CHAPTER 1.

INTRODUCTION AND REVIEW OF LITERATURE
Chapter 1. Introduction and Review of Literature

1.1 Population and food security: a growing concern

Population of the world is increasing exponentially day by day and it had crossed & billion mark on March 12 2012, according to the estimates of United States census bureau (USCB). There is a strong correlation between population, poverty and hunger. About 925 million people around the world face chronic hunger due to poverty, while up to 2 billion people worldwide are not secure about their daily meal, intermittently due to varying degree of poverty as per FAO, 2010. According to the UN projection by the year 2030, the global population would exceed the 8.3 billion mark and by this time, India might become the most populous country in the world, beating its nearest rival China. It has been projected that by 2020 our food grain demand will be 294 million ton. This rapid and continuous increase in population put an extra burden to fulfill the demand for food. So we need a better policy and continuous effort to enhance the production and to put a curb on the growing population.

As we, know that in India almost two-third of the population resides in villages; where agriculture is the only means of livelihood which employs nearly sixty two percent of the country’s total population that occupies forty two percent of its total geographical area. Agriculture as the other allied sector contributes largely in the country’s Gross Domestic product (GDP), but there is a steady decline in the contribution experienced since India achieved Independence. It has shrunk from 55% in 1951-52 to 14.6% in the present; a fact that reflects the massive number of people lives in poverty. Though the total food grain production has increased from 217.28 million tones in 2006-07 to 241.56 million tons in 2010-11, India’s population has expanded by almost 9.7% but net food grains production has increased by a mere 2.08%, it seems to trail behind the growth rate percent of population which was one of the major causes behind the increase in the population of the people surviving below poverty line as per the Director Institute of social and economic change.
It’s the agriculture from which three quarters of the world’s poor make their living, the food and fodder demand is likely to be doubled in the next forty years as the global population approaches more than 9 billion mark. There is a powerful argument for providing food security to the 445 million Indians who still live on less than Rs 26 per day. "A dangerous mix of the global economic slowdown combined with stubbornly high food prices in many countries has pushed some 100 million more people than last year into chronic hunger and poverty," FAO Director-General Jacques Diouf said. The long term interests of both the rural and urban poor lie in modernizing agriculture and cutting the fiscal deficit. That will sharply enhance farm productivity and control inflation, which will move India from a policy of food entitlement to food empowerment. (The Times of India, November 2, 2011). Growing sufficient food will require people to make changes such as, investing in irrigation, judicious use of fertilizers, pesticides, to reduce the post harvest loss, improving soil fertility, and the most important is to make use of abandoned land.

1.2 Soil degradation: upcoming threat:

Soil degradation stand for the loss of the vitality required for the healthy crop production. Factors such as salinisation, erosion, pollution, over grazing and uncontrolled fire are some of the main causes responsible for the land degradation. Due to improper agricultural practices viz; over doze of pesticides and fertilizers, lack of crop rotation, planting without soil and water test report, to burnout the field after harvest etc, led to deplete the organic matter, beneficial microorganisms, nutrient quality and thereby fertility of the soil. Approximately 24% of global land area and 40% of the world’s agricultural land is seriously degraded. Each year approximately 12 million hectares of land; the area 3 times the size of the Switzerland, have been lost due to desertification. Land degradation cost approximately 37.5 billion USD that directly affects 1.5 billion people globally (UN conference, 17 June 24, 2012 at Rio). About 228 million hector area out of 328 million hector, which accounts to sixty nine percent of India’s total geographic area, falls under dry land ecosystem. Dry lands support nearly half of the world’s food production systems, accounting for more than 40 percent of the land mass.
Environmental degradation, lack of resources and purchasing power are the major problem in dryland area. An estimate of about thirty-two percent of the India’s total land area is affected by land degradation; of which desertification is the main component (Ministry of environment and forest, New Delhi. 07 July 2011). In order to restore the fertility in these areas, it is important to protect the land from deforestation, fragmentation, degradation and drought. Sustaining healthy soil and restoring degraded land in dry lands can ensure, food security, alleviate rural poverty and hunger. Soil conservation not only helps us to increase biodiversity but also mitigate our food security issue.

1.3 Abiotic stress: An escalating hurdle

Normally, when a particular crop is subjected to stress conditions, its growth is affected and become physiologically more susceptible to various pathogenic disorders, as a consequence it not only debase the quality of the product but also reduce the per hectare yield of the crop. There are various factors contribute their parts towards the demeaning of agricultural situation. One of the main culprit to which our economically important crops get susceptible is the abiotic stress conditions which is defined as the harmful effect generated by the non-living factors, that has direct or indirect effect on the biotic community under a particular climatic condition. It is considered as the most harmful stress factor related to the crop production globally. The most common stress factors are extreme temperature, cold, high wind, drought, flood and salinity. It has been claimed that alone abiotic stress factor causes 50% reduction in the crop potential yield than any other factor. Among them salinity is considered as one of the most significant environmental factors limiting plant growth and productivity (Tian et al., 2004).

Salinity addresses its presence across the globe, as about 1000 million ha area in more than hundred countries is affected by this menace. About 6.73 million hectare of land area, alone in India is being confined under salinity; which is becoming a growing concern towards achieving self-sufficiency in providing quality food to its ever increasing population. So it’s a need of hour to understand and act accordingly to tackle the salinity menace.
1.4 Salinity a major abiotic factor:

Salinity is a unit by which one can estimate the extent of salt at a particular place; it precedes human civilization and thought to be the first, ever, manmade environmental problem. With the advent of irrigation practice, the problem came into existence, the earlier written evidence of salty land date back to 2400 BC, which was recorded in Tigris-Euphrates alluvial plains of Iraq (Russel et al., 1965). According to Richards (1954) saline soils are those which have an electrical conductivity of saturation soil extract (ECe) of more than 4 ds/m at 25°C. Salinisation usually develop when it receive salts through the carriers such as water and wind. It’s a continuous and a long process of chemical weathering of rocks by hydration, oxidation, carbonation and hydrolysis that leads to an excessive increase of water-soluble salts in the soil. Climate, soil characteristics, nature of salts, available water resources, land use and topography are the important factors affecting improvement of salt affected soils.

