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RESTORATION OF SOIL MICROBIAL BIOMASS USING MULTIPURPOSE TREES

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Abstract

Planting of multipurpose tree species (MPT's) are the imperative option for rehabilitating the vast degraded lands in the coastal agroecosystems. Soil microbes are strongly altered by numerous factors including abiotic environmental conditions and plant characteristics. Field experiments were conducted in coastal degraded agricultural lands with eight MPT's. The highest bacteria, fungi and actinomycete populations were recorded in the rhizosphere of *Pongamia pinnata*, *Ceiba pentandra*, *Tamarindus indica* and *Casuarina equisetifolia* planted degraded soils. It exhibited that plants have species-specific effects on their associated living microbial biomass, activity and communities.

Key words: Afforestation, coastal agroecosystem, degraded lands, microbial community, reclamation, rhizosphere soil.

Introduction

Reclamation is a management strategy applied in restoration of degraded areas. It gained worldwide acceptance recognizing the need to have a sustainable approach. It is the planned process that aims to regain ecological integrity and enhance human wellbeing in degraded ecosystems (Chazdon, 2019). Degraded soil reclamation can restore many ecosystem functions and recover several components of the original biodiversity. It is often endeavoured with fast-growing multipurpose tree species with the aim of fulfilling community demand for wood products, minimizing incursions into natural forest and allowing establishment of woody species following amelioration of soil conditions. Chemical reclamation of coastal degraded lands is expensive; growing trees to reclaim these soils offers a cost-effective and promising option (phyto-remediation) (Rex Immanuel and Ganapathy, 2020).

Afforestation of coastal agricultural degraded lands has a profound impact on the maintenance and stability of ecosystem processes. Introduction of multipurpose tree species (MPT's) for the degraded coastal agroecosystem could offer ecological sustainability and economic security to the farming communities (Rex Immanuel *et al*., 2018a). Research has shown that the effects of MPT's can be very site specific, especially on degraded sites (Rex Immanuel *et al*., 2018b; Rex Immanuel, 2019; Rex Immanuel and Ganapathy, 2020). It has been suggested that appropriate tree species for afforesting the degraded lands in the coastal agroecosystem exhibits high survival rates, quick initial growth, a rapid establishment, adaptations of the root systems and the ability to cope with poor nutrient, saline, water logging and drought stressed conditions (Rex Immanuel and Ganapathy, 2019b; Rex Immanuel and Ganapathy, 2019c).

The rhizosphere is the narrow zone of soil that surrounds roots and links root traits to functions such as the site of nutrient acquisition, nutrient cycling and microbial community formation (Philippot *et al*., 2013; Qiu *et al*., 2014; Mommer *et al*., 2016). Microbial communities in rhizosphere soil are fundamental for healthy ecosystem function, owing to their role in mediating various functions such as soil organic carbon and nutrient cycling. It changed constantly with plant development and root growth and indicates the mutual relationship between microorganisms and plants. Restoration of soil microbial community is an important indicator of the health and sustainability of an ecosystem. Therefore, understanding shifts in soil microbial community under complex environmental conditions is vital for effective vegetation re-establishment in degraded soils.

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Materials and Methods

India is grouped into 20 agro-ecological regions and 60 agro-ecological sub regions (Velayutham *et al*., 1999). From among them, North Tamil Nadu Coastal Plains (S7Dm 4) was purposively selected for tree planting, because the presence of considerable extent of degraded soils hampered the agricultural productivity, leaves larger area as fallow. It offers a scope for scientists to reclaim and re-instate to its original form with the help of multipurpose tree farming. Accordingly field experiments were conducted to study the ameliorative effects of selected MPT's on biological properties of rhizosphere soil. The study sites are located between Northern Coleroon river basin to North Chennai and covering the degraded coastal agricultural lands of Cuddalore, Villupuram, Kanchipuram and Thiruvalluar districts.

The coastal agro-ecosystem of the region extends from semi arid to sub-humid climate with mean annual rainfall of 1350 mm, of which 80 per cent is received during North-East monsoon (Oct. – Dec.) and the remaining is through South West monsoon and summer showers. The potential evapotranspiration varies from 1700 to 1900 mm resulting in an annual water deficit of 350 – 550 mm. The length of the crop growing period varies from 80 to 120 days. The mean annual maximum and minimum temperatures are 33.5^{o}C and 23.5^{o}C, respectively.

Based on the outcome of the pot culture experiments (Rex Immanuel, 2019; Rex Immanuel *et al*., 2019) two MPT's per location were used for different degraded soils (Table 1).

