CHAPTER -2

REVIEW OF LITERATURE

2.1. Uniqueness of rubber plantations

Plantation floor, particularly for that of rubber, stands midway between forest floor and cultivated land. In the humid tropics, Hevea plantations are often considered a sustainable system, which in some cases might even upgrade the level of soil fertility (Gilot et al., 1995).

Since rubber plantations have deciduous nature, its ecosystem remains a major contributor to the nutrient cycling pathway wherein large amount of nutrients are being returned to the plantation floor (Kush et al., 1990).

*Hevea brasiliensis* is an exotic and deciduous plant showing maximum litter fall during February -March, with annual litter addition to plantation floor amounting to 7 tones per hectare (Jacob, 2000). Rubber plantations are considered as an environmentally acceptable closed ecosystem with a constant cycle of uptake and return of soil nutrients (Delabarre and Serier, 2000).

In rubber and oil palm, the rate of canopy growth increases up to the age of 6-7 years and intercepts more than 80 per cent of the incident light and permits only less than 20 per cent of the light to reach the floor. During the subsequent years of growth, there can only be a small change to this values, but by the time the plantations attain 15-20 years of growth, the canopies open up slightly again permitting significant amount of light (Wahab, 2001).

Alcala (2007) reported that rubber has been declared as one of the top five priority commodities of the Department of Agriculture in Philippines since it generated employment in the rural areas and planting rubber in idle hilly lands and uplands enhanced environmental rehabilitation. Besides, these facts, rubber have been identified as a good plant species for enhancing sequestration of carbon dioxide.

Rubber litter is an important source of nutrients for soil microorganisms (Abraham and Chudek, 2008) and litter input are always found to increase soil
enzyme activity (Dornbush, 2007). Since the rubber plantations are monoculture, the ecological components differ to the forest in terms of nutrient cycling and soil conservation (Gazia and Chaverri, 2010).

2.2. Cover crops in rubber plantations

Cover crops are crops planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in agro ecosystems (Lu et al., 2000). Cover crops do smother the weeds and reduce their competition for light, moisture and plant nutrients with rubber and also prevent the weeds from serving as alternate hosts for insects and pathogens.

Watson et al. (1964) described a variety of advantage in maintaining cover crops particularly leguminous group in rubber plantations. According to them, the cover crops prevent the beating action of rain and effectively reduces run off, increase the soil moisture and keep down the temperature during summer, smother weeds, add large quantities of organic matter and improve soil structure, fix atmospheric nitrogen ultimately resulting in improved soil fertility.

Good management of cover crop and fertilizer in rubber plantation can advance rubber trees to production in five or six years, reducing the immature and unproductive period by one or two years. (Watson, 1966). According to him, cover crops apart from protecting the soil, helps in maintaining or even raising the overall fertility of soil. Broughton (1977) conducted several years of experiments with various types of cover crops and fertilizers, especially nitrogen and suggested that the nitrogen requirement of young rubber trees can be reduced after the third or forth year from planting, provided a good legume cover is maintained. Krishnakumar and Potty (1989) reported that cover crops in rubber plantations favoured the formation of large size soil aggregates and such formations facilitated enhanced infiltration capacity.

According to Ahenkora and Nuertey (1999) leguminous cover crops have their innate potential for weed suppression and providing nutrition besides sustaining growth and yield of the main crop. They further reported that cover crops play an important role in soil erosion control and do help in conserving soil moisture in plantation crops.

Abraham and Chudek (2008) reported that Pueraria, Mucuna, and teak soils were comparable for their biological properties while rubber soil recorded
comparatively lower microbial activity. They also reported that the resource quality of litter based on alkyl-C to O-alkyl-C ratio can be arranged in the order Pueraria > teak > Mucuna > forest > rubber. Suvannang et al. (2010) monitored the decomposition process of Pueraria litter and reported that, within 160 days about 43 per cent of the initial nitrogen was released.

2.3. Litter addition and factors influencing litter decomposition

Different crops can produce different exudates and organic components from root systems and crop residues, which influence microbial activity differently. Tian et al. (1992). The rubber tree plantations are characterized by low input farming where cover crops and natural litter addition provide the required organics in the management process (Broughton, 1977).

Improvement of physical properties of plantation soil had been demonstrated by Yadav (1968) consequent to leaf litter addition, who concluded that the kind of vegetation which provided the litter determined the soil physical properties. Organic substances play an important role in determining the physical chemical and biological quality of a soil. (Beare et al., 1994) Besides, they act as a source of energy and provide nutrition for organisms and plants (Dick, 1994). They help to improve structure and aggregate stability in soil. Further, they help to increase water retention, chelate metals, and regulate the holding or release of nutrients. The buffering action of soil is also mediated by organic segments present in soil.

Gosz et al. (1976) indicated that in a decomposition cycle, there are critical carbon/element and element/P ratios for many nutrients. These ratios reflect nutrient demand by decomposers and only after these ratios are reduced below critical levels, the end products of mineralization appear in soil.

Swift et al. (1979) reported that soil organic carbon and distribution at any time in a plantation floor reflects the past inputs and long term accumulation. According to them, organic carbon addition in forest plantations can also happen through fine root turnover in the surface soils. Further, they positively correlated the decomposition rate with the amount of polysaccharides, hemicelluloses and pectin available in the decomposing source.
Soil fauna play an important role in the initial breakdown of complex and large pieces of organic matter, making it easier for soil microorganisms to release carbon and plant nutrients from the material as they continue the process of decomposition (Jenny, 1980).

Hendrickson (1985) suggested that initial plant leaf residue with C:N ratios greater than 25:1 has been identified as the threshold value controlling immobilization while that for mineralization, the ratio should be less than 25:1. Plant materials above these thresholds are expected to decompose slowly and to immobilize nitrogen due to the formation of stable polymers between polyphenolic and amino groups.

The effect of the vegetal cover, influence soil structure and the organic matter content determined the microbial biomass and respiratory activity in soil and the observed decrease in activity at lower depth can be attributed to the changes in the above parameters (Fialho et al., 1991). (Palm and Sanchez, 1991) reported that differential rates of nitrogen mineralization among species are mainly because of the variations in the leaf chemistry. The initial polyphenol content and polyphenols: nitrogen ratio was more strongly correlated with nitrogen mineralization from leguminous green manures than lignin, nitrogen, or lignin:nitrogen ratios. The amount of lignin and tannins present in any organic litter decided their decomposition rate in soil and it was observed that there was a negative correlation between their contents and decomposition rate (Slapokas and Granhall, 1991). Gallardo and Merino (1993) reported that presence of high concentrations of cellulose and lignin in the litter retards their easy decomposition by hindering the activity of microorganisms.