Salt affected land occurs at various altitudes and in almost all-climatic regions right from the inland and coastal regions to polar and humid tropics, but it exists predominantly in arid and semi arid climatic conditions. It restricts plant growth and biomass production especially in these areas (Apse et al; 1999). In India, these soils are commonly found in Andhra Pradesh, West Bengal, Orissa, Tamil Nadu and Andaman and Nicobar islands on the east coast covering an area of 756239 ha (11.2%) and Gujarat, Kerala, Karnataka and Maharashtra on the west coast, covering 634958 ha (9.4%). The presence of heavy textured soil, poor drainage condition and lack of good quality irrigation water, enhances salinity development in this region. The regular use of saline water for irrigation purpose together with poor management practices, aggravate the problem of salinity (Framji, 1976). In arid region the excess mineral ions are not efficiently expelled out, which is either due to restriction in proper drainage, low permeability, high ground water table and transpiration rate inadequate rainfall. Excess of soluble salts in soils reduces availability of soil moisture (Holfman G.J. et al., 1980), which is the root cause of nutritional imbalance in the plants (Barea J M. et al., 1991).
A salt affected soil can be identified through the principle characteristics which it posses (i) by measuring pH, E.C. of the saturated extract and (ii) Exchangeable sodium percentage. Physico-chemical properties of salt-affected soils, normally reflects the amount and the type of salt present. Salt affected soils are thus, broadly classified into saline and alkali soils (Bhargava et al., 1976; Bhumbla, 1977; Abrol and Bhumbla, 1978). A soil is said to be saline if it contain an excess of soluble salts (dominantly Na₂SO₄, NaCl) and sodic if it contain a high amount of exchangeable sodium capable of alkaline hydrolysis (dominantly Na₂CO₃ and NaHCO₃). The basic differences between the two categories are presented in Table 1. given below.

Table 1. Characteristics of saline and alkali soils.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Characteristics</th>
<th>Saline soil</th>
<th>Sodic soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Appearance</td>
<td>White crust on surface</td>
<td>Dark with hard surface</td>
</tr>
<tr>
<td>2.</td>
<td>E.C.</td>
<td>&gt;4ds/m at 25°C</td>
<td>&lt;4ds/m at 25°C</td>
</tr>
<tr>
<td>3.</td>
<td>E.S.P.</td>
<td>&lt;15</td>
<td>&gt;15</td>
</tr>
<tr>
<td>4.</td>
<td>S.A.R.</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>&lt;8.5</td>
<td>&gt;8.5</td>
</tr>
<tr>
<td>6.</td>
<td>Hydraulic conductivity</td>
<td>More</td>
<td>less</td>
</tr>
<tr>
<td>7.</td>
<td>Salts</td>
<td>Sodium and chloride</td>
<td>Carbonates &amp; bicarbonates</td>
</tr>
<tr>
<td>8.</td>
<td>Organic matter</td>
<td>Generally poor</td>
<td>Generally rich</td>
</tr>
<tr>
<td>9.</td>
<td>Neutral salts</td>
<td>Dominant</td>
<td>Absent</td>
</tr>
<tr>
<td>10.</td>
<td>Effect on soil particles</td>
<td>Aggregation</td>
<td>Dispersion</td>
</tr>
</tbody>
</table>

According to the Abrol and Fireman 1977 there are some possible sources of excess salts in the soil (i) High salt deposits inherited by the soil from the original parent material during soil forming processes. (ii) Salts contained in irrigation water applied or water lost in conveyance through irrigation distribution systems. (iii) More salts in water inflows (seepage) from upslope. (iv) Salts coming through upward movement (capillary action) of water from ground close to soil surface. (v) High, sub-soil water table, aridity and poor drainage. (vi) Back water flow or intrusion of sea water in coastal area.
1.5 Salinisation types:

Salinisation of the soil can be characterized into two categories i.e. primary and secondary salinisation processes.

1.5.1 Primary salinisation:

In this, the soil gets saline through natural processes over a long period of time either due to a high salt content of the parent material or in groundwater. Two natural processes involved in this, first by the weathering processes, which is related to the breakdown of rocks to marl and eluvium, thereby subsequent release of soluble salts which accumulates in low lying pans. Second one is the deposition of oceanic salt carried in wind and rain and is mainly sodium chloride. The amount of salt stored in the soil varies with the soil type, being low for sandy soils and high for soils contain a high percentage of clay minerals. It also varies inversely with average annual rainfall.

1.5.2 Secondary salinisation:

Secondary salinisation generally develop due to human interventions such as land clearing and the replacement of perennial vegetation with annual crops, inappropriate irrigation practices viz. irrigation with high salt water, application of fertilizers without soil testing, insufficient drainage etc. It alters the hydrologic balance of the soil, when compared to water applied and water consumed by the plant through transpiration. Land Clearing and irrigation changed this balance, practising flood irrigation that provided more water than the crops could use. The excess water raises water table and mobilises salts previously stored in the subsoil and brings them up to the root zone. Plants use the water and leave the salt behind until the soil water becomes too salty for further water uptake by roots. The water table continues to rise, and when it comes close to the surface, water evaporates leaving salts behind on the surface and thus forming a ‘salt scald’. The mobilised salt can also move laterally to water courses and increase their salinity. This all together added with the illiteracy have caused secondary salinity, sodicity or waterlogging a growing menace to the present world.
1.6 Effect of salinity on soil fertility:

Saline soil differs greatly from the normal soil in many important morphological features, physical properties and chemical characteristics. Excessive amounts of salt have a range of adverse effects on the physical and chemical properties of soil, microbiological processes and plant growth (Yuang et al., 2007; Zhu, 2002). Due to salinity, the soil lacks, structural B-horizon and is very poor in humus substance (below 1%). They are generally deficient in nitrogen and phosphorous elements (N\textsubscript{2} and P\textsubscript{2}O\textsubscript{5}). The microbial activities were found to be low under saline-sodic conditions. The amount of salt stored in the soil, varies with the soil type, its low for sandy soil and high for clay. It also fluctuates with the rainfall having almost inverse relationship.

