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SCOPE AND ROLE OF PGPR IN CROPPING SYSTEMS IN PLANTATION CROPS AND SPICES IN RELATION TO THEIR AGRONOMY AND PATHOLOGY

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In India, Plantation Crops and Spices are grown over an area of 3.2 million ha accounting for 1.82% of the total crop area contributing to the export earnings of 18% of the agricultural commodities. The diverse agroclimatic situations prevailing in India offer abundant scope for cultivation of these crops. Some crops like Coffee, Tea, Rubber and Cardamom are location specific while others like Coconut, Arecanut, Cocoa and Cashew are adapted to varied climate. Spices specially Black pepper, Cardamom, Vanilla, Tree spices like Clove, Nutmeg, Cinnamon and Allspice generally are mix-cropped in some of the perennial cropping systems even though monocropping is also practiced. Mixed cropping (perennial) and intercropping systems (annuals) are practiced by the farming community to optimise the production per unit area per unit time taking into consideration the optimum utilization of solar energy and water. (Nair, 1979)

Agronomy of plantation based cropping system

Since most of the farmers cultivating these plantation crops are small and marginal holders, it is not very ideal to depend on any particular crop, which most often suffers due to fluctuations of yield and price thereby ending up low remunerative income to farmers.

Multiple cropping or farming systems helps efficient use of natural resources, buffer against price fluctuations, generates more employment opportunities and production of commodities for varied end uses and thus ensures crop diversity. Hence it is all the more important to changeover from such low efficiency system to a production system, which is more sustainable involving different crops/livestock husbandry that can not only provide basic needs like food, fodder, fibre, timber, but also meet the nutritional requirements of the farm families and to generate sustainable income for them to tide over adverse economic situations.

Cropping and farming systems are dynamic interactive practices aimed at better use of the production components such as air space, water, soil, solar radiation and all other inputs on a sustainable basis. Perennial crops with their large canopy and deep root system can exploit the production components to a greater extent than annuals. These systems got evolved over decades by innovative efforts of farmers and very successful models have come to stay in many countries. Plantation crops mentioned above provide ample scope for the adoption of cropping systems in an efficient manner.

Coconut and Arecanut based cropping system

The vertical distribution of the roots of coconut have shown that the top 30 cm layer of soil is devoid of functional roots and that above 86% of the roots are found between 30 and 120 cm depth from the surface (Kushwah et al, 1973). The canopy of coconut is known to intercept only 44% incident solar radiation due to its poor light use efficiency of 1.4g dm/MJ (Liyange, 1994). The amount of light transmitted ranges from 20% under 10-20 year old palm to 50% in a plantation of 40 years and above (Opio, 1999). However, the morphological feature of the palms warrants its planting at a spacing of 7.5 x 7.5 m. These observations point out that only around 25% of the total available land area in a pure stand of coconut is effectively utilized by the coconut roots and the remaining ¾ of the area is left unutilized and it provides scope for growing other inter/mixed crops.

When palms grow up, slant rays of sunshine will add to light coming in between the leaves. When palms grow old, after about 50 years, a gradual reduction occurs and more light will penetrate (Fig1).

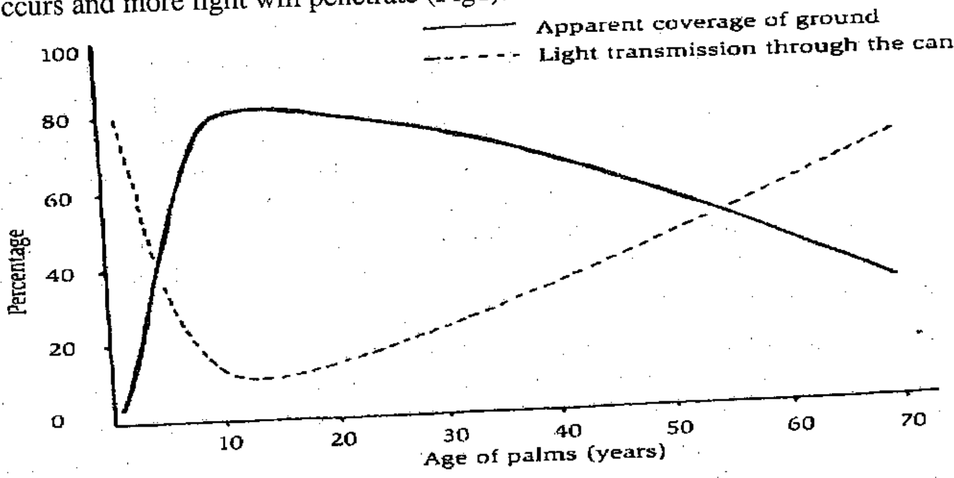

Fig. 1. Apparent ground coverage and light transmission in coconut plantation (Nelliyat, et al, 1974).

