BIOFERTILIZER EFFECT OF HALOPHILIC PSB
7.0. BIOFERTILIZER EFFECT OF HALOPHILIC PHOSPHATE SOLUBILIZING BACTERIA (PSB) ON THE GROWTH OF MANGROVE SEEDLINGS AND COASTAL RICE CROP

7.1. Introduction

Accelerated coastal erosion threatens private and public property in many areas of the world (Will and Sylvia, 1990). Such erosion is considered critical in India, especially in the study area because of continuing high investments in shoreline development and the revenues generated sea based industries especially fibre retting, aquaculture, fish processing, salt pan industries etc. Lost sand is replaced with material of compatible physical properties which is shaped to the desired ecosystem and planted with plants. The major factors limiting establishment and early vigorous growth of the plants in the face of environmental extremes are infertility and poor germination. Rhizosphere microorganisms may allow plants to overcome these environmental extremes (Abdul Wahab and Wareing, 1980), particularly in mangrove seedlings, which show a serious problem of poor growth (Kathiresan, 1992).
Phosphobacteria is one among the soil microorganisms which plays an important role in improving the chemical and physical nature of the soil, adding organic matter to soil, solubilizing the insoluble phosphates increasing availability and utilization of vital nutrients, secreting growth accelerating substances and reducing the input cost without affecting yield (Wahab et al., 2001). Jones Nirmalanath and Sreenivasa (1993) observed significantly higher population of p-solubilizers in the rhizosphere of sunflower inoculated with *Pseudomonas striata* enhanced the yield. Inoculation of rhizosphere microorganisms significantly increased the yield of rice, pod yield of groundnut and seed yield of soyabean etc. have been reported (Table 20). Considering all these facts, the present study was undertaken to study the effects of halophilic phosphobacteria on the growth of mangrove seedlings and coastal crop plants.
<table>
<thead>
<tr>
<th>Year</th>
<th>Author (s)</th>
<th>Aspect(s) studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>Smith et al.</td>
<td>Phosphobacteria as a soil inoculant</td>
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<tr>
<td>1966</td>
<td>Chandrasekaran</td>
<td>Studies on the interrelationship between plants and soil microorganisms in respect to phosphorus solubilization</td>
</tr>
<tr>
<td>1970</td>
<td>Barea et al.</td>
<td>Absorption of nutrients by plants as a response to inoculation of phosphobacteria</td>
</tr>
<tr>
<td>1972</td>
<td>Gaur</td>
<td>Role of phosphate solubilizing microorganisms and organic matter in soil productivity</td>
</tr>
<tr>
<td>1972</td>
<td>Gaur and Ostwal</td>
<td>Influence of phosphate dissolving bacilli on yield and phosphate uptake of wheat crop</td>
</tr>
<tr>
<td>1978</td>
<td>Banik and Dey</td>
<td>Phytohormone producing ability of phosphate solubilizing bacteria</td>
</tr>
<tr>
<td>1981</td>
<td>Banik and Dey</td>
<td>Phosphate solubilizing microorganisms of a lateritic soil: III – effect of inoculation of some tri-calcium phosphate solubilizing microorganisms on available phosphorus content of rhizosphere soils of rice (Oryza sativa L. Cv. IR 20) plants and their uptake of phosphorus</td>
</tr>
<tr>
<td>1982</td>
<td>Banik and Dey</td>
<td>Available phosphate content of an alluvial soil is influenced by inoculation of some isolated phosphate – solubilizing microorganisms</td>
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<tr>
<td>1982</td>
<td>Datta et al.</td>
<td>Studies on the efficacy of a phytohormone producing phosphate solubilizing bacteria Bacillus firmus in augmenting paddy yield in acid soils of Nagaland</td>
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<tr>
<td>1983</td>
<td>Barea et al.</td>
<td>Interactions between phosphate solubilizing bacteria and VA mycorrhiza to improve plant utilization of rock phosphate in non acidic soils</td>
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<tr>
<td>Year</td>
<td>Authors</td>
<td>Title</td>
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<tr>
<td>1984</td>
<td>Kundu and Gaur</td>
<td>Rice response to inoculation with N₂-fixing and P-solubilizing microorganisms</td>
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<td>1987</td>
<td>Piccini and Azcon</td>
<td>Effect of phosphate – solubilizing bacteria and vesicular arbuscular mycorrhizal (VAM) on the utilization of bayoran rock phosphate by alfalfa plants using a sand vermiculate medium</td>
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<tr>
<td>1988</td>
<td>Banik and Datta</td>
<td>Effect of inoculation of a phosphate – solubilizing phytohormone producing <em>Bacillus formus</em> on the growth and yield of soybean (<em>Glycine max</em>) grown in acid soil of Nagaland</td>
</tr>
<tr>
<td>1989</td>
<td>Domey and Lippmann</td>
<td>Stimulation of plant growth by phosphate solubilizing bacteria</td>
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<tr>
<td>1989</td>
<td>Kloeppe er et al.</td>
<td>Free living bacterial inocula for enhancing crop productivity</td>
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<tr>
<td>1990</td>
<td>Patil</td>
<td>Studies on the influence of P-solublizers and sources of P on soybean</td>
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<tr>
<td>1990</td>
<td>Gaur</td>
<td>Phosphorous solubilizing microorganisms as biofertilizer</td>
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<td>1992</td>
<td>Alagawadi and Gaur</td>
<td>Inoculation of <em>Azospirillum brasilense</em> and phosphate solubilizing bacteria on the yield of Sorghum (<em>Sorghum bicolor</em> L.)</td>
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<td>1992</td>
<td>Datta et al.</td>
<td>Effect of inoculation of phosphate dissolving bacteria on rice (<em>Oryza sativa</em>) on acid soil</td>
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<tr>
<td>1997</td>
<td>Subba Rao</td>
<td>Biofertilizers in Agricultural and Forestry</td>
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<tr>
<td>1994</td>
<td>Datta and Banik</td>
<td>Effect of poultry manure and phosphate – dissolving bacteria on rice (<em>Oryza sativa</em>) in acid soil</td>
</tr>
<tr>
<td>1994</td>
<td>Gupta et al.</td>
<td>A modified plate assay for screening phosphate solubilizing microorganisms</td>
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<tr>
<td>1995</td>
<td>Glick</td>
<td>The enhancement of plant growth by free-living bacteria</td>
</tr>
<tr>
<td>Year</td>
<td>Authors</td>
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<tr>
<td>------</td>
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<tr>
<td>1995</td>
<td>Emmiamath and Gundappagol</td>
<td>Biofertilizers for enhanced productivity of pigeon pea</td>
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<tr>
<td>1995</td>
<td>Kennedy and Smith</td>
<td>Soil microbial diversity and the sustainability of agriculture soils</td>
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<tr>
<td>1996</td>
<td>Tomar et al.</td>
<td>Efficacy of phosphate solubilizing bacterial biofertilizers with phosphorus on the growth and yield of gram</td>
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<tr>
<td>1997</td>
<td>Toro et al.</td>
<td>Improvement of Arbuscular mycorrhiza development by inoculation of soil with phosphate-solubilizing rhizobacteria to improve rock phosphate bioactivity ($^{32}$p) and nutrient cycling</td>
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<tr>
<td>1998</td>
<td>Agasimani et al.</td>
<td>Influence of phosphate solubilizing microorganisms and sources of phosphate on growth and yield of ground nut</td>
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<tr>
<td>1998</td>
<td>Dubey</td>
<td>Response of soybean (Glycine max) to bio-fertilizers with and without nitrogen, phosphorus and potassium in swell-shrink soil</td>
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<tr>
<td>1998</td>
<td>Kim et al.</td>
<td>Effect of phosphate – solubilizing bacteria and vesicular arbuscular mycorrhizae on tomato growth and soil microbial activity</td>
</tr>
<tr>
<td>1999</td>
<td>Rodriguez and Fraga</td>
<td>Phosphate solubilizing bacteria and their role in plant growth promotion</td>
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<tr>
<td>1999</td>
<td>Ramazan cakmakci et al.</td>
<td>Sugar beet and Barley yields in relation to Bacillus polymyxa and Bacillus megaterium var. Phosphaticum</td>
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<tr>
<td>1999</td>
<td>Pal et al.</td>
<td>Enhancement of ground nut growth and yield by plant growth promoting rhizobacteria</td>
</tr>
<tr>
<td>1999</td>
<td>Sarawgi et al.</td>
<td>Uptake and balance sheet of nitrogen and phosphorus in gram (Cicer arietinum) as influenced by phosphorus, biofertilizers and micronutrients under rain fed condition</td>
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<tr>
<td>2000</td>
<td>Rodriguez et al.</td>
<td>Expression of a mineral phosphate solubilizing gene from Erwinia herbicola in rhizobacterial strains</td>
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<tr>
<td>2001</td>
<td>Richardson</td>
<td>Prospects for using microorganisms to improve the acquisition of phosphorus by plants</td>
</tr>
<tr>
<td>Year</td>
<td>Author(s)</td>
<td>Title</td>
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<tr>
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<tr>
<td>2001</td>
<td>Igual et al.</td>
<td>Phosphate – solubilizing bacteria as inoculants for agriculture : use of updated molecular techniques in their study</td>
</tr>
<tr>
<td>2001</td>
<td>Peix et al.</td>
<td>Growth promotion of chick pea and barley by a phosphate solubilizing strain of <em>Mesorhizobium mediterraneum</em> under growth chamber conditions</td>
</tr>
<tr>
<td>2001</td>
<td>Richardson et al.</td>
<td>Utilization of phosphorus by Pasture plants supplied with myo-inositol hexa phosphate is enhanced by the presence of soil microorganisms</td>
</tr>
<tr>
<td>2001</td>
<td>Barea et al.</td>
<td>Interactive effects of phosphate – solubilizing bacteria and mycorrhizal fungi at increasing plant P availability and their evaluation by using isotopic techniques.</td>
</tr>
<tr>
<td>2002</td>
<td>Vasudevan</td>
<td>Role of biological preparations in enhancement</td>
</tr>
<tr>
<td>2002</td>
<td>Datta et al.</td>
<td>Efficacy of a phosphobacterium (<em>Bacillus firmus</em>) in combination with phosphates and organics on rice productivity in acid soils</td>
</tr>
<tr>
<td>2002</td>
<td>Ravikumar et al.</td>
<td>Quantification of halophlic phosphobacteria from Pichavaram mangroves and their potential application to crop culture</td>
</tr>
<tr>
<td>2002</td>
<td>Hafeez et al.</td>
<td>Effect of phosphate solubilizing bacteria on the growth of chick pea, lentil and wheat isolated from different crops</td>
</tr>
<tr>
<td>2002</td>
<td>Ponnusamy et al.</td>
<td>Integrated nutrient management for rainfed Sorghum</td>
</tr>
<tr>
<td>2002</td>
<td>Sundara et al.</td>
<td>Influence of phosphorous solubilizing bacteria in the changes in soil available phosphorous and sugarcane and sugar yields</td>
</tr>
<tr>
<td>2004</td>
<td>Gull et al.</td>
<td>Phosphate – uptake and growth promotion of chick pea (<em>Cicer arietinum</em> L. with co-inoculation of mineral phosphate solubilizing bacteria and a mixed rhizobium culture</td>
</tr>
<tr>
<td>2004</td>
<td>Hafeez et al.</td>
<td>Efficacy of various phosphate solubilizing bacteria for growth promotion of wheat</td>
</tr>
</tbody>
</table>
7.2. Materials and Methods

