Research Review Article

Indian Journal of Agricultural Sciences **85** (8): 987–95, August 2015/ReviewArticle

Sustainable banana (*Musa* spp) production through integrated plant nutrition system – A review

T K HAZARIKA[1], B P NAUTIYAL[2] and R K BHATTACHARYYA[3]

Mizoram University, Aizawl 796 004

Received: 11 December 2014; Accepted: 9 March 2015

ABSTRACT

Nutrient depletion is a reversible constraint and therefore high agricultural production can be realized with appropriate soil nutrient management. Careful manipulation of nutrient stocks and flows, in order to achieve satisfactory and sustainable level of agricultural production is the Integrated Plant Nutrient System (IPNS). IPNS is holistic and sustainable approach to attain the maximum profitability and cost benefit ratio for the farmers. It is nutrient saving, controls erosion and recycles crop residues, manures and other biomass or nutrient adding. Different IPNS packages have been reported to improve growth and yield of banana (*Musa* spp). Through combined application of chemical fertilizers, organic manures, bio-fertilizers and bio-control agents in IPNS have profound effect in improving quality parameters like total soluble solids (TSS), ascorbic acid, total reducing and non-reducing sugars of banana. It also improves the physical, chemical and biological properties of soil, especially the number of beneficial soil microflora. Considering the ill effects of chemical fertilizers, it is high time to use IPNS in banana cultivation instead of using chemical fertilizers alone. The paper reviews all the literature on various aspects of banana cultivation from the IPNS perspective for better understanding and future strategies for improved production as well as quality of banana.

Key words: Banana, Biofertilizers, Chemical fertilizers, Fruits, IPNS, Organic manure

Banana (*Musa* spp), family Musaceae, is the world's largest monocotyledonous, monoecious, monocarpic, perennial herb with 1 000 varieties in the world and is the fourth in the list of the developing world's most important food crops after rice, wheat and maize. With 55 million tonnes, production of desert banana is the second highest of all fruits in the world, just behind the oranges (Anonymous 2000).

Banana is a heavy feeder of nutrients for optimal growth, development and yield. Inorganic fertilizers generally supply the requirements of these nutrients. However, long term and indiscriminate application of inorganic fertilizers without sufficient integration of organic manures results in depletion of soil organic matter. This ultimately checks the microbial biomass of the soil profile and lost its biological dynamics and often results in extreme situations for the soil, crop and climate involved. An excess use of inorganic fertilizers could be the main cause of pollution in surface and ground water (Vandanashiva 1992). The fertile soils become degraded under the influence of indiscriminate and uncontrolled use of inorganic fertilizers. Romero (1998) pointed out that the intensive banana culture has caused a gradual decrease in soil fertility to such an extent that today 100% more fertilizer is required to produce the same yield that was previously obtained. The indiscriminate and imbalanced use of fertilizers in agriculture is the main reason behind depletion of productivity and loss of soil fertility (Swaminathan 1996).

In recent years, a new concept for utilization of available resources, viz. organic, inorganic and microbial inoculants with an integrated approach for sustainable economic yield termed as 'Integrated Plant Nutrition System' (IPNS) has emerged. The basic principle of IPNS is to maintain soil fertility to an optimum level, sustaining the increased productivity and improving farmers profitability through a judicious use of mineral fertilizers, organic manures, vermicompost and biofertilizers. The IPNS is ecologically sound and economically viable farming system that empowers economy and efficiency in fertilizer use and favourably affects the physical, chemical and biological environment of the soil (Tandon 1991).

In general, IPNS maintains soil fertility and 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

[1]Assistant Professor (e mail: tridip28@gmail.com), Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl; [2]Dean (e mail: bhagwatinautiyal@gmail.com), College of Horticulture, Uttarakhand University of Horticulture and Forestry, Bharsar, Uttarakhand; [3]Professor (e mail: ranjitkb2010@gmail.com), Department of Horticulture, Assam Agricultural University, Jorhat, Asom (e mail: ranjitkb2010@gmail.com)

(Yadav *et al.* 2011). The components of IPNS are less expensive, eco-friendly and sustainable and do not require non-renewable source of energy during their production. Considering the environmental and ecological problems and present energy crisis, IPNS has been gaining popularity all over the world.

The research works conducted throughout the world on the influence of IPNS on growth, yield, quality and economics of banana is therefore being reviewed in this paper.

IPNS on growth parameters of banana

Nutrients are the most important factor affecting vegetative growth of banana. Application of IPNS plays an important role in growth and development of the banana. Kumar and Shanmugavelu (1980) reported that, both soil and foliar application of nitrogen in combination with *Azotobacter* improved the growth parameters (plant height, girth, influence the leaf number, leaf area, phyllochron and sucker production) of banana significantly. *Azospirillum* inoculation in general enhanced the height and girth of pseudostem, leaf production and leaf area in cv. Poovan. Inoculation of *Azospirillum* with 75% of N also had significant effect on the vegetative parameters and reducing the phyllochron (Jeeva *et al.* 1988). The length, fresh and dry weight of roots of plants of cv. Dwarf Cavendish increased when plants inoculated with *Glomus fasciculatum* mycorrhizae (Umesh *et al.* 1988). Similarly, green manuring with *Sesbania rostrata* at 50 kg/ha improved plant growth characters, bunch characters, reduced crop cycle and compensated the extra cost leading to higher cost benefit ratio. Biofertilizers like *Azotobacter*, *Mycorrhiza*, *Phosphorine* induced greater vigour and faster development of banana plantlets and reduced the phase of pre-adaptation to field conditions by 15 to 20 days (Ruiz *et al.* 1992). Furthermore, a combination of 25% N as FYM + 50% as *Azadirachta indica* cake + 25% as urea reduced the crop duration of cv. Rasthali followed by application of 25% N as *Azadirachta indica* cake + 75% as urea (Prabhuram and Sathiamoorthy 1993). Gubbuk *et al.* (1993) obtained highest growth rate of cv. Cavendish with the integration of 80 g N/mat and 225 kg FYM/mat and a combination of 320 g N/mat with 150 kg FYM/mat for cv Basrai. Tissue-cultured banana plants enriched with organic manure resulted in greater plant growth and dry matter (Smith 1994). Alonso-Reyes *et al.* (1995) reported that when banana cv. Parecidoal Rey inoculated with *Glomus fasciculatum* and phosphate mobilizing bacterium (MOSP *Pseudomonas fluorescens*), increased plant height. Inoculated Williams banana with vesicular-arbuscular endomycorrhizae (VAM) and P fertilizer increased vegetative growth such as pseudostem length and number of green leaves (El-Demerdash *et al.* 1995). Likewise, Hemeng *et al.* (1995) obtained significantly higher plant height, girth and early flowering in plantain in poultry manure alone or poultry manure in combination with 25% inorganic NPK. Tissue cultured plantlets of cv. Giant Cavendish grown in an alluvial soil with 2% of organic matter and half of the recommended dose of fertilizer N was optimal to the physiological requirements of the entire crop cycle (Chiang *et al.* 1996). Dibut *et al.* (1996) investigated the potentiality of *Azotobacter chroococcum* as a nitrogen fixer and biostimulant for cv Giant Cavendish and Burro CEMSA. They reported that bacterial inoculation stimulated the plant height, number of leaves and shoots and pseudostem diameter after 6 months for Giant Cavendish and after 3 months for Burro CBMSA. Similarly, Roy and Yadav (1996) studied the effect of combined application of inorganic fertilizers with organic manures and reported that 25% FYM and 75% inorganic fertilizers not only improved vegetative growth but also shortened the time required for emergence of bunch. Combined use of *Azotobacter,* mycorrhiza and phosphorine as biological growth stimulant also reported to increase the dry weight of *in-vitro* plants and reduced the hardening stage (Ruiz 1997). Pinochet *et al.* (1997**)** found that inoculation with *Glomus intraradices* significantly increased growth of plants in relation to non-mycorrhizal plants. Inoculation of cv. Grand Naine with *Glomus mosseae (*Jaizme-Vega *et al.* 1998) and in combination with *Glomus aggregatum* (Jaizme-Vega and Pionchet 1997) encourages most of the growth parameters. Similarly, application of organic manure in combination with mycorrhizal inoculation resulted in increasing pseudostem circumference of Grand Naine banana (Smith 1998). Plant inoculation with *Azotobacter* enhanced infection and spore production by VAM. This synergistic interaction may lead to substantial increase in growth (Ischac and Mostafa 1998). Inoculation of suckers of cv. Giant Governor with *Azospirillum* with 50% recommended dose of N resulted in maximum plant height and leaf size (Tiwari *et al.* 1998). On the other hand, combined effect of commercial mixture of microorganisms containing N-fixing bacteria, humus-producing bacteria, moulds and algae improved pseudostem circumference and advanced the flowering time (Fernandez *et al.* 1998). In another experiment, 75% of recommended NPK with 2 kg of vermicompost recorded minimum number of days (236.30) for shooting and shortened the crop duration by 13.2 days over inorganic fertilizers in cv. Rajapuri (Athani *et al.* 1999).