Texture plays an important role in irrigation i.e. if the soil texture is light, it would be more tolerant to the saline water. Electrical conductivity (EC) of loamy sand soil is 83% of the irrigation water. EC of irrigated soils was 1/2, ¾, one and half times of EC of waters actually used for irrigation, on soil containing clay less then10, 10-20, 20-30% respectively.

Water, which is present in the soil between the pores, in the form of capillary, is the only source by which plant can absorb nutrition, necessary for its growth and development. The excess of soluble ions can damage soil structure by increasing the osmotic potential of the soil solution. As in the case of chloride salts, they are highly soluble and capable of salinising the soil in the proportion of their own salt content, whereas sulphates salinise half of their concentration. Normally the negatively charged clay particles are held together by divalent cations; however, in the case of sodic soil, when monovalent cation such as Na\textsuperscript{+} displace the divalent cations on the soil complex and the concentration of free soluble salts is low, the complex swells and the clay particle disperse which further reduces the pore size. That is it occupies the cation exchange and thereby makes the soil compact, which ultimately blocks the soil aeration. It creates a water deficit situation at the root zone despite of the presence of water there.
1.7 Effect of salt stress on plant:

Soil salinity is a problem of grave concern, because it adversely affects growth and development of plants, especially in arid and semi-arid regions (Pitman & Läuchli; 2004). Those plants holding a healthy soil have a higher probability to cope up the abiotic stress conditions (Gao et al., 2007). Salt stress has been found to disrupt several physiological processes leading to reduction in growth and yield (Yurtseven et al. 2005). Salts, by their own do not get concentrated in the growing tissues which inhibit their growth: meristematic tissues generally exclude the salt, which they get from phloem and rapidly elongating cells can accommodate the salt that arrives in the xylem within their expanding vacuoles. So, the salt taken up by the plant does not directly inhibit the growth of new leaves but its continuous supply could cause serious injury to the older leaves. Chloride induces elongation of the palisade cells, which leads to leaves becoming succulent.

Plants in the saline soil, not only suffer from high sodium levels, but are also affected by some degree of hypoxia. Due to salinity, osmotic potential of the cell sap becomes high, which in turn restricts ion exchange that plays an important role in cell elongation and enlargement. Reduced shoot growth caused by salinity originates in the growing tissues, as a result leaves and stem of the diseased plant appear to be stunted (Munns et al., 1982). When the water containing a large amount of dissolved salt is brought into contact with a plant cell, the protoplasmic lining starts to shrink. This action is known as plasmolysis, which increases with the concentration of the salt solution and if the condition remain grim and unabated, the cell collapses, and if the salt reaches the transpiration stream, it not only alters the metabolic activity of the cells of the leaves by inhibit enzymatic activity but also reduces photosynthesis in it, a sign of ion-excess effect of salinity (Greenway and Munns, 1980). The cause of the injury is probably due to the salt load exceeding the ability of the cells to compartmentalize salts in the vacuole. The direct effects of salts on plant growth may involve: (a) reduction in the osmotic potential of the soil solution that reduces the amount of water available to the plant, causing physiological drought.
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To counteract the problem of salinity, plants have to maintain lower internal osmotic potentials in order to prevent water movement from roots into the soil (Feng et al., 2002; Jahromi et al., 2008). (b) toxicity of excessive Na\(^+\) and Cl\(^-\) ions towards the cell – the toxic effects include disruption to the structure of enzymes and other macromolecules, damage to cell organelles and plasma membrane, disruption of photosynthesis, respiration and protein synthesis (Juniper and Abbott, 1993; Feng et al., 2002). Alternatively, they might build up in the cell walls and dehydrate the cell (Flowers et al., 1991) which results in wilting up.

Saline water exerts drastic effect on the growing crops like the stunted height, small leaves, marginal burn on leaves (especially lower, older leaves), early senescence, reduction in grain size and quality. It also reduces dry matter content and increase root to shoot ratio, which attributes reduction in the number of seed, spikelet and tiller. This may be due to excess accumulation of the ions in cell sap as stated by Walter (1955). Excess of salt can induce delay in seed germination and high concentration of it in the root zone depresses the plant growth by increasing the osmotic pressure of the soil solution.

It forces the plant to spend more energy to absorb water and to maintain the ionic environment of the cell against the concentration gradient. Salts mostly damage the young plantlets, which are in the process to acclimatize with the surroundings. It has also been reported that salinity imparts change in the level of plant hormones, such as abscisic acid (Moorby and Besford, 1983) and cytokinin. Several steps involved in protein synthesis are very sensitive to changes in the ionic environment and may result in impairment of protein metabolism (Wyn Jones et al., 1979). Salt affects cellular and nuclear volume, induces endopolyploidy, and induces nucleic acid and protein synthesis (Leopold and Willing, 1984).