7.2.1. Collection of propagules

Healthy propagules of *Rhizophora mucronata* Lamk. (25 ± 2 cm length), *Ceriops decandra* (Griff.) Ding Hou., (8 ± 2 cm length) and *Avicennia officinalis* (Forsk) Vierb., seeds were collected from Pichavaram mangrove forest, South East coast of India (Lat. 11° 27’ N, Long. 79° 46’ E). The collected seeds were separated into different groups based upon their size and maturity for sowing.

7.2.2. Soil conditions used

Soil used for the treatment was subjected to the analysis of soil characteristics (APHA, 1985) are represented here under:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Concentration</th>
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<tr>
<td>PH</td>
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</tr>
<tr>
<td>Salinity (FC)</td>
<td>1.58</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>36.00 μg·g⁻¹</td>
</tr>
<tr>
<td>Phosphorous (P₂O₅)</td>
<td>4.85 μg·g⁻¹</td>
</tr>
<tr>
<td>Potassium</td>
<td>67.80 μg·g⁻¹</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>0.65 %</td>
</tr>
<tr>
<td>Iron</td>
<td>2.82 ppm</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.46 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>0.29 ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.99 ppm</td>
</tr>
</tbody>
</table>
7.2.3. Preparation of bacterial inoculum

A loopful inoculum of identified pure culture of phosphobacterial species viz. *Bacillus subtilis*, *Escherichia coli*, *Arthrobacter ilaris*, *Micrococcus roseus*, *Bacillus cereus*, *Bacillus megaterium*, *Pseudomonas aeruginosa*, *Enterobacter aerogenes*, *Micrococcus luteus* from mangrove environment were inoculated separately into each conical flask containing 100 ml of Pikovskya's broth. All the inoculated flasks were incubated for 5 days at 28 ± 1°C in a thermostat shaker (Orbital shaking incubator, Expo-Hitech). After incubation, the cultures were centrifuged at 12,00 rpm for 15 minute (Suprafuge, Hewlett Packard, USA). The pellets were suspended in phosphate buffer (NaH$_2$PO$_4$.2H$_2$O - 31.2g, Na$_2$HPO$_4$ - 28.39g in 100 ml sterile distilled water) and washed repeatedly with the buffer and were resuspended in the same buffer solution.

7.2.4. Phosphobacteria induced growth in mangroves

To study the influence of bacterial species on the growth of mangrove seedlings, an experiment was conducted. 100 ml of suspended culture (10$^8$ cells ml$^{-1}$) of halophilic phosphobacterial species were mixed separately with 1 kg of soil (sterilized at 121°C for 1 hr) and were kept in sterilized polybags. Propagules of mangrove plant species were planted into the soil and were irrigated with sterile water –100 ml per bag per kilogram of soil. Five replicates of ten propagules were maintained for each treatment. The propagules without treatment were maintained as control.
After 60 days, the root growth characteristic of mangrove seedlings such as number of primary roots, number of secondary roots, average number of primary roots, maximum root length and root biomass were recorded. The shoot growth characteristics such as shoot biomass, shoot height and leaf area were also recorded.

Chlorophylls (a, b, total) and carotenoids were extracted in DMSO from leaves were measured in a Spectrophotometer (E205 Hitachi, Japan) by following the method of Hiscox and Israelstan (1979). The biochemical constituents viz. carbohydrate, protein and amino acid were estimated by phenol, H₂SO₄ method (Dubois et al., 1956), Folin-phenol reagent method (Lowry et al., 1951), ninhydrin method (Moore and Stein, 1948) respectively.

The results were statistically analysed for significance. The results are shown in tables mainly for statistically significant values among the bacterial species.

7.2.5. Phosphobacteria induced growth on *Oryza sativa*

To study the effect of phosphobacteria on the growth of coastal rice crop, an experiment was conducted. Certified seeds of paddy (IR36) were procured from Department of Agriculture, Thirupathisaram, Kanyakumari district. The seeds were surface sterilized with 0.1% HgCl₂ for 5 minutes and the seeds were soaked for 1 hr in liquid cell suspension (10⁸ cells ml⁻¹) separately and spreaded on to the soil moistured with sterile distilled water. Five replicates of 100 seeds of paddy were maintained for each bacterial species. The seeds without bacterial treatment served as control. After 2 – 4 days, the percentage of germination was recorded.
After 20 days of treatment, the plant growth characteristics *viz.*, average root length, average shoot length, number of roots, root and shoot biomass were analyzed. The pigments such as total chlorophyll, chlorophyll-a, chlorophyll-b and carotenoids and the biochemical constituents *viz.* carbohydrate, protein, amino acids were estimated as previously mentioned standard methods as mentioned in 7.2.4.
7.3. Results

7.3.1. Effect of phosphate solubilizing bacteria on *Rhizophora mucronata* seedlings

The effect of phosphobacterial inoculation of different species of phosphate solubilizing bacteria on the growth parameters of *Rhizophora mucronata* is depicted in Table 21. Among the bacterial species, the *Micrococcus luteus* improved the root length significantly by 19.09% over control (Fig. 56).

Fig 56. Effect of PSB on the average root length of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

![Fig 56](image)

Bacterial species
- B. s. - *Bacillus subtilis*
- E. c. - *Escherichia coli*
- A. i. - *Arthrobacter ilicis*
- M. r. - *Micrococcus roseus*
- B. c. - *Bacillus cereus*
- B. m. - *Bacillus megaterium*
- P. a. - *Pseudomonas aeruginosa*
- E. a. - *Enterobacter aerogenes*
- M. l. - *Micrococcus luteus*

The effect of different species of phosphate solubilizing bacteria on the average shoot length reveals that, the bacterial species of *Bacillus megaterium* enhanced the shoot length by 21.26% over control (Fig. 57).
Fig. 57. Effect of PS on the average shoot length of *Rhizophora mucronata* seedlings as percentage increase or decrease over control.

![Graph showing the effect of PS on shoot length with bacterial species](chart1.png)

Bacterial species:
- B. s: Bacillus subtilis
- E. c: Escherichia coli
- A. I: Arthrobacter ilicis
- M. r: Micrococcus roseus
- B. c: Bacillus cereus
- B. m: *Bacillus megaterium*
- P. a: Pseudomonas aeruginosa
- E. a: Enterobacter aerogenes
- M. I: Micrococcus luteus

The different species of phosphate solubilizing bacterial inoculation on the number of primary and secondary roots is represented in Table 21. The bacterial species of *Bacillus megaterium*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Enterobacter aerogenes* were enhanced the number of primary roots significantly by 19.57% over control, whereas the number of secondary roots is enhanced with the inoculation of *Bacillus megaterium* by 21.28% over control (Fig. 58 and 59).

Fig. 58. Effect of PSB on the number of primary root of *Rhizophora mucronata* seedlings as percentage increase or decrease over control.

![Graph showing the effect of PSB on primary roots with bacterial species](chart2.png)

Bacterial species:
- B. s: Bacillus subtilis
- E. c: Escherichia coli
- A. I: Arthrobacter ilicis
- M. r: Micrococcus roseus
- B. c: Bacillus cereus
- B. m: *Bacillus megaterium*
- P. a: Pseudomonas aeruginosa
- E. a: Enterobacter aerogenes
- M. I: Micrococcus luteus
Fig 59. Effect of PSB on the number of secondary root of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

![Graph showing the effect of PSB on secondary root number](image)

Bacterial species
- B.s. - *Bacillus subtilis*
- E.c. - *Escherichia coli*
- A.i. - *Arthrobacter ilicis*
- M.r. - *Micrococcus roseus*
- B.c. - *Bacillus cereus*
- B.m. - *Bacillus megaterium*
- P.a. - *Pseudomonas aeruginosa*
- E.a. - *Enterobacter aerogenes*
- M.l. - *Micrococcus luteus*

The different species of phosphate solubilizing bacterial inoculation on the shoot biomass and root biomass was significantly increased by the inoculation of *Bacillus megaterium* by 47.33% and 41.18% respectively when compared with the control (Fig. 60 and 61).

