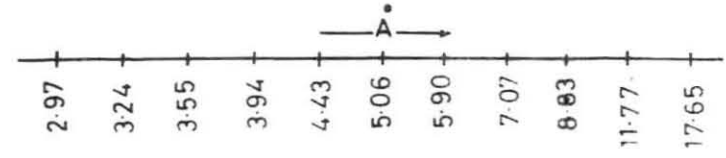
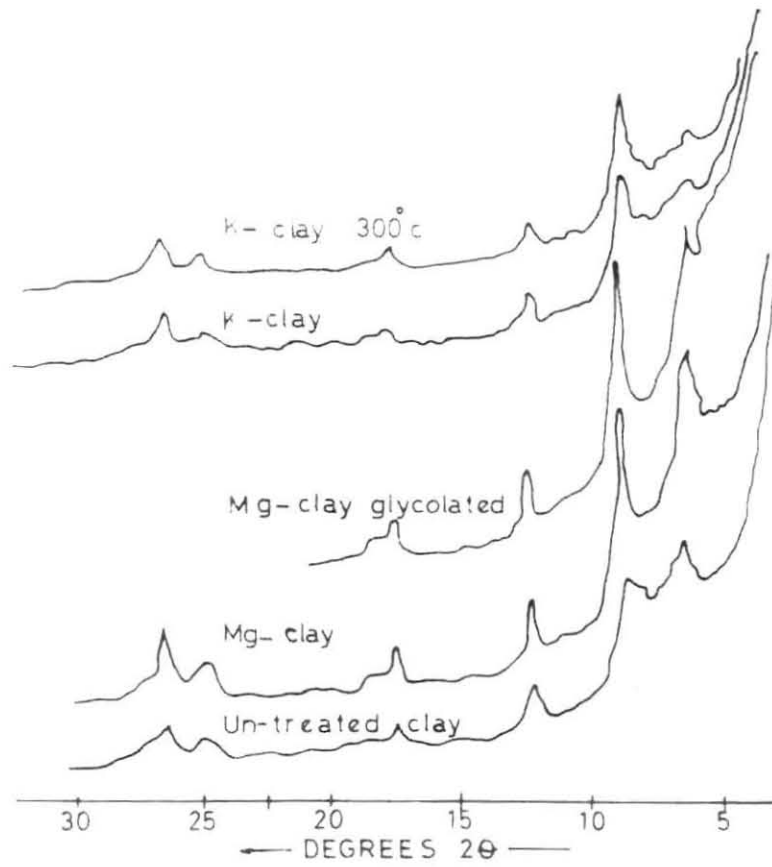


FIG.2 X RAY DIFFRACTOGRAMS
OF CLAY FRACTION

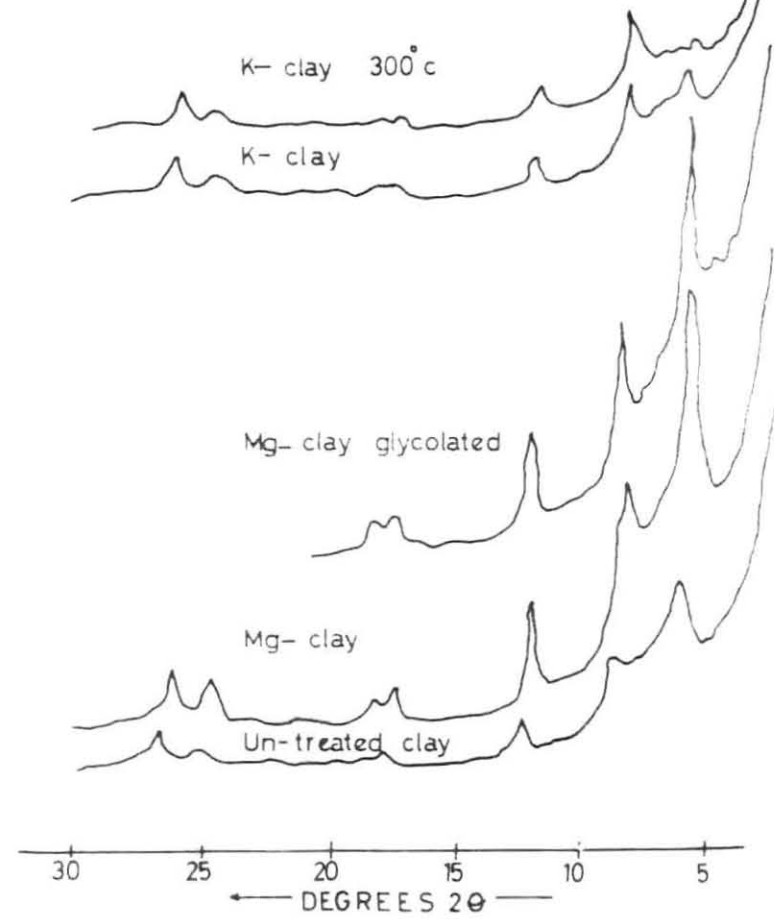


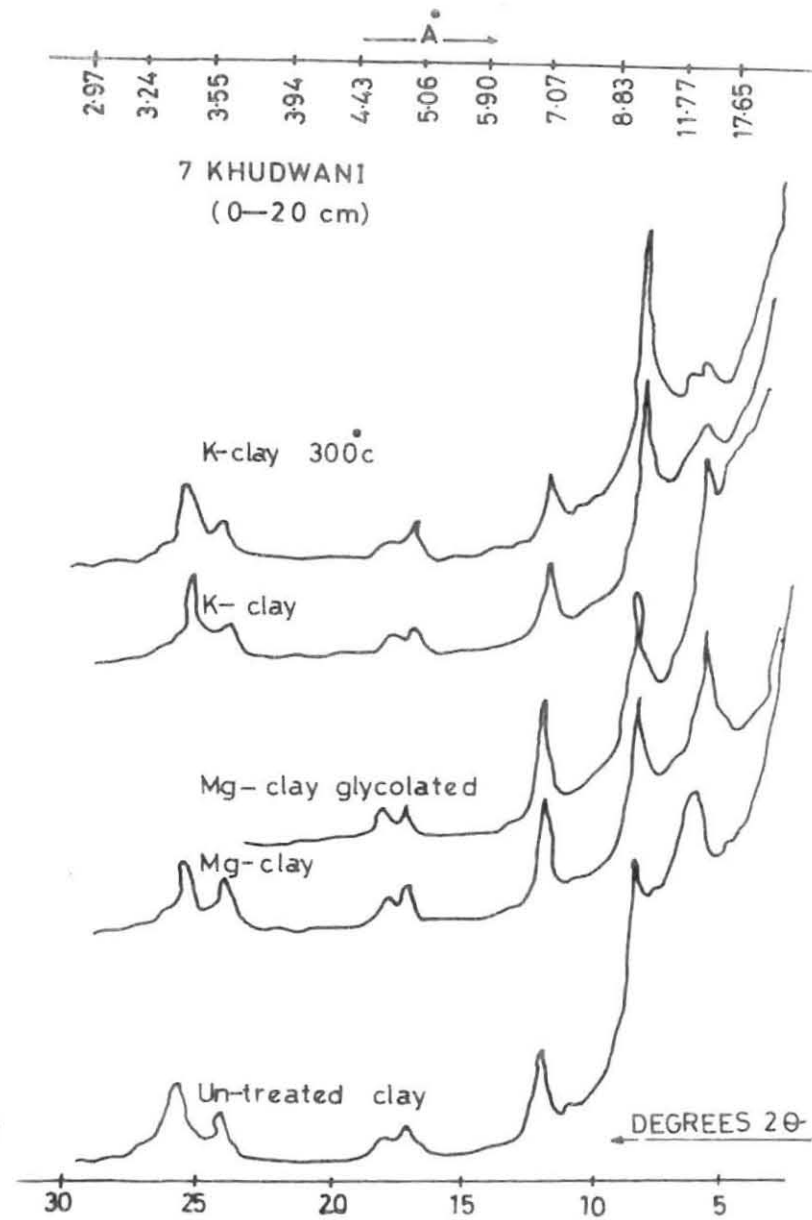
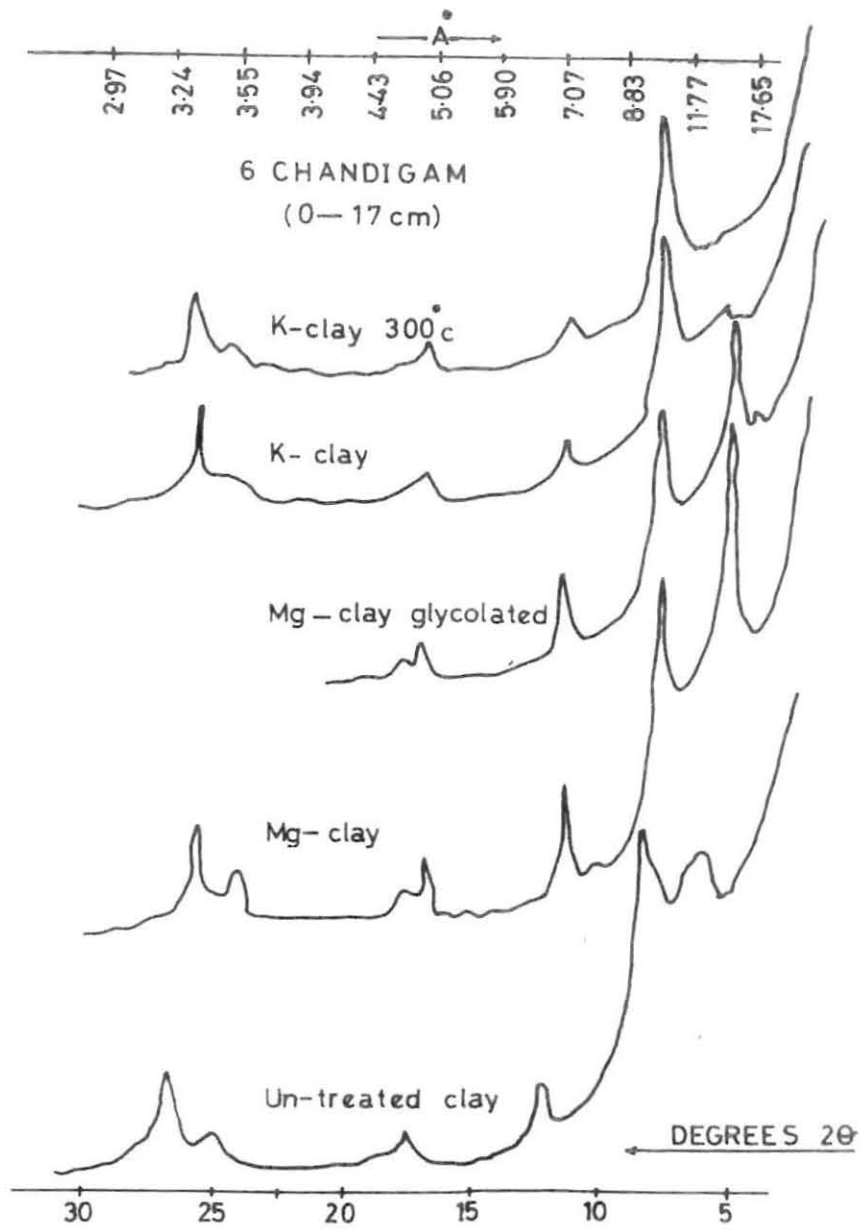


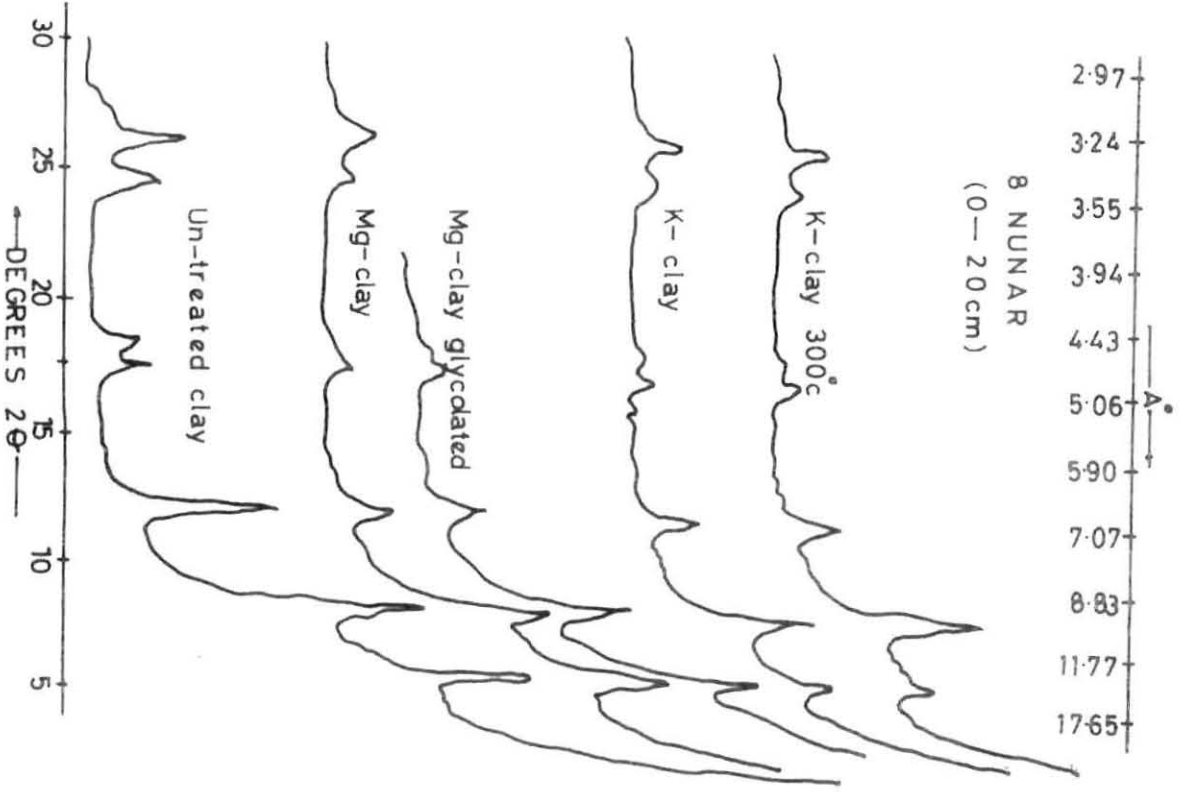
4 SONAMARG
(0-20 cm)

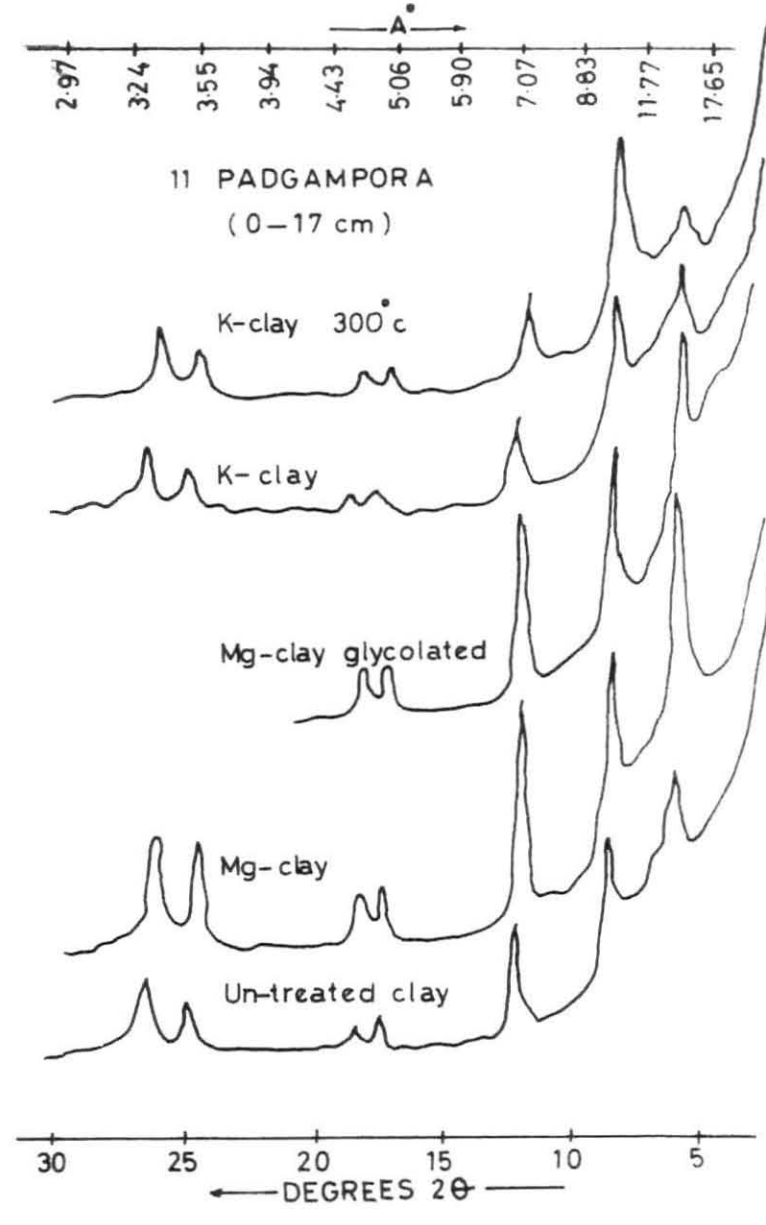
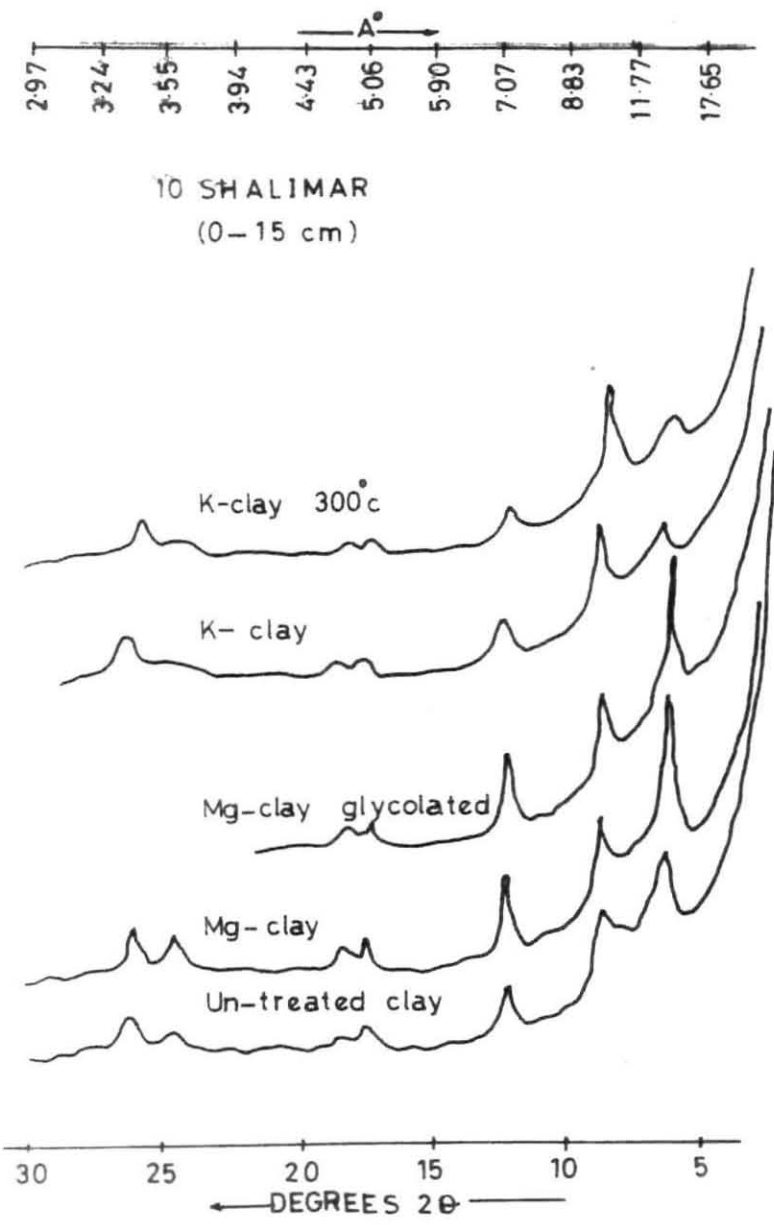