The deciduous layer was first removed. Then, the rhizosphere soil at about 15 cm depth was collected, placed in a sterile bag, and stored on controlled condition. The soil samples were passed through a 2 mm screen. Within each plot, three trees were randomly selected for rhizosphere soil collection, and three rhizospheric soils were mixed into one soil sample. Thus, each treatment includes three replicates. Serial dilution technique (Parlinson *et al*., 1971) was adopted for enumerating the population of bacteria (10^6 dilution), fungi (10^3 dilution) and actinomycetes (10^4 dilutions).

Results

The data recorded on the rhizosphere microbial population (bacteria, fungi and actinomycetes) for the 1st, 2nd and 3rd years after planting are presented for the different sub zones.

The results showed that bacterial population of rhizosphere soil was increased many folds in degraded soils after planting the MPT's. Among the MPT's planted, the highest increment of 34.17 per cent (SZ_1), 37.13 per cent (SZ_2), 41.77 per cent (SZ_4) and 29.35 per cent (SZ_7) were observed in Pongamia pinnata. Similarly the highest bacterial population of 36.62 per cent in Pondicherry (SZ_3), 28.86 per cent in Northern Palar delta (SZ_5) and 59.93 per cent in Mahabalipuram (SZ_6) were registered by planting Ceiba pentandra, Tamarindus indica and Casuarina equisetifolia, respectively (Table 2 & 3).

Planting of Pongamia pinnata appreciably increased the fungi population over the initial status and the increment of 56.54, 39.89, 41.52 and 47.24 per cent were observed in the degraded soils of Northern Cauvery delta (SZ_1), Ponaiyar delta (SZ_2), Southern Palar delta (SZ_4) and North Chennai (SZ_7), respectively. Correspondingly the maximum fungi populations of 33.33 per cent in Pondicherry (SZ_3), 39.68 percent in Northern Palar delta

Table 1: Details of MPT's used in different degraded locations.

Sl. No.	Degraded locations	Geographical location	Multipurpose trees	Spacing	Plot size	No. of trees plot^{-1}
1	Moderately saline	11°242 N	T_1 - *Pongamia pinnata*	4.0m x 4.0m	150m^2	09
	waterlogged clay (SZ_1)	79°452 E	T_2 - *Acacia nilotica*	3.0m x 3.0m	150m^2	17
2	Strongly saline waterlogged	11°392 N	T_1 - *Pongamia pinnata*	4.0m x 4.0m	250m^2	16
	clay soil (SZ_2)	79°472 E	T_2 - *Tamarindus indica*	5.0m x 5.0m	250m^2	10
3	Moderately saline non-waterlogged	11°582 N	T_1 - *Anacardium occidentale*	5.0m x 5.0m	250m^2	10
	sandy clay loam soil (SZ_3)	79°522 E	T_2 - *Ceiba pentandra*	5.0m x 5.0m	250m^2	10
4	Strongly saline non-waterlogged	12°172 N	T_1 - *Anacardium occidentale*	5.0m x 5.0m	250m^2	10
	sandy loam soil (SZ_4)	80°002 E	T_2 - *Pongamia pinnata*	4.0m x 4.0m	250m^2	16
5	Strongly saline non-waterlogged	12°322 N	T_1 - *Anacardium occidentale*	5.0m x 5.0m	250m^2	10
	sandy loam soil (SZ_5)	80°092 E	T_2 - *Tamarindus indica*	5.0m x 5.0m	250m^2	10
6	Moderately saline non-waterlogged	12°422 N	T_1 - *Anacardium occidentale*	5.0m x 5.0m	250m^2	10
	sandy soil (SZ_6)	80°132 E	T_2 - *Casuarina equisetifolia*	2.0m x 2.0m	150m^2	37
7	Strongly saline non-waterlogged	13°222 N	T_1 - *Acacia ferruginea*	3.0m x 3.0m	150m^2	17
	sandy soil (SZ_7)	80°162 E	T_2 - *Pongamia pinnata*	4.0m x 4.0 m	200m^2	13

(SZ_5) and 72.95 per cent in Mahabalipuram (SZ_6) were registered by planting Ceiba pentandra, Tamarindus indica and Casuarina equisetifolia, respectively (Table 4 & 5).

{(SZ_1T_1 - *Pongamia pinnata*, SZ_1T_2 - *Acacia nilotica*); (SZ_2T_1 - *Pongamia pinnata*, SZ_2T_2 - *Tamarindus indica*); (SZ_3T_1 - *Anacardium occidentale*, SZ_3T_2 - *Ceiba pentandra*); (SZ_4T_1 - *Anacardium occidentale*, SZ_4T_2 - *Pongamia pinnata*); (SZ_5T_1- *Anacardium occidentale*, SZ_5T_2 - *Pongamia pinnata*); (SZ_6T_1 - *Anacardium occidentale*, SZ_6T_2 - *Casuarina equisetifolia*); (SZ_7T_1 - *Acacia ferruginea*, SZ_7T_2 - *Pongamia pinnata*)}.

