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**Mahadevaswamy**

Head of the department,  
Department of Agricultural  
Microbiology, College of  
Agriculture, UAS, Raichur,  
Karnataka, India

**Yalavarthi Nagaraju**

Ph. D scholar, Department of  
Agricultural Microbiology,  
University of Agricultural  
Sciences UAS, Raichur,  
Karnataka, India

## Role of halophilic microorganisms in agriculture

Mahadevaswamy and Yalavarthi Nagaraju

**Abstract**

Salinity of soils have a profound effect on crop growth and yield, obviously it is a big challenge for scientists to culminate salinity permanently still, avoidance may conserve the natural geochemical cycles and its workers (microorganisms). As the environment changes it makes few changes in the organism as well as organism must change for their survival of the fittest. Through the process of evolution many of the microorganisms has adopted to the changes in the environment but some live under normal conditions and some live under extreme conditions. Microorganisms which live under extreme conditions have developed many strategies to overcome stress and nutrient limitation. Some of them have an impeccable potentiality to enhance the growth of crops under saline conditions by using myriad of mechanisms viz., fixing nitrogen, siderophore production, zinc solubilization, phosphorous solubilization, ACC deaminase production, commercial enzymes production etc. in this review we try to Explored the ways to utilize the microorganisms for commercial crop application under saline conditions to enhance the growth and yield of crops.

**Keywords:** triclosan, TCS, determination, detection, sensor

**Introduction**

Soil salinity, which is on the rise globally, poses a major hindrance to the realization of actual yield potentials of most crop plants (Boyer, 1972) [17]. Salt affected soils occur in all continents and under almost all climatic conditions. Their distribution, however, is relatively more extensive in the arid and semi-arid regions compared to the humid regions. The nature and properties of these soils are also diverse such that they require specific approaches for their reclamation and management to maintain their long term productivity (FAO). India is one of the most salt effected countries in the world after USSR, China, Argentina and Iran. Presently India is having 6.7 mha of total salt affected area. Indian conditions like subtropical areas, ill distribution of rains, excess use of inorganic fertilizers etc., tend to enhancing the area under the salinity year by year, if conditions persist similarly in feature days, growing of crops become a tragedy. The distribution of salt affected soils in agroclimatic zones (ACZs) showed occurrence in Gujarat plain, East Coast plains, Upper-Gangetic plain, Trans-Gangetic plain, Central Plateau, Lower-Gangetic plain and Southern Plateau of the country. Many of the soils become barren and it is growing due to excess salt concentrations. There are many physical and chemical ways to reclaim the saline soils but practically it is so costly. Keeping the long term goals for reclamation of salt affected soils.

The presence of salts affects the plant uptake of nutrients and the microbiological activity in the soil. During the past decades, the studies on ecology, physiology, and taxonomy of halophilic organisms revealed an impressive diversity. Till now haloalkaliphiles were studied extensively for the microbiological classification and phylogeny; only limited attempts have been made to explore molecular basis of adaptation, enzymatic potential and their other biotechnological implications. The diversity of the halophilic, haloalkaliphilic and alkaliphilic microbes has been studied from the hyper saline and hyper alkaline environment. Many hyper saline environments originated by evaporation of sea water are known as thalassohaline environments. Athalassohaline environments are those, in which the ionic composition differs greatly from that of sea water and in which the salts are of non-marine proportion. The soil habitat is inherently inhomogeneous and wide range of salinities might be present in any saline soil (Grant, 1991) [88]. Saline soils appear to yield mostly halotolerant rather than halophilic microorganisms, presumably reflecting adaptation to periodic episodes of relatively high dilution. Halophiles are microorganisms that adapt to moderate and high salt concentrations. They are found in all three domains of life: *Archaea*, *Bacteria* and *Eukarya*. Halophilic bacteria grow over an extended range of salt concentrations (3–15% NaCl, w/v and above), unlike the truly halophilic archaea whose growth is restricted to high saline environments (Litchfield, 2002) [46]. Salinity tolerance comes from genes that limit the rate of salt uptake from the soil or water and the transport of salt throughout the plant adjust the ionic and

**Correspondence****Yalavarthi Nagaraju**

Ph. D scholar, Department of  
Agricultural Microbiology,  
University of Agricultural  
Sciences UAS, Raichur,  
Karnataka, India

osmotic balance of cells in roots and shoots and regulate leaf development and the onset of senescence. Internal pH maintenance in alkaliphilic bacteria is achieved by both; active (sodium ion channels) and passive regulation (through cytoplasmic pools of polyamines and low membrane permeability). The accumulation of organic solutes is a prerequisite for osmotic adjustment of all organisms. Archaea synthesize unusual solutes such as  $\beta$ -amino acids, N-acetyl- $\beta$ -lysine, mannosylglycerate and di-*myo*-inositol phosphate. Among all of them, uptake of solutes such as glycine betaine is preferred over *de novo* synthesis. Most interestingly, some solutes are not only produced in response to salt but also to temperature stress. The ability of the organism to survive both high salt concentrations and low temperatures is attributed mainly to the accumulation of the compatible solute glycine betaine. One of the most effective compatible solutes widely used by bacteria is glycine betaine, the N-trimethyl derivative of glycine, which can be accumulated intracellularly at high concentration through either synthesis or uptake or both. *Bacillus subtilis* has been shown to possess three transport systems for glycine betaine: the secondary uptake system opuD and two binding-protein-dependent transport systems, opuA and opuC (proU).

The cell wall halophilic archaea *Halobacterium* has a high proportion of the acidic amino acids; aspartate and glutamate as sodium salts. Interestingly, this sodium binding is essential to maintain the cell wall and dilution of the medium leads to repulsion between the free carboxylate groups leading to cell wall disintegration and cell lysis. Some alkaliphilic bacteria, however, have developed sodium ion channels that actively drive the entry of protons across the membrane through H<sup>+</sup>/Na<sup>+</sup> antiporters, thus decreasing the overall pH of the cytoplasm. Besides controlling protons, Na<sup>+</sup> dependent pH homeostasis requires reentry of Na<sup>+</sup> into the cell. Na<sup>+</sup> coupled solute symporter and Na<sup>+</sup>-driven flagella rotation ensure a net sodium balance. It was claimed that cyanobacteria absorbed and permanently immobilized Na<sup>+</sup> intracellularly, resulting in decreased soil salinity. The possibility of simultaneously augmenting the carbon and nitrogen status of saline soils was suggested to be an additional attraction of such a reclamation strategy (Singh, 1961) [74]. The salt tolerance exhibited by many cyanobacteria has been exploited with some success in reclamation of brackish soils (Singh, 1950). Halophilic archaea live in shallow evaporation pond encounter with very high temperature and ultraviolet light. They have developed a special retinal pigments called carotenoid. These pigments provide protective barrier to the ultraviolet light. These pigments not only found in halophilic archaea. Marine microbes are known to play an essential role in the global cycling of nitrogen, carbon, oxygen, phosphorous, iron, sulfur and trace elements (Nada *et al.*, 2011). Nitrogen fixing species are also characterized by their capacity to produce phytohormones, solubilize phosphorous and control the access of phytopathogens in plants (Seldin *et al.*, 1998; Holguin *et al.*, 1992) [71, 31]. In this review we highlighted the importance of halophiles in agriculture and their utilization.