The rubber tree plantations are characterized by low input farming where cover crops and natural litter addition provide the required organics in the management process. (Annual Report, 1994). (Becker et al., 1994) explained the differences in the decomposition patterns of residues by emphasizing the variations in lignin: N ratios existing in them. According to Vitousek and Turner (1994) the moisture levels controlled the litter decomposition and within the same site, dry areas permitted decomposition more than twice as rapidly as litter from sufficiently wet sites.

According to Rao et al. (1997) the higher potassium content in the surface layers could be due to more intense weathering, addition of leaf litter from different
crops in cropping system, release of labile potassium from organic residues, application of potassium fertilizers or upward translocation of potassium from lower depths with capillary rise of ground water. The availability of soil potassium is directly correlated with the soil texture and the type of clay minerals (Raychaudhary and Sanyal, 1999).

According to Chadwick et al. (1998) the major source of organic residues in plantations comes from the decomposition of leaf litter that is accumulated on the surface of the soil. However, they also indicated that the contribution of dead roots of the plants can’t be under rated. The chemical elements contained in the litter mass is being mineralized and released with the help of decomposing agents under the influence of heat and moisture which hasten the mineralization (Guo and Sims, 1999). According to them, the released elements are mobilized and re-absorbed by the roots, giving rise to a new system of bio-cycling particularly when soils are considered to have low fertility.

Wedderburn and Carter (1999) reported that there was a reduction of soluble substances from added litter mass which occurred gradually due to mineralization and that there was relative enrichment in the proportion of cellulose and lignin in the residue in the months of February-March. They also indicated the sequence of loss of chemical components from litter. Accordingly, soluble components are rapidly lost, followed by polysaccharides, cellulose, hemicellulose and, finally lignin.

Studies of Fioretto et al. (2000) have specifically indicated that it is the litter quality which influences various enzyme activities in either increasing or decreasing its decomposition in the soil. Maharudrappa et al. (2000) compared the effects of litter addition of Eucalyptus, Teak Casuarinas and Acacia on the availability of calcium and magnesium. According to them, Eucalyptus and Teak treatments recorded higher amount of calcium and magnesium than Casuarinas or Acacia at the same level of litter application. Further, they indicated that the quantity and the quality of litter decided the release of potassium to soil pool. Musvoto et al. (2000) indicated that during mineralization of the litter mass, liberation of soluble and easily decomposable components occur leading to gradual losses of added litter mass. High levels of tannins in the decomposing sources might exert negative influence soil mineralization and humus formation, decreasing soil fertility (Wurzburger and Hendrick, 2007).
In conventional rubber planting, 85 per cent of the exposed areas is drastically reduced to 45 per cent in second year by canopy coverage and at the end of third year, there is complete coverage leading to possibility of contribution of sufficient litter annually in mature rubber plantations. (Ghani and Zulkefly, 2001). Reversat and Loumeto (2002) reported that litter fall serves three main functions in the ecosystem *viz.*, energy input for soil micro flora and fauna, nutrient input for plant nutrition, and material input for soil organic matter building up. According to them, the first two functions are completed through decomposition and mineralization, and the third one through decomposition and humification.

Younger organic material, from recently added roots, litter residues, dead organisms, or waste products, is the most biologically “active” fraction which supports the living soil biological community. This fraction is more readily decomposed and has been shown to have a strong response to management practices, such as tillage, residue handling and crop rotations (Carter, 2002). Coleman *et al.* (2004) highlighted the interaction of organic matter components with soil particles and associated influence in enhancing the CEC of soils. They also suggested that soil organic matter is a primary factor in the development and modification of soil structure. Bot and Benites (2005) reported that in the absence of sufficient soil organic matter, there is considerable loss of rain water from fields particularly through runoff, which favoured earlier drought leading to reduction in crop yields. Fernandes *et al.* (2005) reported that there had been a decrease in microbial biomass and respiratory activity from the surface soil to the deeper layers. According to them, the reduction of CO₂ production with soil depth was due to more availability of organic sources at the soil surface. They further justified their observation and indicated that the leaves located at the surface of soil are more exposed to environmental variations than the buried leaves. Kannangara and Deshapriya (2005) reported that differences in resource quality, such as nitrogen and the presence of inhibitory tannin concentrations determine the decay process and hence they are important in biodegradation.

Among the different decomposing agents, which act on the litter, bacteria and fungus have a dominant role due to their greater biomass and respiratory metabolism (Torres *et al.*, 2005). External addition of 2.5 per cent urea reportedly increased the biomass of most groups of saprophytic microorganisms which accelerated litter decomposition. However, when the application of urea was enhanced to 5 per cent,
the decomposition was retarded. (Green et al., 2006). Zhang et al. (2007) reported that rubber cultivation resulted in significant decline of soil organic carbon and microbial biomass carbon.

According to Abraham and Chudek (2008) plant litter from rubber and teak serve as an important source of nutrients for soil microorganisms. Suvannang et al. (2010) reported that rate of litter decomposition could also vary according to the quality of the residues. According to them, residues from legumes have a more important short term impact on soil fertility, whereas residues from grass plants have a more significant and long term impact. The difference is often explained by the lower C/N ratio of legumes compared to grass residues.

2.4. Litter decomposition and soil environment

Litter input, particularly from broad leaved plants in forest soils was estimated to be 3.5 t/ha per year (Bray and Gorham, 1964) which, together with the input from plant roots represents the main source of organic matter in forest soils (Litton et al., 2003). Berg and Staaf (1980) have shown that, during the initial stages (0–3 months) of leaf breakdown, small soluble carbon-based molecules, such as starch and amino acids, are lost, leaving behind more recalcitrant molecules, such as lignin. According to them, decomposition during this first phase is rapid because these small, soluble carbon-based molecules are energy rich and easily broken down, which allows the greater fungal growth associated with this stage.

Melillo et al. (1982) indicated that within a given region, where soil type and climate do not change, the decomposition rates and limits are primarily governed by the litter quality as indexed by the lignin:nitrogen and C:N ratios. Since the mostly intact forest floor surface layer may dry out more quickly than the soil, dry conditions may limit surface litter decomposition more than fragmented litter and humus (Warring and Schlesinger, 1985).

