CHAPTER 1

1.1 INTRODUCTION

The North East (NE) region of India lies between 21°51’ to 29°28’N Latitude and 85°34’ to 97°24’ E Longitude. The region has geographical area of 262.2 thousand square km which is 7.97% area of India. The area is predominantly hilly; having more than 72% of the area is under this category and could be broadly classified as

1. Hills and mountains
2. Plateaus, and
3. Plains

The altitudinal differences coupled with varied physiographical features give rise to distinct and varied type of climate ranging from near tropical to temperate and alpine. Out of the total geographical area of 262.2 thousand square km, 85% of the area is reported for effective land use. Again out of this 85% land, 63% area is put under forest, 5.5% under non-agricultural use, 10% soils are uncultivable/barren, 6% area is fallow and only 15.5% are is under net sown area. Cropping intensity of this region is only 118% as field is generally devoid of any crop during winter. However, there is extremely good potential for raising horticulture, agro-forestry and perennial crops like rubber in this region. The region has about 36.2% of degraded land. Agro-forestry and perennial crop like rubber intervention according to the local need will be beneficial for effective land use and to check further degradation of soil.

In NE Region, soil and environment degradation is a big problem. This is further aggravated due to ecologically unsuitable shifting cultivation though the local tribes/indigenous people are socio-culturally and economically very much attached with this form of land use. The shifting cultivation is usually preceded by burning the organic debris. As a result, organic matter content of soils the soils is decreased; beneficial microorganisms are reduced and soils are degenerated. As a result, jhuming is no more economical. Hence,
efforts are there to wean away the shifting cultivators from this practice by various
government agencies through various welfare schemes. Though the forest soils are rich in
OM, but soils of humid sub-tropical region especially Tripura and other foot hills of NE Region are highly deficient in OM, available P and K. About 95 % of these soils are acidic
which could be attributed to higher leaching loss of essential bases. As a result fertility
status of these soils is poor. Besides water, soil fertility is probably the single most important
determinant factor producing good crops and yield. Therefore, it is paramount important to
know the soil fertility status of any given soil for adopting better management practices to
get sustainable crop yield.

In North East India, rubber is now gainfully cultivated. It is estimated that about 4.5
lakh hectares of land could be brought under rubber cultivation. However, yield potential of
rubber is quite low (1000-1100 kg/ha; Krishnakumar and Meenatoor, 2000) in comparison
to national average (1700-1780 kg/ha). The reason might be due to low organic carbon
content of soil, poor soil fertility status, soil moisture stress during winter. However, rubber
responds well to nutrition particularly where soils are poor in nutrient content. Therefore, a
good management practices for rubber has to be envisaged for sustained growth and yield.
Knowledge on the physico-chemical properties of any given soil is, therefore, of paramount
importance. Since cultivation of rubber is relatively new in this region, so not much
information about the physico-chemical and mineralogical properties of potential rubber
growing soils in NE-region are available.

Potassium (K) is one of the major essential plant nutrients which plays a major role
in plant metabolism, growth and yield. K is reported to activate more than sixty enzymes in
plant and involved in several biosynthetic processes such as CO₂ assimilation, photo
phosphorylation, ATP synthesis etc. It also improves the water use efficiency, provides
resistance to cold stress, lodging and disease to plants. Therefore, nutrient supply to plant
particularly K has to be monitored continuously in view of the crop needs and the capacity
of soils to fulfill such needs.

Potassium content of a given soil is largely controlled by the mineralogical make up
of soil, as greater proportion of total K is present as an integral part of the crystal structure of
various silicate minerals such as K-feldspars, muscovite, biotite, illite and inter stratified minerals (hydroxy - interlayered -vermiculites). The content of K bearing minerals and rate and amount of K being released from soil are important in determining the K status of soils. Information about mineralogy of soil K are, therefore, of much relevance for assessing long range availability of this essential plant nutrient. The presence or deficient of plant available K in soils suggests the importance of relationship between K uptakes by plants, physico-chemical and mineralogical make up of soil and dynamic relationship of various pools of K.

However, not much information about the physico-chemical and mineralogical properties of potential rubber growing soils of NE Region vis-a-vis K-dynamics are available for efficient nutrient management. Therefore, the present work was undertaken with the following Objectives:

1. To make a general survey on soil potassium (K) status of potential rubber growing soils of NE-region as well as to assess nutrient dynamics in relation to spatial and temporal variation of soil
2. To establish Quantity-Intensity (Q/I) relationship of soil K and to relate with soil properties
3. To investigate kinetics of non-exchangeable K release from some bench mark soils under mature rubber plantation and to study their K fixation behavior
4. To evaluate suitable extractant(s) for assessment of plant available K for rubber growing soils
5. To study the effect K-fertilization on growth of rubber plants and to work out K-balance under rubber soils.

1.2 Review of Literature:

Soil is the basic natural resource to support living beings on the planet earth. Maintaining this valuable resource in a state of higher productivity on a sustainable manner is utmost important. Therefore, basic and useful information on soils under rubber has become the imperative need to formulate better management practices. Though rubber cultivation in this region is relatively new, but it gave a tremendous economic support to the
indigenous people. Since the productivity of rubber in this region is low, therefore it is felt to generate some basic information on soil physico-chemical and mineralogical properties with special reference to K status and dynamics under three potential rubber growing states of NE Region viz., Assam, Meghalaya and Tripura.

The relevant literature, pertaining to the present study has been documented in this chapter as under:

1.2.1. Physico-Chemical Properties of soils in NE Region

Surfaces soils (0-30 cm) of the hilly region belong to the textural groups namely, sandy loam or sandy clay loam or loam and contain small amount of concretionary matters (Raychaudhuri et al., 1963; Patgiri, 1985). Most of these soils are also granular blocky in the subsurface horizons (Chakraborty et al., 1980).

Assam soils of Darrang, Kamrup and Nowgong are generally lighter to medium in texture. The southern part of Brahmaputra is usually sandy loam to silty loam to silty clay loam in texture (Anon, 1986). The upland soils are silty clay loam to clay on surface soil and their subsoils are, in general, heavy textured (Patgiri and Baruah, 1997). There is an increase in the fine clay/coarse clay ratio (1:3.5) and fine clay/coarse clay ratio (0.5-0.77) in the lower horizons of the upland profiles, indicating the presence of argillic horizons (Karmakar, 1997). In Brahmaputra valley, soil texture varies from sandy loam to silty to clay loam. Heavy textured soils are pronounced down the profile. In Barak valley, soil texture is varying from sandy loam to silty to clay loam. Heavy textured soils are found down the profile. The bulk density of the soils is in general higher down the profiles which ranged from 1.36-2.1 kg/m³ (Chakraborty et al., 1980). Better developed soils recorded higher bulk density as compared to soils of recently developed (Zaman, 1991; Nayak, 1992).

