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# Microbial Inputs Regime for the Sustainable Production of Banana

KEYWORDS: soil conditioner, efficient microbes, PGR, Fly ash, chemical fertilizers, IPNM

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**ABSTRACT** *A fair attempt has been made to explore if low / biotech input regime provides sustainable production of banana (Musa paradisiaca, Shrimanti variety), without compromising with the fertility of soil, interests of farmers, expectations of consumers and health of eco-system. For this purpose, randomized block experimental layout (RBD) is implemented, incorporating 12 treatments. These comprised of permutations and combinations of (a) soil conditioner (SC) prepared by solid state fermentation of banana pseudostem for improving organic carbon content and porous texture of soil, (b) consortium of nitrogen fixer, phosphate solubilizer, heterotrophic sulphur oxidizer and endogenously present endomycorrhizae (VAM) for sustained release of plant nutrients and protecting chemcials, (c) fly ash for supplying Ca, phosphate and micro-nutrients and (d) amino acids based plant growth regulator (PGR) for enhancing chlorophyll content in leaves. Control carried out simultaneously used recommended dose of chemical fertilizers. Using this layout, outcome of two trials carried out on 0.5 acre and 4.0 acres during 1998-99 and 1999-2000 is as follows : (1) Approximately 4 million MT of pseudostem and leaf biomass per year were used to produce a soil conditioner, using solid-state fermentation for organic carbon and nutrient recycling. (2) Amino acids-based plant growth regulators, produced by hydrolyzing locally available protein-rich by-product, increased the survival rate of transplanted plants and banana productivity. (3) Efficient microbes were isolated from the rhizosphere of elite banana plants and preserved for commercial exploitation in a consortium of biofertilisers. (4) Fly ash has shown potential as a partial substitute for phosphatic and potassic fertilizers and imported micro-nutrients, in conjunction with phosphate solubilizing fungi and mycorrhizae. (5) Drip irrigation has reduced the quantity of water used, electricity consumption and, as a result, soil salinization. (6) Using these biotech inputs, chemical fertilizers were reduced by 50%, which made possible the conversion of heavily eroded, barren and unused land into cultivable agricultural land. (7) Trials in two geo-climatic conditions at North Maharashtra University and Bajirao Agro-Tech have shown broadly the same trend in observations and productivity, indicating the reliability of integrated plant nutrition management technology.*

**Introduction**

Brain-storming sessions with farmers and critical analysis of literature revealed that traditional methods of banana cultivation solely relying upon (i) indiscriminate application of chemical fertilizers, (ii) high frequency and quantum of flood irrigation, (iii) non-application of organic carbon and (iv) reduction of beneficial micro-flora of soil have rendered soil saline / infertile, stagnated banana production between 12–15 kg per bunch and polluted underground aquifers. To address these problems, it was considered desirable to replace traditional method of banana cultivation by low / biotech inputs farming system for sustainable banana production. To implement this strategy into practise, use of biotech inputs such as (a) dwarf Cavendish AAA, Basrai variety (Musa paradisiaca L, Shrimanti sub-variety), (b) plant growth regulator (PGR), (c) soil conditioner (SC), (d) consortium of biofertilizers (BFs), (e) 50% reduced dose of chemical fertilizers (CFs), (f) fly ash (FA) and (g) drip irrigation (DI) were used. The outcome of this strategy is discussed in this article.

**Materials and Methods**

**Chemicals and microbial media**

Analytical grade chemicals and reagents were used. Microbial media were procured from Hi-Media, Mumbai.

**Water**

Water for analytical purposes was demineralised (Millipore India Ltd., Bangalore), while water for irrigation contained [cations (meq./ L): Ca 3.8; Na 3.4 and Mg 2.0; anions (meq./ L): bicarbonates 7.8; chlorides 2.4 and carbonates 0.2; sodium adsorption ratio 2.0; residual sodium carbonate 2.2; pH 7.4; EC 1.41 mmho/cm].

**Elite suckers**

Elite suckers of dwarf Musa paradisiaca L. variety Shrimanti were procured from Faizpur (Dist. Jalgaon) for planting.

**Fertilizers**

Urea (46% $N_2$), SSP(16% $P_2O_5$), sulphur (12%) and muriate of potash (60% $K_2O$) were procured from local market.

**Soil conditioner**

It was prepared by solid state fermentation of shredded banana pseudostem waste under aerobic condition, 40% humidity and ambient temperature by mixed culture technology (Phirke et al., 2001).