Dried green manures decompose more slowly than fresh material (Wilson et al., 1986) and their reduction in size is found to accelerate the breakdown rates due to increased availability of surface, promoting microbial activity. Azhar et al. (1989) reported that the exact mechanism by which polyphenols inhibited net nitrogen release is not known, but it is possible that nitrite formed during partial nitrification was combined with phenolic compounds. According to Oglesby and Fownes (1992)
neither the initial percent nitrogen nor lignin:nitrogen ratio was strongly correlated with nitrogen mineralization. The best chemical index of nitrogen release was the initial polyphenol:nitrogen ratio. This study indicate that nitrogen mineralization from tropical legumes is controlled more by soluble polyphenols than by lignin or nitrogen content. Decomposition processes are regulated by a number of abiotic and biotic factors. These comprise: (1) microclimate, mainly temperature and humidity (Meentemeyer, 1995), (2) litter quality, in particular nitrogen, lignin and polyphenol concentrations and ratios (Wood, 1995), (3) soil nutrient content (Verhoeven and Toth, 1995), and (4) the qualitative and quantitative compositions of decomposer communities including bacteria, fungi and invertebrates (Swift et al., 1979).

Variations in enzyme activity have been mainly brought in by climatic factors where temperature and soil moisture play key roles (Dilly and Munch, 1996). They reported that seasonal differences in enzyme activities were dependent on the chemical composition of litter. Further, they indicated that the lignin content of litter material was strongly influenced by the season. Decomposition rates of existing litter at any point of time can be considered as an indicator of the functionality of the biogenic process in the ecosystem that occurs below-ground. This relates to the central role played by soil organisms in litter decomposition, nutrient supply and nutrient cycling (Tian et al., 1997).

Due to heat, moisture and the action of decomposing agents, the chemical elements contained in the litter mass are mobilized and re-absorbed by the roots even under soils of low fertility (Guo and Sims, 1999). Moorhead and Sinsabaugh (2000) have reported that the activities of extra cellular enzymes, especially all those participating in lignin and cellulose degradation, are very much correlated with litter decay. Saiya-Cork et al. (2002) observed that nitrogen application had increased litter decomposition rate and depressed soil organic matter decomposition. According to them, enzyme activities in the decaying green materials were low during the first 10-18 days, where decomposition of low molecular substrates were predominant, but steadily increased during the later stages. According to Caldwell (2005) such enzymes are also used for nutrient acquisition by microorganisms in the deeper soil horizons.

Kannangara and Deshapriya (2005) reported that decomposition of organic substrates is mainly carried out by various fungal groups. No single fungal species is capable of using all the components available in a substrate and hence succession of
different fungal groups will be involved in the final degradation. It is presumed that litter decomposition in temperate forests is driven mainly by the activity of saprotrophic fungi (Hattenschwiler et al., 2005; Baldrian, 2008). Duxa et al. (2006) concluded that type of plant leaf residue had a strong impact on mass loss and nutrient release particularly that of nitrogen and phosphorous from decomposing weed residues. Further, all low input farming systems in the humid tropical regions have both weed problems and land degradation which could well be addressed if proper knowledge on resource use efficiency of invading weeds. According to them, weed residues differ in quality and availability of nutrient in soils will be a reflection of their contents. Snajdr et al. (2008) detected considerable production of ligno-cellulose degrading enzymes during litter decomposition and reported that the activities of extra cellular enzymes in forest soils and litter show considerable variation over time and space.

2.5. Soil enzymes and biological activity in soils

Among the many factors that influence enzyme activity in soils, the major ones are the soil organic matter status, nature and composition of soil organic matter, the soil nutrient status, the soil moisture content, nature and amount of clay, colloidal fractions besides physical properties that control temperature, moisture and aeration of soil. However, the most important factor that governs the microbial load of the soil is the organic matter status.

According to Halstead (1964) the activity of phosphatase enzyme was influenced by organic sources and positive correlation existed between phosphatase activity and organic matter content. Ernst and Glubrecht (1966) also endorsed similar view. According to Ernst (1967) less than eight per cent of the natural degradation of organic sources accounted in an agricultural soil was due to inorganic catalysis and about 20-50 per cent was due to the involvement of extracellular enzymes.

Muresanu and Goian (1969) reported that with moderate application of fertilizers, phosphatase activity increased and when the doses were enhanced, the activity was curtailed.

Rankov and Dimitrov (1971) studied the phosphatase activity in soil and observed how they responded to inorganic fertilizer additions and organic soil amendments. Based on their observation, they reported that there had been an
attendant increase in phosphatase activity with fertilizer addition and incorporation of organic soil amendments.

Plant roots exudates a wide range of organic substances that act as a substrate for certain group of microorganisms. These exudates influence biological and chemical properties of soil and are important in plant nutrition and to some extent control of root diseases (Rovaria, 1969). Howard (1972) emphasized that the enzymes are substrate specific and individual measurement of an enzyme or its quantification cannot be taken as index of the soil fertility or the possible nutrient status associated with that soil. Soil enzymes catalyze many reactions in soils which ultimately lead to the transformation of many nutrients like carbon, nitrogen, phosphorous and sulphur (Kiss et al., 1975). All enzymes which are seen to be accumulated in soil plus those secreted by proliferating cells during normal growth have been designated with a new term “abiotic” by Skujins (1976). Soil enzymes form a part of soil matrix as exoenzymes and endoenzymes in viable cells, whose activities are commonly correlated with many microbial parameters (Casida, 1977).

Skujins (1978) reported that the activities of urease, phosphatase, protease, invertase and catalase can be used as fertility indices of soil to complement soil chemical analyses to predict the nutrient availability and crop yield. Burns (1982) reported that soil enzymes play a significant role in mineralization of nutrients and is generally associated with inorganic and organic colloids. The amount of extracellular enzyme activity may be indicative of the biological capacity of soil for the enzymatic conversion of the substrate.

Reports of Stevenson (1982) indicated that soils contained a wide variety of active free enzymes which display remarkable stability even under adverse soil conditions. Tabatabai (1982) reported the mediation of various enzymes derived from microorganisms in the biochemical processes occurring in soils. However, the state of existence of these enzymes in soil or its measurement and interpretation had been difficult (Ladd, 1985).

Tan (1982) reported that when higher rate of urea is applied to soils with low urease activity, there is a heavy possibility of either leaching of unhydrolyzed urea down to lower depths or could be washed away, especially if heavy torrential rain starts soon after fertilizer application. Mc Gill et al. (1986) opined that the soil
microbial biomass can act as a source and sink for plant nutrients and their active participation in nutrient recycling thus can serve as a fertility factor.

Powlson et al. (1987) studied the fluctuations in the microbial biomass and indicated that microbial biomass can be taken as an early indicator of changes that happen to the entire soil organic matter content. Verstraete and Voets (1987) reported absence of a valid relationship between enzyme activity, microbial activity and soil fertility. Specific role of microbial enzymes in the mineralization process and other soil biological reactions has been established by Tate (1987).