Fig 60. Effect of PSB on the shoot biomass of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

![Graph showing the effect of PSB on shoot biomass](image)

Bacterial species
- B.s. - *Bacillus subtilis*
- E.c. - *Escherichia coli*
- A.i. - *Arthrobacter ilicis*
- M.r. - *Micrococcus roseus*
- B.c. - *Bacillus cereus*
- B.m. - *Bacillus megaterium*
- P.a. - *Pseudomonas aeruginosa*
- E.a. - *Enterobacter aerogenes*
- M.l. - *Micrococcus luteus*
Fig 61. Effect of PSB on the root biomass of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Root biomass (%)</th>
</tr>
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<tbody>
<tr>
<td>B. s.</td>
<td>37.50</td>
</tr>
<tr>
<td>E. c.</td>
<td>33.33</td>
</tr>
<tr>
<td>A. l.</td>
<td>-47.06</td>
</tr>
<tr>
<td>M. r.</td>
<td>41.18</td>
</tr>
<tr>
<td>B. c.</td>
<td>28.57</td>
</tr>
<tr>
<td>B. m.</td>
<td>28.57</td>
</tr>
<tr>
<td>P. a.</td>
<td>-30.00</td>
</tr>
<tr>
<td>E. a.</td>
<td>-35.14</td>
</tr>
<tr>
<td>M. l.</td>
<td>-28.21</td>
</tr>
</tbody>
</table>

The different species of phosphate solubilizing bacterial inoculation on the leaf area is presented in Table 21. Among the bacterial species, the leaf area was significantly increased by 44.76% with the inoculation of *Enterobacter aerogenes* (Fig. 62).

Fig 62. Effect of PSB on the leaf area of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Leaf area (%)</th>
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<tbody>
<tr>
<td>B. s.</td>
<td>41.01</td>
</tr>
<tr>
<td>E. c.</td>
<td>35.64</td>
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<tr>
<td>A. l.</td>
<td>34.65</td>
</tr>
<tr>
<td>M. r.</td>
<td>36.09</td>
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<tr>
<td>B. c.</td>
<td>33.81</td>
</tr>
<tr>
<td>B. m.</td>
<td>32.75</td>
</tr>
<tr>
<td>P. a.</td>
<td>22.67</td>
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<tr>
<td>E. a.</td>
<td>44.76</td>
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<td>M. l.</td>
<td>33.81</td>
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</table>

The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the content of total chlorophyll indicates that, the bacterial species of *Micrococcus luteus* increased the content of total chlorophyll by 61.11% over control. The *Bacillus megaterium* significantly increased the content of chlorophyll-a by 41.86% over control (Fig. 63 and 64).

**Fig. 63.** Effect of PSB on the total chlorophyll of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

![Bar graph showing the effect of PSB on total chlorophyll](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Total Chlorophyll (%)</th>
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<tr>
<td>B. s.</td>
<td>51.39</td>
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<tr>
<td>E. c.</td>
<td>16.67</td>
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<tr>
<td>A. l.</td>
<td>7.89</td>
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<tr>
<td>M. r.</td>
<td>12.50</td>
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<tr>
<td>B. m.</td>
<td>52.70</td>
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<td>P. a.</td>
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<tr>
<td>E. a.</td>
<td>42.62</td>
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<tr>
<td>M. l.</td>
<td>61.11</td>
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*Legend*:
- B. s.: Bacillus subtilis
- E. c.: Escherichia coli
- A. l.: Arthrobacter ilicis
- M. r.: Micrococcus roseus
- B. c.: Bacillus cereus
- B. m.: Bacillus megaterium
- P. a.: Pseudomonas aeruginosa
- E. a.: Enterobacter aerogenes
- M. l.: Micrococcus luteus

**Fig. 64.** Effect of PSB on the chlorophyll-a of *Rhizophora mucronata* seedlings as percentage increase or decrease over control

![Bar graph showing the effect of PSB on chlorophyll-a](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
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<tr>
<td>B. s.</td>
<td>38.86</td>
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<td>E. c.</td>
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<tr>
<td>A. l.</td>
<td>-2.74</td>
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<tr>
<td>M. r.</td>
<td>16.67</td>
</tr>
<tr>
<td>B. c.</td>
<td>18.18</td>
</tr>
<tr>
<td>B. m.</td>
<td>16.67</td>
</tr>
<tr>
<td>P. a.</td>
<td>18.67</td>
</tr>
<tr>
<td>E. a.</td>
<td>37.50</td>
</tr>
<tr>
<td>M. l.</td>
<td>13.46</td>
</tr>
</tbody>
</table>

*Legend*:
- B. s.: Bacillus subtilis
- E. c.: Escherichia coli
- A. l.: Arthrobacter ilicis
- M. r.: Micrococcus roseus
- B. c.: Bacillus cereus
- B. m.: Bacillus megaterium
- P. a.: Pseudomonas aeruginosa
- E. a.: Enterobacter aerogenes
- M. l.: Micrococcus luteus
The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the content of chlorophyll-b is depicted in Table 21. The bacterial species of *Bacillus megaterium* and *Bacillus subtilis* significantly enhanced the content of chlorophyll-b by 55.56% over control. But the content of carotenoid was significantly enhanced by 64.29% with the inoculation of *Bacillus subtilis* (Fig. 65 and 66).

**Fig 65. Effect of PSB on the chlorophyll-b of *Rhizophora mucronata* seedlings as percentage increase or decrease over control**

![Graph showing the effect of PSB on the chlorophyll-b of *Rhizophora mucronata* seedlings as percentage increase or decrease over control.]

**Bacterial species**

B.s.- *Bacillus subtilis*; E.c.- *Escherichia coli*; A.i.- *Arthrobacter ilicis*; M.r.- *Micrococcus roseus*; B.c.- *Bacillus cereus*; B. m.- *Bacillus megaterium*; P. a.- *Pseudomonas aeruginosa*; E. a.- *Enterobacter aerogenes*; M. l.- *Micrococcus luteus*

**Fig 66. Effect of PSB on the carotenoid of *Rhizophora mucronata* seedlings as percentage increase or decrease over control**

![Graph showing the effect of PSB on the carotenoid of *Rhizophora mucronata* seedlings as percentage increase or decrease over control.]

**Bacterial species**

B.s.- *Bacillus subtilis*; E.c.- *Escherichia coli*; A.i.- *Arthrobacter ilicis*; M.r.- *Micrococcus roseus*; B.c.- *Bacillus cereus*; B. m.- *Bacillus megaterium*; P. a.- *Pseudomonas aeruginosa*; E. a.- *Enterobacter aerogenes*; M. l.- *Micrococcus luteus*
The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the contents of carbohydrate, protein and amino acid are depicted in Table 21. Among the bacterial species, *Bacillus megaterium* increased the content of carbohydrate by 40.34%, protein by 43.56% and amino acid by 25.71% respectively over control than the other bacterial species (Fig. 67 - 69).

**Fig 67. Effect of PSB on the carbohydrate content of *Rhizophora mucronata* seedlings as percentage increase or decrease over control**

![Carbohydrate content graph](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Carbohydrate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>21.36</td>
</tr>
<tr>
<td>E. c.</td>
<td>26.07</td>
</tr>
<tr>
<td>A. i.</td>
<td>27.92</td>
</tr>
<tr>
<td>M. r.</td>
<td>11.28</td>
</tr>
<tr>
<td>B. c.</td>
<td>40.34</td>
</tr>
<tr>
<td>B. m.</td>
<td>-39.52</td>
</tr>
<tr>
<td>P. a.</td>
<td>-1.76</td>
</tr>
<tr>
<td>E. a.</td>
<td>32.16</td>
</tr>
<tr>
<td>M. l.</td>
<td>4.42</td>
</tr>
</tbody>
</table>

B.s.-Bacillus subtilis ; E.c.-Escherichia coli ; A.i.-Arthrobacter ilicis ; M.r.-Micrococcus roseus ; B.c. - Bacillus cereus ; B. m.-Bacillus megaterium ; P. a. -Pseudomonas aeruginosa ; E. a.- Enterobacter aerogenes ; M. l. - Micrococcus luteus

**Fig 68. Effect of PSB on the protein content of *Rhizophora mucronata* seedlings as percentage increase or decrease over control**

![Protein content graph](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>42.50</td>
</tr>
<tr>
<td>E. c.</td>
<td>38.67</td>
</tr>
<tr>
<td>A. i.</td>
<td>37.84</td>
</tr>
<tr>
<td>M. r.</td>
<td>29.23</td>
</tr>
<tr>
<td>B. c.</td>
<td>37.41</td>
</tr>
<tr>
<td>B. m.</td>
<td>43.56</td>
</tr>
<tr>
<td>P. a.</td>
<td>36.55</td>
</tr>
<tr>
<td>E. a.</td>
<td>41.77</td>
</tr>
<tr>
<td>M. l.</td>
<td>31.85</td>
</tr>
</tbody>
</table>