**Biofertilizers**

Nitrogen fixing Azotobacter sp. and phosphate solubilizing Aspergillus awamorii were isolated from the rhizosphere of elite banana. Sulphur oxidiser Thiobacillus thiooxidans and Tricholoma imbricatum were respectively procured from National Collection of Industrial Microbes (NCIM, NCL, Pune) and Tata Energy Research Institute (TERI), New Delhi.

These microbes were cultivated in pilot fermenter (25 L, Navin Process Systems Ltd., Pune), using Burk's medium, soy flour – CSL medium, sulphur medium (Paknikar and Agate, 1995) and glucose – CSL medium (Cudlin et al., 1992) as per Kothari (1995) and served as biofertilizers.

**Fly ash**

It was procured from Bhusawal Thermal Power Station, Deep Nagar (District Jalgaon).

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**PGR**

It was prepared from enzymatically upgraded corn gluten (75% protein) as per the method of Sharma et al. (1995).

**Experimental**

Farm trials to explore the suitability and adequacy of using these biotech inputs for devising an integrated plant nutrition management (IPNM) protocol for banana production were conducted during July 1998 – Oct. 1999 and July 1999 – Oct. 2000, as per details given in the experimental design.

**Experimental design**

To establish a cause and effect relationship in a statistically meaningful manner, a randomized block design (RBD) was chosen. Each plot of 25 plants with a spacing of 1.5 m x 1.5 m was triplicated on approximately 0.52 acre farm. Total numbers of treatments were twelve as summarized in Table I.

**Table 1: RBD experimental layout for banana cultivation**

| Treatment | Description | Treatment | Description |
|---|---|---|---|
| T-1 | 50% CF | T-7 | SC (10 Mt/ha) |
| T-2 | 100% CF | T-8 | SC + BF |
| T-3 | 150% CF | T-9 | SC + FA |
| T-4 | BF | T-10 | SC + FA + BF |
| T-5 | FA (5 MT/ha) | T-11 | PGR |
| T-6 | FA + BF | T-12 | SC + FA + BF + PGR |

CF = Chemical Fertilizers; BF = Biofertilizers; FA = Fly ash; SC = Soil Conditioner; PGR = Plant Growth Regulator; MT/ha = Metric tonnes per hectare; 50% CF = N @ 450 kg/ha + $P_2O_5$ @ 175 kg/ha + $K_2O$ @ 450 kg/ha; SSP and MOP applied in two splits (at plantation and two months after plantation in T1 – T3); The 50% basal lot of CFs in T4-T12 was distributed over 240 days through fertigation; BF comprised of equal (20L, v/v) mixture of Azotobacter + Aspergillus + Thiobacillus + T. imbricatum, totally 80 L diluted to 800 L and applied @ 180 ml around each planted sucker. An aliquot of 6 ml PGR was diluted to 1 L and suckers dipped into it while planting. Subsequently, three foliar sprays, each of 1.5 L PGR diluted to 250 L were applied per hectare after 2, 4 and 6 months of plantation.

**Post-plantation care**

Drip irrigation was resorted to, two months after plantation, when frequency of Monsoon reduced. Rest of the post-plantation care was taken as per the recommended agricultural practices used by banana growing farmers (Patil, 1996). For example, periodic harrowing (twice a month), earthling up (after second and fourth month), weed management (as and when necessary), sucker management (once in 45 days until 4 months), dried banana leaf removal (once in two months), mulching by old leaves in furrows, propping (to support banana fruit bunch from toppling by strong winds), denavelling and bunch covering to avoid scorching heat of summer were implemented.

**Monitoring of banana orchards**

From fourth month onwards, percent survival, height, girth and number of leaves were counted as per Deo et al. (1998). Analysis of N was carried out as per Kjeldahl method (Tandon, 1993), P as per Jayaraman (1994) and K by flame photometry (Tandon, 1993).

N, P and K uptake was computed by analysis before and 8 months after plantation from a composite foliar sample derived form the randomly selected plants from each replication. Chlorophyll content of these foliar samples was monitored as per Jayaraman (1996). Total viable count (TVC) of soil before plantation and after banana harvesting was monitored as per Subba Rao (1977). Counting and identification of VAM spores was done as per Schenck and Perez (1990). Percent VAM infection to roots was determined by root slide technique (Phillips and Hayman, 1970). Siderophore content was estimated as per Schwyn and Nielands (1987).