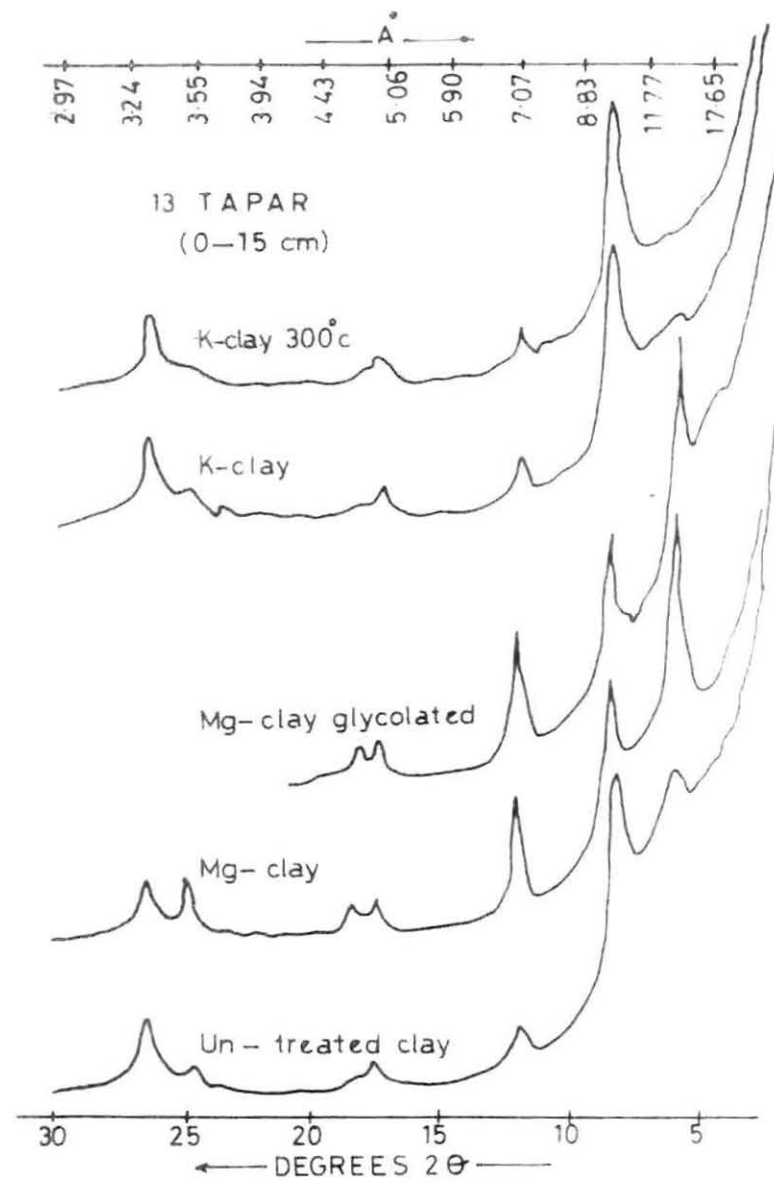
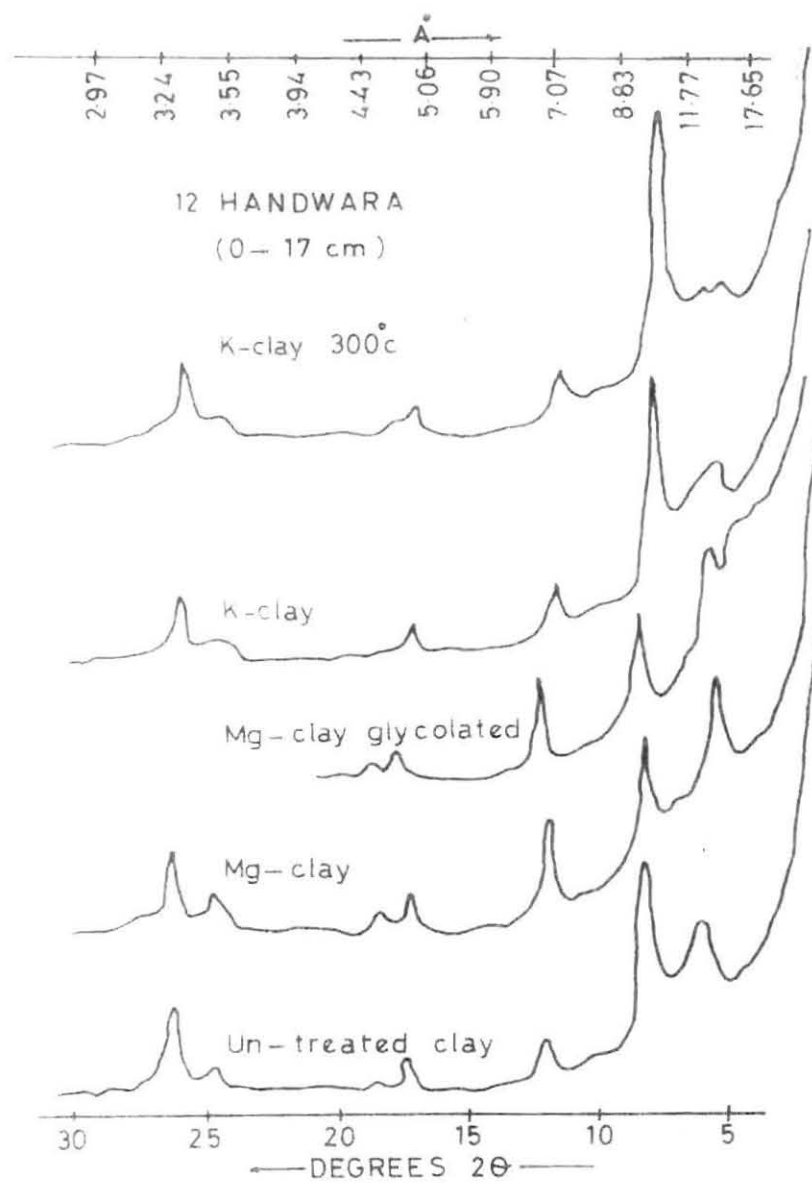
5 GULMARG
(90-150 cm)

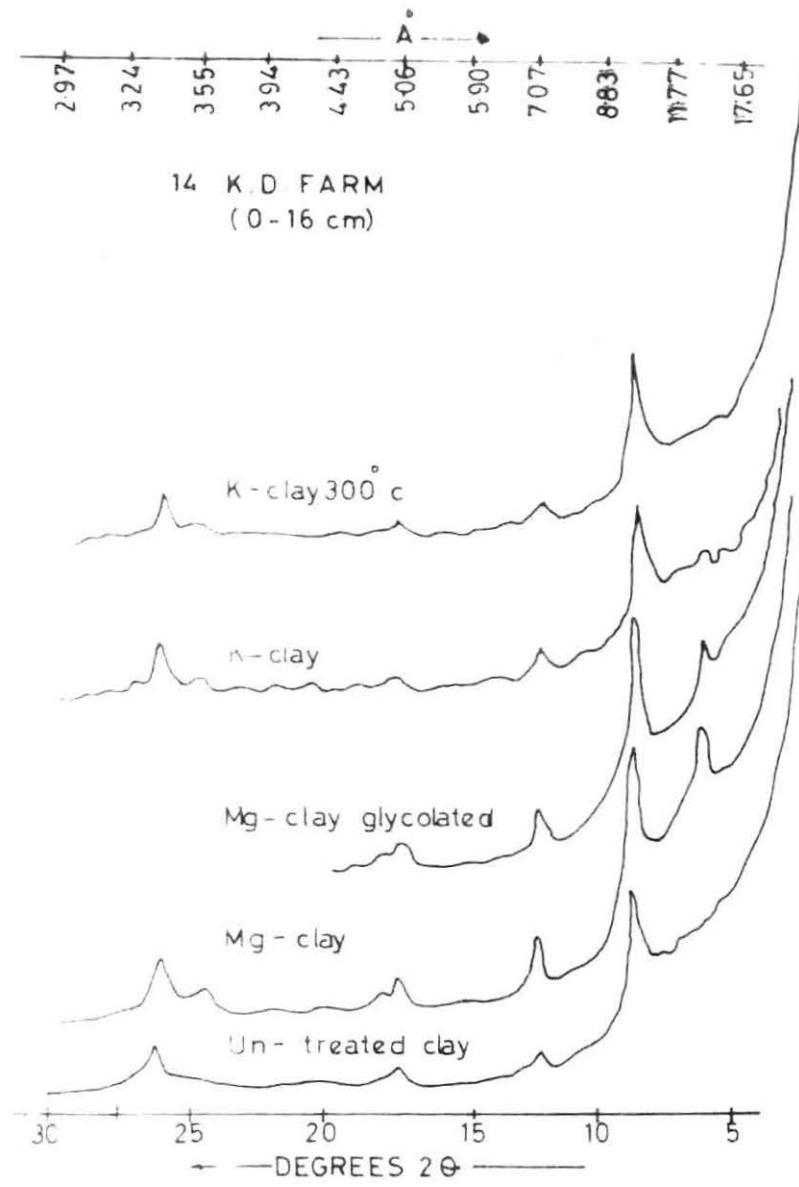




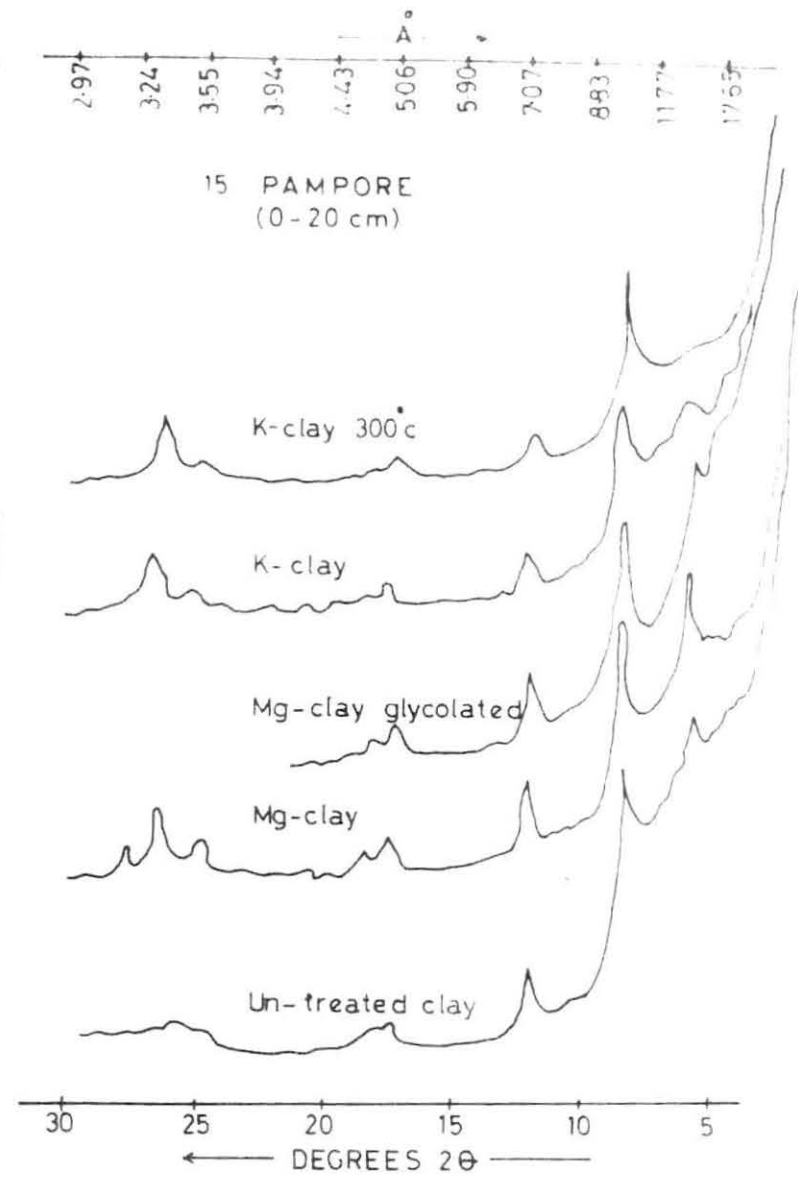




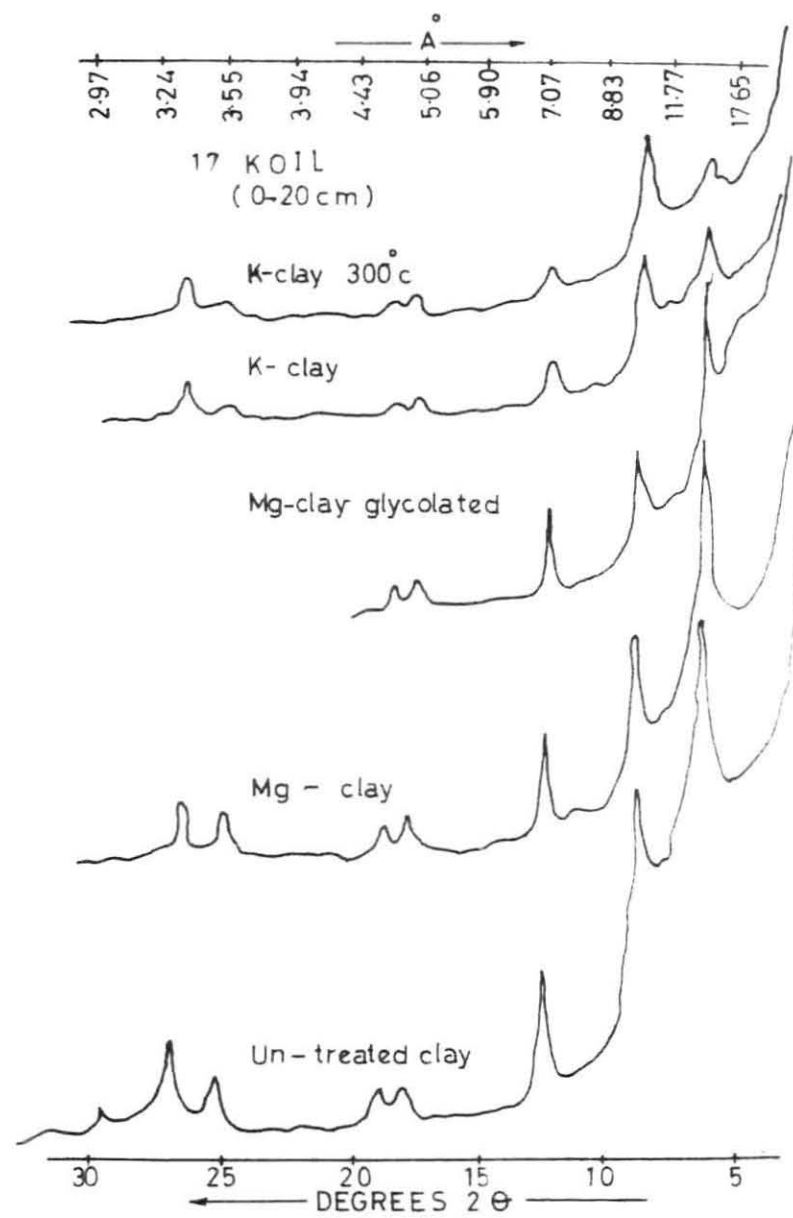
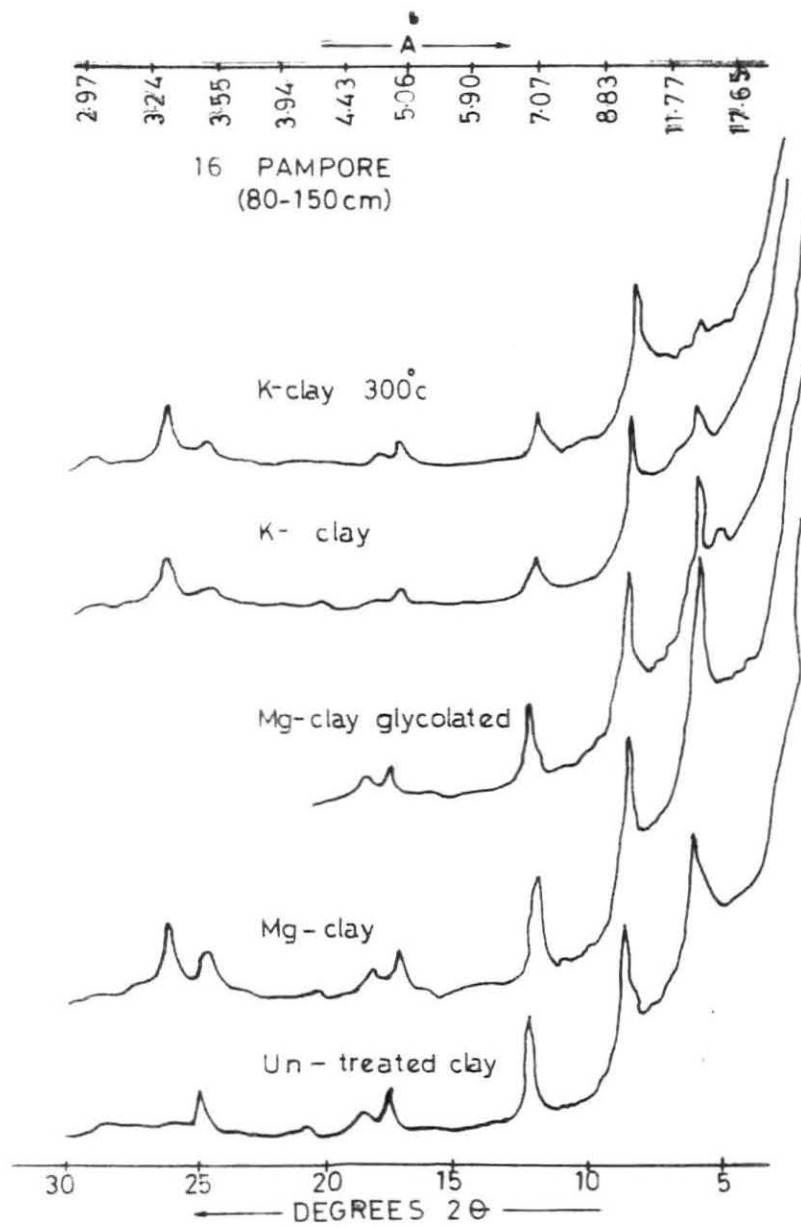




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or reduction in 14\AA° peak on K- saturation and on heating to 350°C and the increase in intensity of 10\AA° reflection indicates the possible presence of vermiculite in Larnoo and Chandigarh samples. However, on K saturation and heating the 14\AA° peak persisted in Pahalgam, Sonamarg and Gulmarg soil clays, thus pointing towards the presence of chlorite in these samples. The higher order reflections observed at 7.07 to 7.55 and 3.50 to 3.63\AA° , their intensities decreased with thermal treatment. The presence of chlorite, therefore, is inferred in all the samples of this zone but relatively in smaller quantities in Larnoo and Chandigarh.

Minerals of kaolinite group are characterized by strong reflections at 7.2 and 3.6\AA° which disappear or decrease in intensity on thermal treatment. The reflections observed in these samples at 7.07 to 7.55\AA° and 3.55 to 3.67\AA° are relatively weak and decreased in intensity after heating, thus the presence of kaolinite is inferred. The presence of kaolinite was confirmed by HCl treatment which decomposed the chlorite mineral and the 7.2\AA° peak persisted in all the samples. Quartz and feldspar seems to be absent or present in traces only as their characteristic reflections at 4.26\AA° and 3.2\AA° were missing.

The inter-stratified or mixed layer mineral group may be regular when these occur with a fixed periodicity while random or irregular is used if the opposite is the case.

Table 9: Important d-specings (A^0) of untreated clay samples from different zones of Kashmir .

Location/depth(cm)	Deflection
High Altitude soils	
Pahalgam(0-15)	3.36, 3.55, 5.06, 7.07, 10.04 and 14.24
Larnoo(0-18)	3.36, 3.63, 5.06, 7.36, 10.39 and 14.24
Sonmarg(0-20)	3.36, 3.61, 5.06, 7.30, 10.39 and 14.47
Gulmarg(0-20)	3.36, 3.55, 5.03, 7.24, 10.27 and 14.71
Gulmarg(90-150)	3.36, 4.79, 7.07, 10.04 and 14.24
Chandigam(0-17)	3.33, 3.57, 5.06, 7.18, 10.04 and 13.58
Valley basin soils	
Khudwani(0-20)	3.36, 3.58, 4.79, 5.06, 7.24, 10.27 and 14.01
Nunar(0-20)	3.38, 3.61, 4.79, 5.06, 7.36, 10.39 and 14.71
Nunar(75-150)	3.29, 7.07, 10.04, and 13.58
Shalimar(0-15)	3.36, 3.60, 5.06, 7.24, 10.15 and 14.24
Badgampora(0-17)	3.36, 3.55, 4.79, 5.06, 10.27 and 14.71
Handwara(0-17)	3.39, 5.06, 7.30, 10.39 and 14.01
Karewa soils	
Tapar(0-15)	3.39, 3.63, 5.06, 7.36, 10.39 and 14.24
K.D.Farm(0-16)	3.34, 5.06, 7.07 and 10.04
Pampore(0-20)	3.63, 5.06, 7.30, 10.39 and 14.71
Pampore(85-150)	3.36, 3.57, 4.76, 5.06, 7.24, 10.39 and 14.71
Koila(0-20)	3.05, 3.29, 3.53, 4.66, 4.92, 7.07, 10.04 and 14.01

Table 10: Important d-spacings (A⁹) of Magnesium saturated and Glycolated clay samples from different zones of Kashmir.

Location/depth (cm)	Mg Saturated	Mg Glycolated
High Altitude soils		
Pahalgam(0-15)	3.45, 3.65, 4.92, 5.15, 7.36, 10.52 and 15.22	4.66, 5.06, 7.30, 10.27 and 14.71
Larnoo(0-18)	3.38, 3.63, 5.09, 7.36, 10.39, and 14.47	4.79, 5.06, 7.24 and 10.27
Sonmarg(0-20)	3.32, 3.55, 5.00, 7.07, 10.04 and 14.24	4.81, 5.06, 7.24, 10.27 and 14.71
Gulmarg(0-20)	3.36, 3.58, 4.74, 5.03, 7.13, 10.15 and 14.47	4.79, 5.06, 7.18, 10.04 and 14.71
Gulmarg(90-150)	3.41, 3.63, 4.76, 5.06, 7.30, 10.39 and 15.22	4.79, 5.06, 7.18, 10.04 and 14.71
Chendigar(0-17)	3.45, 3.67, 4.74, 5.21, 7.55, 10.51 and 15.22	4.79, 5.06, 7.36, 10.39 and 14.96
Valley basin soils		
Khudwani(0-20)	3.39, 3.63, 4.79, 5.46, 7.30, 10.39 and 14.96	4.79, 5.06, 7.36, 10.39 and 14.71
Nunarn(0-20)	3.36, 3.63, 5.03, 7.30, 10.39 and 14.71	4.81, 5.06, 7.36, 10.27 and 14.71
Nunarn(75-150)	3.36, 3.57, 4.74, 5.06, 7.24, 10.27 and 14.47	4.79, 5.06, 7.13, 10.04 and 14.71
Sholimar(0-15)	3.36, 3.58, 4.79, 5.06, 7.13, 10.27 and 14.47	4.79, 5.06, 7.13, 10.27 and 14.71
Padgampora(0-17)	3.37, 3.58, 4.81, 5.12, 7.30, 10.15 and 14.71	4.79, 5.06, 10.04, and 14.71
Handwara(0-17)	3.38, 3.61, 4.81, 5.12, 7.30, 10.39 and 15.22	4.60, 4.97, 7.07, 9.81 and 14.23
Karewa soils		
Tapar(0-15)	3.36, 3.58, 4.79, 5.06, 7.24, 10.39 and 14.71	4.79, 5.06, 7.07, 10.04 and 14.71
K.D. Farm(0-16)	3.36, 3.60, 5.06, 7.24, 10.15 and 14.47	5.06, 7.18, 10.15 and 14.71
Pampore(0-20)	3.37, 3.60, 5.06, 7.24, 10.27 and 14.71	5.12, 7.30, 10.04 and 14.71
Pampore(85-150)	3.38, 3.61, 4.76, 5.06, 7.18, 10.04 and 14.71	4.81, 5.03, 7.07, 10.04 and 14.24
Koill(0-20)	3.38, 3.61, 4.79, 5.06, 7.18, 10.04 and 14.47	4.81, 5.06, 7.18, 10.04 and 14.71

Table 11 : Important d -spacings (Å^0) of Potassium saturated and heated clay samples from different Zones of Kashmir.