El-Naby (2000) studied the effect of banana compost as an organic manure on the growth of Maghrabi cv. Banana compost enriched with 50 or 25% chemical fertilizer NPK + sulphur improved the vegetative growth of banana. Besides, the largest number of suckers also obtained with banana compost + 75% NPK + sulphur. Soliman (2001) observed that banana plants inoculated with free nitrogen fixing bacteria, mycorrhizal fungi and yeast increased the pseudostem height, total number of leaves and the dimensions of the third leaf from the top of plants. A foliar spray of active dry yeast at 1.0, 1.5, 2.0, 2.5 and 3.0 g/litre twice a year effectively increased pseudostem length and leaf area (El Shammaa 2001). El Aziz (2002) studied the effect of Biogein, Nitrobein and Microbein biofertilizers and organic manure (El-Neel) on growth and productivity of Williams banana and revealed that organic manure at 37.5 kg/stool/

year + 3 biofertilizers improved all the vegetative growth characteristics under observations. However, the highest values recorded for biogein followed by Nitrobein and Microbein at 100 g/stool. In addition, El-Moniem and Radwan (2003) studied the effect of phosphate solubilizing bacteria, *Azospirillum* spp. and *Pseudomonas* spp with reduced doses of chemical fertilizers (25, 50 and 75% NPK) on Williams banana and revealed that standard treatment (100% NPK) increased the length and diameter of pseudostem, number of green leaves and leaf area. The plants receiving 25 or 50% NPK plus biofertilizer showed slight increase in vegetative growth parameters. Likewise, treatment of 400 g N and 200 g microbein biofertilizer/ plant/year produced the maximum height and girth of pseudostem and total leaf area of Williams and Cavendish bananas (Hammam *et al.* 2003).

The treatments of 100% recommended dose of NPK +VAM + PSB + *Azospirillum* + *Trichoderma harzianum* and, 75% of RD of NPK + VAM + PSB + *Azospirillum* + *Trichoderma harzianum* in banana registered vigorous growth in terms of pseudostem height and girth, and leaf area (Kanamadi *et al.* 2004). Similarly, significantly higher plant height, plant girth, number of total and functional leaves and minimum days to shooting and maturity reported in banana cv. Dwarf Cavendish in VAM + 300 g N + 75 g P_2O_5 + 300 g K_2O treatment (Singh and Singh 2004). Babu and Sharma (2005) in another study reported the highest value of plant height and girth of banana under the treatment 100% NPK + 20 kg FYM + 10 kg *Azolla*. Likewise, the treatment of 50% NPK + 20 kg FYM + 10 kg *Azolla* recorded the minimum time requirement for shooting, maturity and shortest crop duration. The profound effect of IPNS reported on leaf emission rate, leaf senescence rate, total leaf production and crop duration of banana (Babu Ratan *et al.* 2008). Likewise, Athani *et al.* (2009) reported that combined application of inorganic fertilizers and vermicompost was advantageous in increasing the plant height, girth, number of functional leaves, leaf area and number of suckers in banana cv. Rajapuri. Again, the application of 100% recommended dose of NPK through inorganic sources + 10 kg FYM/plant + biofertilizer recorded the maximum plant height and stem girth in tissue cultured banana cv. Grand Naine (Bhalerao *et al.* 2009).

The inoculation of roots of banana plantlets with combination of nitrogen and plant growth promoting rhizobacteria (PGPR) as a bio enhancer and biofertilizer resulted into early flowering and increased the plant height, leaf area, leaf mineral content and bunch yield (Mia *et al.* 2010). Similarly, the inoculation of tissue cultured banana plantlets with N and PGPR improved shoot length and root length (Mia *et al.* 2010a).