### What are saline soils?

A saline soil is generally defined as one in which the electrical conductivity (EC) of the saturation extract (EC<sub>e</sub>) in the root zone exceeds 4 dS m<sup>-1</sup> (approximately 40 mM NaCl) at 25 °C and has an exchangeable sodium of 15%. The yield of most crop plants is reduced at this EC<sub>e</sub>, though many crops exhibit yield reduction at lower EC<sub>e</sub>s (Munns, 2005; Jamil *et al.*, 2011) [53]. It has been estimated that worldwide 20% of

total cultivated and 33% of irrigated agricultural lands are afflicted by high salinity. Furthermore, the salinized areas are increasing at a rate of 10% annually for various reasons, including low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices. It has been estimated that more than 50% of the arable land would be salinized by the year 2050 (Jamil *et al.*, 2011) [40].

### What are halophiles?

Halophiles are salt-loving organisms that inhabit hypersaline environments. Although salts are required for all life forms, halophiles are distinguished by their requirement of hypersaline conditions for growth. They may be classified according to their salt requirement: slight halophiles grow optimally at 0.2–0.85 molL<sup>-1</sup> (2–5%) NaCl; moderate halophiles grow optimally at 0.85–3.4 molL<sup>-1</sup> (5–20%) NaCl; and extreme halophiles grow optimally above 3.4–5.1 molL<sup>-1</sup> (20–30%) NaCl. In contrast, non-halophiles grow optimally at less than 0.2 molL<sup>-1</sup> NaCl. Halotolerant organisms can grow both in high salinity and in the absence of a high concentration of salts (Shiladitya and Priya, 2001). Microbes adapted to life at high salt concentrations are found in all three domains of life: *Archaea*, *Bacteria*, and *Eukarya*. Often, these microbes are not only challenged by one extreme, but multiple, and thus they are “polyextremophile” (Mesbah and Wiegel, 2008) [50]. In some ecosystems salt-loving microorganisms live in such large numbers that their presence can be recognized without the need for a microscope (Yanhe *et al.*, 2010). Halophiles include mainly prokaryotic and eukaryotic microorganisms with the capacity to balance the osmotic pressure of the environment and resist the denaturing effects of salts. Among halophilic microorganisms are a variety of heterotrophic and methanogenic archaea; photosynthetic, lithotrophic, and heterotrophic bacteria; and photosynthetic and heterotrophic eukaryotes (Yanhe *et al.*, 2010) [88]. Examples of well-adapted and widely distributed extremely halophilic microorganisms include archaeal *Halobacterium* species, cyanobacteria such as *Aphanothece halophytica*, and the green alga *Dunaliella salina*. Among multicellular eukaryotes, species of brine shrimp and brine flies are commonly found in hypersaline environments.

### Formation of saline soils and lakes

High saline waters originate either by seawater condensation (thalassohaline) or by evaporation of inland surface water (athalassohaline). The salt composition of thalassohaline waters resembles that of seawater, with NaCl as the main constituent. Athalassohaline lakes can differ in their ion composition from seawater-derived lakes. Some athalassohaline waters have a very high concentration of divalent cations (e.g., the Dead Sea with Mg<sup>2+</sup>, not Na<sup>+</sup>, as the main cation), while others are free of magnesium and calcium due to the presence of high levels of carbonate. Increased carbonate concentrations lead to the formation of soda lakes, which have pH-values well above 10 (e.g., the Wadi Natrun in Egypt). Microflora have been found in all of the above types of saline waters, indicating that halophilic microorganisms tolerate high salinity and can adapt to additional different stressors like high pH or extreme temperatures. The cytoplasmic membranes of halophilic *Archaea* of the family *Halobacteriaceae* contain interesting ether lipids and often have retinal proteins (bacteriorhodopsin, halorhodopsin, and sensory rhodopsins). Heiko Patzelt (Muscat, Oman) showed that

unsaturated ether lipids are far more common in the halophilic *Archaea* than generally assumed. Such unsaturated diether lipids were earlier reported from the psychrotolerant haloarchaeon *Halorubrum lacusprofundi* (Gibson *et al.*, 2005) [30]. Ectoine and hydroxyectoine biosynthesis is widely found in halophilic and halotolerant microorganisms, and the expression of the *ect* structural genes is induced by salt stress. But the solutes provide protection not only against salt stress but also against temperature stress in *Bacillus subtilis* and other salt-tolerant bacilli, as shown by Erhard Bremer (Marburg, Germany).

### Impact of soil salinity on plant growth

The impacts of salinity include- low agricultural productivity, low economic returns and soil erosions, (Hu and Schmidhalter, 2002) [38]. Salinity effects are the results of complex interactions among morphological, physiological, and biochemical processes including seed germination, plant growth, and water and nutrient uptake (Akbarimoghaddam *et al.*, 2011; Singh and Chatrath, 2001) [76]. Salinity affects almost all aspects of plant development including: germination, vegetative growth and reproductive development. Soil salinity imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency and oxidative stress on plants, and thus limits water uptake from soil. Soil salinity significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Ca ions (Bano and Fatima, 2009) [10]. Some elements, such as sodium, chlorine, and boron, have specific toxic effects on plants. Excessive accumulation of sodium in cell walls can rapidly lead to osmotic stress and cell death (Munns, 2002) [52]. Salinity adversely affects reproductive development by inhabiting microsporogenesis and stamen filament elongation, enhancing programmed cell death in some tissue types, ovule abortion and senescence of fertilized embryos. The saline growth medium causes many adverse effects on plant growth, due to a low osmotic potential of soil solution (osmotic stress), specific ion effects (salt stress), nutritional imbalances, or a combination of these factors (Ashraf, 2004) [7]. All these factors cause adverse effects on plant growth and development at physiological and biochemical levels (Munns and James, 2003) [51], and at the molecular level (Tester and Davenport, 2003) [82].