Location/Depth(cm)	K-saturated	Heated
High altitude soils		
Pahalgam(0-15)	3.40, 3.60, 5.06, 7.37, 10.39 and 14.24	3.38, 5.06, 7.36, 10.39 and 14.24
Larnoo(0-18)	3.45, 3.70, 5.21, 7.36, 10.64 and 15.35	3.42, 3.55, 5.15, 7.36 and 10.39
Sonamarg(0-20)	3.37, 3.60, 5.06, 7.180, 10.39 and 14.717	3.36, 3.55, 5.03, 7.24, 10.39 and 14.71
Gulmarg(0-20)	3.29, 3.49, 4.92, 6.96, 10.04 and 14.01	3.36, 3.55, 4.74, 5.06, 7.18, 10.04 and 14.71
Gulmarg(90-150)	3.37, 5.06, 7.18, 10.27, and 14.24	3.37, 5.06, 7.36, 10.39 and 14.71
Chandigam(0-17)	3.39, 5.09, 7.36, 10.39 and 14.47	3.36, 3.53, 5.06, 7.24 and 10.27
Valley basin		
Khudwani(0-20)	3.41, 3.63, 4.79, 5.04, 7.36, 10.39 and 14.71	3.38, 3.58, 4.74, 5.06, 7.36, 10.30 and 14.71
Nunar(0-20)	3.36, 3.55, 5.06, 7.30, 10.39 and 14.71	3.36, 3.55, 5.06, 7.30, 10.27 and 14.7
Nunar(75-150)	3.37, 5.09, 7.24, 13.39 and 14.0	3.36, 5.06, 7.24 and 10.27
Sha limar(0-15)	3.38, 3.50, 4.97, 7.07, 10.04 and 14.01	3.36, 3.55, 5.06, 7.13, 10.27 and 14.47
Padgampora(0-17)	3.36, 3.55, 4.71, 5.03, 7.13, 10.27 and 14.47	3.37, 3.55, 4.79, 5.06, 7.24, 10.27 and 14.71
Handiwara(0-17)	3.39, 5.06, 7.18, 10.39 and 14.71	3.37, 5.06, 7.36, 10.39 and 14.71
Karewa soils		
Tape r (0-15)	3.36, 3.64, 5.06, 7.24, 10.39 and 14.71	3.36, 3.53, 5.06, 7.24 and 10.15
K.D.Farm(0-16)	3.32, 7.13, 10.15 and 13.58	3.38, 5.06, 7.24 and 10.27
Pampora	3.33, 5.36, 7.07, 10.04 and 13.79	3.36, 5.06, 7.24 and 10.04
Pampora (85 150)	3.37, 7.24, 10.27 and 14.47	3.36, 3.55, 5.06, 7.13, 10.04 and 14.71
Koill	3.36, 5.06, 7.18, 10.27 and 14.24	3.36, 5.06, 7.24, 10.27 and 14.47

The intensity of 14A° reflection reduced due to heating with relative increase in 10A° reflection; this may suggest the presence of micro-vermiculite as mixed layer in Larnoo and Chandigam samples. The K saturated and heated samples showed a very small reflection at 12.0A° indicating the presence of mixed layer mineral. However the absence of higher order of this reflection suggested random interstratification of 10 and 14A° components. The fact that 12.6A° reflection is noticeable in the heated samples suggested that the 14A° component is chloritic in nature.

The clay samples from valley basin zone gave strong reflections at 10.04 to 10.39 in Mg-saturated samples and on glycolation. There was no expansion of the peaks due to heating but the reflections became relatively intense. The higher order peaks observed are 5.03 to 5.46A° and 3.37 to 3.38A° . Thus the presence of illite is inferred as the dominant mineral in the soil clays from this zone. The Mg-saturated samples from this zone except that of Padgampore and Nunar (75-150 cm) samples exhibited 10A° peak as asymmetric with a tail extending towards low 2θ angles pointing towards the degraded nature of illite. The 14A° reflection in Mg-saturated samples occurred at 14.47 to 15.22A° and persisted after heating except in Nunar (75-150 cm). The intensities of higher order peaks at 7.13 to 7.30A° and 3.36 to 3.39A° found in these samples decreased due to thermal treatment thus indicating the presence of chlorite

in these samples. The 14Å° peak disappeared in Muner sample (75-150 cm) due to heating suggesting the presence of vermiculite in this sample. The reflections observed between 7.13 and 7.30Å° and 3.57 and 3.63Å° with a decrease in intensity on thermal treatment indicated the presence of kaolinite in all the samples of this zone. The presence of kaolinite was confirmed by HCl treatment.

The presence of smectite and non-clay material could not be inferred due to absence of relevant peaks. The presence of mica-vermiculite and illite-chlorite as interstratified mineral was also observed in the soil clays from this zone.

The soil clays from Karewa zone gave strong reflections at 10.04 to 10.39Å° in Mg-saturated samples and on glycolation the reflections were observed at 10.04Å° . Due to thermal treatment the reflections became intense. The higher order peaks observed in Mg saturated samples were 5.06Å° and $3.36 - 3.38\text{Å}^{\circ}$, thus the presence of illite as the dominant clay in all the samples of this zone is inferred. The asymmetrical nature of 10Å° peak which broadened towards low 2θ angles indicated the degraded nature of illite. The 14Å° peak persisted on K-saturation and heating in pampore (85-150 cm) and Koil samples pointing towards the presence of chlorite. The content of chlorite in other samples may be relatively less because of presence of higher order peaks. In Tapar, K. D. Farm and Pampore samples, the 14.0Å° peak disappeared due to heating which suggested

the presence of vermiculite. The presence of kaolinite is also inferred in the soil clays of this zone because of 7.0A⁰ peak which disappeared or decreased in intensity on heating. Its presence was confirmed by HCl treatment. The inter-stratified minerals, such as illite, vermiculite and illite, chlorite were also present in the Karewa soil clays.

4.3 Potassium chemistry

Experimental findings pertaining to the potassium chemistry of the soils under investigation are presented under the following heads:

1. Forms and distribution of potassium
2. Green House studies
3. Quantity/Intensity relationship.

4.3.1 Forms and distribution of potassium in the Soil

The results in respect of various forms of potassium are presented in Table 12. A perusal of the data indicates that K-fixing capacity of the high altitude soil varied from 260 to 280 ppm with an average value of 267 ppm, the highest K fixing capacity (280 ppm) was shown by the Pehalgam soil. The soils from the valley basin had comparatively lower K-fixing capacity (254 ppm) than in the soil from high altitude zone. It varied from 240 to 265 ppm, whereas in the lacustrine deposited zone of Karewa the K-fixing capacity was lowest and varied from 230 to 255 ppm and the average value worked as 245 ppm. The lowest K-fixing capacity of 230 ppm was exhibited by the Koil sample in the Karewa zone.

Table 12: Forms of Potassium in soils of different zones of Kashmir.

Location	Depth (cm)	K fixing capacity (ppm)	Water Soluble K (ppm)	Ex K (ppm)	Fixed K (ppm)	Total K (%)
1	2	3	4	5	6	7
High Altitude soils						
Pahalgam	0-15	280	22	120	828	2.00
	15-35		19	104	745	2.15
	35-50		15	108	982	2.68
	50-125		18	106	995	2.20
	125-150		21	97	863	2.15
	Weighted average		19	111	921	2.21
Larnoo	0-18	260	24	110	929	2.30
	18-70		21	105	992	2.25
	70-120		18	108	905	2.18
	120-150		26	102	865	2.40
	Weighted average		21	106	930	2.26
Sonmarg	0-20	270	21	110	835	2.02
	20-60		20	85	762	2.04
	60-90		18	80	920	2.23
	90-128		19	105	975	2.40
	128-150		15	90	860	2.65
	Weighted average		18	93	871	2.25
Gulmarg	0-20	265	18	120	895	1.46
	20-50		15	110	742	1.61
	50-90		22	116	938	1.52
	90-150		18	96	946	1.78
	Weighted average		18	107	896	1.63
Chandigam	0-17	260	18	115	845	1.92
	17-60		16	85	920	2.08
	60-90		15	100	845	2.02
	90-150		20	95	872	2.35
	Weighted average		17	95	877	2.15
Valley basin soils						
Khudwani	0-20	265	20	95	780	1.52
	20-40		18	88	672	1.65
	40-70		18	80	526	1.80
	70-120		15	60	610	2.16
	120-150		20	78	505	2.25
	Weighted average		17	91	603	1.95

contd....

1	2	3	4	5	6	7
Mungr	0-20	240	15	80	626	1.95
	20-40		12	75	765	2.08
	40-75		10	70	850	1.85
	75-150		11	95	942	2.01
	Weighted average		11	84	855	1.97
Shr limar	0-15	255	22	102	840	1.52
	15-45		19	105	725	1.85
	45-90		18	95	695	1.60
	90-150		15	82	705	2.20
	Weighted average		17	92	719	1.88
Padgampora	0-17	260	20	90	840	2.15
	17-85		15	85	755	2.08
	85-110		15	95	805	1.95
	Weighted average		15	88	779	2.06
Handwara	0-17	250	18	85	610	1.60
	17-35		15	70	580	1.68
	35-85		12	65	550	1.95
	85-150		12	90	620	1.85
	Weighted average		13	78	590	1.83
Karewa soils						
Tapsar	0-15	240	20	85	750	2.02
	15-35		18	75	690	2.10
	35-60		18	70	545	2.10
	60-90		15	80	605	1.95
	90-150		12	95	625	2.20
	Weighted average		15	84	629	2.10
K.D. Farm	0-16	255	19	105	825	1.95
	16-31		17	95	740	2.10
	31-47		20	85	655	1.85
	47-97		18	78	605	1.95
	97-150		15	82	655	1.95
	Weighted average		17	84	665	1.95
Pampore	0-20	255	19	95	740	1.85
	20-60		15	85	785	2.05
	60-85		12	70	695	2.05
	85-150		10	62	760	1.95
	Weighted average		13	74	753	1.98
Koil	0-20	230	15	80	665	1.70
	20-50		12	75	615	1.65
	50-85		10	65	750	1.85
	85-150		10	70	615	1.95
	Weighted average		11	71	653	1.83

The contents of water soluble K in the high altitude zone varied from 15 to 26 ppm and the weighted average values ranged between 17.62 and 21.36 ppm. The distribution of water soluble K in this zone did not show any specific trend down the profile. The contents of water soluble K in the valley basin soils ranged from 10 to 22 ppm and in the Karewa soils from 10 to 20 ppm. The corresponding weighted average values ranged from 11.43 to 17.66 ppm and 11.06 to 17.16 ppm in these soils. The contents of water soluble K were lowest in the Karewa belt than in the other two zones. The data revealed that water soluble K constituted the lowest fraction.

The exchangeable potassium (NH_4OAcK) varied from 80 to 120, 60 to 105 and 62 to 105 ppm in the high altitude, valley basin and Karewa soils respectively. The surface samples from Pehlgaem and Gulmarg had the higher content (120 ppm) of exchangeable K. The weighted average values ranged from 93.13 to 111.43, 78.70 to 92.50 and 71.16 to 84.74 ppm in the high altitude, valley basin and Karewa soils respectively. The Karewa soils had relatively lower content of exchangeable K than in the other zones. However, the surface samples of the K D. Farm exhibited a fairly high amount (105 ppm) of exchangeable K.

The fixed potassium (NH_4OAc soluble K) varied from 742 to 992, 505 to 942 and 545 to 825 ppm in high altitude zone, valley basin and Karewa soils respectively.

The higher content of 995 ppm was encountered in the E-horizon (50-125 cm) of Pahalgam profile and the lowest content (505 ppm) in the Khudwani profile (120-150 cm). The weighted average values ranged from 871.66 to 930.04, 590.73 to 854.80 and 628.83 to 753.16 ppm K in high altitude soil, valley basin and Karewa soils, respectively. The valley basin and Karewa soil had relatively lesser content of non-exchangeable K as compared to those of high altitude zones. The distribution of non-exchangeable K in the various soil down the profile did not specify any trend. The total K-content in the high altitude zone ranged from 1.46 to 2.68 per cent and the weighted average values varied from 1.63 to 2.26 per cent. Generally the lower horizons had a higher content of total K but the trend was not uniform. In the valley basin soils the total K content ranged from 1.52 to 2.25 per cent and the weighted average from 1.83 to 2.06 per cent. The lowest content (1.83 per cent) was found in Handwara soil profile. The Karewa soils contained 1.65 to 2.20 per cent and the weighted average values ranged from 1.83 to 2.10 per cent. These soils had relatively a lesser content of total K than in the soils from high altitude zone. the lowest content (1.65 per cent) was observed in the Koil profile (20-50 cm).

Relationship between forms of K and soil fractions:

The data pertaining to the fractionation of K in various soil fractions (clay, silt and fine sand) of

surface and selected sub-surface samples are presented in Table 13. It is evident from the Table that total K in the fine sand from high altitude zone varied from 1.45 to 2.20 per cent; in silt from 1.90 to 2.80 per cent and in clay from 2.85 to 4.40 per cent. The HCl soluble K was in the range of 0.35 to 0.68 , 1.14 to 1.48 and 1.40 to 1.80 per cent in fine sand, silt and clay fractions respectively.

The fixed K (INHNO_3 Soluble K) varied from 0.15 to 0.25, 0.22 to 0.42 and 0.45 to 0.86 per cent in fine sand, silt and clay respectively. In the valley basin soils the total K varied from 1.25 to 1.65, 1.80 to 2.35 and 2.70 to 3.75 in fine sand, silt and clay respectively. The contents of HCl soluble K ranged from 0.28 to 0.50, 1.10 to 1.40 and 1.48 to 1.85 per cent in **fine** sand , silt and clay respectively. The sand, silt and clay fractions from this zone had fixed K (INHNO_3K) ranging from 0.10 to 0.20 , 0.20 to 0.45 and 0.60 to 0.76 per cent respectively.

The total K in the soil samples from Karewa zone varied from 1.25 to 1.60, 1.80 to 2.45 and 2.25 to 3.15 per cent in fine sand, silt and clay respectively. The HCl soluble K in the sand varied from 0.35 to 0.65 per cent. Regarding the contents of fixed K it varied from 0.15 to 0.28, 0.51 to 0.65 and 0.75 to 1.05 per cent in fine sand, silt and clay respectively. The contribution from finer particles was relatively **more** than the sand towards the various forms of K in all the soils. On an average clay

Table 13: Potassium content and contribution of soil fractions to different forms of K in the various zones of Kashmir. (per cent)

Location/ depth(cm)	Fraction	Total K	Contri- bution	HCl Sol.K	Contri- bution	Fixed K (1NHNO ₃)	Contri- bution
1	2	3	4	5	6	7	8
High Altitude soils							
Pahalgam (0-15)	Fine sand	1.60	7.56	0.68	8.46	0.20	7.51
	Silt	2.80	41.48	1.16	45.22	0.26	30.64
	Clay	4.40	50.94	1.52	46.31	0.67	61.69
Larnoo (0-18)	Fine sand	1.60	6.42	0.54	4.86	0.22	4.72
	Silt	2.80	59.48	1.44	45.03	0.39	29.17
	Clay	3.20	66.17	1.56	50.10	0.86	66.07
Sonmarg (0-20)	Fine sand	1.45	8.77	0.45	6.28	0.25	11.12
	Silt	2.30	33.37	1.20	40.24	0.32	34.14
	Clay	3.50	57.85	1.20	53.46	0.45	54.72
Gulmarg (0-20)	Fine sand	1.80	11.12	0.35	4.38	0.15	7.30
	Silt	2.45	43.04	1.48	52.72	0.22	30.51
	Clay	3.90	45.83	1.80	42.89	0.67	62.18
Gulmarg (90-150)	Fine sand	2.20	12.01	0.42	5.00	0.21	8.44
	Silt	2.65	44.02	1.20	47.12	0.30	37.04
	Clay	3.35	43.50	1.52	46.31	0.58	54.49
Chandigam (0-17)	Fine sand	1.75	17.16	0.38	7.03	0.15	6.32
	Silt	1.90	37.53	1.14	42.52	0.42	35.63
	Clay	2.85	45.30	1.68	50.43	0.85	58.04
Valley basin soils							
Khudwani (0-20)	Fine sand	1.35	12.86	0.50	9.94	0.18	10.40
	Silt	1.80	32.62	1.16	43.90	0.32	35.21
	Clay	3.65	54.50	1.48	46.14	0.60	54.37
Junar (0-20)	Fine sand	1.25	10.70	0.42	8.01	0.16	8.93
	Silt	2.21	37.01	1.20	44.49	0.25	27.14
	Clay	3.60	52.20	1.48	47.49	0.68	63.91

contd.....

1	2	3	4	5	6	7	8
Nunar (75-150)	Fine sand	1.50	10.90	0.48	7.25	0.20	8.42
	Silt	2.35	35.93	1.40	44.49	0.33	29.21
	Clay	3.75	53.15	1.64	48.30	0.76	62.36
Shelimar (0-15)	Fine sand	1.65	13.48	0.28	4.80	0.10	5.06
	Silt	2.05	36.62	1.16	43.56	0.29	32.10
	Clay	3.25	49.89	1.60	51.63	0.66	62.82
Padgampora (0-17)	Fine sand	1.40	14.12	0.45	7.63	0.15	9.31
	Silt	1.85	43.67	1.10	43.69	0.20	29.06
	Clay	2.70	42.20	1.85	48.66	0.64	61.61
Hondware (0-17)	Fine sand	1.65	12.66	0.50	7.39	0.20	7.31
	Silt	2.20	52.59	1.18	54.35	0.45	51.28
	Clay	2.80	34.74	1.60	38.25	0.70	41.40
Karewa soils							
Tapar (0-15)	Fine sand	1.50	11.92	0.60	7.62	0.21	5.22
	Silt	1.85	40.94	1.25	44.25	0.55	38.17
	Clay	2.35	47.14	1.50	48.11	0.90	56.60
K. D. Farm (0-16)	Fine sand	1.60	11.12	0.50	6.90	0.25	5.90
	Silt	2.05	38.57	1.34	50.29	0.65	41.85
	Clay	3.15	50.29	1.35	42.79	0.96	52.20
Pampore (0-20)	Fine sand	1.25	10.04	0.65	9.22	0.28	6.79
	Silt	2.15	44.53	1.20	43.88	0.62	38.81
	Clay	2.65	45.41	1.55	46.89	1.05	54.39
Pampore (85-150)	Fine sand	1.35	7.9	0.65	6.00	0.28	6.40
	Silt	2.45	40.8	1.26	38.00	0.51	33.28
	Clay	2.80	51.25	1.65	55.00	0.84	60.28
Koil (0-20)	Fine sand	1.25	13.27	0.35	6.37	0.15	5.19
	Silt	1.80	45.44	1.10	47.79	0.60	49.65
	Clay	2.25	41.31	1.45	45.82	0.75	45.15

contributed from 34.74 to 66.17 per cent, silt 32.62 to 59.48 per cent and fine sand 6.42 to 13.23 per cent towards total K in these soils. The contribution from clay, silt and fine sand to HCl soluble K varied from 38.25 to 53.46, 38.0 to 50.29 and 4.3 to 9.94 per cent respectively and in case of NH_4NO_3 soluble K the contribution varied from 41.85 to 66.07, 27.14 to 49.65 and 4.72 to 10.42 per cent- clay, silt and fine sand respectively.

4.3.2 Green House studies

The experimental findings obtained from a green house studies on the soils from the different zones of Kashmir with wheat as a test crop applying three levels of K viz. K_0 , K_{200} and K_{400} ppm, are presented in Table 14.

a. Dry matter accumulation:- The data obtained from the yield of dry matter with the different levels of K at half flowering stage (60 days) was found to increase with the application of 200 ppm K. Higher dose of 400 ppm K did not show any increase in dry matter over the treatment of 200 ppm K, though there was a conspicuous increase in the dry matter production over control. The trend was observed in all soils except in Tapar and Koil (Karewa zone) where increasing the level of K from 0 to 400 ppm increased the dry matter production. The highest dry matter yield of 2.21 g was obtained in Pahalgam soil with application of 200 ppm K. The mean dry matter yield varied from 1.68 to 1.83 in high altitude zone, 0.94 to 1.77 in valley basin and 1.02 to 1.81 gm in the Karewa soils.

Potassium concentration:- The soils under study differed remarkably with respect to K-concentration in the plants. The concentration of K in the plants increased with the increase in K doses. The K-concentration was lowest in control but with the addition of 200 ppm K the concentration increased from 1.21 to 3.03 per cent in high altitude zone, and from 0.75 to 2.53 per cent in valley basin and 0.36 to 1.81 per cent in Karewa soils. With the addition of higher K dose i.e. 400 ppm K, the K concentration increased to 3.9, 3.0 and 2.5 per cent in high altitude, valley basin and Karewa soils respectively. The overall mean value of K concentration in control was 0.78, with K200ppm it was 2.50 and with 400 ppm K the concentration increased to 3.20 per cent.

Potassium uptake:- The effect of applied K on the uptake of wheat crop synchronized with the contents of K in the plants in all the soils. The uptake of K increased with an increase in K-levels. The mean values for uptake exhibited by high altitude soils ranged from 39.40 to 59.30 in valley basin from 16.23 to 45.64 and in the Karewa zones from 14.17 to 33.43 mgm K. The mean value of uptake at control (K 0) was 10.33 mgm K, with 200 ppm K it increased to 47.29 mgm K and with 400 ppm K the uptake further increased to 54.15 mgm K. In general potassium application resulted in a significant increase in K-uptake in plants. The K 200 ppm dose was superior over control in view of remarkable increase in K-uptake (4 to 8 times) whereas K400 did not increase the K-uptake in the same magnitude.

Table 15: Contents of exchangeable and fixed K (ppm) in soils of different zones of Kashmir after wheat crop.

Location	Treatment ppm K	Exchangeable K		Fixed K	
1	2	3	4	5	6
High Altitude soils					
Pahalgam	0	84	(120)*	765	(828)
	200	120		890	
	400	140		975	
Larnoo	0	75	(110)	828	(929)
	200	130		940	
	400	155		985	
Sonamarg	0	82	(110)	728	(835)
	200	140		910	
	400	190		980	
Gulmarg	0	72	(120)	685	(895)
	200	105		730	
	400	140		810	
Chandigam	0	80	(115)	750	(845)
	200	95		840	
	400	140		915	
Valley basin soils					
Khudwani	0	70	(95)	650	(780)
	200	85		825	
	400	110		915	
Nunar	0	60	(80)	510	(626)
	200	85		625	
	400	105		735	
Shalimar	0	80	(102)	695	(840)
	200	120		825	
	400	145		970	

contd....