IPNS and leaf biomass and nutrient contents

The integrated use of inorganic nitrogen and organic manure in Robusta banana crop triggered an increase in leaf phosphorus and nitrogen content than organic manure alone (Lyengar *et al.* 1984). Besides improving leaf morphology by mycorrhizal treatment of both Maghrabi and Hendi banana, fresh and dry weight of leaves also increased (El-Demerdash 1988). Jeeva *et al.* (1988) found that inoculation with *Azospirillum* with 100% nitrogen enhanced the leaf production and leaf area. El-Demerdash *et al.* (1995) indicated that the inoculated Williams banana with endomycorrhizae (VAM) and P increased leaf N, P and K contents. The addition of a liquid suspension from Retflopx 357, a commercial mixture of microorganisms to the banana cv. Dwarf Cavendish, increased phosphorus content in leaves (Fernandez *et al.* 1998). Inoculation of banana cv. Grand Naine plants with *Glomus mosseae* enhanced levels of leaf N, P, K, Ca and Mg in comparison with non-mycorrhizal plants (Jaizme-Vega *et al.* 1998). Likewise, Tiwari *et al.* (1999) obtained highest leaf nitrogen content (2.83%) in suckers inoculated with *Azospirillum* in combination with 100% nitrogen and phosphorus. In addition, suckers, inoculated with *Azotobacter* and receiving 100% nitrogen had highest leaf potassium content (3.74%), followed by *Azospirillum* inoculated suckers (3.69%) at the vegetative stage. Similarly, both FYM and banana compost along with 100% chemical fertilizer + sulphur produced high contents of N, P and K in the leaves of Maghrabi banana (EI-Naby 2000). Similarly, banana plants inoculated with free nitrogen fixing bacteria, yeast and mycorrhizal or their combinations significantly increased N, P and K contents in roots and leaves as compared to untreated control (Soliman 2001). El-Shammaa (2001) reported that banana plants treated with active dry yeast as foliar spray with different concentrations, effectively increased leaf chlorophyll and plant nutritional status. The leaf nitrogen, phosphorus and potassium content are increased by increasing the rates of biofertilizers and organic manure on Williams banana plants El-Aziz (2002).

IPNS in yield parameters and yield of banana

The careful and composed use of organic manures, biofertilizers and inorganic fertilizers have been found beneficial in improving the yield parameters as well as yield of different fruits including banana. The number of fruits/ bunch and crop yield of banana cv. Embul increased by the application of cattle manure and cattle shed waste (Herath *et al.* 1977). The combination of urea and castor cake (1:1) reported economically best for improving yield in banana cv. Basrai (Chundawat *et al.* 1983). The bunch weight-determinants, i.e. number of hands and fingers in banana significantly influenced by foliar application of urea with *Azotobacter* (Kumar and Shanmugavelu 1988). Jeeva *et al.* (1988) reported that the bunch weight of banana cv. Poovan (AAB) was increased by 8.2% for plants inoculated with *Azospirillum* compared to non-inoculated control receiving 100% N plants. The highest bunch weight (10.9 kg) of banana cv. Prata was obtained from plots receiving FYM+NPK (Gomes *et al.* 1988). Gubbuk *et al.* (1993) obtained the highest stem and fruit growth rates with 225 kg FYM/mat for dwarf Cavendish and 150 kg FYM/mat for Basrai banana. The FYM also reduced the time for fruit

development compared to inorganic N. The usefulness of organic sources of nutrient could also be witnessed from the study of Bananuka and Rubaihayo (1994) and they obtained 37.6% greater bunch weight and 66% greater yield in banana grown in backyard garden than distant banana garden due to continuous supply of compost and household waste. Likewise, Hemeng *et al.* (1995) observed higher yield in plantain by applying poultry manure alone or in combination with 25% NPK. Similarly, Dibut *et al.* (1996) studied the potential of *Azotobacter chroococcum* as a nitrogen fixer and bio stimulant for banana production on c.v. Giant Cavendish in Cuba and reported that bacterial inoculation could compensate 20% of the N fertilizer without changing the yield corresponding to 30 g N/plantlet. Dorel and Besson (1996) reported that although organic matter application is costly and labour intensive, it had profound beneficial effects on yield parameters as well as yield of banana. Roy and Yadav (1996) also reported highest yield in banana with the combination of organic manures and inorganic fertilizers. In addition, Singh *et al.* 1996 reported that the combination of nitrogen (300 g), potassium (200 g), oilcake (100 g) and planofix 150 ppm in two splits gave the highest yield with early maturity in banana. Similarly, biofertilizers like *Azotobacter*, mycorrhiza, phosphorine increased commercial yield by 25-30%, enabling a saving of up to 50% on inorganic fertilizer (Ruiz 1997). Vermicompost as organic sources to supplement 200 g nitrogen/plant in banana cv. Njalipoovan recorded highest number of fingers/hand, mean weight of hands and highest yield (Ushakumari *et al.* 1997). Romero (1998) reported the increased yield of banana by using compost, animal manure, vermicompost and green manure crops like *Crotolaria* sp. and *Clitoria* sp. to supplement chemical fertilizers. Similarly, organic manures in combination with 100% NPK increased the bunch weight by 4.43 and 5.10 kg over control and lowered days to harvest in cv. Grand Naine (Smith 1998). Cattle manure, crop residues and lime either singly or in combination had influence on yield, cycle length and bunch weight (Gomes *et al.* 1998). Fernandez *et al.* (1998) found that the number of fingers per hand for cv. Dwarf Cavendish by using of Retflopx 357 (a commercial mixture of microorganisms). Again, Tiwari *et al.* (1998) obtained higher number of hands per bunch and highest yield of 69.15 tonnes/ha when plants were inoculated with *Azospirillum.* Application of bio-fertilizers (*Azospirillum, phosphobacteria* and VAM) and organic manure (FYM) along with 75% NPK increased bunch weight up to 15.3 kg in hill banana Virupakshi (Chezhiyan *et al.* 1999). On the other hand, inoculation with *Azotobacter* could substitute 50% nitrogen requirement of banana and produce higher yield over full dose of nitrogen application (Tiwari *et al.* 1999).

Application of banana compost with 25 or 50% chemical fertilizers and sulphur reported higher yield in banana in terms of number of fingers, finger length and circumference (El-Naby 2000). IPNS package consisting of green manure or vermicompost at 5 kg/plant and 75% of the recommended dose of N reported to be very much effective for higher yield of banana cv. Nendran (Geetha and Nair 2000). *Azotobacter* and organic sources as N supplements increased bunch weight, yield and leaf relative water content in banana cv. Barjahaji (Sharma 2002).

Hammam *et al.* (2003) found that application of N in combination of organic and mineral sources significantly improved the physical characters of the bunch namely number of hands/bunch, number of fingers/hand, weight of hands and finger and pulp/peel than the application of inorganic N alone. The highest number and weight of bunch, fingers/hand, weight of second hand and harvest index of banana was obtained in *Azospirillum* +PSB + ½ RD of N + RD of P_2O_5 and K_2O (Gogoi *et al.* 2004). In addition, Singh and Singh (2004) observed significantly higher finger length, fingers/bunch, hands/bunch and bunch weight in banana cv. Dwarf Cavendish applied with VAM + 300 g N + 75 g P_2O_5 + 300 g K_2O. The treatment 50% NPK + 20 kg FYM + 10 kg *Azolla* recorded the maximum number of fingers per bunch and yield in banana cv. Jahajee (Babu and Sharma 2005). Mia *et al.* (2005) found that number of hands per bunch, weight of hand, bunch weight and yield increased with 50% or 33% recommended dose of N along with *Azospirillum* + phosphate solubilising bacteria or plant growth promoting rhizobacterium.