**HPLC profiles**

Presence of heavy metals ($Cd^{2+}$, $Pb^{2+}$ and $Hg^{2+}$), if any, into biomass was estimated by HPLC method [column IC-Cl; detector CDD-6A; mobile phase (4 mM tartaric acid +2 mM ethylene diamine, 1:1, v/v); $40^{o}$ C; flow rate 1.5 ml/min], by simultaneously running respective standards (Bradshaw and Chadwick, 1980).

**Banana yield**

At maturity, banana bunches were harvested, segregated treatment-wise, weighed and recorded. Total production per experimental plot divided by the number of bunches was used for determination of an average banana bunch weight.

**Statistical analysis**

Statistical significance of the results was analyzed using ANOVA software (Panse and Sukhatme, 1995).

**Results and Discussion**

While a broad consensus appeared on the use of organic manures, nobody has systematically attempted their use for (i) want of viable technology for the production of organic manures and (ii) fear of getting less yield. Through the present trials on banana production, we wish to dispel both the myths.

**Production and application of CFs – hazardous to soil**

Application of CFs is capital, energy, cost and pollution intensive due to release of hazardous oxides of nitrogen and sulphur, fluorides and particulate matter during their manufacture in air, water and soil. Further, its application to meet nutrient requirements has substantially reduced micro-flora of soil, rendering it infertile, besides altering its physico-chemical composition. The net result is stagnation in productivity of banana at 52 MT/ha.

**Forgotten merits of use of organic manure**

Analysis of vast soil samples over the years indicated the presence of as low as 0.10-0.15% organic carbon. Experience before 1965 had revealed that with the application of cattle dung manure, farmers were able to grow equal or more quantity of banana, at a substantially less cost due to no or negligible input of CFs and no need of pest control. These observations made by several old farmers indicated the feasibility of banana cultivation using organic manure. Since cattle dung manure was not available in desired quantity, recycling of pseudostems was desired to prepare SC.

**Conversion of waste in to wealth**

Jalgaon district witnessed about 3.6 million MT of banana pseudostems forming a voluminous organic waste from 40,000 ha cultivation per annum. It is disposed off on the farm boundaries for (i) per se phyto-inhibitory nature, (ii) slower biodegradability, (iii) low bulk density and (iv) incin-

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eration upon solar drying (agriculture Epitome, 1996). This practice causes loss of 7650 MT K, 5338 MT N and 782 MT P per crop cycle. In these trials, these pseudostems have been gainfully utilized by conversion into soil conditioner as optimized by Phirke et al. (2001). Its kinetics of composting and composition is summarized in Table 2.

**Table 2 : Physico-chemical changes during conversion of pseudostem into SC**

| Characteristics | CP | After 30 days | After 60 days |
|---|---|---|---|
| Dry matter (kg) | 100 | 91.5 | 77.3 |
| Moisture (%) | 90 | 54.2 | 34.7 |
| Organic matter | 93.1 | 84.3 | 69.8 |
| Cellulose content | 11.3 | 10.1 | 8.2 |
| Total carbon | 54.0 | 48.9 | 40.5 |
| N | 1.57 | 2.15 | 2.34 |
| P | 0.23 | 0.34 | 0.36 |
| K | 2.25 | 2.79 | 3.04 |
| C/N ratio | 34.4 | 22.7 | 17.3 |
| Bio-efficacy * | -ve | -ve | +ve |

CP = Chopped pseudostem; organic matter, cellulose content, total carbon, N, P and K are expressed on dry weight basis. Percent germination, height and chlorophyll content of the test plants, similar to / or lesser than that of the control plants reflected –ve bioefficacy, while more than that of the control plants reflected +ve bioefficacy.

**Purpose in applying SC**
It was multi-fold : (i) to achieve higher percentage of survival of plantlets upon transplantation (Ramamurthy et al., 1996), (ii) to induce more ramification of root system in larger rhizosphere for acquiring more nutrition (Ramamurthy et al., 1998), (iii) to serve as a matrix for the growth and sustenance of beneficial microbes (Phirke et al., 2002) and (iv) to provide sustained release of moisture, nutrition, growth promoters and plant protecting principles, thereby affording higher growth rate, more vigour of biomass and more yield of banana (Phirke et al., 2003).

**Optimized quantum of SC for application**
While 1 kg SC per plant was inadequate to discharge its functions optimally, especially in soils of varying fertility index, 4 kg SC per plant appeared cost prohibitive as it merely grew more biomass, weeds and productivity was not commensurate with quantum. However, 2-3 kg SC per plant appeared optimal.