1	2	3	4	5	6
Padgampora	0 200 400	65 125 150	(90)	630 785 825	(840)
Handwara	0 200 400	50 65 100	(85)	505 675 695	(610)
Korewa soils					
Tapar	0 200 400	60 105 135	(85)	675 810 905	(750)
K. D. Farm	0 200 400	80 135 150	(105)	780 845 910	(825)
Pampore	0 200 400	70 115 130	(95)	650 725 905	(740)
Koil	0 200 400	55 80 110	(80)	575 705 840	(665)

* Figures in brackets indicate initial contentss.

4.3.3 Potassium content in the soil after the crop removal

The soil samples, after the harvest of the wheat crops, were collected, processed and analysed for exchangeable K ($\text{NH}_4\text{O AcK}$) and fixed K (INHNO_3K) so as to study the effect of crop removal on the native and applied K. The results are presented in Table 15. While perusing the data, it is revealed that there was a marked change in exchangeable and fixed K due to crop removal, both showed a decrease indicating that plants not only consumed exchangeable K but also met part of its requirements from non-exchangeable K reserves. The exchangeable K in the high altitude zone before cropping ranged from 110 to 120 ppm and after cropping it reduced to 72 to 84 ppm. The initial non-exchangeable K in the soil varied from 828 to 929 ppm and after cropping it ranged from 685 to 825 ppm showing thereby a decline by 83 to 86 per cent. Similar trend was depicted in the valley basin and Karewa soils. The plants derived K from both exchangeable and non-exchangeable reserves. With the addition of 200 ppm K and 400 ppm K the soils gave correspondingly higher values of both exchangeable and non-exchangeable K illustrating that applied K was partly consumed by the plant and partly entered into the equilibrium which the various forms of K are known to have amongst each other.

4.3.4 Immediate quantity/intensity relationships

The quantity/intensity (Q/I) parameters were computed from the soil before growing the crop and after the crop was harvested. The results of Q/I parameters i.e. activity

ratio; free energy, labile K and potential buffering capacity are presented in Table 16. The Quantity/Intensity relations of representative soils is given in Fig.3.

a. Activity Ratio (AR_0^k (Moles/L) $^{\frac{1}{2}}$) :- The adoption of activity ratio as a measure of K-status of a soil which Beckett(1964a) called the K-potential is considered as an indirect measure of the chemical potential of K on the solid phase. It is also called Intensity factor. From a perusal of the data, the initial values of AR_0^k (activity ratio) in all the equilibrated soil samples of the three zones were high but the values of AR_0^k after crop removal were comparatively low.

Value of initial AR_0^k in high altitude soil was $4.78(M/L)^{\frac{1}{2}} 10^{-3}$ and the value decreased to $1.94 (M/L)^{\frac{1}{2}} 10^{-3}$ after the crop was harvested. In the valley basin soils, the initial AR_0^k was $4.62 (M/L)^{\frac{1}{2}} 10^{-3}$ and after harvest it reduced to $1.66 (M/L)^{\frac{1}{2}} 10^{-3}$. The initial activity ratio in Karewa soil was $4.2 (M/L)^{\frac{1}{2}} 10^{-3}$ and after crop harvest it declined to $1.67(M/L)^{\frac{1}{2}} 10^{-3}$. The highest value of $0.0068(M/L)^{\frac{1}{2}}$ was observed in Pahalgam soil before the crop was sown and the lowest value of AR_0^k was in Sonamarg sample $(0.0019) (M/L)^{\frac{1}{2}}$. The lowest value of AR_0^k found after crop harvest was $0.0011(M/L)^{\frac{1}{2}}$ in Sonamarg and Padgampora soils. The decrease in activity ratio observed in the samples taken after the crop harvest demonstrated that K was taken by the plants.

Table 16: Some parameters derived from Quantity/Intensity relationship before and after cropping in control pots in soils from different zones of Kashmir.

Location	Cropstage	Activity Ratio $\frac{AR^K}{O} (M/L)^{\frac{1}{2}}$	Free Energy F $2.303RT \log_{10} \frac{a_{Ca}}{a_{Mg}}$ Cal. equiv	Labile K - - KO me/100g	$\frac{PECK}{(me/100g)} (M/L)^{-1}$
High Altitude soils					
Pahalgam	Before	0.0068	-2955.73	0.136	20.00
	After	0.0020	-3680.51	0.092	46.00
Larnoo	Before	0.0044	-3213.46	0.118	26.81
	After	0.0018	-3742.83	0.078	43.37
Sonmarg	Before	0.0019	-3710.79	0.116	61.05
	After	0.0011	-4034.52	0.056	50.90
Gulmarg	Before	0.0057	-3060.18	0.111	19.47
	After	0.0016	-3812.65	0.060	37.50
Chendigar	Before	0.0051	-3126.05	0.158	23.13
	After	0.0032	-3402.19	0.118	49.37
Mean	Before	0.0047	-3213.24	0.127	30.09
	After	0.0019	-3734.55	0.080	45.42
Valley basin soils					
Khudwani	Before	0.0053	-3103.28	0.104	19.62
	After	0.0030	-3440.37	0.096	32.00
Nunar	Before	0.0040	-3269.92	0.120	30.00
	After	0.0012	-3982.97	0.060	50.00
Sholimar	Before	0.0041	-3255.32	0.110	26.82
	After	0.0015	-3850.83	0.080	53.33
Padgampora	Before	0.0052	-3126.05	0.170	32.69
	After	0.0011	-4034.52	0.105	41.81
Handwara	Before	0.0045	-3200.23	0.120	26.66
	After	0.0015	-3850.83	0.062	41.33
Mean	Before	0.0046	-3190.96	0.1248	27.15
	After	0.0016	-3871.90	0.0806	43.69
Karewa soils					
Topar	Before	0.0054	-3092.23	0.126	23.33
	After	0.0016	-3812.65	0.062	38.75
K.D. Farm	Before	0.0042	-3241.14	0.052	12.38
	After	0.0016	-3812.65	0.048	30.00
Pompore	Before	0.0036	-3332.37	0.123	26.11
	After	0.0012	-3982.97	0.092	40.00
Koil	Before	0.0037	-3316.14	0.145	28.10
	After	0.0023	-3597.74	0.130	38.26
Mean	Before	0.0042	-3245.47	0.111	22.48
	After	0.0016	-3801.50	0.083	36.75

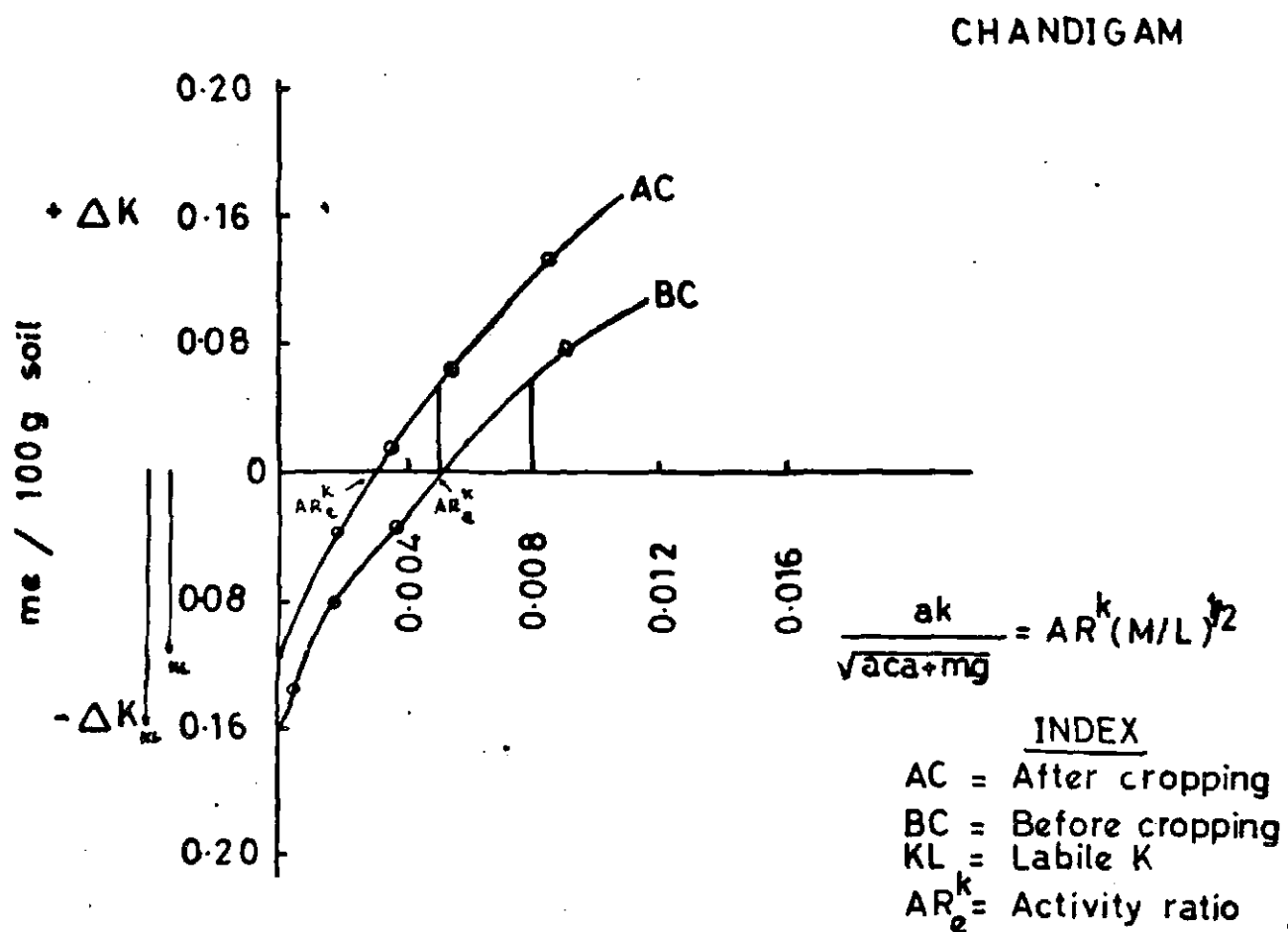
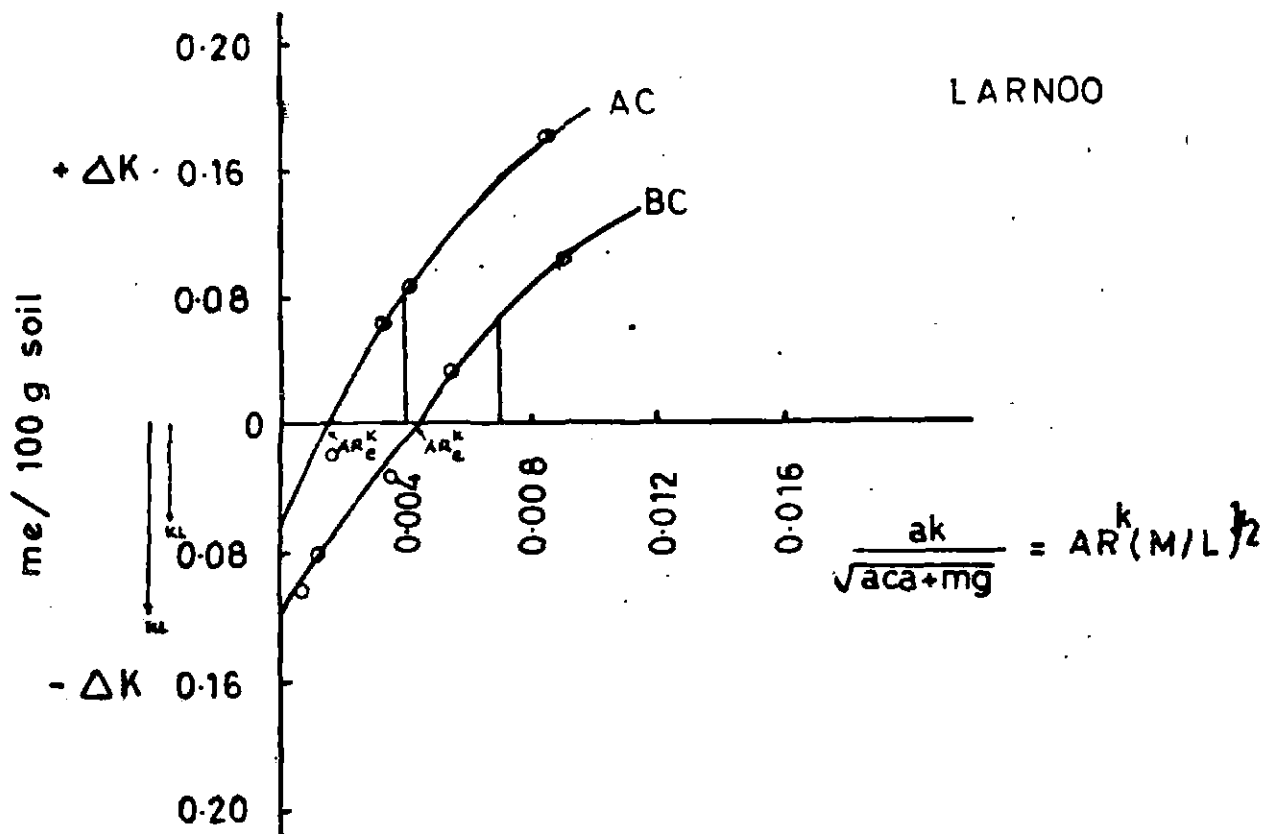
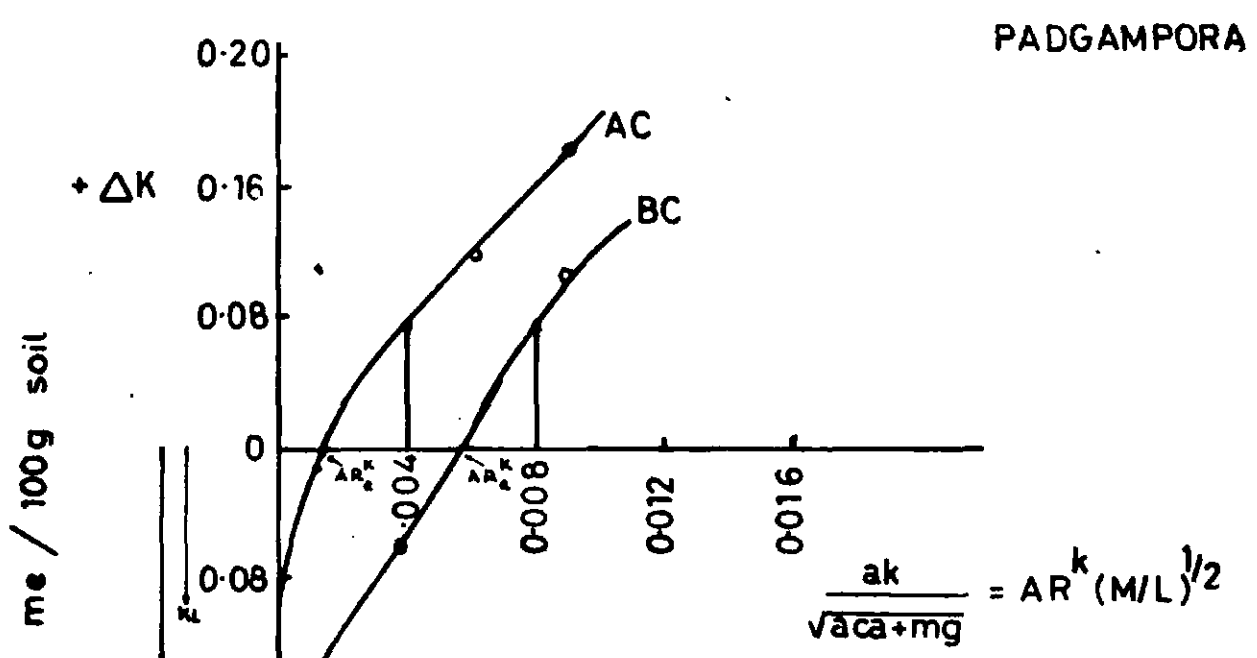
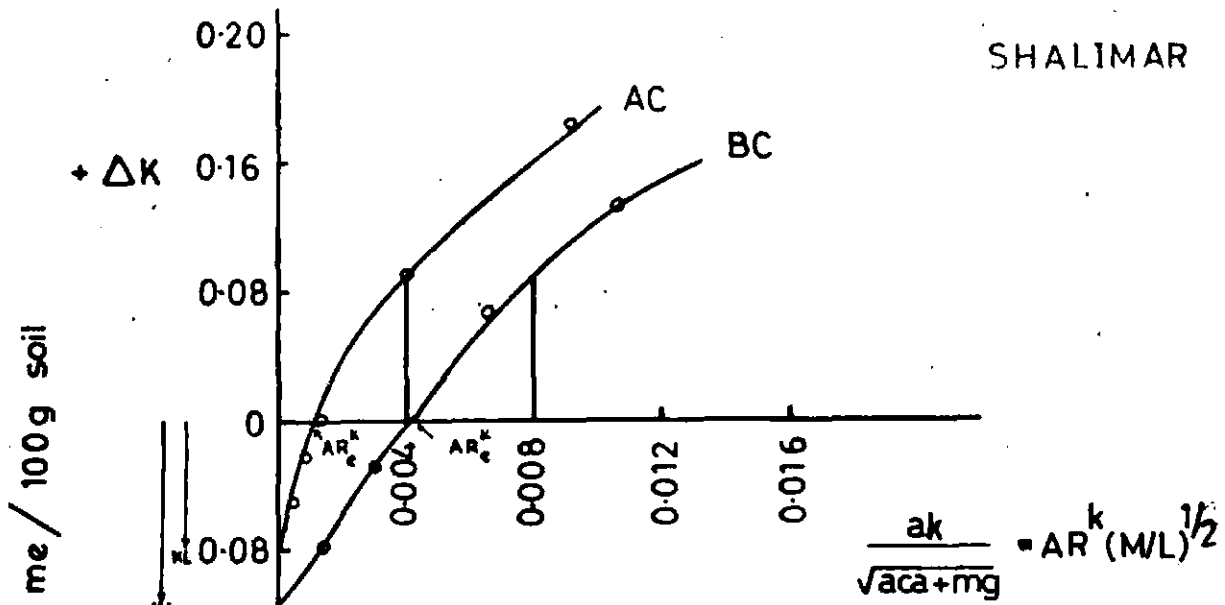
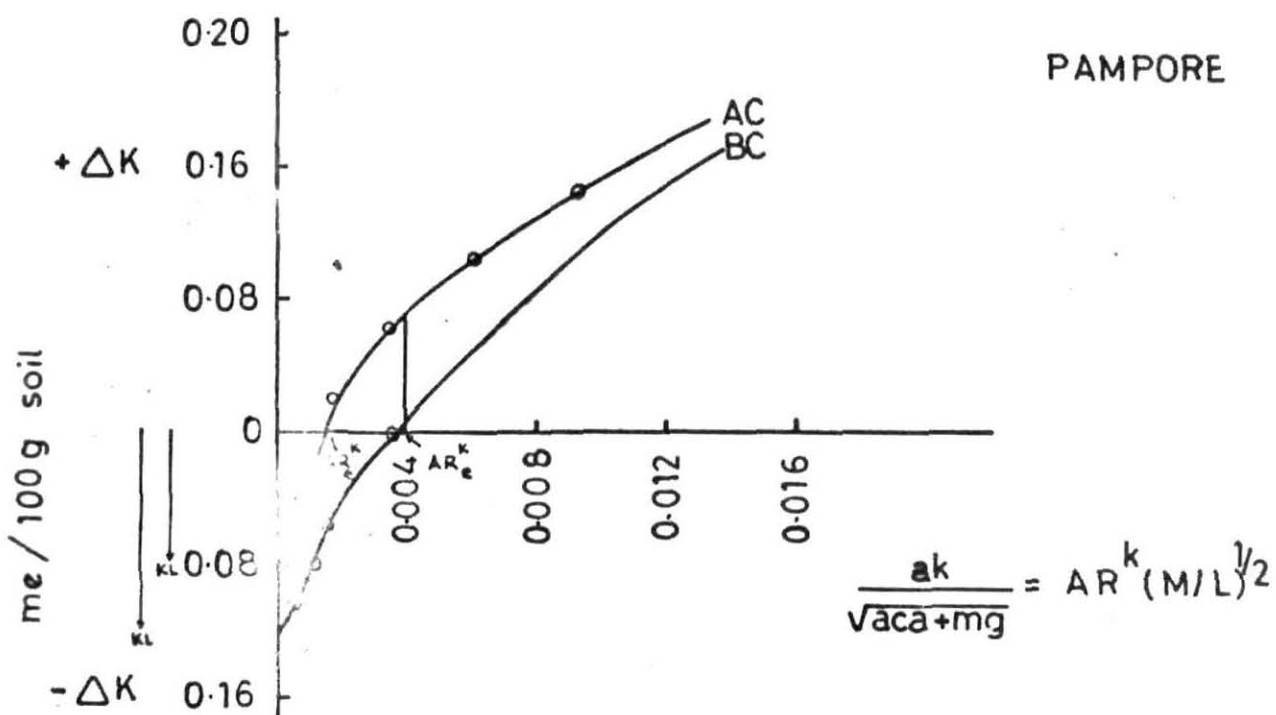
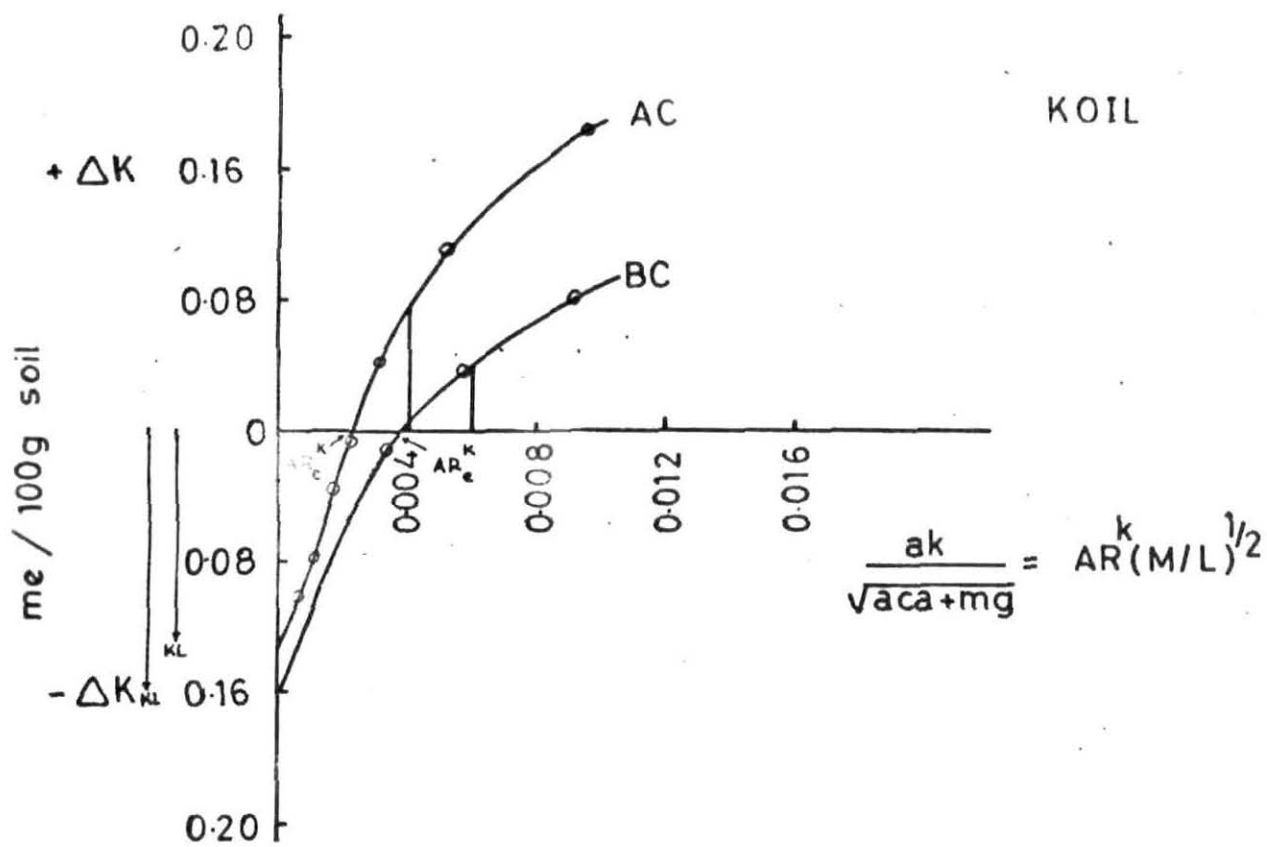


