

BENEFICIAL MICROBES IN THE NUTRITION OF COCONUT*

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ABSTRACT

The association of beneficial micro-organisms such as nitrogen fixing bacteria, vesicular-arbuscular mycorrhizal (VAM) fungi and phosphate solubilisers with the roots and rhizosphere of coconut has been well established. The non-symbiotic *Beijerinckia* and associative symbiotic *Azospirillum* are the predominant nitrogen fixing bacteria associated with coconut. The green manure/cover legume-*Rhizobium* association can also contribute substantial quantities of biologically fixed nitrogen in the basins and interspaces of coconut. The palm forms symbiotic association with VAM fungi belonging to the four genera viz., *Glomus*, *Gigaspora*, *Sclerocystis* and *Acaulospora*. Bacteria and fungi capable of solubilising insoluble phosphates are also found in large numbers in rhizosphere of coconut. The research work carried out on beneficial microbes associated with coconut is reviewed and the future areas of research outlined.

INTRODUCTION

The coconut palm (*Cocos nucifera* Linn.) is largely grown as a rainfed crop on nutritionally poor acidic soils of the tropics. The palm responds to inputs of fertilizers, yet most of the cultivation is without the use of fertilizers. This is particularly true in case of farmers with small holdings who constitute the majority of the coconut growers. The continuous mining of nutrients by the palm over a number of years causes depletion of nutrients from the soil with a result the yield of the palm gradually declines. In such situations proposal for exploiting the low cost microbial processes gains importance. Research efforts in this direction have been mainly concentrated on microbial processes such as biological nitrogen fixation, vesicular-arbuscular mycorrhizal symbiosis and phosphate solubilisation. The extent of association of beneficial microbes with the coconut palm, the factors affecting their distribution and the

nutrient transformations carried out by them are discussed in this review.

Biological nitrogen fixation

The bacteria which have potential for reducing gaseous atmospheric nitrogen to a biologically usable form can be a source of nitrogen to the palm. The occurrence of N_2 fixing bacteria in the rhizosphere soils and roots of the coconut palm is well established (Table I). The N_2 fixing bacteria reported to be associated with the palm include the non-symbiotic bacteria *Beijerinckia* and *Azotobacter* and the associative bacterium, *Azospirillum*.

Non-symbiotic N_2 fixers

The enumeration and isolation of non-symbiotic N_2 fixing bacteria have been done from rhizosphere and root region soils of coconut by dilution plating technique using specific N_2 free media. Beckings medium (Becking, 1959) and Jenson's medium (Jenson,

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1951) were the commonly used media for the enumeration of *Beijerinckia* and *Azotobacter*, respectively. The population of non-symbiotic N₂ fixing bacteria was reported to be in the range of 10³ to 10⁵ per g of rhizosphere soil (Table I).

Coconut rhizosphere soils harboured higher population of non-symbiotic N₂ fixing bacteria when intercropped with hybrid napier (Potty and Jayasankar, 1983), tuber crops (Antony, 1983) and when mix cropped with cocoa (Nair and Subba Rao, 1977a) and tree spices (Rohini Iyer, 1983) compared to the monocropping system. Coconut under basin management with green manure legumes (Thomas, 1987), multistoreyed cropping and mixed farming (Bopaiah, 1988) also had higher population of *Beijerinckia* when compared to the respective monocropping system. Subba Rao (1983) reported the occurrence of *Azotobacter* in addition to *Beijerinckia* in coconut rhi-

zosphere soils. Multistoreyed cropping and mixed farming systems were found to be superior to the neglected conditions, farmers gardens and plots receiving fertilizer + manure + tillage in maintaining a higher population of *Beijerinckia* in the rhizosphere of coconut (Thomas, G. V., unpublished).