Soil aggregation is another important soil physical properties which have direct bearings on soil health vis-à-vis plant nutrition. Red and lateritic soils of this region are well aggregated to the tune of 67%. Distribution of total and macro water stable aggregates followed in the order of old alluvial (Inceptisol)> new alluvial (Entisol)> hill/upland soil (Alfisol) (Datta, 1974; Das, 1977; Sharma, 1991). It is also observed that free iron oxides
were the most important aggregating agents in the larger sized aggregates of the red soil (Das, 1977). In addition to that various cations and and aluminium acted on the clay domains to form larger aggregates in Alfisol and ultisol (Patgiri and Das, 1995). In case of Entisol and Inceptisol, organic matter played a major role in soil aggregation.

Water retention capacity of various soils in NE-region could be related to soil texture. Saturated water content of light textured soil ranged from 23-36 %, while in case of medium textured soil, it ranged from 27-45%; for heavy textured soil, it varied from 32-56 % (Baruah and Patgiri, 1997; Zaman, 1991; Nayak, 1992). Moisture content at permanent wilting point (1500 KPa) ranged from 6-13 % in light textured soil, 10-16% in medium textured soils and 14-21% in heavy textured soils. Moisture retention of soils followed the order of : Inceptisol>Alfisol>Ultisol>Entisol (Patgiri et al., 1993). It is also observed that available water capacity, readily available water and water holding capacity were significantly influenced by clay, silt and aggregate size of soils.

Determination of soil pH is an important chemical parameter of soils. The region experienced a high degree of rainfall which causes an enormous loss of essential cations. In a rough estimation, 94% of soils in this region are acidic in reaction. Besides rainfall, the degree of development of soils was also responsible for increasing the the acidity of soils (Ray Chaudhuri et al., 1963; Chakraborty, 1977). Organic carbon content of any soil indicates the state of soil health. Organic matter is the store house of nutrient. Therefore, data on OC content of rubber soils is important for adopting sound management practices. The organic matter content of soils in this region varied from place to place due to nature of vegetation, degree of decomposition, rainfall pattern and cropping intensity. Low temperature and high rainfall retard the rate of decomposition of organic matter, so higher organic carbon is recorded in the temperate zones of Arunachal, higher reaches of Nagaland and Mizoram. However due to widespread shifting cultivation in Tripura and part of Meghalaya organic matter content is low.

In Arunachal Pradesh, 96% of the cultivated soils of the state are acidic and contain high amount of organic matter, medium in available N. Except for certain locations, all the soils are low in available phosphorus. Soils of Subansiri district are low in available K,
whereas Kameng and Siang districts are low to medium in available K status. The remaining
districts are relatively high in available K content (Venkatesh et. al., 2001). DTPA
extractable micronutrient cations (ppm) are found in the range of: Fe: 34-68; Mn: 3.9-25.4;

In Assam, 75% of soils in non-riverine tracts are acidic. Some recent flood plain
areas of south Brahmaputra soil recorded neutral soil pH. Impeded drainage for low lying
soils and incomplete leaching due to impermeable subsurface may be another reason for
neutral pH in some pockets of Assam (Chakraborty, 1977). Organic carbon content ranged
from as low as 0.25 to as high as 4.5% with an average 1.8 % OC content of soils. Total N
content of soils varied from 0.013 to 0.217% in Brahmaputra Valley Zone. Available P in
the soils of plains is low to medium, whereas in the hill districts of Assam viz., NC Hills and
Karbi Anglong, it is rated very low. Available K in Cachar area is medium, while in other
districts it is low. Different forms of K in three major soil orders of Assam clearly indicate
that Entisol has higher amount of non-exchangeable K, whereas Alfisol has higher amount
of exchangeable K (Barua and Nath, 1992). Cation exchange capacity of soils holds its
importance in regard to retention and availability of nutrients to plants. A wide variation of
CEC was reported in hill districts of Assam (Bhattacharya, 1983). The CEC of surface soils
varied from 12-28.8 cmol (p+)kg\(^{-1}\) soil. In general, CEC decreased with depth of profile. OM
contributes significantly towards CEC (Chakraborty and Baruah, 1983). In UBVZ, CEC
varied from 9-14.2 cmol (p+)kg\(^{-1}\) soil. The corresponding values for soils of CBVZ and
LBVZ of Assam are 11-17 and 9-12.8 cmol (p+)kg\(^{-1}\) soil (Moral and Borah,1992). CEC of
Barak valley soils ranged from 7.5-14. cmol (p+)kg\(^{-1}\) soil (Datta, 1974). Exchangeable
cations of these soils are generally low because of leaching losses of soluble bases. In recent
alluvium and low lying soils, exch. Ca\(^{2+}\) and Mg\(^{2+}\) are dominant. In general, exch. Mg\(^{2+}\) is
rich, particularly in surface soils of Assam (Moral and Borah,1992). Exchange behavior of
Ca, Mg, K and NH\(_4\) ions in soils of Assam was carried out to see the level of leaching loss of
these nutrient elements due to rain. Acid soils of Assam generally suffer from deficiency of
nutrients and accumulation of aluminium in the adsorbed phase of soil. Therefore, a high
concentration of Ca ions should be maintained in soil-solution during the active growth
phase of plant. Higher selectivity of K-ions over Al-ions in Ultisol of Assam characterized
by micaceous clay (19.2%) together with smectite (15.7%) and vermiculite (11.5%) (Bhattacharya, 1983; Bora, 1991). Therefore, it is expected that the plants under Ultisol may respond to K-fertilization if split application of higher K-dose is practiced. DTPA-extractable Fe, Mn, Cu and Zn in jute growing soils of Assam ranged from 6-422, 11-86, 78-2.88 and 0.7-20.2 ppm, respectively (Barthakur and Barua, 1992). Zn conc. decreased in the order of: Red lateritic soil (Alfisol/Ultisol)> Old alluvial (Inceptisol)> New alluvial (Entisol) (Bora et al. 1992).

Soils of Manipur are also acidic in reaction with pH varied from 4.25-6.5. OC content of soil ranged from 1.2-4.5% in hill soils and from 0.2-5.2 % in valley soils. The wide difference in OC values in Manipur soils is due to nature of vegetation, intensity of cultivation and transpiration of soil from hill to valley. In general soils of Manipur showed poor plant available P (1.3-23.1 ppm) and medium exchangeable K values (0.127-1.329 cmol (p+)kg-1 soil) (Kailash Kumar and Raychaudhuri, 1995).