FIG.3 QUANTITY / INTENSITY RELATIONS OF SOIL



INDEX

- AC = After cropping
- BC = Before cropping
- KL = Labile K
- AR_e^k = Activity ratio



INDEX

- AC = After cropping
- BC = Before cropping
- KL = Labile K
- AR_e^k = Activity ratio

b. The free energy value (ΔG):- The free energy value (ΔG) is one of the better generalized criterion for soil K-availability than exchangeable K. It is evident from the data that mean initial free energy ($-\Delta F$) value was - 3213.24 cal/eq. in high altitude soils. After crop harvest it changed to - 3734.55 cal/eq. Thus the decrease in average free energy due to cropping was 521.31 cal/equiv. The valley basin soil showed the mean initial free energy value as - 3190 cal/eq. which after cropping changed to 3871.90 cal/eq. showing a decrease of 680.94 cal/eq. The Karewa soils had initial free energy value of -3245.47 cal/eq. which changed to - 3801.50 after crop removal from these soils and the reduction in free energy due to crop removal was 556.03 cal/eq.

c. Labile K (ΔK^0):- The labile K (ΔK^0) is index of availability or of uptake and the average labile K content was 0.127 me/100 g in high altitude zone and changed to 0.080 me/100g after crop harvest. The average decrease in labile K with cropping was 0.047 me/100gm. Before cropping the labile K averaged to 0.1248 me/100g in the valley basin soil and 0.1115 me/100g in Karewa soils. The labile K changed to 0.0806 and 0.0830 me/100g after the crop removal in valley basin and Karewa soils respectively. The decrease in labile K with cropping signifies its utilization by the plant. The values for exchangeable K were higher than labile K in all the soils. In general soil with high labile K show higher value of AR_0^k .

d. Potential buffering capacity (PBC^k):- The potential buffering capacity which indicates the capacity of the soil to replenish supply of K to soil solution is suitable measure of K-availability. The average PBC^k value before cropping was 30.09, 27.15 and 22.48 me/100g $(M/L)^{\frac{1}{2}}$ in high altitude soils, valley basin and Karewa soils respectively. On cropping the PBC^k values increased to 45.42, 43.69 and 36.75 me/100g $(M/L)^{\frac{1}{2}}$ in high altitude soils, valley basin and Karewa soils respectively. The higher value of 61.05 me/100g $(M/L)^{\frac{1}{2}}$ was observed in the Sonamarg soil and the soils from K.D.Farm had the lowest (12.38 me/100g) $(M/L)^{\frac{1}{2}}$. The difference between initial PBC^k and PBC^k after crop removal was very narrow and ranged between 14 and 16 me/100g $(M/L)^{\frac{1}{2}}$. The soils in the present investigation have medium PBC^k , low AR_o^k , ΔF and ΔK_o and will thus require K fertilization for sustained crop production.

CHAPTER V

DISCUSSION

Studies relating to the pedogenesis and potassium supplying capacity were undertaken on the bench mark soils of Kashmir in the Jammu and Kashmir State. The study was confined to i) high altitude zone, located above 1800 m, colluvial in nature ii) valley basin of alluvial origin and iii, the table lands of lacustrine deposits. Fourteen pedons representing the entire study area were exposed and soil samples collected horizon-wise after studying their morphological characteristics. Bulk surface soil samples were also collected for green house studies. The results obtained are discussed under the following heads:

- a. Pedological characteristics
- b. Mineralogical studies
- c. Potassium supplying capacity

5.1 Pedological characteristics:

5.1.1 Morphological features:

A detailed description on the morphological characteristics of fourteen pedons exposed in the study area are given in Appendix I. The soils in the three zones differed morphologically in respect of a number of characteristics. The surface soils from high altitude zone were very dark greyish brown (10YR 3/2) to dark yellowish brown (10YR 4/4) and from yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4) in valley basin

surface soils. The karewa soils were relatively light coloured and the colour varied from brown (7.5YR 5/4) to dark brown (10YR 4/3).

The predominantly darker matrix colour in the high altitude soils appear to have resulted from high organic matter (2.4 to 4.9 per cent) of these soils as compared with the soils in other zones. Angular blocky structure in B-horizon was generally found in these soils. The soils were **deep with** well-developed B-horizon as was evident by illuviation and presence of argillans in the lower horizons. The high altitude and karewa soils were well drained but those in the valley were generally poorly drained which resulted in the formation of light grey (7.5YR 7/1) mottles.

5.1.2 Physico-chemical properties:

Mechanical composition influences the nutrient supplying power, drainage and aeration of the soil. The determination of the amount of clay gives useful information about the development of the soil profile. The data on the mechanical composition of the soils are presented in Table 4. The distribution of various soil separates revealed that fine sand and silt were relatively more in valley basin soils whereas the content of clay was more in high altitude soils. The karewa soils showed a slight variation in respect of various fractions in comparison to the soils from other zones. The weighted average values for coarse sand ranged from 0.38 to 2.25 per cent and fine sand from 11.89 to 21.01 per cent. The weighted average values for silt ranged from 38.87 to 48.25 per cent and in case of clay it showed a variation of 32.28 to 44.27 per cent **in high altitude**

soils. The weighted average values for coarse sand fraction in the valley basin soil varied from 0.38 to 1.08 per cent and fine sand content varied from 17.40 to 22.07 per cent. The values for silt and clay varied from 41.32 to 54.21 per cent and 28.14 to 36.92 per cent respectively. In karewa soils the weighted average values for coarse sand, fine sand, silt and clay fraction ranged from 0.13 to 0.97 per cent, 15.56 to 19.19 per cent, 43.32 to 45.74 per cent and 33.27 to 39.25 per cent, respectively. The sub-soils in high altitude zone had relatively more finer fractions which may be attributed to relatively high rainfall (1000 mm). This consequently accelerated weathering thereby increasing the infiltration, this resulted in the development of B-horizon with argillans (Bt). The soils in the valley basin were more silty than clayey which may be attributed to their fluvial nature. The soils of the karewa were also silty in nature. The soils in the study area with clay loam to silty clay loam as the dominant texture and fall under heavy textured class. Similar results were also reported by (Gupta et al 1977), Iyer and Dutta (1982) and Handoo (1983).

5.1.3 Chemical characteristics of the soil

The study of chemical composition of the soil is important as it gives information regarding soil forming processes. The data on the chemical composition of the soils is presented in Table 5.

Soil reaction: The results for weighted averages of pH values in the high altitude soils varied from 6.38 to 7.60, in

valley basin soils from 7.40 to 8.37 and from 7.64 to 8.18 in karewa soils. The pH in both these zones was higher than in the high altitude zone, which may be attributed to the comparatively higher precipitation in the high altitude zone. The higher pH was observed in Padgampora profile and ranged from 8.2 to 8.5 which may be attributed to higher water table. The lowest pH values (6.2 to 6.5) were observed in Gulmarg soil due to higher rainfall and organic matter content. Similar observation were made by Gupta et al (1977) and Handoo (1983).

Calcium carbonate (CaCO_3): From a perusal of the data it is observed that the weighted average values of CaCO_3 ranged from 1.36 to 2.54 per cent, 0.85 to 4.86 per cent and 2.31 to 8.73 per cent in high altitude, valley basin and karewa soils, respectively. The higher CaCO_3 content (12.0 per cent) was observed in karewa soils in Pampore profile (85-150 cm) and was attributed to the calcareous nature of the soils. The distribution of CaCO_3 in high altitude soils and valley basin soils does not show any specific trend while in the karewa soils it generally increased with the increase in the profile depth. Calcareous nature of the karewa soils was also reported by Varadan (1969) and Talib (1973).

Organic carbon: The weighted average values of organic carbon varied from 1.37 to 2.89, 1.10 to 1.54 and 0.47 to 1.00 per cent in soils of high altitude, valley basin and karewa zone, respectively. The surface horizons showed higher content of organic carbon and it decreased uniformly with the increase in depth of the profile. High altitude soils had higher content of organic carbon than the soils in other zones, which may be

attributed to altitude, forest vegetation, accumulation of annual crop residues and low microbial activity because of low temperature. Minhas and Bora (1982) also related higher organic carbon content to higher precipitation and lower temperature. Similar results were also obtained by Gupta et al (1977) and Handoo (1983).

Total nitrogen: The nitrogen content varied markedly in different regions of Kashmir because of variation in precipitation, vegetation and altitude. The weighted average values for total nitrogen ranged from 0.09 to 0.18, 0.08 to 0.10 and 0.03 to 0.06 per cent in the high altitude, valley basin and karewa soils, respectively. The nitrogen content was high in surface samples and decreased with an increase in the depth of the profile. Minhas and Bora (1982), Satyanarayan and Biswas (1970) reported that in general the N content increased alongwith an increase in the organic carbon content and presence of higher organic carbon content in surface layers. Similar trend was observed in present investigation.

Available phosphorus and potassium: The weighted average values for available phosphorus varied from 18.5 to 25.7, 16.0 to 20.4 and 15.3 to 23.4 kg/h in the soils of high altitude, valley basin and karewa soils, respectively. Surface soils had higher content of available P_2O_5 which may be attributed to the presence of adequate amount of organic matter and neutral soil reaction. Gupta et al (1977) and Handoo (1983) reported the similar results.

The available potassium ($\text{NH}_4\text{OAc K}$) varied from 251 to 285, 209 to 249 and 191 to 244 kg/h in the soils of high altitude, valley, basin and karewa zone, respectively. The available potassium status was adequate and may be attributed to the presence of illite type of clay mineral in these soils (Talib, 1973).

Cation exchange capacity (CEC) and exchangeable cations: The study of the cation exchange is important as it is a good measure of the available nutrients in the soil. Besides it influences the physical properties. Its weighted average values ranged from 22.49 to 28.98, 15.80 to 22.31 and 15.01 to 20.14 me/100g in the soils of high altitude, valley basin and karewa zone, respectively. The CEC of the high altitude soils was more than in the soils of other zones, which may be due to higher content of organic matter and clay. Gupta et al (1980) and Handoo (1983) reported similar results. Exchangeable calcium was the dominant cation in all the soils studied. The weighted average values showed a variation from 12.50 to 15.96, 8.87 to 13.04 and 8.38 to 12.48 me/100g in high altitude, valley basin and karewa soils, respectively. It was comparatively higher in high altitude soils. The karewa soils were relatively more calcareous which did not synchronize with the content of exchangeable Ca present in these soils and may be attributed to the presence of inert form of nodules of lime kankar.

Exchangeable Mg varied from 5.62 to 9.51, 4.95 to 7.58 and 4.69 to 6.20 me/100g in high altitude, valley basin

and karewa soils, respectively. Presence of adequate content of exchangeable Mg signified the presence of chlorite and degraded illite in these soils. The exchangeable K varied from 0.31 to 0.81, 0.23 to 0.40 and 0.23 to 0.52 me/100g in high altitude, valley basin and karewa soils, respectively. The soils studied were adequate in exchangeable K content, the high altitude soils having relatively higher content than the soil in other zones. It is attributed to the presence of illite clay mineral in these soils. Similar results were obtained by Talib (1973) and Gupta et al (1977).

5.1.4 Pedogenesis:

The studies on soils of Kashmir (Hoon, 1938) revealed that the soils developed under deodar and blue pine showed podzol characteristics and those under deodar from Batote range (Jammu division) resembled brown earths. Raychaudhuri and Govinda Rajan (1971) classified them into sub-montane soils. Soil survey conducted (Iyer and Dutta, 1982) in Pohru catchment of Kashmir revealed that vegetation was the dominant soil forming factor influencing soil formation in these soils through the process of melanization. The present study which was confined to the cultivated lands did not observe pedzolic type of soil in the high altitude zone. The soils were observed to be under the influence of climate and vegetation as the distribution of rainfall/snowfall favoured leaching and illuviation as was reflected in the observed clay cutans on ped faces. Distinctly finer texture in sub-surface horizons further supported these observations. In a fairly well developed soils as a result of pedogenic process

the clay content increases with depth so as to attain a maximum and then decrease until it further remain constant or completely disappears (Barshad, 1964). In the soils under investigation the clay content increased from a minimum at the surface horizon to a maximum value in the horizon of maximum accumulation of clay, occurring generally within 90-150 cm .

5.1.5 Classification:

The soils in the high altitude zone (Table 17) were predominantly Mollisols and Alfisols with Argiudolls and Hapludalfs as dominant great groups. The higher content of organic matter present in these soils has imparted a dark colour, a criterion necessary for Mollisols. Due to the illuviation of clay, a well developed B-horizon was observed particularly in high altitude soil. The soils in the valley region are generally classified as Alfisols (Hapludalfs, Ochraqualfs) and Inceptisols (Eutrochrepts, Dystrochrepts). The soils in this zone were both of old and recent alluvium. Pockets of Udorthents were also existing in the area particularly on the lands with poor vegetation (Iyer and Dutta, 1982). The soils in the karewa zone fall under Alfisols with Hapludalfs, the main great group. Handoo (1983) also classified the Kashmir soils into similar taxonomic units.

5.2 Mineralogical studies:

5.2.1 Petrographic study of sand fraction of soil:

The sand fraction contains mainly primary and accessory minerals derived from parent rocks by the process

Table 17: Classification of soils from Kashmir

Location	Order	Sub-order	Great group	Sub-group	Family
<u>High Altitude soils</u>					
Pahalgam	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Larnoe	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Sonamarg	Mollisols	Udolls	Argiudolls	Typic Argiudolls	Typic Argiudolls clayey mixed thermic.
Gulmarg	Mollisols	Udolls	Argiudolls	Typic Argiudolls	Typic Argiudolls clayey mixed thermic.
Chandigam	Mollisols	Udolls	Argiudolls	Typic Argiudolls	Typic Argiudolls clayey mixed thermic.
<u>Valley Basin soils</u>					
Khudwani	Alfisols	Aqualfs	Ochraqualfs	Typic Ochraqualfs	Typic Ochraqualfs clayey mixed thermic.
Nunar	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Shalimar	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Padgampora	Incepti- sols	Aquepts	Haplaquepts	Typic Haplaquepts	Typic Haplaquept fine silty mixed thermic.
Handwara	Incepti- sols	Ochrepts	Dystro- chrepts.	Typic Dystr- ochrepts.	Typic Dystrochrepts fine silty mixed thermic.
<u>Karewa soils</u>					
Tapar	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
K.D. Farm	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Pampore	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs clayey mixed thermic.
Koil	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Typic Hapludalfs fine silty mixed thermic.

of weathering. In subsequent stages of soil development, the weatherable minerals of this fraction undergo physical comminution and chemical decomposition and supply the reactant component of the soil material for the weathering reaction resulting in the genesis of secondary minerals in the soil. The resistant minerals of this fraction determine the uniformity of parent material down the profile and the source of parent material. The effect of weathering process on the disintegration and disappearance of minerals and the formation of new secondary minerals is also influenced by sand mineralogy.

The studies on sand mineralogy revealed that the light minerals constituted 96 to 98 per cent and heavy minerals 2 to 4 per cent of total sand. The former fraction was dominated by quartz, feldspar (plagioclase and orthoclase) muscovite and kaolin and the latter constituted biotite, magnetite, opaque minerals, tourmaline, chlorite, augite, hornblende, ilmenite and zircon. The mineral assemblage observed in these soils reflected closely the composition of the metamorphic parent rocks which are usually rich in these accessory minerals. The important features of various light and heavy minerals as observed under a microscope are described below:

High altitude soils:

i. Quartz: From the consideration of the parent material, gneisses and schists which contain quartz in appreciable amounts, the high content of quartz in sand fraction is expected and is present in the order of 55 to 65 per cent in these soils. It was observed from a petrographic study that quartz grains were heavily stained and had varying shapes; subrounded to

sub-angular with coloured inclusions. Fresh rounded grains of quartz were observed in Larnoo and Pahalgam soils. Higher content of quartz and feldspar were present in Gulmarg sample which may be attributed to the presence of conglomerate - granite rocks.

ii. Feldspar: The gneiss and schists also contain appreciable quantities of plagioclase and albite. The occurrence of these minerals in minor quantities (18 to 24 per cent) in fine sand fraction of this zone indicate their break down and transformation into clay minerals. The weathering condition of the soil in question is neutral and as a consequence of which the alteration of feldspar group is restricted. The weathering has affected the more susceptible variety of plagioclase. The feldspar **grains** were observed to be relatively small in size than quartz, had rectangular to platy shape and were light grey to yellowish coloured.

iii. Muscovite: Muscovite mica grains were present as thin platy flakes and were generally coloured. The distribution of muscovite was uniform and varied between 7 to 10 per cent. Kaolin and microcline were also present in small amounts. The presence of appreciable quantity of mica in all the samples may be related with the formation of illite in clay fraction.

Amongst the heavy minerals, biotite (about 10 per cent) present in all these soils, was light brown to dark brown with cleaved flakes which exhibited pleochroism from light to dark brown. Augite and hornblende were mostly dark black and or dark green in colour and were prismatic to angular in shape. Chlorite grains were coloured, rounded and constituted small amount of the

fraction. Zircon, tourmaline and opaque minerals were present in relatively higher quantity and may be attributed to the parent rocks.

Valley basin soils: These soils have resulted from alluvium deposition by major rivers like Jhelum, Indus and their tributaries. From a perusal of the data (Table 7), it is observed that quartz, feldspar, muscovite, kaolin and microcline were the principle light minerals identified in the sand fraction but were present relatively in less proportion than in the soils of high altitude zone. Quartz and feldspar were the main light minerals and constituted about 60 to 75 per cent of the fabric. Quartz grains were sub-angular to sub-rounded with coloured inclusions indicating their recent deposition. Muscovite, kaoline and microcline were also present. Amongst the heavy minerals, biotite, augite, chlorite, tourmaline, magnetite, ilmenite, zircon and opaque minerals were the main heavy minerals present in this zone. The opaque minerals, zircon and tourmaline were relatively less, may be because of the alluvial nature of the zone. But biotite, augite and hornblende were slightly higher than in high altitude zone. It may be attributed to the youthful nature of the soil profiles. Biotite was present as light brown to dark brown with cleaved flakes and generally exhibited red stains which could possibly be due to oxidation of Fe^{++} . The heavy mineral assemblage suggested changes of provenance during the deposition of fluvial parent material. The mineralogical make up of these flood plain soil suggested an influence of metamorphic and acid igneous rocks.

Karewa soils: Karewa soils which constitute roughly half of the valley area, are lacustrine deposits and lithologically consist of blue, grey and buff silts, sand partly compacted conglomerates and embedded moraines.

Quartz and feldspar were the dominant light minerals and varied from 60 to 75 per cent. Kaolin, muscovite and microcline were also present. Augite, biotite, chlorite constituted 20 per cent and garnet, ilmenite and magnetite constituted 10 per cent of the heavy minerals. The petrographic analysis of fine sand fractions for this zone did not reveal any significant variation which may be due to similar geological formation and environment prevailing in this zone.

Gupta, et al (1981) reported quartz, feldspar and muscovite mica were the main light minerals and the heavy mineral suite was dominated by ferruginous minerals followed by biotite and amphibole group of minerals, epidote, tourmaline and chlorite in some Himachal Pradesh soils. Roonwal and Garralepuri (1982) reported that quartz, mica, chlorite and feldspar and heavy resistant minerals such as tourmaline, garnet, zircon, apatite, gypsum were present in Indo Gangetic alluvial soils. The presence of illite and chlorite was related to muscovite, biotite and chlorite found in sand fractions. While working on Kashmir soils, Dutta (1960), Kanwar and Raychaudhuri (1971) reported almost similar mineral assemblage and concluded that influence of metamorphic rocks on the occurrence of primary minerals was quite conspicuous in Kashmir soils.