The rhizosphere effect of coconut on *Beijerinckia* population was studied from farmer's gardens under laterite and sandy soil types in the coconut growing soils of Kerala (Merilyn and Thomas, 1991 a). The R:S ratio varied from 1.22 to 5.09 in different locations. The proportion of *Beijerinckia* in the total bacterial population was 0.20–1.29% in rhizosphere when compared to 0.17 to 0.91% in non-rhizosphere soil. *Beijerinckia* population was recorded from coconut nurseries at a range of 0.84 to 16.35 x 10³ g⁻¹ soil.

Table I. Occurrence of nitrogen fixing bacteria in the roots and rhizosphere soils of coconut

Location/Experiment	Bacteria	Population per g soil	In vitro Nitrogen Fixation	Reference
Coconut-Cocoa mixed cropping, Kasaragod	<i>Beijerinckia</i>	2.0 – 6.0x10 ⁵	9.83 mg N/g	Nair & Subba Rao 1977 b
Coconut-hybrid napier intercropping, Kayangulam	N ₂ fixers	1.20–1.77x10 ⁴	—	Potty, George and Jayasankar, 1977
Mixed cropping in tree spices, Kasaragod	„	1.43–3.96x10 ⁵	—	Rohini Iyer, 1983
Coconut Plantations, Kerala	<i>Beijerinckia</i> <i>Azotobacter</i>	9 x 10 ⁴ 6 x 10 ⁴	—	Subba Rao, 1983
Basin management with green manures, Kayangulam	N ₂ fixers	50.11–74.99x10 ⁴	—	Thomas, 1987
Coconut based multistoreyed cropping, Kasaragod	<i>Beijerinckia</i>	4.28 x 10 ⁵	7.0–15.6 mg/g C source	Bopaiah, 1988
Coconut based mixed farming, Kasaragod	„	4.18 x 10 ⁵	8.4 to 12.2 mg/g C source	„
Farmers gardens in different locations in Kerala	<i>Beijerinckia</i>	1.00x8.77x10 ³	2.71 78.94 nMC ₂ H ₄ tube ⁻¹ h ⁻¹	Merilyn and Thomas, 1991a
Coconut in different cropping systems, Kasaragod	<i>Azospirillum</i>	17–25% roots	10.05 nMC ₂ H ₄ ml ⁻¹ media h ⁻¹	Ghai and Thomas 1989

The identity of cultures as *Beijerinckia* was confirmed on the basis of morphological, cultural and physiological tests as described in the VIIIth edition of the Bergey's Manual of Determinative Bacteriology (Becking, 1974). Another advantage of the bacteria was that it produced lot of polysaccharides which may be important in soil aggregation under field conditions. The cultures showed growth and N₂ fixation at a wide range of pH ranging from 3 to 10 and a pH level of 4 to 7 was better than lower and higher levels (Merilyn, 1989).

The effect of different concentrations of the fungicides on growth and N₂ fixation by *Beijerinckia* was studied under *in vitro* conditions (Merilyn and Thomas, 1991 b). Dithane M-45 caused reduction in growth and N₂ fixation at 100, 250 and 500 ppm levels whereas aureofungin-sol was inhibitory only at 250 and 500 ppm levels and bavistin at 500 ppm levels.

Azospirillum

After the rediscovery of *Azospirillum* sp. by Dobereiner and Day (1976) (originally described as *Spirillum lipoferum*) a great deal of interest has been centered on the association of this bacterium with roots of various crop plants particularly grasses and cereals. Electron microscopic studies have established colonisation of cortical region of roots by *Azospirillum* spp. and they were reported to be more efficient than the nonsymbiotic N₂ fixers in fixation of nitrogen. Subba Rao (1983) reported the incidence of *Azospirillum* in coconut roots.

Ghai and Thomas (1989) studied the extent of occurrence of *Azospirillum* in surface sterilised roots of coconut by 2, 3, 5 triphenyl tetrazolium reduction test and by culturing root fragments in N₂ free semisolid malate medium. They reported the incidence of *Azospirillum* in the roots

of coconut and component crops forming the cropping systems such as high density multispecies cropping, multistoreyed cropping, mixed cropping with tea and coffee, inter-cropping with tropical tubers and mixed farming. Two species of *Azospirillum* viz., *A. lipoferum* and *A. brasilense* constituted 42 and 45 % of the isolates respectively, in coconut based cropping systems.