### Mechanisms of survival of halophiles

Halophilic prokaryotes, which require more than 0.5 mol L<sup>-1</sup> NaCl, have developed two different basic mechanisms of osmoregulatory solute accumulation to cope with ionic strength and the considerable water stress. Different types of halophiles have solved the problem how to cope with salt stress (and often with other forms of stress as well) in different ways, so that the study of microbial life at high salt concentrations can answer many basic questions on the adaptation of microorganisms to their environments. Most known halophiles are relatively easy to grow, and genera such as *Halobacterium*, *Haloferax*, and *Haloarcula* have become popular models for studies of the archaeal domain as they are much simpler to handle than methanogenic and hyperthermophilic *Archaea*. Some halophilic and halotolerant microorganisms have found interesting biotechnological applications as well (Yanhe *et al.*, 2010) [88]. There are basically two strategies that enable halophilic and halotolerant microorganisms to live in high salt concentrations. The “high-salt-in” strategy (used by the *Halobacteriaceae*, *Salinibacter*, and the anaerobic *Halanaerobiales*) requires all intracellular

proteins to be stable and active in the presence of molar concentrations of KCl and other salts. The “low-salt, organic-solutes-in” strategy is based on the biosynthesis and/or accumulation of organic solutes that do not interfere greatly with the activity of normal enzymes. But even such organisms need to have salt-adapted proteins in the membrane exposed to the saline medium. It is remarkable that already in the early 1930s Baas Becking concluded that *Dunaliella* must have a highly acidic surface, based on the insensitivity of the alga to certain otherwise toxic anions (Baas, 1934). These mechanisms allow halophiles to proliferate in high saline solutions of varying salt composition, even at saturated concentration.

### Mechanisms of plant growth promotion by microorganisms

#### a) Salt stress Alleviation in crops

Besides developing mechanisms for stress tolerance, microorganisms can also impart some degree of tolerance to plants towards abiotic stresses like drought, chilling injury, salinity, metal toxicity and high temperature. In the last decade, bacteria belonging to different genera including *Rhizobium*, *Bacillus*, *Pseudomonas*, *Pantoea*, *Paeni bacillus*, *Burkholderia*, *Achromobacter*, *Azospirillum*, *Microbacterium*, *Methylobacterium*, *Variovorax*, *Enterobacter* etc. have been reported to provide tolerance to host plants under different abiotic stress environments (Grover *et al.*, 2011) [32]. Use of these microorganisms per se can alleviate stresses in agriculture thus opening a new and emerging application of microorganisms. Microbial elicited stress tolerance in plants may be due to a variety of mechanisms proposed from time to time based on studies done. Production of indole acetic acid, gibberellins and some unknown determinants by PGPR, results in increased root length, root surface area and number of root tips, leading to an enhanced uptake of nutrients thereby improving plant health under stress conditions (Egamberdieva and Kucharova, 2009) [27]. Plant growth promoting bacteria have been found to improve growth of tomato, pepper, canola, bean and lettuce under saline conditions (Barassi *et al.*, 2006; Yildirim and Taylor, 2005) [11, 90].

Some PGPR strains produce cytokinin and antioxidants, which result in abscisic acid (ABA) accumulation and degradation of reactive oxygen species. High activities of antioxidant enzymes are linked with oxidative stress tolerance (Stajner *et al.*, 1997) [77]. Another PGPR strain, *Achromobacter piechaudii* ARV8 which produced 1-aminocyclopropane-1-carboxylate (ACC) deaminase, conferred IST against drought and salt in pepper and tomato (Mayak *et al.*, 2004). Microbial polysaccharides can bind soil particles to form microaggregates and macroaggregates. Plant roots and fungal hyphae fit in the pores between microaggregates and thus stabilize macroaggregates. Plants treated with Exo-poly saccharides (EPS) producing bacteria display increased resistance to water and salinity stress due to improved soil structure (Sandhya *et al.*, 2009) [32]. EPS can also bind to cations including Na<sup>+</sup> thus making it unavailable to plants under saline conditions. Chen *et al.*, 2007 [21], correlated proline accumulation with drought and salt tolerance in plants. Introduction of proBA genes derived from *B. subtilis* into *A. thaliana* resulted in production of higher levels of free proline resulting in increased tolerance to osmotic stress in the transgenic plants. Increased production of proline along with decreased electrolyte leakage, maintenance of relative water content of leaves and selective

uptake of K ions resulted in salt tolerance in *Zea mays* co-inoculated with *Rhizobium* and *Pseudomonas* (Bano and Fatima, 2009) [10]. Rhizobacteria inhabiting the sites exposed to frequent stress conditions, are likely to be more adaptive or tolerant and may serve as better plant growth promoters under stressful conditions. Moreover Yao *et al.*, 2010 [89], reported that inoculation with *P. putida* Rs 198 promoted cotton growth and germination under conditions of salt stress. Jha *et al.*, 2011 [43], reported that *P. pseudoalcaligenes*, an endophytic bacterium in combination with a rhizospheric *B. pumilus* paddy was able to protect the plant from abiotic stress by induction of osmoprotectant and antioxidant proteins than by the rhizospheric or endophytic bacteria alone at early stages of growth. Plants inoculated with endophytic bacterium *P. pseudoalcaligenes* showed a significantly higher concentration of glycine betaine-like quaternary compounds and higher shoot biomass at lower salinity levels. While at higher salinity levels, a mixture of both *P. pseudoalcaligenes* and *B. pumilus* showed better response against the adverse effects of salinity. Nia *et al.*, 2012 studied the effect of inoculation of *Azospirillum* strains isolated from saline or non-saline soil on yield and yield components of wheat in salinity and they observed that inoculation with the two isolates increased salinity tolerance of wheat plants; the saline-adapted isolate significantly increased shoot dry weight and grain yield under severe water salinity. The component of grain yield most affected by inoculation was grains per plant. Plants inoculated with saline-adapted *Azospirillum* strains had higher N concentrations at all water salinity levels. More recently Ramadoss *et al.*, 2013, [43] studied the effect of five plant growth promoting halotolerant bacteria on wheat growth and found that inoculation of those halotolerant bacterial strains to ameliorate salt stress (80, 160 and 320 mM) in wheat seedlings produced an increase in root length of 71.7 % in comparison with uninoculated positive controls. In particular, *Hallobacillus sp.* and *B. halodenitrificans* showed more than 90 % increase in root elongation and 17.4 % increase in dry weight when compared to uninoculated wheat seedlings at 320 mM NaCl stress indicating a significant reduction of the deleterious effects of NaCl. These results indicate that halotolerant bacteria isolated from saline environments have potential to enhance plant growth under saline stress through direct or indirect mechanisms and would be most appropriate as bioinoculants under such conditions.