The IPNS package consisting of 20 tonnes FYM, 5 kg *Azospirillum, phosphobacteria*, 250 g neem cake and 200:35:330 g NPK/plant along with foliar application of 0.5% $ZnSO_4$, 0.2% $FeSO_4$, 0.2% $CuSO_4$ and 0.1% Borax was also beneficial in getting highest bunch length, hands/bunch, finger/bunch, bunch weight and yield/ha of banana cv. Rasthali (Thangaselvabai *et al.* 2009). Likewise, integrated use of inorganic fertilizers and vermicompost also reported beneficial by Atahni *et al.* (2009) as the yield/plant in banana cv. Rajapuri was improved. Again, Bhalerao *et al.* (2009) reported that the application of 100% recommended dose of NPK with 10 kg FYM and biofertilizer recorded maximum hands/bunch, fingers/bunch, bunch weight and yieldha in tissue cultured banana cv. Grand Naine. Barakat *et al.* (2011) studied the performance of different organic manures on yield and yield-determining parameters of Williams banana and reported that different organic fertilizer treatments increased the bunch weight, number of hands, weight of hands, number of fingers and finger weight.

IPNS and quality parameters of banana

Application of IPNS has significant contribution in improving the quality of banana. It plays an important role in betterment of quality parameters in terms of moisture, titrable acidity, ascorbic acid, TSS, total sugars, reducing sugars, non-reducing sugars and sugar acid ratio of juice and taste of banana.

Umesh *et al.* (1988) found that fruit quality parameters, viz. N, P, K, Ca, Mg contents, reducing and total sugars percentage were increased when plants of cv. Dwarf Cavendish were inoculated with *Glomus fasciculatum* mycorrhizae. Tissue cultured plantlets of banana cv. Giant

Cavendish treated with organic matter and half of the recommended dose of N improved the quality in terms of shelf-life and TSS content (Chiang *et al.*1996). Similarly, combination of nitrogen (300 g), potassium (200 g), oilcake (100 g) and planofix 150 ppm in two splits improved TSS, acidity, sugar, sugar-acid ratio and ascorbic acid (Singh *et al.* 1996). Ushakumari *et al.* (1997) reported that the vermicompost treatment in cv. Njalipoovan was very effective to increase sweetness and sugar-acid ratio and improve other quality parameters of the fruits as well. A higher TSS and reducing sugar content also reported in *Azotobacter* inoculated plants of cv. Giant Governor (Tiwari *et al.* 1998). EI-Naby (2000) found that cv. Maghrabi treated with banana compost + 50 or 25% chemical fertilizers and sulphur resulted into the best quality fruits in terms of total soluble solids/acid ratio. Likewise, higher pulp-peel ratio, TSS and lower acidity was reported in cv. Rajapuri by using 100% recommended dose NPK +VAM + PSB + *Azospirillum* + *Trichoderma harzianum* (Kanamadi *et al.* 2004). Similarly, the inoculation of biofertilizers along with the application of recommended dose of fertilizers proved most effective in improving the fruit quality of dwarf cavendish banana cv. Giant Governor (Suresh and Hasan 2001). Hammam *et al.* (2003) found that the application of N from organic and mineral sources significantly improved all chemical characters such as TSS, total and reducing sugars and decreasing starch and total acidity as compared to the treatment comprised of N through inorganic source alone. The fruit quality of banana also improved by the application of biofertilizers including phosphate solubilising bacteria, *Azospirillum* spp and *Pseudomonas* spp with NPK. The treatment combination of biofertilizers and 75% NPK produced the best quality fruits in terms of total soluble solids, total sugars, acidity and starch (El Moniem and Radwan 2003). Similarly, significantly superior quality parameters in cv. Rasthali in terms of TSS, reducing sugars, ascorbic acid and starch were obtained by using 100:30:330 g NPK/plant and *Azospirillum* (Thangaselvabai *et al.* 2009). Mia *et al.* (2010) improved the physical attributes of fruit quality of banana by inoculation of banana roots with plant growth promoting rhizobacteria (PGPR).

IPNS and soil health

Soil properties and nutrient availability: IPNS has been using in banana cultivation throughout the world. The preference given is mainly due to the positive effect they have on the physical, chemical and biological properties of the soil. Continuous use of FYM along with NPK fertilizers improved the physical properties of soil in addition to the status of available P_2O_5, K_2O, Zn and Fe, CEC and C:N ratio (Prasad and Singh 1980, Manna and Ganguli 1998, Santhy *et al.* 1999). The importance of earthworms in improving the soil fertility was established during the mid-1980s (Satchel 1958). Similarly, Das and Chaudhury (1981) reported that the addition of organic manures with inorganic fertilizers helped in increasing the organic matter contents and structural status of the soil. Incorporation of organic manures improved the soil properties in turn, influenced the productivity (Chowdhuri *et al.* 1981). An application of green manure and organic composts along with chemical fertilizers increased available nutrients of soil (Subba Rao 1982, Sen and Patil 1988). Larson and Clapp (1984) observed structural changes in soils due to addition of organic manures, through the changes in pore size both within and between the soil aggregates. Vermicompost improved the physico-chemical properties of soil in the form of mixing top soil, formation of soil aggregates, improvement of drainage, porosity and aeration (Lee 1985). Nutrient added through inorganic and organic sources in combination has many beneficial effects like moisture retention; nutrient conservation, root growth (Tandon 1991) and better utilized than inorganic alone and therefore maintained the soil health (Talashilkar and Vimal 1986, Sarvanan *et al.* 1986). According to Bhadoria (1987), rice husk, FYM, *Azadirachta indica* cake and sawdust reduced the bulk density of the soil and increased moisture retention capacity of soil. In general, organic inputs enrich soil nutrient contents when used in conjunction with chemical fertilizers; prevent unproductive nutrient loss by forming organo-mineral complexes, which makes the nutrients more available to the plant. It also has biological functions, which provides carbon as an energy source to the soil microbes and enhances the plant growth, root initiation, yield, nutrient uptake and chlorophyll synthesis (Prakash and McGregor 1983, Garcia *et al.* 1998).

The effect of inoculation of *Azotobacter* alone or in combination with *Azospirillum* was more pronounced on the build up of available soil K_2O and the response of single or double inoculation was not consistent and conclusive (Tiwari *et al.* 1999).

