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Review on integrated nutrient management of tea (*Camellia sinensis* L.)

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Abstract: 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 [Camellia sinensis (L.) O. Kuntze]. Tea is grown in more than 50 countries, mostly as plantation. The principal categories of tea—green, black and oolong—originate from a single tea plant, *Camellia sinensis L.* a white-flowered evergreen. The appropriate combination of mineral fertilizers, organic manures, crop residues and 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 the government have become the cause of concern to the government, fertilizer industry and farmers. The world has been shifting to environmentally safe and economically viable alternatives for crop production. Hence, to meet the increasing demand of tea, crop production has to be increased per unit area of land. Manmade fertilizers containing nitrogen, phosphorus and potassium have 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. It can be accomplished through the application of biological

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PUBLIC INTEREST STATEMENT

Tea (*Camellia sinensis L.*) is an aromatic beverage commonly prepared by pouring hot or boiling water over cured leaves of the tea, an evergreen shrub (bush) native to Asia. After water, it is the most widely consumed drink in the world. This perspective review article focused on the use of fertilizing materials to improve the production and quality of tea plants in the world. Rather than using inorganic fertilizers, there is now a global shift to environmentally safe and economically viable alternatives for good production. Hence, to satisfy the growing demand of tea, we need to aim at increasing production within a small area. Therefore, the strategy for improving agricultural production in developing countries should consider supplementing nitrogen and phosphorous through microbial processes. It can be accomplished through the application of biological fertilizers (organic). With this, the present review concentrated on the integrated nutrient management of the plant.

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Subjects: Agriculture & Environmental Sciences; Botany; Soil Sciences

Keywords: organic fertilizer; tea plant; soil fertility; and integrated nutrient management

1. Introduction

The original home or "the primary centre of origin" of tea was Southeast Asia, i.e. at the point of intersection between the 29o N (latitude) and 98o E (longitude) near the source of the Irrawaddy river at the confluence of Northeast India, North Burma, Southwest China and Tibet provinces. Tea thrives well within the latitudinal ranges between 45o N and 34o S that cross about 52 countries. Tea is the oldest, most popular, non-alcoholic caffeine-containing beverage in the world (Monda et al.,2004). Chinese were the first to use tea as a medicinal drink, later as beverage, and have been doing so for the past 3000 years (Eden, 1958). From the earliest times, tea has been renowned for its properties as a healthy, refreshing drink. The modern term "tea" derives from early Chinese dialect words such as *Tchai, Cha* and *Tay* used to describe both the beverage and the leaf. Tea was introduced to Japan in 805 AD as a medicine by Zen Buddhist missionaries because of its meditation-enhancing properties. In 1484, the sacred Japanese Tea Ceremony was introduced.

In the 1500s, tea arrived in Portugal, as the Portuguese were the first to establish trade relations with China. In the 1600s, the French and the Dutch served tea in restaurants and introduced tea to America by exporting through the Dutch colonists. Ironically, the British, who are known as a great nation of tea drinkers, were the last of the seafaring nations to be introduced to tea drinking. It was after its good distribution in Asian countries that tea was introduced to Africa. It was first successfully introduced to Nyasaland (now Malawi) in 1886, and the first estate was planted in 1891. Tea was introduced to East Africa in the beginning of the twentieth century, which led to commercial production in the 1920s and 1930s in Kenya, Tanzania and Uganda. Briefly, it was first planted in East Africa in 1900 in Entebbe in Uganda. The growth of the tea industry was initially slow, and by 1925 there was only 130 ha of production area in East Africa (Mondal et al., 2004).

Compatible properties of beneficial organisms with synthetic and or organic fertilizers could be very much useful to agriculture crops for higher yield and healthy soil environment. The NK mixture at a lower dose supported bioinoculants, whereas a higher dose suppressed them. Similarly, the populations of *Azotobacter* and *Azospirillum* in the soil after harvest were markedly increased with the integrated use of biofertilizers, organic manure and chemical fertilizer system and were reduced with the exclusive application of chemical fertilizers (Rao & Venkateswaralu, 1985a, 1985b).

