Nitrogen is one of the most important and essential nutrients for the growth of both young and mature tea. Knowledge on availability of N in soil, derived from native and applied fertilizer sources, and its uptake by tea is essential for judicious use of nitrogenous fertilizer for maximum utilisation by tea.

In the past, particularly in the last two decades, a large number of experiments were conducted to study different aspects of N nutrition of tea both under controlled and field conditions mainly by conventional methods; however, limited work was done by N-15 tracer technique under controlled simulated conditions.

It was clearly demonstrated that tea responds to N application depending on agro-climatic conditions, type of planting materials and other cultural practices (Cooper, 1946; Wight, 1951; Gokhale, 1956; Barua and Dutta, 1959; Barua, 1962; Akhundove, 1966; Fernando et al., 1969; Sharma, 1971; Ranganathan, 1975; Marwaha et al., 1977; Krishnapillai, 1981). Rahman (1977) published a comprehensive review on different aspects of N nutrition in tea under North East Indian conditions. It was stated that response to N by tea decreased gradually with growing of age and was limited to 90-135 kg N/ha/yr. Rahman and Sharma (1979) reviewed the results obtained from agronomic trials on N manuring in tea carried out in different tea growing countries. Response to N by tea was found to be inevitable but the optimum response varied widely between different tea growing countries due to wide range of variation on agro-climatic conditions and other factors like shade, age, plucking, nutrients status, planting materials, spacing, pruning cycle, N sources, methods and time of nitrogenous fertilizer application, etc. However, literature under present area of investigation is quite meagre.
An attempt has been made to review the pertinent literature available which has bearing on the present area of study. Where relevant literature was not available on specific subject, literature concerning more or less similar studies on other crops and soils have been reviewed to have a basic understanding of the subject. The literature has been reviewed under the following broad heads:

2.1. Response to nitrogen application
2.2. Transformation and availability of nitrogen in soil
2.3. Use efficiency of applied nitrogen

2.1 Response to nitrogen application

2.1.1. Productivity of tea in relation to nitrogen application:

Analysis of a large number of tea shoot samples at Tocklai, Jorhat showed that percentage of the total N present in the leaf was proportional to the quantity of N applied to the soil with a maximum limit of 180 kg N/ha/yr which was correlated with enhanced yield of plucked shoot. However, the percentage of N diminished with the age and type of tea plant and at different months of the year. For mature tea in N.E. India, supply of available N was found to be very important for crop production. In 15 successive years of manuring of the unshaded tea with ammonium sulphate showed a linear response of increase in yield to N application up to a level of 135 kg N/ha/yr (Barua and Dutta, 1959; Barua and Deb, 1960; Barua, 1962; Dutta and Sharma, 1962). In China, Lin (1967) also observed the significant relationship between leaf N concentration and annual yield of tea leaf.

In Sri Lanka, Bhavanandan and Manipura (1969) found a highly significant response in clonal tea to N application up to 300 lb/acre annually. From the regional trials conducted in the Assam Valley, Cachar and the Dooars, Sharma (1971) reported that there was no gain from ammonium sulphate application beyond 110-112 kg N/ha/yr level applied in single and split doses at different pruning cycles except in one experiment in Darjeeling where significant response was obtained at 200 kg N/ha which, however, did not show any difference
between single and split methods of application.

Data from 14 trials in Sri Lanka showed that the application of 120-160 lb N/acre was capable of supporting high yields (4000-5000 lb/acre). Return from N application above 240 lb/acre was unlikely to exceed yield of 2 lb made tea per lb N (Wettasinghe, 1972-73).

Rahman (1975) observed from different field experiments in Tocklai that yield of tea, initially at all levels of N fertilization viz. 0, 45, 90 & 180 kg/ha/yr increased with increasing N levels and later the response maxima declined with the increasing age of bush.

In a field trial during 1967-71 with China hybrid tea to which N was applied at a rate of 0, 90, 180 & 270 kg/ha/yr as a split dressing in February and July, Marwaha et al. (1977) at Palampur, Himachal Pradesh, found that the total yield and the yield of first flush increased with increasing N up to the maximum level. Raja (1979) found in a N fertilization trial on mature tea at an elevation of 565 m above sea level at Mauritius that the highest yield over a 3-year cycle was obtained at 375 kg N/ha/yr level. However, Rikhter and Lyashko (1979) in Georgia (U.S.S.R.) found in a 3-year field trials on 26-year old tea plantation at N levels of 300, 450 or 600 kg/ha/yr, the highest average yield (5031 kg/ha) in plots which received the lowest N rate. Field trial in Malawi (East Africa) showed that increased N application from 45 to 315 kg N/ha as ammonium sulphate or urea progressively decreased the dry matter content of tea shoots. There was also distinct variation among the type of clonal materials in terms of response to applied N (Coughley, 1981).

It was observed at Tocklai that reduction or cessation of N from the optimum rate of 90-135 kg/ha/yr depressed the yield of tea. Any reduction of N from optimum rate of 90 kg/ha/yr depressed the crop and application of N thereafter at 135 kg/ha could not boost up the yield up to the original level. It was also reported that N response varies at different zones of N.E. India under adequate supply of phosphorus and potassium (Jain et al., 1981; Jain, 1981).

Combined analyses of four years (1979-82) yield data in one of the field trials at Tocklai showed that yield of plucked shoot
increased with increasing N levels upto 300 kg N/ha/yr though no significant difference between 100 and 200 kg N/ha/yr was observed. There was progressive increasing trend in yield with N upto 300 kg/ha/yr in the form of urea for 6 years with basal application of 150 kg K2O/ha/yr and 50 kg P2O5/ha/yr. A substantial gain in soil N was recorded due to continuous application of N fertilizer for 5 years. Relationships between total N content in soil and the shoot N with the corresponding yield were positive and consistent for the years (Ann. Sci. Rep., TRA, 1984-85). Kobaliya et al. (1987) observed that increasing N application at 100 or 200 kg/ha in a single dose or at 300 kg/ha in a single or split doses in the form of ammonium nitrate increased shoot production of tea in Georgia. Ranganathan and Natesan (1987) reported economic return of N application upto a maximum of 390 kg/ha under split manuring practices.

2.1.2. Efficiency of different nitrogen sources on productivity of tea:

The results of 29 experiments during 1920-46 at Tocklai and other field experiments showed that ammonium sulphate was most efficient N source as compared to other N sources, e.g. oil cake, calcium cyanamide and sodium nitrate. There was little difference among other inorganic nitrogenous fertilizers. The efficiency of the organic manures was much lower as compared to nitrogenous inorganic fertilizers. Organic sources of N, e.g. cattle manure was found only half as efficient as ammonium sulphate (Cooper, 1946; Gokhale, 1956; Chanda, 1959). Dutta and Sharma (1962) reviewed the field experiments of Tocklai upto 1961 and concluded that ammonium sulphate was the best source of N amongst oil cake, ammonium sulphate, calcium nitrate, urea, ammonium chloride, ammonium sulphate nitrate. Ammonium nitrate was found equally efficient but it had the disadvantages of being hygroscopic and explosive.

Later studies, however, revealed that urea was equally efficient in most of the experiments. Wood et al. (1964) found no significant difference of yield between ammonium sulphate and urea treated plots and also beneficial effect on increasing yield was not found in between single or split application.
Bhavanandan and Sunderalingam (1971) found no significant difference among three N forms tested during first 7 years of field experiments in Sri Lanka, but in the last 2 years, ammonium sulphate was found to be superior to urea at 336 kg N/ha/yr; the reverse was true at 181 kg N/ha/yr and both were superior to calcium ammonium nitrate (CAN). All the N forms reduced the soil pH, but ammonium sulphate reduced the most. The urease activity in ammonium sulphate treated soil was less by about 40% than urea treated soil.