Based on the growth habit of the palm and the amount of light transmitted through its canopy, the life span of coconut palm could be divided into three distinct phases from the point of view of intercropping.

Table 1. Age of coconut palm in relation to successful crops grown

Growing condition	Age of palm (years)	Light transmission	Suitability of intercrops
Planting till full development of canopy	Up to 8	Good initially, decreases with age	For growing annuals, biennials, intercrops have minimal competition with coconut plants
Young palms	9 to 25	Maximum ground coverage (80%), Poor light availability	Not ideal for intercropping. If wider spacing is followed, annuals can be grown, suitable for vanilla
Grown up palms	> 25	Gradual increase in light availability	Ideal for annual/ perennial crops

Similarly the compact nature of arecanut crown varies and above the ground (10-15m) allows more sunlight to pass down the ground and maintains high humidity, which ensures excellent growth of shade loving crops. Studies done at CPCRI have shown that the orientation and structure of arecanut canopy permits 32.7 to 47.8% of incident radiation to penetrate down, depending on the time of the day (Muralidharan, 1980). Normally in an areca garden spaced at 2.7 x2.7m, the light energy reaches the ground and is wasted. Rooting pattern studies have shown that arecanut palms planted at this spacing could use effectively only 30% of the land area (Bhat and Leela, 1968). The normal cultural operations are also confined within about 75-80 cm radius from the base. Thus the arecanut palm exploits only around 31%(2.27m^2) land area out of 7.29m^2 land available for each palm.

Thus making use of the unutilized soil space and the solar radiation in monocropping of coconut or arecanut stands, a variety of crops having different stature, canopy shape and size of rooting habits can be accommodated as inter/mixed crops to form compatible crop systems. Such a cropping system will help to intercept and utilize light at different vertical intervals and forage soil at different depths thus maximizing biomass production per unit of area land, time and other inputs.

Multistoried cropping system

The practice of growing multiple species of compatible crops with varied morphological and physiological features is called multistoried cropping. Each of these crop species, according to their canopy orientation and root spread enables intercepting and harvesting solar energy and soil reserves at varying vertical and horizontal distances and obtains a higher efficiency of their utilization. Coconut palms above 20 years old are suitable for this system and black pepper can be trained on the palms and allowed to occupy 2 to 8 m height of the trunk to form as the second floor. An ideal example of such a system is coconut +cocoa +pine apple. Leaf canopies of these crop species located at different vertical heights give the appearance of a multistoreyed crop building. By adopting this in addition to 175 coconut palms (4-8 m height) and pepper vines trailed on it, about 600 cocoa and 3500 pine apple plants can be accommodated in one ha area yielding about 17500 coconuts, 100 kg dry pepper, 750 kg dry cocoa beans and about 5000 kg pine apple fruits. In multistoried cropping system, the top floor determines the agronomic desirability of the nature and type of crops that could be combined (Jacob John and Nair, 1999). As such, adjusting the light levels in the under storey by manipulating the over storey strata to increase light penetration assumes greater importance. Selective pruning of trees should be done once the tree canopy becomes closed. Root crops such as sweet potato, cassava, colocasia are reasonably tolerant to mutual shading and shading by taller crops (Buck,1986). Intercropping of tuber crops found successful in coconut based cropping system (Sheeba and Pushpakumari, 2000; Varghese, 1993).

Table 2. Tuber crops in coconut based cropping system

Tuber crop	Variety	Spacing	Yield
Tapioca	Sreevisakhom	Mounds, 90 x 90 cm interspace (8400 plants / ha)	2 kg/plant
Yam –greater yam	Indu	Pits 1m x 1m	20-22 t/ha
-lesser yam	Sreelatha	Mounds, 75 x 75 cm	15 t/ha
Aroids			
Elephant foot yam	Local	Pits 90 x 90 cm	
Cocoyam	Local	do	

Table 3. Yield performance of tuberous and rhizomatous crops under coconut plantation.