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. 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 nutritionally important elements are made available to the plants (Lian, 2002). Tea is a non-leguminous crop that hosts colonizing asymbiotic nitrogen fixers and phosphate-solubilizing bacteria in its rhizosphere (Katznelson, 1965). 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. Literature reviews that focus on INM in tea plants are barely available, and hence the objective of this paper is to review INM of tea plants (Heydorn, 1988).

2. Literature review

2.1. Tea production in the world

The world's total tea-growing area in 2003 was 2.41 million ha, with an annual production of a total of 3.21 million tons of tea. In the same year, countries with world tea-growing area coverage were India (18%), China (37%), Sri Lanka (9%), Kenya (6%) and others (30%), and the leading tea-producing countries, with percentage of world tea production, were India (28%), China (25%), Sri Lanka (9%), Kenya (9%) and others (29%). The principal types of tea produced and consumed in the world are black and green tea, with small amounts of other types. The major tea producers are India, China, Sri Lanka and Kenya, while the major consumers are India, China, Turkey, Japan, Russia and the United Kingdom. The largest annual consumption per capita (kg head^{-1} year^{-1}) is Ireland (2.71), followed by Libya (2.65), Kuwait (2.29) and the United Kingdom (2.28). Other countries consuming more than 2 kg per capita per year are Iraq, Qatar and Turkey (Ruan, 2005).

The major tea-producing countries in Africa include Kenya, Malawi, Tanzania, Zimbabwe and South Africa, together producing about 25% of the world exports amounting to some 250,000 tons of tea per year. Most recently, Eastern Africa has emerged as a major force among tea growers producing excellent teas, which are used for blending all over the world. In Ethiopia, during 2004–2005, a total of 5,387 tons of black tea was produced, which constitute only 0.14% of the world tea production. Of the 5,387 tons of tea produced, 56.7% was consumed domestically, while 43.3% was exported for world market (Buchmann, 2005).

2.2. Chemical composition of tea

The most commonly known antioxidants are vitamins C, E and β-carotene, found in fruits, vegetables, cereals and some vegetable oils. The amount and type of flavonoids in tea depend on the variety, the amount of tea used in the pot or cup, and brewing habit. The chemical composition of tea leaves and manufactured tea is very complex and consists of tanning substances, flavonols, alkaloids, proteins and amino acids, enzymes, aroma-forming substances, vitamins, minerals and trace elements (Kumar, Nair, Reddy, & Garg, 2005).

Various reports have discussed the potential health implications of trace metals in tea, particularly since tea bush is known to accumulate trace metals. It was pointed out that some of the beneficial effects of drinking tea are prevention of chronic and cardiovascular disease, cancer, antioxidative detoxification and removal of cadmium in administered rates (Behera et al., 2007; Ranganathan, & Natesan, 1985).

To date, few negative effects have been reported from drinking green tea. One is insomnia, due to the fact that it contains caffeine. On the other hand, tea leaf contains approximately 8% toxic substances. The toxic elements in tea quietly and gradually affect the body parts and permanently damage them. The toxic effects of most metals can be traced to their ability to disrupt the function of essential biological molecules, such as proteins, enzymes and DNA. In some cases, this involves displacing chemically related metal ions that are required for important biological functions such as cell growth, division and repair. www.miyerbamate.com

2.3. Biofertilizers

Biofertilizers are apparently environment- and farmer-friendly renewable sources of non-bulky, low-cost organic agro-input. While *Rhizobium*, blue green algae (BGA) and *Azolla* are crop specific, bioinoculants like *Azotobacter, Azospirillum*, phosphorus solubilizing bacteria (PSB), vesicular arbuscular mycorrhiza (VAM), and so on could be regarded as broad spectrum biofertilizers. Since biofertilizers are based on renewable energy sources, they are cost effective, eco-friendly and act as supplements to chemical fertilizers (Baby, 2006). For this, efficient strains of organisms have to be found out, mass multiplied and incorporated into the soil. By the application of biofertilizers, the chemical fertilizers can be reduced considerably in the fertilizer schedule.