**Implications of SC application**
Looking at (i) abundant availability of pseudostem as a substrate, which had no alternate application in sight, (ii) simplicity of SC production technology, (iii) shorter duration required for SC production, (iv) its stability, permitting problem-free transport and application , (v) immediate benefit to consumers for superior quality banana, (vi) short range benefit to farmers by virture of this economical input, (vii) long range benefit to eco-system and (viii) far reaching implications of waste recycling for stabilishing soil fertility through microbial action, SC application enjoys national as well as international approval too (Ramamurthy et al., 1998).

**Rationale behind the use of dwarf Basrai**
High yielding sub-variety shrimanti of Basrai (dwarf) was purposefully used to invest less energy in biomass and channelise more energy in banana output, qualitatively and quantitatively.

**Effect of a consortium of BFs**
A consortium of 4 bio-fertilizers was applied @ 4-5 ml per plantlet. Their one time application in nursery prior to plantation by root drenching not only hardened the plants, but also afforded economy for application due to reduced labour and time requirement. Judged from the vigour of these plants, their application seemed to provide a sustained release of balanced nutrition. For example, rate of $PO_4$ solubilization was such that it showed a perceptiible higher uptake by the plants, as judged by phospho-molybdic stannous chloride method (Jayaraman, 1996).

**Cost of BF application**
As per the prevailing market price for freshly prepared liquid inoculum (1 x $10^9$ cells / ml), cost of application of consortium of 4 biofertilizers per hectare was US$116.

**Net savings from BFs application**
In the light of literature survey, it was presumed that the use of CFs could be reduced by 50% by the application of SC and DI due to increased efficiency of their utilization and augmenting their supplies due to colonization of BFs (Varma and Bhattacharya, 1992; DARE/ICAR, 1995-96). Our contention was independently based on a decreasing trend in productivity with an increasing dose (toxicity) of application of CFs in the last decade in Jalgaon District. Therefore, in the present studies, recommended dose of CFs was reduced to 50%. On the basis of 20% more yield of banana in T-12 over control (T-1 to T-3), it is concluded that the above contention was realistic. Such reduction in the use of CFs from the amount recommended (Pawar et al., 1997), the savings per ha amounted to 956 kg urea, 1,100 kg SSP and 734 kg MOP (totaling to 2,790 kg). Assuming an average cost of these CFs to be US$ 0.1 per kg, the saving is 2,790 x 0.1 = US$ 279 per hectare. It is a substantial saving in inputs due to an incremental cost of US$ 116 in biofertilizers per hectare.

**Physico-chemical properties of PGR**
Amino acids based PGR was applied (i) by root drenching at the time of plantation and (ii) through three foliar sprays 2, 4 and 6 months after plantation in view of large surface area of banana leaves. Its physico-chemical properties are summarized in Table 3.

**Table 3 : Physico-chemical properties of PGR**

| Sr.No | Characteristics | Properties |
|---|---|---|
| 1 | Physical state | Liquid |
| 2 | Colour | Dark brown |
| 3 | TDS | 50 |
| 4 | PH | 4.9 ± 0.2 |
| 5 | a-amino nitrogen | 3.8 |
| 6 | Total nitrogen | 5.3 |
| 7 | Minerals | 2.4 |

**TDS, a-amino nitrogen, total nitrogen and minerals are expressed on % dry weight basis.**

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**Cost of PGR application**

According to Yadav et al.(1995), total cost of PGR application comes out to be US$ 50/L. In the present trials, totally 5 L were used. Thus, total cost of PGR application was 50 x 5 = US$ 250.

**Direct savings due to drenching in PGR**

PGR application was effective, as it enhanced the survival of plants by 20%, presumably by nullifying the effect of transplantation shock as compared to survival in control. At the cost of US$ 0.04 per plantlet and 4400 plantlets planted per hectare, from the total cost of US$ 176, right away 20% saving due to higher % survival from transplantation shock amounts to US$ 35/hectare.

**Indirect savings**

PGR sprays imparted 15 – 40% more chlorophyll and in turn, overall vigour to plants to reflect in productivity. Assuming an average yield of 15 kg/plant and an average cost of banana as US$ 4 per 100 kg, potential extra income from saved 880 (20%) plants is (880 x 15 x 0.04) = US$ 528 per hectare.