Soils of Meghalaya are acidic in reaction. Organic carbon content of soils in high altitude is found higher than lower altitude and it ranged from 0.95-6.41% in Khasi hills and 0.9-5.1% in Garo hills. Available P is higher in Khasi hills (14.3 mg P/kg soil) than that of Garo hill soils (9.5 mg P/kg soil). More than 50% soils under cultivated land in Meghalaya are low in plant available P. Available K ranged from 60-74 ppm in Khasi hills and 50-75.8 ppm in Garo-Hills (Singh et al., 1989). An appraisal of fertility status in valley soils of Meghalaya revealed that 15% soils is deficient in OC, 83% in P and 10% in K (Singh, 1988). DTPA-extractable micronutrients viz. Zn, Cu and Mn in upland soils of Meghalaya ranged from 0.7-3.2, 0.6-3.1 and 2.3-162 ppm respectively. It is reported that 46 % soils of Meghalaya are low in available Zn and Mn (Patiram, 1989).

In Mizoram, the entire soils are acidic in reaction with soil pH ranged from 4.2-5.5. OC and total N of the soils are high which could be attributed to low mineralization of the organic matter. 45% of the soils are deficient in plant available P and available K is medium in status (Singh, 1989; 1999; Lakshminarayan and Patiram, 2004).
The soils of Nagaland are also acidic in reaction, highly weathered and prone to erosion. Essential cations were leached out. However plants showed good response towards NPK addition to soil (Singh et.al., 1999a).

In Tripura majority of the upland soils are low to medium in OC and highly acidic in reaction (pH= 3.77-5.2). Entire soils are low in available P and poor in available K status (Datta and Munnaram, 1993). DTPA extractable Mn, Fe, Cu and Zn are above critical limits whereas B and Mo are reported as low in soils of Tripura (Datta and Munnaram, 1993; Bhattacharya et.al., 2003).

1.2.2. Physico-chemical properties of soils under rubber

1.2.2.1. In traditional rubber soils:

Soils under rubber (Hevea brasiliensis) have developed either under warm humid equatorial monsoon climate with a little or no dry spell or under tropical wet-dry monsoon climate with variable duration of dry season. The major rock types in Kerala and other adjoining rubber areas are charnockite, khondalite, pyroxene etc and the soils are laterites, lateritic and red soils in catenary sequence with laterites (Krishna Kumar, 1989). Physiographic features such as degree of slope, aspect, soil depth, rockiness etc have profound influence on growth and yield of rubber. Soil depth upto a distance of 100 cm has been considered good for optimum plant growth (Puspadas and Karthikakutttyamma, 1980). A slope up to 25% is found favourable for growth of plants. The rubber soils of Kerala varied from clay to sandy loam in texture. Soils of loamy textured soils are best suited for cultivation of rubber (Puspadas and Karthikakutttyamma, 1980). Feeder root development has been found to be affected by soil texture (Philip, 1997; Jessy, 2011). In India, clay content (%) is relatively high but it is moderated by the presence of higher amount sesquioxides (Krishnakumar and Potty, 1992). Rubber is a rain fed crop; therefore its productivity is highly influenced by the moisture retention characteristics of soils. The kaolin-iron oxide aggregates present in high clay in tropical soils tend to hold more moisture at lower tension. The mineralogy of clays present in the soils largely influences the physical and chemical properties of a given soil. Cations such as Ca, Mg, K play an important role in the nutrition of rubber and the dynamics of these minerals is governed by type of clay
minerals. The clay fractions in the soils under rubber in India are dominated by kaolinite. The presence of oxides of iron and aluminum in clay fractions leads to poor release of nutrients. Inconsistent response of rubber to K was observed by many workers (Ananth, 1966; Potty et al., 1976, Karthikakuttyamma et al., 1991; Mongia, et al., 2000). The optimum pH for rubber is reported to be in the range of 4-6.5. CEC of the rubber soils in traditional rubber growing tracts ranged from 3-18.1 c.mol (p+/kg (Puspadas and Karthikakuttyamma, 1980). In soils with a pH less than 5, preponderance of ex-Al is generally observed. In general OM under rubber soils have been found to be rich compared to other agricultural crops. However, OM content is more in the upper horizon in the soil and a decline in the sub-surface horizon was reported (Krishna Kumar and Potty, 1992). A slow pace of oxidation inside the rubber plantation helps to maintain higher OM status and range of 1.11- 3.76 % of OC values has been reported in the soil under rubber in India. C:N ratio was around 10 indicating the stable nature of OM in these soils. Available N content of soils ranged from 116-388 kg/ha (Krishna Kumar, 1989). A wide spread deficiency of available P and K in soils under Hevea had been reported (George, 1997). Available Ca content of soils is in lower range and Magnesium content exhibits varied distribution (Pushpadas et al., 1978, Potty et al., 1980; Joseph et al., 1996; Jessy, 2011).

1.2.2. In North-Eastern region (non-traditional): A general overview of rubber growing soils of Tripura has been presented by Bhattacharya et al., (1996) though it is lacking from nutritional aspects. Major rubber soils of Tripura are Ultisols and Alfisols. These soils are acidic in reaction (pH 4.5-5.5) and OC values of soils are low (0.72-0.93%). Mean available P, K and Mg content of soils (0-30 cm depths) are 0.32, 4.5 and 4.93 mg/100gms. Soils under rubber in Assam are red soils of both laterized and non-laterized nature (Borah and Das, 1972). OC content ranged from 0.9-1.1% and available P,K and Mg in surface soils are 0.27, 5.98 and 8.3 mg/100gms respectively. In soils of Meghalaya, non-laterized red soils are encountered (Bora and Das, 1972). These soils are also acidic in reaction (pH= 4.9-5.80 and OC content ranged from 0.98-1.12% in the surface soils. Rubber soils of Tripura are highly weathered, poor in nutrient status and acidic in reaction (Philip, 1997; Chaudhuri et al., 2001). However rubber responded well to fertilizer application particularly where soils were low in nutrient status (Philip et al., 1992; 1993). Krishnakumar et al., (1990)
examined the status of soils under rubber and adjacent fallow land (once subjected to shifting cultivation) and found that OC status of soils were improved due to rubber cultivation. Mandal et. al. (2011) evaluated the fertility status of soils under rubber in Tripura and reported that major rubber growing soils are low in fertility status. In an isolated attempt, Singh et. al. (1999) investigated physico-chemical properties of some potential rubber growing soils at Nayekgaon (Lower Brahmaputra Valley) and found that soils are low in OC and available P but medium in available K status. Mandal et. al. (2001) showed the beneficial role played by rubber plants on soil health in respect of soil properties and microbial count in comparison to adjacent fallow land. In Mendipather (East-Garo Hill District), Mandal et. al. (2000) reported higher exchangeable Mg under rubber. In an isolated attempt, Satisha et. al. (2000) reported low to medium available N status under rubber soils of Mizoram and low in available Zn. Though rubber grown well in acid soils, but hardly any work has been carried out to see the influence of various acidity components on nutrient availability in these soils. Similarly, many places in NE-region, deficiency in micronutrients particularly Zn and Mn were reported but status of micronutrients under rubber soils did not well documented. In this present study, an attempt has been made to investigate on soil acidity components and distribution of micronutrients (Mn, Fe, Cu, Zn) under rubber soils in NE-region.