Intercrop	Method of planting	Spacing	Yield (t/ha) of gross area of coconut
Elephant foot yam	Pits	m x 1.0 m	12.85
Tapioca	Pits	0.9 m x 0.9m	10.51
Sweet potato	Ridges& furrows	50 cm between rows	9.53
Yam	Pits	m x 1.0 m	12.72
Lesser yam	Pits	0.75 m x 0.75m	9.00
Coleus	Beds	4 rows in beds	6.00
Ginger	Beds	and 20 cm between	11.50
Turmeric	Beds	plants in bed	12.93

An increase in net returns to the tune of Rs.13, 300/ha was obtained in mixed cropping pepper in coconut gardens at CPCRI, Kasaragod is given below.

Table 4. Economics of coconut-pepper mixed cropping at CPCRI, Kasaragod (Rs/ha/year at 2000-2001 prices)

System	Invest. cost	Annuity value	Total annual cost	Yield of pepper (kg/ha)	Unit value of pepper (Rs)	Gross returns	Net returns
Coconut monocrop	60,000	17,000	24,500	-	--	46,800	22,300
Coconut+ Pepper	70,000	19,600	28,800	175	100	64,300	35,500

(Source: CPCRI Technical bulletin, No.24)

Economics of coconut based intercropping system (Horticultural Research Station, Mondouri, BCKV, West Bengal (Anon, 2001b) is given below.

In West Bengal also ginger was found to be highly remunerative as intercrop in coconut. The profit was Rs.40,250/ha whereas, it was Rs.23,450/ha from turmeric.

Table 5. Economics of intercropping of spices in coconut based cropping system (Rs./ha).

System	Cost of cultivation	Gross return	Net return	Return from intercrop	Cost for intercrop	Profit from intercrop
Coconut alone	19,000	37,170	18,170	--	--	--
Coconut+ Turmeric	47,000	88,620	41,620	51,450	28,000	23,450
Coconut+ Ginger	73,950	1,32,370	58,420	95,200	54,950	40,250

Selling price: Coconut: Rs 3.5/nut, Ginger Rs.8.0/kg, Turmeric: Rs.3.5/kg

Korikanthimath et al (1999) studied the feasibility of growing vanilla as a mixed crop in coconut garden spaced at 9x9 m in lower elevation (plains) and low rainfall area under assured irrigation. Cost of cultivation of vanilla in the pre bearing, first year of bearing and of coconut (average 4 years from 94-95 to 97-98), gross and net return of mixed cropping vanilla under coconut is given in the table 6. The

importance and commercial potential of coffee-pepper and cardamom was also indicated (Korikanthimath 2001).

Table 6. Yield, cost and return of mixed cropping of vanilla under coconut (Rs./ha)

Year	Yield		Price		Gross return	Cost of cultivation	Net return
	Coconut (nuts/ha)	Vanilla (kg/ha)	Coconut (Rs./nut)	Vanilla (Rs./kg)			
94-95	8,333	---	3.0	--	24,999	1,32,489	1,07,490
95-96	12,500	---	3.2	--	40,000	27,538	12,462
96-97	18,750	---	4.5	--	84,375	30,687	53,688
97-98	25,000	85	4.0	1500	2,27,500	41,171	1,86,329
Average					94,219	57,971	36,247

The negative net return during the first year was mainly on account of high cost of planting material for vanilla. The crop comes to bearing only three year after planting. They recorded a gross and net profit of Rs. 94,219/- and 36,247/ha, respectively over a period of 4 years and the BC ratio was 1.34 time by that cultivation of vanilla, as a mixed crop in coconut plantation is profitable.

High Density Multi Species Cropping System (HDMSCS)

A coconut based high density multispecies cropping system (HDMSCS) model was established at CPCRI, Kasaragod in 1983 with 17 species of annuals/perennials planted at a high density of 14,976 planting points / ha of coconut plantation (Bavappa et al, 1986). As the perennials grew and utilized more and more space, the annual crops except banana were removed from the system. The present system includes crops such as banana, clove, nutmeg and pineapple in coconut stand. It is maintained under three fertilizer levels. The yield of coconut and component crops is as follows.