### b) Nitrogen fixation

Nitrogen fixation is considered as one of the significant biological processes in soil and it is influenced drastically by environmental factors such as temperature, pH (Sorokin *et al.*, 2008) [75], oxygen, and mineral nutrients (Buresh *et al.*, 1980) [19]. One of the major factor that affects the nitrogenase activity is salinity of the soil or water. Some studies have found that concentrations of NaCl as low as 75 mM had a negative effect on nitrogenase activity in symbiotic nitrogen fixers (Bolanos *et al.*, 2006) [15]. In saline ecosystems the conditions created by the density of the soil and the water regime are limiting for nitrogen fixation (Rice and Paul, 1971) [64]. Although, in saline soil and salt marshes, high rates of nitrogen fixation were detected (Casselmann *et al.*, 1981; Jones, 1974 [44]; Wollenweb and Zechmeist, 1989; Dicker and Smith, 1980 [1]; Gandy and Yoch, 1988 [29]; Hanson, 1977 [33]; Teal *et al.*, 1979 [81]; Whiting and Morris, 1986). Nitrogen fixation in salt marsh sediments and saline soils has been attributed to sulphate reducing bacteria, *Clostridia*

*alkalicellum* (Zahilina *et al.*, 2005), *Rhizobium spp* (Zahram, 1999), *Geoalkalibacter ferrihydritucus* (Zavarzina *et al.*, 2006), Cyanobacteria (Wei and Yujie, 2008) [86], *Bacillus spp* (Zahran *et al.*, 1995), *Penibacillus spp* (Baskar and Prabakaran, 2011) [112] and *Azotobacter spp* (Dicker and Smith, 1981 [25]; Wollenweb and Zechmeist, 1989). *Anabaena torulosa* could successfully grow and fix nitrogen on moderately saline “Kharland” soils (soil conductivity 5–8.50 dSm<sup>-1</sup>), typical of Indian coastline.

### c) Phosphate solubilization

Phosphorus is the most important key element in the nutrition of plants, next to nitrogen (N). It plays an important role in virtually all major metabolic processes in plant including photosynthesis, energy transfer, signal transduction, macromolecular biosynthesis and respiration (Khan *et al.*, 2010) [45]. However, a large portion of the applied phosphorus is rapidly immobilized, being unavailable to plants (Goldstein, 1986) [31]. The availability of P to plants for uptake and utilization is messed up in alkaline and calcareous soils due to formation of poorly soluble calcium phosphate raw materials and hence fixation and precipitation of applied P. Presence of lime in alkaline soils further exacerbates its availability and in calcareous soils, lime reacts with soil solution P to form strong calcium phosphate compounds. The resulting effect of low P solubility in calcareous alkaline soils is relatively poor P fertilizer efficiency.

Plants grown on such soils can be stunted with shortened internodes and poor root system due to P deficiency (Imdad *et al.*, 2013) [39]. In average, the content of phosphorus of soil is about 0.05% (w/w); however, only 0.1% of them are usable for plants (Scheffer *et al.*, 1992) [69]. Although P is abundant in soils in both inorganic and organic forms, it is a major limiting factor for plant growth as it is in an unavailable form for root uptake. Inorganic P occurs in soil, mostly in insoluble mineral complexes, some of them appearing after frequent application of chemical fertilizers. These insoluble, precipitated forms cannot be absorbed by plants (Rengel and Marschner, 2005) [63]. There are several microflora which can able to solubilize the unavailable phosphorous to make it available to plants. The main P solubilization mechanisms employed by soil microorganisms include: (1) release of complexing or mineral dissolving compounds e.g. organic acid anions, siderophores, protons, hydroxyl ions, CO<sub>2</sub>, (2) liberation of extracellular enzymes (biochemical P mineralization) and (3) the release of P during substrate degradation (biological P mineralization) (McGill and Cole 1981). Several authors has reported that the inoculation of halophilic phosphate solubilizing microorganisms has enhanced the growth and yield of Rice (Tiwari *et al.*, 1989) [83], maize (Pal, 1999) [58] and other cereals (Afzal *et al.*, 2005 [2]; Ozturk *et al.*, 2003) [57]. Use of phosphate solubilizing bacteria has been reported promising in reducing phosphate fixation and increasing the phosphorous availability from soluble and insoluble phosphatic fertilizers. Beneficial effect of inoculation of phosphate solubilizers on the uptake of nutrients and on the yield of crops has been reported by many workers. Tank and Saraf (2010) [79] showed that PGPRs which are able to solubilize phosphate, produce phytohormones and siderophores in salt condition promote growth of tomato plants under 2 % NaCl stress. Several halophilic bacteria *Kushneria sinocarni* have also been isolated from the sediment of Daqiao saltern on the eastern coast of China, which may be useful in stress conditions; salt affected agricultural soils (Zhu *et al.* 2011) [96].

**d) Siderophore production**

Iron is the fourth most abundant element of the earth's crust. While iron is widespread in the environment, it is often considered biologically unavailable as it is often only found in the form of highly insoluble Fe (III) oxides. Owing to the aerobic atmosphere of the planet iron occurs mostly as ferric oxyhydroxide polymers that have low solubility ion. Therefore, to overcome this limitation bacteria have adopted strategies like production of siderophores (Sandy and Butler, 2009) [68]. These siderophores form complexes with the iron and helps transport in across to the bacterial cell (Neilands, 1995 [54]; Hider and Kong, 2010) [34]. Sadeghi *et al.*, 2012 reported the plant growth promoting activity of an auxin and siderophore producing isolate of *Streptomyces* under saline soil conditions and reported increases in growth and development of wheat plant. They observed significant increases in germination rate, percentage and uniformity, shoot length and dry weight compared to the control. Applying the bacterial inoculum increased the concentration of N, P, Fe and Mn in wheat shoots grown in normal and saline soil and thus concluded that *Streptomyces* isolate has potential to be utilized as biofertilizers in saline soils. There are several microorganisms which produce siderophores under saline conditions Eg: Nine haloarchaea isolates viz. *Halobacterium salinarum*, *Halobacterium* sp.1, *Halobacterium* sp.2, *Halobaculum* sp., *Halococcus saccharolyticus*, *Halorubrum saccharovororum*, *Haloterrigena turkmenica*, *Halogeometricum* sp. and *Natrialba* sp. were reported to produce siderophores by Dave *et al.*, 2005 [23]. Some biotechnological application of siderophores include: plant growth promoting that occurs via the removal of pathogens, antimicrobial activity, removing toxic metals off the soils, medical and therapeutic purposes.

**e) Antagonistic activity**

Several soil bacteria isolated from saline soils shown the inhibition of several pathogens. Plant Growth Promoting isolates from the rhizosphere soils of zinger has shown > 70 % inhibitory effect on *Pythium myriotylum* (Raghavaran *et al.*, 2015). Several enzymes are reported from halophilic microorganisms have potential biocontrol activity like antifungal protease activity from a halotolerant strain M3-16 of *Bacillus pumilus*, isolated from a shallow salt lake in Tunisia was reported by Badiia *et al.*, 2009 [9]. Tiwari *et al.*, (2011) also isolated PGPRs that were halotolerant based on their ability to tolerate 2–25 % NaCl; these included *Bacillus pumilus*, *Pseudomonas mendocina*, *Arthrobacter* sp.