5.2.2 Clay mineralogy:

The determination of the mineralogical composition is essential for a complete elucidation and clay behaviour including characteristic electro-chemical properties of the soil system. A knowledge of the nature of clay minerals is essential for complete information on development and genesis of the soil and to determine the source of parent material. The results for clay minerals of the selected surface and sub-surface horizons representing the three zones, as was obtained through physico-chemical analysis and X-ray diffraction technique are discussed here under:

5.2.2.1 Physico-chemical analysis:

The cation exchange capacity as well as the pedogenic oxides of clay (Table 8) were used for the identification of clay minerals. It is observed that cation exchange capacity ranged from 36.42 to 44.81, 28.36 to 36.42 and 26.40 to 36.48 me/100g in high altitude, valley basin and karewa soil clays respectively. The higher CEC of the high altitude soils may be related to its higher content of organic matter and the type of clay. The CEC for chlorite has been indicated to vary from 30 to 36 me/100g (Martin, 1955) and that of illite between 10 and 40 me/100g (Grim, 1968). According to these standards these soils may, therefore, be considered dominant in illite and chlorite. Higher CEC observed in some of the soil clays, may be attributed to degraded nature of illite as the CEC of degraded illite is reported (Gupta, 1968) to be between 41 to 65.8 me/100g. Many workers reported the similar values for

Kashmir soils (Varadan, 1969 and Gupta et al, 1977). The silica content showed a variation from 42.48 to 46.52, 41.68 to 44.80 and 41.46 to 46.52 per cent in soil clays from high altitude, valley basin and karewa soils, respectively. The iron oxide (Fe_2O_3) varied from 11.92 to 14.42, 12.62 to 16.25 and 11.94 to 18.42 per cent in high altitude, valley basin and karewa soil clays, respectively. The Al_2O_3 content varied from 20.26 to 22.42, 21.48 to 24.48 and 22.60 to 25.88 per cent in soil clay from high altitude, valley basin and karewa soils, respectively. The clay samples from the study area contained fairly high content of K_2O ranging from 3.36 to 5.76 per cent, 3.35 to 5.52 per cent and 3.88 to 5.36 per cent in high altitude, valley basin and karewa soil clays, respectively. Potassium content of soil clays has been used for determining approximate content of illite (Sarker and Raj, 1973), Grim (1968) reported that K_2O content of illite may average to 6.2 per cent and on the basis of this criterion the percentage of illite would be 54 to 90 per cent, 52 to 88 per cent and 60 to 80 per cent in high altitude, valley basin and karewa soils, respectively, denoting the dominance of illite. The presence of mica especially muscovite in the fine sand fraction also supported its formation and the dominance. Similar results were reported about the Kashmir soils (Biswas, 1961; Varadan, 1969, Talib, 1973 and Gupta et al, 1980).

Molar ratios: The molecular ratios of silica sesquioxide, silica, alumina and alumina potassium were computed from the clay analysis data and are presented in Table

Silica Sesquioxide ratio ($\text{SiO}_2 : \text{R}_2\text{O}_3$): The ratio varied from 2.5 to 2.7, 2.1 to 2.9 and 2.0 to 2.2 in high altitude, valley basin and karewa soil clays, respectively. The range of 2 to 3 as observed in these soils indicated (Ukil et al 1944) inter layer clay minerals of 2:1 and 2:2 type i.e. illite and chlorite. But Sarkar and Raj (1973) attributed the ratio of 2 to 3 to admixture of illite, chlorite, kaolinite and montmorillonite. Similar ratios were also reported by Biswas (1961), Varadan (1969) and Talib (1973).

Silica alumina ratio ($\text{SiO}_2 : \text{Al}_2\text{O}_3$): The silica alumina ratio ranged from 3.2 to 3.9, 2.8 to 3.5 and 2.8 to 3.2 in the soil clays from high altitude, valley basin and karewa, respectively. The values are in the range of 3 to 4 which was ascribed (Grim, 1968) to the presence of illite and chlorite. Biswas (1961) Varadan (1969) and Talib (1973) also reported the similar values for the Kashmir soil.

Alumina - potassium ratio ($\text{Al}_2\text{O}_3 : \text{K}_2\text{O}$): The alumina - potassium ratios varied from 3.5 to 5.5, 4.0 to 6.3 and 4.3 to 6.0 in high altitude, valley basin and karewa soil clays, respectively. These ratios suggested the presence of illite and kaolinite and was in agreement with the findings of Biswas (1961), Talib (1973). The presence of mica especially muscovite in the fine sand fraction also supported the presence of illite in these soils.

5.2.2.2 X-ray diffraction studies:

Illite, chlorite, vermiculite, kaolinite and inter-stratified minerals in the order of predominance were the

main clay minerals (Fig. 2) identified through X-ray diffraction in these soils and varied in proportion (Table 18). The non-clay material i.e. quartz and feldspar could not be identified and may be present in traces. The presence of orthoclase feldspar (Table 7) in fine sand fraction of the soil and its absence in clay fraction (Table 18) clearly suggest that feldspars are weathering much faster and thus releasing, among other K in the ionic environment of the soils. Since quartz and feldspar constituted the bulk of light minerals fraction of the fine sand with relatively less mica, it can be safely assumed that bulk of clay minerals are secondary formation from quartz and feldspar as these cannot directly transform to layer silicates without undergoing major structural changes. The necessary cationic environment for these secondary formations is provided by the constant exchange of the surrounding solution by the cations held during the weathering of minerals present in sand and silt. Illite was invariably the predominant clay mineral in all the samples studied. The dominant presence of illite in clay samples has been reported to be due to degradation or hydrolysis of muscovite and biotite (Bear, 1968) and due to partial hydrolysis of feldspar (Meyer and Hemley, 1959) present in sand fraction. The mechanism of illite formation from feldspar is reported to be the result of metamorphic processes (Reichenbach and Rich, 1975). Hydromica may also originate primarily by inheritance from parent rock or may be formed in soil. The Petrographic analysis of the fine sand fraction indicated the presence of feldspar and muscovite in higher proportion than

biotite. The feldspar was observed to be sufficiently weathered (altered). The predominant presence of illite in the soil samples of the present study appeared, therefore, through the partial hydrolysis of feldspar and inherited from the parent rock also. The transformation of feldspar into illite may be visualised as follows:

Altered K - feldspar - sericitized mica in fine sand - illite in clay. Similar transformations have been reported by Verma (1979) for Himachal Pradesh soils and Sarma and Sidhu (1982) for alluvial soils of India. As regards the nature of illite, in most of the samples it was found as degraded type. Its formation in these soils might be explained due to high rainfall/snowfall and environmental conditions.

Chlorite constituted the next predominant clay mineral and was present in all the samples. The samples from Larnoo, Chandigarh, Nunar (85 - 150 cm) K.D. Farm and Pampor contained relatively less amount of chlorite than in the other samples. The presence of chlorite could be due to the degradation of illite and or may be the result of transformation of primary mineral chlorite present in the granite gneiss parent rocks and schists found in these soils. It may also have formed from alteration of Ca, Mg and Fe rich primary minerals like augite, biotite and hornblende. The other minerals identified in the samples were vermiculite, kaolinite and inter-stratified minerals. Vermiculite was present in all the samples in relatively less proportion. Several mechanisms, may be put forth for its development in these soils. (a) the illite or mica transforms to vermiculite under

moderate weathering conditions (b) the transformation of chlorite may lead to the genesis of vermiculite by the exchange of Mg from brucite layer ($Mg(OH)_2$) on weathering. The chlorite present in these soils may also transform to vermiculite. Gilkes and Little (1972) postulated that the main changes in weathering of chlorite were progressive degeneration of chlorite mineral into vermiculite by oxidation of ferrous iron and loss of Fe and Mg from the brucite layer. Kaolinite was the next important clay mineral observed in the studied samples. It is pertinent to mention that kaolinite was found to be present even in those soils where free $CaCO_3$ was present. According to Grim (1968), Millot (1970) the presence of $CaCO_3$ blocks the formation of kaolinite in soils until the carbonates have been leached out. The presence of kaolinite in the soils under investigation having free $CaCO_3$ could be explained either due to its inheritance from the parental rocks or due to the deposition of alluvium soil carrying this mineral. Sehgal (1974) also reported kaolinite in recent alluvial soil due to inheritance. It may also be formed through the weathering of feldspar or mica as: (a) by chemical processes the lattices of feldspar are completely broken in course of time and bases like K, Ca, Na are released which react with Al^{3+} , Si^{4+} , Fe^{2+} , OH^- giving rise to colloidal aggregates that crystallize to produce clay minerals mainly illite and kaolinite. (b) Sand (1956) reported that mica weathers to kaolinite under fairly intensive weathering environment, when mica weathers, H ion gradually replaces K^+ ions and minerals becomes hydrated

forming hydrous mica (Bates, 1960) ultimately passing on to kaolinite. Millet (1970) suggested that the genesis of clay depends both on inheritance from the parent material and transformation and neoformation due to weathering. It is probable that the presence of kaolinite in the soils under investigation was mainly due to inheritance from the parent material. While working in some North Western Indian soils, Sehgal and De Connik (1971), Sehgal (1973) reported the presence of kaolinite in less amounts and ascribed it to inheritance. The insitu formation of kaolinite is attributed to chemical weathering accelerated by higher rainfall. It thus created depleting environment followed by dissolution of silica and hence favoured the formation of 1:1 clay mineral through 2:1:1 type phase. The kaolinite is present in relatively less amounts in the Kashmir soils, may be attributed to moderate weathering processes going on in the area. Though kaolinite may be formed from feldspar through an intermediate stage, it now appears that it is usually formed by neosynthesis from the products of hydrolytic decomposition of feldspar and other primary minerals. The presence of inter-stratified minerals in these clay samples may be ascribed to the transformation of primary phyllosilicates (micas and chlorite). Random inter-stratified material of illite - smectite, smectite - chlorite might be the result of alteration of the pre-existing mica and illite. On the basis of physico-chemical analysis and X-ray diffraction, it may be inferred that illite followed by chlorite constituted the predominant clay mineral in

these soils. Vermiculite, kaolinite and inter-stratified minerals were also inferred to be present in the soils of Kashmir (Table 18).

5.3 Potassium supplying capacity:

Potassium is one of the macro-nutrients and usually is present in plants in quantities larger than those of any mineral nutrient derived from soil with the exception of H and N. Potassium is a relatively abundant and widely distributed constituent of the surface rocks of the earth making up an estimated 2.6 per cent of the earth crust by weight. The K content of the soils of the various regions is related to parent material and the degree of weathering.

5.3.1 Forms and distribution of potassium in the soil:

Soil potassium is often divided into three categories; non-exchangeable, exchangeable and water soluble. It is important to know the magnitude of different forms of K for a proper appraisal of a quantity factor contributed by different forms of K. Besides, it gives a picture of the potentiality of the soil with respect of K-supply to crops. A perusal of the data (Table 12) revealed that the weighted average values for water soluble K ranged from 17.62 to 21.36, 13.04 to 17.66 and 11.06 to 17.16 ppm in the soils from high altitude, valley basin and karewa zone, respectively. The corresponding values for exchangeable K varied from 93.13 to 111.43, 78.70 to 92.50 and 71.16 to 84.16 ppm in these zones. The contents of available K (water soluble and exchangeable K) were relatively more in the high altitude soils and the

Table 18: Mineralogical composition of clay fraction of soils from different zones of Kashmir, based on Physico-chemical analysis and X-ray Diffraction.

Location/ Depth (cm)	Illite	Chlorite	Vermiculite	Kaolinite	Mixed layer minerals
<u>High Altitude soils</u>					
Pahalgam (0-15)	++++	+++	++	++	++
Larnoo (0-18)	++++	++	+++	++	++
Sonamarg (0-20)	++++	+++	++	++	++
Gulmarg (0-20)	++++	+++	++	++	++
Gulmarg (90-150)	++++	+++	++	++	++
Chandigam (0-17)	++++	++	+++	++	++
<u>Valley Basin soil</u>					
Khudwani (0-20)	++++	+++	++	++	++
Nunar (0-20)	++++	+++	++	++	++
Nunar (75-150)	++++	++	+++	++	++
Shalimar (0-15)	++++	+++	++	++	++
Padgampora (0-17)	++++	+++	++	++	++
Handwara (0-17)	++++	+++	++	++	++
<u>Karewa soils</u>					
Tapar (0-15)	++++	++	+++	++	++
K.D.Farm (0-16)	++++	++	+++	++	++
Pampore (0-20)	++++	++	+++	++	++
Pampore (85-150)	++++	+++	++	++	++
Koila (0-20)	++++	+++	++	++	++

Note: ++++ = Abundant +++ = Moderate ++ = Low

karawa soils had the lowest. The distribution of available K did not follow any uniform trend in these soil profiles. The higher available K status of these soils especially in absence of K-fertilization may be attributed to friable nature of these soils due to fair amount of organic matter present wherein the roots proliferate deeper to get their K-supply and to the presence of illite type of clay minerals. It could also be due to the equilibrium which is observed to exist between the various forms of K, and to their alluvial nature. Misra and Hari Shanker (1970), Ghosh and Hasan (1976) also reported the higher available K-status for the alluvial soils of India and attributed it to illite mineral. In the conventional scale of fertility assessment a simplified assumption has been universally accepted that all the K-extractable by molar NH_4OAc or an equivalent solution are fairly available for plant nutrition with complete disregard to the rate at which they may be available under natural plant growing conditions. Though these soils were rated high in available K, the activity ratio $ak / \sqrt{c} (\text{Ca}+\text{Mg})$ was rather low and did not corroborate with the high rating.

The contents of non-exchangeable K ($\text{INHNO}_3 \text{ K}$) present in these soils was high. The weighted average values ranged from 872 to 930, 591 to 855 and 629 to 753 ppm in high altitude, valley basin and karawa soils, respectively and on an average comprised 3.5 to 5.5 per cent of total K. The distribution of non-exchangeable K was inconsistent with the increase in the depth of the profile. All the soils exhibited adequate amount of fixed K, as the boiling HNO_3 attacked the

crystal structure of the clay minerals and thus extracted much more K than was in equilibrium with the soil solution. Mehrotra and Singh (1970) supported the above findings while working on some alluvial soils of India. The release from non-exchangeable K in the illite dominant soils was highest and the inherent K fertility depends on the K release from this source (Arnold, 1962a).

The weighted average values for total K varied from 1.63 to 2.26, 1.83 to 2.06 and 1.83 to 2.10 per cent in high altitude, valley basin and karewa soils, respectively. The higher content of total K may be attributed to the dominance of micas and feldspar as primary potash bearing minerals and to the illite clay mineral. The higher organic matter content favours the dissolution from the primary minerals and thus more quantity of total K in these soils (Chatterjee, 1976). Besides, CO₂ enriched water has been found effective in releasing K from primary minerals (Diest, 1978). Higher K status of Kashmir soils was also reported by Handoo (1973) and Talib (1973), Grewal and Kanwar (1976) reported high total K in some Punjab and Himachal Pradesh soils and attributed it to primary and secondary minerals.

The mean K-fixing capacity was 267, 254 and 245 ppm in high altitude, valley basin and karewa soils, respectively. It may be related to the presence of illite type of clay mineral and to the higher concentration of potassium in these soils which increases the K-fixation because more K goes into the exchange complex. Grewal and Kanwar (1976) reported

relatively less values (227 ppm) for some Punjab soils while Suresh (1979) reported higher values (500 ppm) for some soils of Himachal Pradesh.

Correlation studies: Multiple regression equations for various forms of K with soil properties were computed and are presented in Appendix II. It is inferred that:

- a. pH, Organic carbon, clay, silt and sand contributed 32.73 per cent towards water soluble K and on stepwise regression analysis, the contribution from pH and sand was 31.99 per cent but the contribution of pH was highly significant.
- b. For exchangeable K, the contribution from pH, organic carbon, clay, silt and CEC was 48.38 per cent and in stepwise regression analysis the organic carbon and CEC contributed significantly to the tune of 46.34 per cent.
- c. The contribution from pH, organic carbon, clay, silt sand and CEC towards non-exchangeable K was 31.61 per cent and on stepwise regression analysis the contribution from organic carbon and CEC was 25.41 per cent only, the contribution from CEC was, however, significant.
- d. The contribution for total K by pH, organic carbon, clay, silt sand and CEC was to the tune of 39.63 per cent and subsequently clay alone contributed significantly (36.57 per cent) towards total K.

The coefficient of correlations obtained between forms of K, physico-chemical properties and soil fractions are presented in Table 19. It is observed that:

- a. Water soluble K was positively correlated with organic carbon ($r = 0.456$), CEC ($r = 0.377$), exchangeable K ($r = 0.597$) and non-exchangeable K ($r = 0.312$).
- b. Exchangeable K was positively correlated with organic carbon ($r = 0.610$), CEC ($r = 0.590$) and non-exchangeable K ($r = 0.63$).
- c. Non-exchangeable K was positively correlated with organic carbon ($r = 0.392$), CEC ($r = 0.481$) and total K ($r = 0.306$).
- d. Total K was positively correlated with clay ($r = 0.504$) but had negative correlation with sand ($r = 0.447$) and silt ($r = 0.410$).
- e. K-fixing capacity was significantly correlated with organic carbon ($r = 0.913$), CEC ($r = 0.970$), sand ($r = 0.743$), silt ($r = 0.578$) and clay ($r = 0.908$).

The relationship between the forms of K has been observed in these soils. The basic concept of such an equilibrium is that a change in magnitude of one of the forms will tend to be compensated by movement from and between all the other forms (Reitemeier, 1951). Similar equilibrium was reported about Punjab soils (Grewal and Kanwar, 1976), in Nagaland soils (Ghosh and Ghosh, 1976) and in some Haryana soils (Chahal et al, 1976). A number of studies have also shown significant positive correlation of K-fixation with silt and clay fractions (Ghosh and Hasan, 1976), Ramanathan and Krishnamoorthy, 1976). The positive and significant correlation between non-exchangeable K and CEC indicated that

perhaps some K was adsorbed on inter-lattice sites which could not be exchanged by NH_4^+ but could be extracted with OH^- having selectivity of K (Vanschouwenburg and Schuffelen, 1963).

5.3.2 K-forms in soil fractions:

The potassium status of a soil may be assessed in its content of K-bearing minerals since the amount of these minerals in a soil gives some indication of the potential source of K to plants. But more important in determining the K-supply to plants are the soil K-fractions, (Mengel and Kirkby, 1980).

Distribution of total K in the soils of Kashmir was found to vary from 2.25 to 4.40, 1.80 to 2.80 and 1.25 to 1.80 per cent in clay, silt and fine sand fraction, respectively. The HCl soluble K varied from 1.35 to 1.80, 1.10 to 1.48 and 0.28 to 0.68 per cent in clay, silt and fine sand fraction, respectively and the 1NHNO_3 soluble K varied from 0.45 to 1.05, 0.20 to 0.65 and 0.10 to 0.28 per cent in clay, silt and fine sand, respectively. On an average clay fraction contributed 49, 47 and 57 per cent of total K HCl soluble and 1NHNO_3 soluble K, respectively. The contribution from fine sand fraction averaged to 11, 7 and 7 per cent of total, HCl and fixed K of soils, respectively. Higher contents of total K in these soils may be attributed to finer texture, presence of potassium bearing primary minerals (feldspar, muscovite) and illite which through the action of water in general and carbonic acids in

particular release large quantities of cations on weathering and thus giving higher values of K (Kovda, 1965). Kanwar and Grewal (1966), Lodha and Seth (1970) and Mehrotra et al (1975) reported similar values for the soils of Punjab, Rajasthan and Uttar Pradesh soils, respectively.

5.3.3 Green house studies:

Green house studies are capable of describing or measuring that portion of the nutrient in the soil that is available to plants. They reflect the quantity of plant available nutrient in a unit weight or volume of soil and are more rapid and more precise than field determinations.

The data pertaining to the pot culture studies (Table 14) revealed that dry matter production was relatively more in high altitude soils than in the soils of other zones. The application of different levels of K did not increase it correspondingly. The mean dry matter yield at K0 (control) was 1.245 gm which increased to 1.818 gm with the addition of K200 ppm and decreased to 1.635 gm with a higher K dose (400 ppm). There was no significant interaction between soils and K-levels. The soils differed significantly with respect to K-concentration in plants. The concentration increased with the increase in the K levels. The mean K-concentration in the plant at control was 0.786 per cent, it further increased to 2.503 per cent with application of K200 ppm and to 3.201 per cent with K400 ppm. The increase in K-concentration with

the increase in K levels though it was significant but the treatment of K200 ppm gave remarkably higher values of K-concentration in the plants than K400 in all the zones.

The influence of applied K on its uptake by a wheat crop (Table 14) revealed that mean uptake at control was 10.53 mgm K and it increased to 47.29 mgm K with K200 ppm and to 54.15 mgm K with 400 ppm. The increase in the K-uptake with the increase in K-levels was statistically significant. The interaction between soils and K levels was also significant. The increase in K uptake with the increase in K-levels did not show a corresponding increase in the production of dry matter which may be attributed to luxury consumption of K. As a result of potash application there was a higher K-content in wheat crop resulting in an increase in the uptake of K in all these soils. The higher dry matter yield obtained with 200 ppm K may be attributed to adequate amount of soil K which was utilized by the plants. The plants harvested at half flowering stage gave higher values of K concentration. Sandil (1979), Rejado (1978), Lodha et al (1969) and Singh and Singh (1981) reported that concentration of K in the plant increased with the age of the plant till the stage of maximum dry matter production and thereafter it declines. The K content in 40-45 days wheat plant varied from 2.96 to 5.36 per cent K (Sandil 1979; Lodha et al 1969 and Singh and Singh 1981). The results obtained in the green house experiment are in agreement with those reported earlier. The increased K uptake may be due to the synergetic and adequate N-supply.

Correlation studies: The coefficient of correlation between dry matter yield, K-concentration, uptake with forms of K were computed and are presented in Table 20. It is observed that (i) dry matter yield was significantly and positively correlated with exchangeable K, ($r = 0.677$) (ii) K-concentration and K-uptake were correlated with exchangeable K ($r = 0.773$ and $r = 0.809$) (iii) K-concentration and uptake of K of wheat plant was positively significantly correlated with fixed K ($r = 0.671$ and $r = 0.667$), respectively (iv) The water soluble K did not reach the level of significance, maybe it was too less to meet the plant requirement. The contents of total K were also not related with dry matter, K-concentration and K-uptake. Non-exchangeable K is reported to be highly correlated with that removed by plant under intensive cropping (MacLean, 1961 and Acquaye, 1973).