The effect of *Azospirillum* inoculation on the total yield increase in field grown cereals generally ranged from 10 to 30% (Bashan and Levany, 1990). *Azospirillum* inoculation in cereals often resulted in increase in total plant dry weight, amount of nitrogen in shoots and grains, increased grain weight and greater development of root system. The principal mechanism by which *Azospirillum* increases growth is N₂ fixation, hormonal effects and bacterial nitrate reductase activity in roots. Although the effect of inoculation of *Azospirillum* on growth of a number of crop plants has been established, the growth response of coconut is yet to be studied.

Testing for N₂ fixing efficiency

Nitrogen fixation by bacteria was earlier evaluated by determining nitrogen increment in culture broth by classical Kjeldahl method. The advent of acetylene reduction technique provided a sensitive tool for measuring nitrogenase activity. The assay is based on the principle that nitrogenase, the enzyme responsible for reducing the N₂ to ammonia, also reduces acetylene (C₂ H₂) to ethylene (C₂ H₄). Ethylene and acetylene can be readily measured by flame ionization gas chromatography.

Beijerinckia isolates from coconut based cropping systems fixed 7.0 to 15.6 mg N/g carbon source when tested by Kjeldahl method (Nair and Subba Rao, 1977 a;

Bopaiah, 1988). Ghai and Thomas (1989) reported acetylene reduction activity (ARA) of $10.05 \text{ nM C}_2\text{H}_4 \text{ m}^{-1} \text{ media h}^{-1}$ by the *Azospirillum* isolates from coconut roots. The different *Beijerinckia* isolates from management plots and genotypes of coconut exhibited ARA in the range of 1.58 to $139.62 \text{ n M C}_2\text{H}_4 \text{ tube}^{-1} \text{ h}^{-1}$ (Thomas, G. V. unpublished) while the cultures from farmers plots showed ARA of 2.71 to $78.94 \text{ nM C}_2\text{H}_4 \text{ tube}^{-1} \text{ h}^{-1}$ (Merilyn, 1989). These studies revealed the occurrence of a mixed population of effective and less effective strains of bacteria in the rhizosphere and roots of coconut. The introduction of efficient cultures is therefore important to harness fully the benefits from the nitrogen fixing potential of bacteria.

Green manure/cover legumes as source of nutrients

The nitrogen fixing potential of *Rhizobium*-green manure legume symbiosis can be utilised as a source of nutrients for coconut by growing the legumes either as cover crops or green manure crops. Cover crops are not incorporated into soil, but maintained only as a semipermanent vegetation in the interspace. Fast growing creeping type of legumes are generally grown as cover crops. *Pueraria* and *Calopogonium* have been reported as efficient cover crops in the major coconut growing countries such as Philippines (Cabato, 1970) and Indonesia (Redshaw, 1982) for growing in the interspaces in coconut gardens. When grown as green manures, the green plant material of legumes are incorporated or ploughed into soil at the maximum vegetative stage of growth. More benefits in terms of nutrient addition are obtained when the legumes are used as green manures than when used as cover crops.

Experiments conducted in farmers' gardens at Kayangulam revealed the feasibility of

growing leguminous green manure crops in basins of coconut palms for generating organic manure (Thomas and Shantaram, 1984). The basin area of 1.8 meter radius around the bole of the palm is generally not used for any purpose. Screening of nine species of legumes in the basin area in laterite and sandy soil types revealed the superiority of *Pueraria phaseoloides*, *Mimosa invisa* and *Calopogonium mucunoids* in green matter production and nitrogen yield. Other legumes such as *Mucuna bracteata*, *Crotalaria juncea* and *Macroptilium atropurpureum* were also better whereas legumes such as *Macrotyloma axillaire*, *Centrosema pubescens*, *Leucaena leucocephala* and *Sesbania aegyptica* did not establish well. Seeds of the legumes were sown with the onset of monsoons in June at the rate of 20 g per basin. When harvested after four months growth, they contributed 15–30 kg of green matter and 150–200 g of nitrogen in the basin of a coconut palm. This is about one-third of the annual requirement of nitrogen for the coconut palm (Thomas and Shantaram 1984; 1986 b).