*Halomonas* sp., and *Nitrincola lacisaponensis* with plant growth-promoting traits like phosphorus (P) solubilization and the ability to produce IAA, siderophores, and 1-aminocyclopropane-1-carboxylate (ACC) deaminase. These are considered PGP traits due to their ability to provide P to the plant under P-limiting conditions, promote plant growth by functioning as a phytohormone (IAA), provide Fe to the plant via chelation and uptake (siderophores), and deplete a precursor to the plant stress hormone ethylene (ACC deaminase). Distinct genera of halotolerant bacteria have been isolated from distinct halophytic plants such as *Rosa rugosa* (Bibi *et al.*, 2011) [14], *Salicornia bigelovii* (Rueda-Puente *et al.*, 2010), *Salicornia brachiata* (Jha *et al.*, 2012) [12] [41], *Halocnemum strobilaceum* (Al-Mailem *et al.*, 2010) [4], *Acacia* spp. (Boukhatem *et al.*, 2012) [16], *Sesuvium portulacastrum* (Bian *et al.*, 2011 [13]; Anburaj *et al.*, 2012) [5], and *Avicennia marina* (El-Tarabily and Youssef, 2010) [28], and from a wide range of habitats such as extreme alkali-

saline soils, desert soils, and saline soils (Antón *et al.*, 2002 [6]; Ventosa *et al.*, 2008 [84]; Abou-Elela *et al.*, 2010 [1]; Shi *et al.*, 2012 [76]; Zhou *et al.*, 2012 [15]; Ruppel *et al.*, 2013) [66]. Many of these halotolerant bacteria exhibited an ability to promote plant growth.

**f) Heavy metal tolerance**

Heavy metals are elements with atomic masses higher than 50 amu (Weast, 1984) [85]. At trace concentrations (i.e. in the nanomolar to micromolar range), a number of heavy metals (e.g. Co, Cu, Fe, Mn, Ni and Zn) serve as essential micronutrients in metabolic reactions and enzyme stabilization (Bruins, Kapil and Oehme, 2000) [66]. Oxidized forms of iron (Fe<sup>3+</sup>), manganese (Mn<sup>4+</sup>), arsenic (As<sup>5+</sup>) or selenium (Se<sup>6+</sup>) may be used as electron acceptors during anaerobic respiration in *Bacteria* and *Archaea* (Dowdle, Laverman and Oremland 1996; Switzer Blum *et al.* 1998; Lovley 2013) [47]. At high (above 1 mM) concentration, heavy metals become poisonous for various components of ecosystems including the human body tending to bioaccumulate in organisms (through bioconcentration) or within the food chain (biomagnification) (Tchounwou *et al.* 2012 [88]; Chaudhary *et al.* 2014). Silver, lead, cadmium, aluminum, mercury, gold and arsenic do not have significant biological roles but are regarded as toxic for nearly all microorganisms, substituting essential metals from their natural binding sites or interacting with other specific ligands. Moreover, at high concentrations, metals kill cells by disrupting cell membranes, altering enzymatic specificity or denaturing DNA (Nies 1999 [56]; Hobman and Crossman 2015) [35]. The increase of heavy metal concentration in the environment often triggers activation of mechanisms leading to metal resistance (Srivastava and Kowshik, 2013) [76]. Metal contamination acts as a driving force in the co-selection of heavy metal and antibiotic resistant microorganisms, raising additional ecological and human health concerns (Seiler and Berendonk, 2012) [70]. Microorganisms which can resist high concentration of toxic heavy metals are often considered as effective tools of bioremediation from such pollutants. Heavy metal pollution of soil and water is a severe environmental problem. Physicochemical remediation of metal-polluted environments is inconvenient due to high energy consumption, high costs and incomplete removal of metals (Malik, 2004) [37]. Bioremediation mediated by metal resistant microorganisms seems a cost-effective alternative for decontamination of polluted ecosystems (Hryniewicz and Baum, 2014) [37]. Heavy metal pollution represents an important environmental problem due to the toxic effects of metals. Extremely halophilic archaea require high salt concentrations for growth and inhabit hypersaline environments (solar salterns, salt lakes and salt mines), where the NaCl concentration exceeds 200 – 250 g l<sup>-1</sup> or reaches saturation. Frequently, hypersaline environments are contaminated with toxic compounds. A plant growth-promoting bacterium, *Kluyvera ascorbate* SUD165, resistant to the toxic effects of Ni<sup>2+</sup>, Pb<sup>2+</sup>, Zn<sup>2+</sup>, and CrO<sub>4</sub><sup>-</sup>, by producing a siderophore(s), and displayed 1-aminocyclopropane-1-carboxylic acid deaminase activity and protect the plants from heavy metal toxicity (Genrich *et al.*, 1998). The remediation of environments metal contaminated through physicochemical methods present major disadvantages such as high energy consumption, high costs and incomplete removal of metal ions. Biosorption of heavy metals by microorganisms is an alternative method that involves low costs. Active elimination process of heavy

metals ions provided by living cells, especially by their components and extracellular products represent a potential way of removing toxic heavy metals from industrial wastewaters.

### Conclusion

One of the most important constraints to agricultural production in world is abiotic stress conditions prevailing in the environment. Among the different abiotic stresses salt stress leads to the poor yields and loss of crop. Salt affected soils threaten the growth of plants as well as yields. The development of stress tolerant crop varieties through genetic engineering and plant breeding is essential but a long drawn and expensive process. Although there are several commercially available soil reclamation processes, microbial reclamation have a great importance. Microbial reclamation costs minimum, ecofriendly, enhance the soil physical and chemical characters in turn enhance the plant growth and survival. Several plant growth promoting rhizobacteria helpful in alleviation of salt stress in plants with a gamut of mechanisms. Fixation of nitrogen, phosphorous solubilization, compatible solutes production and secretion of plant growth promoting substances are the few highly useful characters. Halophiles are an interesting class of extremophilic organisms that have adapted to harsh, hypersaline conditions. They are able to compete successfully for water and resist the denaturing effects of salts.

Adaptation to hypersaline conditions is interesting from an evolutionary standpoint. Future studies will provide greater insights into these fascinating questions. The diversity of microorganisms in hypersaline environments is also of growing interest. Few hypersaline environments have been carefully surveyed using molecular methods. The recent finding of bacterial and archaeal metabolic activities suggests that these environments may harbor diverse consortia of microbes that are not easily cultured. The extremes of hypersaline environments, e.g. in salinity (high magnesium and potassium concentration in bitterns), in anaerobic zones, and in high and low pH and temperature habitats, may yield especially interesting species.

