



Impact of seasonal variations on photosynthetic behavior of subtropical Krishna mangroves, East coast of India

K. Vijaya kumar¹, K. Babu^{2*}, N. Tirupathi Swamy³

¹Department of Botany, Government Degree College, Uppal, Hyderabad, Telangana – 500039, India

^{2*}Department of Botany and Microbiology, Acharya Nagarjuna University, Nagarjunanagar – 522510, Guntur, Andhra Pradesh, India. *drbabu.botany@gmail.com

³Department of Botany, T.R.R. Government Degree College, Kandukur, Andhra Pradesh-523105, India

Abstract

Gilakaladindi and Malakayalanka are two mangrove growing estuaries of Krishna District located at latitudes 16° 8'56.1624'', 15°58'34.5354 and longitudes 81°9'46.029'', 81°5'53.3616'' respectively. Photosynthetic performance in terms of photosynthetic rate ($\mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂ fixed), stomatal conductance ($\text{m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$), transpiration ($\text{mmol m}^{-2}\text{s}^{-1}$), internal CO₂ concentration ($\mu\text{mol mol}^{-1}$) and water use efficiency was recorded at 1600 Quanta ($\mu\text{mol quanta m}^{-2}\text{s}^{-1}$) on eight mangroves such as *Lumnitzera racemosa*, *Ceriopsis tagil*, *Avicennia marina*, *Rhizophora apiculata*, *Avicennia officinalis*, *Bruguiera cylindrica*, *Xylocarpus granatum* and *Exocaria agallocha* growing at Gilakaladindi and Malakayalanka sites was investigated during mid-summer with a mean temperature of around 38 ± 1 . The pH and electrical conductivity values at Gilakaladindi and Malakayalanka estuaries were reported as 8.1, 8.3 and 14.98, 15.44 respectively. At these high pH and Electrical conductivity conditions, mangroves growing at Gilakaladindi such as *Avicennia marina* and *Rhizophora apiculata* showed highest photosynthetic rate ($8.63 \mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂, $7.85 \mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂) along with high stomatal conductance ($0.13 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $0.11 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$), transpiration rate ($2.98 \text{ mmol m}^{-2}\text{s}^{-1}$, $2.46 \text{ mmol m}^{-2}\text{s}^{-1}$), internal CO₂ concentration ($249.92 \mu\text{mol mol}^{-1}$, $258.86 \mu\text{mol mol}^{-1}$ and $235.97 \mu\text{mol mol}^{-1}$, $231.21 \mu\text{mol mol}^{-1}$) and water use efficiency ($2.89 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$, $2.88 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$ and $3.19 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$, $2.83 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$). Mangrove species *Xylocarpus granatum*, *Rhizophora apiculata* and *Ceriopsis tagil* even though showing high water use efficiency ($3.23 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$, $3.19 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$ and $3.08 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$) but unable to perform more photosynthetic rate and this is may be due to low stomatal conductance ($0.08 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $0.11 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and $0.08 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$) and high transpiration (2.08, 2.46 and 1.99) respectively. In mangroves growing at Malakayalanka i.e. and *Rhizophora apiculata* reported high photosynthetic rate ($8.31 \mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂), stomatal conductance ($0.13 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$) and transpiration rate ($3.00 \text{ mmol m}^{-2}\text{s}^{-1}$) coupled with high internal CO₂ concentration ($235.97 \mu\text{mol mol}^{-1}$) in turn results in high water use efficiency ($2.88 \mu\text{mol quanta m}^{-2}\text{s}^{-1}$). In both of these ecosystems the minimum photosynthetic performance was observed in *Lumnitzera racemosa* and *Bruguiera cylindrica* with a photosynthetic rate of $3.53 \mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂, $3.53 \mu\text{moles m}^{-2}\text{s}^{-1}$ CO₂, stomatal conductance $0.03 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $0.03 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and transpiration rate 1.13, 1.08 respectively. The decrease in photosynthetic performance of these species may be because of reduced internal CO₂ concentration in Gilakaladindi ($204.61 \mu\text{mol mol}^{-1}$, $206.10 \mu\text{mol mol}^{-1}$) and Malakayalanka ($199.07 \mu\text{mol mol}^{-1}$, $173.82 \mu\text{mol mol}^{-1}$) coupled with low stomatal conductance ($0.05 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $0.06 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and $0.03 \text{ m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$).

Keywords: Mangrove, Seasonal, Estuary, Krishna and Photosynthesis.

Introduction

Krishna mangrove wetland is located in the Krishna delta between 15°42' – 15°55' N and 80°42' – 81°01' E in Krishna and Guntur districts of Andhra Pradesh, India. Geo-morphologically Krishna delta comprises bays, tidal creeks extensive tidal mudflats, spits and sand bars (SAC, 2012). The total area of the drainage basin of river Krishna is about $2.6 \times 105 \text{ km}^2$. The mangrove wet land of Krishna delta receives fresh water for about six months of the year. Reduction in the quantity and periodicity of fresh water flowing into mangrove wetlands affects the density as well as diversity of the mangroves through increasing water and soil salinity (SAC, 2012). The salinity level in the Krishna river is 15% more than that in the Godavari river (Sarin *et al.*, 1985). The maximum high water level during the high tide is 1.10 m and the minimum high water level in high tide is 0.20 m.

The Krishna deltaic region is in subtropical humid climate with hot summers and moderate winters, which get annual rainfall due to south west monsoon. In a subtropical mangrove region there could be a seasonal decrease in net primary productivity (Saenger, 2002) and growth (Raven *et al.*, 1992). On the other side the seasonal distribution of abiotic and biotic processes affect the nutrient cycle of different coastal environments (Chowdary and Panigrahy, 1991).

In subtropical mangrove forests where fresh water availability is seasonal, precipitation patterns could affect the physiological development of mangrove trees resulting in an increase or decrease of ground salinity (Field, 1995). Studies showed that salt stress by itself has little effect on the PSII photochemical efficiency and on photosynthetic pigment content under low light levels. But at higher light PSII can be damaged along with alterations in photosynthetic pigment composition (Mishra *et al.*, 1991; Tuffers *et al.*, 2001; Naidoo *et al.*, 2002). Responses of mangroves to salinity

reflect alterations in photosynthesis, photosynthetic pigment content, transpiration rate and functioning of photosynthetic apparatus (ZHU, 2001). In mangroves the concentration of leaf pigments can be associated with environmental factors such as ambient temperature/sunlight (Saenger, 2002) water availability (Lacerda, 2002) and salinity (Steinke *et al.*, 1993). Of the various leaf pigments, chlorophyll a (Chl a) is a key compound involved in photosynthesis. Changes in *Chl a* can indicate plants growth (Raven *et al.*, 1992) or disturbances from stressors (Black Burn, 2007).

Avicennia corniculatum and *Brugiera gymnorhiza* showed a decrease in the photosynthesis where as *Avicennia marina* was not affected by salinity (Takemura *et al.*, 2000). Each species of mangroves has a particular range of tolerance to environmental factors (Raven *et al.*, 1992 and Ciganda *et al.*, 2009). These differences among the species and between seasons could be assessed by photosynthetic attributes such as photosynthetic rate (A), stomatal conductance (Gs), transpiration rate (T), internal CO₂ concentration (Ci), chlorophyll content. Even by measuring the leaf temperature we can assess the seasonal variation effects on photosynthesis and its constituents (Salisbury and Ross, 1995).