B.s.-Bacillus subtilis ; E.c.-Escherichia coli ; A.i.-Arthrobacter ilicis ; M.r.-Micrococcus roseus ; B.c. - Bacillus cereus ; B. m.-Bacillus megaterium ; P. a. -Pseudomonas aeruginosa ; E. a.- Enterobacter aerogenes ; M. l. - Micrococcus luteus
Table 21. Effect of phosphate solubilizing bacteria (PSB) on the root and shoot growth characteristics of *Rhizophora mucronata* seedlings after 60 days treatment

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Average root length (cm)</th>
<th>Average shoot length (cm)</th>
<th>No. of primary root / seedling</th>
<th>No. of sec. root / seedling</th>
<th>Shoot biomass (g)</th>
<th>Root biomass (g)</th>
<th>Leaf Area (cm²)</th>
<th>Total chlorophyll (g·g⁻¹)</th>
<th>Chlorophyll-a (g·g⁻¹)</th>
<th>Chlorophyll-b (g·g⁻¹)</th>
<th>Carotenoid (g·g⁻¹)</th>
<th>Carbohydrate (g·g⁻¹)</th>
<th>Protein (g·g⁻¹)</th>
<th>Amino acid (g·g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudomonas putida</em></td>
<td>7.380</td>
<td>27.900</td>
<td>9.200</td>
<td>460.000</td>
<td>1.230</td>
<td>0.800</td>
<td>78.660</td>
<td>0.072</td>
<td>0.037</td>
<td>0.036</td>
<td>0.056</td>
<td>2.200</td>
<td>1.600</td>
<td>0.700</td>
</tr>
<tr>
<td><em>Erwinia chrysanthemi</em></td>
<td>6.440</td>
<td>28.600</td>
<td>8.600</td>
<td>430.000</td>
<td>1.430</td>
<td>0.370</td>
<td>72.100</td>
<td>0.042</td>
<td>0.026</td>
<td>0.017</td>
<td>0.020</td>
<td>2.340</td>
<td>1.500</td>
<td>0.470</td>
</tr>
<tr>
<td><em>Bacillus licheniformis</em></td>
<td>8.300</td>
<td>27.000</td>
<td>8.200</td>
<td>410.000</td>
<td>1.300</td>
<td>0.750</td>
<td>71.000</td>
<td>0.038</td>
<td>0.022</td>
<td>0.016</td>
<td>0.010</td>
<td>2.400</td>
<td>1.480</td>
<td>0.490</td>
</tr>
<tr>
<td><em>Proteus vulgaris</em></td>
<td>2.940</td>
<td>20.400</td>
<td>7.000</td>
<td>350.000</td>
<td>0.980</td>
<td>0.340</td>
<td>72.600</td>
<td>0.040</td>
<td>0.027</td>
<td>0.021</td>
<td>0.030</td>
<td>1.700</td>
<td>1.300</td>
<td>0.550</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>8.380</td>
<td>26.800</td>
<td>8.200</td>
<td>410.000</td>
<td>1.100</td>
<td>0.400</td>
<td>70.100</td>
<td>0.049</td>
<td>0.028</td>
<td>0.026</td>
<td>0.030</td>
<td>1.950</td>
<td>1.470</td>
<td>0.560</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>8.110</td>
<td>30.100</td>
<td>9.200</td>
<td>460.000</td>
<td>1.500</td>
<td>0.850</td>
<td>69.000</td>
<td>0.074</td>
<td>0.039</td>
<td>0.036</td>
<td>0.020</td>
<td>2.900</td>
<td>1.630</td>
<td>0.700</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>8.440</td>
<td>26.500</td>
<td>9.200</td>
<td>460.000</td>
<td>0.890</td>
<td>0.700</td>
<td>60.000</td>
<td>0.049</td>
<td>0.027</td>
<td>0.021</td>
<td>0.020</td>
<td>1.240</td>
<td>1.450</td>
<td>0.510</td>
</tr>
<tr>
<td><em>Salmonella typhimurium</em></td>
<td>7.320</td>
<td>30.080</td>
<td>9.200</td>
<td>460.000</td>
<td>0.940</td>
<td>0.420</td>
<td>84.000</td>
<td>0.061</td>
<td>0.036</td>
<td>0.026</td>
<td>0.040</td>
<td>2.550</td>
<td>1.580</td>
<td>0.570</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>8.800</td>
<td>28.360</td>
<td>9.000</td>
<td>400.000</td>
<td>0.860</td>
<td>0.390</td>
<td>70.100</td>
<td>0.090</td>
<td>0.026</td>
<td>0.013</td>
<td>0.030</td>
<td>1.810</td>
<td>1.350</td>
<td>0.500</td>
</tr>
<tr>
<td><em>Bacillus thuringiensis</em></td>
<td>8.110</td>
<td>30.100</td>
<td>9.200</td>
<td>460.000</td>
<td>0.960</td>
<td>0.420</td>
<td>84.000</td>
<td>0.061</td>
<td>0.036</td>
<td>0.026</td>
<td>0.040</td>
<td>2.550</td>
<td>1.580</td>
<td>0.570</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>8.380</td>
<td>26.800</td>
<td>8.200</td>
<td>410.000</td>
<td>1.100</td>
<td>0.400</td>
<td>70.100</td>
<td>0.049</td>
<td>0.028</td>
<td>0.026</td>
<td>0.020</td>
<td>1.240</td>
<td>1.450</td>
<td>0.510</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>7.120</td>
<td>23.700</td>
<td>7.400</td>
<td>370.000</td>
<td>0.790</td>
<td>0.500</td>
<td>46.400</td>
<td>0.035</td>
<td>0.023</td>
<td>0.016</td>
<td>0.020</td>
<td>1.730</td>
<td>0.920</td>
<td>0.520</td>
</tr>
</tbody>
</table>

Values are average of 50 seedlings and are significant between bacterial species at 1% level for average root length, shoot biomass, root biomass, leaf area, chlorophyll-a, chlorophyll-b, carotenoid, carbohydrate, protein and amino acid; Non significant in the average shoot length, number of primary root, number of secondary root and total chlorophyll.
Phosphobacteria inoculated
Rhizophora mucronata seedlings in nursery

Shoot and Root growth characteristics of
Phosphobacteria treated Rhizophora mucronata seedlings

Bs - Bacillus subtilis
Ec - Escherichia coli
Ai - Arthrobacter ilicis
Mr - Micrococcus roseus
Bc - Bacillus cereus

Bm - Bacillus megaterium
Pa - Pseudomonas aeruginosa
Ea - Enterobacter aerogenes
MI - Micrococcus luteus
C - Control
7.3.2. Effect of phosphate solubilizing bacteria on *Avicennia officinalis* seedlings

The effect of phosphobacterial inoculation of different species of phosphate solubilizing bacteria on the growth parameters in *Avicennia officinalis* seedlings is depicted in Table 22. The average root length was significantly enhanced by the bacterial species of *Bacillus subtilis* by 43.43% and average shoot length was significantly enhanced by 40.0% by the *Pseudomonas aeruginosa* when compared with the control (Fig. 70 and 71).
The phosphate solubilizing bacterial inoculation on the maximum number of primary and secondary root is presented in Table 22. The bacterial species of *Arthrobacter ilicis* significantly enhanced the number of primary roots by 53.57% over control. But, the bacterial species of *Micrococcus luteus* enhanced the number of secondary roots by 59.74% over control (Fig. 72 and 73).
The bacterial species of *Bacillus subtilis* significantly enhanced the shoot biomass by 69.39%, whereas the root biomass was significantly enhanced by *Pseudomonas aeruginosa* by 26.32% (Fig. 74 and 75) over control.
Fig 74. Effect of PSB on the shoot biomass of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Shoot biomass graph](image)

Bacterial species:
- **B.s.** - Bacillus subtilis
- **E.c.** - Escherichia coli
- **A.i.** - Arthrobacter ilicis
- **M.r.** - Micrococcus roseus
- **B.c.** - Bacillus cereus
- **B.m.** - Bacillus megaterium
- **P.a.** - Pseudomonas aeruginosa
- **E.a.** - Enterobacter aerogenes
- **M.i.** - Micrococcus luteus

Fig 75. Effect of PSB on the root biomass of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Root biomass graph](image)

Bacterial species:
- **B.s.** - Bacillus subtilis
- **E.c.** - Escherichia coli
- **A.i.** - Arthrobacter ilicis
- **M.r.** - Micrococcus roseus
- **B.c.** - Bacillus cereus
- **B.m.** - Bacillus megaterium
- **P.a.** - Pseudomonas aeruginosa
- **E.a.** - Enterobacter aerogenes
- **M.i.** - Micrococcus luteus
The different species of phosphate solubilizing bacterial inoculation on the leaf area reveals that the bacterial species, the leaf area was significantly enhanced by 70.55% with the inoculation of Bacillus subtilis (Fig. 76).