### References

1. Abou-Elela SI, Kamel MM, Fawzy ME. Biological treatment of saline wastewater using a salt-tolerant microorganism. *Desalination*. 2010; 250:1-5.
2. Afzal A, Ashraf M, Asad SA, Farooq M. Effect of phosphate solubilizing microorganisms on phosphorus uptake, yield and yield traits of wheat (*Triticum aestivum* L) in rainfed area. *Int. J. Agric. Biol.* 2005; 7:207-209.
3. Akbarimoghaddam H, Galavi M, Ghanbari A, Panjehkeh N. Salinity effects on seed germination and seedling growth of bread wheat cultivars. *Trakia J. Sci.* 2011; 9(1):43-50.
4. Al-Mailem DM, Sorkhoh NA, Marafie M, Al-Awadhi H, Eliyas M, Radwan SS. Oil phytoremediation potential of hypersaline coasts of the Arabian Gulf using rhizosphere technology. *Bioresour. Technol.* 2010; 101:5786-5792.
5. Anburaj R, Nabeel MA, Sivakumar T, Kathiresan K. The role of rhizobacteria in salinity effects on biochemical constituents of the halophyte *Sesuvium portulacastrum*. *Russ. J. Plant Physiol.* 2012; 59:115-119.
6. Antón J, Oren A, Benlloch S, Rodríguez-Valera F, Amann R, Rosselló-Mora R. *Salinibacter ruber* gen. nov., sp. nov., a novel, extremely halophilic member of the Bacteria from saltern crystallizer ponds. *Int. J. Syst. Evol. Microbiol.* 2002; 52:485-491.
7. Ashraf M. Some important physiological selection criteria for salt tolerance in plants. *Flora*, 2004; 199:361-376.
8. Baas Becking, LGM. *Geobiologie of inleiding tot the milieukunde*. W. P. van Stockum and Zoon, The Hague, Netherlands. 1934.
9. Badiaa E, Mohammed B, Haissam J, Abdellatif B, Najla SZ. High salt-tolerant protease from a potential biocontrol agent *Bacillus pumilus* M3-16. *Annals of Microbiology*. 2009; 59:553.
10. Bano A, Fatima M. Salt tolerance in *Zea mays* (L.) following inoculation with *Rhizobium* and *Pseudomonas*. *Biol. Fertility Soils*. 2009; 45:405-413.
11. Barassi CA, Ayrault G, Creus CM, Sueldo RJ, Sobero MT. Seed inoculation with *Azospirillum mitigates* NaCl effects on lettuce. *Sci. Horticulturae (Amsterdam)*. 2006; 109:8-14.
12. Baskar B, Prabakaran P. Characterization of mangrove associated nitrogen fixing halophilic bacterium. *Paenibacillus* sp. *International Journal of Current Research*. 2011; 3(9):065-067.
13. Bian G, Zhang Y, Qin S, Xing K, Xie H, Jiang J. Isolation and biodiversity of heavy metal tolerant endophytic bacteria from halotolerant plant species located in coastal shoal of Nantong. *Wei Sheng Wu Xue Bao*. 2011; 51:1538-1547.
14. Bibi F, Chung EJ, Yoon HS, Song GC, Jeon CO, Chung YR. *Haloferula luteola* sp. nov., an endophytic bacterium isolated from the root of a halophyte, *Rosa rugosa*, and emended description of the genus *Haloferula*. *Int. J. Syst. Evol. Microbiol.* 2011; 61:1837-1841.
15. Bolanos L, Martin M, El-Hamdaoui A, Rivilla R, Bonilla I. Nitrogenase inhibition in nodules from Pea plants grown under salt stress occurs at the physiological level and can be alleviated by B and Ca. *Plant and Soil*. 2006; 280:135-142.
16. Boukhatem ZF, Domergue O, Bekki A, Merabet C, Sekkour S, Bouazza F. Symbiotic characterization and diversity of rhizobia associated with native and introduced acacias in arid and semi-arid regions in Algeria. *FEMS Microbiol. Ecol.* 2012; 80:534-547.
17. Boyer JS. Plant productivity and environment. *Science*. 1972; 218:443-448.
18. Bruins MR, Kapil S, Oehme FW. Microbial resistance to metals in the environment *Ecotox Environ Safe*. 2000; 45:198-207.
19. Bureshr J, Casselmamn Em, Patrickw H Jr. Nitrogen fixation in flood soil systems, a review. *Adv. Agron.* 1980; 23:149-192.
20. Casselmamn E, Patrickw H Jr, De Launer D. Nitrogen fixation in a Gulf coast salt marsh. *Soil Sci. Soc. Am. J.* 1981; 45:51-55.
21. Chen M, Wei H, Cao J, Liu R, Wang Y, Zheng C. Expression of *Bacillus subtilis* proAB genes and reduction of feedback inhibition of proline synthesis increases proline production and confers osmotolerance in transgenic *Arabidopsis*. *J. Biochem. Mol. Biol.* 2007; 40(3):396-403.
22. Christopher R. Review of "Adaptation to life at high salt concentrations in Archaea, Bacteria, and Eukarya". *Saline Systems*. 2005, 9.