The effect of application of organic manures on enzyme activity was evaluated in an incubation study by Shinnawi et al. (1988). According to them, there had been a general escalation in activity of dehydrogenase on addition of manures while a reverse trend in activity was observed for nitrogenase activity in such soils. However, nitrogenase activity picked up in the manured soils after a period of one month of incubation. Further, they indicated that sandy soil witnessed higher dehydrogenase and lower nitrogenase activities than the clay loam soil.

Shukla et al. (1989) observed that fungi contributed more to the dehydrogenase activity than bacteria. Nannipieri et al. (1990) failed to find out any kind of correlation existing between soil enzyme activity and crop productivity in a given soil. Dick (1992) reported that the activities of cellulase and urease enzymes were generally higher in grass fields than in cultivated fields and that the variation in activity is a reflection of the existing difference in organic build up.

A close relationship between microbial respiration and biomass was established by Asmer et al. (1992). They were also successful in correlating the enzyme activities of alkaline phosphatase, amidase and catalase with various biotic factors of the soil. Beyer et al. (1992) indicated that the quantification of microbial biomass, dehydrogenase activity and alkaline phosphatase activity of soil can effectively deliver a comprehensive idea of the existing soil fertility. The involvement of soil enzymes in mediating the growth of plants have been reported by Huystee and Cairns (1992).

According to Dick (1994), the soil enzyme activities serve as a potential indicator of soil quality and only certain methods provided the most accurate values. According to him, the enzyme values in soil depended on many parameter like pre-
treatment of soil samples, assay procedures and standardization of these factors. According to Jones et al. (1994), the soil quality is always associated with its biological activity and ensuring soil quality is the fundamental need in any crop production program.

Studies of Nannipieri (1994) revealed that enzymes have different locations in soil and is usually associated with various biotic and abiotic components. Roper et al. (1994) indicated a reduction in nitrogenase activity consequent to addition of nitrogen fertilizers. However according to them, other cultivation practices encouraged the nitrogenase activity and they reported very low activity in zero tilled soils. According to Tabatabai (1994) the enzymes are constantly being synthesized, accumulated, inactivated and decomposed in the soil, hence playing an important role in agriculture and particularly in nutrients cycling.

Jordan et al. (1995) indicated that quantification of microbial carbon, phospholipids analysis; direct counts of fungal and bacterial biomass together with the estimation of phosphatase enzymes serve as reliable indicators of soil quality. Kennedy and Papendick (1995) considered measurement of soil enzyme activities as one of the numerous measurements that reflect soil microbial quality and it is popular mainly on account of the ease of measurement.

Effect of chemical effluents on the activity of a range of enzymes present in soils has been studied by Palaniswami and Ramulu (1995) and according to them the activities of invertase, catalase and peroxidase dropped to very low levels due to presence of effluents. It was observed by Dharmakeerthi and Thenabadu (1996) that the conversion of urea to NH$_4^+$ ion was governed by the level of urease activity in the soil. Park and Seaton (1996) reported that soil enzyme activities can be used as indicators or key variables for assessment of soil sustainability.

Nannipieri (1994) reported that a certain level of extra cellular enzyme activity always existed in soils particularly those secreted by living cells during normal cell activity or actively leaked from extant cells or released from lyzed cells are short lived. Monreal et al. (1998) indicated that whenever elevated enzyme activities get noted in soil, it is associated with conditions promoting microbial synthesis of enzymes and such situations are effective indicators of changes in soil quality. The
activity of urease was greater in cultivated soil than uncultivated land and presence of organic matter is a prerequisite for ensuring higher urease activity (Hasan, 2000).

The insoluble macromolecules of soil organic matter (SOM) are tuned into smaller and soluble molecules in the presence of extra cellular enzymes which allow microbes to access the otherwise biologically unavailable carbon and nutrients in SOM (Burns and Dick, 2002). There were significant correlations of soil enzyme activities with total organic carbon, and carbon and nitrogen microbial biomass. These results indicated that in undisturbed soil there was increased microbial soil enzyme activity which is a sensitive indicator to the alterations in soil quality by management (Balota et al., 2004). Freeman et al. (2004) indicated that low hydrolyse activities in soils can be indirectly attributed to the existence of oxygen constraints on phenol oxidase activity which facilitate conditions that inhibit decomposition of organic sources.

According to Gutierrez et al. (2004) the organic phosphorous comprises around 50 per cent of the total soil phosphorous and it becomes plant available only after mineralization. The entire rhizosphere processes in this connection are mediated by plants, microorganisms and arbuscular mycorrhiza. Soil enzymes are produced by plants, animals and microorganisms, and may be present in dead cells and cell debris and also adsorbed by clay or incorporated into humic substances (Allison, 2005). Liang et al. (2005) indicated that the placement of organic manure both inside and outside rhizobags significantly increased the activity of urease, alkaline phosphatase and dehydrogenase, along with an increase in respiration rate in both rhizosphere and bulk soils. Mora et al. (2005) observed that enzymes are the main mediators of soil biological processes like organic matter degradation, mineralization and nutrient cycling.

Selmants et al. (2005) reported that in the cellulose degradation of forest litter, mass involvement and activities of nine extra cellular enzymes have been identified. Their involvement was more associated with the mineralization of organic nitrogen, phosphate, and sulfate compounds. They also reported that the rate of mineralization in forest soils compared to pure conifer soils were higher. Snajdr et al. (2008) also reported similar view while evaluating the transformation of organic matter in forest soils.
Soil enzyme activities have been identified as useful indicators of soil quality (Zornoza et al., 2006) since they are very sensitive to any disturbance that sensitize their activities. Although, chemical and physical properties of soil have been taken as crude index of soil productivity, there is ample evidence that soil biological parameters hold equal potential and are also considered as sensitive indicators of soil productivity or soil ecological stress or restoration.

Zornoza et al. (2006) reported that air-drying of soils hardly affected the activities of some enzymes like urease, phosphatase and β-glucosidase. Allison et al. (2007) reported that efficiency of enzymes in mineral soils was negatively correlated with soil nutrient availability.

Dornbush (2007) indicated that soil enzyme activity particularly urease, β-glucosidase was triggered by litter inputs. He further observed that the maximum activities were identified in areas between the trees where litter accumulation was abundant.

Marinari et al. (2008) reported that multiple soil enzymes are required for effective degradation of different chemical fractions of soil organic matter. They also indicated that soil physical matrix is also quite diverse and this further necessitates the need for multiple soil enzymes. According to them, some of the more abundant soil organic compounds that are degraded enzymatically include lignin, cellulose, starch, lipids, chitin and proteins. Shan et al. (2008) concluded that soil enzyme activity maintained a close correlation with both physical and chemical properties of soil. According to them, the important parameters which influenced the activity were texture, pH, organic carbon, total nitrogen, available potassium, available phosphorous, cation exchange capacity (CEC) and microbial biomass.