In situ cultivation and incorporation of the green manure legumes was also effective in enhancing the soil fertility parameters in coconut basin soil. There was increase in the population of total microflora, symbiotic N_2 fixers and phosphate solubilisers in green manured basins when compared to the control during the maximum vegetative stage of green manures and at 30 days after the incorporation (Thomas, 1987). Soil enzyme activities (dehydrogenase, phosphatase and urease), mineralisation of carbon and VA mycorrhizal association was also higher in green manured basins when compared to the control. Analysis of soil samples collected at 30 days of incorporation also revealed greater concentrations of major nutrients such as nitrogen, phosphorus and potassium in green manured basins as

compared to control. Basin management studies with green manure legumes in a root (wilt) diseased garden over a period of five years revealed the effectiveness of this technique to enhance the yield of coconut palms without causing further deterioration in disease condition. On the other hand, the root (wilt) disease index of the palms increased in control palms which did not receive the green manuring treatment (Thomas and George, 1990). Basin management technique is now considered as an important component in the management programme for root (wilt) disease of coconut (Muralidharan et al., 1991).

Rhizobial association

The green manure legumes should have association with an efficient strain of *Rhizobium* to add substantial quantities of nitrogen to the soil. Comparative study of nodulation under field conditions revealed that *P. phaseoloides* and *M. invisa* were well nodulated by native soil rhizobia when compared to the other legumes tested (Thomas and Shantaram, 1984). In locations where native nodulation is poor the seeds of legumes should be inoculated with an efficient *Rhizobium* culture.

In order to develop rhizobial inoculants rhizobial cultures isolated from forage/cover legumes grown in local soil and commercial cultures were tested on *Pueraria* and *Calopogonium*. Screening of the rhizobial isolates from eight different legumes in Leonard jar assemblies revealed that the above two legumes were promiscuous in their rhizobial requirement. The best symbiotic efficiency in case of *C. mucunoides* was by an isolate (No.4) from *Desmodium intortum* while isolate No.5 obtained from *Macrotyloma axillare* nodulated and also produced maximum dry matter yield in *P. phaseoloides*. These two cultures (No. 4 and 5) and two composite NifTAL inoculants

were tested in the field on *P. phaseoloides* and *C. mucunoides*. The NifTAL culture containing a combination of strains TAL S304, 310 and 658 was effective in nodulating and increasing dry matter production in *C. mucunoides*. *P. phaseoloides* was effectively nodulated by native soil rhizobia and hence did not respond to the inoculation (Thomas and Shantaram, 1987). There is a need to protect the introduced strains of rhizobia from the acidic soil conditions in the coconut soils. Seed pelleting with charcoal, dolomite, rock phosphate and lime significantly improved the nodulation and nitrogen yield of *C. mucunoides* and *L. leucocephala*. Comparative studies on nodule occupancy by introduced and native strains of rhizobia by using drug resistant cultures revealed better nodulation by introduced strains when seed pelleting was done (Thomas and Ghai, 1988).

The perennial type of legumes like *Leucaena* (Subabul), *Glyricidia* and some species of *Sesbania* can be grown on borders of coconut gardens as a source of green manure. Rhizobial inoculation trials conducted with *Leucaena* showed significant increase in dry matter and nitrogen yield to the extent of 50 per cent over control in K-67 cultivar when inoculated with the UAS culture in acidic coconut soil (Thomas, Shantaram and Hegde, 1985). The green manure legume-*Rhizobium* system offers a potential source of nitrogen to substitute at least a part of the nitrogen requirement of coconut palm.