Table 2: The effect of MPT's on the rhizosphere bacterial population (x10^6 g^{-1} shade dry soil) of different degraded coastal agro ecological sub zones.

MPT's	Sub zones						
	SZ_1	SZ_2	SZ_3	SZ_4	SZ_5	SZ_6	SZ_7
Initial	5.18	4.39	4.26	3.95	4.12	2.97	3.68
	12 months after planting						
T_1	5.10	4.12	4.50	3.50	3.80	2.78	3.10
T_2	5.30	4.34	4.85	3.81	4.21	3.67	2.82
	24 months after planting						
T_1	5.42	4.72	4.63	3.82	4.10	3.05	3.42
T_2	5.25	4.43	5.10	4.15	4.52	3.91	3.16
	36 months after planting						
T_1	6.95	6.02	5.27	4.53	4.83	3.17	4.58
T_2	6.57	5.37	5.82	5.60	5.31	4.75	4.76

(Data statistically not analyzed)

Table 3: The effect of MPT's on the changes of rhizosphere bacterial population (%) in different degraded coastal agro ecological sub zones (36 months after planting).

MPT's	Sub zones						
	SZ_1	SZ_2	SZ_3	SZ_4	SZ_5	SZ_6	SZ_7
T_1	34.17^{a}	37.13^{a}	23.71^{b}	14.68^{b}	17.23^{b}	06.73^{b}	24.46^{b}
T_2	26.83^{b}	22.32^{b}	36.62^{a}	41.77^{a}	28.86^{a}	59.93^{a}	29.35^{a}

Table 4: The effect of MPT's on the rhizosphere fungi population (x 10^3 g^{-1} shade dry soil) of different degraded coastal agro ecological sub zones.

MPT's	Sub zones						
	SZ_1	SZ_2	SZ_3	SZ_4	SZ_5	SZ_6	SZ_7
Initial	2.14	1.88	1.47	1.71	1.89	1.22	1.63
	12 months after planting						
T_1	2.36	1.76	1.51	1.48	1.80	1.14	1.74
T_2	2.15	1.95	1.63	1.63	1.91	1.23	1.68
	24 months after planting						
T_1	2.87	2.26	1.59	1.83	1.84	1.17	1.95
T_2	2.42	2.09	1.87	2.10	2.16	1.65	2.06
	36 months after planting						
T_1	3.35	2.63	1.73	1.93	1.75	1.39	2.27
T_2	3.08	2.47	1.96	2.42	2.64	2.11	2.40

(Data statistically not analyzed)

{(SZ_1T_1 - *Pongamia pinnata*, SZ_1T_2 - *Acacia nilotica*); (SZ_2T_1 - *Pongamia pinnata*, SZ_2T_2 - *Tamarindus indica*); (SZ_3T_1 - *Anacardium occidentale*, SZ_3T_2 - *Ceiba pentandra*); (SZ_4T_1 - *Anacardium occidentale*, SZ_4T_2 - *Pongamia pinnata*); (SZ_5T_1- *Anacardium occidentale*, SZ_5T_2 - *Pongamia pinnata*); (SZ_6T_1 - *Anacardium occidentale*, SZ_6T_2 - *Casuarina equisetifolia*); (SZ_7T_1 - *Acacia ferruginea*, SZ_7T_2 - *Pongamia pinnata*)}.

The microbial analytical results showed that the actinomycetes population of rhizosphere soil increased

Table 5: The effect of MPT's on the changes of rhizosphere fungal population (%) in different degraded coastal agro ecological sub zones (36 months after planting).

MPT's	Sub zones						
	SZ_1	SZ_2	SZ_3	SZ_4	SZ_5	SZ_6	SZ_7
T_1	56.54^{a}	39.89^{a}	17.69^{b}	11.40^{b}	-07.41^{b}	13.93^{b}	39.26^{b}
T_2	43.92^{b}	31.38^{b}	33.33^{a}	41.52^{a}	39.68^{a}	72.95^{a}	47.24^{a}

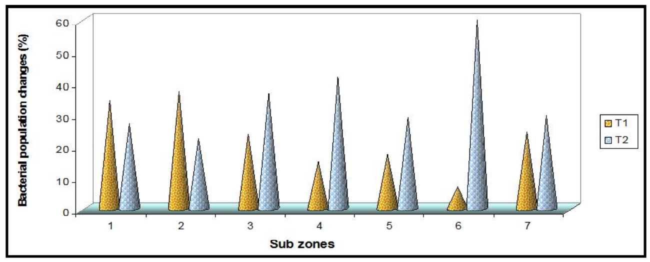

Fig. 1: Ameliorative effect of MPT's on the per cent changes of rhizosphere bacterial population in different degraded agro ecological sub zones.