Combined application of urea and FYM significantly increased organic carbon and available N status of soil over equivalent N addition through urea alone. Available P_2O_5 and K_2O contents of the soil decreased with successive rise in levels of N addition through urea whereas the status of these nutrients increased in combined application of urea and manures (Gupta *et al.* 2000). Application of *Azotobacter,* oil cake and 25% fertilizer N improved soil health and proliferation of *Azotobacter* population as compared to 100% N fertilizer alone (Sharma 2002).

Soil characteristics like pH, total N, available P, exchangeable K status and organic carbon significantly influenced by the combined application of biofertilizers and inorganic fertilizers. Application of PSB along with SSP significantly increased the available P_2O_5 status in the soil compared to application of SSP alone (Gogoi *et al*. 2004). IPNS consisting of 50% RDF + lime + FYM improved the soil physical condition, available nutrient status and organic matter contents of the soil (Senapati *et al.* 2005). Babu and Sharma (2005) reported that IPNS was beneficial for improving the soil fertility by reducing the soil pH, EC and bulk density and increasing the soil organic carbon, CEC and water holding capacity as well as available N, P and K contents of the soil. Similarly, Kannan *et al.* (2005) reported

that application of 75% of N as vermicompost with *Azospirillum* improved soil health by increasing beneficial bacterial and fungal population in the soil. The soil physical, biological and chemical properties i.e. soil pH, EC and P_2O_5 contents influenced greatly by application of 50% FYM + 50% inorganic fertilizers (Korwar *et al.* 2006).

Hazarika and Ansari (2010) reported that combined application of NPK, FYM and biofertilizers have beneficial effects in mobilizing the nutrients availability from unusable form to usable form by their biological activities. Similarly, maximum soil pH, organic C and available N, P_2O_5 and K_2O was reported by integrating 100% RDF, VAM, *Azospirillum*, PSB, and *Trichoderma harzianum* (Hazarika *et al.* 2011).

Soil microflora: The soil microflora plays an important role in maintenance of soil fertility. They have an ability to carry out biochemical transformation by improving soil physical and biological conditions (Roy and Braun 1987). Weda *et al.* (1988) reported that combined application of organic materials and inorganic fertilizers improved soil microflora. Similarly, regular organic manures and biofertilizers acting as substrate base provide energy and enhanced population and activity of beneficial soil microbes and their activities such as organic matter decomposition (Yaduvanshi *et al.* 1985, Hussain *et al.* 1988, Gaur and Pareek 1974); biological nitrogen fixation (Bhardwaj and Gaur 1970, Mukherjee and Gaur 1980) and solubilisation of insoluble phosphates (Gaur 1972). Loquet *et al.* (1977) and Kale *et al.* (1992) reported an enhancement in the population of N-fixers due to application of vermicompost. The application of FYM stimulated the microbial proliferation and the processes related to N cycling in soil (Sutopo and Kuwatsuka 1992), while repeated and excessive application of inorganic fertilizers affects microorganisms which are essential for maintaining biological health of soil (Sharma 1994). The quantities of microorganisms beneficial for the soil increased considerably due to application of *Azotobacter*, mycorrhiza and phosphorin (Ruiz *et al.* 1992). In general, integrated use of organic manures along with chemical fertilizers enhanced the microbial biomass with increased level of urease and phosphatase activities (Sarkar *et al.* 1996).

Single inoculation with *Azospirillum* and double inoculation of *Azotobacter* and *Azospirillum* induced maximum number of N-fixing microbial colony during the vegetative stage, shooting and harvesting of banana and supplemented the recommended dose of nitrogen by 50% (Tiwari *et al.* 1999). Similar results on use of organic manures in augmenting microbial population in soil also obtained by Maheswarappa *et al.* (1999), Saha *et al.* (1995) and Sharma (1999). In addition, Tiwari *et al.* (2001) reported that incorporation of leguminous and non-leguminous green manuring crops improve biological properties of the soil. Similarly, Gogoi *et al.* (2004) recorded maximum number of microbial biomass population and dehydrogenase activity in the soil by using *Azospirillum* +PSB + ½ RD of N + RD of P and K.

IPNS in economics of cultivation of banana

The review of literature reveals that IPNS packages are superior to any other fertilizer management to mend the economics of cultivation and subsequently, to achieve maximum cost benefit ratio (C: B) in banana.

The combined application of organic and inorganic fertilizers appeared to be the best way to achieve good development of the plants and good financial return in banana (Borges 1994). Chundawat *et al.* (1983) reported that the combination of urea and castor cake (1:1) was the economically best combination for improving yield in banana cv. Basrai. Similarly, an application of banana compost with 25% or 50% chemical fertilizers and sulphur involved low production cost in banana compared to chemical fertilizers alone (El Naby 2000). Thangaselvabai *et al.* (2009) obtained highest cost benefit ratio of 2.41 and net profit of ‘ 75 743/ ha in the treatment 100:30:330 g NPK/plant in two splits and *Azospirillum* under field trials conducted on banana cv. Rasthali. Similarly, the application of 100% recommended dose of NPK with 10 kg FYM/plant + biofertilizer recorded the maximum monetary return of ‘ 229 500, net profit Rs 7459/ha and C:B ratio of 1.48. This treatment followed by the use of 50% NPK through FYM and green manure and 50% through inorganic sources + biofertilizers (Bhalerao *et al.* 2009). Hazarika *et al.* (2014) obtained the highest C:B ratio of 4.22 in the IPNS package with 100% RDF + VAM + *Azospirillum* + PSB + *Trichoderma harzianum* followed by C:B ratio of 4.05 in 75% RDF + VAM + *Azospirillum* + PSB + *Trichoderma harzianum* in tissue cultured plantlets of banana cv Grande Naine in India.

The literature relevant to IPNS in growth, yield and quality with special reference to banana cultivation reviewed in this paper. A thorough knowledge of the critical levels of different nutrient elements, time and method of application of nutrients is essential to get better growth and yields, and also to maintain optimum nutrient balancing, a prerequisite enhancing nutrient use efficiency. Efficient nutrient management plays an important role for better production of banana. These information will definitely be useful in better understanding of IPNS package as a holistic and sustainable approach to improve the productivity and profitability of fruit cultivation as well as to improve soil health.

REFERENCES

Alonso-Reyes R, Gonzalcz-parra M and Fxposito-Carcia L. 1995. The influence of mycorrhizae and phosphate solubilizing bacteria on the growth and development of banana vitro plants. *Inibmusa* **4**: 9–10.

Anonymous. 2000. Bananas. *Musa Doc*. 2000, INIBAP, French.

Athani S I, Hulamani N C and Shirol A M. 1999. Effect of vermicompost on maturity and yield of banana cv. Rajapuri (*Musa* AAB). *South Indian Horticulture* **47**: 4–7.

Athani S I, Revanappa and Dharmatti P R. 2009. Influence of organic fertilizer doses and vermicompost on growth and yield of banana. *Karnataka Journal of Agricultural Science* **22**: 147–50.