5.3.4 Effect of K-fertilization on the soil after crop harvest:

The soil samples after the crop harvest were analysed for NH_4OAc K and 1NHNO_3 soluble K and the data are presented in Table 15. A comparison of the initial and post harvest K status revealed that there was a considerable decrease in both NH_4OAc K and 1NHNO_3 K contents of the soil. It indicated that plants were able to take more K from the soil than was present in the available form, suggesting that K was released from non-exchangeable sources for use by the crop plants. The addition of K to the soil gave correspondingly higher values of both NH_4OAc K and non-exchangeable K. It, therefore, suggested that most of the added K got fixed and

Table 19: Relationship between forms of K, soil properties and soil fractions of the soils from the different zones of Kashmir.

Forms of K	Organic carbon	CEC	Sand	Silt	Clay	Exchangeable K	Fixed K	Total K
Water soluble	0.436**	0.377**	0.107	-0.031	-0.027	0.591**	0.312*	0.083
Exchangeable	0.610**	0.590**	0.007	0.085	-0.048	-	0.630**	0.029
Fixed	0.392**	0.481**	-0.202	-0.084	0.210	-	-	0.306*
Total	-0.220	-0.022	-0.477**	-0.410**	0.604*	-	-	-
K-Fixing capacity	0.913**	0.970**	0.743**	0.578**	0.908**	-	-	-

** Significant at 1 per cent level

* Significant at 5 per cent level

Table 20. Relationship between dry matter yield, K-concentration and K-uptake of wheat crop with forms of K in the soils from different zones of Kashmir.

	<u>Water soluble K</u>	<u>Exchangeable K</u>	<u>Fixed K</u>	<u>Total K</u>
Dry matter yield	0.401	0.677**	0.499	0.296
K-concentration	0.507	0.773**	0.671**	0.195
K-uptake	0.506	0.809**	0.667**	0.248

** Significant at 1 per cent level

* Significant at 5 per cent level

the plant met part of its requirements from the native K. This was substantiated by the equilibrium which exist between forms of K in these soils. Similar observations were made by Arnold and Close (1961). The reliance on K-release from non-exchangeable pool leads to a decline in the fertility status of the soil and the release may not cope up with the demand of vigorously growing crops (Grimme, 1974).

5.3.5 Quantity/Intensity relationship:

The quantity factor (ΔK) and the intensity factor (AR^k) proposed by Beckett (1964) provide a better picture about the potassium supplying power of a soil than available K or the ionic activity ratio of K.

5.3.5.1 Activity ratio $(AR_0^k) (N/L)^{\frac{1}{2}}$:

Activity ratio or K-potential or the intensity factor as a means of K-status of the soil has been advocated by Beckett (1964a) as it gives a better picture of the potassium supplying power of a soil than the available K provided the soils do not differ widely in calcium status.

The activity ratio and other quantity/intensity parameters computed from the soils of the three zones before sowing the crop and after harvest are presented in Table 16 and in Fig. 3. The mean initial activity ratio was 0.00478, 0.0046 and 0.0042 $(\text{mole/L})^{\frac{1}{2}}$ in high altitude, valley basin and karewa soils, respectively and the corresponding mean values after crop harvest were 0.00194, 0.00166 and 0.00167 $(\text{moles/L})^{\frac{1}{2}}$. The decrease in activity ratio from the initial

values due to crop uptake illustrated the potassium uptake by the plants. The mean activity ratio in the beginning in high altitude soils was relatively higher than the soils in other zones and may be attributed to higher organic matter content present in these soils.

Maji (1980) reported similar values (0.0057 to 0.0013 (moles/L)²) for soils rich in organic matter (2.0 to 4.5 per cent). Ramakrishnayya and Chatterjee (1976) report higher values (12.5 to 20.8 (moles/L)² x 10⁻³) for some red soils and low values (1.0 to 1.8 (moles/L)² x 10⁻³) for some black soils, indicating that K is available to a lesser degree in black soil than the red soils. Decrease in activity ratio due to uptake of K by plants is also reported by Patra (1978); Acquaye et al (1967) Le Roux and Sumner (1968). Maji (1979) reported almost similar values for alluvial soils from Kanpur, Delhi and Palampur (2 to 6.75 (moles/L)² x 10⁻³).

The activity ratio had negative non-significant correlation with clay content (Table 21) and with uptake of K by wheat (Table 22), indicating that the activity ratio was controlled more by the type of clay than by the amount of clay. Predominance of illite type of clay mineral seems to be primarily responsible for low AR_K (activity ratio) values of these soils as k is held preferentially by mica than by other minerals. Thus, the values of the activity ratio computed from the soils of Kashmir indicated low intensity parameter for immediate k-supplying and thus shall respond to

the K-application as illustrated by the decreases in the activity ratio due to cropping.

5.3.5.2 Free energy (ΔF):

The mean initial free energy values were -3213, -3191 and -3245 calories/equiv. in high altitude, valley basin and karewa soils, respectively and the corresponding mean values after crop harvest were -3735, -3872 and -3802 calories/equiv. (Table 16). The values of ΔF after cropping exhibited a decrease of -522, -681, and -557 calories/equiv. in high altitude, valley basin and karewa soils, respectively, indicating the presence of K in the soil solution.

Nielson (1977) reported about Denmark soil that with exhaustive cropping the free energy of soil decreased to -4000 calories/equiv. and further K-uptake was restricted to non-exchangeable K reserves. Maji (1979) reported wide variation in the free energy values in some alluvial soils of India. The values reported for Kanpur, Delhi and Palampur soils were -5727.43, -4483.74 and -4597.50 calories/equiv., respectively. Doverat (1962) reported that when ΔG values were below -4200 to -4300 calories/equiv., the K-deficiency was evident in pasture soils. Suresh (1979) found almost similar values (-2812.9 cal/equiv.) before cropping and after cropping (-3586.8 cal/equiv.) and advocated the use of K-fertilizers for some Himachal Pradesh soils.

The mean values of free energy in the soils studied were conspicuously less than the threshold values of -4000

Table 21: Relationship of Quantity/Intensity parameters, soil properties and forms of K in the various zones of Kashmir.

Q/I parameter	Stage	Organic carbon	Clay	Exchangeable K	Fixed K
Activity ratio	Before cropping	0.030	-0.362	0.259	0.208
	After cropping	-0.055	-0.187	0.209	0.107
Free Energy	Before cropping	-0.108	-0.447	0.141	0.160
	After cropping	-0.070	-0.196	0.220	0.111
Labile K	Before cropping	0.526	-0.041	0.993**	-0.907**
	After cropping	0.047	0.038	0.318	0.157
Potential buffering capacity	Before cropping	0.327	0.591*	-0.059	-0.022
	After cropping	0.238	0.492	0.156	0.048

** Significant at 1 per cent level

* Significant at 5 per cent level

Table 22. Coefficient of correlation between uptake of K by wheat and Quantity/Intensity relations of soils from Kashmir.

	Stage	Activity ratio	Free energy	Labile K	Potential buffering capacity.
Uptake of K by wheat	Before cropping	-0.050	-0.179	0.143	0.373
	After cropping	-0.175	-0.024	0.221	0.510.

cal/equiv. and above (Woodruff, 1955 and Arnold, 1962) when the soils are deficient in available K, whereas the values between -2500 to -3000 cal/equiv. have an optimum amount of available K and values less than -2000 cal/equiv. have excessive amount of available K. Consequently the soils in the present investigation before cropping, approach to second category (-2500 to 3000) indicating optimum amount of available K but with uptake the values correspond to the first category i.e. -3500 to -4000 cal/equiv., wherein the soil are reported to be deficient in available K and thus may meet their subsequent requirements from non-exchangeable pool, suggesting application of K-fertilizers to these soils.

The values of F did not show any correlation with organic carbon, clay content, $\text{Nd}_4\text{OAc K}$, fixed I. and with uptake of K by wheat (Table 21 and 22). It, therefore, did not offer any specified advantage over the more easily estimated exchangeable K.

5.3.5.3 Labile K (KL) K₀

Labile K represents the amount of K that must be removed to reduce the activity ratio to zero and is reported to be (Beckett, 1964) a measure of the total amount of labile K present and capable of taking part in the exchange reactions. The contents of labile K computed from the soils before sowing of the crop and after its harvest are presented in Table 16. The mean initial values for labile K were 0.1272, 0.1248 and 0.1115 me/100g for high altitude, valley basin and karewa soils, respectively and the corresponding values after the harvest of

the crop were 0.0809, 0.0806 and 0.0831 me/100g, respectively. On cropping the labile K decreased by 0.0463, 0.0442 and 0.0285 me/100g in the high altitude, valley basin and karewa soils, respectively.

Maji and Sen Gupta (1982) reported that values of labile K were low except for black soils and KL was significantly correlated with available K. The values reported for black, red, alluvial soils of Delhi, Kanpur and Palampur as 0.65, 0.44, 0.12, 0.07 and 0.13 me/100g, respectively. Khandekar (1980) reported about the black soils that Q/I relations of different soils from the same series differ more in K_L than in other parameters and attributed to clay content and management.

In the case of Kashmir soils, the exchangeable K was found to be more than the labile K. Considerably the spatial double layer arrangement of counterions on the colloidal surfaces, the source of labile K may be from diffused layer only. This was in line with the findings of Beckett et al (1966). It means not necessarily that entire amount of exchangeable K will take part in an exchange equilibria. The higher values of labile K for control than treated plots as is evident from the Table 16 are in agreement with the findings of Acquaye et al (1967); Le Roux and Sumner (1968), the decrease in the labile K may be attributed to uptake by plants.

The results obtained in the present investigation are in agreement with Roux and Sumner (1968) who reported that an increase in the amount of K taken up by the plants is accompanied

by a decrease in pool of labile K with plant growth. Consequently the plants obtain K from non-labile sources. This relative ability of the soil to release K is in agreement with the dominance of illite type clay minerals observed in these soils. When the labile K falls to a minimum in soils being intensively cropped after which the pool serves as the vehicle by which K from inter-lattice sites becomes available to the plants.

From a perusal of the data, it is observed (Table 21 and 22) that the labile K was positively significantly correlated ($r = 0.993$) with $\text{NH}_4\text{OAc K}$ and negatively significantly correlated with fixed K ($r = 0.907$) but had no correlation with uptake of K by wheat. The positive significant correlation with available K indicated no specified advantage was offered over the more easily estimated exchangeable K. Similar correlations were also observed by Maji and Sen Gupta (1982) about some alluvial soils of India and by Khandekar (1980) about black soils of India. The value of labile K in the present investigation were low indicating adequate availability of K to the plants, but since the plants extract most of its K requirements from non-labile K, addition of K-fertilizer will be quite responsive and beneficial as it will not exhaust the soil of its potassium reserves.

5.3.5.4 Potential buffering capacity (PBC^K):

Beckett (1964c) proposed a new parameter, potential buffering capacity of soil with respect to potassium, combining in one parameter the quantity and intensity factors. Addiscot and Talibudeen (1969) later defined PBC as the change in K (exchangeable K) in the soil for unit change in the potential

or work term. This parameter provides a good measure of replenishment power of the soil as k is withdrawn from the labile pool. The mean initial values (Table 16) for PBC^k were 30.09, 27.16 and 22.48 me/100g (M/L)^{1/2} and their corresponding values after crop harvest were 45.42, 43.69 and 36.75 me/100g (M/L)^{1/2} in high altitude, valley basin and karewa soils, respectively. The values of PBC^k due to cropping showed an increase to the tune of 14.33, 16.53 and 14.27 me/100g (M/L)^{1/2} in high altitude, valley basin and karewa soils, respectively. Under cropping conditions no change or increase in PBC^k values have been reported by different workers (Zandstra and Mackenzie, 1968). The higher values of PBC^k implies that degree of immediate k availability to plants would be less.

Maji and Sen Gupta (1982) reported almost similar values i.e. 23.3, 12.4 and 36.2 me/100g (M/L)^{1/2} for alluvial soils of Delhi, Palampur and Kanpur, respectively. Gupta et al (1933) reported a variation of 5.6 to 19.6 me/100g (M/L)^{1/2} for some Nagaland soils. The value for PBC^k for black soils were reported quite high, 100-130 me/100g (M/L)^{1/2} (Ramakrishnayya and Chatterjee, 1976)(Rao, 1977) which was attributed to the dominance of smectite clay mineral. Low values of red soils (5.0 to 21.0 me/100g (M/L)^{1/2}) were attributed to kaolinite type of clay mineral present in these soils and were reported to respond to K fertilization (Ramakrishnayya and Chatterjee, 1976).

The results obtained in the present investigation were in the inter-mediate range between those of smectite dominant soils and kaolinitic dominant soils. This may be attributed to

illite type of clay minerals found in these soils. Le Roux and Sumner (1968) reported that PBC^k of illite dominant soils vary from 33 to 57 me/100g $(M/L)^{\frac{1}{2}}$ and for kaolinite dominant soils 6-8 me/100g $(M/L)^{\frac{1}{2}}$ and report that the soil is being depleted of K by continuous cropping its PBC^k will increase. Such increase in PBC^k are most marked in soils having mica as the dominant mineral and as a result of its preference for K-especially at very low K-saturations. Therefore, soils with low PBC^k are unable to maintain the pool to the same extent as soils with high PBC^k . Therefore, on the basis of immediate Q/I parameters it is possible to state that soils with higher PBC^k have the greater capacity of K supply than the other soil with low PBC^k . This type of information cannot be obtained from the empirical extraction methods. It appears likely that in any one season, the response of plants to K application under field conditions will depend mainly on the labile pool at the beginning of the season. Nevertheless the release of fixed K to the pool will be important in the winter months during which soil with high $PBC^k > 30$ will be able to replenish the pool to some extent.

The value of PBC^k was positively correlated with clay ($r = 0.59$) (Table 21) but did not reach the level of significance with uptake of K by wheat (Table 22). Similar correlations were obtained by Acquaye and MacLean (1966); Pati Ram (1981) and Ghosh and Ghosh (1976).

CHAPTER VI

SUMMARY AND CONCLUSION

The prediction of response to applied K is a complex matter and among others the mineralogy of the soil has been reported to be the most important factor. The type and amount of clay mineral is also important in determining the availability of native and applied K. With regard to nutrient availability, it is being felt that both the quantity of the nutrient and its intensity, among others are equally important in determining the responsiveness of the crops to applied K. Beckett (1964) has tried to combine both the factors for predicting available K. This approach appears to have great potential but has not been always better than simple measurement of solution or exchangeable K in predicting availability of K to plants.

The present study was undertaken with the following objectives:

- a. To characterise the typical soil pedons of Kashmir for their morphological, physico-chemical properties, genesis and their classification into Taxonomic Units of USDA comprehensive system.
- b. To identify primary and clay minerals in the selected soil profiles.
- c. To find out the relationship between different K-fractions, important physico-chemical properties and mineralogy of the soil.
- d. To find out the relationship of soil separates with various forms of K and K-fixing capacity.

e. To find out the free energy, content of labile K and potential buffering capacity before and after cropping from Q/I ratios and their relationship with K-uptake.

Fourteen pedons were exposed in the three regions of the Kashmir viz. (a) five profiles in high altitude zone which is colluvial formations of gneiss, schists and other material and are located above 1800 m m.s.l. (b) five profiles in valley basin which is alluvial in nature and located between 1700 to 1800 m m.s.l. and (c) four pedons were exposed in karewa zone of lacustrine origin. The major findings of this investigation are summarized below:

6.1 Pedological characteristics:

- i. Morphologically the soil differed in respect of many features. The high altitude soils were generally dark coloured, the colour varying from very dark greyish brown (10YR 3/2) to dark yellowish brown (10YR 4/4) and from yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4) in valley basin and in karewa soil from brown (7.5 YR 5/4) to dark brown (10YR 4/3).
- ii. Clay cutans were found on the ped faces. This has resulted in the formation of B2t horizon. All soils were predominantly under the influence of climate and vegetation.
- iii. The soils in the study area were heavy textured; the clay percentage relatively more (26 to 52 per cent) in high altitude soils, whereas in valley basin and karewa soils the silt content (42 to 54 per cent) was more than in high altitude soils.

iv. The soils in the high altitude zone had neutral pH (weighted average 6.4 to 7.6) whereas in the other zones it was comparatively more but was within the safe limits. The CaCO_3 content was higher in karewa soils (weighted average 2.30 to 8.73 per cent) but was low in high altitude and valley basin soils.

v. Organic carbon content in the high altitude soil was relatively more (1.4 to 2.9 per cent) than in the valley basin (1.09 to 1.54 per cent) and karewa soils (0.45 to 1.0 per cent). There was also a marked variation in total nitrogen content (weighted average) varying from 0.09 to 0.18 per cent, 0.08 to 0.10 and 0.03 to 0.06 per cent in high altitude, valley basin and karewa soils, respectively. The surface soils had relatively more content of N than the sub-surface horizons.

vi. The available P_2O_5 content in these soils was medium and the available K-status was in general high, the high altitude soils had relatively higher content of both these nutrients.

vii. The weighted average values for CEC ranged from 22.5 to 29.0, 15.80 to 22.31 and 15.01 to 20.14 me/100g in high altitude valley basin and karewa soils, respectively. Amongst the exchangeable cations, calcium was found to be the dominant cation in all the soils followed by Mg and K. The weighted average values for exchangeable Ca were 12.50 to 15.95, 8.87 to 13.04 and 8.38 to 12.48 me/100g in high altitude, valley basin and karewa soils, respectively, the corresponding values for exchangeable Mg were 5.62 to 9.51, 4.95 to 7.58 and 4.69 to 6.20 me/100g and for exchangeable K 0.31 to 0.81, 0.23 to 0.40 and 0.23 to 0.52 me/100g in these soils.

viii. The soils in the high altitude zone, because of dark colour, higher organic matter content, presence of argillic horizon were generally classified as Argiudolls but Hapludalfs were also present. The soils in the valley basin were mostly Hapludalfs but Ochraqualfs and Dystrochrepts were also encountered. The karewa soils were predominantly Alfisols with Hapludalfs as the main great group.

6.2 Mineralogical studies:

i. The light mineral constituted 96 to 98 per cent and were dominated by quartz and feldspar. Muscovite and kaolin were also present, whereas the heavy mineral suite constituted 2 to 4 per cent and comprised of biotite magnetite, opaque mineral, tourmaline, chlorite, augite, hornblende, ilmenite and zircon. Mineral assemblage observed in these soils reflected their origin from metamorphic rocks present in the area. The mineralogy was almost similar in the three zones but varied in proportion.

ii. The cation exchange capacity of the clay samples varied from 36.42 to 44.81, 28.36 to 36.42 and 26.40 to 36.48 me/100g in high altitude, valley basin and karewa soils, respectively which showed the presence of illite and chlorite. On the basis of molar ratios the $\text{SiO}_2/\text{R}_2\text{O}_3$ of 2 to 3 observed in these soils supported the presence of illite and chlorite. Similarly, $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios found between 3 and 4 suggested the presence of illite and chlorite, $\text{Al}_2\text{O}_3:\text{K}_2\text{O}$ (3.5 to 6.3) indicated the presence of illite and kaolinite in these soil clays.

iii. X-ray diffraction studies revealed the presence of illite, chlorite, vermiculite, kaolinite and inter-stratified minerals,

(in the order of abundance) in these soils. Illite may have formed due to hydrolysis of feldspar and inherited from parent material also. Chlorite was present in all the samples and might have been formed due to transformation of primary mineral and due to the degradation of illite. Vermiculite may have formed from illite and chlorite. Kaolinite though present in relatively small amounts may have been inherited from the parent rocks and by alluvium. Degraded illite was also present.

6.3 Studies on potassium:

i. The available K varied from 111.87 to 130.29, 91.74 to 109.90 and 82.22 to 101.90 ppm in high altitude, valley basin and karewa soils, respectively. On the conventional soil fertility evaluation scale, these soils are rated high in available K status.

ii. The contents of non-exchangeable K ($1\text{NHNO}_3\text{ K}$) present in the three zones was adequate. The weighted average values ranged from 872 to 930, 591 to 855 and 629 to 753 ppm in high altitude, valley basin and karewa soils, respectively. The soils were high in total K and the weighted average values ranged from 1.63 to 2.26, 1.83 to 2.06 and 1.83 to 2.10 per cent in high altitude, valley basin and karewa soils, respectively. The higher content of total K may be attributed to the presence of orthoclase, muscovite and illite. The K-fixing capacity of these soils was 267, 254 and 245 ppm in the high altitude, valley basin and karewa soils, respectively and was significantly correlated with organic carbon, CEC, silt, sand, clay and CaCO_3 .

iii. The total K as extracted by HF in clay, silt and fine sand fraction averaged to 2.25 to 4.40, 1.80 to 2.80 and 1.25 to 1.80 per cent, respectively. The HCl soluble K varied from 1.35 to 1.80, 1.10 to 1.48 and 0.28 to 0.68 per cent in clay silt and fine sand, respectively and the corresponding values with 1NHNO_3 were 0.45 to 1.05, 0.20 to 0.65 and 0.10 to 0.28 per cent. The contents of these forms of K had a negative correlation with the size of the particle. The contribution of clay was comparatively more towards all forms of K indicating the predominance of illite in these soils.

iv. Green house studies revealed that dry matter production was 1.25 gm/3 plant with K0, it increased to 1.82 gm/ with K200. It did not show the corresponding increase with K400 but was more (1.63 gm) than control. The content of K in the wheat plant increased with the increase in K levels. The K content in plant was 0.78 per cent with control, with K200 ppm it increased to 2.50 per cent with K400 ppm it increased to 3.20 per cent. The uptake of K by wheat plant with K200 ppm was remarkably superior over control and the uptake with 400 ppm K though significant over control was not in the same proportion. Dry matter yield was significantly and positively correlated with exchangeable K. K concentration and K-uptake was significantly correlated with exchangeable and non-exchangeable K.

v. The post harvest analysis of K in the soil samples showed that the contents of NH_4OAc I, and 1NHNO_3 K were relatively less than the initial corresponding values. There was an average decrease from 25 to 36 ppm in NH_4OAc I. and 65 to 210 ppm

in 1NHNO_3 K due to cropping. The addition of K increased the contents of exchangeable and non-exchangeable K in these soils.

vi. Amongst the Quantity/Intensity relations, potassium activity ratio $a_k/\sqrt{a(\text{Ca}+\text{Mg})}$ did not provide any significant correlation with K-uptake and was negatively correlated with clay content. The ratio was of the order of 10^{-3} indicating a low intensity parameter for immediate K-supply. The mean initial activity ratio values ranged from 4.2 to 4.7 $(\text{M/L})^{\frac{1}{2}}10^{-3}$ and after cropping the values averaged 1.6 to 1.9 $(\text{M/L})^{\frac{1}{2}}10^{-3}$ in these soils. The free energy values indicated optimum amount of available K in the soil. The values changed with the crop harvest; the depletion due to uptake caused deficiency of available K in these soils. The initial values of ΔF ranged from -3190.96 to 3245.47 and after crop harvest it varied from -3734.55 to 3871.90 calories/equiv. The values of ΔF were not correlated with uptake of K, clay, NH_4OAc K and fixed K. The initial values of labile K ranged from 0.1115 to 0.1272 me/100g and the values after crop harvest ranged from 0.080 to 0.083 me/100g in these soils. The labile K was less than the available K in all these soils, thus indicating the removal of K by crop from non-labile pool. Labile K was not correlated with uptake of K by plants but was positively correlated with available K. Depletion of non-labile K by plants is likely to shrink the potassium reserves. The initial potential buffering capacity values ranged from 22.48 to 30.09 me/100g $(\text{M/L})^{\frac{1}{2}}$ and after cropping the values ranged from 36.75 to 45.42 me/100g $(\text{M/L})^{\frac{1}{2}}$. The values observed were low but intermediate to those

of high value of smectite dominant and low values of kaolinite dominant soils. It is attributed to the dominance of illite in these soils. The low PBC^k suggested the need for K-fertilization to these soils. The values did not reach the level of significance with uptake of K by plant and was positively correlated with clay.