In different regional trials under North East Indian conditions, no significant difference in yield between urea and ammonium sulphate treated plots was observed and it was therefore concluded that urea as a cheaper N fertilizer could effectively substitute ammonium sulphate for N manuring, but to supplement sulphur into the soil, application of urea for two years followed by one year of ammonium sulphate by rotation was considered to be more judicious (Sharma, 1971; Rahman, 1977). A study on the effect of 4 forms of nitrogenous fertilizers applied at 5 different rates on the growth and uptake of N, P, K and Ca by young tea grown in sand culture in Sri Lanka showed that with increased N supply growth improved up to a point beyond which it was not utilized further. Ammonium sulphate was exceptional in reducing growth with the increasing rate and also resulted ammonium toxicity in leaf at higher rates. The contents of N, P, K and Ca in the leaves were increased with increased supply of N by both ammonium nitrate and urea. Lower rates of N increased root starch which was almost completely exhausted at the highest level of N. Urea was found satisfactory form of N for young tea plants which resulted in increased root starch at all levels of N supply (Krishnapillai and Pethiyagoda, 1980; Krishnapillai, 1981).

15 field trials in tea seedlings conducted for 8 years in up-country tea districts of Sri Lanka with ammonium sulphate, urea and CAN as sources of N showed that in 13 trials yields were not affected by the form of N fertilizers, but in 2 trials highest yield was noticed by ammonium sulphate application. Response to N varied widely from 269 to 403 kg N/ha/yr when K was restricted to 50 to 67 kg K₂O/ha/yr levels only (Sandanam et al., 1980). Pot trials conducted...
at Kusuka, on Mambilla plateau in Nigeria, tea cuttings (clone 143) in plastic buckets treated with 150 kg N/ha in the form of urea and ammonium sulphate, showed that after 180 days, urea treated plants were taller and showed a significant increase in the rate of formation of foliage leaves and the growth of lateral shoots (Obatolu, 1985).

Ranganathan et al. (1987) observed in 3 long-term experiments at different elevations of South India that ammonium sulphate gave better yield than CAN or urea.

Sharangiya (1987) worked out the cost-benefit ratio of N applied at 100, 150, 200, 300 or 400 kg/ha to tea as ammonium nitrate, ammonium sulphate or urea in Georgia and found that all the treatments increased green leaf yields significantly compared with control and were profitable. The 150 kg/ha application rate of all N sources was the highest, it produced the maximum returns from the additional yield where urea was the most profitable N source.

2.1.3. Interactions of different parameters and applied nitrogen on productivity of tea:

From field trials at Tocklai, Jorhat, Wight (1951) observed that N was less effective with increased shade, and the shade alone (without N) produced yield which was equal to that obtained from an appreciable dose of N, as half of the tea did not respond to excess N under shade. Othieno (1983) found in a field trial in Kenya that with annual N rate increased from 0 to 270 kg N/ha, average yield was highest (1719 kg made tea/ha) under unshaded condition, lowest (1136 kg made tea/ha) under natural shade of Grevillea robusta and intermediate (1653 kg made tea/ha) under artificial shade of wirenetting of bamboo slats at a height of 2.5 m. Kulasegaram and Kathiravetpillai (1983) observed in young potted tea plants in a glass house in Sri Lanka that at any level of water supply or N, less accumulation of N was in shaded plants and more nutrients were accumulated in actively growing shoots of unshaded plants.

Tiwari (1978) reported that response to N in terms of yield varied with the length of pruning cycle and pruning types. Response
to 120 kg N/ha by 7-15 years old tea bush was better than that of 60 year old bush in respect to yield. Krishnapillai (1983) studied the pruning operations in relation to uptake and utilization of N by young tea in Sri Lanka and observed that uptake of N declined immediately after pruning, the decline was related to reduced leaf area due to pruning. In bushes where some leaves were retained, N uptake continued at a reduced rate and increased as the new leaves started emerging. In completely defoliated plants, N uptake ceased and the plants failed to recover.

In a field trial carried out by Marwaha (1976) in Palampur, Himachal Pradesh under rainfed conditions with 0 to 300 kg N/ha levels applied to tea (jats), the optimum N rate was found to be 232 + 17.5 kg/ha in the year of high rainfall (1973) and 195 + 15 kg/ha in the year of normal rainfall (1974). Yield at all N rates were nearly twice as high in 1973 as in 1974 respectively which showed the response of N is highly dependent on rainfall pattern. Salardini (1978) observed large differences in green leaf yield due to differences in precipitation in two locations of Northern Iran. In both the locations, irrigation (420 mm) during the 6-month growing period was more effective in increasing yield than the rate of fertilizer alone. Ammonium sulphate produced 15-20% higher yield than urea. Application of S together with urea reduced the difference in yield.

Response of tea to N application is also highly influenced by the presence of major plant nutrients in soil particularly P and K. Jayaraman (1962) reported need of P and K for maximum benefit of N for tea in South India. Akhundov (1966) observed in U.S.S.R. that application of N along with P and K greatly increased green leaf yield of tea. N application also increased total N and caffeine-N in tea leaf. In another pot experiment in which N-15 labelled fertilizer was applied to a 1-year-old plant, the utilisation of soil N was increased, but utilisation of fertilizer N to produce caffeine was less when P and K were applied along with N than with P alone. Sen (1967) emphasized the beneficial effect of P and K for increased productivity of tea by N application in N.E. India. However, in long-term field
trials with clonal tea in Sri Lanka, Fernando et al. (1969) found mean yield of 3195 lb of made tea/acre/yr maintained over a period of 6 years with 75 lb N/acre/yr level. Increasing K level beyond 50 lb K₂O/acre/yr did not increase in the first 4 years though in two subsequent years yield increased by 5% with increasing K level from 50 to 150 lb K₂O/acre/yr and further increase from 100 to 150 lb K₂O/acre/yr decreased the yield. Willson and Freeman (1970) observed a balance between N and basic nutrients like K, Ca and Mg, variations of which often related to yield on the basis of analysis of important components of 3rd leaf of tea in Sri Lanka. Results suggested that yield responses were likely to follow with the rate of fertilizer application if the ratio of N to basic nutrients in soil was maintained at definite range.

Inadequate N and imbalanced fertilizer application altered bush physiology adversely, affecting recovery after pruning in field trials in South India. Fertilizer levels at 110 kg N, 70 kg P₂O₅ and 140 K₂O/ha/yr were the most economical rates of application. High nutrients status were required by tea plants in the year of pruning. Part of these requirements were retained by pruning litter (Ranganathan, 1973; 1975). Willson (1975) reported that beneficial effect of K fertilizer leading to an improved return from N fertilizer occurred when soil pH was 4.9 or lower in a series of experiments.

Studies on tea latosols in South India revealed that as C.E.C. of the soil is low and having lack of fixation sites for K, application of N and K in split doses, four times or more in a year, produced significant crop increase as compared to single or two applications. High levels of N upto 420 kg/ha/yr were felt necessary to support the large crops produced in South Indian growing condition. The efficiency of urea was enhanced by high levels of K (Ram, 1980). Kemmler (1985) reviewed the fertilizer use in Sri Lanka and South India with special reference to N and K nutrition in relation to yield of tea. Both yield and N;P & K rates in South India were more than twice as high as in Sri Lanka, and the N:K₂O ratio was 1:1 as compared to a ratio of about 1:0.5 in Sri Lanka. The average yield for the year 1980 (3-year average) of South India and Sri Lanka were
1748 and 832 kg/ha/yr and corresponding N:K\textsubscript{2}O ratio's were 1:1 and 1:0.52 respectively. It was concluded that for increasing yields the balance between N and K application in soil was more important. At high level of N application in the form of urea, increase of K rate could prove useful for drought tolerance, recovery after pruning, yield improvement and yield stabilization.

In field experiments at Tocklai on N and K interaction for two complete pruning cycles, it was observed that for every level of N (50, 100 & 150 kg/ha/yr) addition of 100 kg K\textsubscript{2}O/ha/yr resulted in significant increase in yield in all the years. It was also observed that the plots which received 200 kg N/ha/yr along with 200 kg K\textsubscript{2}O/ha/yr showed highest yield and highest level of available K\textsubscript{2}O in soil as compared to other treatments received upto 300 kg/ha/yr of N and K. Increasing trend in soil available potash and yield was also observed when N and K\textsubscript{2}O were applied in 1:1 ratio upto 200 kg N and K\textsubscript{2}O/ha/yr. Another field experiment on clone TV 2 with 180 kg N/ha along with 0, 45, 90 and 180 kg K\textsubscript{2}O/ha showed that root starch increased with increased dose of K. A gradual decline of the starch level in the root of tea bush received 100, 200 and 300 kg N/ha with 100 kg K\textsubscript{2}O/ha was recorded in clones TV 1 and TV 9 (Ann. Sci. Rep., TRA, 1984-85; 85-86; 86-87).