Wongcharoen et al. (2011) reported that in the collar region of the rubber trees, the enzyme activities were generally low as these zones did not accumulate much leaf litter and the enzyme activities were confined to regions where soil organic matter accumulated.

2.6. Soil enzymes, their persistence and stability in soil

Under natural soil conditions soil enzymes are continuously being synthesized and accumulated, inactivated and decomposed. Since many enzymes are produced by living organisms and any action altering their life functions could indirectly question
their persistence and stability. The stabilization of soil enzymes have been studied by Mortland (1970) who suggested several possibilities. According to him, the enzymes could get absorbed either to internal or external clay surfaces or complexed with humic colloids by adsorption and cross linking or there could be micro encapsulation of enzymes or in some cases there could be co- polymerization while associating with clays and humus in soil. Martin and Haider (1971) reported that many phenolic constituents of humus are able to auto oxidize the soil enzyme and inactivate them.

Immobilization of soil enzymes are effectively achieved in soil by either binding them to clay or complex organic molecules (Verma et al., 1975). Decrease in microbial activity with the increase in cultivation has been observed by Gupta and Germida (1988). They also reported that in cultivated soils, the aggregates size fractions were lower and enzyme activities associated with such small aggregates have always been on the lower side than native soils.

Different aspects of biology of soils amended with organic matters have been studied in detail by many workers and according to them, number of microorganisms involved, the biomass of bacteria and fungi, the enzyme activities and the biochemical properties of both soil and organic sources decided the ease of mineralization (Nishio and Kusano, 1980; Kandeler et al., 1999; Lundquist et al., 1999).

According to Mateos and Carcedo (1985) the highest activities of all catalase, dehydrogenase and urease were observed on soil particles with diameter less than 50 micrometer in the presence of humic molecules. Lahdesmaki and Piispanen (1992) reported the importance clay and humic colloids in providing the stability to enzymes from thermal stress particularly when heating or repeated freezing thawing cycles occur.

Foster and Doormar (1993) reported that soil enzymes may be of plant, animal or microbial origin and justified the occurrence of acid phosphatase in cap cells of roots, soil fungi, bacteria as well as in mucilaginous covering of roots. Enzymes are measured indirectly by determining their activity in the laboratory using biochemical assays. Enzyme assays reflect potential activity and do not represent true in situ activity levels and must be viewed as an index (Tabatabai, 1994).

According to Zhang et al. (1995) several factors like water content, organic carbon content and the thickness of the ploughed horizon are important considerations
for the measurement of spatial dependence of soil enzymes. According to Bandick and Dick (1999), the main sources of soil enzymes originate from living and dead microbes, plant roots and residues, and soil animals. They further indicated that enzymes get stabilized in the soil matrix or get accumulated or form complexes with organic matter (humus), clay, and humus-clay complexes, but are no longer associated with viable cells.

2.6.1. Cellulase

Cellulase is a group of extra cellular enzymes which hydrolyse the insoluble cellulose polymers into soluble sugars and act as primary agents of organic matter degradation. As cellulose is insoluble and cannot be directly assimilated by microorganisms, they need to be hydrolyzed by cellulase. Ambroz (1973) reported that prior incubation of soils with cellulose enhanced the cellulase activity by accelerating the process of hydrolysis. Cellulase enzyme activities can be more influenced by type of organic matter than the quantity of organic matter (Pancholy and Rice, 1973). Kanzawa and Miyashita (1987) reported that the activity of cellulase decreased with increasing soil depth, even though the soils were rich in humus.

Mc Claugherty and Linkins (1988) studied the influence of pH on the extractability of cellulase in two horizons of a forest soil and reported that the extractability of cellulase enhanced as the pH was raised from 3.5 to 5.6. Hope and Burns (1989) reported that the major portion of cellulase enzyme was bound to and protected by soil colloids. Ishaque and Kluepfel (1980) reported that cellulase is synthesized and secreted to the surrounding medium by a group of microorganisms which includes bacteria, actinomycetes and fungi and that the actinomycetes possessed a cellulase system more similar to that of fungi than bacteria. Brown (1991) indicated that variations observed in the activity of cellulase could be due to difference in the climate and he could locate higher cellulase activity in the range of 30-80 ppm of glucose hydrolyzed g⁻¹ of soil 24 hrs⁻¹ in semi arid regions compared to humid regions. Sandor and Eash (1991) studied the activity of cellulase in temperate regions and found that additions of farm yard manure or green manure stimulated the activity of cellulase.

Schinner (1993) reported the need for an ambient temperature for cellulase activity and he observed that cellulase activity in the arctic region increased
considerably after the thawing of frozen top soils. Mishra et al. (1993) reported that presence of organic matter or humus immobilized cellulase enzyme by binding them to active sites. Engasser and Horvath (1974) reported that when cellulase gets attached to organic complexes, there is a considerable reduction in the mobility of enzyme in soil and this protects the enzyme from physical and biological degradation. Dick et al. (1994) indicated that the long term cultivation hardly affected the cellulase activity as long as the organic carbon level is maintained. According to them, the cellulase activity is correlated with many factors like organic carbon, water content and depth of sampling. However, the observations of Pennock et al. (1994) were quite contradictory and did not support correlation between moisture content and cellulase activity.

According to Wongcharoen et al. (2011) cellulase activity associated with healthy rubber trees were generally higher than unhealthy trees and these enzymes very much involved with the breakdown of carbohydrates and subsequent release of energy as glucose. This effect may result from the difference in chemical composition between the leaves from healthy and affected trees which could have an impact on the quality of the litter and consequently on enzyme activities.

2.6.2. Urease

Urease is released from living and disintegrated microbial cells and in the soil it can exist as an extracellular enzyme absorbed on clay particles or encapsulated in humic complexes. Silva and Perera (1971) reported that soil texture had marked relevance on the level of urease activity and indicated that sandy soils tend to have a lower activity than heavy textured soils. They also observed that the poor activity in sandy soils could be enhanced with organic matter additions. The higher urease activity in the earthworm casts can be attributed to higher levels of organic matter since urease is known to be bound with organic matter (Beri et al., 1978).

Kandeler and Gerber (1988) observed that the activity of urease increased with increase in moisture content of the soil and vice versa. However, positive effect of moisture on urease activity can not be accounted at very high moisture levels. The depth of sampling is a crucial factor deciding the urease activity. According to Fenn et al. (1992) a decrease in the urease activity was observed with increasing depth and activity was poor below the plough depth.
Torello and Wehner (1993) indicated that the urease activity depended very much on the amount of the urea available in that soil and that any presence of NH$_3$ in that soil from any known or unknown source resulted in suppression of urease activity. Sequi et al. (1995) correlated the activity of urease with the soil physical properties and indicated that the soil pores played a significant role in regulating the enzyme activity. Park and Seaton (1996) reported that the activity of urease was greater in the surface soils than in the lower horizon, and they associated the variation in activity with the amount of organic carbon content.