Table 7. Yield of coconut in relation to fertilizer, space and biomass production in HDMSCS at CPCRI, Kasaragod (Bavappa et al,1986).

Observations	Yield of coconut (nuts/ha)		
	1983-84	1984-85	1985-86
Fertilizer			
Full dose	9719	9344	27097
Two-thirds	11029	11778	25912
One-third	10374	8908	29141
Air space utilization (%)	32.4	31.0	30.9
Biomass-coconut (t/ha)	35.1	37.9	50.1
Other crops (t/ha)	7.0	7.0	7.4
Total economic yield in coconut (t/ha)	6.5	6.2	17.1

In the coconut based high density cropping system maintained at CPCRI, Kasaragod, the yield of coconut increased form 9700 to 27,000 nuts/ha in three years time. However, there was no marked difference in yield among various fertilizer levels in different years. The airspace utilization, on an average was 31%. Subsequent analysis made by Reddy et al(2000) is as follows.

Table 8. Productivity of crops under different levels of fertilizers in coconut based HDMSCS(mean of 1995-96 to 1998-99) (Reddy *et al.*, 2000)

Crop/treatment	Yield (unit)	Control	Fertilizer dose				
			1/5	¼	1/3	2/3	Full
Coconut	Nut/palm	131	124	133	147	152	150
Clove	g/tree	98	227	328	277	621	419
Pineapple	g/fruit	645	706	754	707	795	820
Banana	kg/bunch	3.31	3.20	3.92	4.54	5.12	5.54

Table 9. Mean production and economic returns (Rs/ha) in coconut based HDMSCS with Coconut 157, Banana 345, Clove 112 and Pine apple 2250 plants/ha (Reddy *et al.*, 2000).

Treatments/crops	Mean production/ha (95-96 to 98-99)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net profit (Rs/ha)
1.Control		29127	79745	50618
Coconut(nuts/palm)	19807			(25.4%)
Clove (g/tree)	10.51			
Pineapple(g/fruit)	1393			
Banana(kg/bunch)	1096			
2. One-fifth		30255	79797	49452
Coconut(nuts/palm)	18749			(29.5%)
Clove(g/tree)	24.30			
Pineapple(g/fruit)	1525			
Banana(kg/bunch)	1060			
3. One-fourth		30291	88826	58535
Coconut(nuts/palm)	20110			(32.1%)
Clove(g/tree)	35.20			
Pineapple(g/fruit)	1629			
Banana(kg/bunch)	1298			
4. One-third		30535	95316	64781
Coconut(nuts/palm)	22226			(30.0%)
Clove(g/tree)	29.70			
Pineapple(g/fruit)	1527			
Banana(kg/bunch)	1504			
5. Two-third		32507	107832	75325
Coconut(nuts/palm)	22982			(36.0%)
Clove(g/tree)	66.60			
Pineapple(g/fruit)	1717			
Banana(kg/bunch)	1696			
6.Full		34363	104161	69798
Coconut(nuts/palm)	22680			(34.6%)
Clove(g/tree)	44.90			
Pineapple(g/fruit)	1771			
Banana(kg/bunch)	1835			

Table 10. Efficiency of HDMSCS under root (wilt) affected garden of coconut in 1.0ha area. [Maheswarappa et al (2003)]

Crop	Plant population	Yield on Kg
Coconut: Adult (WCT)	125 (1995-98)	6286 nuts
Seedling/Juvenile	112 (1998-2001)	-
	152	-
Nutmeg (local)	45	10 mace +16 nut
Black pepper (Karimunda)	30	27
Banana (different varieties)	500	849
Pine apple (Kew)	3600	308
Tuber crops:		
Amorphophallus (local)	100	322
Colocasia (local)	100	214
Dioscorea (local)	100	292

Table 11. Yield of Clove in High Density Multispecies Cropping System under Coconut

Fertilizer dose	Yield of clove (dry, kg/plant)		Average yield (dry, kg/plant)
	2000	2001	
Full	1.34	1.18	1.26
2/3	1.35	1.07	1.21
1/3	0.86	0.87	0.87
¼	--	0.49	0.25
1/5	--	--	--
Control	--	--	--

Source: Anon, 2001a

In root wilt affected area HDMSCS system, the coconut yield increased from 30 nuts/palm/year to 76 during 2000-01 (Maheswarappa et al (2003)). The higher benefit: cost ratio of 2.28 and positive net present worth (Rs. 1,80,016) indicated that the HDMSCS is economically viable in root (wilt) affected coconut areas.