In Malawi (Central Africa) results of 6- or 7-year old clones and natural clones (15-19 yr old) in response to N at 0-250 kg/ha/yr and polyclonal seedlings in response to N at 75-375 kg/ha/yr, showed that in immature clones yield response to N application was almost linear. The highest average yield amounted to 3691 kg/ha/yr with N at 250 kg/ha/yr. In mature clones and the polyclonal seedlings, average yields also increased with the N levels but the rate of increase diminished above 275 kg N/ha/yr level of application. The highest average yield amounted to 5259 kg/ha (Malenga, 1987).

Sanikidze and Glonti (1988) observed the wide variations in response of yield to N applications in different regions. Long-term records from tea plantations in 4 agro-climatic regions in Western Georgia, manured with various rates of N as ammonium sulphate, showed that highest yield in the Makharadze region was noticed at 200 kg N/ha,
2.1.4. Productivity of other crops in relation to nitrogen application:

Nitrogen plays key role in increasing vegetative growth of other crops whether annuals or perennials.

Garaudeaux and Chevalier (1975) observed that higher rates of N along with adequate K increased the yield of some crops (potato, wheat, sugarbeet and forage crops) and improved the quality of crops whose yields it did not increase.

The increasing levels of nitrate, urea or ammonium N enriched with N-15 in the range 150-550 kg/ha on fibre flax yield showed that yield decreased at high rate of N in the more mobile nitrate form and urea. Fibre content was least affected by ammonium N. N concentration in plants rose with increasing N application. The proportion of N taken up from the fertilizer was directly dependent on its mobility and was greatest for the nitrate form (Lahola, 1976).

Application of N alone increased yield and leaf N content of Nabali olives. Application of K gave additional increase in yield and leaf N content. Yield was positively correlated at a few locations (Klein and Lavee, 1977).

Increasing N levels increased average leaf weight from 1.97 to 2.27 t/ha as well as total alkaloids and total N of 6 tobacco CV. grown under 89.6, 112.0, 134.4 or 156.8 kg N/ha levels in field trials. In another experiment it was observed that yield of tobacco was increased with increased N rate from 0 to 50 kg/ha (Aycock and Me Kee, 1979; Ryding, 1981). Shawky et al. (1979) found that yield of a navel orange orchard, received 600, 1200 or 1800 g N/tree annually in 2, 3 or 4 applications, increased with N rate and number of treatments and the recommended N treatment of 1200 g N in 4 applications increased the yield by 48% over the usual recommendation at 600 g N in 3 replications. Increasing rates of N from 0 to 120 kg/ha increased sunflower seed yields from 0.66 to 1.26 t/ha (Chauhan, 1979).
Raghavaiah and Singh (1980) carried out trials with the sugarcane CVS Co. 1148, B.0.54 and Co. 1336 received N at 0, 50, 100, 150 or 200 kg/ha and observed that cane yield was highest (98.5 t/ha) in CV. Co. 1148 with N at 150 kg/ha and in B.0.54 (87.3 t/ha) and Co. 1336 (118 t/ha) with N at 100 kg/ha.

Perl et al. (1982) reported that application of N fertilizer, e.g. urea, ammonium sulphate, and ammonium nitrate for consecutive 10 years reduced pH of soil which was improved by liming and increased yields of certain field crops.

N at a rate of 50 or 100 kg/ha as urea, ammonium sulphate or ammonium sulphate nitrate in split doses to Papaver somniferam showed that the maximum mean rate of N absorption occurred during early plant growth (upto 81 days after sowing), earlier (35-50 days after sowing) in plants receiving urea or ammonium sulphate at 50 kg N/ha (Prasad and Tungnawat, 1983).

Increasing rate of N application as urea significantly increased leaf N content of golden delicious trees on M. 2 rootstocks of apple variety (Bojie et al., 1985). Applications of N, P & K at different rates and combinations to cocoa crop showed that the highest total 3-year cocoa yield (2573 g/tree) was obtained from trees receiving 72 kg N + 48 kg P\textsubscript{2}O\textsubscript{5} + 24 kg K\textsubscript{2}O/ha (Calvo, 1985).

Orphanos et al. (1986) reported that increasing N rate increased yield of orange tree of 8 years old linearly in the 1st half. However, in last 4 years, N in excess of 90 kg/ha slightly reduced yield.

Kanwar et al. (1987) observed in long-term trials with N, P & K applied to young Dashehari mango trees in differing rates and combinations that tree growth was not significantly affected by the differences in fertilizer treatments and the lowest N rate (100 g N/tree per year of tree age) was sufficient for good tree growth and cropping. Papp et al. (1987) found that increasing N rate reduced fruit size & weight and raised fruit N content of apple tree (M.9 root stocks) when N was applied at a rate of 0 to 800 kg/ha for 5 years (1981-85) as ammonium nitrate.
Sud and Bhutani (1988) studied new castle tree (apricot) in a field with 3 levels of N (200, 400, 600 g/tree) and 4 modes of application (soil application alone or supplemented with 1-3 urea sprays, 1% urea per tree) and found that N at 400 g/tree supplemented with 2 foliar sprays of urea, resulted optimum vegetative growth, large fruits, high yields and improved tree N status.

2.2. **Transformation and availability of nitrogen in soil**

The availability of N in arable soil depends on various factors out of which soil is the major factor. Transformation of organic N to inorganic available N in general can be shown as follows:

Proteins and near proteins + Enzymic digestion $\rightarrow$

Complex amino compounds + CO$_2$ + Other products + E

(E = Energy)

This process of transforming soil organic compounds into amino compounds by enzymic digestion is known as aminization. The amino compounds transform further to NH$_4^+$ forms by enzymic process known as ammonification as shown below:

$$R-\text{NH}_2 + \text{HOH} \xrightarrow{\text{Enzyme hydrolysis}} R-\text{OH} + \text{NH}_3 + E$$

Amino combination

$$2\text{NH}_3 + \text{H}_2\text{CO}_3 \rightarrow (\text{NH}_4)_2 \text{CO}_3 \leftrightarrow 2\text{NH}_4^+ + \text{CO}_3^-$$

(R = Large organic complexes with which NH$_2$ is associated in amino compounds)

The NH$_4^+$ forms finally undergo enzymic oxidation known as nitrification resulting NO$_3^-$ compounds through intermediate formation of NO$_2^-$ compounds. The nitrifying organisms, *nitrosomonas*, convert NH$_4^+$ compounds to NO$_2^-$ compounds which are further converted by
organisms, nitrobacter, to NO₃⁻ compounds as shown in general steps:

\[
2\text{NH}_4^+ + 3\text{O}_2 \xrightarrow{\text{Enzymic oxidation}} 2\text{NO}_2^- + 2\text{H}_2\text{O} + 4\text{H}^+ + \text{E}
\]

\[
2\text{NO}_2^- + \text{O}_2 \xrightarrow{\text{Enzymic oxidation}} 2\text{NO}_3^- + \text{E}
\]

(Buckman and Brady, 1960)

Sen et al. (1988) showed schematically the transformation of N fertilizers particularly urea and ammonium sulphate in tea growing acid soil as follows:

- Urea (added to soil)
  - Urea molecular loss in heavy rainfall within 1-2 days
  - Urea hydrolysis by urease enzyme (less in acid soil and also inhibited by polyphenols)

- Ammonium sulphate (added to soil)
  - Ammonium carbonate
  - Dissociation
  - Sulphuric acid
  - Ammonium ions (+ ve charge)
  - Carbonic acid
  - Water and Carbon dioxide
  - Nitric acid
  - Taken up by plant
  - Adsorbed by clay colloids (- ve charge)
  - Nitrite (unstable in acid soil)
  - Nitrate
  - Loss due to leaching and denitrification
A large number of experiments were conducted to study the transformation and availability of fertilizer N in soil; however, work on tea growing acid soil is very limited.