Babu N and Sharma A. 2005. Effect of Integrated nutrient

management on productivity of 'Jahajee' banana and soil properties under Nagaland foot hill condition. *Orissa Journal of Horticulture* **33**:31–5.

Babu Ratan P, Raghava Rao D V, Reddy Y N and Madhava Rao D. 2008. Organic banana production system: Leaf emission, leaf senescence and crop duration in plant and ratoon cycles. *Indian Journal of Horticulture* **65**:134–6.

Bananuka J A and Rubaihayo P R. 1994. Backyard banana cultivation in Uganda.*Infomusa* **3**: 17.

Barakat M R, El-Kosary S and Abd-EINafea M H. 2011. Enhancing Willimas banana cropping using osme organic fertilization treatments. *Journal of Horticulture Science and Ornamental Plants* **3**: 29–31.

Bhadoria P G S. 1987. Physical properties and rice yield as related to organic amendments and depth of mixing. *Journal of Agronomy and Crop Science* **159**: 229–31.

Bhalerao V P, Patil N M, Badgujar C D and Patil, D R. 2009. Studies on Integrated Nutrient Manament for tissue cultured Grand Naine Banana. *Indian Journal of Agricultural Research* **43**: 107–12.

Bhardwaj K K R and Gaur A C. 1970. The effect of humic acid and fulvic acids on the growth and efficiency of nitrogen fixation by *Azotobacter chroococcum. Folia microbial* **15**: 364.

Borges A L. 1994. Liming and fertilizing banana. CNPMF Rep, pp 2

Chezhiyan N, Balasubramani P, Harris C V and Anathan M. 1999. Effect of inorganic and biofertilizer on growth and yield of hill banana var. Virupakshi. *South Indian Horticulture* **47**:161.

Chiang S C, Chang C M and Chen M J. 1996. The growth, yield and post harvest quality of Giant Cavendish as affected by rate of nitrogen. *Journal of Chinese Society of Horticultural Science* **42**: 68–77.

Chowdhury M L, Singh J P and Narwal R P. 1981. Effect of long term application of P, K and FYM on some soil properties. *Journal of Indian Society of Soil Science* **29**: 81.

Chundawat B S, Dave S K and Patil N L. 1983. Effect of sources of nitrogen on yield and economics of banana cv. Basrai. *Haryana Journal of Horticultural Science* **12**: 156–9.

Das D K and Chaudhury K G. 1981. Infiltration and residuation of soil water as influenced by crust formation cultivation and FYM application. *Journal of Indian Society of Soil Science* **29**: 543–6.

Dibut A B, Rodriguez N A, Perez A, Martine Z and Viera R. 1996. The effect of Azotoryza's double function on banana (*Musa spp*). *INFOMUSA* **5**: 20–3.

Dorel M and Besson N. 1996. Organic fertilizer use in banana growing. *CIRAD-FLHOR*, Fort de France, Musarama 9:15.

EI-Moniem E A A and Radwan S M A. 2003. Response of Williams banana plants to biofertilization in relation to growth, productivity and fruit quality. *Arab University Journal of Agricultural Science* **11**: 751–63.

El-Naby S K M A. 2000. Effect of banana compost as organic on growth, nutrient status, yield and fruit quality of Magharabi banana. *Assiut Journal of Agricultural Science* **31**:101–4.

El-Aziz A B K. 2002. Physiological studied on biofertilization of banana plants cv. Williams. Ph D Thesis, Faculty of Agriculture, Minia University.

El-Demerdash A M. 1988. Effect of salinity and some nutrient elements on growth and mineral content of banana plants. Ph D Thesis, Faculty of Agriculture, Ain Shams University, Cairo, Egypt.

El-Demerdash A M, Abdel-Al A A and El-Makhtoun F M B. 1995**.** Effect of soil inoculation with endomycorrhizae and fertilization with different sources of phosphate on the growth and leaf mineral content of Williams banana plants grown in sandy soils. *Minufiya Journal of Agricultural Research* **20**: 2093–103.

El-Shammaa M S. 2001. Effect of biofertilizers on growth and yield of banana plants (Williams cv.). *Assiut Journal of Agricultural Science* **32**: 157–66.

Fernandez F M, Enrique A C and Borges R A. 1998. Bacteria enriched inoculants enhance banana development and influences nutrition. *Fruits* **53**: 2.

Garcia R, Guijarro R, Milan O. 1998. Alternate fertilizers for banana and plantain production in Cuba. *(In) Proceedings of Organic/Environmentally Friendly Banana Production.* Rosales F E, Tripon S C and Cerna J (Eds). Costa Rica, pH 86.

Gaur A C. 1972. Role of phosphate solubilizing microorganisms and organic matter in soil productivity. *(In) Proceedings of Symposium on Soil Productivity,* National Academy of Science India*,* pH 259.

Gaur A C and Pareek R P. 1974. Organic acids in soil during decomposition of organic residues. *Indian National Science Academy* **40**B: 68.

Geetha K and Nair R R. 2000. Integrated plant nutrition system for banana. *Annals of Agricultural Research* **21**:499–503.

Gogoi D, Kotoky U and Hazarika S. 2004. Effect of biofertilizers on productivity and soil characteristics in banana. *Indian Journal of Horticulture* **61**:354–6.

Gomes J A, Nobrega A C, Salgado J S, Rocha A C and Da-Roch A C. 1988.Utilization of organic matter in banana cultivar Prata in the state of Espirito Santo, Communicado Tecnico Epresa Capixaba de Pesquisa Agropecuria. *EMCAPA* **49**:48.

Gomes J A, Nobrega A C and Salgado J S 1998. Utilization of cattle manure, cultural residues and liming on banana cv. Prata (AAB group, subgroup prata) in Espirito Santo State, Brazil. *Revista Brasilereira de Fruiticultura.* **20**: 28–32.

Gubbuk H, Paydas S and Kasak N. 1993. Effects of different nitrogen and farm yard manure levels on the stem and finger growth and the durations of fruit development of Cavendish and Basrai banana clones. *Doga Turk Tarim Ve Ormancilik Dergisi* **17**: 239–253.

Gupta R K, Arora B R, Sharma K N and Ahluwalia S K. 2000. Influence of biogas slurry and farm yard manure application on the changes in soil fertility under rice-wheat sequence. *Journal of Indian Society for Soil Science* **48**: 500–5.

Hammam M S, Ibrahim E G and Mansour A E M. 2003. Response of Williams banana to some organic nitrogen fertilizers. *Egypt Journal of Horticulture* **30**: 51–65.

Hazarika B N and Ansari S. 2010. Effect of integrated nutrient management on growth and yield of banana cv. Jahaji. *Indian Journal of Horticulture* **67**:270–3.