Biofertilizer is a major source of N and P inputs in tea. Biological N is an attractive and economic source for meeting the N requirements of tea bush. Asymbiotic N fixers *Azotobacter* and *Azospirillum* are best suited for standing crops 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. PSBs like *Bacillus* and *Pseudomonas* spp. play an important role in improving the efficiency of P nutrition for the total growth of tea plants. 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).

2.4. Mechanism of nitrogen fixation

Biological nitrogen fixation by non-symbiotic nitrogen-fixing bacteria like *Azotobacter* and *Azospirillum* requires a complex enzyme system since the reaction is highly endergonic and it is widely being exploited all over the world for non-leguminous crops. *Azospirillum* is a rhizospheric bacterium colonizing the roots of crop plants in large numbers, making use of root exudates and fixing substantial amounts of atmospheric nitrogen. The protons and electrons required for this process are generated in metabolic reactions and catalysed by an enzyme nitrogenase. It is found only in prokaryotic microorganisms and thus eukaryotes can benefit from nitrogen fixation only if they interact with nitrogen-fixing prokaryotes to obtain the fixed nitrogen after their death and decomposition. Nitrogenase enzyme is highly essential for reducing nitrogen to ammonia and is composed of Fe (dinitrogenase) and Mo-Fe protein of nitrogenase, which have been sequenced and characterized from a variety of nitrogen-fixing bacteria (Burgess & Lowe, 1996).

Okon and Vanderleyden (1997) exerted the beneficial effects of *Azospirillum* on the growth and yield of many economically important crops. They are extensively used in rice and other cereal crops as biofertilizers (Singh, 2010). These are free-living bacteria and fix atmospheric nitrogen in cereal crops without any symbiosis. Many *Azospirillum* strains produce plant hormones both in liquid culture and in natural situation. Colonization of *Azospirillum* in roots was known to be non-homogenous. The bacterial cells were observed throughout the entire root system of many plant species; however, they preferred root tips and the zone of elongation (Levanony, Bashan, Romano, & Klein, 1989).

The colonization of root tips was advantageous for *Azospirillum* cells because when the roots penetrate deeper into the soil layer, the oxygen supply was lower and competition with the aerobic bacterial population of the rhizosphere was therefore reduced; however, analysis of *Azospirillum* sites along the roots revealed that they are found particularly on young roots and much less frequently on the older parts of the roots (Cohen, Man, & Mazzola, 2004). They have the ability to produce antifungal compounds against many plant pathogens. They also increase germination and vigour in young plants, leading to an improved stand in crops.

2.5. Phosphate solubilizers

Phosphorus is another major element required for plant growth and higher yields. Rock phosphate is one of the basic raw materials for phosphatic fertilizers. Direct application of rock phosphate is limited to acidic soil, while in other types of soil the applied phosphate becomes insoluble within a short time. Monocalcium phosphates are converted to dicalcium phosphate, which is slowly available to plants. Under such conditions, a large amount of phosphorus is fixed in the soil, which is unavailable to the plants. The most efficient phosphate-solubilizing bacteria include *Bacillus* and *Pseudomonas* and those of fungi include species of *Aspergillus* and *Penicillium* (Baby, 2002).

The main mechanism in solubilizing insoluble phosphate by soil microbes is their ability to secrete organic acids. The organic acids bring down the soil pH, resulting in the dissolution of immobile forms of phosphate (Hedge & Dwivedi, 1994) and the production of organic acid by *Pseudomonas* strains decreases the soil pH, as reported by Rashid, Khail, Ayub, Alam, and Latif (2004). The effect of phosphate solubilizers on plants is attributed to P solubilization, along with other factors like release of phytohormones, supporting nitrogen fixation, mineralization and mobilization of other nutrients, antagonism to plant pathogens and promotion of plant growth-promoting rhizosphere microorganisms (Gaur, 1990). Furthermore, the potential of phosphate solubilizers in solubilizing P and mycorrhizae in mobilizing P made agricultural scientists ponder over the possibility of exploiting these organisms in the INM programme.