23. Dave BP, Kena A, Puja H. Siderophores of halophilic archaea and their chemical characterization. *Indian journal of experimental Biology*. 2005.
24. Dickerh J, Smith DW. Physiological ecology of acetylene reduction (nitrogen fixation) in a Delaware salt marsh. *Microb. Ecol.* 1980; 6:161-171.
25. Dickerh J, Smkhd W. Effect of salinity on acetylene reduction (nitrogen fixation) and respiration in a marine *Azotobacter*. *Appl. Environ. Microbiol.* 1981; 42:740-744.
26. Dowdle PR, Laverman AM, Oremland RS. Bacterial dissimilatory reduction of arsenic (V) to arsenic (III) in anoxic sediments. *Appl Environ Microbiol.* 1996; 62:664-9.
27. Egamberdieva D, Kucharova Z. Selection for root colonizing bacteria stimulating wheat growth in saline soils. *Biol. Fertility Soil.* 2009; 45:563-571.
28. El-Tarabily KA, Youssef T. Enhancement of morphological, anatomical and physiological characteristics of seedlings of the mangrove *Avicennia marina* inoculated with a native phosphate-solubilizing isolate of *Oceanobacillus picturae* under greenhouse conditions. *Plant Soil.* 2010; 332:147-162.
29. Gandye L, Yoch DC. Relationship between nitrogen fixing sulphate reducers and fermenters in salt marsh sediments and roots of *Spartina alterniflora*. *Appl. Environ. Microbiol.* 1988; 54(203):1-2036.
30. Gibson JAE, Miller, MR, Davies NW, Neill GP, Nichols DS, Volkmann JK. Unsaturated diether lipids in the psychrotrophic archaeon *Haloquadratum walsbyi*. *Syst. Evol. Microbiol.* 2005; 28:19-26.
31. Goldstein AH. Bacterial solubilization of mineral phosphates: historical perspectives and future prospects. *American Journal of Alternative Agriculture.* 1986; 1:57-65.
32. Grover M, Ali SZ, Sandhya V, Rasul A, Venkateswarlu B. Role of microorganisms in adaptation of agriculture crops to abiotic stresses. *World J. Microbiol. Biotechnol.* 2011; 27:1231-1240.
33. Hanson B. Comparison of nitrogen fixation activity in tall and short *Spartina alterniflora* salt marsh soils. *Appl. Environ. Microbiol.* 1977; 33:596-602.
34. Hider RC, Kong X. Chemistry and biology of siderophores. *Nat Prod Rep.* 2010; 27:637-657.
35. Hobman JL, Crossman L. Bacterial antimicrobial metal ion resistance. *J Med Microbiol.* 2014; 64:471-97.
36. Holguin G, Guzman MA, Bashan Y. Two new nitrogen-fixing bacteria from the rhizosphere of mangrove trees: their isolation, identification and in vitro interaction with rhizosphere *Staphylococcus* sp. *FEMS Microbiology Ecology.* 1992; 101:207-216.
37. Hrynkiewicz K, Baum C. Application of microorganisms in bioremediation of environment from heavy metals, In: Malik A, Grohmann E, Akhtar R (eds.), *Environmental Deterioration and Human Health*. Dordrecht: Springer. 2014, 215-227.
38. Hu Y, Schmidhalter U. Limitation of salt stress to plant growth. In: Hock B., Elstner C.F., editors. *Plant Toxicology*. Marcel Dekker Inc.; New York. 2002, 91-224.
39. Imdad AM, Arshad A, Muhammad A, Armghan S, Tariq S, Fayyaz H. Phosphorus Availability in Different Salt-affected Soils as Influenced by Crop Residue Incorporation. *International Journal of Agriculture & Biology.* 2013; 15(3):472-478.
40. Jamil A, Riaz S, Ashraf M, Foolad MR. Gene expression profiling of plants under salt stress. *Crit. Rev. Plant Sci.* 2011; 30(5):435-458.
41. Jha B, Gontia I, Hartmann A. The roots of the halophyte *Salicornia brachiata* are a source of new halotolerant diazotrophic bacteria with plant growth-promoting potential. *Plant Soil.* 2012; 356:265-277.
42. Jha Y, Subramanian RB, Patel S. Combination of endophytic and rhizospheric plant growth promoting rhizobacteria in *Oryza sativa* shows higher accumulation of osmoprotectant against saline stress. *Acta Physiol. Plant.* 2011; 33:797-802.
43. Jonesk. Nitrogen fixation in a salt marsh. *J. Ecol.* 1974; 62:553-565.
44. Khan MS, Zaidi A, Ahemad, M, Oves M, Wani PA. Plant growth promotion by phosphate solubilizing fungi-current perspective. *Arch Agron Soil Sci.* 2010; 56:73-98.
45. Litchfield CD. Halophiles. *J. Ind. Microbiol. Biotechnol.* 2002; 28:21-22.
46. Lovley D. Dissimilatory Fe (III) and Mn (IV) reducing prokaryotes, In: Rosenberg E, DeLong EF, Lory S, Stackebrandt E, Thompson F (eds.) *The Prokaryotes. Prokaryotic Physiology and Biochemistry*. Berlin: Springer. 2013, 287-308.
47. Malik A. Metal bioremediation through growing cells, *Environ Int.* 2004; 30:261-78.
48. McGill WB, Cole CV. Comparative aspects of cycling of organic C, N, S and P through soil organic matter. *Geoderma.* 1981; 26:267-268.
49. Mesbah NM, Wiegel J. Life at extreme limits: the anaerobic halophilic alkalithermophiles. *Ann. N. Y. Acad. Sci.* 2008; 1125:44-57.
50. Munns R, James RA. Screening methods for salinity tolerance: a case study with tetraploid wheat. *Plant Soil.* 2003; 253:201-218.
51. Munns R. Comparative physiology of salt and water stress. *Plant Cell Environ.* 2002; 25:239-250.
52. Munns R. Genes and salt tolerance: bringing them together. *New Phytol.* 2005; 167:645-663.
53. Neilands JB. Siderophores: structure, function of microbial iron transport compounds. *J Biochem.* 1995; 270:26723-26726.
54. Nia SH, Zarea MJ, Rejali F, Varma A. Yield and yield components of wheat as affected by salinity and inoculation with *Azospirillum* strains from saline or non-saline soil. *J. Saudi Soc. Agric. Sci.* 2012; 11:113-121.
55. Nies DH. Microbial heavy-metal resistance. *Appl Microbiol Biotechnol.* 1999; 51:730-50.
56. Ozturk A, Caglar O, Sahin F. Yield response of wheat and barley to inoculation of plant growth promoting rhizobacteria at various levels of nitrogen fertilization. *J. Plant Nutr. Soil. Sci.* 2003; 166:1-5.
57. Pal S. Interaction of an acid tolerant strain of phosphate solubilizing bacteria with a few acid tolerant crops. *Plant Soil.* 1999; 213:221-30.
58. Raghavan D, Muthuswamy A, Aundy K, Yogyar KB, Kizhakke PS, Ravindran A. Isolation, characterization, and evaluation of multi-trait plant growth promoting rhizobacteria for their growth promoting and disease suppressing effects on ginger. *Microbiological Research.* 2015; 173:34-43.
59. Ramadoss D, Lakkineni VK, Bose P, Ali S, Annapurna K. Mitigation of salt stress in wheat seedlings by