**Fig 76. Effect of PSB on the leaf area of Avicennia officinalis seedlings as percentage increase or decrease over control**

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Leaf area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>70.55</td>
</tr>
<tr>
<td>E. c.</td>
<td>43.70</td>
</tr>
<tr>
<td>A. l.</td>
<td>31.28</td>
</tr>
<tr>
<td>M. r.</td>
<td>45.08</td>
</tr>
<tr>
<td>B. c.</td>
<td>67.32</td>
</tr>
<tr>
<td>B. m.</td>
<td>48.26</td>
</tr>
<tr>
<td>P. a.</td>
<td>47.45</td>
</tr>
<tr>
<td>E. a.</td>
<td>52.14</td>
</tr>
<tr>
<td>M. l.</td>
<td>56.63</td>
</tr>
</tbody>
</table>

B.s.-Bacillus subtilis ; E.c.-Escherchia coli ; A.l.-Arthrobacter ilicis ; M.r.-Micrococcus roseus ; B.c.- Bacillus cereus ; B. m.-Bacillus megaterium ; P. a.-Pseudomonas aeruginosa ; E. a.- Enterobacter aerogenes ; M. l.- Micrococcus luteus

The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the contents of pigments is presented in Table 22. Among the bacterial species, Bacillus megaterium significantly increased the content of total chlorophyll by 54.22% (Fig. 77), the Bacillus cereus significantly increased the contents of chlorophyll-a by 43.18% (Fig. 78), the Bacillus subtilis significantly increased the contents of chlorophyll-b by 69.77% (Fig. 79), the Escherichia coli significantly increased the content of carotenoids by 90.00% over control (Fig. 80).
Fig 77. Effect of PSB on the total chlorophyll of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Graph showing effect of PSB on total chlorophyll](image)

*B.s.* Bacillus subtilis; *E.c.* Escherichia coli; *A.i.* Arthrobacter ilicis; *M.r.* Micrococcus roseus; *B.c.* Bacillus cereus; *B.m.* Bacillus megaterium; *P.a.* Pseudomonas aeruginosa; *E.a.* Enterobacter aerogenes; *M.l.* Micrococcus luteus

Fig 78. Effect of PSB on the chlorophyll-a of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Graph showing effect of PSB on chlorophyll-a](image)

Fig 79. Effect of PSB on the chlorophyll-b of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Graph showing effect of PSB on chlorophyll-b](image)

Bacterial species:
- *B.s.* Bacillus subtilis
- *E.c.* Escherichia coli
- *A.i.* Arthrobacter ilicis
- *M.r.* Micrococcus roseus
- *B.c.* Bacillus cereus
- *B.m.* Bacillus megaterium
- *P.a.* Pseudomonas aeruginosa
- *E.a.* Enterobacter aerogenes
- *M.l.* Micrococcus luteus
The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the biochemical constituents is represented in Table 22. The bacterial species of *Micrococcus roseus* significantly increased the content of carbohydrate by 61.88% (Fig. 81), the *Bacillus megaterium* significantly enhanced the content of protein by 52.38% (Fig. 82), the amino acid content was significantly enhanced by *Bacillus subtilis* and *Enterobacter aerogenes* respectively by 27.85% over control (Fig. 83).
Fig 82. Effect of PSB on the protein content of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Graph showing protein content of different bacterial species](image)

Bacterial species:
- B. s. - *Bacillus subtilis*
- E. c. - *Escherichia coli*
- A. l. - *Arthrobacter liliis*
- M. r. - *Micrococcus roseus*
- B. c. - *Bacillus cereus*
- B. m. - *Bacillus megaterium*
- P. a. - *Pseudomonas aeruginosa*
- E. a. - *Enterobacter aerogenes*
- M. l. - *Micrococcus luteus*

Fig 83. Effect of PSB on the amino acid of *Avicennia officinalis* seedlings as percentage increase or decrease over control

![Graph showing amino acid content of different bacterial species](image)

Bacterial species:
- B. s. - *Bacillus subtilis*
- E. c. - *Escherichia coli*
- A. l. - *Arthrobacter liliis*
- M. r. - *Micrococcus roseus*
- B. c. - *Bacillus cereus*
- B. m. - *Bacillus megaterium*
- P. a. - *Pseudomonas aeruginosa*
- E. a. - *Enterobacter aerogenes*
- M. l. - *Micrococcus luteus*
Table 22. Effect of phosphate solubilizing bacteria (PSB) on the root and shoot growth characteristics of *Avicennia officinalis* seedlings after 60 days treatment

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Average root length (cm)</th>
<th>Average shoot length (cm)</th>
<th>No. of primary root / seedling</th>
<th>No. of sec. root / seedling</th>
<th>Shoot biomass (g)</th>
<th>Root biomass (g)</th>
<th>Leaf Area (cm²)</th>
<th>Total chlorophyll (g.g⁻¹)</th>
<th>Chlorophyll-a (g.g⁻¹)</th>
<th>Chlorophyll-b (g.g⁻¹)</th>
<th>Carotenoid (g.g⁻¹)</th>
<th>Carbohydrate (g.g⁻¹)</th>
<th>Protein (g.g⁻¹)</th>
<th>Amino acid (g.g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Streptococcus</em></td>
<td>10.890</td>
<td>32.480</td>
<td>13.200</td>
<td>424.000</td>
<td>0.980</td>
<td>0.320</td>
<td>45.500</td>
<td>0.082</td>
<td>0.038</td>
<td>0.043</td>
<td>0.074</td>
<td>1.490</td>
<td>1.390</td>
<td>0.790</td>
</tr>
<tr>
<td><em>Proteus</em></td>
<td>7.450</td>
<td>31.400</td>
<td>10.600</td>
<td>416.000</td>
<td>0.880</td>
<td>0.260</td>
<td>23.800</td>
<td>0.068</td>
<td>0.034</td>
<td>0.033</td>
<td>0.010</td>
<td>1.110</td>
<td>1.510</td>
<td>0.595</td>
</tr>
<tr>
<td><em>Rhodococcus</em></td>
<td>5.480</td>
<td>23.700</td>
<td>14.000</td>
<td>560.000</td>
<td>0.860</td>
<td>0.230</td>
<td>19.500</td>
<td>0.067</td>
<td>0.036</td>
<td>0.031</td>
<td>0.010</td>
<td>0.550</td>
<td>1.370</td>
<td>0.570</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>9.840</td>
<td>25.000</td>
<td>11.600</td>
<td>456.000</td>
<td>0.910</td>
<td>0.270</td>
<td>24.400</td>
<td>0.075</td>
<td>0.042</td>
<td>0.033</td>
<td>0.033</td>
<td>0.010</td>
<td>0.770</td>
<td>0.420</td>
</tr>
<tr>
<td><em>Bacillus</em></td>
<td>7.110</td>
<td>24.200</td>
<td>9.200</td>
<td>368.000</td>
<td>0.880</td>
<td>0.250</td>
<td>41.000</td>
<td>0.082</td>
<td>0.034</td>
<td>0.033</td>
<td>0.010</td>
<td>1.190</td>
<td>1.540</td>
<td>0.740</td>
</tr>
<tr>
<td><em>Bacillus licheniformis</em></td>
<td>8.300</td>
<td>32.600</td>
<td>13.600</td>
<td>536.000</td>
<td>0.960</td>
<td>0.300</td>
<td>25.900</td>
<td>0.083</td>
<td>0.040</td>
<td>0.042</td>
<td>0.060</td>
<td>1.590</td>
<td>1.890</td>
<td>0.800</td>
</tr>
<tr>
<td><em>Bacillus licheniformis</em></td>
<td>7.250</td>
<td>35.000</td>
<td>12.200</td>
<td>488.000</td>
<td>0.660</td>
<td>0.380</td>
<td>25.500</td>
<td>0.073</td>
<td>0.036</td>
<td>0.036</td>
<td>0.030</td>
<td>1.230</td>
<td>1.230</td>
<td>0.700</td>
</tr>
<tr>
<td><em>Staphylococcus</em></td>
<td>8.270</td>
<td>19.200</td>
<td>12.000</td>
<td>480.000</td>
<td>0.900</td>
<td>0.290</td>
<td>28.000</td>
<td>0.078</td>
<td>0.037</td>
<td>0.034</td>
<td>0.040</td>
<td>1.380</td>
<td>1.810</td>
<td>0.790</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>6.390</td>
<td>24.900</td>
<td>12.400</td>
<td>616.000</td>
<td>0.760</td>
<td>0.250</td>
<td>13.400</td>
<td>0.050</td>
<td>0.025</td>
<td>0.028</td>
<td>0.040</td>
<td>1.020</td>
<td>1.350</td>
<td>0.750</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>6.160</td>
<td>21.000</td>
<td>6.500</td>
<td>248.000</td>
<td>0.300</td>
<td>0.280</td>
<td>30.900</td>
<td>0.038</td>
<td>0.025</td>
<td>0.013</td>
<td>0.010</td>
<td>0.850</td>
<td>0.900</td>
<td>0.650</td>
</tr>
</tbody>
</table>

These are average of 50 seedlings and are significant between treatments at 1% level for average root length, number of primary root, number of secondary root biomass, shoot biomass, leaf area, chlorophyll-a, chlorophyll-b, carbohydrate, protein, amino acid and 5% level for average shoot length, total chlorophyll and non-significant for carotenoids.
Phosphobacteria inoculated Avicennia officinalis seedlings in nursery

Shoot and Root growth characteristics of Phosphobacteria treated Avicennia officinalis seedlings

Bs - Bacillus subtilis
Ec - Escherichia coli
Ai - Arthrobacter ilicis
Mr - Micrococcus roseus
Bc - Bacillus cereus
Pa - Pseudomonas aeruginosa
Bm - Bacillus megaterium
Ea - Enterobacter aerogenes
MI - Micrococcus luteus
C - Control
7.3.3. Effect of phosphate solubilizing bacteria on Ceriops decandra seedlings

The effect of different species of bacterial inoculation on the growth characteristics is represented in Table 23. The average root length was significantly increased by the bacterial species of Micrococcus luteus by 10.80% (Fig. 84), the number of primary roots and the secondary roots were significantly increased by the inoculation of Bacillus megaterium by 8.70% each respectively (Fig. 85 and 86), but the root biomass was significantly increased by the inoculation of Bacillus subtilis by 34.34% (Fig. 87).