2.2.1. **Transformation and availability of nitrogen in soil under controlled condition:**

Non-isotopic laboratory incubation study of N releasing characteristics in tea growing sandy loam soil with N levels of 0, 60, 120, & 180 kg/ha as ammonium sulphate under aerobic and anaerobic conditions at Tocklai, showed no significant variation of NO$_3$-N released from soil under different N levels for a period of 5 months under aerobic condition. The release of N from soil was in the form of ammonia in anaerobic condition. Peak mineralisation of fertilizer or native N took place within 2 weeks under aerobic condition and release of NO$_3$-N at that highest rate continued up to 8th or 10th weeks under low and high N levels respectively which steadily declined and was negligible at the end of 3, 4 and 4½ months at all N levels. The releasing of NH$_4$-N pattern under anaerobic condition revealed that mineralisation rate reached at highest level within 2-3 weeks, and at 2 to 2½ months time release of NH$_4$-N became negligible (Ann. Sci. Rep., TRA, 1972-73).

Similarly in another pot experiment study by nonisotopic method at Tocklai with N levels of 0, 100 & 200 kg/ha in the form of urea and ammonium sulphate, it was observed that gaseous loss, although insignificant, was almost double in case of urea as compared to ammonium sulphate irrespective of N levels. Highest leaching losses took place one month after application of urea irrespective of N levels. Total quantities of loss increased with increase of N levels and mostly in the form of NO$_3$-N. Loss of NH$_4$-N through leaching was found to be insignificant (Ann. Sci. Rep., TRA, 1975-76).

Sandanam et al. (1978) studied the rate of nitrification in acid red yellow podzolic tea soil in Sri Lanka received ammonium sulphate and urea. Irrespective of N sources nitrification was appreciable in the soil represented a good cover of high yielding clonal tea than the soil collected from a bare plot adjoining the tea field.
Golden et al. (1981) conducted two long-term trials in tea growing soils in Sri Lanka where in (1) a factorial combination of 3 levels of N, P & K with ammonium sulphate as only source of N were used and in (2) the different N-sources, urea and ammonium sulphate, were compared at three levels. Results showed the faster initial nitrification in urea treated soils than that of ammonium sulphate treated soil. Laboratory incubation data did not follow the same trend as that of field nitrification rate.

Wickremasinghe et al. (1981) observed that conversion of urea to ammonium in four acid tea soils of Sri Lanka was rapid and almost complete within less than 4 days and the hydrolysis rate was independent of soil moisture. Urea hydrolysis rate was inversely related to the soil polyphenol concentration derived from pruning litter and had no relationship with the organic carbon content or the soil texture.

A number of experiments were also conducted to study transformations of fertilizer N under controlled conditions in soil besides tea growing soil. With various N fertilizers, viz. ammonium sulphate, ammonium chloride, urea and CAN, Misra and Singh (1969) observed that volatilization losses varied between 4.96 and 36.78% of the added N in black, alluvial, red and saline soils of Uttar Pradesh. Maximum losses occurred from urea (except for the saline soil from which losses were greater for ammonium sulphate) and from the black soil; losses were lowest from the red soil.

Incubation studies on urea-N transformation and simultaneous changes in different forms of soil N in five soils of India showed that concentration of NH$_4^-$-N increased to maximum during three days of incubation in all soils received urea. In soils not received urea, the NH$_4^-$-N concentration either decreased or no change was noted. The increase in NH$_4^-$-N was not in proportion to the amount of urea hydrolysed or changes in organic-N content. The differential NH$_4^-$-N accumulation in different soils was attributed to the losses of N to atmosphere, conversion of organic-N to NH$_4^-$-, NO$_2^-$- and NO$_3^-$-N, and biological immobilization of hydrolysed urea-N. Concentration of NO$_3^-$-N was generally higher in urea treated than untreated soils and also was higher in light textured than heavy textured soil. Changes
in NO₃-N concentration with longer incubation period were more in light textured than heavy textured soil which were attributed to their conversion to other forms of N and losses. In most of the soils, a major portion of the total loss of applied N occurred immediately after addition and within one day of incubation. N losses were generally more in light textured than heavy textured soils. Soils containing high N content lost more N on quantity basis than soils low in native N content. It was reported that from 57 to 82 percent of added 200 ppm N as urea was hydrolysed within one day of incubation in laboratory experiment. Maximum NH₄-N was found in soil during the first 3 days of incubation, and later the concentration of NH₄-N was dependent on the soil types (Shankhyan and Shukla, 1976; 1978).

Christianson et al. (1979) studied transformation of urea enriched with 52.4% N-15 which was added to Orthic Black soil of pH 6.1, analysis of the soil samples indicated gradual nitrification of the urea with production of NO₂⁻-N and NO₃⁻-N. Analysis of the gas following incubation with containers closed indicated that the vessels remained partially aerobic and 20% of the added urea was denitrified. About 60% of the loss was N₂O and N₂ derived entirely from the enriched NO₂⁻. The remaining 40% of the loss was N₂, in which one half of the N originated from urea and the other half from soil N.

In laboratory study on transformation of urea and ammonium sulphate in Ladwa sandy loam and Balsamand sand, Mahendra Singh and Yadav (1981) observed that at least 1 week in the sandy loam and 2 weeks in the sandy soil were required for complete hydrolysis of urea. There was no nitrification up to 3 days in the sandy loam and up to 7 days in the sandy soil, but immobilization of NO₃⁻-N occurred during these initial periods.

Studies on plant availability of residual fertilizer N for the next crop in chernozen and pseudogley soils, where release of N was examined after incubation at 3 and 30°C, showed that the use of increased doses of N fertilizer (ammonium nitrate) led to an increased release of residual fertilizer N into plant available
forms. The release of this N fraction was 5-10 times faster in comparison with the remaining soil N (Jakovljevic et al., 1983).

Skiba and Wain Wright (1984) found that urea was hydrolysed in all sand and soil samples with complete hydrolysis occurring after 6 and 3 weeks in the rhizosphere sand and sanddune soil compared with only 4 days in the fertile loam. One third of the added urea was still present in the uncolonized sand samples 6 weeks after the beginning of the incubation period. Urea hydrolysis was broadly correlated with urease activity. The liberated NH$_4^+$ was oxidized to NO$_3^-$ in all samples. Urea stimulated the release of N from native organic matter in the two soils, but not in the sands, presumably owing to the low organic matter content of the latter.

In a laboratory incubation study with N-15 labelled ammonium sulphate and urea, Okereke and Meints (1985) observed that approximately 1, 5 and 10% of the applied ammonium sulphate-N was immobilized in cropped sandy loam soil, forest sandy loam mineral soil and organic soil, respectively, after 12 hr of incubation where N immobilization was measured by the detection of N-15 in the soil organic N fractions. After the same length of incubation, 2 to 3% and 9 to 10% of the applied urea-N were immobilized in cropped sandy loam soil and organic soil, respectively. A readily available carbon source appeared to be limiting immobilization. When soils were enriched with 4 mg glucose/g soil, immobilization of added urea-N increased from 2 to 18% in the cropped soil and from 20 to 25% in the organic soil.

A greenhouse experiment with Lolium multiflorum showed that fertilizer N-15 was incorporated into all fractions of the soil organic matter (Shabaev et al., 1985). The total amount of fertilizer N fixed in organic form increased with increasing amount of fertilizer applied. Immobilized fertilizer N was associated mainly with the humin fraction (41-56%) and also with the humic and fulvic acid fractions (22-25% and 23-34% respectively).

In a study of N mineralization (300 days incubation at 20°C) in 16 cultivated soils in relation to their physico-chemical characteristics, Dolphin (1986) observed that mineralizable N was closely correlated with total N.
Triboi (1987) found that the immobilization of mineral N, applied as N-15 labelled fertilizers (360 kg N/ha) in grass land was very significant (40-50%) in the first year. The N recovered in soil after 2 years was 40% of the N fertilizer applied; 19% was in free organic matter and 21% in organo-mineral fractions. The immobilization of N was greater in the surface soil (68% in the first 5 cm depth).