Vesicular-arbuscular mycorrhizae (VAM)

Like many other tropical crops, coconut also forms vesicular-arbuscular mycorrhizal associations with many fungi. This symbiotic association is known to help the plants in the absorption of phosphorus and other immobile elements in addition to their role

in the suppression of root pathogens. VAM fungi also help plants in the uptake of water under water stress conditions. Mycorrhizal association would be one of the factors that contribute towards the establishment and survival of coconut in nutrient poor soils and also in drought conditions.

Vesicular - arbuscular mycorrhizal association in coconut was first reported by Johnston (1949). Lilly (1975) reported the occurrence of *Endogone fasciculata* in root (wilt) diseased and healthy palms in Kerala. Subsequently a number of fungi belonging to four genera viz., *Glomus*, *Gigaspora*, *Sclerocystis* and *Acaulospora* have been found to be forming mycorrhizal associations with coconut (Table II). The occurrence of a mixed populations of VAM has been

commonly recorded from the coconut rhizosphere soils.

Factors affecting VAM symbiosis in coconut

Fertilizers:

Ramesh and Rohini Iyer (1979) reported that unfertilized soils yielded more VAM than fertilized plots as revealed by the abundance of arbuscules, vesicles and hyphal distribution within and outside roots. The younger roots were better colonised than the older ones.

The effect of different levels of fertilizers on the distribution of various species of VAM fungi was studied using West Coast Tall palms in an NPK experiment (Khan H. H., personal communication). It was observed

Table II. VAM fungi associated with coconut

Fungus	Reference	Remarks
1. <i>Acaulospora bireticulata</i> Rothwell & Trappe	Harikumar, 1990 Sosamma et al., 1990	
2. <i>A. laevis</i> Gerdemann & Trappe	"	
3. <i>A. scrobiculata</i> Trappe	Harikumar, 1990	
4. <i>A. trappei</i> Ames & Linderman	Sosamma et al., 1990	
5. * <i>Gigaspora aurigloba</i> (Hall) Walker & Sanders	Thomas & Ghai, 1987 Sosamma et al., 1990	*Now changed to <i>Scutellospora aurigloba</i>
6.* <i>G. coralloidea</i> (Trappe, Gerdemann & Ho.) Walker & Sanders	Thomas & Ghai, 1987 Sosamma et al., 1990	* Now changed to <i>Scutellospora coralloidea</i>
7. <i>G. decipiens</i> Hall & Abbott	Harikumar, 1990 and Thomas & Ghai, 1987	
8*. <i>G. gilmorei</i> (Trappe & Gerd) Walker & Sanders	Ramesh, 1982	* Now changed to <i>Scutellospora gilmorei</i>

(contd.)

Fungus	Reference	Remarks
9. <i>G. margarita</i> Becker & Hall	Harikumar, 1990 Sosamma et al., 1990	
10* <i>G. nigra</i> Redhead	..	*Now changed to <i>Scutellospora nigra</i>
11* <i>G. pellucida</i> Nicolson & Schenck	..	*Now changed to <i>Scutellospora pellucida</i>
12. <i>G. rosea</i> Nicolson & Schenck	Thomas & Ghai, 1987	
13. <i>Glomus aggregatum</i> Shenck and Smith emend. Koske	Harikumar, 1990	
14. <i>G. fasciculatum</i> (Thaxter sensu Gerdemann) Gerdemann & Trappe emend. Walker and Koske	*Lilly, 1975. Thomas & Ghai, 1987. Sosamma et al., 1990 & Harikumar, 1990	*Earlier referred to as <i>Endogone Fasciculatus</i>
15. <i>G. fuegianum</i> Trappe & Gerdemann	Sosamma et al., 1990	
16. <i>G. invermaius</i> Hall	..	
17. <i>G. macrocarpum</i> Tul. & Tul.	Ramesh, 1982	
18. <i>G. microcarpum</i> (Tul. & Tul.)	..	
19. <i>G. multicaulae</i> Gerdemann & Bakshi	Thomas & Ghai, 1987 Harikumar, 1990	
20. <i>G. pallidum</i> Hall	Sosamma et al., 1990	
21. <i>Sclerocystis coremioides</i> Berk & Broome	Sosamma et al., 1990	
22. <i>S. microcarpus</i> Iqbal & Bushra	..	
23. <i>S. rubiformis</i> Gerdemann & Trappe	..	
24. <i>S. sinuosa</i> Gerdemann & Bakshi	..	

