A Novel Strategy to Improve Crop Productivity under Sustainable Agriculture

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Abstract

Shift in crop ecology due to climate change is a major concern for world's food production. It is predicted that global warming is going to be a major challenge for future crop improvement programmes. It is associated with several abiotic stresses such as heat, drought, flooding and salinity are threatening food security and drastically reducing crop productivity under sustainable agriculture. Therefore, there is a great necessity of scientists to develop strategy for combating these menaces. The objective of this paper is to develop new technologies for selecting crops for tolerance to various abiotic stresses. Concerted efforts have been directed by scientists to evaluate world germplasms to select crop genotypes tolerant to various abiotic stresses and finally selected cultivars with high tolerance but with poor agronomic background. Resistance to biotic and abiotic stress is negatively related to yield. In this respect, insignificant progress has been achieved to increase production under sustainable agriculture in farmers. Therefore, there is a need to adopt a new strategy for increasing crop production under sustainable agriculture. This paper addresses to put forward novel strategies and developing technologies from pipe line hybrids. Here, author described simple, efficient and cheap techniques for identifying tolerant lines of several fields including few vegetable crops for several abiotic stresses such as drought, salinity, flooding etc. The strategy is outlined by developing new efficient technologies (standardization and testing its reliability), screening and selecting pipeline hybrids and varieties, confirming the selected lines in the field under stress conditions and transfer of technology from lab to land.

1. Introduction

With increasing population there is an increasing demand of food and other commodities but the productivity of crops is endangered with ever increasing global warming, heat stress, drought, salinity and other abiotic stresses, thereby threatening food security and causing starvation death especially in African countries. Under this situation, it needs to be mentioned that 1/5th arable land of the world is arid and semi-arid and 2/3rd of it is saline; thereby affecting crop productivity severely. Under this situation, the selection of drought and salt tolerant crop cultivars is considered as a feasible alternative to sustain the productivity of the crops in these regions.

Though enormous researches have been undertaken, the results of which are published in reputed journals on various aspects with special reference to the mechanism of resistance to these stresses and their management, but insignificant progress has been attained for their practical utility in the farmer's fields. It has been argued by the eminent plant breeders namely T.J. Flowers that salinity and drought resistances are complex traits, very difficult to manage for genetic improvement. However, good successes have been achieved to use molecular biology such as marker assisted selection, transgenic tools, but the practical use of these techniques are beyond the reach of developing countries for high cost involved in developing and transferring these technologies to farmers' field.

Successful establishment, survival and productivity of a crop mainly depend on adaptation of the crop to environmental conditions (abiotic) in which the crop grows. Several morphological, anatomical, physiological, biochemical and molecular mechanisms play important roles in adaption of the crop to abiotic stress factors.Various abiotic stresses reduce crop productivity remarkably. It mainly affects the various growth stages which ultimately resulted loss in the yield. Physiological process such as flowering, grain filling and maturation was highly effected abiotic stresses. Plant metabolisms which include photosynthesis, enzyme activity, mineral nutrition, and respiration are affected by several abiotic stress factors such as drought, salinity, heat, and chilling, stress. In the context of abiotic stress, there is a need to develop ideal strategies to screen & identify stress resistant lines. To achieve the success, both inter-disciplinary and multi-disciplinary research should work together.

Global warming affect crop productivity in various ways as depicted in the following diagram (Figure 1).

In this aspect an expansion of industrialization, agriculture and deforestation leads to emission of green house gases viz. CO_2,

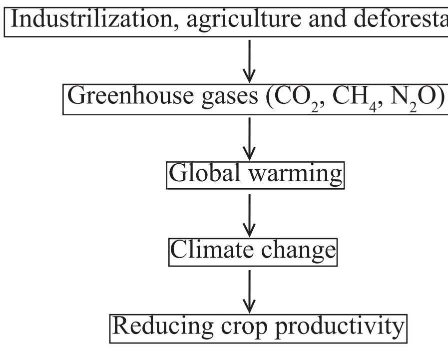


Figure 1: Global warming affect crop productivity

CH_3, N_2O which in turn increase global warming. This causes climate changes thereby reducing crop yield

During the last decades the emission of green house gases owing to different components are depicted below. It is observed that from 1970 to 2004, there is an increase of green house gases from 28 to 49%, fossil fuel emitting maximum amount of CO_2 as noted below.

2. How will climate change due to increasing GHGs?

Many changes projected by the models that are robust and reliable. Examples of changes that are very likely over the next 100 years include:

- Planet will warm, more so in middle and high latitudes than in the tropics
- Hydrologic cycle will speed up
- Area covered by snow and sea ice in winter will decrease
- Sea level will rise
- Increased flooding in some areas
- Change in vegetation pattern, ecological imbalance

These changes will be much, much greater than the changes seen over the past 150 years that have been attributed to increased GHGs and aerosols.