It is well known that crop production is low in saline soil, mainly due to salt toxicity to plants leading to a decrease in plant water-holding capacity, the imbalance of nutrient uptake, and toxicity of ions towards plant photosynthesis (Katerji et al. 1998; van Hoorn et al. 2001).
1.8 Relative salt-tolerance limits of crops:

Every plant possesses its own limit to face the salinity or any other stress factor and it’s of immense importance to know the ability of these crops to grow well under abiotic stress conditions so that we could make use of our farm efficiently. Salt tolerance limit causing fifty percent crop yields reductions, of some important crops were as follows

(i) **Field crops:** like Barley (*Hordeum vulgare*), Cotton (*Gossypium hirsutum*), Sugar beet (*Beta vulgaris*), Wheat (*Triticum aestivum*), Sugarcane (*Saccharum officinarum*), Groundnut (*Arachis hypogaea*), Maize (Zea Mays) Soybean (*Glycine max*), Rice (*Oryza sativa*), Sorghum(*Sorghum bicolor*) Sunflower (*Helianthus annuus*) could tolerate up to 18, 16.0, 15.0, 13.0, 10.0, 4.9, 6.0, 8.0, 10.0 and 14.0 ds/m respectively.

(ii) **Vegetable crops:** like Beet, garden (*Beta vulgaris*), Spinach (*Spinacia oleracea*), Tomato (*Lycopersicon esculentum*), Cabbage (*Brassica oleracea*), Cauliflower (*Brassica oleracea*), Potato (*Solanum tuberosum*), Cucumber (*Cucumis sativus*), Sweet Potato (*Ipomoea batatas*), French bean (*Phaseolus vulgaris*), Carrot (*Daucus carota*), Bell pepper (*Capsicum annuum*), Sweet corn (*Zea mays*), Radish (*Raphanus sativus*), Onion (*Allium cepa*), could be cultivated with 9.6, 8.0, 8.0, 7.0, 6.0, 6.0, 6.3, 6.0, 3.5, 4.5, 5.0, 6.0, 5.0, and 4.0 ds/m respectively.

(iii) **Fruit Crops:** like Date (*Phoenix dactylifera*), Pomegranate (*punica granatum*), Grapefruit (*Citrus paradisi*), Grape(*Vitis spp.*), Pear (*Prunus communis*), Apple (*Malus sylvestris*), Orange (*Citrus sinensis*), Almond (*Prunus dulcis*), Apricot (*Prunus persica*), Strawberry (*Fragaria spp.*), could be grown up to salt limit of 18.0, 8.4, 4.9, 6.7, 4.8, 4.8, 4.8, 4.1, 3.7 and 2.5 respectively.

(iv) **Forge Crops:** like Kallar grass(*Leptochloa fusca*), Bermuda grass (*Cynodon dactylon*), Mustard (*Brassica campestris*), Alfaalfa(*Medicago sativa*), Barley, hay(*Hordeum vulgare*), Cowpea(*Vigna unguiculata*), could be successfully cultivated for salt concentration up to 22.0, 15.0, 14.0, 9.0, 13.5 ds/m.
1.9 Approaches for saline soil Reclamation:

Salts exclusion from the rhizosphere is perhaps the most effective and long lasting way to ameliorate or even eliminate the detrimental effects of salinity but it’s quit expensive; the process requires large quantities of water and effective soil drainage. As a result, it is not always possible or feasible to carry out a reclamation operation. A number of different approaches involving removal or reducing the salts are being practised.

1.9.1 Physiochemical Methods:

1. **Gypsum**: The most commonly used method for replacing the sodium ions is by applying large quantities of gypsum (calcium sulphate) to the soil and followed by water pounding. The applied gypsum slowly dissolves in the water releasing calcium ions which replace sodium ions from the soil into the downward moving water which is finally carried out of the field in the drainage water. The reclaimed soils can become saline again unless appropriate management practices are followed.

2. **Scraping** (removal of surface soil): Due to continuous evaporation from the field, salt tend to concentrate on the surface of the soil. The top soil can be scraped and transported out of the field. It has been practiced in many parts of the world (Qureshi et al., 2003). But, as the top soil is the most fertile part of the agricultural field, this approach cannot be considered as the efficient way of reclamation.

3. **Leaching**: Pre-sowing irrigation with good quality water: It is the process of dissolving and transporting the soluble salts by the downward movement of the water through the soil. Irrigation of the salt affected field with good quality water prior to sowing helps in the removal of salts from the top soil. It is accomplished by ponding adequate amount of water on the soil surface by means of dikes or ridges and thereby maintaining downward water movement through the soil. This helps in promoting better seed germination and seedling establishment. The benefits of this practice have been documented in a long-term study by Goyal et al (1999). During leaching, the applied water that passes through the root zone; which carries salts below the zone. Leaching without proper drainage would be ineffective and if more than 30% passes through the root zone, the cost of drainage, or the risk of rising water tables, becomes far great.
4. **Mulching**: Spreading crop residue over the soil, such as straw, reduces evaporation from the soil surface which restricts the upward movement of salts. Reduced evaporation also reduces the need to irrigate. As a result there would be no problem in seed germination but it is not feasible for the deep rooted crops or the field where the water table is high.

5. **Deep Tillage**: Salts generally tend to accumulate closer to the surface of the soil. Deep tillage would mix the salts into a much larger volume of soil and hence reduce its concentration and impact. This would improve water infiltration and simultaneous downward movement of salts. But this process is time consuming, laborious and expensive and is not the long lasting reclamative measure.

6. **Drainage**: It is the process by which one can get-rid of excess water from the soil. If it is accomplished over the soil surface it is known as surface drainage and if it flows through the soil it is called as subsurface drainage. Insufficient aeration of the soil may directly relate to the inadequate drainage, which results in stunted growth of plants and severe damage to the rhizosphere.