1.2.2.3. Nutritional requirement of rubber: Nutritional studies on rubber received low priority as it was treated as forest crop. But with the introduction of high yielding varities and higher productivity, scientists are now working on this aspect (Khan et. al.,2001; Jessy, 2011). However, rubber responds well to NPK fertilizers particularly in those soils which are deficient in nutrients. Mineral composition of rubber is also greatly influenced by soil fertility status (Jones, 1954). The tree immobilize sustained amount of nutrients in trunk, branches and roots and half of the nutrients (728 kg NPK/ha) is locked during the first seven year of plantations. The resultant nutrient depletion leaves the soil less fertile and situation demands judicious fertilization (Kishnakumar and Potty, 1992). Soil fertility status for available P is increase by application of rock phosphste @30kg/ha (from 0.47 to 2.4 mg P/100gms). Similarly addition of K helped in raising the av K status of soil from 3.52 to 5.94 mg/100gms of soil by the application of 20 kg K₂O/ha (Kishnakumar and Potty,
Beneficial effects of P and K on the stability of latex was reported by Philip, (1997). Addition of K in soils of Vietnam has increased the yield of rubber by decreasing the Mg/P ratio. Deficiency of K of plants is reflected by yellowing of the leaves followed by necrosis. On young unbranched trees, the symptoms appear first on the older flushes of leaves and extend to mid-storey in advanced stages of deficiency. In mature tree, leaf size is reduced and symptoms are visible in August (Karthikakutttyamma et. al., 2000). Rubber soils of NE Region are highly degenerated and poor in nutrient content. This necessitates higher input of fertilizers. Experiments with graded doses of P and K indicate that application of higher amount of these nutrients increased their content in soil over time and leaf as well (Philip et. al., 1993). Application of K also influences plant growth during winter and irrigation helps in mitigating the deleterious effect of stress to certain extent (Philip, 1997). Quantity-intensity relationship of soil-K under rubber growing soils of Kerala and Tripura are compared by Rao and Pothen (1996) and found that AReK values for Tripura is higher than Kerala suggesting that long term availability of K in rubber soils of Tripura will be less. Influence of bio-mass yield of rubber seedlings under Assam condition have been evaluated by Singh et.al, (2003) and found that lower requirement of P than N and K during nursery stage. Mandal et.al.( 2001) reported that available NPK content under rubber of 20 years old has been improved considerably in comparison to adjacent fallow land. In the slope land of Mizoram, Satisha et. al. (2000) reported a medium status for av. N and K and poor P status. DTPA extractable Fe, Mn and Cu are found adequate whereas Zn was low.

1.2.3. Soil Acidity in NE States:

In India, 0.93 million km$^2$ of geographical area has acidic reaction and 0.49 million km$^2$ cultivated area has pH in the acidic range. It is well known that soil acidity leads to deficiency of some essential plant nutrients as well as creates elemental toxicity, thereby adversely affecting the crop growth. The optimum congenial pH for nutrient availability to crop remains non-existence in acid soils. Prasad et.al, (1985) reported that more than 80% of soils in NE region are acidic in reaction and majority of the soils exhibited a pH less than 5.6. The extent of soil acidity in NE region is presented in the following Table (1.1).
Table 1.1: Distribution of area (‘000ha) under different soil pH in NE Region.

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Range</th>
<th>AP</th>
<th>Assam</th>
<th>Manipur</th>
<th>Meghalaya</th>
<th>Tripura</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;4.5</td>
<td>Extremely acidic</td>
<td>131</td>
<td>------</td>
<td>482</td>
<td>------</td>
<td>409</td>
</tr>
<tr>
<td>4.5-5.0</td>
<td>Very strongly acidic</td>
<td>1835</td>
<td>2471</td>
<td>1426</td>
<td>1161</td>
<td>514</td>
</tr>
<tr>
<td>5.1-5.5</td>
<td>Strongly acidic</td>
<td>3294</td>
<td>2441</td>
<td>------</td>
<td>298</td>
<td>73</td>
</tr>
<tr>
<td>5.6-6.0</td>
<td>Moderately acidic</td>
<td>1027</td>
<td>2293</td>
<td>--------</td>
<td>419</td>
<td>63</td>
</tr>
<tr>
<td>6.1-6.5</td>
<td>Slightly acidic</td>
<td>849</td>
<td>------</td>
<td>182</td>
<td>364</td>
<td>------</td>
</tr>
</tbody>
</table>


The major contributing factors for producing different kinds of soil acidity are exchangeable hydrogen, exchangeable-, non-exchangeable- and extractable- aluminum and organic matter. Fe and Mn-ions also cause soil acidity due to hydrolysis. Al$^{+3}$ ion is active below pH 4.7 which undergoes hydrolysis to monomeric and polymeric hydroxyl-aluminum complexes thus liberating H$^+$ ions (Mukherjee and Chatterjee, 1942). Acidity of soil could be classified as

i. Active acidity referring to H$^+$ ions in soil solution
ii. Exchange acidity including both H$^+$ ions and Al$^{+3}$
iii. Reserve acidity (acidity due to OM)
iv. Total acidity (including pH dependent acidity, residual acidity and exchangeable acidity)

The acidity of soils in NE Region is developed due to

i. High precipitation
ii. Nature of vegetation cover
iii. Laterization of various degrees in humid and sub-humid zones
iv. Nature of parent material
In general, soils of NE Region have been broadly classified into:

i. Red loam soils
ii. Red and yellow soils
iii. Lateritic soils
iv. Brown hill soils
v. Old and new alluvial soils

As per taxonomic classification, the major soils of NE Region could be brought under the following four orders (Sharma, 1992):

i. Ultisols,
ii. Alfisols
iii. Inceptisols
iv. Entisols

The soil reaction in acid soils extensively distributed in NE States from strongly acidic to mild acidic. In Assam, acid soils have been physiographically distinguished into five types (Mandal et al., 1982). Electrostatically bonded H⁺ ions and Al³⁺ ions comprised 21 and 79% of exchange complex of soil, whereas pH dependent and exchange acidity contributes only 7% towards total acidity (Sharma et al., 1990). The rest of the unaccounted acidity of soil is attributed to hydrolysis of Fe and Mn. In UBVZ of Assam, soil pH ranged from 4.5-5.0, whereas mean exch. H-ions and Al-ions and extractable Al-ions were recorded in the tune of 0.15, 0.70 and 1.8 c.mol (p⁺) /kg soil respectively (Sharma et al., 1990). The pH dependent acidity comprises 60% of the total acidity in these soils. Acidity of soils under Meghalaya were studied in detail by Ram et al., (1987); Singh et al., (1989); Nair and Chamuah (1993). pH, exchangeable and extractable Al(+3) ranged from 4.7-5.4, 0.04 to 3.53 and 0.06 to 5.44 cmol(p⁺)kg⁻¹, respectively. It was also found that exch. Al⁺³ was negatively correlated with soil pH (Prasad et al., 1978). In soils of Manipur, pH ranged from 4.6-6.8 (Rao and Kumar, 1991). Exch. H and extractable Al⁺³ ranged between traces to 8.18 and 0.64-10.80 cmol (p⁺)kg⁻¹, respectively. pH-dependent acidity ranging from 3.22 to 23.22 cmol (p⁺)kg⁻¹ contributed 60.9 to 99.3% of total acidity in soils. In Nagaland, pH varied from 4.3 to 6.6 (Gupta et al., 1983). Ex. H and Al⁺³ were present in substantial amount (Datta and Gupta, 1984a) with mean values 1.08 to 0.43 cmol (p⁺)kg⁻¹ soil whereas
1.2.4. Potassium status in Indian soils