Conclusion:

The present investigation revealed informations of applied nature which hitherto were not known in detail besides, bringing out some new facts into light about the soils of Kashmir. There exist good reserves of potassium in Kashmir soils but with better agriculture, these reserves which in principle are not in exhaustable, may not keep pace with the huge removal of K due to cropping and fruit production. Thus the need for K fertilization.

The present study though first of its kind on Kashmir soils needs further investigations in various soil zones with main agriculture and horticultural crops so that many of the mysteries of soil potassium are unraveled and a sound policy is developed for efficient potassium fertilization for accelerating agricultural production without unduly exhausting the potassium reserves of the soil.

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Appendix I. Morphological characteristics of soil profiles from various zones of Kashmir.

Profile No. 1	Pahalgam
Classification	Typic Hapludalfs, clayey mixed thermic.
Location	Maize Research Farm
Physiography	Mid slope of hills with moderate undulations, 2-4 per cent slope.
Elevation	2200 m
Vegetation	Cultivated, surrounded by coniferous vegetation.
Parent material	Sand stone, shale, gneiss, schist.

<u>Horizon</u>	<u>Depth (cm)</u>	<u>Description</u>
Ap	0-15	Light yellowish brown (10YR 6/4) dry, dark yellowish brown (10YR 4/4) moist, clay loam, medium moderate sub angular blocky, slightly hard friable, slightly sticky and slightly plastic, many fine to medium roots, gradual smooth boundary.
B1	15-35	Light yellowish brown (10YR 6/4) dry, yellowish brown (10YR 5/4) moist, clay loam, medium moderate sub angular blocky, slightly hard friable slightly sticky and plastic, many fine to medium roots, gradual smooth boundary.
B21	35-50	Brown (7.5YR 5/4) dry, dark brown (7.5YR 4/4) moist, silty clay loam, coarse strong sub angular blocky, hard firm, sticky and plastic, few thin patchy clay skins on peds, few fine roots, diffuse smooth boundary.
B22t	50-125	Light brown (7.5YR 6/4) dry, dark brown (7.5YR 4/4) moist, silty clay loam, medium strong sub angular blocky, hard firm sticky and plastic, thick patchy clay skins on ped faces, diffuse smooth boundary.
B23t	125-150	Pale brown (10YR 6/3) dry, dark brown (10YR 4/3) moist silty clay, coarse strong sub angular blocky, hard, firm sticky and plastic, thick patchy clay skins on ped faces.

Profile No.2	Larnoo
Classification	Typic Hapludalfs, clayey mixed thermic
Location	East of Rice Research Farm (200 m away).
Physiography	Foot slope, terraced surrounded by hills. 1-2 per cent slope.
Elevation	2200 m
Vegetation	Cultivated, surrounded by coniferous vegetation.
Parent material	Sand stone, shale, gneiss, schist.

(ii)

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-18	Light yellowish brown (10YR 6/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay loam medium weak sub-angular blocky, slightly hard friable slightly sticky and slightly plastic, many fine to medium roots, gradual smooth boundary
B1	18-70	Brown(7.5 YR 5/4) moist, silty clay, medium moderate sub angular blocky, sticky and plastic many fine to medium roots, gradual smooth boundary.
B21t	70-120	Dark brown (7.5YR 3/2)moist, silty clay medium moderate sub-angular blocky, firm sticky and plastic, few fine patchy clay skins on peds, diffuse smooth boundary.
B22t	120-150	Dark brown (7.5YR 3/2) moist, silty clay medium moderate subangular blocky, firm sticky and plastic, thick patchy clay skins on ped faces.

Profile No. 3.

Sonamarg

Classification

Typic Argiudolls, clayey, mixed thermic.

Location

Meadow land on the bank of river Sindh.

Physiography

Undulating upland surrounded by hills 2-4 per cent slope.

Elevation

2600 m

Vegetation

Pastures surrounded by coniferous vegetation

Parent material

Gneiss, schist and slate.

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-20	Greyish brown (10YR 5/2) dry, very dark greyish brown (10YR 3/2) moist, clayloam, medium weak sub-angular blocky, soft friable slightly sticky and slightly plastic, many medium coarse roots, gradual smooth boundary.
B1	20-60	Dark grey brown (10YR 4/2) dry, very dark brown (10YR 2/2) moist, clayloam, medium moderate sub-angular blocky, soft, friable slightly sticky and slightly plastic, many medium coarse roots, gradual smooth boundary.
B21t	60-90	Brown (10YR 5/3) dry, dark brown (10YR 4/3) moist, silty clay loam, medium moderate sub-angular blocky, slightly hard friable sticky and slightly plastic, few thin patchy clay skins on peds, few fine roots, gradual smooth boundary.
B22t	90-120	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay, medium moderate sub angular blocky, hard and firm sticky and plastic, many thick patchy clay skins on ped faces, gradual smooth boundary.

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120-150	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay, coarse strong sub angular blocky, hard and firm sticky and plastic, many thick patchy clay skins on ped faces.
Profile No.4	Gulmarg
Classification	Typic Argiudolls clayey mixed thermic
Location	Potato farm.
Physiography	Hummocky upland, terraced 2-3 per cent slope.
Elevation	2540 m
Vegetation	Cultivated, surrounded by coniferous vegetation
Parent material	Sand stone , Conglomerate, schist.

<u>Depth(cm)</u>	<u>Description</u>
0-20	Light brownish grey (10YR 6/2) dry, very dark greyish brown (10YR 3/2) moist, silt loam, medium weak subangular blocky, soft friable slightly sticky and slightly plastic, many medium coarse roots, abrupt smooth boundary
20-50	Very dark greyish brown (10YR 3/2) moist silt loam, medium weak subangular blocky, slightly sticky and slightly plastic, many medium coarse roots abrupt smooth boundary.
50-90	Very dark greyish brown (10YR 3/2)moist silty clay loam, medium moderate subangular blocky, slightly hard friable sticky and plastic, few thin patchy clay skins on ped faces, few fine roots, gradual smooth boundary.
90-150	Light yellowish brown (10YR 6/4)moist silty clayloam, medium moderate subangular blocky, slightly hard, friable, sticky and plastic, many thick patchy clay skins on peds.

Profile No. 5	Chandigam (Sogam)
Classification	Typic Argiudolls clayey mixed thermic.
Location	Forest 200 m away from tourist hut.
Physiography	Mid slope of a hill with forest vegetation
Elevation	1900 m
Vegetation	Coniferous vegetation
Parent material	Sand stone - shales.

(iv)

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-17	Dark, greyish brown (10YR 4/2) dry, very dark greyish brown (10YR 3/2) moist, silt loam, medium weak sub angular blocky, soft, friable slightly sticky and slightly plastic, many medium coarse roots, abrupt smooth boundary.
B21t	17-60	Brown (10YR 5/3) dry, dark brown (10YR 4/3) moist, silt loam, medium weak subangular blocky, slightly hard friable slightly sticky and slightly plastic, thin patchy clay skins on ped faces, many medium coarse roots, gradual smooth boundary.
B22t	60-90	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay loam, medium moderate subangular blocky, hard firm sticky and plastic, many thick patchy clay skins on ped faces, few fine roots gradual smooth boundary.
B23t	90-150	Dark yellowish brown (10YR 4/4) moist, clayloam, medium moderate subangular blocky, hard, firm, sticky and plastic, many thick patchy clay skins on ped faces.

Profile No. 6.	Khudwani
Classification	Typic Ochraqualfs, clayey mixed thermic
Location	Rice Research Farm
Physiography	Old alluvial plain, 2 per cent slope
Elevation	1700 m
Vegetation	Cultivated, willows, Acacia, Poplars..
Parent material	Alluvium

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-20	Pale brown (10YR 6/3) dry, dark brown (10YR 4/3) moist, silt loam, medium weak subangular blocky, slightly hard friable non-sticky and non-plastic, many fine to medium roots gradual smooth boundary.
B1	20-40	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 3/4) moist, clayloam, medium moderate subangular blocky, slightly hard friable slightly sticky and slightly plastic, many fine to medium roots, gradual smooth boundary.
B21t	40-70	Yellowish brown (10YR 5/4) moist clayloam, medium moderate subangular blocky friable, slightly sticky and slightly plastic few thin patchy clay skins on peds, few medium faint light grey mottles present, few fine roots, gradual smooth boundary.

(v)

B22t 70-120 Brown (7.5YR 5/4) moist, silty clayloam, medium strong subangular blocky, friable, slightly sticky and slightly plastic, few thin patchy clay skins on peds, many medium light grey mottles (7.5YR 7/1), gradual smooth boundary.

B23t 120-150 Dark brown (7.5YR 4/4) moist, silty clayloam medium strong subangular blocky, firm, sticky and plastic, many thin patchy clay skins on peds, many medium light grey mottles(7.5YR 7/1).

Profile No.7 Nunar (Ganderbol)
Classification Typic Hapludalfs clayey mixed thermic
Location Fodder Development Farm
Physiography Old alluvial plain 2-3 per cent slope.
Elevation 1650 m
Vegetation Cultivated, Acacia, Poplars, Willows.
Parent material Old alluvium.

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-20	Pale brown (10YR 6/3) dry, dark brown (10YR 4/3) moist, clayloam medium weak subangular blocky, slightly hard, friable slightly sticky and slightly plastic, slightly calcareous, many medium coarse roots, abrupt smooth boundary.
B21t	20-40	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, clayloam, medium moderate subangular blocky, slightly hard friable slightly sticky and slightly plastic, slightly calcareous, thin few patchy clay skins on ped faces, many medium coarse roots, gradual smooth boundary.
B211t	40-75	Brown (7.5YR 5/4) dry, dark brown(7.5YR 4/4) moist, silty clayloam, medium moderate subangular blocky, slightly hard firm slightly sticky and slightly plastic, slightly calcareous, many thin patchy clay skins on ped faces, few fine roots, gradual smooth boundary.
B22t	75-150	Brown (7.5YR 5/4) dry, dark brown (7.5YR 4/4) moist, silty clayloam, medium moderate subangular blocky, slightly hard, firm, sticky and plastic, many thin patchy clay skins on ped faces.

B1	17-85	Dark greyish brown (10YR 4/2) moist, silty clayloam, medium weak subangular blocky slightly hard, friable, slightly sticky and slightly plastic, moderately calcareous, few medium faint yellowish brown mottles, many medium coarse roots, gradual smooth boundary.
B2	85-110	Dark yellowish brown (10YR 4/4) moist, silty clayloam, medium weak subangular blocky, friable, slightly sticky and slightly plastic, moderately calcareous, few medium faint yellowish brown mottles.
	110	Water seeping out

Profile No. 10	Handwara
Classification	Typic Dystrochrept, fine silty mixed thermic
Location	Horticultural Nursery - Chogul
Physiography	Alluvial fan with 2 per cent slope
Elevation	1630 m
Vegetation	Fruit nursery plants, willows, Poplars
Parent material	Alluvium.

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap.	0-17	Pale brown (10YR 6/3) dry, yellowish brown (10YR 5/4) moist, silt loam, medium weak subangular blocky, slightly hard, friable, slightly sticky and slightly plastic, many fine to medium roots, gradual smooth boundary.
B1	17-35	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silt loam, medium weak subangular blocky, slightly hard friable, slightly sticky and slightly plastic many fine to medium roots, gradual smooth boundary.
B2	35-85	Dark yellowish brown (10YR 4/4) moist, silt loam, medium weak subangular blocky friable, slightly sticky and plastic, few fine roots, gradual smooth boundary.
B21	85-150	Dark yellowish brown (10YR 4/4) moist, silty clayloam medium moderate subangular blocky firm slightly sticky and slightly plastic.

Profile No. 11	Tapar
Classification	Typic Hapludalfs clayey mixed thermic
Location	Agri: Farm
Physiography	Plain uplands 2-3 per cent slope
Elevation	1700 m
Vegetation	Cultivated, Poplars, Willows
Parent material	Loestrine deposits

(viii)

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-15	Light yellowish brown (10YR 6/4) dry, dark brown (10YR 4/3) moist, clayloam, medium moderate subangular blocky, friable, slightly sticky and slightly plastic, many fine to medium roots, abrupt smooth boundary.
B1	15-35	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay loam, medium moderate subangular blocky, firm, sticky and plastic many fine to medium roots, gradual smooth boundary.
B21t	35-60	Greyish brown (10YR 5/2) dry, very dark, greyish brown (10YR 3/2) moist, silty clayloam, medium moderate subangular blocky, firm sticky and plastic, few thin patchy clay skins on peds, few fine roots, diffuse smooth boundary.
B22t	60-90	Dark greyish brown (10YR 4/2) dry, very dark greyish brown (10YR 3/2) moist, silty clayloam, medium moderate subangular blocky, firm, sticky and plastic, many thin patchy clay skins on peds, diffuse smooth boundary.
B23t	90-150	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay, medium moderate subangular blocky, firm, sticky and plastic, many thick patchy clay skins on peds.

Profile No. 12.

Karewa Damodar Farm

Classification

Typic Hapludalfs, clayey mixed thermic

Location

Maize Research Farm

Physiography

Table lands of lacustrine deposits, plain 2 per cent slope.

Elevation

1600 m

Vegetation

Cultivated, Willows, Poplars

Parent material

Lacustrine deposits

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
	0-16	Pale brown (10YR 6/3) dry, dark brown (10YR 4/3) moist, silt loam, medium weak, subangular blocky slightly hard, friable, slightly sticky and slightly plastic, many medium coarse roots, abrupt smooth boundary.
	16-31	Light brown (7.5YR 6/4) dry, dark brown (7.5YR 4/4) moist, silt loam, medium moderate subangular blocky, hard, friable, slightly sticky and slightly plastic, many medium coarse roots, gradual smooth boundary.
B1t	31-47	Dark brown (7.5YR 4/2) dry, and (7.5YR 3/2) moist, clayloam, medium moderate subangular blocky hard, firm, sticky and plastic, slightly calcareous, few thin patchy clay skins on ped faces, few fine roots, gradual smooth boundary.

- 11t 47-97 Dark yellowish brown (10YR 4/4) dry, dark brown (10YR 4/3) moist, silty clayloam, medium moderate subangular blocky, hard, firm, sticky and plastic, slightly calcareous, thick many patchy clay skins on ped faces, gradual smooth boundary.
- 2t 97-150 Pale brown (10YR 6/3) dry, brown (10YR 5/3) moist, silty clay medium strong subangular blocky, hard, firm, sticky and plastic lime concretions (2 mm), calcareous, many thick clay skins on ped faces.

Profile No. 13. Pampore
 Classification Typic Hapludalfs clayey mixed thermic
 Location Saffron Farm
 Physiography Lacustrine deposit, plain 2-3 per cent slope.
 Elevation 1600 m
 Vegetation Under cultivation, Poplars, Willows
 Parent material Lacustrine deposit

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
	0-20	Yellowish brown (10YR 5/5) dry, dark yellowish brown (10YR 4/4) moist, silt loam medium weak subangular blocky, slightly hard, slightly sticky, slightly plastic, friable, slightly calcareous, many fine to medium roots, abrupt smooth boundary.
1t	20-60	Brown (7.5YR 5/4) dry, dark brown (7.5YR 4/4) moist, silt loam, medium moderate subangular blocky slightly hard, friable, slightly sticky and slightly plastic, lime concretions (2-5 mm), calcareous, few fine patchy clay skins on peds, many fine to medium roots, gradual smooth boundary.
1t	60-85	Brown (7.5YR 5/2) dry, dark brown (7.5YR 4/2) moist silty clay loam, medium moderate subangular blocky, hard, firm, sticky and plastic, lime concretions (2-5 mm), calcareous, many thick patchy clay skins a peds, few fine roots, gradual smooth boundary.
t	85-150	Very pale brown (10YR 7/4) dry, yellowish brown (10YR 5/4) moist silty clay, medium moderate subangular blocky, hard firm, sticky and plastic, lime concretion (2-5 mm), calcareous, many thin patchy clay skins on peds

(x)

Profile No. 14. Koil (Pulwama)
Classification Typic Hapludalfs fine silty mixed thermic
Location Padgampora Pulwama road. Right hand side.
Physiography Table lands of lacustrine deposit, (Karawa)
plain, 2-3 per cent slope.
Elevation 1650 m
Vegetation Under cultivation, fruit plants
Parent material Lacustrine deposit.

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-20	Light brown (7.5YR 6/4) dry, brown(7.5YR 5/4) moist silt loam, medium weak subangular blocky, slightly hard, friable, slightly sticky and slightly plastic, moderately calcareous, many fine to medium roots, gradual smooth boundary.
B1	20-50	Light brown (7.5YR 6/4) dry, brown(7.5YR 5/4) moist, silt loam, medium moderate subangular blocky, slightly hard, friable, slightly sticky and slightly plastic, moderately calcareous, many fine to medium roots, gradual smooth boundary.
B21t	50-85	Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 4/4) moist, silty clay loam, medium moderate subangular blocky, slightly hard, firm, sticky and plastic, lime concretion (2-5 mm) calcareous, many thin patchy clay skins on peds, few fine roots, abrupt smooth boundary.
B22t	85-150	Yellowish (10YR 8/6) dry, yellowish brown (10YR 5/8) moist, silty clayloam, medium moderate subangular blocky, hard firm, sticky and plastic, lime concretion (2-5 mm), calcareous, many thick clay skins on peds.

Appendix II: Multiple regression equations indicating the relationship between forms of K and properties of soils from various zones of Kashmir.

a) Water soluble K =

$$\begin{aligned}
 & 7.271 - 3.458^{**} \text{ pH} + 0.216 \text{ organic carbon} \\
 & + 0.320 \text{ clay} + 0.340 \text{ silt} + 0.424 \text{ sand} \quad R^2=0.3273^{**} \\
 = & 10.233 - 3.718^{**} \text{ pH} + 0.314 \text{ clay} + 0.333 \\
 & \text{silt} + 0.426 \text{ sand} \quad R^2=0.3262^{**} \\
 = & 42.164 - 3.840^{**} \text{ pH} + 0.021 \text{ silt} + \\
 & 0.119 \text{ sand} \quad R^2=0.3210^{**} \\
 = & 42.90 - 3.812^{**} \text{ pH} + 0.120 \text{ sand} \quad R^2=0.3199^{**}
 \end{aligned}$$

b) Exchangeable K =

$$\begin{aligned}
 = & 90.74 - 6.159 \text{ pH} + 5.796^* \text{ organic} \\
 & \text{carbon} + 0.054 \text{ clay} + 0.288 \text{ silt} + \\
 & 1.022 \text{ CEC} \quad R^2=0.4838^{**} \\
 = & 95.99 - 6.348 + 5.560^* \text{ organic carbon} \\
 & + 0.237 \text{ silt} + 1.054 \text{ CEC} \quad R^2=0.4835^{**} \\
 = & 46.364 + 7.006^{**} \text{ organic carbon} + \\
 & 1.577^{**} \text{ CEC} \quad R^2=0.4634^{**}
 \end{aligned}$$

c) Non-exchangeable K =

$$\begin{aligned}
 = & 6.207 - 31.456 \text{ pH} + 40.44 \text{ organic} \\
 & \text{carbon} + 9.887 \text{ clay} + 8.040 \text{ silt} + \\
 & 4.437 \text{ sand} + 6.576 \text{ CEC} \quad R^2=0.3161^* \\
 = & 470.79 - 34.444 \text{ pH} + 40.920 \text{ organic} \\
 & \text{carbon} + 5.515 \text{ clay} + 3.702 \text{ silt} + \\
 & 6.16 \text{ CEC} \quad R^2=0.3153^* \\
 = & 127.192 + 50.220^* \text{ organic carbon} + \\
 & 6.081 \text{ clay} + 3.76 \text{ silt} + 8.583 \text{ CEC} \quad R^2=0.3089^* \\
 = & 347.876 + 43.02 \text{ organic carbon} + \\
 & 3.783 \text{ clay} + 10.467 \text{ CEC} \quad R^2=0.2982^* \\
 = & 422.32 + 26.564 \text{ organic carbon} + \\
 & 14.24^{**} \text{ CEC} \quad R^2=0.2541^*
 \end{aligned}$$

d) Total K =

$$\begin{aligned}
 = & 5156.40 - 630.66 \text{ pH} - 100.68 \text{ organic} \\
 & \text{carbon} + 354.05 \text{ clay} + 182.92 \text{ silt} \\
 & + 128.52 \text{ sand} - 161.67 \text{ CEC} \quad R^2=0.3963^{**}
 \end{aligned}$$

(xii)

= 4543.28 - 544.91 pH + 356.06 clay + 182.93 silt + 123.69 sand - 168.7 CEC	$R^2=0.3959^{**}$
= 17645.54 - 639.96 pH + 233.29** clay + 61.39 silt - 179.27 CEC	$R_2^2=0.3944^{**}$
= 11784.93 + 231.79** clay + 52.29 silt - 105.42 CEC	$R^2=0.3871^{**}$
= 14900.64 + 203.63** clay - 94.79 CEC	$R^2=0.3813^{**}$
= 13129.05 + 196.78** clay	$R^2=0.3657^{**}$

** Significant at 1% level

* Significant at 5% level