Nutrient management in cropping system

Integrated nutrient management is an integral part of plantation based cropping system. While the main and component crops receive inorganic nutrients based on individual crop requirements, the organic addition brought through leaf litter recycling and microbial activity would lead to integrated nutrient management for enhanced system productivity.

Synergistic effects in cropping system

The multiple cropping system results in the continuous uptake, addition of biomass and higher level of nutrient recycling. That would lead to a positive influence on the physico-chemical and biological properties of soil. Consequently application of fertilizers into the system can be reduced without affecting the yield of coconut and other component crops. In the HDMSCS model at CPCRI, Kasaragod, there was no significant difference in yield of crops under lower doses of fertilizer than the full dose. In the system there was build up of P and K, while, the levels of N and Mg did not increase as a result of introduction of various crops. The microbial biomass, the organic content, total N, P and K were higher in the root region soils of multistoreyed cropping system when compared to the levels in coconut monocrop

(Bopaiah and Shetty,1991). Thus a higher productivity is achieved in cropping systems as a result of synergistic interaction among the crops raised in the same filed. The microclimate inside a mixed cropping system is characterized by lower maximum temperature, smaller diurnal variations and less evaporative demand compared to pure stands. The beneficial effects are reflected on enhanced soil fertility status, enhanced microbial activity and better utilization of natural resources for the benefit of plant growth and sustainable crop productivity.

Table 12. Availability of onfarm biomass in plantation sector in plantation crops in India (Biddappa et al, 1996)

Crop	Quantity of biomass available
Coconut	11.2 mt
Arecanut	0.43 mt
Cocoa	
Shed leaves	360.03 t
Prunings	12056.33 t
Pod husk	32900 t
Coffee	
Husk	0.18 mt
Tea	
Waste	0.22 mt

On farm waste recycling in cropping system

It has been estimated that the biomass production by coconut-pineapple cropping system was 4.3 times more than that of pure stands and hence this combination can be considered to be one of the optimum systems for tropical areas (Peng al, 1996). Studies at CPCRI have shown that when cocoa is mix cropped in coconut garden, it adds 818 and 1985 kg (oven dry weight)/ha/year of biomass under single and double hedge system, respectively. Under double hedge system this helps to return as much as 50,9 and 21 kg NPK/ha/year to the soil(Varghese et al,1978). The addition of large amount of organic biomass definitely helps in improvement in soil fertility and thereby enhancing crop yield.

PGPRs for nutrient management

Under intensive multiple cropping system nutrient balance becomes basic prerequisite to ensure optimum production (Khan et al. 2002). As such fertilizer will be required to replenish the exhausted nutrients based on the crop output. Their dosages can be minimized through microbial consortia inoculants along with organics. The momentum is gaining for organic agriculture and the scope for these in tropical agriculture through microbiological manipulation is high (Thomas, Rohini Iyer and Bopaiah 1991).

In all the compatible cropping systems the increased growth and production and productivity is linked to the microbiological activity specially the beneficial ones through their rhizosphere effects and root exudation (Bopaiah, Shekhar Shetty and Nagaraja 1987; Bopaiah and Shetty 1991). The presence of *Azospirillum* reported in the Coconut based cropping is of great relevance (Ghai and Thomas, 1969) and needs to be exploited. So also several P. solubilisers present in several perennial cropping systems (Bopaiah and Thomas, 1993). Since the majority of the plantation soils are acidic and several PGPRs isolated from the rhizosphere of black pepper and other spice crops were found growth productive, disease suppressive and incidentally are efficient P. solubilizers.

In Coconut and Cocoa mixed crop increased activity of *Beijerinckia* sp, *Aspergillus niger* and *Pseudomonas* spp. which also included growth promoting substance like IAA and GA (Nair and Subba Rao 1977) was recorded which reflected on the yield increase in the crop mix. Similarly increased N.fixers and P. solubilisers were reported in Coconut – Tree spices (Cinnamon, Clove, Nutmeg) mixed crop system (Rohini Iyer, 1983).