- halotolerant bacteria isolated from saline habitats. Springer Plus. 2013; 2(6):1-7.
61. Ravikumar S, Ramanathan N, Suba N, Jeyseeli. Quantification of halophilic *Azospirillum* from mangroves. Indian Journal of Marine sciences. 2002; 31(2):157-160.
  62. Ravikumar S, Shanthi S, Kalaiarasi, Sumaya. The Biofertilizer Effect of Halophilic Phosphate Solubilizing Bacteria on *Oryza sativa*. Middle-East Journal of Scientific Research. 2014; 19(10):1406-1411.
  63. Rengel Z, Marschner P. Nutrient availability and management in the rhizosphere: exploiting genotypic differences. New Phytology. 2005; 168:305-312.
  64. Rice WD, Paulm EA. An acetylene reduction assay for measuring nitrogen fixation in waterlogged soil. Can. J. Microbiol. 1971; 17:1049-1056.
  65. Rueda-Puente EO, Castellanos-Cervantes T, Díaz de León-Álvarez JL, Preciado-Rangel P, Almaguer-Vargas G. Bacterial community of rhizosphere associated to the annual halophyte *Salicornia bigelovii* (Torr.). Terra Latinoamericana. 2010; 28:345-353.
  66. Ruppel S, Franken P, Witzel K. Properties of the halophyte microbiome and their implications for plant salt tolerance. Funct. Plant Biol. 2013; 40:940-951.
  67. Sandhya V, Ali SZ, Grover M, Reddy G, Venkateswarlu B. Alleviation of drought stress effects in sunflower seedlings by exopolysaccharides producing *Pseudomonas putida* strain P45. Biol. Fertility Soil. 2009; 46:17-26.
  68. Sandy M, Butler A. Microbial iron acquisition: marine and terrestrial siderophores. Chem Rev. 2009 109:4580–4595.
  69. Scheffer, F and Schachtschabel, P. 1992. Lehrbuch der Bodenkunde, Ferdinand Enke Verlag, Stuttgart, Germany. 2009.
  70. Seiler C, Berendonk TU. Heavy metal driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture. Front Microbiol. 2012; 3:399.
  71. Seldin L, Rosado AS, Da-Cruz DW, Nobrega A, Van-Elsas JD, Paiva E. Comparison of *Paenibacillus* azotofixans strains isolated from rhizosphere, rhizosphere, and non-root-associated soil from maize planted in two different Brazilian soils. Applied and Environmental Microbiology. 1998; 64:3860-3868.
  72. Shi W, Takano T, Liu S. Isolation and characterization of novel bacterial taxa from extreme alkali-saline soil. World J. Microbiol. Biotechnol. 2012; 28:2147-2157.
  73. Singh KN, Chatrath R. Salinity tolerance. In: Reynolds M.P., Monasterio J.I.O., McNab A., editors. Application of Physiology in Wheat Breeding. CIMMYT; Mexico, DF. 2001, 101-110.
  74. Singh RN. Reclamation of usar lands. In role of blue green algae in nitrogen economy of Indian agriculture. Indian Council of Agricultural Research, New Delhi. 1996, 83-98.
  75. Sorokin ID, Kravchenko IK, Doroshenko EV, Boulygina ES, Zadorina E, Tourova TP. *Et al.* Haloalkaliphilic diazotrophs in soda solonchak soils. FEMS Microbiology Ecology. 2008; 65:425-433.
  76. Srivastava P, Kowshik M. Mechanisms of metal resistance and homeostasis in haloarchaea. Archaea. 2013, 732-864.
  77. Stajner D, Kevresan S, Gasic O, Mimica-Dukic N, Zongli H. Nitrogen and *Azotobacter chroococcum* enhance oxidative stress tolerance in sugar beet. Biol. Plantarum. 1997; 39(3):441-445.
  78. Switzer BJ, Burns BA, Buzzelli J. *Bacillus arsenicoselenatis*, sp. nov., and *Bacillus selenitireducens*, sp. nov.: two haloalkaliphiles from Mono Lake, California that respire oxyanions of selenium and arsenic. Arch Microbiol. 1998; 171:19-30.
  79. Tank N, Saraf M. Salinity-resistant plant growth promoting rhizobacteria ameliorates sodium chloride stress on tomato plants. J. Plant Interact. 2010; 5:51-58.
  80. Tchounwou PB, Yedjou CG, Patlolla AK. Heavy metal toxicity and the environment. In: Luch A (ed.) Molecular, Clinical and Environmental Toxicology. Basel: Springer. 2012, 133-164.
  81. Tealij M, Valielai, Berlod. Nitrogen fixation by rhizosphere and free-living bacteria in salt marsh sediments. Limnol. Oceanogr. 1979; 24:126-132.
  82. Tester M, Davenportm R. Na<sup>+</sup> tolerance and Na<sup>+</sup> transport in higher plants. Ann. Bot. 2003; 91:503-507.
  83. Tiwari VN, Lehri LK, Pathak AN. Effect of inoculating crops with phosphor microbes. Exp Agric. 1989; 25:47-50.
  84. Ventosa A, Mellado E, Sanchez-Porro C, Marquez MC. Halophilic and halotolerant micro-organisms from soils,” in Microbiology of Extreme Soils, eds P. Dion and C. S. Nautiyal (Berlin; Heidelberg: Springer). 2008; 87-115.
  85. Weast RC. CRC Handbook of Chemistry and Physics 64th edn Boca Raton CRC Press. 1984.
  86. Wei Z, Yujie F. Characterization of nitrogen-fixing moderate halophilic cyanobacteria isolated from saline soils of Songnen Plain in China. Progress in Natural Science. 2008; 18:769-773.
  87. Wollenweber, zechmeister-Boltentstse W. Nitrogen fixation and nitrogen assimilation in a temperate saline ecosystem. Botanica Acta. 2008; 102:96-105.
  88. Yanhe M, Erwin A, Galinski William D, Grant Aharon O, Antonio V. Halophiles: Life in Saline Environments. Appl Environ Microbiol. 2010; 76(21):6971–6981.
  89. Yao L, Wu Z, Zheng Y, Kaleem I, Li C. Growth promotion and protection against salt stress by *Pseudomonas putida* Rs-198 on cotton. Eur. J. Soil Biol. 2010; 46:49-54.
  90. Yildirim E, Taylor AG. Effect of biological treatments on growth of bean plants under salt stress. Ann. Rep. Bean Improvement Cooperative. 2005; 48:176-177.
  91. Zahran HH. Rhizobium-Legume Symbiosis and Nitrogen Fixation under Severe Conditions and in an Arid Climate. Microbiology and Molecular Biology Reviews. 1999; 63: 968-989.
  92. Zahranm HH, Ahmad S, EA Afkar. Isolation and characterization of nitrogen fixing moderate halophilic bacteria from saline soils of Egypt. J. Basic Microbiol. 1995; 35(4):269-275.
  93. Zavarzina DG, Kolganova TV, Bulygina ES, Kostrikina NA, Turova TP, Zavarzin GA. *Geoalkalibacter ferrihydriticus* gen. nov., sp. nov., the first alkaliphilic representative of the family Geobacteraceae, isolated from a Soda Lake. Mikrobiologia. 2006; 75:775-785.
  94. Zhilina TN, Kevbrin VV, Tourova TP, Lysenko AM, Kostrikina NA, Zavarzin GA. *Clostridium alkalicellum* sp. nov., an obligately alkaliphilic cellulolytic bacterium from a Soda Lake in the Baikal Region. Mikrobiologia. 2005; 74:642-653.



95. Zhou M, Chen W, Chen H, Wei G. Draft genome sequence of *Mesorhizobium alhagi* CCNWXJ12-2T, a novel salt-resistant species isolated from the Desert of Northwestern China. *J. Bacteriol.* 2012; 194:1261-1262.
96. Zhu F, Qu L, Hong X, Sun X. Isolation and characterization of a phosphate-solubilizing halophilic bacterium *Kushneria* sp. YCWA18 from Daqiao Saltern on the coast of Yellow Sea of China. *Alternative Med.* 2011; 615032:6.