Hazarika T K, Nautiyal B P and Bhattacharyya R K. 2011. Effect of IPNS on productivity and soil characteristics of tissue cultured banana cv. Grand Naine in Mizoram, India. *Progressive Horticulture* **43**: 30–5.

Hazarika T K, Nautiyal B P and Bhattacharyya R K. 2014. Economic analysis of tissue cultured banana (*Musa* × *paradisiaca*) production under the influence of integrated nutrient management. *Indian Journal of Agricultural Sciences* **84**: 656–60.

Hemeng O B, Asante J S and Ferris R S B. 1995. Influence of poultry manure and inorganic fertilizer on plantain growth and

yield. *Musafrica* **3**:2–4.

Herath H M E, Pinto M E R and Ariyaratne R M. 1977. The response of Embul banana to organic manuring.*Tropical Agriculture* **33**: 177–219.

Hussain I, Manhot S C and Mathur A M. 1988. Biogas plant slurry- A promising organic manure. (*In) Management and Utilization of Biogas Plant Slurry,* pp 31–6. Himanchu Publication, Udaipur.

Ischac Y Z and Mostafa M M. 1998. Interaction of *Azotobacter* and vascular arbuscular mycorrhiza. *Arab Universiy Journal of Agricultural Science* **6**: 77–97.

Jaizme-Vega M C and Pinochet J. 1997. Growth response of banana to three mycorrhizal fungi in pratylenchus goodcvi infested soil. *Nematropica* **27**: 69–76.

Jaizme-Vega M C, Sosa-Hernandez B, Hernandez-Hernandez J M and Galan Sauco V. 1998. Interaction of arbuscular mycorrhizal fungi and the soil pathogen *Fusarium oxysprornm f. sp. cubcnse* on the first stage of micropropagated Grand Naine banana. *Acta Horiculturae* **490**: 285–95.

Jeeva S, Kulasekharan M, Shanmugavelu K G and Obilisami G. 1988. Effect of Azospirillum on growth and development of banana cv. Poovan (AAB). *South Indian Horticulture* **36**:1–4.

Kale R D, Mallesh B C, Bano K and Bhagyaraj D J. 1992. Influence of vermicompost application on the available micronutrients on selected microbial population in paddy field. *Soil Biology and Biochemistry*. **24**:1 319–20.

Kanamadi V C, Shirol A M and Athani S I. 2004. Effect of biofertilizers on growth and yield of banana cv. Rajapuri. (*In) Proceedings of. National Seminar on Banana Industry-Present Scenario on Future Strategies.* Bandopadhya B, Sarkar S K, Mishra D K, Barui F K (Eds). BCKV, Kalyani, India, pp 157–61.

Kannan P, Saravanan A, Krishnakumar S and Natarajan S K. 2005. Biological properties of soil as influenced by different organic manures. *Research Journal of Agricultural and Biological Science* **1**: 181–3.

Korwar G R, Pratibha G, Ravi V and Palanikumar D. 2006. Influence of organics and inorganics on growth, yield of aonla (*Emblica officinalis*) and soli quality in semi arid tropics. *Indian Journal of Agricultural Science* **76**: 457–61.

Kumar A and Shanmugavelu K G. 1980. Studies on the effect of *Azotobacter* and *Azospirillum* on banana. *(In) Proceedings of the National Seminar on Banana Production Technology.* Muthukrishnan C R and Abdulkhader J B M (Eds). TNAU, Coimbatore, India, pp 125–130.

Kumar A and Shanmugavelu K G. 1988. Effects of foliar spray of urea and *Azotobacter* applied to soil on banana cv. Robusta. *Banana Newsletter* **11**:11–2.

Larson W E and Clapp C E. 1984. Organic matter and rice. IRRI, Los Bonos, Laguna, Philippines, p 363.

Lee K E. 1985. Earthworms, their ecology and their relation with soil and land use. Academic Press, Sydney.

Loquet M, Bhatnagar T, Bouche M B and Rouelle J. 1977. Estimation of the ecological influence of earthworms on micro-organisms, *Pedobiologica* **17**:400–17.

Lyengar B R V, Kohli R R and Chacko E K. 1984. Effect of poultry manure on the nutrient composition of Robusta banana. *Banana Newsletter*. **7**: 16–7.

Maheswarappa H P, Nanjappa H V and Hedge M R. 1999. Influence of organic manures on yield of arrow root, soil physico-chemical and biological properties when grown as intercrop in coconut garden. *Annals of Agricultural Research* **20**: 318–23.

Manna M C and Ganguli T K. 1998. Recycling of organic wastes: its potential, turnover and maintenance in soil- A review. *Agricultural Reviews* **19**:86–104.

Mia M A B, Shamsuddin Z H, Zakaria W and Mahmood M. 2005. High yielding and quality banana production through plant growth promoting rhizobacerial (PGPR) inoculation. *Fruits* **60**:1 79–85.

Mia M A B, Shamsuddin Z H and Marziah M. 2010. Use of plant growth promoting bacteria in banana: A new insight for sustainable banana production. *International Journal of Agriculture and Biology* **12**: 459–67.

Mia M A B, Shamsuddin Z H, Wahab Z and Marziah M. 2010a. Effect of plant growth promoting rhizobacterial (PGPR) inoculation on growth and nitrogen incorporation of tissue-cultured Musa plantlets under nitrogen-free hydroponics condition. *Australian Journal of Crop Science* **4**: 85–90.

Mukharjee D and Gaur A C. 1980. A study on the influence of straw incorporation on soil organic matter maintenance, nutrient release and asymbiotic nitrogen fixation. Zentarablat Bahtiol Abstracts II. **135**: 663–8.

Pinochet J, Fernandez C, Jaizme M X and Tenoury P. 1997. Micropropagated banana infected with *Mcloiclogyne javanica* responds to *Glonnis intraradices* and phosphorus. *Hort Science* **32**: 101–3.

Prabhuram R and Sathiamoorthy S. 1993. Effect of organic manures on duration of cropping in banana. *South Indian Horticulture* **41**: 370–1.

Prakash A and McGregor D J. 1983. Environmental and human health significance of humic materials: an overview. *(In) Aquatic and Terrestrial humic materials,* pp 481–94. Christman R F and Gjessing E T (Eds).

Prasad B and Singh A B. 1980. Changes in soil properties with long term use of fertilizers, lime and FYM. *Journal of Indian Society for Soil Science* **28**: 465–8.

Romero J O. 1998. Organic fertilizers and their application in banana cropping. (*In) Proceeding of Organic Environment Friendly Banana Production Costa Rica.* Rosales F E, Tripon S C and Cerna J (Eds). pp 79–85.

Roy P K and Yadav J P. 1996. Effect of combined use of organic manures and chemical fertilizers on growth and productivity of banana. *Annals of Agricultural Research* **17**: 366–9.