Fig 84. Effect of PSB on the average root length of Ceriops decandra seedlings as percentage increase or decrease over control

Fig 85. Effect of PSB on the number of primary root of Ceriops decandra seedlings as percentage increase or decrease over control
The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the average shoot length and shoot biomass were studied. Among the bacterial species, significant enhancement was noticed in the average shoot length by *Bacillus subtilis* by 32.69%, the shoot biomass was significantly increased by 29.42% with the inoculation of *Bacillus megaterium* (Fig. 88 and 89).
Fig 88. Effect of PSB on the average shoot length of *Ceriops decandra* seedlings as percentage increase or decrease over control

![Bar chart showing the effect of PSB on the average shoot length of *Ceriops decandra* seedlings.](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Average shoot length (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>32.69</td>
</tr>
<tr>
<td>E. c.</td>
<td>16.00</td>
</tr>
<tr>
<td>A. l.</td>
<td>27.59</td>
</tr>
<tr>
<td>M. r.</td>
<td>14.29</td>
</tr>
<tr>
<td>B. c.</td>
<td>27.59</td>
</tr>
<tr>
<td>B. m.</td>
<td>30.00</td>
</tr>
<tr>
<td>P. a.</td>
<td>5.41</td>
</tr>
<tr>
<td>E. a.</td>
<td>12.50</td>
</tr>
<tr>
<td>M. l.</td>
<td>27.59</td>
</tr>
</tbody>
</table>

B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.l.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus

Fig 89. Effect of PSB on the shoot biomass of *Ceriops decandra* seedlings as percentage increase or decrease over control

![Bar chart showing the effect of PSB on the shoot biomass of *Ceriops decandra* seedlings.](image)

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Shoot biomass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>20.65</td>
</tr>
<tr>
<td>E. c.</td>
<td>17.99</td>
</tr>
<tr>
<td>A. l.</td>
<td>19.85</td>
</tr>
<tr>
<td>M. r.</td>
<td>8.86</td>
</tr>
<tr>
<td>B. c.</td>
<td>18.21</td>
</tr>
<tr>
<td>B. m.</td>
<td>29.42</td>
</tr>
<tr>
<td>P. a.</td>
<td>13.32</td>
</tr>
<tr>
<td>E. a.</td>
<td>23.32</td>
</tr>
<tr>
<td>M. l.</td>
<td>15.16</td>
</tr>
</tbody>
</table>

B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.l.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus

The bacterial inoculation of different species of phosphate solubilizing bacteria on the leaf area was significantly increased by *Bacillus cereus* by 40.30% over control (Fig. 90).
Fig 90. Effect of PSB on the leaf area of *Ceriops decandra* seedlings as percentage increase or decrease over control

![Bar chart showing the effect of PSB on leaf area of *Ceriops decandra* seedlings.]

The different species of phosphate solubilizing bacterial effect on the content of pigments is shown in Table 10. The bacterial species of *Bacillus subtilis* increased the content of total chlorophyll by 56.10% (Fig. 91), the content of chlorophyll-a was significantly increased by 53.82% (Fig. 92) over control.

Fig 91. Effect of PSB on the total chlorophyll of *Ceriops decandra* seedlings as percentage increase or decrease over control

![Bar chart showing the effect of PSB on total chlorophyll of *Ceriops decandra* seedlings.]

* B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.l.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus
The content of chlorophyll-b was significantly increased by 60.61% by the inoculation of Enterobacter aerogenes (Fig. 93), the species of Escherichia coli significantly enhanced the content of carotenoid by 71.83% over control (Fig. 94).
The effect of bacterial inoculation of different species of phosphate solubilizing bacteria on the content of carbohydrate and protein indicates that the bacterial species of *Bacillus megaterium* significantly increased the content of carbohydrate by 55.08% (Fig. 95) and the protein content by 50.00% (Fig. 96) respectively over control. Whereas, the content of amino acid was significantly increased by the inoculation of *Bacillus subtilis* by 52.81% over control (Fig. 97).
Fig 96. Effect of PSB on the protein content of Ceriops decandra seedlings as percentage increase or decrease over control

![Bar chart showing protein content changes for different bacterial species.]

B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.i.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus

Fig 97. Effect of PSB on the amino acid of Ceriops decandra seedlings as percentage increase or decrease over control

![Bar chart showing amino acid changes for different bacterial species.]

B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.i.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus
Table 23. Effect of phosphate solubilizing bacteria (PSB) on the root and shoot growth characteristics of *Ceriops decandra* seedlings after 60 days treatment

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Average root length (cm)</th>
<th>Average shoot length (cm)</th>
<th>No. of primary root/seedling</th>
<th>No. of sec. root/seedling</th>
<th>Shoot biomass (g)</th>
<th>Root biomass (g)</th>
<th>Leaf Area (cm²)</th>
<th>Total chlorophyll (g·g⁻¹)</th>
<th>Chlorophyll-a (g·g⁻¹)</th>
<th>Chlorophyll-b (g·g⁻¹)</th>
<th>Carotenoid (g·g⁻¹)</th>
<th>Carbohydrate (g·g⁻¹)</th>
<th>Protein (g·g⁻¹)</th>
<th>Amino acid (g·g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>5.260</td>
<td>6.240</td>
<td>4.400</td>
<td>88.000</td>
<td>0.402</td>
<td>0.198</td>
<td>5.700</td>
<td>0.082</td>
<td>0.050</td>
<td>0.032</td>
<td>0.020</td>
<td>1.060</td>
<td>1.120</td>
<td>0.890</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>4.120</td>
<td>5.000</td>
<td>3.400</td>
<td>68.000</td>
<td>0.389</td>
<td>0.163</td>
<td>4.850</td>
<td>0.040</td>
<td>0.025</td>
<td>0.014</td>
<td>0.071</td>
<td>0.800</td>
<td>0.620</td>
<td>0.570</td>
</tr>
<tr>
<td><em>Arthrobacter ilicis</em></td>
<td>5.640</td>
<td>5.800</td>
<td>4.200</td>
<td>84.000</td>
<td>0.398</td>
<td>0.164</td>
<td>4.900</td>
<td>0.039</td>
<td>0.022</td>
<td>0.018</td>
<td>0.030</td>
<td>0.800</td>
<td>0.600</td>
<td>0.550</td>
</tr>
<tr>
<td><em>Microoccus roseus</em></td>
<td>5.540</td>
<td>4.900</td>
<td>3.800</td>
<td>76.000</td>
<td>0.350</td>
<td>0.159</td>
<td>4.350</td>
<td>0.069</td>
<td>0.028</td>
<td>0.017</td>
<td>0.020</td>
<td>0.600</td>
<td>0.880</td>
<td>0.496</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>4.380</td>
<td>5.800</td>
<td>4.200</td>
<td>84.000</td>
<td>0.390</td>
<td>0.178</td>
<td>6.700</td>
<td>0.071</td>
<td>0.037</td>
<td>0.032</td>
<td>0.025</td>
<td>1.020</td>
<td>0.720</td>
<td>0.790</td>
</tr>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>4.840</td>
<td>6.000</td>
<td>4.600</td>
<td>92.000</td>
<td>0.452</td>
<td>0.188</td>
<td>5.450</td>
<td>0.068</td>
<td>0.038</td>
<td>0.026</td>
<td>0.010</td>
<td>1.180</td>
<td>1.200</td>
<td>0.820</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>5.240</td>
<td>4.440</td>
<td>4.400</td>
<td>64.000</td>
<td>0.368</td>
<td>0.160</td>
<td>4.350</td>
<td>0.039</td>
<td>0.032</td>
<td>0.025</td>
<td>0.020</td>
<td>0.610</td>
<td>0.690</td>
<td>0.460</td>
</tr>
<tr>
<td><em>Enterobacter aerogenes</em></td>
<td>5.580</td>
<td>5.800</td>
<td>4.400</td>
<td>88.000</td>
<td>0.416</td>
<td>0.182</td>
<td>5.350</td>
<td>0.068</td>
<td>0.034</td>
<td>0.033</td>
<td>0.020</td>
<td>0.710</td>
<td>0.910</td>
<td>0.720</td>
</tr>
<tr>
<td><em>Micrococcus luteus</em></td>
<td>5.740</td>
<td>4.800</td>
<td>4.200</td>
<td>84.000</td>
<td>0.376</td>
<td>0.172</td>
<td>4.060</td>
<td>0.050</td>
<td>0.029</td>
<td>0.020</td>
<td>0.020</td>
<td>0.890</td>
<td>0.650</td>
<td>0.470</td>
</tr>
<tr>
<td>Control</td>
<td>5.120</td>
<td>4.200</td>
<td>4.200</td>
<td>84.000</td>
<td>0.319</td>
<td>0.130</td>
<td>4.000</td>
<td>0.036</td>
<td>0.023</td>
<td>0.013</td>
<td>0.020</td>
<td>0.530</td>
<td>0.600</td>
<td>0.420</td>
</tr>
</tbody>
</table>

Values are average of 50 seedlings and are significant between treatments at 1% level for shoot biomass, root biomass, leaf area, total chlorophyll, carotenoid, carbohydrate, protein and amino acid; Non significant for average root length, average shoot length, number of primary roots, number of secondary roots, chlorophyll-a, chlorophyll-b.
Phosphobacteria inoculated Ceriops decandra seedlings in nursery

Shoot and Root growth characteristics of Phosphobacteria treated Ceriops decandra seedlings

Bs - Bacillus subtilis
Ec - Escherichia coli
Ai - Arthrobacter ilicis
Mr - Micrococcus roseus
Bc - Bacillus cereus
Bm - Bacillus megaterium
Pa - Pseudomonas aeruginosa
Ea - Enterobacter aerogenes
ML - Micrococcus luteus
C - Control
7.3.4. The biofertilizer effect of halophilic phosphate solubilizing bacteria on *Oryza sativa*

The effect of phosphate solubilizing bacterial isolates on the root, shoot and biochemical characteristics of *Oryza sativa* is depicted in Table 24. The average root length was significantly increased maximum by 32.95% by the inoculation of *Micrococcus roseus* (Fig. 98), the number of root per seedling was significantly increased (38.46%) by the inoculation of *Bacillus megaterium* and *Enterobacter aerogenes* (Fig. 99), the root biomass was increased maximum by 3.77% by the inoculation of *Escherichia coli*, *Arthrobacter ilicis*, *Micrococcus roseus*, *Bacillus cereus* and *Enterobacter aerogenes* respectively (Fig. 100).