2.2.2. Transformation and availability of nitrogen under field conditions:

Cooper (1946) concluded from field data received from the trials conducted at different regions of N.E. India that no soil however old contained less than about 0.05% N in the surface and was enough to produce 40,000 lb of made tea before it was all used. Organic matter content of soil enhanced immobilization of fertilizer N. Gokhale (1960) reported from field experimental results, conducted at Tocklai, that N status of tea soil showed a progressive deterioration under continuous cropping and manuring and resulted in lower N status at the end of 26 years of continuous N application than the unmanured plots. Soil N data showed that the shade and the application of P and K under shade were highly beneficial to improve soil N status.

It was calculated that under normal cropping conditions, organic matter decomposed at the rate of 1% per annum and the release of soil N was confined to one-twentieth of the total loss of soil organic matter over a 40 years cropping period. It was also observed that by restoring the pruning litters alone for successive 3 years, organic matter content of top 30 cm soil was considerably increased and consequently the yield increased by an average of 16% per year (Dey, 1966; 1969).

Dey et al. (1966) reported that during the month of April, about 20% of urea-N, applied by broadcast and mixed with 2.5 cm top soil having soil temperature of 20-26°C at 5 cm depth and soil moisture content of 14-17%, was lost due to volatilization within one month. The maximum loss took place during the first 7 days amounting to more than half of the total loss for the month and thereafter the
rate of loss was practically negligible.

Krishnapillai and Pethiyagoda (1980) found in tea soil in Sri Lanka that increase of pH increased nitrification of nitrogenous fertilizers e.g. ammonium sulphate, urea and CAN. Nitrification from urea treated soil was faster than other two forms of N. Nitrification was unaffected between 20° and 30°C temperature while it was greatly inhibited at 40°C. Nitrification progressively increased at the rate of 20 to 40% at 10% (w/w) moisture level and delayed at 50% moisture (w/w). Top soil showed faster nitrification rate than sub-soil indicating that essential organic nutrients and/or NO₃⁻N producing organisms were more in the top soil than in the sub-soil.

Wickremasinghe et al. (1985) studied hydrolysis, leaching and nitrification of urea and ammonium sulphate fertilizers in tea soils under simulated field conditions in Sri Lanka. Unhydrolysed urea was not detected in the first 10 cm or any other soil depth indicating the leaching of unhydrolysed urea into deeper soil layers beyond root zone of tea did not occur. Despite the high soil acidity, urea and ammonium sulphate were nitrified equally rapidly and NO₃⁻N in the soil solution reached a peak concentration between 25-30 days after the addition of fertilizer N.

Coonjan (1986) observed that when various levels of N, P & K fertilizers were applied in tea soils under field condition in Mauritius, increasing rates of applied N decreased soil pH but did not affect soil N levels.

Extensive work was also done to study transformation of fertilizer N in soil other than tea growing soil. Kolenbrander (1969) observed considerable loss of fertilizer N as NO₃⁻N in drain water from cropped arable land and grass land. NO₃⁻N content of 1-2 mg/l was found in drain water from grass land and 4-10 mg/l in arable land. Very little N was lost from soil with clay content >35%. On sandy soils (0-10% clay), about 60 kg N/ha was lost annually and about 20% of the applied N was leached out of the profile.

Tahir and Mian (1971) found in field experiments with ammonium sulphate, urea and ammonium nitrate applied to a sandy loam
that NO$_3^-\text{-N}$ moved to 30 inch depth with 3 inch of irrigation water and to 42 inch depth with increased irrigation. NH$_4^-\text{-N}$ moved to 18 inch depth with the maximum irrigation rate (24 inch). Ammonium nitrate gave the highest recovery of NO$_3^-\text{-N}$ followed by urea and ammonium sulphate whereas ammonium sulphate gave the highest recovery of NH$_4^-\text{-N}$ followed by urea and ammonium nitrate. Lateral movement for N was 24 and 16 inch for NO$_3^-\text{-N}$ and NH$_4^-\text{-N}$ respectively.

Power (1972) found that upto 200 kg/ha out of 540 kg/ha of fertilizer N in mixed prairic grasses was immobilized during the first year in grass roots, soil organic matter and fixed NH$_4^-\text{-N}$. Immobilization and leaching increased to about 350 kg fertilizer N after 3-4 years and remained constant thereafter.

Allen et al. (1973) studied the chemical distribution of the residual N in fields previously amended with N-15 labelled urea and oxamide and observed that 25 to 40% of the fertilizer N was present in soil (0-25 cm) after the first growing season, about half of which still remained after 5 years. Essentially all of the fertilizer derived N (97%) occurred in organic combination and only a small fraction (3%) was accounted for inorganic forms chiefly as fixed NH$_4^+$. The findings suggested that fertilizer N once incorporated into soil organic matter, was converted to increasingly stable form with time and not readily mineralized or subject to leaching.

In a study on microplot with N-15 labelled urea at rate of 100 kg N/ha in the form of small pellets or tablets to Pinus sylvestris, forest flower, Nommik (1973) found that volatilization losses for 13, 31 & 39 days exposure were 24.9%, 26.6% & 33.6% for pellets and 12.1%, 15.2% & 47.8% for tablets respectively.

Martinez (1976) reported from a lysimeter experiment with Lolium perenne that downward movement of N-15 labelled NO$_3^-\text{-N}$ took place in three stages: a first rapid stage immediately after fertilizer application, which accounted for 30-40% of the total fertilizer in the percolation water; a second stage at a rate of about 1.7 to 2.8 mm/cm depth and a third stage at 65 days after N-15 application and which was related to plant growth.
Koren'kov et al. (1976) observed that repeated application of N fertilizers promoted the mineralization of previously immobilized fertilizer N.

In a 4-year field experiment with wheat and barley, Diez and Sommer (1979) observed that mineral N content in soil after fertilizer application was often greater than the calculated content and that "Priming effect" was attributed to stimulation of certain microorganisms by the applied N. Priming occurred when the N content of the soil was particularly low but did not last long. The temporary sharp decrease in mineral N soon after application of N was due to much more binding in organic form in the soil crumb than to uptake by plants or leaching.

Results of small and micro-plot experiments with N-15 labelled and unlabelled urea, ammonium nitrate and calcium nitrate showed that absolute gaseous losses of fertilizer N increased with an increase in fertilizer rate and were highest with NO$_3$-form. Gaseous losses of fertilizer N were 19-27% & 8-12% under plants (oats and barley) and 58-80% & 11-28% under fallow in the first and second year respectively (Makarov and Geraschanko, 1981).

N-15 study of plant uptake, incubation-extraction and acid hydrolysis on field soil samples which had varying properties of residual fertilizer N-15 as clay-fixed ammonium and organic N, showed that availability of N-15 to plants was positively correlated with percent of N-15 as organic N. It was also observed that fertilizer N once incorporated into organic forms was much less available to plants than fertilizer N in the form of clay-fixed NH$_4$-N (Preston, 1982).

Lysimeter experiments (1966-74) with oats and barley involving N-15 labelled ammonium sulphate showed that the uptake of fertilizer N by crops and the amount of residual N accumulating in the 0-20 cm soil layer were greater in a clay loam soil than in a sandy loam soil. The total N content in soils after 9 years decreased. The average annual loss of N amounted to 15.9 and 18.1 mg/kg for a clay loam soil and a sandy loam soil respectively (Varyushkina and Nikiforova, 1982).
In an experiment with N-15 labelled ammonium sulphate applied at a rate of 100 kg N/ha to sugar beet on 47 sites in Austria, it was observed that the amount of available soil N was generally high and consequently N fertilizer uptake was low and when the amount of available soil N was moderate, yields and N fertilizer utilization were significantly increased by band placement of N at seeding time (Broeshart, 1983).

Rankov and Ivanova (1983) studied the effect of application of ammonium sulphate, ammonium nitrate, sodium nitrate and urea at rates of 0, 120, 240, 360, 480 & 600 kg N/ha on the mineralization of organic N under controlled temperature and moisture conditions in different type of soils and observed that N application (with basal P & K) increased the number of ammonifying bacteria and the intensity of ammonification. Ammonium sulphate, ammonium nitrate & urea had a more pronounced and lasting effect on ammonification than sodium nitrate. The effect of N fertilizers was greater in soils of lighter texture and with relatively low humus content.