Pikovskaya (1948) made a pioneering attempt in isolating an organism capable of actively solubilizing tricalcium phosphate and coined the name "Bacterium P". Later, he had formulated a medium having glucose as the carbon source and ammonium sulphate as the nitrogen source with enrichment technique and special media for the isolation of acid-producing and phosphate-dissolving microorganisms from soils and rhizosphere. Mahmoud, Abdel Hafex, El—Secy, and Hanefy (1973) made a comparative study of the population of PSB in the rhizosphere of broad bean and wheat. Broad bean had more population of phosphate solubilizers than the wheat plants. Phosphate-solubilizing microorganisms were found in all soils, but their number varies with soil climate as well as history (Gupta, Bhardwaj, Marwah, & Tripati, 1986). Soil samples collected from the sugarcane-growing belt of north Bihar indicated that the population level of phosphate solubilizers ranges from 27 to 112 × 103 per gram of soil. This large variation in their distribution in different soils might be due to the differences in organic carbon content (Yadav & Singh, 1991).

Bacteria, fungi and actinomycetes are active in solubilizing insoluble inorganic phosphate with high efficiency. Parameters affecting the ability of PGPR to express different attributes include soil and environmental conditions, microbes–plant host interactions and microbes—microbes interactions (Dey, Pal, Bhatt, & Chauhan, 2004). De Freitas *et al.* (1997) assessed the potential use of P-solubilizing *Bacilli* and other rhizobacteria as biofertilizers for canola and reported that *Bacillus thuringiensis* isolate was the most effective inoculant, which significantly increased the number and weight of pods and seed yield without rock phosphate. Kundu, Gera, Sharma, Bhatia, and Sharma (2002) studied host specificity of phosphate-solubilizing bacteria isolated from different crop rhizospheres and observed greater establishment of the isolates in the rhizosphere of their respective crop plants than other plants.

2.6. Mechanism of phosphate solubilization

Phosphate-solubilizing microorganisms were found to produce mono carboxylic acids (acetic acid, formic acid), monocarboxylic hydroxyl acids (lactic, gluconic) dicarboxylic acids (oxalic, succinic), dicarboxylic hydroxyl acids (malic, maleic) and tricarboxylic hydroxyl acids (citric) in liquid medium from simple carbohydrates. A fall in pH accompanied phosphate solubilization due to the production of organic acids, but no correlation could be established between acidic pH and quantity of P_2O_5 liberated (Dave & Patel, 1999).

Kapoor, Mishra, and Kamlesh (1989) reported that organic acid produced and their quantity differ with different microorganisms. Tri- and dicarboxylic acids are more effective compared to mono basic acids and aromatic acids. Aliphatic acids are also found to be effective in P solubilization than phenolic acids, while citric acid and fumaric acid have the highest P-solubilization ability. The organic acid production by PSB is capable of solubilizing the inorganic phosphorus into the available state so as to nourish the crop. This is the main mechanism to achieve an acidic soil environment that retains higher phosphorus content, as reported by Rashid. et al. (2004).

2.7. Arbuscular mycorrhizae fungi (AMF)

The symbiotic association between plant roots and fungal mycelia is termed as mycorrhiza (fungal roots). AM fungi are known for their mutualistic association with most of the vascular plants and for helping in the absorption and assimilation of elements that are less soluble and nonavailable to the plants, i.e. P, Zn, Cu, etc., from the rhizosphere, thereby increasing the growth and productivity of the plants (Neelima, Gautam, & Verma, 2002).

These fungi are obligate symbionts and have not been cultured on nutrient media. AMF fungi infect and spread inside the root system. They possess special structures known as vesicles and arbuscules. The arbuscules help in the transfer of nutrients from soil to the root system, and the vesicles, which are saclike structures, store P as phospholipids. AM fungi colonize the root cortex of plants and develop an extrametrical hyphal network that can absorb nutrients from the soil. Enhanced plant growth due to arbuscular mycorhizae (AM) association was well documented by Bagyaraj (1984).