7. **Incorporation of Organic matter**: Incorporating crop residues or green-manure crops improves soil tilth, structure, and improves water infiltration which provides safeguard against adverse effects of salinity. To make this effective, regular additions of organic matter (crop residue, manure, sludge, compost) must be done but again this will not solve the problem of salinity completely. As such, we have to strive to develop technologies that are acceptable to the farmers both in economic and the environment terms.

1.9.2 **Biological methods**:  
As we are aware of the fact that, for the normal healthy growth of a plant, their lies a synergistic contribution of the microflora, that is present in the immediate vicinity of the rhizosphere of that particular plant species. Since, normal microflora in the soil is extremely sensitive to saline stress; therefore, salt tolerant microflora should be investigated.
Arbuscular Mycorrhizal Fungi (AMF) have been known to occur naturally in saline environments (Khan, 1974; Allen and Cunningham, 1983; Pond et al., 1984; Rozema et al., 1986; Sengupta and Chaudhuri, 1990; Carvalho et al., 2001; Hilderbrandt et al., 2001; Harisnaut et al., 2003; Yamato et al., 2008; Wang and Liu 2001; Rozema et al. 1986). Several studies have demonstrated that inoculation with mycorrhizal fungi improves growth and productivity of plants under a variety of salt stress conditions (Al-Karaki et al., 2001; Feng et al., 2002; Giri et al., 2004). As AMF play an important role in protecting plants against salt stress, they have been considered as bio-ameliorators of saline soils (Feng et al., 2002). Numerous attempts have been made in order to improve the salt tolerance of crops i.e. by traditional breeding programs and by genetic transformation of plants but they are not able to achieve commercial success due to complexity of trait: genetically and physiologically (Flowers and Flowers 2005; Munns R., 2005).

Considering the role played by mycorrhiza in promoting plant growth, further studies are needed to study ameliorative response under salinity stress with special concern to economically important crops in Indian context. Below given is a brief summary, on basic aspects of ‘Mycorrhiza fungi’.

1.10 Mycorrhiza:

The word mycorrhiza gets its name from Mykes= mushroom in association with the rhiza= roots; given by the German botanist ‘Frank’ (1885) and has initiated world wide interest in it. In the broad sense, it is a symbiotic association of a fungus with the root of the plant. Early land plants, dwelling in a rich carbon atmosphere have had abundant carbon compounds which they transform into the soil, deficient in minerals.

Nature has evolved a mechanism to get rid of the excess of carbon compound and to fulfill the need of nutrients. As a result mycorrhizal association came into existence, which also provide the plant with growth hormones it needed and protect the plant against pathogens. It’s a highly interdependent mutualistic relationship, where the host plant receives mineral nutrients, while the fungus obtains photosynthetically derived carbon compounds (Harley & Smith 1983).
Events in the first stage of fungi evolution were (i) Due to carbon rich exudates on the root surface a signal is transferred to the receptor of the fungi and it starts to trace the signal pathway to the root. (ii) then, it develops the mechanism to enter the host cell without causing harm to it. (iii) Now, the fungus becomes an important channel of transporting minerals to the plant and thereby assessing the beneficial carbon compounds necessary for its development.

It has been assessed by the studies of palaeobotanical, morphological and DNA based phylogenies that the first bryophytes like land plants, in the early Devonian (400 million years ago) had endophytic associations similar to that of VAM, even before the root evolved (Mark C. B., 2002). Molecular evidence provides greater insight, suggest that they diverge from other living organisms deep in the Proterozoic era, 1500 millions years ago (Wang et al 1999). As the terrestrial plants came into existence in early Paleozoic era 440 million years ago, it is probable that the first terrestrial fungi colonized land, long before plants did.

In the course of evolution, in the late Mesozoic era (135 million years ago) where the angiosperms were in full fledge ectomycorrhizal, ericoid, and orchid mycorrhiza, along with the non mycorrhizal roots got evolved. Mycorrhizae are highly evolved, mutualistic associations between soil fungi and plant roots, which helps the plant to grow better in the adverse conditions. The partners in this association are members of the fungus kingdom (Basidiomycetes, Ascomycetes and Zygomycetes) and most vascular plants (Harley and Smith 1983, Kendrick 1992, Brundrett 1991). Mycorrhiza mostly gets associated with the secondary root of the plants, and in all mycorrhizal association only the cortical part of the roots, gets involved; this is the part between the epidermis and the vascular tissues figure 1.

1.10.1 Classification of Mycorrhiza:

Mycorrhiza has been classified according to the associations they form with their respective hosts. On the basis of which there are seven different types involving distinct group of fungi and the morphology pattern.
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Fig. 1 Diagram represents ecto and endo Mycorrhizal association.

(i) Endomycorrhiza Mycorrhiza: This is the most common and found associated from Bryophytes to Angiosperms. They are classified in the family Endogonaceae, order Endogonales and class Zygomycetes of the phycomycetous group (Trappe and Schenck, 1982). Hyphae penetrate the root cortical cell and form the fan like structure as a point of exchange known as arbuscules and a lipid filled globular structure known as vesicles.

(ii) Ectomycorrhiza: These were found associated to roots of woody perennials (Marks and Kozlowski, 1973). The fungi belong to families of Basidiomycotina and Ascomycotina. Fungal sheath is present around the growing secondary roots; there is no hyphal penetration of cells.
(iii) **Ericoid mycorrhiza**: Here the fungal members are usually Basidiomycotina and one *Hymenoscyphus*, belong to Ascomycotina. This is found in the roots of the plants belonging to the order Ericales. In this, the hyphal branches penetrate the cortical cells.

(iv) **Orchid mycorrhiza**: These fungi belong to the family Basidiomycotina and colonise only the member of family Orchidaceae. Here the septate hyphae enter the cell and form coils known as “peltrons”.

(v) **Ectendo mycorrhiza**: Characteristics are same as Ectomycorrhiza but the hyphae penetrate the root cell and form coil.