![Fig 98. Effect of PSB on the average root length of *Oryza sativa* seedlings as percentage increase or decrease over control](image)

*Fig 98. Effect of PSB on the average root length of *Oryza sativa* seedlings as percentage increase or decrease over control*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Average root length (%)</td>
<td>5.75</td>
<td>18.16</td>
<td>22.93</td>
<td>32.95</td>
<td>23.29</td>
<td>7.87</td>
<td>22.05</td>
<td>27.50</td>
<td>10.68</td>
</tr>
</tbody>
</table>

*B. s.*-Bacillus subtilis; *E. c.*-Escherichia coli; *A. l.*-Arthrobacter ilicis; *M. r.*-Micrococcus roseus; *B. c.*-Bacillus cereus; *B. m.*-Bacillus megaterium; *P. a.*-Pseudomonas aeruginosa; *E. a.*-Enterobacter aerogenes; *M. l.*-Micrococcus luteus
Fig 99. Effect of PSB on the number of root of Oryza sativa seedlings as percentage increase or decrease over control

![Graph showing the effect of different bacterial species on the number of root of Oryza sativa seedlings.]

Bacterial species:
- B. s. - Bacillus subtilis
- E. c. - Escherichia coli
- A. i. - Arthrobacter ilicis
- M. r. - Micrococcus roseus
- B. c. - Bacillus cereus
- B. m. - Bacillus megaterium
- P. a. - Pseudomonas aeruginosa
- E. a. - Enterobacter aerogenes
- M. l. - Micrococcus luteus

The average shoot length and shoot biomass was significantly increased by 11.00% and 90.48% by the inoculation of Arthrobacter ilicis and Escherichia coli respectively (Fig. 101 and 102).
The content of total chlorophyll, chlorophyll-a and chlorophyll-b in *Oryza sativa* seedlings were found to be increased by 68.70%, 53.50% and 80.47% respectively by the inoculation of the bacterial species of *Enterobacter aerogenes* (Fig. 103 - 105), the content of carotenoids was increased by 45.83% by the inoculation of *Micrococcus luteus* (Fig. 106).
Fig 103. Effect of PSB on the total chlorophyll of *Oryza sativa* seedlings as percentage increase or decrease over control

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Total Chlorophyll (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>27.27</td>
</tr>
<tr>
<td>E. c.</td>
<td>20.44</td>
</tr>
<tr>
<td>A. i.</td>
<td>25.39</td>
</tr>
<tr>
<td>M. r.</td>
<td>13.77</td>
</tr>
<tr>
<td>B. c.</td>
<td>24.21</td>
</tr>
<tr>
<td>B. m.</td>
<td>51.35</td>
</tr>
<tr>
<td>P. a.</td>
<td>40.25</td>
</tr>
<tr>
<td>E. a.</td>
<td>68.70</td>
</tr>
<tr>
<td>M. l.</td>
<td>58.74</td>
</tr>
</tbody>
</table>

*B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.i.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus*

Fig 104. Effect of PSB on the chlorophyll-a of *Oryza sativa* seedlings as percentage increase or decrease over control

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Chlorophyll-a (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>-29.17</td>
</tr>
<tr>
<td>E. c.</td>
<td>17.70</td>
</tr>
<tr>
<td>A. i.</td>
<td>9.71</td>
</tr>
<tr>
<td>M. r.</td>
<td>3.13</td>
</tr>
<tr>
<td>B. c.</td>
<td>12.26</td>
</tr>
<tr>
<td>B. m.</td>
<td>13.89</td>
</tr>
<tr>
<td>P. a.</td>
<td>53.50</td>
</tr>
<tr>
<td>E. a.</td>
<td>51.81</td>
</tr>
<tr>
<td>M. l.</td>
<td></td>
</tr>
</tbody>
</table>

*B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.i.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus*

Fig 105. Effect of PSB on the chlorophyll-b of *Oryza sativa* seedlings as percentage increase or decrease over control

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Chlorophyll-b (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. s.</td>
<td>54.13</td>
</tr>
<tr>
<td>E. c.</td>
<td>25.37</td>
</tr>
<tr>
<td>A. i.</td>
<td>57.98</td>
</tr>
<tr>
<td>M. r.</td>
<td>16.67</td>
</tr>
<tr>
<td>B. c.</td>
<td>46.81</td>
</tr>
<tr>
<td>B. m.</td>
<td>73.26</td>
</tr>
<tr>
<td>P. a.</td>
<td>61.54</td>
</tr>
<tr>
<td>E. a.</td>
<td>80.47</td>
</tr>
<tr>
<td>M. l.</td>
<td>67.32</td>
</tr>
</tbody>
</table>

*B.s.-Bacillus subtilis; E.c.-Escherichia coli; A.i.-Arthrobacter ilicis; M.r.-Micrococcus roseus; B.c.-Bacillus cereus; B.m.-Bacillus megaterium; P.a.-Pseudomonas aeruginosa; E.a.-Enterobacter aerogenes; M.l.-Micrococcus luteus*
Fig 106. Effect of PSB on the carotenoid of *Oryza sativa* seedlings as percentage increase or decrease over control

![Carotenoid Graph]

Bacterial species:
- B.s.- *Bacillus subtilis*
- E.c.- *Escherichia coli*
- A.l.- *Arthrobacter ilaris*
- M.r.- *Micrococcus roseus*
- B.c.- *Bacillus cereus*
- B.m.- *Bacillus megaterium*
- P.a.- *Pseudomonas aeruginosa*
- E.a.- *Enterobacter aerogenes*
- M.I.- *Micrococcus luteus*

Fig 107. Effect of PSB on the carbohydrate content of *Oryza sativa* seedlings as percentage increase or decrease over control

![Carbohydrate Graph]

Bacterial species:
- B.s.- *Bacillus subtilis*
- E.c.- *Escherichia coli*
- A.l.- *Arthrobacter ilaris*
- M.r.- *Micrococcus roseus*
- B.c.- *Bacillus cereus*
- B.m.- *Bacillus megaterium*
- P.a.- *Pseudomonas aeruginosa*
- E.a.- *Enterobacter aerogenes*
- M.I.- *Micrococcus luteus*

Fig 108. Effect of PSB on the protein content of *Oryza sativa* seedlings as percentage increase or decrease over control

![Protein Graph]

Bacterial species:
- B.s.- *Bacillus subtilis*
- E.c.- *Escherichia coli*
- A.l.- *Arthrobacter ilaris*
- M.r.- *Micrococcus roseus*
- B.c.- *Bacillus cereus*
- B.m.- *Bacillus megaterium*
- P.a.- *Pseudomonas aeruginosa*
- E.a.- *Enterobacter aerogenes*
- M.I.- *Micrococcus luteus*
The content of carbohydrate was increased by 33.33% by **Bacillus cereus** (Fig. 107) and the content of protein was increased maximum by 41.21% by the inoculation of **Bacillus megaterium** (Fig. 108), the amino acid content was increased by 30.23% by **Bacillus subtilis** (Fig. 109) over control.
Table 24. Effect of phosphate solubilizing bacteria (PSB) on the root and shoot growth characteristics of *Oryza sativa* seedlings after 20 days treatment