Potassium (K) is one of the three major nutrients after N and P required for the build-up of biomass in plants. It is the seventh most abundant element in earth’s crust and lithosphere contains an average of 1.9% K (Tisdale et. al., 1985). In India, it ranged from as low as 0.35 to 4.65% (Sekhon et.al., 1992). Importance of K in plant growth, development and yield has been known for more than 150 years. Most of the crops take more K than N. About 70-75% of K absorbed is retained by leaves, straw and stover and the remaining is found in harvested portion such as grain, fruits and nuts etc. Soils containing less than 130 kg K2O/ha was categorized as ‘low’, between 130-335 K2O/ha as ‘medium’ and above 335 K2O/ha as ‘high’ (Ghosh and Hasan, 1980). Hasan (2002) observed that out of 371 districts of India, the respective numbers of districts characterized as low, medium and high are 76, 190 and 105, respectively. It is also observed that the low and high category of soil K have decreased in the tune of 0.6 and 6.4%, respectively; while medium category increased by 7%. Therefore, it is understood that K-fertilization to soils in India is scantily applied. Lack of response to applied K may be another reason for poor K-fertilization. To overcome such situations, an intensive research is very much needed for proper management of soil-K keeping in mind the different crop demand and various agro-ecological situations.

1.2.5. Mineralogy of soil potassium: The important K-bearing minerals that are prevalent in soils are dioctahedral micas { (muscovite, glauconitic and illite (hydrous mica)), trioctahedral micas (biotite, phlogopite) and feldspars (sanidine, orthoclase and microcline, Sparks, 2001). Micas are more important than K-feldspars in supplying K to plants (Pal et. al., 1987). However, plant uptake of k is related to the weathering of feldspars and micas in soil environments. Igneous rocks of the Earth’s crust have higher K contents than sedimentary rocks. In sedimentary rocks, clayey shales contain 30 g K/kg. Mineral soils extractable Al+3 ranged from 0.23 to 0.95 cmol (p+)kg⁻¹ soil. Soils of Tripura are also acidic in reaction (Laskar et.al., 1983). About 90% of soils have pH below 5.6. Exch. Al+3 did not exceed 0.5 cmol (p+)kg⁻¹ in 95% of soils, but Fe +3 and H⁺ seemed to have their contribution in soil acidity. Upland soils were having more saturation H⁺ and Al+3 as compared to lowland soils (Datta and Ram, 1993).
generally ranged between 3000 and 1,00,000 kg/ha in the upper 0.2 m of soil profile. Of this total K content, 98% is bound in mineral form and only 2% is in soil solution and exchangeable phase (Sparks, 1987).

Research work in India on the fundamental aspects of K-release and adsorption/fixation reactions in relation to the mineralogy of soils took place since eighties (Pal et al., 1993; Srinivas and Khera, 1994; Subba Rao and Srinivas Rao, 1996; Chandran, et al., 2004). The most important work was to proper identification of the mineral and their quantification. Mineralogy of the alluvial soils of north-west India was studied by Sidhu and Gilkes (1977) and found K-feldspars and micas are the two principal K-bearing minerals present in these soils. K-bearings species present mica minerals are muscovite and biotite in the coarse fractions and illite in the finer fractions of soil. Ghosh and Bhattacharya (1984) studied extensively the mineralogy of soils Bihar, UP, Gujarat and Rajasthan. The red sandy soils contain illite, chlorite, goethite and quartz. The clays of red and yellow soils are dominated by kaolinite with appreciable amounts of illite and a chlorite-like mineral but in parts, the dominant clay mineral is illite, associated with kaolinite and occasionally chlorite, Soils from western and central UP have illite and chlorite as the dominant clay minerals. Soil clays of western UP have smectite as the dominant mineral along with illite, chlorite, kaolinite, feldspars and allophanes. Terai soils contain largely illite and chlorite minerals. Desert soils have illite as the dominant mineral in the clay fractions with appreciable amount of smectite and minor amounts of kaolinite and attapulgite.

The costal alluvial soils have mica as the dominant mineral in association with smectite and kaolinite. Mukhopadhayay and Mukhopadhayay (1985) described the mineralogy of soils of West-bengal, Assam and the North Eastern hills. Most of the soil clays of hill and Terai are dominated by illite and chlorite minerals with smectite and kaolinite in small amounts. Clays in some red soils are dominated by kaolinite and in others by illite. Lateritic soil clays are dominated by kaolinite and halloysite. Pal et al. (1987, 1993, 2001) have discussed the mineralogy and chemistry of soil potassium in vertisol in India. These soils are developed in different parent materials, such as basalt, granite, granite-gneiss, limestone, amphibolites and chlorite schist. In a systematic study of mineralogical composition in the 29 established soil series, Sekhon et al. (1982) reported that all the
alluvial soils with the exception of one each from J&K and Orissa and two from West Bengal, had illite as the dominant mineral in their clay fraction. All black soils had smectite as the dominant clay mineral while quartz was dominant mineral in the silt fraction.

1.2.6. Forms of Soil Potassium

Soil K exists in four forms in soil: water soluble potassium (ws-K), exchangeable-potassium (ex-K), non-exchangeable potassium (nonex-K) and mineral/structural potassium (min-K). The bulk of the total K is in the mineral pool of K (98% of total K). The K-content and its fractions in soil mainly depend on the nature of parent material, mineralogical make up, particle size distribution, degree of weathering and topographical features of the area. All the four forms exists in a dynamic equilibrium with each other. Knowledge of different forms of K in soil together with their distribution and release behavior is of great relevance in assessing the long term availability of K to crops and to formulate a sound fertilizer recommendation.