(vi) **Arbutoid mycorrhiza**: They are Basidiomycetous and form symbiosis with plant roots belonging to the order Ericales. In this the septate hyphae penetrate only the epidermal cells.

(vii) **Monotropoid mycorrhiza**: These belong to Basidiomycotina colonizing achlorophyllous member of family Monotropaceae of Angiosperms. They form haustorial pegs inside epidermal cells.

### 1.10.1.1 **Endomycorrhiza Mycorrhiza**:

As there are seven different types of mycorrhiza, but the Arbuscular mycorrhizal fungi, another name of endomycorrhiza, got its name from the association it form with their host, is the most abundant type which is found associated with more than 80% of the total plant species. They play an important role in determining the diversity in the tropical and subtropical ecosystem. The AMF is placed in Zygomycete, order Glomales in the genera namely *Glomus, Acaulospora, Scutellospora, Gigaspora, Paraglomus* and *Archaeospora* (Morton & Redecker, 2001). These fungi are considered to be primitive due to their relatively simple spores, and lack of sexual reproduction. They are incapable of growth without plants. Ribosomal genome diversity within these fungi is consistent with the absence of sexual reproduction and makes it difficult to define species and individuals (Hosny et al., 1999; Pringle et al 2000).
Introduction and Review of Literature

Studies on the application of Mycorrhizal fungi for the improvement in plant productivity under abiotic stress conditions

The AMF form two phase mycelial system; an external which remain in the close proximity with the roots of the host plant and an internal, where the mycelium intracellularly forms a hyphal network in the cortex region of the root. The external mycelium is dimorphic in nature and consists of permanent, coarse, thick-walled generally aseptate hyphae and numerous fine, thin walled highly branched lateral hyphae which become septate at maturity and are ephemeral in nature. The thick walled mycelia detect the entry point on the external surface of the root and form a lens shaped multinucleate structure which is 20-40 μm long called the ‘appressoria’. This appressorium is the gate pass for the mycorrhiza to enter and form association with the host plant, from where the hyphae spread intracellularly in the root cortex.

In the cortical cells they form arbuscules, which are dichotomously branched, microscopic tree like structure they formed in the early phase of the association having life not more then 4-15 days. The arbuscule is surrounded by the host plasmalemma and they were only responsible for the bi-directional transfer of the nutrients and the carbon compounds. There is another important structure, which were reported to form in some genera of AMF known as ‘vesicles’, which is generally developed in the later phase of the association, as a terminal or intercalary swellings of hyphae. Vesicles are thick walled, spherical to oval in shape which uses to store oil and polyphosphate granules, which are utilized by the plant under deficiency condition.

1.11 Applications of Mycorrhizal fungi:

Most of the experiments have indicated that vesicular-arbuscular mycorrhiza (VAM) alter water relation of its host plants. This property is of great importance when AMF could be used as bioinoculant. Mycorrhizas have many potential applications especially in agricultural practices.

- **As a Biofertilizer:** Mycorrhizal biofertilizer increase the growth and surface area of the feeder roots. It accomplish the above processes by forming mental in case of ectomycorrhiza and spreading mycelia into the soil that provide the plant with better access to the limited nutrients available in the rhizosphere.
Plants can better confer growth because of the availability of such nutrients as S, Ca, Fe, Br, Cu, P, Mn, Zn etc. resulting in enhanced growth. Mycorrhizal association results in the beneficial physiological effect on host plant by increasing uptake of Phosphorus (Gerdemann, 1968).

- **As a natural Buffer**: In tissue culture problems generally arise with raising plants which include poor rooting in case of cuttings and high mortality rate during acclimatization. Mycorrhizal inoculation of cuttings has been found to enhance rooting and enhance growth at nursery stage as well as in field planting as it avoid transient transplant shock.

- **To enhance soil quality and Structure**: Mycorrhiza is reported to absorb nutrients directly from the decomposing organic litter, which prevent it from being washed away through leaching (Went and Stark, 1968). Physical entanglement of plant roots and hyphae of mycorrhizal fungi are known to be involved in binding of micro aggregate with macro aggregate. The process of this soil aggregation may be enhanced by the secretion of chemical exudates by the hyphae of Mycorrhizal fungi.

- **Role in sustainable agriculture**: Crops associated with mycorrhiza shows improved growth, health and resistance to abiotic and biotic stress as compared with non–mycorrhizal controls. *Vesicular Arbuscular Mycorrhizal* fungi, is helpful in soil conservation and wasteland management. Mycorrhizal symbiosis is essential for the normal growth of many forest plants, so they also help in forestation. It has been found that *Mycorrhizal* fungi inoculated seeds, shows early germination than the noninoculated one.

- **As an ameliorator**: Mycorrhiza are also known for their phytoremediation role; it protect the plants from adverse conditions such as heavy metal contaminated sites, high salt level, water logging and drought conditions etc.

There is a positive effect of VAM on morphology, metabolism and protective adaptation of host plants in the condition of drought stress. Mechanism by which VAM can enhance resistance of drought stress in host plant may include many possible aspects: (1) VAM improves the properties of soil in Rhisosphere. (2) VAM enlarges root areas of host
plants, and improves its efficiency of water absorption. (3) VAM enhances the absorption of P and other nutritional elements, and then improves nutritional status of host plant. (4) VAM activates defence system of host plant quickly. (5) VAM protects against oxidative damage generated by drought. (6) VAM affects the expression of genetic material (Song, 2005). VAM symbiosis improved absorption capacity, and increased the growth of its host plant, which was proved in sugarcane, mung bean, apple, orange, wheat, tomato and wild jujube (Wu Q. et al 2004).

