Introduction

Tea crop

Tea is the most popular, inexpensive beverage throughout the world because of its characteristic aroma and flavour produced from the shoots of the commercially cultivated tea plants \([\text{Camellia sinensis} \ (\text{L.}) \ O. \ Kuntze]\). Tea is grown in more than 50 countries, mostly as plantation. It prefers a warm humid climate with well distributed rainfall and long sun shine hours. India with around 4, 40,000 ha under tea cultivation is the largest producer and consumer of black tea in the world. The world annual tea production reaches 2.5 million tonnes and an average of 2 billion cups of tea is consumed every day (Baby, 2004). In India, tea is cultivated in the north eastern region particularly Assam and West Bengal, besides in certain pockets in Himachal Pradesh and Uttar Pradesh. Tea gardens of southern India are spread in Western Ghats in the three states of Karnataka, Kerala and Tamil Nadu. Variables such as soil, altitude, weather and manuring practice affect the quality of tea.

Among the various plantation crops, tea requires relatively higher quantum of nutrients. Constant uptake of nutrients to produce more yields resulting in depletion of nutrient from the soil. Nutrient management strategies in south India have undergone lot of changes over the years. The concept of manuring in tea is based on replacement theory, \(i.e.,\) nutrient utilized from the soil by the plant during its metabolism, is replenished to maintain the equilibrium of nutrients in tea soils. Hence adequate inputs of inorganic fertilizers are essential for sustainable yield. Depletion of soil nutrients by crop uptake occurs to produce more leaf materials and hence adequate inputs of nitrogenous and phosphatic fertilizers are essentially needed to obtain maximum leaf yield. Tea plantation system is involving the usage of chemical fertilizers especially nitrogenous and phosphatic ones to improve the soil fertility. Continuous use of chemical fertilizers resulted in the decline of organic matter content of the soil, leading to depletion of beneficial organisms in the soil and no single source of nutrient can meet the nutrient requirement for sustainable productivity of tea. This can be overcome by reducing chemical fertilizers and
supplementing with organic manure and biofertilizers. New fertilizers have necessitated to develop economically viable and eco-friendly farming practices utilizing the biological and organic sources to help and check the depletion of plant nutrients and to maintain soil fertility to achieve higher productivity.

Tea soil

Generally, tea soils differ widely in their geological origin and geographical formation. In India, tea soils are highly acidic, well-withered and rich loamy of great depth. South Indian tea soils, in nature, are lateritic and derived from granite and gneissick rocks and are classified as latosol (Verma et al., 2001). Though the soils of different part vary considerably, they are all sedimentary soils (Arunachalam, 1995), rich in nitrogen (Ranganathan and Natesan, 1985). Whatever may be their nature; all tea soils are distinctly acidic. It is governed by a number of physical, chemical and biological factors which in turn affect the root growth and productivity. So, structure of the soil has been regarded as the key to the soil fertility. The soil fertility status depends on organic matter possessed and retained in it which may be influenced very much by macro and micro nutrients levels through application of inorganic, organic fertilizers and beneficial microorganisms (Jayathilake et al., 2006). Moreover, tea soil contains certain limit of minerals which are not able to nourish the crop satisfactorily and they should be incorporated high for obtaining better yield and quality. Fertilizers are applied to soil to increase crop yields by providing two or more elements that are essentials nutrients for plant growth. It is one of the most important inputs for enhancing crop productivity. The investments on fertilizers are required regularly (every year) and return in definite (Verma et al., 2001).

Nitrogen is the most important element required by the plants. Even though about 80 per cent of Earth’s atmosphere composed of nitrogen, plants cannot directly utilize it. Plants can absorb nitrogen only in the form of nitrate nitrogen and ammoniacal nitrogen. Tea crop requires large amount of nitrogen for the growth and development of tender shoots. Nitrogen (N) is an important
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constituent of plants parts and plays a vital role in the physiology of the tea plant (Sedaghatoor et al., 2009). Potassium is the second major nutrient for tea after nitrogen. Among the minerals, potassium and nitrogen are required in large quantities than other elements. It is generally absorbed as K⁺ ions.

Potassium is mainly presents in the meristematic tissues and encourages the formation of strong root and enhances the ability of the plants to resist diseases and insect attacks, cold and other adverse conditions. Phosphorus is another major plant nutrient required in optimum amount for proper plant growth. Phosphorus is known to involve in a plethora of functions in the plant growth and metabolism. The cellular machinery is difficult to be imaged without phosphorus being involved in its metabolic continuity and even perpetuation. Only about 25 per cent of the phosphorus applied to the soil is available for the crops and the rest become unavailable due to chemical fixation with aluminum, iron in acidic soils (Karthikeyini, 2002). Indian soils are characterized by poor medium status with respect to available phosphorous.