The activity of the urease enzymes was greatly affected by drought indicating that activities were very much associated with the moisture content of soil. It was also observed that the activity of the enzyme strongly decreased with soil depth (Sardans and Penuelas, 2005). Urease is released from living and disintegrated microbial cells, and in the soil it can exist as an extracellular enzyme absorbed on clay particles or encapsulated in humic complexes. (Mohammadi, 2011a).

### 2.6.3. Phosphatase

Alkaline phosphatase controls the mineralization of soil esters of phosphorus (Speir and Ross, 1978) to produce inorganic phosphate. Spiers and McGill (1979) reported that phosphatase enzymes are stimulated only when the phosphate levels are low in soils. Harrison (1983) observed a positive relationship between phosphatase and organic matter content since the enzyme was mostly seen associated with humic-protein complex.

Nannipieri (1984) indicated that the environmental factors such as pH, moisture, surface charges and redox conditions at local level are of crucial factors associated with the activity of various forms of phosphatase. Phosphatase is a broad group of enzymes that hydrolyzes esters and anhydrides of phosphoric acid. Both acid and alkaline phosphatase activity varies widely due to soil management, fertilizer application and tillage operations (Dick, et al., 1988; Kandeler et al., 1999).

McLaren (1985) observed a negative correlation of phosphatase activity with clay and silt content of soils. Ladd (1985) justified the high levels of phosphatase activity observed in the rhizosphere by associating it with enhanced microbial activity promoted by plant residues.
Rao and Tarafdar (1998) reported that legume straw incorporation resulted in the higher production of phosphatase which could be due to the presence of some stimulatory compounds present in it. Tarafdar and Junk (1988) observed that acid and alkaline phosphatase activity were higher in the rhizosphere and particularly near the root surface. This observation is in conformity with the reports of Haussling and Marschner (1989) who also observed higher activity of phosphatase in the rhizosphere than in the bulk soils.

According to Kandeler (1990) there could be sorption of the enzyme on humic substances and this can result in partial inhibition of phosphatase activities. The phosphatase activities of pasture lands, its relationship with plant productivity and phosphorous fertility indices were worked out by Speir and Cowling (1991). According to them, there was negative effect of phosphorous fertilization on the activity of phosphatase. Collins et al. (1992) observed a sudden spurt in activity of acid phosphatase on application of phosphorous fertilizers to those lands which had been abandoned for a long time in the past without cultivation. The observed lack of correlation between phosphatase and available phosphorus may be due to the fact that soil phosphatase activity got suppressed on account of application of inorganic phosphate fertilizer (Haynes and Williams, 1992). Chhonkar and Tarafdar (1994) observed a positive correlation between phosphatase activity and organic matter content of soils.

According to McLachlan (1994) plant age and soil moisture content are the decisive factors that rule the efficiency of acid phosphatase in cultivated land. He further observed that the phosphatase activity can be indirectly correlated for predicting the grain yield and plant phosphorous status. Phosphatase catalyses the hydrolysis of both organic phosphate esters and anhydrides of phosphoric acid into inorganic phosphorus. Phosphatase activity may originate from the plant roots (and associated mycorrhiza and other fungi), or from bacteria (Tarafdar and Marschner, 1994). Acid phosphatase is a key enzyme involved in the hydrolysis of organic phosphorous to orthophosphate ions in acid soils (Tabatabai, 1994) and its activity can be located in the soil water phase or stabilized humic or clay colloids (Nannipieri et al., 1996).

Cooper and Warman (1997) reported that the applications of chicken manure compost significantly increased the phosphatase activity, particularly when they are
applied to soils which are inherently low in organic matter content. They also recorded that this effect was more pronounced when the texture remained silty or clayey in nature and that similar effects cannot be expected in a sandy loam soil. Baligar et al. (1998) observed a decline in phosphatase activity with increasing sampling depth which they attributed to low organic matter content at lower depth. Rogar et al. (1998) compared the activity of the alkaline phosphatase enzyme in soil under three situations viz., on application of compost, on application of ammonium nitrate and when the soils were left unfertilized. According to them, the maximum enzyme activity was supported when compost application was practiced.

Rao and Tarafdar (1998) reported that legume straw incorporation resulted in the higher production of phosphatase which could be due to the presence of some stimulatory compounds present in it. According to Schneider et al. (2000) the presence and activity of acid phosphatase played a key role in phosphorous mineralization, phosphorus nutrition of plants and phosphorous cycling in soil. They further indicated that several factors like temperature, pH, application of fertilizers and organic matter influenced the activity of phosphatase. Enhancement of acid phosphatase activity to the extent of 46 per cent and increase of alkaline phosphatase activities to the extent of 61 per cent due to non till in the surface layer indicated that these enzymes are sensitive to disturbance (Balota et al., 2004).

2.6.4. Dehydrogenase

Dehydrogenase being an indicator of soil microbial activity is highly sensitive to management practices such as fertilization, addition of amendments such as lime, manures and compost and also to the seasonal variations. According to Ross (1970) dehydrogenase activity scaled down when the soil was air dried at room temperature and stored. Dehydrogenase are considered to play an essential role in the initial stages of the oxidation of soil organic matter (Ross, 1971) by transferring hydrogen and electrons from substrates to acceptors. Many different intracellular enzymes or enzyme systems contribute to the total soil dehydrogenase activity. According to Pancholy and Rice (1972) the dehydrogenase activity came down heavily when the soil was stored in moist conditions at 4°C.
Dehydrogenase is considered as one of the best indicators of microbial activity since it occurs only within living cells, unlike other enzymes which are mostly extracellular (Burns, 1978).

Bolton et al. (1985) compared the dehydrogenase activity existing in conventional and organic systems and concluded that the dehydrogenase activity (DHA) was higher in the organic systems. Dehydrogenase enzymes play a significant role in the biological oxidation of soil organic matter by transferring protons and electrons from substrates to acceptors. These processes, being a part of respiration pathways of soil microorganisms, are also closely related to soil air-water conditions (Glinski and Stepniewski, 1985).

The contamination by heavy metals arising from sludge applications had high inhibitory effect on the dehydrogenase activity (Reddy et al., 1987). Sparrow and Cochran (1988) compared the enzyme activity with microbial biomass and reported that changes in dehydrogenase activity was more closely associated to microbial biomass changes than changes in either phosphatase or urease activity. Doran (1990) reported that various tillage practices affect microbial biomass and consequently intracellular dehydrogenase activity was reduced.