that mycorrhizal infection in roots was negatively related to the available soil P ($r=0.89$) and (0.91). The average infection of 82.3% was observed when available P was 7.6 ppm and this was reduced to 57.3% and 42.5%, respectively, when available P increased to 257.9 ppm and 384.5 ppm due to continuous application of fertilizers over the years. Changes in the concentrations of P fractions were influential in effecting changes in VAM infection as well as spore density. Significant positive relationship between percentage colonisation and Fe-P ($r=0.79$), reductant soluble - P ($r=0.83$), occluded -P ($r=0.88$) and Ca - P ($r=0.81$) indicate the effectiveness of VAM fungi to utilise sparingly available sources of soil P. VAM colonisation in coconut roots and spore counts in root region soil were higher in coconut when P application was skipped for a period of 14 years when compared to that in plots receiving the full and half the dose of recommended P application (Khan et al., 1990)

Harikumar (1990) reported that mycorrhizal association in three genotypes of coconut, (WCT, COD x WCT and WCT x COD) was adversely affected by the application of fertilizers. There was 32.7% reduction in root colonisation at the recommended level of fertilizers and 55.5% reduction at the higher level of application. A similar reduction was observed in the intensity of infection and spore counts of soil in root region. The palms under irrigation treatment had a higher level of mycorrhizal colonisation when compared to that in the unirrigated palms. Observations in the permanent manurial experiment at CPCRI, Kasaragod also revealed drastic reduction in mycorrhizal colonisation of coconut palms under manuring, tillage, herbicide and fertilizer treatments when compared to that in the neglected plot.

Thus it is evident that in soils poor in nutrient mycorrhizal colonisation is more probably because a good number of VAM fungi can withstand only low concentrations of soil nutrients. However, their abundance in such soils helps the palm in getting nutrients and thus works as an insurance in poor soils. However it has been observed that VAM is still found in nutrient rich soils and are not eliminated. Here again, there is scope to isolate and multiply these organisms to use them to the best of our advantage.

Host genotype:

A study on one year old seedlings of 17 coconut cultivars and 4 hybrids revealed genotype dependent variation in VA mycorrhizal colonisation (Thomas and Ghai, 1987). Tall cultivars were found to be superior to the dwarfs and hybrids in harbouring VAM in their roots. Laccadive Ordinary and British Solomon Islands were the cultivars which showed the highest percentage (95.2 and 94.4, respectively) of root mycorrhizal colonisation. Studies conducted on adult palms in a genotype-nutrient interaction experiment at Kasaragod showed highest percentage of root colonisation in WCT (43.65), followed by that in WCT x COD (40.48) and COD x WCT (33.73). The difference in colonisation between WCT and COD x WCT was statistically significant (Harikumar, 1990).

Inter/mixed cropping:

The quantitative and qualitative distribution of VAM also varied in response to introduction of a single crop or a combination of crops in the interspaces of coconut. Ramesh (1982) reported the variability of VA mycorrhizal population associated with plants forming coconut-based multistoreyed cropping system viz., coconut, cocoa, cinnamon

and black pepper. *Gigaspora gigantea*, *Gigaspora gilmorei*, *Glomus macrocarpum* and *Glomus fasciculatum* were associated with all the four crops whereas *Glomus microcarpum* was associated with coconut and pepper and *Sclerocystis* sp. with cinnamon only. The mycorrhizal status of coconut was improved in an agroforestry system when intercropped with subabul, casuarina, eucalyptus, mango and jack (Rohini Iyer, Kalpana Sastry and Kailasam, 1986). Thomas (1988) reported that intercropping with hybrid napier improved the mycorrhizal status of root (wilt) diseased coconut palms when compared to the monocropping system and mixed cropping with cocoa. The spore population decreased with the increase in soil depth. The spore counts were 72.3% less at 25–50 cm depth and 83.5% less at 50–100 cm in the coconut basins than at 0–25 cm. Basin management with green manure legumes such as *P. phaseoloides*, *C. mucunoides* and *M. invisa* also improved mycorrhizal status of coconut.