Soil microorganism

Soil microorganisms makes the soil living and dynamic and also influence on its fertility status and productivity through nitrogen fixation, degradation of organic materials and nutrient release, solubilization of insoluble phosphorus, improvement of soil structure and soil reclamation. Though almost all the soil has various beneficial organisms, their population will most often be at suboptimal level. Hence their activity may not be sufficient to yield significant benefit to the plants. Further, the bioefficacy of all the strains may not be the same. Addition of potential strains of these organisms to the soil becomes essential in this context. The irrigation practice of tea plantation will immensely provides the activation of soil microbes and making the fertilizers use efficiency high during dry season. Further, their indiscriminate use leads to pollute the soil, environment and ground water. Microorganisms offer a biological system having evolved the fixation of nitrogen and phosphate solubilizing traits to acquire sufficient nitrogen and phosphorus respectively.
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Several soil bacteria, particularly those belonging to the genera *Azospirillum*, *Pseudomonas* and *Bacillus* possess the ability to fix nitrogen and convert the insoluble phosphate into soluble form by secreting organic acids (Thenmozhi, 2002) resulting improve minerals availability to the plants and higher growth.

**Biofertilizers**

Biofertilizers are apparently environment and farmers friendly renewable source of non-bulky, low cost organic agro-input. While *Rhizobium*, Blue Green Algae (BGA) and *Azolla* are crop specific, bio-inoculants like *Azotobacter*, *Azospirillum*, Phosphorus Solubilizing Bacteria (PSB), Vesicular Arbuscular Mycorrhiza (VAM) etc. could be regarded as broad spectrum biofertilizers. Since biofertilizers are based on renewable energy source they are cost effective, ecofriendly and are supplement to chemical fertilizers (Baby, 2006). For this, efficient strains of organisms have to be found out, mass multiplied and incorporated into soil. By the application of biofertilizers, the chemical fertilizers can be reduced considerably in the fertilizer schedule.

Biofertilizers is a major source of N and P inputs in tea. Biological N is attractive and economic source for meeting the N requirements of tea bush. Asymbiotic N fixers *Azotobacter* and *Azospirillum* are best suited for standing crop like tea. However, it is obvious that biofertilizers alone cannot meet the entire requirement of nitrogen in tea. It has been estimated that 20 – 50 kg N/ha. can be supplied by N fixers. Phosphates solubilizing bacteria (PSB) like *Bacillus* and *Pseudomonas* spp. plays important role in improving the efficiency of P nutrition for total growth of tea plant. They increase the solubility/availability of P which is already present in tea soil, but in an insoluble form. The PSBs can supply 30-50 kg P/ha. in tea for instant uptake (Baby, 2006). They are carrier based preparations containing beneficial microorganisms in a viable state. The demand for chemical fertilizers keeps on increasing widening the gap between the demand and supply. Such a gap would be difficult to bridge in the wake of the energy crisis. Therefore, the strategy for
improving agricultural production in developing countries should consider with nitrogen and phosphorus through microbial processes which can be accomplished through the application of biofertilizers. It is essential that only 50% of the applied nitrogenous fertilizer is utilized by the plants, the rest being lost by denitrification or leaching. Among the most promising organisms capable of colonizing roots and excreting this miracle process is the bacterium belonging to the genus *Azospirillum*. The use of biofertilizers in combination with chemical fertilizers and organic manure offers a great opportunity to increase the crop productivity with less cost at different growth stages of tea crop. Integrated schedule of biofertilizers with possible reduction of inorganic fertilizers in plantation crop like tea has not yet been explored.

**Benefits of bioinoculants**

Use of naturally occurring, free living bacterial species, which can protect and promote plant growth by colonizing and multiplying along the root surface/root cortex of the inoculated plant is said to be one such safe and suitable alternative (Mishra *et al.*, 2005). The organisms that establish positive interactions with plant roots and show observable benefits on the plant growth are collectively called as Plant Growth Promoting Rhizobacteria (PGPRs). The important traits of PGPRs include fixation of atmospheric nitrogen, solubilization of insoluble inorganic phosphates, production of plant hormones, siderophores, bacteriocins etc. These organisms also provide protection to plants against diseases by suppressing deleterious and pathogenic microorganisms (Mishra *et al.*, 2005). Biofertilizer preparations containing these organisms are very cost effective, pollution free and a potentially renewable source of plant nutrients, making an ideal partner and an excellent supplement to chemical fertilizers (Tennakoon, 2007). Biofertilizing agents control the plant pathogenic fungi directly as well as indirectly.
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Sensitivity of biofertilizers to organic and inorganic sources of fertilizers

The integrated nutrient management involves judicious blend of organic, inorganic and biofertilizers aiming at maximization of crop productivity and soil fertility. Integration of organic manures and biofertilizers is more emphasized for greater productivity. It is necessary that the organic and biofertilizers are compatible to each other for better performance. The application of chemical, organic and biofertilizers in a balanced manner can meet the nutrient requirement of the tea plant for sustainable productivity.