Mangroves are rich source of medicinally important phytochemicals (Bandaranayake, 1998; Banerjee *et al.*, 2008; Roome *et al.*, 2011 and Gurudeeban *et al.*, 2012) on the contrary changes in geomorphology and topography of the area, water quality, reduction in the river water flow in to the mangrove ecosystem contribute the degradation of mangroves (Ramasubramanian and Ravishankar, 2004). As natural and anthropogenic disturbances are very common at Krishna estuary (Ramana Murthy *et al.*, 2009, 2011), accurate assessments about mangroves for future conservation measures is necessary. The information about physiological behavior of mangroves at Krishna estuary is scarce and present documentary evidences majorly confined to dry and rainy seasons. Understanding of physiological behavior of mangroves in consecutive seasons may contribute to a better understanding how environmental conditions govern photosynthetic capacity and thus, for better estimating mangrove productivity and also helps in conservation of their population (Okimoto *et al.*, 2008).

Thus the objective of the present study was to evaluate the impact of seasonal changes on various photosynthetic attributes of selected mangroves at two sites i.e, Gilakaladindi and Malakayalanka estuaries during three different seasons.

Materials and Methods

The study was conducted at Gilakaladindi and Malakayalanka, which are two mangrove growing estuaries of Krishna district, Andhra Pradesh, India located at latitudes 16°85', 15°58' and longitudes 81°95', 81°55' respectively. Six mangrove species growing at both sites under field conditions such as *Avicennia marina*, *Rhizophora apiculata*, *Brugiera cylindrica*, *Lumnitza racemosa*, *Ceriopsis tagal* and *Exocaria agallocha* belonging to four families were studied. Differences of physiological characteristics between species at two sites and in between seasons were recorded. Data was collected during 2017-2018 in summer (March to May) rainy (July to September) coinciding with South west monsoons and in winter season (October to February). The distance between the sites was about 25 kms. Field data like temperature, salinity and pH were collected during morning to noon. Water Salinity was estimated with the help of hand refractometer and pH was measured using Elico pH meter (model L.C-120). Soil salinity and pH were estimated, using air dried soil samples collected near each plant. Data were collected for five plants of each species growing in different locations in both the sites. Soils were air-dried, crushed with a wooden mallet, passed through a 2-mm sieve and will be analyzed for inorganic ions using the procedures described by Hunter (1975) and Farina (1981). Saturation extracts of soils were analyzed for electrical conductivity using an electrical conductivity meter. Soil pH was determined on air-dried samples using a 1:2.5 soil to 1 M KCl ratio (Hunter, 1975). Exchangeable Na⁺ was extracted with 1 M ammonium acetate, Ca²⁺ and Mg²⁺ by 1 M KCl, and K⁺, P, Zn²⁺, Cu²⁺ and Mg²⁺ by the Ambic-2 extracting solution (Hunter, 1975).

Chlorophyll and carotenoid contents were determined according to Hiscox and Israelstam (1979) by using Dimethyl sulfoxide (DMSO) method. Chlorophyll a (*Chl a*), chlorophyll b (*Chl b*), total chlorophyll, chlorophyll a/b ratio and carotenoids (*Car*) were calculated using the following equations

$$\text{Chlorophyll a} = (12.7 \times \text{O.D at 663 nm}) - 2.69 \times \text{O.D at 645 nm} \times \frac{V}{10} \times W$$

$$\text{Chlorophyll b} = (22.9 \times \text{O.D at 645 nm}) - (4.68 \times \text{O.D at 663 nm}) \times \frac{V}{10} \times W$$

$$\text{Total chlorophyll} = (20.2 \times \text{O.D at 645 nm} + 8.02 \times \text{O.D at 663 nm}) \times \frac{V}{10} \times W$$

$$\text{Car} = \{ (A_{480} + 0.114 \times A_{663} - 0.638 \times A_{645}) \times V / 112.5 \times \text{leaf fresh weight} \}$$

Chlorophyll stability index was determined by the method of Sairam (1994). The absorbance was recorded at 645 and 663 nm using UV-VIS Spectrophotometer (Elico SL 159). The rate of chlorophyll stability was calculated using the

following formula.

$$\text{CSI} = \frac{\text{Chlorophyll reading with heat treatment}}{\text{Chlorophyll reading without heat treatment}} \times 100$$

Photosynthetic performance in terms of photosynthetic rate ($\mu\text{mol m}^{-2}\text{s}^{-1}$ CO_2 fixed), stomatal conductance ($\text{m mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$), transpiration ($\text{mmol m}^{-2}\text{s}^{-1}$) and internal CO_2 concentration ($\mu\text{mol mol}^{-1}$) were recorded at 1600 Quanta ($\mu\text{mol quanta m}^{-2}\text{s}^{-1}$). Measurements were taken using a portable, infrared gas analyzer (LC-PRO, U.K) under ambient conditions. All measurements were taken on mature, north-facing, fully exposed, sun leaves. On each sampling day measurements were taken on same trees which were tagged earlier.

Stomatal frequency per mm^2 were estimated from epidermal peelings using motic image plus 2.0 software.

$$\text{Stomatal frequency} = \frac{\text{Total number of stomata}}{\text{Microscopic field area}}$$

Results and Discussion

The effects of salinity on photosynthetic potentiality and chlorophyll pigments of mangrove species under field conditions are contradictory. Since these plants are habituated to highly fluid seasonal conditions (Moorthy and Kathiresan, 1997). Thus, results obtained in a specific mangrove are cannot be extrapolated to mangroves situated in other regions.

In present study the rate of photosynthesis was varied significantly in all the seasons at both stations Gilakaladindi and Malakayalanka. The photosynthetic values were ranged from $4.00 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $8.90 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ (summer), $6.00 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $10.70 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ (rainy) and from $3.37 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $7.00 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ (winter) at Gilakaladindi (Figure 1). At Malakayalanka Pr was ranged from $3.65 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $8.70 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $5.00 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $9.20 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and $3.60 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ to $7.40 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ during summer, rainy and winter seasons (Figure 1). In both the stations optimum photosynthetic rate (Pr) was recorded with *R. apiculata* in all the seasons i.e. $8.90 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $10.70 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and $7.00 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ in Gilakaladindi and $8.70 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$, $9.20 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ and $7.40 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ in Malakayalanka estuary during summer, rainy and winter seasons respectively. Among all the seasons maximum photosynthetic rate (Pr) was recorded in rainy season both at Gilakaladindi and Malakayalanka regions (Figure 1). This increased Pr during monsoon may be due to greater influx of fresh water and sea water dilution because of periodic floods (De-Souza *et al.*, 1981, Sai Sastry and Chandra Mohan, 1990). The increased fresh water and decreased salt content may in turn trigger the photosynthetic enzymes like Rubisco (Galmes *et al.*, 2013). This increased Pr may also be due to increased chlorophyll production in all the studied mangrove plants especially in *R. apiculata* 1.49 mg/g and 0.71 mg/g in rainy season at Gilakaladindi and Malakayalanka research stations. The Pr values were comparatively more in mangrove species of Gilakaladindi rather than Malakayalanka in all the seasons. This is due to the lower soil and aquatic salts in Gilakaladindi station (Table 1 and Table 2). The experimental evidences of Parida *et al.* (2004) also suggest that in *B. parviflora*, NaCl has limiting effect on photochemistry which ultimately affects photosynthesis by inhibiting chlorophyll synthesis.