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th>Average root length (cm)</th>
<th>Average shoot length (cm)</th>
<th>No. of root / seedling</th>
<th>Shoot biomass (g) / seedling</th>
<th>Root biomass (g)</th>
<th>Total chlorophyll (g.g⁻¹)</th>
<th>Chlorophyll-a (g.g⁻¹)</th>
<th>Chlorophyll-b (g.g⁻¹)</th>
<th>Carotenoid (g.g⁻¹)</th>
<th>Carbohydrate (g.g⁻¹)</th>
<th>Protein (g.g⁻¹)</th>
<th>Amino acid (g.g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>8.700</td>
<td>17.310</td>
<td>11.000</td>
<td>0.161</td>
<td>0.157</td>
<td>0.198</td>
<td>0.087</td>
<td>0.109</td>
<td>0.090</td>
<td>0.091</td>
<td>0.160</td>
<td>0.043</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>10.020</td>
<td>18.200</td>
<td>6.000</td>
<td>1.650</td>
<td>0.159</td>
<td>0.181</td>
<td>0.113</td>
<td>0.067</td>
<td>0.140</td>
<td>0.079</td>
<td>0.119</td>
<td>0.039</td>
</tr>
<tr>
<td><em>Arthrobacter liliis</em></td>
<td>10.640</td>
<td>18.450</td>
<td>6.000</td>
<td>1.600</td>
<td>0.159</td>
<td>0.193</td>
<td>0.072</td>
<td>0.119</td>
<td>0.030</td>
<td>0.075</td>
<td>0.112</td>
<td>0.037</td>
</tr>
<tr>
<td><em>Micrococcus roseus</em></td>
<td>12.230</td>
<td>18.180</td>
<td>7.000</td>
<td>0.159</td>
<td>0.159</td>
<td>0.167</td>
<td>0.103</td>
<td>0.060</td>
<td>0.020</td>
<td>0.073</td>
<td>0.129</td>
<td>0.036</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>10.690</td>
<td>17.320</td>
<td>11.000</td>
<td>0.168</td>
<td>0.159</td>
<td>0.190</td>
<td>0.096</td>
<td>0.094</td>
<td>0.130</td>
<td>0.102</td>
<td>0.161</td>
<td>0.038</td>
</tr>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>8.900</td>
<td>16.860</td>
<td>13.000</td>
<td>0.167</td>
<td>0.158</td>
<td>0.296</td>
<td>0.106</td>
<td>0.187</td>
<td>0.160</td>
<td>0.094</td>
<td>0.165</td>
<td>0.041</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>10.520</td>
<td>17.070</td>
<td>9.000</td>
<td>0.159</td>
<td>0.156</td>
<td>0.241</td>
<td>0.108</td>
<td>0.130</td>
<td>0.080</td>
<td>0.076</td>
<td>0.101</td>
<td>0.034</td>
</tr>
<tr>
<td><em>Enterobacter aerogenes</em></td>
<td>11.310</td>
<td>18.390</td>
<td>13.000</td>
<td>0.174</td>
<td>0.159</td>
<td>0.460</td>
<td>0.200</td>
<td>0.256</td>
<td>0.211</td>
<td>0.086</td>
<td>0.160</td>
<td>0.036</td>
</tr>
<tr>
<td><em>Micrococcus luteus</em></td>
<td>9.180</td>
<td>16.530</td>
<td>9.000</td>
<td>0.159</td>
<td>0.156</td>
<td>0.349</td>
<td>0.193</td>
<td>0.153</td>
<td>0.240</td>
<td>0.098</td>
<td>0.132</td>
<td>0.034</td>
</tr>
<tr>
<td><em>Control</em></td>
<td>8.200</td>
<td>16.420</td>
<td>8.000</td>
<td>0.157</td>
<td>0.153</td>
<td>0.144</td>
<td>0.093</td>
<td>0.050</td>
<td>0.130</td>
<td>0.068</td>
<td>0.097</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Values are average of 50 seedlings and are significant between treatments at 1% level for average root length, average shoot length, number of roots, shoot biomass, total chlorophyll, chlorophyll-a, chlorophyll-b, carotenoid, carbohydrate, protein and amino acid.
Phosphobacteria inoculated Oryza sativa seedlings in nursery

Shoot and Root growth characteristics of Phosphobacteria treated Oryza sativa seedlings

Bs - Bacillus subtilis
Ec - Escherichia coli
Ai - Arthrobacter ilicis
Mr - Micrococcus roseus
Bc - Bacillus cereus
Bm - Bacillus megaterium
Pa - Pseudomonas aeruginosa
Ea - Enterobacter aerogenes
Mi - Micrococcus luteus
C - Control
7.4. Discussion

Use of P-solubilizing microorganisms has been reported promising in reducing P-fixation and increasing the phosphorous availability from soluble and insoluble phosphatic fertilizers (Shinde and Patil, 1985). Beneficial effect of inoculation of P-solubilizers on the uptake of nutrients and on the yield of crops has been reported by many workers. Gerretson (1948) was the first to demonstrate that plants take up more phosphate from insoluble phosphatic fertilizers in the presence of microorganisms with these ideas in view present investigation was undertaken to see the effect of P-solubilizing microorganisms on growth and yield of mangroves and coastal rice crops. In semi-arid tropics, following clear cutting, mangroves hardly ever revegetate (Cintron et al., 1978) due to very low levels of phosphorous (Holguin et al., 1992). The bacterial species that facilitate phosphate solubilization by inoculation with mangroves are not well characterized, although some of the organisms involved in the inoculation processes have been identified (Ravikumar et al., 2002a; Ravikumar et al., 2002b; Ravikumar et al., 2004).

It was previously observed that mangrove seedlings and coastal rice crops usually grow better after inoculation with the diazotrophic filamentous cyanobacteria (Palaniselvam, 1998), *Azospirillum* (Ravikumar et al., 2002) and *Azotobacter* (Ravikumar et al., 2004). Based on this observation, it was reasoned that mangrove seedlings might also benefit by being inoculated with plant growth promoting bacteria (PGPB) (Bashan and Holguin, 1998). PGPBs have been reported to stimulate regeneration of temperate forests (Toledo et al., 1995b; Bashan and Holguin, 1998; Chanway and Holl, 1992; Li et al., 1992). Phosphobacterial species are well
known PGPBs that facilitate the growth of a wide range of terrestrial plant species (Bashan and Holguin, 1997a ; Bashan and Holguin, 1997b). But there are no reports describing the inoculation of halophilic phosphobacteria onto mangrove plants. Hence, the present study has been carried out to find out the effect of nine halophilic phosphobacteria on the growth of mangroves and coastal rice crops. It reveals that all the 9 phosphobacterial species showed promotory effects on the growth and physiology of *Avicennia officinalis* seedlings, 7 bacterial species are found to have promotory effect on *Oryza sativa*, 6 bacterial species are found to have promotory effect on *Ceriops decandra* and 5 bacterial species enhanced the growth and physiology of *Rhizophora mucronata* seedlings (Table 25). This implies that each bacterial species have the tendency to choose specific plant host for their multiplication and P-fixation. Esther Puente et al. (1999) reported that the total number of bacteria colonizing the black mangrove *Avicennia germinans* root was greater for *A. brasilense* than for *A. halopraeferens*.

In the present study, halophilic phosphobacteria had positive effects on the pigments, organic contents and growth characteristics of mangroves and coastal rice crops. The promotory effect may be attributed to the production of phytohormones by the bacterial species and supply of available phosphorous to the growing seedlings of mangroves which in turn enhances growth and yield (Sattar and Gaur, 1987). However, the production of phytohormones by phosphobacterial species especially, in *Bacillus* sp. and *Pseudomonas* sp. are not well characterized (Vessey, 2003).

In the present study, all the halophilic bacterial species of phosphobacteria are capable of solubilizing the inorganic phosphorous. Moreover it is clear from the present study that, *Bacillus megaterium* and
Bacillus subtilis could enhance the maximum number of mangrove plant growth parameters (Table 25) and hence they are considered to be potent forms for the inoculation purposes for mangroves and coastal rice crops. Subba rao (1997) reported that the commercial biofertilizer under the name “phosphobacterin” was prepared by the incorporation of efficient strains of Bacillus megaterium var. phosphaticum and widely used in the Soviet Union, East European countries and India with successive results. Vasudevan (2002) reported that, the inoculation of Bacillus spp. increase the root growth in pot grown rice culture than the other bacterial genera and also he stated that fast growing ability and out-complete the native bacteria and also the role in organic matter cycling in the rhizosphere could be the reasons for the better plant growth. Datta et al. (2002) reported that the Bacillus firmus found to be the potential strain for the inoculation of rice in acid soils of India.

It was also found that, the halophilic phosphobacteria enhanced the level of photosynthetic pigments in mangrove seedlings and coastal rice crops. It is obvious that, even the salt resistant phosphobacteria could also able to produce phytohormones under salt stress and hence the increased level of pigments were noticed in the present study: Ravikumar et al. (2002; 2004) reported that the inoculation of Azospirillum sp. and Azotobacter sp. enhanced the level of pigments in mangrove seedlings and rice crops due to their ability in producing phytohormones at varied salinity levels.

In general, the inoculation of phosphobacteria into soil enhanced growth performance of mangroves. This experimental results is in agreement with the field observation of Kathiresan and Ramesh (1991) that seedlings of mangrove species grow luxuriant in the rhizosphere soil than those in non-rhizosphere soil. Based upon the maximum number of
positive growth parameters (Table 25) inoculation of *Bacillus megaterium* is recommended for the better growth of *Rhizophora mucronata* and *Ceriops decandra*; *Bacillus subtilis* is recommended for *Avicennia officinalis*; *Enterobacter aerogenes* is recommended for *Oryza sativa* seedlings for better growth.

Further studies on the dual and triple inoculation of *Bacillus subtilis*, *Bacillus megaterium* and *Enterobacter aerogenes* is warranted to find out the synergistic effect of halophilic phosphobacteria on mangrove and coastal rice crop seedlings.

**Table 25. Number of positive growth parameters in phosphobacterial inoculated seedlings**

<table>
<thead>
<tr>
<th>Bacterial species</th>
<th><em>Rhizophora mucronata</em></th>
<th><em>Avicennia officinalis</em></th>
<th><em>Ceriops decandra</em></th>
<th><em>Oryza sativa</em></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><em>Arthrobacter ilicis</em></td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><em>Micrococcus roseus</em></td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><em>Enterobacter aerogenes</em></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td><em>Micrococcus luteus</em></td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>