Soil dehydrogenase activity is often used as a measure of any disruption caused by the influence of pesticides or trace elements or management practices. (Wilke, 1991; Frank and Malkomes, 1993). Beyer et al. (1993) reported the importance of soil type, physicochemical properties and crop management or cultivation practices in regulating the dehydrogenase activity. According to Reicosky et al. (1995) the dehydrogenase activity was apparently high in the conventionally tilled field than in the no tilled field. Dick (1994) reported that the only enzyme that reflects activity of viable cells in soil is dehydrogenase, and is not seen to be stabilized in soil complexes. Ross et al. (1995) reported the influence of various methods of tillage on the activity of dehydrogenase in soil. According to them, the activity was regulated by many factors that supported the microbial population. Kumar and Kapoor (1995) reported that there was tremendous shift in dehydrogenase activity as a result of variation in soil pH and that the activity generally declined with increasing pH, particularly in soils when the pH ranged between 9.5 and 10.0. Baligar et al. (1997) associated the dehydrogenase activity with many soil parameters either positively or negatively. They found that the major soil factors that regulate the
activity of the enzyme were, content of moisture, quantum of organic carbon, total nitrogen, soil texture, forms of phosphorous and sulphur, CEC besides existing ratio of magnesium to calcium in the soil.

According to Cooper and Warman (1997) the application of well rotten compost enhanced dehydrogenase activity in a silty clay soil than the independent application of either other manures or fertilizers. Similarly Tateno (1998) also observed an increased activity of dehydrogenase due to the application of poultry manure in a clay loam soil. Fraser et al. (1998) observed that in a sandy loam soil, the dehydrogenase activity was more linked with the levels of available organic carbon in soils. Dehydrogenase activity increased with increasing age of forest growth. According to them, this could be due to increasing plant cover which indirectly provided greater amount of litter for incorporation into the soil (Maithani et al., 1998). Soil dehydrogenase activity exhibited a strong negative relationship with Eh and a positive relationship with Fe$^{2+}$ content, suggesting that aeration status is the major factor determining the activity (Wlodarczyk et al., 2002). The activity of dehydrogenase is considered to be an indicator of the oxidative metabolism in soils and thus of the microbiological activity, because it is exclusively intracellular and, theoretically, can function only within viable cells (Mohammadi, 2011a).

2.6.5. Nitrogenase

In any nitrogen fixation mechanism, the reduction of molecular nitrogen to ammonia is catalyzed by the nitrogenase enzyme system. Nitrogenase is extremely sensitive to the presence of oxygen. Leghaemoglobin binds to oxygen and facilitate oxygen free areas within the roots of plants where the bacterial nitrogenase can become active. Roper et al. (1994) reported that the application of nitrogenous fertilizer depressed nitrogenase activity and that cultivation encouraged its activity compared to the zero tillage conditions. Seneviratne and Jayasinghearachchi (2005) identified that the presence of low sulphate ions concentration in the soil is conducive for enhanced nitrogenase activity.

2.7. Factors influencing the enzyme activity in soil

2.7.1. Organic matter

Plant roots, exudates a wide range of organic substances that act as a substrate for certain group of microorganisms. These exudates influence biological and
chemical properties of soil and are important in plant nutrition and sometimes in the control of root diseases (Rovira, 1969). The reason for higher organic matter levels supporting greater microbial activity has been identified by Dick (1994) where he argued that organic matter besides supplying greater amounts of energy and nutrients, provided greater amount of humic content, which facilitated the incorporation of soil enzymes into the soil matrix and thereby allowing stabilization of higher exo enzymes in soils. Deng and Tabatabai (1997) observed that higher organic matter content provided a better and congenial environment for stabilization and protection of extra cellular enzymes. Taylor et al. (2002) observed strong positive correlation not only between bacterial abundance and enzyme activities but also with organic matter content. Fontaine et al. (2003) observed that an increase in soil organic matter decomposition rate was associated with fresh organic matter input to soil. This often resulted in general increase in microbial activity particularly due to the higher availability of energy obtained from the decomposition of fresh organic matter.

The biodegradability of water soluble or dissolved organic matter is considered a crucial factor in soil organic matter dynamics because most microbial transformation processes involve the soluble phase (Marschner and Kalbitz, 2003). According to Schimel and Weintraub (2003) soil organic matter decomposition is catalyzed by extra cellular enzymes that are produced by microorganisms. Allison and Jastrow (2006) opined that extracellular enzymes degrade complex organic compounds and contribute to carbon turnover in soils. Nayak et al. (2007) observed that soil organic carbon content showed highly significant positive correlation with dehydrogenase and urease and cellulase in a long-term application of compost under continuous rice growing field. Cepeda et al. (2007) indicated that the soils containing very low amount of organic matter offered very poor activity of all the enzymes irrespective of the temperature regimes in soil. The term ‘recalcitrance’ is used to describe the phenomenon by which plant tissues exhibit the natural resistance against microbial and enzymatic deconstruction (Himmel et al., 2007).

Wichern et al. (2007) reported that release of available carbon compounds in the rhizosphere particularly from roots controlled the microorganisms, which in turn regulated the nutrient mobilization. Bachmann et al. (2008) considered several schools of thought for protection of organic matter in soil. According to them, physical protection of soil organic matter is achieved through occlusion within
aggregates or within small pores. Chemical protection is managed through interaction with mineral surfaces or with other organic molecules. These mechanisms are considered important because they reduce the bioavailability and accessibility of organic matter not only for soil microorganisms but also to soil enzymes. Hancock et al. (2008) in his hypothesis indicated that soil carbon formation would be highest in soils with the highest clay contents (clay loam) and lowest in the soil with the highest sand content (sandy loam).

2.7.2. Nitrogen

McLaren et al. (1975) pointed out that there was a positive and significant correlation between the urease activity, organic matter and total nitrogen contents of soil. Field experiments with various types of cover crops and fertilizers have shown that the amount of fertilizer, especially nitrogen, required by young rubber trees can be reduced after the third or fourth year from planting if a good legume cover is maintained (Broughton, 1977).

Anderson et al. (2004) reported that in the forest litter layers, the cellulase activity was significantly and positively related to the C:N ratio, indicating that enzyme activities decreased with increasing nitrogen availability. Deforest et al. (2004) observed that high levels of inorganic nitrogen are known to suppress the expression of phenol oxidase, an important lignin-degrading enzyme produced by white-rot fungi. According to them, nitrogen addition reduced phenol oxidase activity by 83 per cent and peroxidase activity by 74 per cent when compared to control soils. According to Lucas et al. (2007) the activity of many extracellular enzymes which are associated with lignin degradation, decreased following the addition of inorganic nitrogen in soils.