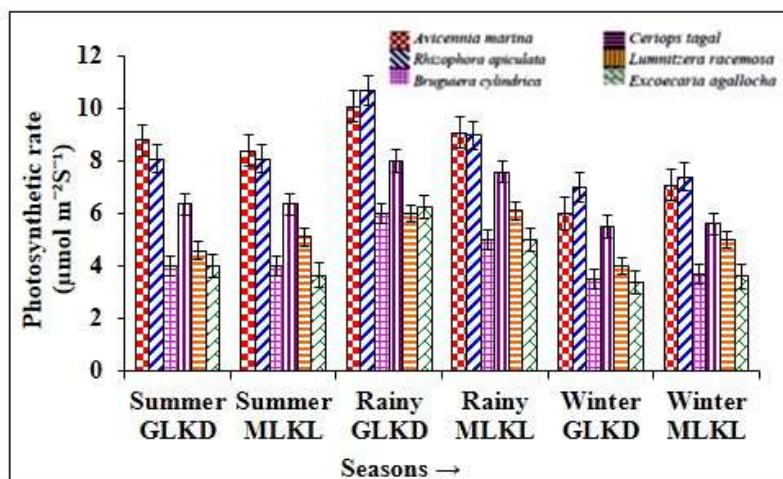


Figure 1. Rate of photosynthesis in various seasons

Stomatal conductance was also found to be varied significantly in all the studied plants (Figure 2) and it was ranged from $0.03 \text{ mol m}^{-2}\text{s}^{-1}$ to $0.12 \text{ mol m}^{-2}\text{s}^{-1}$, $0.08 \text{ mol m}^{-2}\text{s}^{-1}$ to $0.15 \text{ mol m}^{-2}\text{s}^{-1}$ and 0.04 to 0.12 in summer, rainy and winter seasons at Gilakaladindi field station 0.04 to 0.14 , $0.08 \text{ mol m}^{-2}\text{s}^{-1}$ to $0.17 \text{ mol m}^{-2}\text{s}^{-1}$ and $0.04 \text{ mol m}^{-2}\text{s}^{-1}$ to $0.12 \text{ mol m}^{-2}\text{s}^{-1}$ during summer, rainy and winter seasons at Malakayalanka field station. In both the field stations maximum stomatal conductance was observed at Malakayalanka field station in rainy season. Among the entire plants *R. apiculata* recorded high stomatal conductance $0.15 \text{ mol m}^{-2}\text{s}^{-1}$ in rainy season where as stomatal conductance was found to be more in *A. marina* ($0.17 \text{ mol m}^{-2}\text{s}^{-1}$) at Malakayalanka field station. But these results are not correlated

with the results of stomatal frequency and index of the present study where *Exocaria agallocha* showed maximum stomatal density (S: 45.35 mol m⁻²s⁻¹; R: 49.88 mol m⁻²s⁻¹ and W: 46.95 mol m⁻²s⁻¹) index followed by *A. marina* and *B. cylindrica*. Flexas *et al.* (2004) and Galmes *et al.* (2013) stated that salt stress increases the leaf resistance to CO₂ transport and metabolic impairment also happened at intense salinity conditions. In spite of having more salinity conditions plants such as *R. apiculata* (S: 0.12 mol m⁻²s⁻¹, R: 0.15 mol m⁻²s⁻¹, W: 0.11 mol m⁻²s⁻¹ and S: 0.12 mol m⁻²s⁻¹, R: 0.14 mol m⁻²s⁻¹, W: 0.11 mol m⁻²s⁻¹) and *A. marina* (S: 0.12 mol m⁻²s⁻¹, R: 0.14 mol m⁻²s⁻¹, W: 0.12 mol m⁻²s⁻¹ and S: 0.14 mol m⁻²s⁻¹, R: 0.17 mol m⁻²s⁻¹, W: 0.12 mol m⁻²s⁻¹) found to have more Gs in both Gilakaladindi and Malakayalanka estuaries respectively. This increased ability of *R. apiculata* and *A. marina* is may be due to their better adaptation to salt stress in terms of the capacity of their cells to compartmentalize the ions in the vacuole i.e. maintain low Na⁺ content in the cytoplasm and later excluding of Na⁺ ions from leaf cell cytoplasm (Alberico and Cramer, 1993; Neto *et al.*, 2004). It is also opined that a high saline condition prevails at the natural mangrove habitat, and to cope with the physiologically dry soil, the mangrove leaf reduces the transpiration rate by restricting stomatal conductance (Nandy and Ghose, 2001). Simultaneously photosynthesis is markedly lower in mangroves, as reduced stomatal conductance is unfavourable for CO₂ influx in to the leaf cells (Cheeseman *et al.*, 1991). The present results are in agreement with Parida *et al.* (2010) in *A. marina*; Ball and Farquhar (1984) in *Aegiceras corniculatum* and *Avicennia marina*.

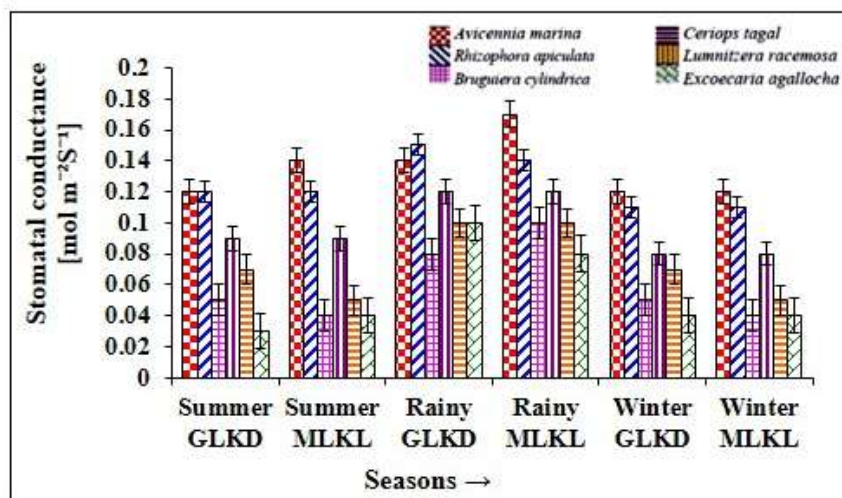


Figure 2. Fate of stomatal conductance in various seasons

All plants showed maximum transpiration during rainy season in both the field stations (Figure 3). The rate of transpiration was ranged from 1.35 mmol m⁻²s⁻¹ to 3.26 mmol m⁻²s⁻¹, 1.80 mmol m⁻²s⁻¹ to 3.76 mmol m⁻²s⁻¹ and 1.89 mmol m⁻²s⁻¹ to 3.37 mmol m⁻²s⁻¹ in summer, rainy and winter seasons at Gilakaladindi field station 1.09 mmol m⁻²s⁻¹ to 3.10 mmol m⁻²s⁻¹, 1.20 mmol m⁻²s⁻¹ to 3.70 mmol m⁻²s⁻¹ and 1.00 mmol m⁻²s⁻¹ to 3.00 mmol m⁻²s⁻¹ during summer, rainy and winter seasons at Malakayalanka field station. The transpiration data of the studied plants suggest that *R. apiculata* (S: 3.26 mmol m⁻²s⁻¹, R: 3.76 mmol m⁻²s⁻¹, W: 3.37 mmol m⁻²s⁻¹ and S: 3.10 mmol m⁻²s⁻¹, R: 3.70 mmol m⁻²s⁻¹, W: 3.00 mmol m⁻²s⁻¹) and *A. marina* (S: 3.19 mmol m⁻²s⁻¹, R: 3.70 mmol m⁻²s⁻¹, W: 3.00 mmol m⁻²s⁻¹ and S: 2.40 mmol m⁻²s⁻¹, R: 3.70 mmol m⁻²s⁻¹, W: 3.00 mmol m⁻²s⁻¹) are better adapted to the salt stress than other plants. This is because of their efficiency in maintaining root hydraulic conductivity during all the seasons (O Leary, 1969; Prisco, 1980 and Neto *et al.*, 2004). But the transpiration rate is tend to be decreased during summer and winter by lowering the root hydraulic conductivity and lowering of water flow from roots to leaves coupled with stomatal closure in order to balance their water status (Prisco, 1980; Robinson *et al.*, 1997 and Neto *et al.*, 2004). On the other side decreased stomatal conductance during summer and winter result in the decreased transpiration and lowered photosynthetic rate (Razzaghi *et al.*, 2011) which in turn lowers the plant development (Kusvuran, 2012). But by maintaining their Gs and transpiration *R. apiculata* and *A. marina* can be able to perform good *Pr* during hard seasons which further useful to have better growth. Similar trend of results were observed in *Bruguiera gymnorrhiza*, *Excoecaria agallocha* and *Xylocarpus granatum* (Nandy *et al.*, 2007); Ball and Farquhar (1984) in *Aegiceras corniculatum* and *Avicennia marina* and Clough and Sim (1989) and Nandy *et al.* (2005) in *Ceriops tagal* and *A. marina*.