1.2.6.1. Water Soluble Potassium (ws-K): This form of K is available as water soluble part in soil-solution and readily available to plants for uptake. It is also subjected to leaching loss. Levels of ws-K are generally low, unless recent amendments of K have been made to the soil. It ranges from 1-80 ppm in humid region and 3-156 ppm in arid region. Level of ws-K is greatly influenced by equilibrium and kinetic reaction that occur between the forms of soil-K, the soil moisture content and the concentration of bivalent cations in soil solution (Sparks, 2001). In bench mark soils of India, ws-K ranged from 4-100 mg/kg soil (Srinivasanrao et.al., 2007). Dhaliwal et. al. (2004) observed a positive and significant relation with clay and OC but negative co-relationship with sand and silt of soil size fractions. In red lateritic soils of West Bengal, Patra et.al., (2000) reported that mean ws-K values of soils analyzed from different part of West-Bengal was 0.026 me/100 gms of soil and contributed 1.1 % towards total K. In North-east India, ws-K and ex-K contributed 5-8% towards total plant available K (Singh et. al.,1999; Bhaskar et. al., 2001). It is also significantly correlated with finer fractions of soil and OM. Tiwari et. al (1999) found that water soluble K decreased with depth in Incetisols and Vertisols of MP. Singh et. al. (1989, 1999) found that only ws-K contributed only 0.08 % towards total K of soil.
1.2.6.2. Exchangeable Potassium (ex-K): Ex-K is the portion of the soil-K that is electrostatically bound as an outer sphere complex to the surface of clay minerals and humic substances. It is readily exchanged with other cations and also it is easily available to plants. Generally the ex-K is higher in surface soil than sub-surface soils. Ammonium-acetate is widely used as an extractant for exchangeable K in soils. The soils of Indo-gangetic plain are generally rich in ex-K (Ghosh and Hasan, 1980). A wide variation in ex-K was observed in the soils of Rajasthan, Gujrat and UP (Shaswal and Dutta, 2000a). While analyzing the different forms of K in Alfisol of AP, it was observed that ex-K ranged from 0.08-0.84 cmol (p⁺)kg⁻¹ soil, which also showed a significant relationship with OC and silt fractions of soil (Padmoja and Srinivasraju, 1999). In vertisols, ex-K ranged from 147-212 mg/kg soil (Yadav et.al., 1999). In the benchmark soils of Andaman where rubber plantations are gainfully cultivated, ex-K varied from 0.26-1.33 cmol (p⁺)kg⁻¹ soil (Mongia et.al., 2000). In some bench mark soils of India, ws-K ranged from 19-820 mg/kg soil (Srinivasrao et.al, 2000). In Terai soils of West Bengal, ex-K contributed 0.55% towards total K (Patra et.al., 2000). Gangopadhyay et. al.(2005) while investigating acid soils of Chotonagpur, reported that ex-K varied from 86-172 mg/kg and it is significantly correlated with CEC. In Manipur, ex-K varied from 176-602 mg/kg soils (Singh et.al., 2003).

1.2.6.3. Non-exchangeable Potassium (non-ex K): Non-exch. K is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and integrated clay minerals such as chloritized minerals. This results in a partial collapse of the crystal structure and the K-ions are physically trapped to varying degrees, making K release a slow and diffusion controlled process (Sparks, 1987). This form of K in the soils is in equilibrium with plant available K and not subjected to leaching and thus acts as important reservoir for slowly or potentially available K-pool of soils. Therefore, a knowledge on the status of non-exch. pool of soil-K is very important for planning long term K-fertilisation to any crop. Singh et. al (1999) reported that non-exch. K varied from 4.03 to 10.9 cmol (p⁺)kg⁻¹ in Alfisol of AP and constituted 12.5% of total K. In the laterite soils under West Bengal, non-ex K varied from 0.22-2.78 cmol (p⁺)kg⁻¹ soil (Das et. al., 2000). Mongia (2000) observed that in mangrove & rubber soils of Andaban, non-ex K varied from 1.86-11.23 cmol (p⁺)kg⁻¹ soil. In some bench mark soils of India, non-ex K ranged from 142 to 1936 mg/kg (Rao
Srinivas et al., 2000). In Assam, non-ex K ranged from 51.5 to 2158.5 mg/kg soils (Bhaskor et al., 2001), whereas in Manipur non-ex K varied from 449-1360 mg/kg soil (Singh et al., 2006). The non-ex K is found positively and significantly correlated with silt and clay fractions of soil.

1.2.6.4. Mineral Potassium (min K): This form of K is found in the crystalline structure of primary minerals which are quite resistant to weathering and usually a very small amount to crop. It contributes 90-95% towards total K and is a function of parent material. Common soil-K bearing minerals in the order of availability to plants, are biotite, muscovite, orthoclase and microcline (Sparks, 1987). Sand and silt fractions of soil are the major source of mineral K. Haylock (1956) proposed that step K and constant rate K are a good measure of mineral pool of K that are available to plants. While step K measures the plant utilizable non-ex K, constant rate K gives an idea about the rate of K-release from mineral lattice. Mineral pool of K is most abundant in illitic alluvial soils followed by smectite vertisols, kaolinitic red soil and lateritic soil. In India total K-content of soil varied from 0.35-2.75 with a mean value of 1.72 % (Sekhon, 1999).

1.2.7. Fixation and Release of soil K: K in soils are present mostly in feldspars and micas. Very little feldspar is available in soil clay though mica are usually found in clay fractions of soil. Chemically K is found in soils in four forms viz. water soluble potassium (ws-K), exchangeable-potassium (ex-K), non-exchangeable potassium (nonex-K) and mineral/structural potassium (min-K). Ws –K and ex-K are considered available to plants, whereas the release of non-ex K to other forms is important in determining the K-supplying ability of soils. Two types of K-fixation have been recognized (Sparks, 2001), one occurring in soil when moist and the other taking place when the soil is dried after addition of K. The fixation process is considered to be an exchange of the interlayer cations by K. While feldspars are quite resistant to weathering, whereas biotite and muscovite weather more rapidly. These minerals determine the total amount of K that enters into the soil formation process and into the subsequent interactions between various forms. The study of K-fixation of soils provides valuable information on the reaction rate of added K, thereby helping in formulating strategies for management of K (Rao Srinivasan et al., 2000). In most of the K-fixation study in soils, the result showed that added K transformed into a form which was
unavailable to crop. Studies also showed that a considerable amount crop K-need was mostly met by non-exch. K in absence of optimum K-supply (Rao et. al., 1993; Raosrinivasan et. al., 2006). The beneficial role of fixed K is explained by RaoSrinivasan et. al. (1997, 1998). Soil pH has a profound effect on K-fixation. In general, K-fixation is higher if pH increases but such a change is not proportional with change in pH. Above pH 5.5, K-fixation increases less rapidly than 3-5.5 and virtually no fixation takes place below pH of 2.5 because of preponderance of hydronium ions (Sparks, 2001). Venkatas h and Satyanarayan (1999) reported that K-ions are adsorbed in three positions on the clay colloids namely edge, planar and inter lattice positions. While the former two positions represent exch. K and the K-ions positioned in interlayer represent non-exchangeable K. Therefore, a highly weathered and degraded soil like jhum soils in NE region, more and more adsorption sites in soils will open for adsorption of K-ions. Higher clay content would offer greater surface area and more number of fixation sites and increased K-fixation. Surface soils of smectitic vertisols and vertic subgroups showed greater fixation (26-32%) followed by illitic inceptisols, alfisols, entisols and aridisols (23-29%); whereas, lower fixation values (17-23%) were found for kaolinitic alfisols and inceptisols (Srinivasan et. al., 2000, 2007).