Foster et al. (1985) found in a study with N-15 labelled urea applied at 200 kg N/ha to a 45-year old natural jackpine forest that after 3 months of fertilization, 25% of the added N had been immobilized in the forest floor and was recovered as organic N.

Haunold (1986) observed that on gently sloping areas denitrification losses were, on average, 10-30% of the fertilizer applied, but in certain cases could exceed 40%. Leaching losses were 10% of the fertilizer applied, but could amount to 60%.

Theodorou (1986) observed that N fertilizer applied as ammonium sulphate depleted rapidly from 0-40 cm zone of sandy soils in 1, 2- and 15-yr old Pinus radiata plantations. Within 1 month of application, 50% to 35% of the applied N moved from the 0-40 cm zone and after 7 month, all of the applied N had left this zone. Nitification in these soils was low and N movement was mainly in the \( \text{NH}_4^+ \) form. Both field and laboratory experiments showed that the presence of litter and humus layer in older plantations helped in retaining the applied N in the rooting zone.
With a combination of mathematical analyses and computer simulation, using parameters readily measured in N-15 field experiment, Barraclough and Smith (1987) observed that mineralization/immobilization was lower at high fertilizer rate.

2.3. **Use efficiency of applied nitrogen**

2.3.1. **Uptake of fertilizer nitrogen vis-a-vis major nitrogen components**

In U.S.S.R., application of fertilizer N at 90-108 kg N/ha in the form of ammonium sulphate along with P and K increased the concentrations of protein, free amino acids, tannin and extract in the dry leaf of tea (Guselnov et al., 1966).

Kularatne and Bhavanandan (1971) studied preferential uptake of fertilizer N as NH$_4$-N and/or NO$_3$-N form by young tea plants in Sri Lanka using sand culture technique. N-15 labelled ammonium sulphate as the source of N was given to one set of plants and to other set of plants, N-15 labelled KNO$_3$ was given as the source of N. At the end of the experiment, nitrogenous components of the plants were fractionated into NH$_4$-, amide-, NO$_3$-, caffeine-, amino acid- and protein-N. The results indicated that total N and fertilizer N assimilated by the plants treated with NH$_4$-N was twice as much as that assimilated by NO$_3$-N treated plants. Pethiyagoda and Krishnapillai (1971) carried out similar study in Sri Lanka to evaluate the relative performance of tea plants in sand culture supplied with their N exclusively in the NO$_3$-N or NH$_4$-N forms or the combinations of the two forms in different concentrations. After 14 months, nitrogenous constituents in leaf samples were categorised into NH$_4$-, NO$_3$-, amino acid-, amide- and total-N. It was observed that plant which received N as 60, 70 or 80% in the NO$_3$-N form were superior in growth while those received 0, 10 and 20% of NO$_3$-N performed poorly. The other treatments showed intermediate results. Wickremasinghe et al. (1984) extended the similar study to mature tea under simulated field conditions in Sri Lanka with N-15 labelled fertilizer in the form of urea and ammonium sulphate and observed that N-15 atom excess and percent N derived from fertilizer (% Ndff) in the flush and 3rd leaf
were directly related to the availability of fertilizer N in the soil while the mature leaf continued to draw steadily and store fertilizer N and serve as a sink under both N sources. The effect of urea and ammonium sulphate fertilizers on crop growth and new shoot production was quite similar and prominent after 6 weeks of fertilizer application. Both were equally efficient sources of fertilizer N for mature tea.

It was observed that fertilizer N had substantial contribution towards different nitrogenous compounds for growth. Peterburgskie and Kilasoniya (1971) found that the optimum rate of 100 kg N/ha/yr along with P and K in tea plantations, upto 5 years old, increased the contents of caffeine and N in the flush. Tsanava and Tsanava (1972) revealed from a 4-year field experiment that protein-N in tea flush increased with increased application of ammonium sulphate. The non-protein-N concentration was maximum at 300 kg N/ha level. Of the non-protein-N, free amino acids concentrations varied mostly from month to month and with N supply. N at 400-500 kg/ha decreased the free amino acids particularly essential amino acids. Selvendran and Selvendran (1974) reported that uptake of N in tea began within 2 days of fertilizer application and was indicated by a marked increase in the amino acid content of the xylem sap. A reciprocal relationship was shown between the changes in the starch of roots and amino acids in the sap after few days from the date of fertilizer application.

It was found that total carbohydrate content in the roots and stems of tea declined at 50 days after collar pruning. However, total N in the roots increased upto 20 days after pruning and then declined owing to translocation to new shoots. N applied immediately after pruning was absorbed within and most of it remained in the roots until the growth of new shoot (Hoshina et al., 1979). It was observed in Japan that theanine and arginine contents in tea roots increased with increasing levels of NH₄-N and subsequently glutamine was synthesized and translocated to the aerial parts. High levels of theanine, glutamine and arginine (amino acids) were noticed in the plants during the winter month (dormant phase) which declined in the
spring after the new growth and remained low until the end of the summer. NH$_4^-$N application in summer increased root theanine content. High rate of ammonium sulphate (80 kg N/ha) applied from late spring until early summer increased the amino acid content of new shoots plucked in late June and early August (Takeo, 1979; 1979a).

Watanabe and Ishigaki (1982) studied young tea plants grown on pots and received N rate from 0 to 300 mg/plant & consequent second application at 300 mg/plant in the spring. It was observed that growth response of new shoots in the spring was greater under autumn applied N, and the response to a spring application was greater when it followed an autumn application. Total N, free amino acid and amide contents of new shoots were much higher in plants received N in the spring than autumn application. The increase of amino acids and amides were associated with the enhanced theanine and arginine contents in the plants.

Chemical analyses of tea shoot and root of Tocklai released clones TV 1, TV 8 and TV 9 showed no increase in the uptake of leaf N with increasing fertilizer N from 100 to 300 kg/ha/yr level; however, total N, soluble N, NO$_3^-$-N and amide-N (particularly theanine) increased in the feeder roots with increasing N levels. Application of increased dose of K in Tingamira jat reduced amide-N and theanine concentration in feeder roots with concomitant increase in the yield of tea (Ann. Sci. Rep., TRA, 1979-80; '81-82; Dev. Choudhury et al., 1983). It was also observed that carbohydrate in plucked shoot of TV 1 decreased with increasing N uptake. Similarly at higher N level (300 kg N/ha/yr) other N-fractions like protein-N, caffeine-N and amino acid-N decreased as compared to N at 200 kg/ha/yr level which indicated the inhibitory effect of enzymes involved in biosynthesis of these compounds. More interesting was that polyphenols, responsible for tea quality, remained unaltered. Both yield and tea quality were found to be favourable at 200 kg N/ha/yr (Srivastava et al., 1982).

Application of increased dose of K favoured protein synthesis in clone TV 2 and enhanced activity of nitrate reductase, the principal enzyme responsible for assimilation of N from soil which

Investigation with N-15 labelled urea-N on foliar application to shoots of 1-year-old tea plants 3 times during 5 days, Karasuyama et al. (1985) reported that 1 day after urea-N application, a large part of applied-N was retained in the form of N compounds soluble in 80% ethanol solution in the leaves and after 7 days the percentage of applied-N in the insoluble fraction increased suggesting that the applied-N was utilized for protein synthesis. Only a few percent of applied N was translocated to the roots, 70% of which was found in insoluble fraction suggesting that N derived from foliar application of urea was assimilated into glutamine first, and then transferred to other amino acids as well as to caffeine and protein.

Owuor et al. (1987) observed that high rates of nitrogenous fertilizers increased the caffeine content as well as those compounds imparting inferior or superior flavour contents in tea in Kenya. The minimum value of theaflavins was produced at about 235 kg N/ha/yr level.

Adequate literature however, is available for uptake of N and its metabolism in other crops. Higher N supply increased yield and incorporation of N-15 labelled NO$_3^-$-N in young sunflower plants within 24 hr. Application of K increased the uptake of NO$_3^-$-N and favoured considerably the conversion of NO$_3^-$-N into amino acid-N. K also promoted the transfer of N from the soluble fraction into protein fraction. The percentage of N-15 in the protein fraction was much higher under abundant K supply along with increasing N rates (Mengel and Koch, 1972-73).