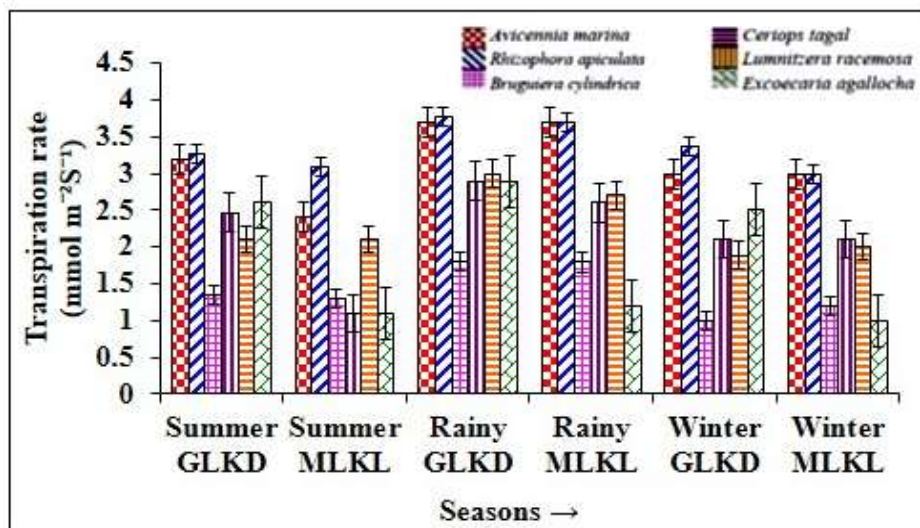


Figure 3. Effect of seasonal variation on rate of transpiration

Chlorophyll content found to be decreased with increased salt concentrations during summer and winter seasons (Figure 4). Total chlorophyll content was ranged from 0.25 mg/g to 1.49 mg/g, 0.71 mg/g to 2.51 mg/g and 0.46 mg/g to 1.20 mg/g in summer, rainy and winter seasons at Gilakaladindi field station, 0.38 mg/g to 0.71 mg/g, 0.90 mg/g to 1.55 mg/g and 0.64 mg/g to 0.91 mg/g during summer, rainy and winter seasons at Malakayalanka field station during all the seasons. This reduction in total chlorophyll content is due to limited CO_2 transport because of ion accumulation and functional disorders found during opening and closing of stomata under increased salt stress in midsummer and winter (Benisan *et al.*, 2009; Molazem *et al.*, 2010; Nawaz *et al.*, 2010 and Acka and Samsunlu, 2012). The decreased chlorophyll content in summer and winter seasons may attributed to the destruction of chlorophyll pigments and stability of the pigment protein complex (Jaleel *et al.*, 2008). But in case of *R. apiculata* and *A. marina* total chlorophyll was observed to be more even in summer and winter seasons (Figure 4). This may be due to effective mechanism of their chloroplast cells to prevent the Mg^{+2} ions replacement with Na^{+} ions results in continuous synthesis of chlorophyll assumed (Katsuhara *et al.*, 1990, Demiroglu *et al.*, 2001 and Acka and Samsunlu, 2012). Decreased chlorophyll content under salinity stress was also reported in *Bruguiera cylindrica*, *Avicennia rumphiana* and *A. marina* (Cram *et al.*, 2002) and *A. marina* and *E. Agallocha* (Nandy *et al.*, 2007).

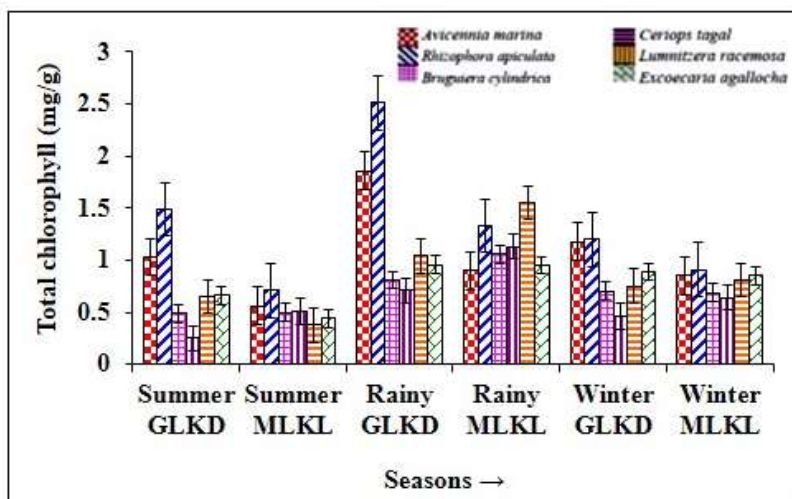


Figure 4. Difference in chlorophyll content in varied seasons

Among all the plants chlorophyll a content found to be high over chlorophyll b and this quantity was found to be reduced in summer and winter seasons (Figure 5 and Figure 6). Reduction in chl b may be attributed to the adaptive capacity of plants, which in turn resulted in decreased photosynthetic rate (Pr) in order to overcome the oxidative stress (Koyro, 2006 and Eisa *et al.*, 2012). But *R. apiculata* and *A. marina* regulated their *chl a* and *chl b* quantities by preventing their membrane deterioration (Ashraf and Bhatia, 2000, Dhanapackiyam and Hyes, 2010). This statement is in support with high CSI content in *R. apiculata* (S: 80.21, R: 91.63, W: 72.10 and S: 80.78, R: 88.98, W: 70.02) and *A. marina* (S: 78.25, R: 83.10, W: 70.21 and S: 80.78, R: 85.32, W: 65.81) (Figure 7) even in hard summer and winter seasons. On the other side the quantity of carotenoids also found to be decreased with increased salt content during summer (Gilakaladindi: 0.17 mg/g to 0.46 mg/g; Malakayalanka: 0.20 mg/g to 0.42 mg/g) and winter (Gilakaladindi: 0.31 mg/g to 0.75 mg/g; Malakayalanka: 0.29 mg/g to 0.45 mg/g) seasons in all the plants but the decline is quite less in *R. apiculata* and *A. marina* (Figure 8). Decrease in carotenoid content is due to degradation of β carotene of integral

constituents of thylakoid membranes. This condition directly effects the absorption and transfer of light to chlorophyll there by decreased photosynthetic rate (Sharma e Hall, 1991) and increased photo oxidation of chlorophyll pigments (Lima *et al.*, 2004, Taiz and Zeiger, 2009; Gomes *et al.*, 2011). These results are coinciding with the decreased chlorophyll content and photosynthetic rate in present study. Similar type of observations were made by Upadhyaya and Panda (2005); Gomes *et al.* (2011).