In addition, he reported that improved plant growth is attributed to increased nutrient uptake, especially of phosphorus, tolerance to water stress, root pathogens and adverse soil environments and production of growth-promoting substances. Mycorrhizal fungi enhancing the numerous activities of beneficial soil organisms like nitrogen fixers and phosphate solubilizers with consequential beneficial effect on plant growth have also been substantiated by Mahmoud et al., (1973) (). It has also been suggested that AMF stimulate plant growth by physiological effects other than the enhancement of nutrient uptake or by reducing the severity of diseases caused by soil pathogens.

The mycorrhiza helper bacteria are known to stimulate mycelial growth of mycorrhizal fungi or to enhance mycorrhizal formation. The microbiologically solubilized phosphate could, however, be taken up by a mycorrhizal mycelium, thereby developing a synergistic microbial interaction. Phosphorus (P) is added in the form of phosphatic fertilizers, part of which is utilized by plants and the remainder converted into insoluble fixed forms (Narsian & Patel, 2000). The contribution of their process to plant nutrition is unclear and because of the possible re-fixation of solubilized phosphate ions on their way to the root zone. Mycorrhizal colonization may alter the host root physiology, which may in turn influence the microbial population.

The flow of carbon from shoot to root may be increased by AM colonization, which may alter the carbon availability for bacteria in the rhizosphere. Furthermore, it is well known that root exudates strongly modify microbial composition and activity in the rhizosphere and AM fungi can modify the quantity and quality of root exudates (Andrade, Mihara, Linderman, & Bethlenfalvay, 1997). Mycorrhizal dependency of plant species is often related to the morphological properties of the root; the root system of neem, with short sparse root hairs, tends to make it more mycorrhiza dependent like several other tree species. The enhanced uptake of P in AM-fungi-inoculated seedlings may be due to an increase in the number of uptake sites per unit area of roots and a greater ability of these roots to exploit the soil nutrients (Bolan, 1991). AM fungi allow the root system to exploit a greater volume of soil P by (i) extending away from the roots and translocating P away from the root zone, (ii) exploiting smaller soil pores not reached by the root hairs and (iii) effective acquisition of organic phosphates by the production of extracellular acid phosphatases (Neelima et al., 2002).

Enhancement of uptake of phosphorus and other nutrients by fungal hyphae is the primary mechanism responsible for plant growth stimulation by AMF and improved shoot and root length (Hayman, 1980). However, AM fungi also help in the production of plant hormones such as cytokinins, IAA and IBA, all of which have a role in plant metabolic process. Studies by Muthukumar, Udaiyan, and Rajeshkannan (2001) indicated that microbial inoculations can substantially reduce fertilizer requirement in neem seedling production.

Moreover, mycorrhizal colonization may also alter the pH of the substrate through release of certain substances, which are not well documented (Filion, St-Arnaud, & Fortin, 1999). In addition, *A. brasilense* and phosphobacteria might affect plant growth as a result of their ability to synthesize plant hormones. The colony-forming units of *B. coagulans* and *T. harzianum* were also the highest when all three organisms were inoculated together and the least when these were inoculated alone (Jayanthi, Bagyaraj, & Satyanarayana, 2003).

2.8. Sensitivity of bioinoculants to agrochemicals used in tea

Compatible properties of beneficial organisms with synthetic and/or organic fertilizers could be very much useful to agriculture crops for higher yield and healthy soil environment. The NK mixture at a lower dose supported the bioinoculants, whereas a higher dose suppressed them. Similarly, the populations of *Azotobacter* and *Azospirillum* in the soil after harvest were markedly increased with the integrated use of biofertilizer, organic manure and chemical fertilizer system and were reduced with the exclusive application of chemical fertilizers. The nitrogen fixers present in the soil might have helped in increasing the various growth parameters by exerting their synergistic effect with inorganic fertilizers and biofertilizers (Ramanandan, Ravisankar, & Srihari, 2008).