It is suggested that movement of nitrogenous compounds from roots to shoots takes place mainly through xylem. Under aerobic condition N is available in soil as NO$_3^-$ which is directly absorbed by most of the higher plants and is translocated unchanged or may be first reduced and metabolised in the roots to a range of amino acids.
and amides. \( \text{NH}_4^- \) is metabolised rapidly to other nitrogenous compounds before translocation. In some plant species, e.g. cocklebar, almost all N is translocated as \( \text{NO}_3^- \) or in others, e.g. apple; little or no \( \text{NO}_3^- \) is ever detected in the sap. In most plants, some \( \text{NO}_3^- \) and amino acid synthesis occur in the roots. After reduction of \( \text{NO}_3^- \), the N is incorporated into a limited range of amino acids and amides (Hill - Cottingham and Lloyd-Jones, 1977).

According to Hageman (1977) urea is readily converted to \( \text{NO}_3^- \) in the soil and \( \text{NO}_3^- \) is then predominant form of soil N available to plants as soil organisms rapidly convert ammonical forms of N to \( \text{NO}_3^- \). Although plants are able to utilize ammonical organic forms of N, \( \text{NO}_3^- \) is more favourable form than \( \text{NH}_4^- \) for plant growth. The concept of pathway of \( \text{NO}_3^- \) assimilation into amino acids was suggested as follows:

\[
\text{NO}_3^- \quad \overset{1}{\rightarrow} \quad \text{NO}_2^- \quad \overset{2}{\rightarrow} \quad \text{NH}_4^+ \quad \overset{3}{\rightarrow} \quad \text{Glutamate} \quad \overset{4}{\rightarrow} \quad \text{Glutamate} \quad \overset{5}{\rightarrow} \quad \text{oxoacids} \quad \overset{6}{\rightarrow} \quad \text{amino acids} \quad \overset{7}{\rightarrow} \quad \text{Protein}
\]

1, nitrate reductase (NR)
2, nitrite reductase
3, glutamine synthetase (GS)
4, glutamine : 2-oxoglutarate amino transferase (GOGAT)
5, transaminase

It was indicated that GS/GOGAT system is the major route for incorporation of \( \text{NH}_4^+ \) into amino acids and the previously accepted route via glutamate dehydrogenase has only secondary role (presence of excess \( \text{NH}_3 \), if any) in higher plants.
Michael et al. (1970) investigated the fate of absorbed N in potato plants and found that after the uptake within 7-10 days, greater part of absorbed NO₃⁻-N was transported into the upper parts of the plant than the absorbed NH₄⁺-N. N from absorbed NH₄⁺ was found in higher proportions in the protein fractions of the plants than N from the absorbed NO₃⁻. NH₄⁻-N was therefore incorporated at a greater rate into the N metabolism than NO₃⁻-N. NO₃⁻ was translocated from the roots relatively faster than NH₄⁺, but the incorporation of NO₃⁻ into the roots was slower than with NH₄⁺. Hewitt (1970) also observed in similar type of work that NO₃⁻ was usually superior to NH₄⁺ for growth; however, merits of the two sources varied with plant species and other circumstances. Hewitt et al. (1976) further pointed out that NO₃⁻ is the principal source of N for most higher plants growing under normal field conditions in fertile soils. Nitrification of ammonia is usually rapid when aeration, moisture content, and soil temperature are favourable and are compatible with good growth of plants. The principal forms of inorganic N in plants are NO₃⁻, NO₂⁻ and NH₄⁺. Concentrations of all three may vary considerably, but in general, NO₂⁻ accumulation is rare and concentrations of NH₄⁺ are relatively low (between 0.004 and 0.01 M). NO₃⁻ concentrations vary enormously and sometimes unpredictably relative to the other two forms. Season, climate, plant age or development stage, nutritional status, management and species are all factors that affect NO₃⁻ content.

In an analysis pertaining to N nutrition of cereals particularly wheat grown under field conditions, Abrol and Nair (1976) stressed that soil NO₃⁻ is assimilated via a series of enzymatic steps into amino acids which is subsequently incorporated into proteins and nitrate reductase (NR) is the key enzyme for NO₃⁻ assimilation and rate limiting step. The organic and inorganic N in soil undergoes nitrification and is ultimately converted into NO₃⁻ and most of the higher plants take up N from the soil in this form. Some plants like rice, however, take up N as NH₄⁺. NO₃⁻ once taken up by the plants is reduced to NO₂⁻ by NR and is converted through a series of steps to ammonia. Ammonia once formed is metabolised immediately to form initially glutamine and then glutamic acid.
latter is the key amino acid in the biosynthesis of other amino acids which are subsequently incorporated into proteins. These proteins were involved in various metabolic functions of growing tissues.

Kato (1980) investigated the assimilation of N-15 labelled NH$_4^+$ and NO$_3^-$ in 3-year-old satsuma trees and found that in fine roots, absorbed NH$_4^+$ was actively incorporated into glutamine and then into glutamic acid and aspargine. When feeding NO$_3^-$, however, glutamic acid and aspargine were actively synthesized, but glutamine synthesis was low compared with that in NH$_4^+$ feeding.

2.3.2. Utilisation of fertilizer nitrogen:

Literature available pertaining to utilisation of fertilizer N by tea is quite meagre as compared to other crops. Attempts have been made to review some relevant literature to depict the range of utilisation in general.

Field experiment with N-15 labelled ammonium sulphate applied to mature tea bushes in U.S.S.R. which had previously received no N in one plot and continuously supplied with N in another plot, showed that uptake of N-15 was very rapid in the former. Most of the N in the flush was fertilizer N and even at the end of the vegetative period, 50% of total N was from the fertilizer N sources (Tsanava et al., 1969).

At Tocklai, non-isotopic studies by pot culture technique in 18 months old TV 1 plants grown on sandy loam soil where N was added at a rate of 0, 100 and 200 kg/ha (single and split) as urea along with basal P, K, Zn and Mg, showed that N use efficiency from urea-N was about 30% at all levels and methods of application (Ann. Sci. Rep., TRA, 1977-78).

Westerman and Kurtz (1972) studied the residual effects of N-15 labelled urea and oxamide applied in the previous year at a rate of 0, 56, 112 and 168 kg N/ha to "Sudax S X 11" sorghum sudan grass hybrid grown and harvested three times during the second cropping season. Fertilizer N removed in plant tops during the second year of cropping contained 13.8% of the residual fertilizer N in the
soil at the end of the first season and was equal to 46% of that applied originally in the fertilizers. At the end of the second cropping season, 22 & 26% of the initial application of N in urea and oxamide, respectively, remained in the soil. No evidence was found for loss of residual N by leaching, denitrification, or other processes during the second cropping season. Since removals of N in crops were considerably greater than the additions in fertilizers, it was hypothesized that nearly all inorganic fertilizer N was taken out of the soil and most of the residual fertilizer N was in relatively stable organic forms. The same authors (1973) also studied the "priming effect" on the uptake of soil N by the addition of N-15 labelled fertilizer in the same type of experiment. Addition of N fertilizer increased the uptake of soil N by 17 to 45% in the first experiment in 1966 and by 8 to 27% in the second experiment in 1967. In the residual cuttings of the first experiment, increased uptake of soil N ranged from less than 0 to 29%. The increase in uptake of soil N by the crops was speculated to be due to stimulation of microbial activity by N fertilizers which increased mineralization of soil N, thus making more soil N available for use by plants.

Westerman et al. (1972) found in "Sudax S X 11" sorghum hybrid - treated with N-15 labelled urea and oxamide that 51% of the added N as urea was recovered in the crops and 28% still remained in the soil (0-25 cm) at the end of the growing season. Corresponding figures of oxamide were 52% in the crops and 31% in the soil. Later work of Westerman and Kurtz (1974) on recoveries of fertilizer N by Sudax (S X 11) sorghum - sudangrass hybrid showed that the difference method (non-isotopic) overestimated recovery of urea and oxamide N when compared with the isotopic tracer method and concluded that the tracer technique is necessary for estimating N recovery in many agronomic experiments.