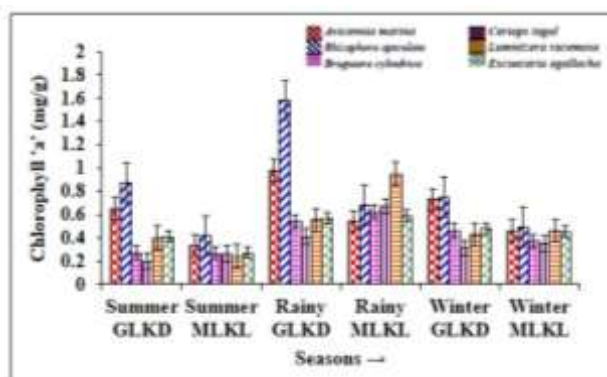


Figure 5. Chlorophyll 'a' various seasons

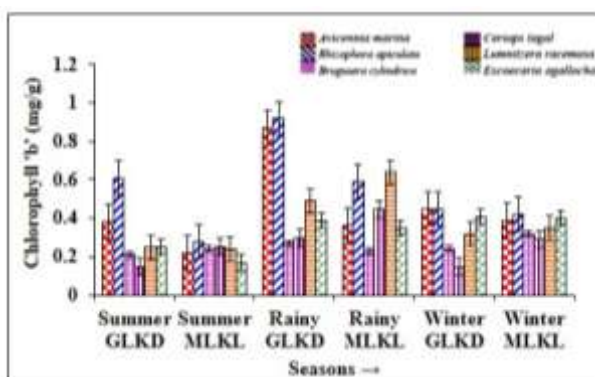


Figure 6. Chlorophyll 'b' in various seasons

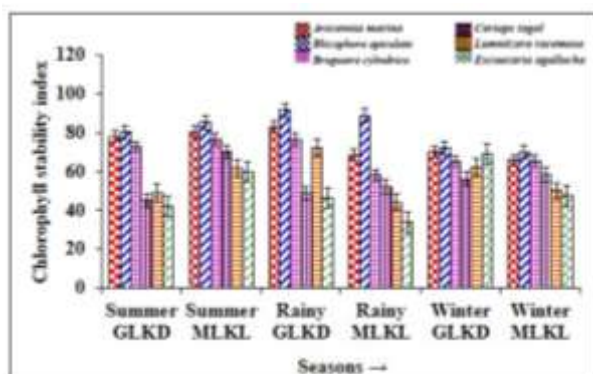


Figure 7. CSI in various seasons

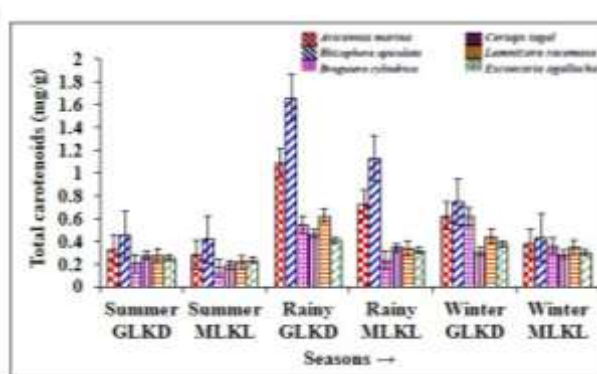


Figure 8. Total carotenoids in various seasons

Stomatal frequency was also varied significantly in present study and it was ranged from 31.74 to 45.35, 37.21 to 49.88 and 32.11 mg/g to 46.95 mg/g in summer, rainy and winter seasons at Gilakaladindi field station, 31.98 to 46.12, 36.28 to 49.99 and 34.56 to 47.00 mg/g during summer, rainy and winter seasons at Malakayalanka field station during all the seasons (Figure 9). *Zho et al.* (2001) and *Zhang et al.* (2003) reported that stomatal number was decreased with increased salt stress. *A. marina*, *A. officinalis*, *B. gymnorhiza*, *B. parviflora* also shows a trend of decline in stomatal frequency with increased salinity (Nandy *et al.*, 2005). The reduction in leaf stomatal density may be due to the interrupted growth of leaf and plants under high salt stress (Ceulemans *et al.*, 1995) in mid summer and winter in present study.

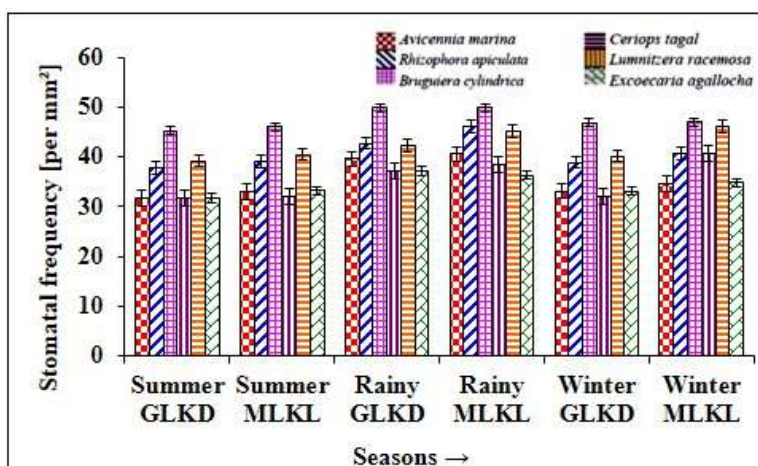


Figure 9. Stomatal frequency in various seasons

Soil and Water analysis

In mangrove ecosystem nutrients are considered as the most important factors that influence growth and development of the plants (Arumugam and Kumar, 2014). The distribution of nutrients is mainly based on season, tidal conditions and fresh water influx from land to sea (Sarvanakumar *et al.*, 2008; Arumugam and Kumar, 2014).

There is no much difference observed between the soil samples of all the seasons (Table 1 and Table 2). As compared with Malakayalanka the soil samples of Gilakaladindi contained less nitrogen (S:81 kg/a; R:81 kg/a and W:80 kg/a), more phosphorus (S:1.99 kg/a; R:1.99 kg/a and W:1.98 kg/a), zinc (S:1.015 ppm; R:1.019 ppm and W:1.015 ppm), iron (S:13.79 ppm; R:13.77 ppm and W:13.78 ppm) and copper (S:6.70 ppm; R:6.54 ppm and W:6.65 ppm).

The maximum phosphate value was recorded during monsoon season and it might be due to intrusion of upwelling seawater during monsoon which increased the level of phosphate (Nair *et al.*, 1984). According to Chandran and Ramamoorthy (1984) the turbulence of water column during monsoon would have released phosphorus from bottom mud into the water. High concentrations of phosphate during the monsoon season were reported earlier by Sankaranarayanan and Qasim (1969) Mishra *et al.*, (1993).

The nitrite and nitrate content in the mangroves were highly variable. The minimum nitrite values were recorded during premonsoon. This reduction in nitrite may be due to consumption by phytoplankton (Saisastry and Chandramohan 1990; Prema, 2000). Higher values of nitrite were observed during rainy season and it may be due to drainage of fresh water containing nitrite ions from catchment area (Das *et al.*, 1997) and weathering of rocks (Gowda *et al.*, 2001).

Table 1. Soil analysis at two field stations

Content	Gilakaladindi			Malakayalanka		
	Summer	Rainy	Winter	Summer	Rainy	Winter
pH	8.0	8.5	8.1	8.0	8.2	8.1
EC	5.75	2.27	4.01	7.58	5.01	6.56
N (Kg/a)	81	81	80	84	84	82
P (Kg/a)	1.99	2.29	1.98	1.87	2.16	1.88
K (kg/a)	247	248	248	244	246	246
Zn (ppm)	0.619	0.806	4.140	1.056	1.289	1.176
Fe (ppm)	13.79	13.71	13.78	6.807	9.594	8.646
Mn (ppm)	21.66	24.48	23.55	24.0	24.0	23.50
Cu (ppm)	6.70	6.54	6.65	2.288	3.808	2.028
S (ppm)	67	71	65	67	68	67