1.12 Mycorrhiza and abiotic stress: Present status

The main focus as our subject of study was on the Endomycorrhiza (VAM) because it’s the most primitive in the group and not only occur in the majority of the plant families (Smith and Read, 1997) but also play a vital role in sustainable agriculture. Many reports document the occurrence of AM in diverse crops of intensively cultivated arable soils. AMF are not only a major component of soil fertility they also play a crucial role in the regulation of soil biological activity. AMF represent up to 20% of the dry biomass of the mycorrhizae (Bethlenfalvay et al., 1982), that can account for 25% of the biomass of the soil microflora and fauna together and has the capability to extend the mycelium more then 9cm beyond the roots. AMF have direct access to plant fixed carbon and distribute this throughout the soil, which is further utilized by soil microorganisms. They can increase plant growth under low-fertility conditions and towards different kind of stressful environment.

Many greenhouse experiments have shown that they could promote plant growth under salinity stress (e.g., Zuccarini and Okurowska 2008; Wu et al. 2010) by providing nutrients (Ruiz-Lozano and Azcón 2000). Several studies have demonstrated that inoculation with AMF improves growth and productivity under salt stress in both glycophytes and halophytes (Asghari et al. 2005; Sannazzaro et al. 2006; Giri et al. 2007). From the research work of many workers, it indicates that VAM was able to alter water relations and played a great role in the growth of host plant in the condition of drought stress (Augé 2001; Sheng et al. 2008).
Bois et al., (2006) have demonstrated that the mycorrhiza isolated from the sodic site were more resistant to higher salt levels (300mM). Carvalho et al., (2004) had shown that the isolates from the salt marsh born Arbuscular mycorrhizal fungi were more tolerant to NaCl condition than the mycorrhiza present at another location. Studies conducted on Medicago sativa (alfalfa) at high salinity level (43.5 dsm\(^{-1}\)) when inoculated with Glomus mosseae found to increase \(N_2\) acquisition, nodule number (R. Azcon et al 1997). Mycorrhizal fungi can form symbiosis with field crops under a range of environmental conditions (Mosse, B 1986; Al-Karaki et al 1997). Mycorrhizal symbiosis is a key component in helping plants survive under adverse environmental conditions (Augé et al. 1992). The efficacy of mycorrhiza has been already proved from the research findings of various workers. Arbuscular mycorrhizal fungi (AMF) widely occur in saline soils (Aliasgharzadeh et al. 2001). Studies conducted by Ghazi N et al., 2001 on two tomato cultivars (sensitive to salt stress and tolerant to salt stress) inoculated with Glomus mosseae at three salt conc. 1.4, 4.9 and 7.1 dsm\(^{-1}\) found to enhance the growth and nutrient concentration in both of these cultivars. Nutrients uptake were found to be higher in salt sensitive variety than tolerant.

Arbuscular mycorrhiza has been shown to improve growth of numerous salt-intolerant crop plants under salt stress conditions (Gupta and Krishnamurthy, 1996). Arbuscular mycorrhizal fungi can alleviate some of the negative effect of high levels of salts and increase plant tolerance to soil salinity (Clark R.B. et al 2000). They have reported reduction in the detrimental effects of soil associated plant stresses such as lack of nutrients, organic matter, high salinity or high pH (Salvia and Williams 1992; Entry et al 2002). Recent investigations showed that salt tolerance of some plants increases under saline conditions, when they are mycorrhizal with certain Arbuscular mycorrhizal fungi (Aboulkhair et al., 1994; Jindal et al., 1993).

Feng and Tang, (2002) studied the tolerance of the maize plant in saline soil in relation with Glomus mosseae species which increased dry weight and chlorophyll concentration in leaves. Munir et al, (2003) while working with the barley at E.C. 16.6 ds/m reported increase in phosphate uptake, increased height and subsequently dry weight of plant, when inoculated with Glomus intraradices.
Studies conducted on *Lycopersicon esculentum* (tomato) at varied salt stress, showed increase in the performance of plant when inoculated with *Glomus mosseae* moreover, high yield in case of root, shoot, dry mass with an increase in leaf area was reported (Ghazi et al., 2000). Interestingly these results indicated that the mycorrhizal tomato plant had greater nutrient acquisition than non-mycorrhizal plants at all salinity levels. In the same year, Ruiz-Lozano & Azcon (2000), found that out of the two species (11AG8903 of *Glomus deserticola* and *Glomus species*) exposed to the range of salinity 1.1 to 1.7ds/m. Increasing salinity reduced the root weight in control and *G. deserticola*-colonized plants but both mycorrhizal treatments had increased root development as compared to control plants.

According to Aliasgharzadeh et al, (2001) abundance and distribution of Arbuscular mycorrhizal fungi in the Tabriz plain was observed where the salinity ranges from 7.3 to severely high 92 ds/ and at 20 ds/m salinity also, barley roots showed 5% mycorrhizal colonization. Gupta & Krishnamurthy (1996) demonstrated the salt and acid tolerant capacity of *Arachis hypogaea* when associated with the mycorrhizal fungi *Glomus caledonium* species. Their findings suggested that Mycorrhizal fungi help the plants to cope up with salt stress condition effectively. They reported that the root colonization was supported effectively upto certain limit by this *Glomus sp*. Raghuwanshi & Upadhyay, (2004) correlated mycorrhizal infection to the various amendments being used to reclaim saline soil has found that the colonization is host dependent and it does not depend on the stress condition.