The role of *P. fluorescens* mediated nutrient flux in the soil microcosm in plant growth promotion was studied with the higher uptake of nutrients by the bacterized plants. Significant uptake of nitrogen (N) and potassium (K) was noticed in the treated black pepper. (Diby Paul *et al*, 2003, 6th Intl. PGPR workshop).

Increased productivity of crops in cropping system through minimal chemical inputs when combined with microbials would be a practical proposition, that too where scope of biomass recycling is high. Increasing the microbiological activity through organics is well documented (Savithri and Khan, HH (1994), Srinivasan et al 2002). In a cropping system the addition of organics due to the leaf fall etc. would also result in organic matter build up which would make greater availability of nutrients (Hameed Khan and Upadhyay, 2002).

PGPRs for biotic stress management

PGPRs have potential scope in the management of biotic stress. Specially in mixed cropping systems involving coconut and arecanut the microclimatic changes that occur would be conducive to several pests and diseases. Some pests and pathogens will have common hosts resulting in preponderance of the biotic stress resulting in severe crop losses. In addition to the main crops like coconut and areca which are also prone to *Ganoderma lucidum, G. aplanta* (Bhaskaran etal 1994; Sampathkumar and Saraswathy 1994) / *Thiclaviopsia paraloxa* (Nambiar 1994), companion crops like Black pepper (Sarma etal 1994), Cocoa (Chandramohanan 1994) and Vanilla are also prone to soil borne pathogens like *P. capsici, P. palmivora* and *Phytophthora meadii. Phytophthora palmivora* (Bud rot of coconut), *P. capsici* (Foot rot of black pepper), *Ganoderma lucidum* (Tanjavur wilt), *Thielaviopsis paradoxa* Stem bleeding of coconut) etc. (Table 13) needs to be considered in our efforts to manage these pathogens through microbiological intervention to ensure optimum crop health and productivity.

The potential microbial communities, which have broad spectrum of growth promoting and disease suppressive activities against major soil borne pathogens as mentioned above is of great relevance. The microbial load of these beneficial microbes in a cropping system need to be ensured with agronomic practices that prevail. The minimum tillage practice that would ensure no or minimum damage to root systems and the associated microbial load would be ideal.

The research on PGPRs in spice crops like black pepper, ginger and Vanilla (which becomes a part of the perennial cropping system) have proved their potential in growth promotion and disease suppression, their effects on other crops in the cropping systems are warranted.

Table 13. Scope and potential of PGPRs for growth promotion and disease suppression of major soil-borne pathogens prevalent in mixed cropping systems of plantation crops

No.	Cropping Systems	Pathogen Profile
1	Coconut + Pepper	*Phytophthora palmivora, P. capsici*
	Ginger and Turmeric	*Ganoderma lucidum, Thielaviopsis paradoxa,* *Pythium aphanidermatum*
	Banana	*Radopholus similis, Meloidogyne incognita*
2	Coconut + Cocoa	* *P. citrophthora, P. parasitica*
3	Coconut + Vanilla	**P. meadii, Fusarium oxysporum f. sp. Vanillae*
4	Arecanut + Pepper	**P. meadii, P. capsici*
5	Arecanut + Cocoa	**P. meadii, P. capsici*
6	Coffee + Pepper	**Fusarium oxysporum f. sp coffeae, P. capsici, R. similis, M. incognita, Fomes noxius, Rosellina*
7	Coffee + Pepper + Cardamom	**Rhizoctonia solani, Pythium vexans*
8	Tea + Pepper	*Poria lateritia, Phomopsis theae*

* In addition to the pathogens in cropping system - 1

PGPRs and their effectiveness has been established on foot rot and slow decline of black pepper and rhizome rot of ginger and clump rot of cardamom. Strains of *Pseudomonas fluorescens* were found to increase the growth and vigor of these crops apart from suppressing the soil borne diseases (Sarma *et al*, 2000). Intensification of research efforts at IISR, Calicut on PGPRs with a major focus on disease suppression in spice crops lead to several important findings.