Utilization of biofertilizers and organic manures becomes essential at this juncture to maintain soil productivity and to supply nutrients to the plants due to its plant growth promoting and disease control abilities. So the synergistic/antagonistic nature among the chemical nutrients and biofertilizers are very much important. Formation of bacterium-mineral complexes upheld by extra-cellular polysaccharides, followed by mineral dissolution and potassium solubilization in the microenvironments within the complexes where lower pH and the presence of organic ligands promote interfacial reactions. The formation of bacterium-mineral complexes may also facilitate the contact between microbial cells and mineral crystals to increase reaction surface area time (Lian, 1998; Lian et al., 2002). Compatible ability of proven bioinoculants with reduced rate of organic and inorganic fertilizers could be efficient nutrition strategy to the tea crop for higher yield and better quality.

Integrated nutrient management in tea

The basic concept underlying the integrated nutrient management (INM) is the maintenance and adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. The appropriate combination of mineral fertilizers, organic manures, crop residues, compost of N-fixing crops varies according to the
system of land use and ecological, social and economic conditions and decreases in subsidy on fertilizers by Government have become the cause of concern to the government, fertilizer industry and farmers. Import of fertilizers to meet the growing demand has imposed a heavy foreign exchange burden on the country. In this context, it is considered necessary for an alternative renewable source of nutrient supply to the crops and as such emphasis has been given to the fertilizers of the biological origin. The biofertilizers and green manures are used in agriculture to combat the ill effects of chemical fertilizers. It is necessary to adopt an integrated nutrient supply system by means of judicious combination of fertilizers, organic manures and biofertilizers, which are basic features of INM.

Fertilization of tea fields is one of the most important activities in tea cultivation and fertility problems are greatly solved by addition of mineral fertilizers. The high cost of chemical fertilizers, the deep gap between supply and demand and their adverse effect on environment have led to look for alternate strategies. Hence, nowadays interest has been shifted to environmentally safe and economically viable alternatives for crop production. Hence to meet the increasing demand, the crop production has to be increased per unit area of land. Man made fertilizers containing nitrogen, phosphorus and potassium, increased the output of agricultural products. Therefore, the strategy for improving agricultural production in developing countries should consider supplementing nitrogen and phosphorous through microbial processes. This can be accomplished through the application of biofertilizers.

Biofertilizers improve soil fertility and promote plant growth and they are broadly classified into nitrogen fixers, phosphate solubilizers and phosphate mobilizers and organic matter decomposers. They enhance certain biological processes by which the nutritionally important elements make available to the plants (Baby, 2002). Tea is a non-leguminous crop which hosts colonizing asymbiotic nitrogen fixers and phosphate solubilizing bacteria in its rhizosphere. The increased uptake of nutrients from soil due to the application
of chemical nutrients and biofertilizers might have produced enough carbohydrate in leaves for translocation to the sink for maximum productivity.

**Importance of INM in tea:**

As in case of any crop plant, there is need for supply of fertilizer nutrients to the plantation crops for their growth and nutrition management. The volume of green leaves of tea plantation crops being high (e.g. tea leaves) the volume of total nutrients demand of and supply to the plantation crops are very high. Heavy use of chemical fertilizers (and pesticides) in plantation crops is a threat to the environment and ecology, especially for the hill ecosystems and deserves containment. The potential downward flow of the chemicals through leaching, run-off etc., multiplies the risk factor a few fold. The residues that remain in plant and soil are added threats to health and environment, these threats can fragile ecosystems under or over the plantation crops, such as tea, generated from dumping of chemicals-fertilizers can be contained without compromising economic yield by adoption of an alternative strategy of growth and nutrition management with biological (Chadhuri, 2006).

So far, tea plantation mainly depends on chemical fertilizers which resulted in decline in organic matter content, soil borne beneficial microorganisms, affects the fertility status and soil tilth. Increasing cost of fertilizers and their high demand in supply, plantations were forced to review the nutrient management and crop productivity. To overcome the prevailing situation, certain strategies were outlined which include reduction in chemical fertilizers application without affecting the yield and supplementing the soil with organic manures and bioinoculants. Moreover, escalating cost of agro inputs, yield stagnation and a threat on fertilizer subsidy withdrawal are certain other limiting factors which geared up the work on exploitation of PGPRs not only in mature tea and also the young plants in replanted area.
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Effect of INM on tea quality

Made tea is generally processed from apical buds of 2-4 tender leaves. Thus the flavor and quality of manufactured tea is largely affected by abundance of chemical constituents and their relative composition in young shoots. The quality and yield of made tea broadly depends on the composition leaves, which in turn is influenced by nutritional practices. The chemical constituents, which greatly affect the flavor of made tea, are derived from metabolic pathways of biosynthesis during the growth of young shoots (Ruan, 2005). Mainly the organic based nutrients provide the high quality over other sources of nutrients, whereas the inorganic fertilizers supply major and minor nutrients to nourish the tea crop meanwhile retain the quality. Integrated application of biofertilizers with possible reduction in use of inorganic and organic fertilizers substantially achieves the better tea quality without any loss in yield too. Each and every minerals are very much related to quality attributes of made tea which influenced by various sources and doses of nutrient supply in tea plantation.