Sengupta & Chaudhuri (2002), while studying on the relation between *Arbuscular mycorrhizal* fungi and mangrove plant, found that the Glomalean endophytes colonize in roots of even the non-mycorrhizal plant families *viz*. Chenopodiaceae, Arnaranthaceae, Aizoaceae and hence it was concluded that these fungi help the mangrove plants to sustain effectively in saline condition. While working on the effect of phosphorus, salinity and moisture on vesicular arbuscular mycorrhizal association in Neem; Pande & Tarafedar (2002) reported that among the other strains of Glomus Sp., *Glomus mosseae* was found to be the most salt resistant species.
Giri and Mukerji (2004) conducted a field experiment on two leguminous plants, “Sesbania aegyptica and Sesbania grandiflora” under salt stress condition (1.58 s/m), exploiting the *Glomus macrocarpum* species, reported more than 40% increase in shoot dry biomass and nodulation by more than 200%. Beside this, the intake of phosphate and magnesium has increased subsequently with the low absorption of sodium ion. David et al, (2006) studied the relation of the colonization of Arbuscular mycorrhizal fungi on a number of mangrove plants along the seashore of Nicobar Island and reported that phosphate solublising bacteria (PSB) increase the efficacy of Arbuscular mycorrhizal fungi that support the plants in saline stress condition. Recently, Gupta & Rautary (2005) have observed reduced colonization of AM fungi in terms of percentage and number of vesicles/root and spore count in the soils in maize, but the plant could grow under such stressed condition of high sodium chloride.

This clearly shows the potential of the AM fungi in the context of plant growth. The mycorrhizal symbiosis therefore is an important potential strategy for phytorestoration schemes (Dodd et al 2002; Renker et al 2004). It is also very important to utilize indigenous organisms for the application because of their adaptation to those particular soil conditions. All these findings enhance our zeal, towards reclamation process.

**1.13 Lag in agricultural productivity:**

The proposed work in 2006-07 was under taken on account of the problem faced by the farmers of Maharashtra under sugarcane cultivation. Sugarcane crop is the lifeline of the farmers mainly at Vidharbh, Western region and southern part of Maharashtra. Here mostly four varieties are dealt with i.e. Coc-671, Co-86032, Co-8014 and Co-85004, but they are not able to abet the salt stress condition, prevail along the region. As we are concern about the upsurge in fuel prices, increase in sugarcane production would definitely prove as an aid, after the ethanol blending approval by agricultural minister.
Major constraints for cane productivity as follows

- Non-availability of high yielding varieties.
- Dearth of good quality seeds.
- Improper water management.
- Use of imbalanced fertilizer doses etc.

If we look at Maharashtra, about 136 lakh ha land of the cultivable land area is confined to degradation. Out of that over 10 lakh ha. suffers from salinity/alkalinity and 6.4 lakh ha area rendered uncultivable. Loosing about - Rs 2500 crores in agriculture; Rs. 540 crores in forest; Rs.1500 crores in livestock. Uptill now the applications of physico-chemical methods have been done towards the reclamation of the saline soil, but these amendments have their own drawbacks. The development of salt tolerant crops or desalination of soil by leaching excessive salts, though successful, is not economical for sustainable agriculture (Hamdy 1990; Cantrell and Linderman 2001).

Fig. 2 State wise area under sugarcane production.

- Maharashtra – 61.8 ton/ha; Karnataka – 105 ton/ha; Tamilnadu – 106.8 ton/ha; etc.
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Table. 2 Yearwise sugarcane production detail.

<table>
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<th>Commercial Crops Production (Million Tonnes)</th>
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<td>Crop/year</td>
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<td>Sugarcane</td>
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Above Figure. 2 and Table 2 clearly indicates that despite large acreage under sugarcane cultivation, total productivity remains low and has been stagnating for the last few decades. In Maharashtra, salinity brings with it other related agricultural problems and in the present scenario, the project stands to be of immense importance, and this will clarify from the following statements.

- India stands second in the sugarcane production after Brazil, though we know that the total area under sugarcane production is large as compared to Brazil. So, there is a great opportunity ahead to become the top most exporter of sugar.

- India, in the past was known for its export of sugar but today, the condition has become such a mean that we have to import sugar in the current fiscal year 2006 – 2007 July, to maintain the upsurge in the price of the sugar, in the country.

- In India, farmers have started diverting their attention from cultivating the sugarcane crop, because it has two main reasons: the unavailability of water, due to inconsistency of the rainfall and the other is the low income from the field due to decrease in the per hectare yield.

- In Maharashtra, sugarcane is the major cash crop, but due to flood irrigation practices and indiscriminate application of fertilizers, fertile agricultural land has been transformed into saline soil, especially in Sangli, Kolhapur and Jalgaon districts. Salination of soil has drastically reduced the yield of sugarcane.
In Maharashtra there are approximately 12 lakh cane growers, out of that 95% of the cultivators are small and medium farmers, they contribute hugely to the sugar industry but receive minimal returns; as cane yields have dropped from 40 to 25 tons a hectare.

The crisis has affected sugar factories too. Only 165 of the 212 registered factories in Maharashtra are functional that too have accumulated loans close to 2000 crore rupees. As many as 120 factories have opted to take the centers bailout package of rupees 1850 crore (The Hindu, 23 (17)).

In the current scenario it becomes a prime importance to pay heed towards the cane production, as it is not only concerned with the livelihood of poor farmers, but also a great aid in overall development. So, it is better to go for a biological, environment friendly and economical method, like the inoculation of mycorrhizal fungi; which is well known not only for its masking effect against the ion toxicity, but also for enhancing yield and quality of the product by increasing the nutrient and mineral uptake even in the disturbed and polluted field sites. On this background the objectives for this study were planned and are

1.14 Objectives of the Research:

1. To study the characteristics of the soil, from which the Mycorrhizal species will be isolated.
2. Screening studies: To screen the mycorrhizae, which would tolerate abiotic stress conditions particularly salt stress.
3. Application studies: To study the effect of Mycorrhizae inoculation on test plant (wheat/sugarcane) under abiotic stress conditions.
4. To test the feasibility of such application at pot level and field level.