The nitrogen (S:84 kg/a; R:84 kg/a and W:82 kg/a), manganese (S:24.0 ppm; R:24.0 ppm and W:23.50 ppm) and sulphur (S:67 ppm; R:68 ppm and W:67 ppm) were found to be more in Malakayalanka in all the seasons. The availability of all these components were slightly increased during rainy season and were decreased during winter season when compared with summer season. This increased availability of these components may tend to the record of high chlorophyll pigments and increased photosynthetic attributes (Rao and Rao, 2014). Water samples did not showed much variation in all the seasons. The pH value was increased during rainy season compared to summer and winter seasons. In general variations in pH values during different seasons of the year is attributed to factors like removal of CO₂ in photosynthesis, through bicarbonate degradation, dilution of seawater by freshwater influx, reduction of salinity, temperature and decomposition of organic matter (Rajasegar 2003; Saravanakumar *et al.*, 2008 and Arumugam and Kumar, 2014). This study is in agreement with previous studies (Rajendran and Kathiresan, 1990; Soundarapandian 2009 and Srilatha *et al.*, 2012). In case of Electrical conductivity much difference was not observed in all the seasons at both research stations. In Gilakaladindi EC was increased 1 m.mmhos/cm during rainy season. Electrical conductivity is an important parameter to evaluate the water quality. Any change in the concentration of chlorides and sulphates may influence the changes in the conductivity. The change in concentration of chlorides and sulphates may be due to pollution by inorganic or organic wastes containing excessive amount of dissolved solids in water (Thomas *et al.*, 2001 and Arumugam and Kumar, 2014). Among all the components the concentration of CO₃ was increased slightly (5.7 m.e.q/Lts) during winter season in Malakayalanka region. The availability of chlorides, sulphates, sodium, potassium were slightly decreased during rainy seasons both in Gilakaladindi and Malakayalanka regions due to high influx of fresh water during heavy rain falls in peak monsoons. This decreased salt concentration may be the reason for the enhanced chlorophyll and photosynthetic rate in present study. On the other hand increased salinity during summer and winter periods influence leaf ion accumulation, thereby membrane stability and synthesis of chlorophyll (Nandy *et al.*, 2007). Generally increased accumulation of Na⁺ is coupled with reduced Mg⁺⁺ and Ca⁺⁺ uptake (Greenway and Munns 1980; Delphine *et al.*, 1998) and sometimes with reduction in carbon assimilation (Parida *et al.*, 2004). Potassium plays a prominent role in osmoregulatory mechanism and protein synthesis, maintaining cell turgour and stimulating photosynthesis (Peoples and Koch 1979). Salt induced reduction in K⁺ content may cause damage to the chloroplasts (Chow *et al.*, 1990). In present study *Rhizophora apiculata* and *Avicinea marina* found to be better adapted to the fluid saline conditions in both the stations and it should be due to the above discussed characteristic features of the plants along with having better salt filtering out at root level (> 90%) in *R. apiculata* (Hemant Karkhanis, 2016) and presence of salt glands in *A. marina* (Parida *et al.*, 2010).

Table 2. Water analysis at two field stations

Content	Gilakaladindi			Malakayalanka		
	Summer	Rainy	Winter	Summer	Rainy	Winter
pH	8.0	8.0	8.0	7.9	8.0	8.2
EC (m.mhos/cm)	12.00	7.18	10.10	14.15	10.80	12.17
CO ₃ (m.e.q/Lts)	5.7	5.5	5.5	5.6	5.6	5.7
HCO ₃ (m.e.q/Lts)	-1.61	-1.61	-1.60	-1.52	-1.50	-1.49
Cl (m.e.q./Lts)	462	456	459	468	460	462
Na+K (m.e.q/Lts)	65	60	62	68	65	66
Ca+Mg (m.e.q/Lts)	135	137	134	136	136	135

Conclusion

In conclusion the present findings and reasoning allow for the hypothesis that *R. Apiculata* and *A. marina* are highly salt tolerant species in terms of photosynthetic rate, as they survive even at fluid saline conditions in different seasons. Salt tolerance in these species is largely conferred by a delicate balance among osmotic adjustment and ion accumulation. Neither osmotic stress nor ion deficiency appears to be determinant for *R. Apiculata* and *A. marina* under high saline conditions during mid summer and winter seasons. In the end we can say that salinity fluctuations during varying seasons tend the plants to have better adapted mechanisms and rainy season was found to be good for better growth and development of mangroves. Moreover by understanding their physiology it will be possible to enhance density of mangroves better further.

References

- Alberico, G. J. and Cramer, G. R. (1993). Is the salt tolerance of maize related to sodium exclusion I. Preliminary screening of seven cultivars, J. Plant Nutr. 16, 2289-2303.
- Arumugam A, Sugirtha P. Kumar. Evaluation of physico-chemical parameters and nutrients in the mangrove ecosystem of Manakudy estuary, southwest coast of India. International Journal of Latest Research in Science and Technology Volume 3, Issue 6: Page No.205-209, November-December 2014.
- Ashraf, MY and Bhatti AS (2000) Effect of salinity on growth and chlorophyll content of Rice. Pak. J. Sci. Ind. Res. 43(2), 130-131.
- Azevedo Neto A, Prisco JT, Filho JE, Lacerda CF, Silva JV, Costa PH, Filho EG (2004). Effects of salt stress on plant growth, stomatal response and solute accumulation of different maize genotypes. Braz. J. Plant Physiol., 16(1): 31-38.
- Ball MC, Farquhar MC (1984) Photosynthetic and stomatal responses of two mangrove species, *Aegiceras corniculatum* and *Avicennia marina*, to long term salinity and humidity conditions. Plant Physiol 74:7-11.
- Bandaranayake WM. Traditional and medicinal uses of mangroves. Mangroves and Salt Marshes. 1998;2:133-48.
- Banerjee D, Chakrabarti S, Hazra AK, Banerjee S, Ray J, Mukherjee B, Antioxidant activity and total phenolics of some mangroves in Sundarbans, Afr J Biotechnol, 2008, 7, 805-10.
- Beinsan C, Camen D, Sumalan R, Babau M (2009) Study concerning salt stress effect on leaf area dynamics and chlorophyll content in four bean local landraces from Banat area. In: Florijancic T, Luzaic R (eds) 44th Croatian and 4th international symposium on agriculture, 16-20 February, pp 416-419.
- Blackburn GA (2007) Hyperspectral remote sensing of plant pigments. J Exp Bot 58: 855-867.
- Ceulemans R, Praet LV, Jiang XN. 1995. Effects of CO₂ enrichment, leaf position and clone on stomatal index and epidermal cell density in poplar (*Populus*). New Phytologist 131, 99-107.
- Chandran, R. and K. Ramamoorthy: Hydrobiological studies in the gradient zone of the Vellar estuary- Nutrients. Mahasagar-Bull. Nat. Inst. Oceanogr., 17, 133-140 (1984).
- Cheeseman, J.M., Clough, B.F., Carter, D.R., Lovelock, C.E., Eong, O.J., Sein, R.G., 1991: The analysis of photosynthetic performance in leaves under field conditions: A case study using *Bruguiera* mangroves. Photosynth. Res. 29, 11-22.
- Cheruth Abdul Jaleel, Beemaroo Sankar, Ramalingam Sridharan, Rajaram Panneerselvam. Soil Salinity Alters Growth, Chlorophyll Content, and Secondary Metabolite Accumulation in *Catharanthus roseus*. Turk J Biol 32 (2008) 79-83.
- Choudhury, S.B. and R.C. Panigrahy: Seasonal distribution and behaviour of nutrients in the creek and coastal waters of Gopalpur, east coast of India. Mahasagar-Bull. Nat. Inst. Oceanogr., 24, 81-88 (1991).
- Chow WS, Ball MC, Anderson JM (1990) Growth and photosynthetic responses of spinach to salinity: implications of K⁺ nutrition for salt tolerance. Aust Journal Physiol 17:563-567.
- Ciganda V, Gitelson A, Schepers J (2009) Non-destructive determination of maize leaf and canopy chlorophyll content. J Plant Physiol 166: 157-167.
- Clough BF, Sim RG (1989) Changes in gas exchange characteristics and water use efficiency of mangroves in response to salinity and vapour pressure deficit. Oecologia 79: 38-44.
- Coastal Zones of India, Space Application Center (ISRO), Ahmedabad, India, 2012, 28-29.
- Das, J., S.N.Das and R.K.Sahoo., 1997. Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India. Indian J. Mar. Sci., 26: 323-326.
- De Souza, R. N., R. Sen Gupta., S. Sujatha and M. D. Raja Gopal. 1981. Studies on nutrients of Mandovi and Zuari river systems. Indian J. Mar. Sci. 10: 314-321.
- Delphine S, Alvino A, Zacchini M, Loreto F (1998) Consequence of salt stress on conductance to CO₂ diffusion,