**Net savings from PGR application**

Thus, PGR application enabled (a) immediate saving to the farmers in the 20% cost of banana suckers (US$ 35) and (b) indirect saving through extra accruals (US$ 528) as a result of their potential from productivity, which was otherwise lost.

**Analytical profiles of FA**

It is accounted for (i) 92-94% by $SiO_2$, $Al_2O_3$ and $Fe_2O_3$, (ii) 3.5-4.5% by CaO and MgO, (iii) 0.5-1.5% by micro-nutrients (Cu, Zn, Co, B, Mn, Mo, V etc), (iv) some quantity of P and K, (v) 0.2-0.5% toxic elements like As, Cd, Cr, Hg, Pb etc. and (vi) almost devoid of N and organic carbon due to their volatilization during combustion of coal.

**Factors considered while fixing FA dose**

Indiscriminate application of FA develops (i) compacted layers, which reduce aeration, water infiltration and root penetration (Bradshaw and Chadwick, 1980), (ii) increased alkalinity / salinity of soil (Jacobs et al., 1991) and (iii) carbonates of Ca and Mg. due to interaction with atmospheric $CO_2$ and moisture To alleviate these problems, FA was applied at the rate of 1.2 kg/plant, which appeared neither less, nor more; it appeared just adequate to meet requirements of Ca, $PO_4$ and micro-nutrients on the basis of their uptake by banana leaves, banana fruit, vegetables, cereals, pulses and forestry crops (Mandal and Saxena, 1998).

**Myths based on mere apprehensions**

Apprehensions that toxic elements could pose health / toxicity problems by entering in to human food chain as a result of uptake by banana seem to be over simplistic and out of proportion. To alleviate them, let us understand the micro-environment of FA application and follow its chemistry at micro-level. The applied dose of FA was 1.2 kg per plant. It got mixed with minimum 120 kg soil around a plant. Thus, mg quantities of toxic ingredients of FA got automatically 100 fold diluted in the micro-environment around banana plants. Here, they are simultaneously subjected to (i) very limited solubilization, (ii) permeation to lower strata of soil, (iii) immobilisation by local alkalinity, (v) complexation by a variety of organic acids generated by local microflora and (vi) micro-encapsulated by native ecto-/endo-mycorrhizae, rendering them physically present, but biologically dormant. The net result is these inherently insoluble oxides diluted to mg / ng quantities due to above activities are barred to enter in the food chain due to contribution of SC and mycorrhizae ( Klubek et al., 1992).

**Non-entry of toxic elements confirmed by HPLC**

Since $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ are highly insoluble, they do not permeate in banana pseudostem. CaO, MgO, P and K were useful nutrients, besides Cu, Zn, Co, B, Mn, Mo, V as micro-nutrients. The toxic elements did not enter into the pseudostem, leave alone banana fruit as confirmed by HPLC.

**Physico-chemical and microbial profiles of soil**

These are summarized in Table 4.

**Table 4 : Analytical profiles of soil before and after banana production trials**

| Sr. No. | Soil characteristics | Particulars before trial | Particulars after trial 1 | Particulars after trial 2 |
|---|---|---|---|---|
| 1 | pH (10% suspension) | 7.6 | 7.9 | 7.5 |
| 2 | Salinity (mmho/cm) | 0.46 | 0.47 | 0.56 |
| 3 | Moisture holding capacity % | 46.3 | 52.4 | 58.7 |
| 4 | Soil density (g/cm3) | 1.48 | 1.28 | 1.12 |
| 5 | Organic carbon (%) | 0.13 | 0.28 | 0.43 |
| 6 | Available N (kg/ha) | 113.6 | 147.3 | 194.4 |
| 7 | Available P205 (kg/ha) | 15.3 | 17.0 | 20.0 |
| 8 | Available K2O (kg/ha) | 513 | 678 | 1084 |
| 9 | Exchangeable Ca | 26.4 | 61.6 | 51.2 |
| 10 | Exchangeable Mg | 4.2 | 10.5 | 9.7 |
| 11 | Exchangeable Na | 21.5 | 50.0 | 41.5 |
| 12 | Mn (mg/g) | 8.9 | 36.6 | 25.1 |
| 13 | Cu (mg/g) | 2.6 | 11.0 | 9.8 |
| 14 | Fe (mg/g) | 1.8 | 3.0 | 2.8 |
| 15 | Zn (mg/g) | 0.9 | 2.1 | 2.9 |
| 16 | Total microbial count (cfu/g) x 10 6 | 19 | 31 | 43 |
| 17 | VAM spore density/g | 4.8 | 14.0 | 18.0 |
| 18 | Nematode population/g | 1.0 | 0.8 | 0.6 |