The beneficial rhizobacteria are termed as Plant growth Promoting Rhizobacteria (PGPRs) because of their ability to improve plant growth through suppression of deleterious root colonizing microorganisms and by production of plant growth regulators (Kloepper, *et al*, 1981 & 1980, Suslow *et al*, 1982).

Out of over thousand collections of rhizobacteria maintained at IISR, few strains have been short listed based on disease suppression, growth promotion and induction of systemic resistance and the efficient strains were studied in-depth in black pepper (Sarma *et al*, 2000, Diby Paul *et al*, 2000). The short listed strains of fluorescent pseudomonads in black pepper were found to produce various volatile and non-volatile metabolites including HCN (Diby *et al*, 2001) against the fungal pathogen (Lisha *et al*, 2002). Antibiotics viz. pyoluteorin, and pyrrolnitrin were detected in these strains by TLC. Kloepper *et al*, (1980) have clearly demonstrated the role of siderophores in rhizobacteria-mediated antagonism. Siderophore mediated antagonism is implicated in *P. capsici* - *P. fluorescens* antagonistic system (Diby Paul *et al*, 2001). The culture filtrate of the bacteria not only inhibited the mycelial growth of *P. capsici*, but also the explosive asexual phase, sporangial production, release of zoospores and germination of zoospores.

In the case of vanilla, IISR 859 was found growth promotion and *Phytophthora* suppressive both under *in* vitro and *in vivo* IISR 147 and IISR 148 were suppressive to *P.meadii* and *F.oxysporum*. Hence consortia consisting of isolates that are suppressive to both these pathogens would be ideal (Sarma *et al.* Unpublished). Basic studies on the nutrient management through PGPRs, their survival, antagonism and stability are needed for exploiting the same for higher production and productivity in the mixed cropping systems of perennials.

The antagonists produced mycolytic enzymes viz. β-1,3 glucanases, β-1,4 glucanases and lipases (Diby Paul *et al*, 2003). Enzymatic degradation of the cell wall of fungal pathogens by biocontrol agents is reported (Fridlender *et al.*,1999). Strains of *Pseudomonas fluorescens* caused cytoplasmic coagulation in the mycelium of *P. capsici* when they were cultured together.

The growth promoting strains of Fluorescent pseudomonads were found to synthesize phytohormones viz. IAA and GA as detected in TLC. The other determinants for growth promotion in black pepper were enhanced production of feeder roots in the plant and also the increased absorptive surface area of the roots.

Van loon *et al* (1998) has hypothesized that if defence mechanisms are triggered by a stimulus prior to infection by a plant pathogen, disease can be reduced. Increased levels of Peroxidase (PO), Catalase, Phenylalanine Ammonia Lyase (PAL) and Poly Phenol Oxidase (PPO) were induced in leaves apart from the roots of treated black pepper plants. There also found a relatively higher quantity of lignification (30 – 100% over control) in the bacterized roots. This was correlated with the lesser root rot in the bacterized plants upon challenge inoculation with the pathogen (Diby Paul and Sarma, 2003 - 6th Intl. PGPR Workshop).

Also the efficient strains of fluorescent pseudomonads were found to be endophytic in black pepper (Diby Paul *et al*, 2000). In the case of coconut an endophyte from coconut leaves, *Bacillus* amyloliquefaciens was found antagonistic to *P.palmivora*, pathogen causing bud rot in coconut. The bioefficacy of bacterium both *in vitro* and *invivo* and needs large scale field testing (Moosa et al. 1998).

PGPRs as consortia for disease management

A greater thrust is given for development of biological consortia with multiple modes of action to suppress the fungal and nematodal pathogens since there is no spatial segregation of these pathogens in cropping systems (Sarma et al. 1994).

Sarma and Anandaraj, (1998) has suggested the consortium approach for disease management in plantation and spice crops. Mutual compatibility of fungal & bacterial antagonists viz. *Trichoderma harzianum* & fluorescent *Pseudomonas* were studied in order to establish an efficient consortium for the management of foot rot of black pepper caused by *Phytophthora capsici*. The study revealed that the fungal and bacterial antagonists are compatible (Jisha *et al*, 2002).