- Rubisco characteristics of spinach leaves. *Aust Journal Plant Physiol* 25:395–402.
22. Demiroğlu, G., M.A. Khalvati and R. Avcioğlu. 2001. Effect of different salt concentrations on the resistance of maize cultivars (2) some physiological characteristics and ion accumulation in early growth; *Turkish Journal of Field Crops*, 6: 55-59.
 23. Farina MPW. 1981. The Hunter system of soil analysis. *Fertilizer Society of South Africa* 1: 39–41.
 24. Field C (1995) Impact of expected climate change on mangroves. *Hydrobiologia* 295: 75–81.
 25. Flexas J, Bota J, Loreto F, Cornic G, Sharkey TD (2004) Diffusive and metabolic limitations to photosynthesis under drought and salinity in C3 plants. *Plant Biol* 6:269–279.
 26. Gowda.G., TRC. Gupta, K.M.Rajesh, H.Gowda, C.Lingadhal and A.M.Ramesh., 2001. Seasonal distribution of phytoplankton in Nethravathi estuary, Mangalore. *J.Mar.Biol. Ass. India.*, 43: 31- 40.
 27. Greenway H, Munns R (1980) Mechanisms of salt tolerance in nonhalophytes. *Annu Rev Plant Physiol* 31:149–190.
 28. Gurudeeban S, Satyavani K, Ramanathan T, Balasubramanian T, Antibabetic effect of a black mangrove species *Aegiceras corniculatum* in alloxan induced diabetic rat, *J Adv Pharm Technol Res*, 2012, 3, 52-6.
 29. Hemant Karkhanis (2016). SoonabaiPirojsha Godrej Marine Ecology Centre, Mangrove Section, <http://www.mangroves.godrej.com/MangroveEcology.htm>
 30. Hiscox, J.D. and Israelstam, G.F. (1979). A method for extraction of chlorophyll from leaf tissue without maceration. *Can. J. Bot.*, 57: 1332-1334.
 31. Hunter A. 1975. New techniques and equipment for routine soil/plant analytical procedures. In: Borremiza E, Alvarado A, eds. *Soil management in tropical America*. Raleigh, NC: North Caroline State University.
 32. JeroniGalme's , Iker Aranjuelo, Hipo'lito Medrano, JaumeFlexas. (2013). Variation in Rubisco content and activity under variable climatic factors. *Photosynthetic Research*.
 33. Katsuhara, M., T. Mimura and M. Tazawa. 1990. ATP-Regulated ion channels in the plasma membrane of a characeae alga, nitellopsis obtuse. *Plant Physiol.*, 93: 343-346.
 34. Koyro HW (2006) Effect of salinity on growth, photosynthesis, water relations and solute composition of the potential cash crop halophyte *Plantago coronopus* (L.). *Environ Exp Bot* 56:136–146.
 35. Lacerda LD (2002) *Mangrove ecosystems: function and management*. Springer, Berlin.
 36. Lima, MGS., Lopes, NF., Bacarin, MA. and Mendes, CR. 2004. Efeito do estresse salino sobre a concentração de pigmentos e prolina em folhas de arroz. *Bragantia*, vol. 63, no. 3, p. 335-340.
 37. M.L. Gomes Soares, M.M. Pereira Tognell, E. Cuevas, and E. Medina. Photosynthetic capacity and intrinsic water-use efficiency of *Rhizophora mangle* at its southernmost western Atlantic range. *PHOTOSYNTHETICA* 53 (X): XXX-XXX, 2015.
 38. mangroves from Sundarbans, India. *J. Plant Biol.* 44, 213–219.
 39. Maria Angélica da Conceição Gomes1, Marina Satika Suzuki1, Maura da Cunha2, Cristiane Ferrante Tullii. Effect of salt stress on nutrient concentration, photosynthetic pigments, proline and foliar morphology of *Salvinia auriculata* Aubl. *Acta Limnologica Brasiliensia*, 2011, vol. 23, no. 2, p. 164-176.
 40. Mishra, S.K.; Subrahmanyam, D.; Singhal, G.S. Interactionship between salt and light stress on the primary process of photosynthesis. *Journal of Plant Physiology*, v. 138, p. 92-96, 1991.
 41. Mishra, S.K.; Subrahmanyam, D.; Singhal, G.S. Interactionship between salt and light stress on the primary process of photosynthesis. *Journal of Plant Physiology*, v. 138, p. 92-96, 1991.
 42. Mishra, Sugatha, D.Panda and R.C.Panigraphy, 1993. Physicochemical characteristics of Bahuda estuary (Orissa) east coast of India. *Ind. J.Mar. Sci.*, 22: 75-77.
 43. Mistra A, Patra KC, and Panigraphy RC, *Bull. Natl. Inst. Oceanogr*, 1990, 23 (1): 55-62.
 44. Molazem, D., E.M. Qurbanov and S.A. Duniyaliyev. 2010. Role of proline, Na and chlorophyll content in salt tolerance of corn (*Zea mays*) L. *American-Eurasian J. Agric. & Environ. Sci.*, 9: 319-324.
 45. Moorthy P and K. Kathiresan Photosynthetic Pigments in Tropical Mangroves: Impacts of Seasonal Flux of UV-B Radiation and Other Environmental Attributes. *Botanica Marina* Vol. 40, 1997, pp. 341 -349.
 46. Naidoo G, Tuffers AV, Willert DJ (2002) Changes in gas exchange and chlorophyll fluorescence characteristics of two mangroves and a mangrove associate in response to salinity in the natural environment. *Trees* 16:140–146.
 47. Nair, P.V.R., C.P. Gopinathan, V.K. Balachandran, K.J. Mathew, A. Regunathan, D.S. Rao and A.V.S. Murty: Ecology of mud banks: Phytoplankton productivity. I Alleppey mudbank. *Bull. Cent. Mar. Fish. Res. Inst.*, 31, 28-34 (1984).
 48. Nandy (Datta) P, Das S, Ghose M (2005) Relation of leaf micromorphology with photosynthesis and water efflux in some Indian mangroves. *Acta Botanica Croatica* 64 (2):331–340.
 49. Nandy(Datta), P., Ghosem., 2001: Photosynthesis and water-use efficiency of some
 50. Nawaz, K., A.I. Talat, K. Hussain and A. Majeed. 2010. Induction of salt tolerance in two cultivars of sorghum (*Sorghum bicolor* L.) by exogenous application of proline at seedling stage, *World Applied Sciences Journal* 10: 93-99.
 51. O'Leary JW (1969) The effect of salinity on the permeability of roots to water. *Israel J. Bot.* 18:1-9.
 52. Okimoto Y, Nose A, Ikeda K, Agarie S, Oshima K, Tateda Y, Ishii T, Nhan DD (2008) An estimation of CO2 fixation capacity in mangrove forest using two methods of CO2 gas exchange and growth curve analysis. *Wetlands Ecol Manag* 16:155–171.
 53. Paramita Nandy (Datta), Sauren Das, Monoranjan Ghose and Robert Spooner-Hart (2007). Effects of salinity on photosynthesis, leaf anatomy, ion accumulation and photosynthetic nitrogen use efficiency in five Indian mangroves *Wetlands Ecol Manage* (2007) 15:347–357.
 54. Parida AK, Das AB, Mitra B (2004) Effect of salt and growth, ion accumulation, photosynthesis and leaf anatomy of