In a greenhouse experiment conducted on three soils with different cropping and fertilization histories, estimates using unenriched fertilizer N were compared with estimates using two N-15 enrichment levels for the amount of plant N derived from fertilizer.
Use of unenriched fertilizer N led to underestimation of the amount of fertilizer N in the plant material in four of the six cases when compared to N-15 enriched fertilizer. Standard deviations of the estimates of fertilizer derived N in plant material were considerably greater when unenriched fertilizer was used (Meints et al., 1975).

Bobritskaya et al. (1975) reported from a model experiment that the average utilization of fertilizer N by oats in a loamy soil was 35-57%, depending on the fertilizer applied, e.g. urea, calcium nitrate, ammonium nitrate, ammonium sulphate. About 30% of the applied N was fixed in the soil. Practically no N was leached from the cropped soil. There was some horizontal movement of applied N in the soil.

Smith and Chalk (1980) studied the efficiency of N-15 labelled urea, aqueous NH$_3$ and ammonium sulphate which were applied to ryegrass (Lolium perenne) in pots and found that total recovery of fertilizer-N in the plant tissues and soil varied from 94 to 100%. There was no significant difference between the total recovery of the three fertilizer forms.

In a series of experiments to study the utilization of applied N-15 labelled fertilizer by the first crop maize and its residual uptake by 17 crops in multiple cropping system involving maize-wheat-moong, Subbiah and Sachdev (1982) found that the maize crop utilized on average about 20% of 120 kg N/ha applied in three equal splits, the variation being from 11.2 to 32.3% depending upon the rainfall pattern. The immediate rainfall effect on the next crop, wheat, was 2.3 to 7% while for the remaining crops, it was less than 1%. A similar experiment with wheat as first crop receiving N-15 labelled fertilizer at 90 kg N/ha showed that 45% was utilized by the first crop, 25% by the second moong crop and 1.5% by the next maize crop, in sequence. For remaining crops it was less than 1%. By labelling different splits, it was found that the partial efficiency of utilization of the first split applied at the time of sowing was 23%, for the second split 26% and for the third split 64% which showed that a critical evaluation of splits will lead to better utilization of applied fertilizer N. In another experiment Prasad and Subbiah (1982) found by N-15 studies that maize utilized only
20.9 to 32.3% of applied N. About 55-65% of applied N continued to be found in soil profile but very little could be utilized even during the following years.

Papanicolaou (1982) reported fertilizer N utilisation by various parts of grape fruit trees, fertilized in July, 1980 as follows: leaves - 14.1%, young branches - 0.6%, branches of last year - 0.4%, older branches - 2.0%, fruit - 2.8% with 1.5% N-15 atom excess labelled NaNO₃ and corresponding values with 1% N-15 atom excess labelled ammonium sulphate were 13.8% (leaves), 0.6% (young branches) and 0.7% (branches of last year) and traces in older branches and fruit. It was observed that most of the fertilizer N taken up by the tree was utilized by leaves (≈70%), while the fertilizer N recovery in wood and fruit was low.

Pang (1982) reported the fertilizer N recovery of four-year old Douglas-fir planted in a 1:1 ratio of sand and peat mixture and fertilized with N-15 labelled urea and ammonium nitrate at 200 kg N/ha level for two growing seasons as follows: foliage - 17.5%, litter fall (foliages) - 0.3%, branches plus stems - 6.8%, roots - 18.5%, soil (1:1 ratio of sand and peat) - 41.2% amounting total of 84.3% in case of urea fertilizer while in case of ammonium nitrate, the corresponding recovery values were 16.6%, 0.7%, 7.3%, 23.6%, 37.6% & 85.8% for ¹⁵NH₄NO₃ and 27.6%, 0.2%, 13.1%, 24.1%, 17.3% & 82.3% for NH₄¹⁵NO₃, respectively. Under the experimental conditions, trees recovered a higher percentage of N-15 from NO₃⁻ than the NH₄⁺ source suggesting NO₃⁻ is the preferred N source for the Douglas-fir. Soil, however, retained a higher percentage of N from NH₄⁺ than the NO₃⁻ source.

### 2.3.3. Fate of fertilizer nitrogen (Balance sheet):

Very limited work was done to compute balance sheet i.e. to quantify the fate of applied fertilizer N in soil & plant and losses through leachate & gases, which is described below for tea and other crops.

Balance sheet of fertilizer N by non-isotopic method in
young tea grown in pots at Tocklai under 0, 50, 100, 150 and 200 kg N/ha levels in the form of ammonium sulphate showed that the recovery of N by tea plant varied from 51 to 42% at 50 to 200 kg N/ha levels, leaching loss of N ranged from 40 to 38% and gaseous loss of N from 8 to 20%, respectively. N loss through leaching increased with increasing N levels which was enhanced with increased rainfall upto 150 cm (60 inch). Recovery of N by tea plant (including root) decreased from fourth month onwards. Percentage N recovery from combined soil and applied fertilizer sources decreased from 10th month in case of 50 and 100 kg N/ha and from fourth & second months in case of 150 and 200 kg N/ha, respectively (Dey, 1975).

Smirnov and Sukov (1968) observed in a pot experiment that oats utilized 55-61% of the N supplied by N-15 labelled ammonium sulphate, urea or aqueous ammonia and corresponding values in a field experiment were 44-47%. Losses of fertilizer N due to denitrification were 17.5-19.5% in a pot experiment and 10-15% in a field experiment; the losses were mainly in the first three weeks after application. Of the applied N, 21-26% was fixed in organic form in the pot experiment and 22-25% in the field.

Koren'kov and Lavrova (1973) in a pot experiment observed that barley utilized 69% and millet and flax 56-61% of the N supplied by N-15 labelled ammonium sulphate or sodium nitrate. Losses of gaseous N were 13-31% from sodium nitrate and 8-12% from ammonium sulphate. Most of the gaseous losses and transformations of fertilizer N into organic N in the soil occurred within 20 days after application of the N. Applied N occurred in all the groups and fractions of organic N, but was liberated from the fulvic acids during the vegetative period.

Smirnov et al. (1980) found in lysimeter trials with corn and winter rye that the coefficients of utilization of N from ammonium nitrate and ammonium sulphate varied with the rates and time of application from 51 to 59%. Fixation of fertilizer N in the soil was 18-33%. N losses from the soil as a result of leaching of NO₃⁻N and NO₂⁻N through lysimeter waters reached 20-23 kg/ha under
corn and 5-10 kg/ha under winter rye, the proportion of fertilizer N not exceeding 1 kg/ha. Losses of fertilizer N were mainly in the gaseous form due to denitrification.

Field studies on Indian Vertisol with N-15 labelled fertilizers applied to dryland sorghum in two successive rainy seasons showed that percentages of applied N recovered in the soil-plant system after harvest were 94%, 74% & 72%, and remained in soil were 39%, 45% & 42% of added N as urea applied as split-band, placement or surface-applied methods respectively (Moraghan et al., 1984).

Mohammed et al. (1984) carried out microplot and lysimeter trials with N-15 labelled urea applied to barley sown on drained silt loam soil subjected to two irrigation treatments corresponding to normal and high rainfall conditions and observed that 90% of the applied N was recovered in soil, plants and leachate 35 days after sowing. 50% of the urea-N was hydrolysed within 3 days of application and a similar percentage was present as organic N in the soil after 20 days. 6% of N was leached from normally irrigated plots and 14% from the wetter plots. Plant N uptake was 32% and 22% of that applied in the normal and wetter plots respectively.

Nommik (1984) studied mature stand of Scots pine treated with N-15 labelled ammonium nitrate at 100 kg N/ha level and trees felled for two growing seasons after fertilization. It was observed that on average 9% of the supplied N was recovered in the trees, half of which occurred in the biomass. Approximately 8% of the applied N was localised to the above-ground parts of the shrub layer and 7% in the roots. Recovery in the soil averaged 46%. In all, 79% of the supplied N was recovered in the soil-plant system and the remaining 21% was probably lost by leaching.