1.2.8. Quantitative-Intensity relationship of soil K: The concentration of K$^+$ in the soil solution, its availability to plants or the release of fixed K is regulated by an index known as equilibrium activity ratio of K \( \text{AREK} = \frac{aK}{(aCa+ aMg)^{1/2}} \). The quantity factor (ΔK) and the intensity factor (AREK) as proposed by Beckett gives a better picture of K supplying power of a given soil than so called available potassium. The Q/I relation of soil K has been applied for characterizing the availability of soil K with physico-chemical characteristics of soils by many workers (Patiram and Prasad, 1981; Gupta et. al., 1983; Roy and Kumar, 1993; Rao and Pothen, 1995; Basumatery, 1999; Sparks, 2001; Gupta et. al., 2006; Subeha and Sood, 2007). The various Q/I parameters have been correlated with different properties of soils. It is observed that K availability status in terms of distribution of various forms of K and AREK (equilibrium activity ratio), \( K_L \) (labile K) and \( PBcK \) (buffering capacity of soil) was greatly influenced by both the mineralogy and various soil properties. In general, soils with high clay content showed high PBcK values. Basumatery (1999) found the existence of a strong correlation between the clay minerals and PBcK in some soils of Assam. Rao
and Pothen (1995) compared the Q/I parameters of two potential rubber growing soils and predicted that potential supplying power of Kerala soils were higher than Tripura. Gupta et. al., (2006) reported that equilibrium activity ratio was associated with texture and clay mineralogy and it was highest for sand to loam kaolinite red soils followed by loamy sand to silty clay illitic alluvial clay loam to silty clay loam smectite black soils. While working with acid soils of Nagaland, Gupta et. al., (1983) found that soil pH and other soil parameter played a key role on AReK values. Different forms of soil potassium and Q/I parameters hold a dynamic equilibrium and showed significant relationships among themselves (Subeha and Sood, 2007). The usefulness of activity ratio of soil K as a satisfactory indication of K-fertility of soil was validated by all the above workers.

1.2.9. Dynamics of soil Potassium : Although K-deficiency is not widespread as that of N but many workers (Ghosh and Hasan,1980 ; Hasan, 2002 ) reported that soil which are initially rich in available K become deficient due to heavy removal of K by harvested crop or locked up in plant part in perennial crop, like rubber. It is also reported that when exch. K is not readily replenished, crops start drawing K from the non-ex. pool of K resulting in a depletion of reserve K . The contribution of non-exchangeable K to crop-K requirement was found substantial (about 90%) under K-stress condition (Prassanakumari, 2010). In Meghalaya, K-release from 30 well representative soils under upland was assessed by exhaustive cropping and found that ex-K decreased by 13.2 to 80 % after five cycles of cropping. While the decline in ex-K was accounted by the first two cycles but the reduction in non-ex K was attributed to last three crop cycle (Ram and Prasad, 1983). In Assam, Nath and Dey (1982) observed that K intensity decreased progressively under exhaustive cropping and estimated uptake of non-ex K in the tune of 0.9-2.74 cmol (p)kg$^{-1}$ soil. Subbarao et. al. (1986) also evaluated parameters influencing K availability in seven representative soils of Andhra Pradesh and found that K extracted by 1N HNO$_3$ had a positive relationship with K-uptake by plants. Similar observation was also reported by Sachadev and Khera (1980), Srinivasrao et. al .(1994), Raosrinivasan et al., (2006) and in the light of above, it is felt that soils which contain fairly large amount of micaceous material, values of non-exchangeable pool of K should be duly taken into consideration
while prescribing K-fertilization rate for any given crop. This is particularly important for perennial crops.

1.2.10. Rubber and Potassium: According to recent studies, majority of rubber growing soils of traditional rubber growing area in India viz., Kerala, Kanyakumari district of Tamilnadu and South-western part of Karnataka, are red ferruginous soil of the order Ultisols /Alfisols and were found to be low to medium in available K status (NBSS&LUP, 1999). In rubber plantation, the harvested crop was hydrocarbon, therefore, it was assumed that mineral demand for rubber should be small (Von Uexkull, 1985). Later on, increase in yield potential, depletion of K from soil matrix and better understanding of the plant nutrients, have made K-fertilisation as established management practises (Pushpadas, 1974; Pushparajah, 1977; Punnoose et.al., 1978). Potassium nutrition for mature rubber in Kerala has been studied in detail by Joseph et. al., (1990, 1996, 1998), Khan et. al. (2001) They found that application of 66.6 kg K/ha is necessary for getting optimum yield. They also worked out the critical values for available K for rubber in Kerala as 6.6 mg/100g of soil (132.6 kg K/ha) and for leaf, the critical value was 1.24-1.35%. Dynamics of K in rubber soils was studied by Joseph et.al. (2000) and found that exch. K was improved in the surface soil (0-39 cm) due to application of K-fertilizer. However, all the other pools of soil-K were higher in sub-surface soil (30-60cm) indicating a downward movement of applied K. Similar observation was reported by Prasannakumari et.al. (2004)