- the mangrove, *Bruguieraparviflora*. *Trees* 18:167–174.
55. Parida AK, Jha B (2010). Salt tolerance mechanisms in mangroves: a review. *Trees - Structure and Function*, 24: 199–217.
 56. Parida, A.K.; Das, A.B.; Mittra, B. Effects of salt on growth, ion accumulation, photosynthesis and leaf anatomy of the mangrove, *Bruguieraparviflora*. *Trees* 2004, 18, 167–174.
 57. Peoples TR, Koch DW (1979) Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. *Plant Physiol* 63:878–881.
 58. Prisco JT (1980) Alguns aspectos da fisiologia do “stress” salino. *Rev. Bras. Bot.* 3:85–94.
 59. Rajasegar, M., 2003. Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *J. Environ. Biol.*, 24: 95–101.
 60. Rajendran N, and Kathiresan K, *Hydrobiologia*, 1999, 394: 193–200.
 61. Ramana Murty, M.V., Ravi Kumar, Ch., and Mruthyunjaya Reddy, K. (2009). Coastal Wetlands modifications using temporal satellite data in Krishna delta, Andhra Pradesh, India. In National Symposium on Advances in Geo-Spatial Technologies. 17–19 September, India, (Nagpur: Indian Society of Remote Sensing) 1–13.
 62. Ramana Murty, M.V., Ravi Kumar, Ch., and Mruthyunjaya Reddy, K. (2011). Marine protected area of Godavari river delta, Andhra Pradesh, India: A geospatial analysis. In National Seminar on DSERE, 12–13 March, India, (Rajahmundry: Adikavi Nannaya University).
 63. Ramasubramanian R and T. Ravishankar. (2004). Mangrove Forest Restoration in Andhra Pradesh, India. M. S. Swaminathan Research Foundation Chennai, India. 13–20.
 64. Raven PH, Evert RF, Eichhorn SE (1992) *Biology of plants*. W. H. Freeman & Company Press, New York, NY.
 65. Razzaghi F, Ahmadi SH, Adolf VI, Jesen CR, Jacobsen SE, Andersen MN (2011). Water relations and transpiration of quinoa (*Chenopodium quinoa* Willd.) under salinity and soil drying. *J. Agron. Crop Sci.*, 197 (5): 348–360.
 66. Roome T, Dar A, Naqvi A, Evaluation of antinociceptive effect of *Aegiceras corniculatum* stems extracts and its possible mechanism of action in rodents, *J Ethnopharmacol*, 2011, 135, 351–8, 2011.
 67. S. Dhanapackiam and M.H. Muhammad Ilyas. Effect of salinity on chlorophyll and carbohydrate contents of *Sesbania grandiflora* seedlings. *Indian Journal of Science and Technology*. Vol.3 No. 1 (Jan 2010). 64–66.
 68. S. Eisa I, S. Hussin, N. Geissler, H.W. Koyro. Effect of NaCl salinity on water relations, photosynthesis and chemical composition of Quinoa (*Chenopodium quinoa* Willd.) as a potential cash crop halophyte. *AJCS* 6(2):357–368 (2012).
 69. Saenger P (2002) *Mangrove ecology, silviculture and conservation*. Kluwer Academic Publishers, Dordrecht.
 70. Sairam, R.K. (1994). Effect of moisture stress on physiological activities of two contrasting wheat genotypes. *Indian J. Exp. Biol.*, 32: 594–597.
 71. Saisastry, A. G. R. and O. Chandramohan. 1990. Physicochemical characteristics of Bashista-Godavari estuary, east coast of India: Pre-Pollution status. *Indian. J. Mar. Sci.* 19: 42–46.
 72. Saisastry, A.G. and R. Chandramohan: Physico-chemical characteristics of Vasishta Godavari estuary, east coast of India: Pre pollution status. *Ind. J. Mar. Sci.*, 19, 42–46 (1990).
 73. Salisbury FB, Ross CW (1995) *Plant Physiology*. Wadsworth Publishing Co, Oxford, pp 179–228.
 74. Saravanakumar, A., M. Rajkumar, J. Sesh Serebiahs and G. A. Trivakaran., 2008, Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat, *J. Environ. Biol.*, 29 (5): 725–732.
 75. Sarin, M.M., Rao, K.S. Bhattacharya, S.K., Ramesh, R., Somayajulu, B.L.K. (1985): *Mahasagar*, 18: 129–143.
 76. Sebnem Kusvuran. Effects of drought and salt stresses on growth, stomatal conductance, leaf water and osmotic potentials of melon genotypes (*Cucumis melo* L.). *African Journal of Agricultural Research* Vol. 7(5), pp. 775–781, 5 February, 2012.
 77. Soundarapandian P, Premkumar T, Dinakaran GK, *Curr. Res. J. Biol. Sci.*, 2009, 1, 102–105.
 78. Srilatha G, Thilagavathi B and Varadharajan D. Studies on the physico-chemical status of muthupettai mangrove, south east coast of INDIA. *Advances in Applied Science Research*, 2012, 3 (1): 201–207
 79. Steinke TD, Holland AJ, Singh Y (1993) Leaching losses during decomposition of mangrove leaf litter. *S Afr J Bot* 59: 21–25.
 80. Taiz, L. and Zeiger, E. 2009. *Fisiologia Vegetal*. 4th ed. Porto Alegre: Editora ARTMED. 848 p.
 81. Takemura T, Hanagata N, Sugihara K, Baba S, Karube I, and Dubinsky Z (2000) Physiological and biochemical responses to salt stress in the mangrove, *Bruguiera gymnorrhiza*. *Aquat Bot* 68: 15–28.
 82. Thomas, Sabu, Hari Krishnan, K., Sanil George, R. Paulmurugan, R and M. R. Das., 2001. Studies on the water quality of Kuttanad wetland ecosystem of Kerala. *Poll. Res.*, 20(1): 59–66.
 83. Thomas, Sabu, Hari Krishnan, K., Sanil George, R. Paulmurugan, R and M. R. Das., 2001. Studies on the water quality of Kuttanad wetland ecosystem of Kerala. *Poll. Res.*, 20(1): 59–66.
 84. Tuffers, A.; Naidoo, G.; Von Willert, D. J. Low salinities adversely affect photosynthetic performance of the mangrove, *Avicennia marina*. *Wetlands Ecology and Management*, v. 9, p. 225–232, 2001.
 85. Upadhyay, R.K. and Panda, S.K. 2005. Salt tolerance of two aquatic macrophytes. *Pistia stratiotes* and *Salvinia molesta*. *Biologia Plantarum*, vol. 49 no. 1,
 86. Yaşar Akça and Esra Samsunlu. The effect of salt stress on growth, chlorophyll content, proline and nutrient accumulation, and K/Na ratio in walnut. *Pak. J. Bot.*, 44(5): 1513–1520, 2012.
 87. Zhang XY, Wang HM, Hou ZD, Wang GX. 2003. Stomatal density and distributions of spring wheat leaves under different planting densities and soil moisture levels. *Acta Phytoecologica Sinica* 27, 133–136.
 88. Zhao RX, Zhang QB, Wu XY, Wang Y. 2001. The effects of drought on epidermal cells and stomatal density of wheat

- leaves. Inner Mongolia Agricultural Science and Technology 6, 6–7.
89. Zhu, J. Plant salt tolerance. Trends in Plant Science, v. 6, p. 66-71, 2001.