Root (wilt) disease:

The root (wilt) disease had an adverse effect on the VA mycorrhizal association in coconut. The extent of root colonisation and population of VA mycorrhizal spores in rhizosphere soils were less in root (wilt) diseased palms in the middle stage of the disease when compared, to that in apparently healthy palms (Thomas, 1988). It has also been reported that management practices such as mixed farming was effective in enhancing the extent of VA mycorrhizal association in root (wilt) diseased palms.

Phosphate solubilising micro-organisms

The phosphate solubilising micro-organisms contribute to the dissolution of phosphate from insoluble P sources in soil and enable the application of low cost phosphatic fertilizers like rock phosphate. The phos-

phate-solubilising micro-organisms were found to be widely distributed in coconut soils and in various coconut based cropping systems. Bacteria constituted the predominant phosphate solubilising micro-organisms in coconut soils, followed by fungi and actinomycetes. The laterite, alluvial and clayey soils harboured more of the P-solubilizing fungi than the sandy soils whereas bacterial population was less in clayey soils when compared to the other three soil types (Thomas, Shantaram and Saraswathy, 1985; Thomas and Shantaram, 1986a).

On the basis of *in vitro* activity to solubilise insoluble phosphates fungi were better and the isolates solubilised upto 72% of the insoluble P supplied as tricalcium phosphate in the medium. Bacteria and actinomycete cultures solubilised 4.39 to 54.0% and 1.00 to 6.99% of insoluble P, respectively. The predominant bacteria solubilising phosphates in coconut soil were *Pseudomonas* sp. and *Bacillus* sp. Various species of *Aspergillus* and *Penicillium* constituted the major P-solubilising fungi in coconut soil (Nair and Subba Rao, 1977 b; Bopaiah, 1988).

Nair and Subba Rao (1977 b) reported positive correlation between the incidence of P-solubilising micro-organisms and available phosphorus content in soil in a coconut-cocoa mixed cropping system. Thomas, Shantaram and Saraswathy (1985) studied competitive saprophytic ability of active P-solubilising fungi and recognised eight cultures with high P-solubilising capacity and competitive saprophytic ability. The available phosphorus content of laterite and sandy soils was increased when inoculated with efficient P-solubilising bacteria after addition of rock phosphate and farm yard manure (Thomas and Shantaram, 1986 a). Inoculation with *Bacillus subtilis* in sandy soil and *Micrococcus roseus* in laterite soil

caused maximum increase in available P content when compared to the other bacteria tested. Studies on survival of the inoculated bacteria revealed that the above two bacteria possessed better capacity to survive in un-amended soil compared to other P-solubilising bacteria tested.

Areas of future research

The nitrogen fixing systems need to be understood in detail, in order to fully harness their potential benefits. Work on *Azospirillum* and *Beijerinckia* needs to be continued with vigour so as to put the systems to work and improve them further. More attention is required to studies pertaining to the establishment and survival of added inoculum and to factors which affect the survival of the inoculated cultures. It

is also necessary to assess the rhizobial requirement of green manure legumes at different locations and also to recognise efficient *Rhizobium* - green manure legume systems to improve nitrogen contribution to the benefit of coconut. The field of VAM study offers a lot of scope for further investigation especially in studying the host-fungus compatibility since it has already brought out that the mycorrhizal dependency is genetically controlled. The details of host-fungus relationship and its effects on nutrient and moisture uptake by the plant needs to be further investigated. There is also a need to examine the benefits of dual inoculation of N₂ fixing bacteria and VA mycorrhizal fungi in order to obtain the benefit of both the microbial processes for the nutrition of the crop.

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