Roy R N and Braun H. 1987. Development of integrated plant nutrition system. *Proceedings of FAI Seminar on fertility Industry Challenges and Strategies,* New Delhi, S-IV/2/1-2.

Ruiz L. 1997. Use of Mycorrhiza, phosphorine and azotobacter as biostimulants of growth *in vitro* plants of banana (*Musa spp.). Agrotecenia de Cuba* **27**: 104–6.

Ruiz M L, Medero V V and Garcia G M. 1992. Biofertilizers, an alternative for the fertilization of food crops in Cuba. *Musarama* **11**:15.

Saha N, Das A C and Mukharjee D. 1995. Effect of decomposition of organic matter on the activities of microorganisms and availability of nitrogen, phosphorus and sulphur in soil. *Journal of Indian Society for Soil Science* **43**: 210–5.

Santhy P, Velusamy M S, Murugappan V and Selvi D. 1999. Effect of inorganic fertilizers and fertilizer manure combination on soil physico-chemical properties and dynamics of microbial biomass in an inceptisol. *Journal of Indian Society for Soil Science* **47**: 479–82.

Sarkar A R, Mathur B S and Sharma A. 1996. Improving fertilizer use for sustaining high crop yield in red and lateritic soils of Eastern India. *Fertilizer News* **41**:31–7.

Sarvanan A, Velu V and Ramanathan K M. 1986. Utilization of chemical sources of organic and inorganic nitrogen for rice. *Oryza* **23**: 213–6.

Satchell J E. 1958. Earthworms and soil fertility. *Soils and Fertility.***21**: 209–19.

Sen S P and Patil P. 1988. Biofertilizers- Potentialities and Problems. *Plant Physiology Forum* 262.

Senapati H K, Pal A K and Samant P K. 2005. Effect of chemical fertilizer, organic manure, lime and biofertilizer on yield of turmeric (*Curcuma longa*). *Indian Journal of Agricultural Science* **75:** 593–5.

Sharma H R. 1994. Environmental friendly input fertilizers. *Haryana Farming* **24**:11.

Sharma R A. 1999. Management of crop residue and farm yard manure for sustainable productivity of rainfed soybean and safflower and soil health under rainfed conditions. *Crop Research* **18**: 370–4.

Sharma R. 2002. 'Effect of nitrogen sources on growth, yield and quality of banana cv. Barjahaji, (*Musa* AAA group, Cavendish sub-group)'. Ph D Thesis, Assam Agricultural University, Jorhat, India, p 175.

Singh A and Singh S P. 2004. Response of banana (*Musa spp*) to VAM and varied levels of inorganic fertilizers. *Indian Journal of Horticulture* **61**: 109–13.

Singh C, Bhagat B K and Roy R N. 1996. Effect of fertilizers, oil cake and auxin on growth, yield and quality of banana. *(In) Procedings of Conference on. Challenges for Banana production and Utilization in 21st century.* Singh H P and Chadha K L (Eds). NRC on Banana, Trichy, India, pp 338–9.

Smith B L. 1994. Nutrition of young tissue cultured banana plants. Inligtings bulletin Instituut Vir Tropiese en Subtropiese Gewasse No. 262, 12.

Smith B L.1998. Microorganisms in soil benefit growth and yield of bananas. *Neltropika Bull* **299**: 22–5.

Soliman M G A. 2001. 'Response of banana and guava plants to some biological and mineral fertilizers'. M Sc Thesis, Faculty of Agriculture, Alex University, Egypt.

Subba Rao N S. 1982. *Azotobacter* Inoculant. (*In) Biofertilizer in Agriculture*. Oxford and IBH Publ., New Delhi.

Suresh C P and Hasan M A. 2001. Studies on response of Dwarf Cavendish banana to biofertilizer inoculation. *Horticultural Journal* **14**: 35–41.

Sutopo G N and Kuwatsuka S. 1992. Concurrent observation of several process of nitrogen metabolism in soil amended with organic materials. *Soil Science and Plant Nutrition* **16**: 275–81.

Swaminathan M S. 1996. Integrated natural resources management-key to sustainable advances in agricultural productivity. *Science and Culture* **65**: 115–23.

Talashilkar S C and Vimal O P. 1986. City solid waste. *Journal of Indian Society for Soil Science* **34**: 780.

Tandon H L S. 1991. Fertilizer equivalent on farmyard manure, green manure and biofertilizers. *Fertilizer News* **36**: 69–79.

Thangaselvabai, Justin C G L, Nirmal Johnson S B and Jayasekhar M. 2009. Influence of nutrients on the quantitative and qualitative traits of banana. *Indian Journal of Agricultural Research* **43**: 274–8.

Tiwari D K, Hasan M A and Chottopadhay P K. 1998. Studies on the effect of inoculation with *Azotobacter* and *Azospirillum* on growth, yield and quality of banana. *Indian Agriculturist* **42**: 235–40.

Tiwari D K, Hasan M A and Chottopadhay P K. 1999. Effect of biofertilizers on soil nutrient status and microbial population in banana (*Musa* AAA sub group Cavendish, cv. Giant Governer) plantation. *Environment and Ecology* **17**: 338–41.

Tiwari V N, Lekhri L K, Tiwari K N and Upadhyay R M. 2001. Integrated nitrogen management through natural green manuring under wheat-mung bean cropping sequences. *Journal of Indian Society for Soil Science* **49**: 271–5.

Umesh K, Krishnappa C and Bagyaraj D J. 1988. Interaction of burrowing nematode, *Radopholus similis* (Cobb, 1893) Thorne 1949 and VA mycorrhiza *Glomus fasciculatum* (Thaxl) Gerd and Trappe in banana *(Musa acuminata* colla). *Indian Journal of Nematology* **18**: 6–1 1.

Ushakumari K, Prabhakumari P and Padmaja P. 1997. Efficiency of vermicompost on yield and quality of banana (AB) cv. Njalipoovan. *South Indian Horticulture* **45**: 158–60.

Vandanashiva. 1992. The violence of green revolution. The other India Press, Mapusa, Goa, India.

Weda K, Kabyashri N and Takahashi 1988. Effect of chromate and organic mendments on the composition and activity of microorganisms flora in soil. *Soil Science and Plant Nutrition* **34**: 233–40.

Yadav A K, Singh J K and Singh H K. 2011. Studies on integrated nutrient management in flowering, fruiting, yield and quality of mango cv. Amrapali under high-density orcharding. *Indian Journal of Horticulture* **68**: 453–60.

Yaduvanshi H S, Tripathy B R, Kunwar R S. 1985. Effect of continuous manuring on some soil properties of an Alfisol. *Journal of Indian Society for Soil Science* **33**: 700–3.