Jayathilake, Reddy, Srihari, and Reddy (2006) indicated that INM with biofertilizer (*Azotobacter* and *Azospirillum*) in combination with 50% inorganic N through organic manure (VC or FYM) and the rest of the N, P and K through chemical fertilizer was considered the most useful for obtaining maximum yield with higher fertility status in the soil for onion cultivation. Chemical fertilizers as nutrient source may have a beneficial influence on microorganisms in the short run (Eno & Blue, 1954). However in due course, they may have adverse effects, especially on soil microflora by way of changes in soil properties. The lowest population of these bacteria in the soil applied with chemical fertilizers (control) may be due to the absence of organic media in the soil and no simulative effect to increase the bacterial population.

Hence, several attempts were made to substitute the synthetic fertilizers with biofertilizer, at least in part in an attempt to maintain the soil health by various workers with different crops. However, the literature pertaining to the use of organics and biofertilizers in crops, particularly in tea, is very much limited. The microbial activity showed satisfactory population in the soil under different levels of chemical fertilizer regimes in combination with biofertilizers (Karthikeyini, 2002).

The present observation indicated that the bioinoculants used were compatible with neem at 25% level of concentration, and they got inhibited by a higher dosage of neem. Bioinoculants can tolerate a particular concentration level, and when it is exceeded, it will be lethal to them. With the increase in concentrations of the neem extracts, a declining trend was noticed in the population level of bacteria. Also it explained that the integration of neem with bioinoculants at optimum concentration will help nutrient requirements of plants for sustainable agriculture under field and/ or nursery conditions of tea crop. Moreover, reports by Behera, Sharma, and Pandey (2007) explained that inoculation of biofertilizer strains with organic manure, e.g. neem cake powder, would give better population of target organisms and provide healthy soil environment than individual application.

Agrochemicals, especially pesticides, fungicides and herbicides, could be used for minimizing pest, diseases and weeds, respectively, in tea plantation. They proved their adverse effect on the growth of beneficial bioinoculants when mixed in the *in vitro* medium. The recommended dose of deltamethrin, quinolphos, COC and combination of glyphosate with kaolin used in tea plantation supported the growth of beneficial organisms. This may be because of biodegradation and bioremediation properties of those beneficial biological organisms to break up the hazardous chemicals that reside in the soil and consume energy from the agrochemicals. When they meet in the soil environment and they got seriously affected with agrochemicals whichever used for pest and disease control and it was evidenced with the report of Gadkari (1987), due to the incorporation of insecticides in the growth media causing either cell disruption or formation of cyst-like bacteria. The pesticides generally reduced the microbial population counts, and the inhibitory effect varied with different pesticides in tea soils (Bezbaruah, 1999).

Half of the recommended dose of NK and neem and the recommended dose of RP supported the growth of bioinoculants. Similarly, application of herbicides at very low concentrations significantly augmented the proliferation of aerobic non-symbiotic nitrogen-fixing bacteria in the rhizosphere, but at higher concentrations, the effect was negative (Debnath, Das, &

Muherjee, 2002). Studies by Pandey and Palni (1996) clearly showed the multiple benefits of the combined use of *Azospirillum/Rhizobium* with PSB plus RP or SSP, MOP and compost in sustaining higher yields, better N, P and Zn assimilation by crops and improved soil quality in acidic soil. These bacterial bioinoculants-based INM formulations with the incorporation of crop residues in a rain-fed cropping system promoted more biological nitrogen fixation, better soil aggregation and earthworm activities and thereby regulated better C and N dynamics in soils.

2.9. Sensitivity of biofertilizers to organic and inorganic sources of fertilizers

The INM 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 with each other for better performance. The application of chemical, organic and biofertilizers in a balanced manner can meet the nutrient requirements of tea plants for sustainable productivity (Patten and Glick, 2002).

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. Thus, the synergistic/antagonistic nature among the chemical nutrients and biofertilizers is very important.