Application of rhizobacteria and *T. harzianum* resulted in enhanced growth of black pepper. The increase was 38.9% for the consortium of *P. fluorescens* strain, IISR-6 and *T. harzianum* (IISR-1369). The treatment with consortium of *P. fluorescens* strain, IISR-6 and *T.harzianum* was superior to IISR-6 alone by producing 28% more cuttings. The root system of the PGPR and the consortium treated plants were disease free. The combination of *Trichoderma* spp (IISR-1369) and *P. fluorescens* (IISR-6) in combination was found to decrease the root rot disease besides increasing the yield in the field trials conducted.

Sarma *et al*, (2000) has established the biocontrol consortium for Black pepper, Ginger and Cardamom. The maximum disease suppression (63%) obtained by the treatment combination, *T. harzianum* isolate, IISR - 1369 and *P. fluorescens* strain, IISR–6 in black pepper and in cardamom, it was 36% over control. The same treatment could impart 66.2 % survival of ginger tillers after challenge inoculation with *Pythium aphanidermatum*. The efficient isolate from black pepper with high rhizosphere competency and adaptability can be used in a cropping system involving black pepper, ginger and cardamom.

In successful cropping system where the economic output per unit area is positive, the underlying microbiological association, diversity, their interaction and the overall impact on the growth and productivity need to be understood for practical utility. Either a single organism or group of organisms (Consortia) which have potential to ensure optimum root health, higher root regeneration need to be identified. This becomes all the more important in coconut / arecanut based cropping systems where several crops like Cocoa, black pepper are grown successfully.

The nematode pathogens of black pepper viz. *Meloidogyne incognita* and *Radopholus similis* also were inhibited by these strains of *P. fluorescens* (Eapen, S.J., Ramana, K.V. and Sarma, Y.R 1997). The suppression of *R.similis* and *M.incognita* has been reported (Aalten *et* al 1998). An economical and ecofriendly multiplication medium was developed for the large-scale production of this biocontrol agent. The industrial waste, molasses (0.1%) supported growth of the bacteria to log 14 cfu/ml in 32h. The Indian Institute of Spices Research has recommended this *P.fluorescens* strain IISR-6 for release to the benefit of farmers.

With magnitude of biotic stress that has become a major production constraint in all the mixed cropping systems, it is imperative to exploit the beneficial microflora for optimum root health to increase the productivity without affecting much of the environmental basis.

Disease complexes

Root wilt (Solomon 1994) and Thattipaka disease of Coconut (Rajamannar and Prasad, J 1994) and Yellow leaf disease of Arecanut (Nair 1994) and spear rot of oilpalm (Kochubabu 1994) are some of the complex diseases where Phytoplasma etiology has been confirmed but in all these cases, root damage is one of the major symptoms. Improvement of the overall health of the affected palms and yield through basin management involving legume culture and recycling organics in HDMCS system indicated the possible role of beneficial microflora and also the root exudates that are reported in Coconut based cropping system (Bapaiah et al 1990, Ghai and Thomas, 1989; Maheswarappa, Anithakumari and Saairam 2003). However, intensive investigations are needed on this.

Future priorities

Complex problems like root wilt of Coconut and Yellow leaf of Arecanut and Slow decline of Black pepper need to be tackled through optimum root health management and soil application of PGPRs either alone or through consortia would be priority. However basic studies on the rhizosphere biology are important to plan practical strategies. Since the soils in the mixed cropping system harbour both fungal and nematodal pathogens, and these pathogens are not spatially segregated and form a component of the same ecosystem, identification of PGPR with multiple mode of action to suppress these pathogens is logical. Similarly treating the seedlings / rooted cuttings (Coconut, Arecanut, Cashew, Cocoa, Cardamom, Black pepper), Ginger, Turmeric and seed spices would ensure their better establishment and further multiplication in the field. To ensure their stability in the soil, soil supplements with organics would be necessary. It should be of paramount importance to study the microbial succession in various crop combinations, nutrient availability at various depths, soil ecology to understand population dynamics of microorganisms. Microbial consortia concept need to be coupled with an ideal and quality product development which the farming community can handle with ease and there by realize the benefits of the PGPR technology for sustainability in the perennial cropping systems. The potential for growth promotion and disease suppression in all the plantation crops through PGPRs is high and need to be exploited for increased productivity and sustainability.

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