**Exchangeable Ca, Mg and N are expressed as meq / 100 g soil.**

From Table 4, it is clear that (i) soil density reduced, indicating more porosity in physical texture of soil conducive for easy root ramification and absorption of moisture / nutrients, (ii) neither pH nor soil salinity increased, (iii) variations in Na, Ca and Mg, as also Mn, Cu, Fe and Zn content fluctuated within the normal range, (iv) on the contrary, its water holding capacity, available N, $P_2O_5$ and $K_2O$ increased, (v) organic carbon content increased by 2-3 fold, (vi) consequently, notable increase in TVC and VAM density, so also infection in the root system, indicating adequate nutrition. All these profiles confirmed that IPNM strategy was right as reflected in sustainability in soil fertility as well as productivity as summarized in Table 5.

**Table 5 : Cause and effect relationship of bioresource management in banana crop**

| Characteristic under consideration | Traditional practice | IPNM strategy |
|---|---|---|
| Plant survival % | 65 – 70 | 90 – 95 |
| Vigour | Less | More |
| Height | More | Less |
| Girth | More | Comparable |
| Chlorophyll | Less | 15-40% more |
| Root ramification | Inefficient | Efficient |
| Siderophore % | Sporadic | Consistently more |
| P uptake | Less | More |
| Toxic elements of FA | Not applicable | Absence confirmed by HPLC |
| Biomass | More | Less |
| Size of fingers | Good | Best |
| Appearance of hands | Curved | Straight |
| Dark spots on banana | Present | Almost absent |
| Average bunch wt. | 16.3 | 19.1 |
| Productivity (kg/ha) | 57,100 | 76, 400 |
| Keeping quality | 2-3 days | 10-12 days |
| Potential for export | Limited | Very good |
| Soil fertility | Stagnated | Improved |
| Net financial earning ($/ha)* | 2284 | 3056 |

**Assumed US$ 40 / MT to be a medium range price of banana.**

**Net outcome**

It is summarized in Table 6.

**Table 6 : Comparative profiles of cost & income as a function of practices**

| Cost of inputs / ha | Traditional practice | IPNM practice |
|---|---|---|
| Rhizomes @ 0.04 / piece | 176 | 176 |
| Chemical fertilizers | 215 * | 108 ** |
| Soil conditioner / plant @ 0.02 / kg | --- | 176 |
| Biofertilizers | --- | 116 |
| Plant growth regulator | --- | 250 |
| Fly ash | --- | 007 |
| Total cost of cultivation / ha | 391 | 726 |
| Total income / ha | 2284 | 3056 |
| Net income / ha | 1893 | 2330 |
| Intangible benefits | | |
| Water consumption % | 100 | 50 |
| Electricity cost | Double | Half |
| Fertility of soil | Deteriorated | Improved |
| Potential productivity estimate | Less / stagnated | Assured more |

All cost and income are expressed in US$ (Rs.50 $\underline{=}$ 1 US$); *For 100% recommended dose; ** For 50% recommended dose; FA being available free of cost, its transportation and application cost is considered; All other expenses in both practices are considered comparable. The results are statistically significant in T-12. In other inputs (T4-T11), banana yield was either less or comparable to the yield by T2.

**Conclusions**

(i) These results are in concurrence with the observations made by Harinikumar and Bagyaraj (1998) that an integrated use of SC, BFs and CFs maintained higher productivity on a sustained basis due to their synergy. (ii) Management practices adopted by the farmers necessitated optimizing various inputs for significant higher yields (Phirke et al., 2002). (iii) Judicious application of FA was complementary to productivity (Jacobs et al., 1991). (iv) DI for sustained availability of moisture and air for root system was desirable. (v) Consortium of BFs was a necessary complement to SC for reduction in CFs (DeClerck et al., 1994). (vi) Application of PGRs was desired for removing physiological constraints in rhizosphere (Sharma et al., 1994). (vii) Application of half the recommended dose of CFs together with SC favoured the build up of native VAM population. (viii) Percent root colonization was related with moderately positive recyclable biowaste, spore density, siderophore presence, nutrient uptake and chlorophyll content. (ix) IPNM treatment showed better nourishment, robust quality and improved productivity of banana.

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