2.7.3. Phosphorous

The activity of phosphatase enzymes was negatively correlated with the concentration of phosphorous in the soil (Allison et al., 2007). According to Araujo et al. (2008) plant growth under phosphorous deficient conditions can be improved by the activity of phosphatase in roots which hydrolyse organic phosphorous sources in the soil to facilitate phosphorous acquisition. However, according to them, role of these enzymes for internal plant metabolism at limited phosphorous conditions is not very clear.
2.7.4. pH

Rovira (1969) reported that the observed drop in pH in the rhizosphere could be either due to the release of H\(^+\) from roots or due to the exudation of low molecular weight organic acids from plant roots or from associated rhizosphere microorganisms. According to Alexander (1977) soil pH is a crucial factor that determines the microbial growth and activity. The optimum pH range of 4.5 and 6.1 was preferred for the growth of bacteria and fungi.

Baligar et al. (1999) reported that they could hardly see any significant correlation between enzyme activities and soil pH except that for phosphatase. Kang and Freeman (1999) reported that observed variations in acid phosphatase activity in soil was correlated closely with soil temperature, soil water content, and pH. Renella et al. (2005) reported that the alkaline phosphatase was more sensitive in the acid and neutral soil whereas the acid phosphatase was more sensitive in the alkaline soil. Wittmann et al. (2004) identified that the pH range of 3-4 was optimum for hemicellulose and cellulose hydrolyzing enzymes. According to Wang et al. (2006) an increase in acidity significantly lowered soil alkaline phosphatase activity and nitrification potential. On the contrary, an increase in acidity enhanced the acid phosphatase activity. Mohammadi (2011b) reported that soil factors like redox potential (Eh) and pH can affect the rate of enzyme mediated reactions by influencing the redox status and ionization. These factors also determine the solubility of enzymes, substrates and cofactors. According to him some enzymes might predominate at specific pH levels.

2.7.5. Fertilizer application

Yogaratnam and Perera (1981) speculated that the higher urease activity in traditional rubber growing areas could in part be due to continuous use of urea as a nitrogen fertilizer which in turn have resulted a proliferation of microorganisms responsible for the release of urease enzyme.

Microorganisms are used by earthworm as a secondary food resource, and that passage through earthworm gut decreases the total soil microbial biomass and increases the active components of microbial biomass (Zhang et al., 2000). Chu et al. (2007) reported that long-term fertilization greatly increased soil microbial biomass carbon and dehydrogenase activity and the effect was significantly higher under
balanced fertilization than imbalanced fertilization. According to them, organic manure had a significantly greater impact on the biomass carbon and the dehydrogenase activity, compared with mineral fertilizers.

Nayak et al. (2007) showed that soil pH was lowest in the inorganic fertilizers amended plots and highest in compost amended plots. Fertilizers may meet up the demand of mineral nutrition required by the microbes but not that of carbon, which is a major component of microbial cells. Integrated application of organic and inorganic materials provides a balanced supply of mineral nutrients as well as carbon. (Mohammadi, 2011a).

2.7.6. Season

Seasonality in enzyme activity may be associated with the factors that regulate various enzyme systems. Acid phosphatase is regulated primarily by microclimate and soil chemical factors, whereas lignocellulose degrading enzymes such as glucosidases and phenol oxidase are more regulated by substrate availability (Sinsabaugh et al., 1992). Rogers and Tate (2001) observed that seasonal variability was found in bacterial populations and dehydrogenase activity, but not in microbial biomass.

The time taken for the decomposition of plant litter varies in different regions, where seasonal influences dominate. The rate of decomposition of plant litter in temperate regions is slower than in other regions while decomposition rate in the tropics is generally more rapid (Tang et al., 2005). Seasonality is one factor that is believed to affect the fungal community. Studies on the diversity of fungi in leaf litter suggest that the communities vary according to the seasons (Kennedy et al., 2006). Zornoza et al. (2006) showed that urease and phosphatase activities were hardly affected by air-drying of soils. Masto et al. (2006) reported that phosphatase activity was influenced more by seasonal or crop variations than fertilizer treatment.

2.7.7. Microbial Biomass

The microbial biomass is defined as the part of organic substance in the soil that consists of living organisms. In the soil only 2–30% of the microbial mass is living biomass (Anderson and Domsch, 1978). Naseby and Lynch (1997) observed that microbial biomass as well as the measured enzyme activities decreased with depth. However, for acid phosphatase, the activity was more or less same at all
depths. Bandick and Dick (1999) reported that 40 to 60 per cent of enzyme activity can come from stabilized enzymes, so activity does not necessarily correlate highly with microbial biomass or respiration. Hence, enzyme activity is the cumulative effect of long term microbial activity and activity of the viable population at sampling.

According to Sharma et al. (2000) limitations of carbon source influenced both microbial population and enzyme production. Sinsabaugh et al. (2002) reported that the turnover and mineralization of litter residues depended on many biological processes that are operating in soil. Again, the role of microorganisms is significant in ensuring recycling of nutrients. They further added that, majority of the plant biomass is comprised of insoluble compounds which necessarily need enzymatic activity to initiate decomposition. Maria and Sridhar (2004) indicated that, the number of fungi population observed during the mature stage of decay of organics was always much higher than at any other stage. Allison and Vitousek (2005) observed that soil microbes produced extra cellular enzymes which facilitated the mineralization of organic matter ensuring the release of both carbon and nutrients that could further be assimilated. Elevated CO$_2$ concentration in the upper 5 cm of the soil resulted in the enhancement of certain enzyme activities but failed to bring in any change in microbial biomass (Kandeler et al., 2006). The rhizosphere soil always had higher biological activities than non-rhizosphere soil (Wang et al., 2006).

Lucas et al. (2007) observed that soil microbial communities get altered in different ways consequent to the application of fertilizer treatments. Soil fungi were observed to decrease with increased inorganic nitrogen supply. They also observed that the fungal population increased with the application of organic sources. According to Demoling et al. (2007) the most common limiting factor in soil for bacterial growth was carbon, although there had been reports of limitation by other nutrients like nitrogen and phosphorous. They further indicated that mere addition of nitrogen to soil always decreased bacterial growth rates while similar addition of phosphorous had little effect. However, combining carbon sources and nitrogen had resulted in enhancement of bacterial growth rates. Mohammadi (2011a) explained that microbial biomass and soil enzyme activity is sensitive in discriminating between organic fertilizers and inorganic fertilizer application on a short-term basis. He further added that soil microbial biomass and enzymatic properties were also closely related with the carbon inputs.