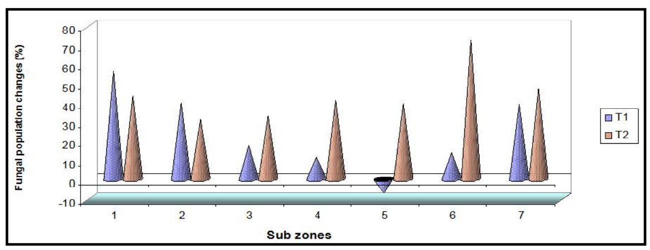

Fig. 2: Ameliorative effect of MPT's on the per cent changes of rhizosphere fungal population in different degraded coastal agro ecological sub zones.

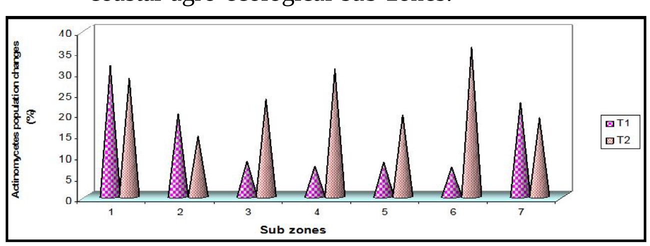

Fig. 3: Ameliorative effect of MPT's on the per cent changes of rhizosphere actinomycetes population in different degraded coastal agro ecological sub zones.

after the planting of MPT's. Among the MPT's, the highest increment of 31.37 per cent (SZ_1), 19.74 per cent (SZ_2) and 30.43 per cent (SZ_4) were observed in *Pongamia pinnata*. Similarly the increment of 23.40 per cent in Pondicherry (SZ_4), 19.67 per cent in Northern Palar delta (SZ_{65}), 35.71 per cent in Mahabalipuram (SZ_6) and 22.64 per cent in North Chennai (SZ_7) were recorded in *Ceiba pentandra*, *Tamarindus indica*, *Casuarina equisetifolia* and *Acacia ferruginea*, respectively (Table 6 & 7).

Discussion

The abundance of bacterial, fungal and actinomycete showed that the composition of the rhizosphere microbial communities associated with the different multipurpose trees differed significantly. The highest bacteria, fungi and actinomycete colony forming units (CFU) were observed in *Pongamia pinnata*, *Ceiba pentandra*, *Tamarindus indica* and *Casuarina equisetifolia* planted degraded soils (Fig. 1 to 3).

The rhizosphere ecosystem of trees is based on a tree-soil-microbe relationship and their interactions with environmental conditions helps to the restoration of soil microbes. The changes resulted from the favored microclimate, root biomass and release of exudates from roots to the rhizosphere soil. The rhizosphere has a high level of microbial activity, particularly because of nutrients secreted by plant roots in the form of soluble root exudates *viz.*, amino and organic acids, sugars, polysaccharides, peptides, proteins and other photosynthates constitute the bulk of the rhizodeposits. The rhizosphere effect states that plants release up to 40 percent of their photosynthetic products into the rhizosphere (Singh *et al.*, 2017), resulting in a phenomenon in which the rhizosphere microbial population density is much higher than that in the surrounding bulk soil (Bais *et al.*, 2006; Berendsen *et al.*, 2012).

Depending on the composition of the exudates secreted by a given plants' root, that plant enhanced the possibilities and success of symbiotic relationships and alter the soil microbial community of the rhizosphere. This created a favorable microclimate for the multiplication of microbes; hence, the population of bacteria, fungi and actinomycete were higher in the rhizosphere of degraded soil. The current results of the studies are in corroborated with the earlier findings of Lambrecht *et al.*, (2000), Pinton *et al.*, (2001), Kourtev *et al.*, (2003), Bais (2004), Jones *et al.*, (2004), Kang and Mills (2004), Herrera (2005), Hinsinger *et al.*, (2006), Six *et al.*, (2006), Srivastava *et al.*, (2015), Urbanova *et al.*, (2015) and Guo *et al.*, (2018).

Conclusion

The enhanced rhizosphere soil microbial community such as bacteria, fungi and actinomycetes varies among tree species and environmental habitats. This rhizospheric microbial community associated with multipurpose tree species is a significant indicator for restoration of degraded coastal agroecosystems. The tree species such as *Pongamia pinnata*, *Ceiba pentandra*, *Tamarindus indica* and *Casuarina equisetifolia* planted degraded soils exhibited the highest bacteria, fungi and actinomycetes colony forming units (CFU). It will provides essential information that can guide appropriate management and vegetation restoration strategies for degraded coastal agroecosystems.

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