1.2.11. Potassium status in soils under certain annual crops in India and some neighboring countries: The combination of rising population and increasing food demand has placed tremendous pressure on the land resource of Bangladesh. The population of Bangladeshis expected to reach 250 million by 2025. Expansion of cultivated land is hardly realistic in this densely populated country, so crop intensification is the main vehicle for increasing food output (Cassman et al., 2003). Rice is the staple food for millions of people in Bangladesh. During the last 30 years of the 20th century, rice cropping was intensified in Bangladesh along with other Asian countries. This intensification in combination with unbalanced fertilization has resulted in depletion of K in soils over large areas in China (Jiyun et al., 1999), India (Hasan, 2002) and other countries in Southeast Asia (Dobermann et. al., 1996). Improved farming practices and use of high yielding crop varieties, along with
fertilizer N application, increased crop production in China significantly in the 1960’s (Jiyun et al., 1999). At the same time, soils were becoming more deficient in plant nutrients, except N. Phosphorus became the next most deficient nutrient and yield limiting factor. Hence, P fertilizer application became important for further increases in crop yield. Increased crop production together with increased use of N and P fertilizers resulted in K-deficiency first in southern China in early 1970 and extended to northern China (Hoa, 2003). Unbalanced fertilizer application, which has more N than P and K, became very common during 1950 to 1980 in China. China attempted to use a more balanced fertilizer beginning in the late 1980’s, but N was still applied at a rate proportionally higher than P and K. Fertilizer use in China today is still not properly balanced. Inadequate K application along with removal of straw from Chinese rice fields has caused increased K-deficiency and significant responses of crop yield to K-fertilizer application (Jiyun et al., 1999). In a similar fashion, Bangladeshi farmers use a large amount of rice straw as animal feed and for domestic fuel thus removing a substantial amount of soil K every year. They also use unbalanced fertilizer formulations, so K deficiency may become widespread throughout the country. Dobermann et al. (1998) reported that coarse-textured and highly weathered soils (Oxisols, Ultisols) typically show K deficiency in South and Southeast Asia. They also noted that most of the soils of the great alluvial floodplains were generally regarded as high in extractable K. It was also thought that K addition through indigenous sources such as irrigation and flood water would make K a rare limiting factor in irrigated rice systems (Kawaguchi and Kyuma, 1977; De Datta and Mikkelsen, 1985; Bajwa, 1994). Potassium inputs in irrigation water may be more than 30 kg ha$^{-1}$ year$^{-1}$ in rice-wheat areas, where ground water is used (Pasricha, 2002). However, widespread K-deficiency has been observed on fine textured soils, which includes alluvial, illitic soils in India (Tiwari et al., 1985), vermiculitic clay soils of central Luzon, Philippines (Oberthuer et al., 1995), and lowland rice soils of Java (Scri Adiningisih et al., 1991). Potassium nutrition has become a very important factor in increasing crop production in Asia. Substantial applications of properly balanced fertilizer replenish the soil K pool which is being removed by intensive cropping systems (Bijay-Singh et al., 2004). Most soils in the Indo-Gangetic Plains are historically deficient in N. Potassium deficiency is emerging in some Indo-Gangetic Plains soils due to the micaceous nature of these soils (Ladha et al., 2002). Several chemical and biochemical changes occur in rice soils during the flooding
season, which influences the transformation and availability of nutrients (Ponnamperuma, 1972, 1985; Cao and Hu, 1995). Submerged soils are regarded as high in exchangeable $K^+$ and $Na^+$ compared to upland soils, especially in the cultivated layer (Bijay-Singh et al., 2004). Flooded soils are different in the control of acidity and alkalinity due to the partial pressure of $CO_2$ buffering carbonates in the flood water. Thus, the changes in pH and redox influence the chemical equilibria and availability of various nutrients to plants. Most chemical changes are reversed during draining (Bijay-Singh et al., 2004). Soil analysis is an important tool when evaluating soil nutrient status, and results are often used as the basis for fertilizer recommendations. This practice is justified in cases where a correlation between soil test results and crop response to fertilizer applications has been established. Generally, crop responses to a fertilizer nutrient should be lower, the higher the content of the nutrient in a soil. A small proportion of the $K$ required by plants comes from direct contact through root interception, whereas the largest fraction of the $K$ needed by plants has to be transported from soil to roots via diffusion. Transport happens mainly in soil solution, the liquid phase of the soil by mass flow (with the water moving to the plant roots) and diffusion along a concentration gradient that is created by the absorbing roots. In the immediate proximity of roots, soil solution is rapidly exhausted of nutrients due to uptake by plants. A continuous supply of $K$ to growing plants is only insured when the rate of $K$ release to soil solution and transport to roots keeps pace with the $K$ uptake. The rate and quantity of the release of non-exch. to exch. and soluble $K^+$ primarily depend on the level of $K^+$ in the soil solution, the type and amount of clay minerals present (Martin and Sparks, 1985; McLean, 1978), the degree of exposure of edges of clay minerals to the soil solution, and the position of non-exch. $K^+$ with respect to outer edges. Soils therefore vary in releasing non-exch. $K^+$ rapidly enough to meet the needs of crop production and may be slow enough to restrict the yield (Bijay-Singh et al., 2004). Plant available $K$ depends on the size of the available $K$ pool in soil and transport mechanisms of $K$ from soil solution to the root zone and from the root zone into plant roots (Barber, 1984). Many plant factors (e.g. variety, root system, antagonistic and synergistic mechanisms in ion uptake) and soil factors (pH, organic materials) also affect plant availability of $K$ (Hoa, 2003). Dry lowland soils containing vermiculite, illite, or other 2:1 layer clay minerals may result in increased $K^+$ fixation and reduced solution concentration during flooding, so that rice depends on non-exch. reserves
for K⁺ uptake. Regmi (1994) observed in a long-term experiment with a rice–wheat rotation in the Tarai plain of southern Nepal that the proportion of added K⁺ that was fixed, ranged from 46 to 56% in a wet/dry equilibration, and fixation was linear with addition rates of up to 25 mM K kg⁻¹ soil. Scientists have a rather poor understanding of the behavior of K in soils subjected to cycles of flooding. Iron is an important and abundant constituent and may be present as Fe (II) (reduced form) or Fe(III) (oxidized form). Iron oxidation state within crystal structures of soil minerals is an important factor in understanding K behavior (Stuki and Shen, 1993). Soils containing appreciable quantities of mica (especially biotite), illite, vermiculite and Fe-containing smectite, structural Fe may undergo reduction during flooding and oxidation during periods of drainage. It has been reported that Fe reduction from Fe³⁺ to Fe²⁺ plays a significant role in fixing K in smectite clay minerals (Stucki and Shen, 1993). Weathering of primary minerals is regarded as an oxidative process. In this process, Fe²⁺ converts to Fe³⁺ and soil minerals become expansive types which release various nutrients including K (Stuki and Shen, 1993). But according to Lear and Stucki (1989), surface charge density increases upon Fe reduction and increases the ability of the minerals to fix K⁺ and other interlayer cations (Chen et al., 1987; Khaled and Stucki, 1991). Stucki and Huo (1996) observed a strong direct correlation between Fe(II) and K⁺ fixation in smectite minerals. But this correlation was weaker and inverse in the case of illite minerals, probably due to the change in electrostatic force between K and structural OH groups. Stucki and Shen (1993) proposed a hypothesis on the behavior of illite in releasing K during Fe reduction. The hypothesis was that Fe (II) is added to the octahedral sheet of illite during reduction; the dipole moment of structural OH groups becomes more canted to the c-axis and therefore creates a weaker attractive bond or stronger repulsive force between clay layer and the interlayer K ions, resulting in release of K to soil solution. The behavior of clay minerals greatly depends on the type of clay mineral that is present (Stucki and Shen 1993). According to their observation, if illite dominates, reduction may enhance availability of K, whereas smectite domination may results in K fixation during reducing conditions. If these minerals are precisely balanced, no net change in K availability would occur, because the amount that one releases would be fixed by the other.