Formation of bacterium-
mineralcomplexes is upheld by extracellular 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 the reaction surface area time (Lian, Fu, Mo, & Liu, 2002). Compatibility of the proven bioinoculants with a reduced rate of organic and inorganic fertilizers could be an efficient nutrition strategy for higher yielding and better quality tea crops.

2.10. INM in tea

The basic concept underlying 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 and compost of N-fixing crops varies according to the system of land use and ecological, social and economic conditions; decreases in subsidy on fertilizers by the 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 (Tennakoon 2007).

In this context, it is necessary to develop an alternative renewable source of nutrient supply for the crops, and thus emphasis has been given to fertilizers of biological origin. 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 the basic features of INM (Thenmozhi 2002).

Fertilization of tea fields is one of the most important activities in tea cultivation, and fertility problems are greatly solved by the 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 shifted to environmentally safe and economically viable alternatives for crop production. Thus, to meet the increasing demand, crop production has to be increased per unit area of land. Man-made fertilizers containing nitrogen, phosphorus and potassium have 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 nutritionally important elements are made available to the plants (Baby, 2002). Tea is a non-leguminous crop that 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.

2.11. Importance of INM in tea

As in the case of any crop plant, there is a need for supply of fertilizer nutrients to plantation crops for their growth and nutrition management. Since the volume of green leaves of tea plantation crops is high (e.g. tea leaves), the volume of total nutrients demand of and supply to the plantation crops is 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 by a few-fold. The chemical residues that remain in the plant and soil are added threats to the 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).

Now a day, tea plantation has mainly been dependent on chemical fertilizers, which has resulted in a decline in organic matter content and soil-borne beneficial microorganisms, affecting the fertility status and soil tilt. Because of the increasing cost of fertilizers and their high demand, 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 the threat to fertilizer subsidy withdrawal are certain other limiting factors that geared up the work on the exploitation of PGPRs not only in mature tea plants but also the young plants in replanted areas.

2.12. Effect of INM on tea quality

Manufactured tea is generally processed from the apical buds of two to four tender leaves. Thus, the flavour and quality of manufactured tea are largely affected by abundance of chemical constituents and their relative composition in young shoots. The quality and yield of manufactured tea broadly depend on the composition of leaves, which in turn is influenced by nutritional practices. The chemical constituents, which greatly affect the flavour of tea, are derived from metabolic pathways of biosynthesis during the growth of young shoots (Ruan, 2005).

Other than inorganic or mineral fertilizers 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 the use of inorganic and organic fertilizers substantially results in better tea quality without any loss in yield too. Each and every mineral is very much related to the quality attributes of manufactured tea, which is influenced by various sources and doses of nutrient supply in tea plantation (Sedaghathoor, Torkashvand, Hashemabadi, & Kaviani, 2009).

3. Conclusion

Tea is an aromatic beverage commonly prepared by pouring hot or boiling water over cured leaves of *Camellia sinensis*, an evergreen shrub (bush) native to Asia. Soil fertility has been described as the capacity of soils to make nutrients available to plants. The nutrient status of arable soils can be related to fertilization. Nutrient management in tea plantations is an important aspect, and nutrients are supplied mainly through chemical fertilizers. However, it is widely accepted that a balanced fertilizer application with efficient use of other inputs is the key to achieve higher crop production. Repeated and heavy applications of chemical mineral fertilizers lead to the deterioration of soil properties besides causing environmental damage. The application of organic manures and bioinoculants could minimize these problems as they are advantageous over chemical fertilizers in improving soil fertility. Thus, it is necessary to integrate three different sources of nutrients, *viz*., organics, chemicals and bioinoculants, for a more efficient and economical productive system in the long run. Bioinoculants are environmentally safer and a cost-effective supplement to chemical fertilizers. The use of organics and biofertilizers in tea crop is very much limited. Hence, there is an urgent need to study the influence of straight or integrated application of organic manure and biofertilizers with possible reduction of inorganic fertilizers on the yield and quality of tea.

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