3. Impacts of Climate Change on Agriculture

The major effects of change in climate due to global warming on agriculture are-

- Increased growing season at high latitudes
- Increased minimum temperature (crop growth and pest/pathogen effects)
- Continental drying in mid-latitudes
- Changes in timing of stream flow in mid and high latitudes (water availability, etc)
- Changes in heat wave frequency and intensity; change in frost days.
- Changing patterns of drought.
- CO_2 ocean acidification, etc.

Thereby, global warming leads to the drastic changes in climates angering plant and animal lives as mentioned herein.

Under these situations there is an urgent necessity to adopt a viable strategy to increase crop productivity under sustainable agriculture. This involves several steps, 1) development of novel technique for screening crop genotypes for tolerance to several abiotic stresses. In general germplasms are used as sources of resistance for various biotic and abiotic stresses, but resistance is negatively correlated to yield. We adopted a novel technology using pipe lines hybrids/parents with high yielding backgrounds for screening for various resistances such as drought, salinity, heat stresses and so.It may be mentioned here the pipe lines hybrids/parents are selected over multi-location trials on the basis of high yield and adaptation. Therefore, seed companies can contribute greatly to fulfil this objective. These are depicted in the diagrams below.

4. Strategy

Development of Novel techniques to identify and develop abiotic stress tolerance in crop varieties / hybrids

- Crop germplasms are the sources of resistance to biotic & abiotic stresses, but resistance is negatively correlated with yield
- Evaluation of pipeline varieties/ hybrids for the tolerance using the novel technique & their conformation in the field. (Responsibility of breeders, physiologists, entomologists, pathologists)
- To maintain optimum yield under sustainable agriculture(Responsibility of breeders)
- Transgenic crop breeding for abiotic stress tolerance (responsibility of biotechnologists)

4.1. Novel strategies to screen for salinity tolerance

4.1.1. Semi-Hydroponic Technique

We developed a novel technique. Semi-hydroponic for selection of salinity tolerant crop cultivars from pipe line hybrids/parents. In the following diagrams are depicted regional distributions of salt-affected soils as well as salinizations country wise. It is observed that India, Soviet Union and America are greatly affected by salinization.

In the following map of India it is observed that western part of India is affected greatly by salinity which in turn affects crop productivity (Figure 2).

In this technique, the seeds were sown at a depth of 2 cm in a plastic pot (height 13 cm, upper diameter 14 cm, lower diameter 12 cm) filled with cocoa peat and then applying

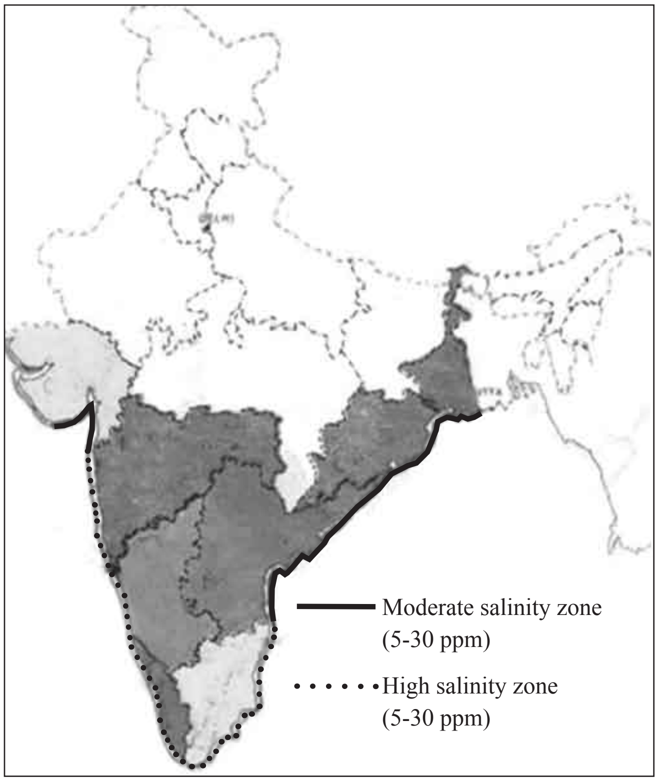


Figure 2: Western part of India is affected greatly by salinity which in turn affects crop productivity). High Salinity areas are Tamilnadu and in western coastal states which includes Maharashtra, Gujarat, Karnataka & Kerala

water or required saline concentration up to two thirds of the pot height (about 70 mm), where the seeds received water by capillarity. The solution, either water or saline was applied only once up to the termination of the experiment (20 days after sowing). To protect seeds from fungal attack, seeds were treated with thiram solution (5 %) for 5 minutes before sowing. Twenty seeds were sown in each pot under control, T_1 (distilled water) along with T_2 (0.2 M NaCl) only to confirm high salinity tolerance. Each of the treatments was replicated thrice for all genotypes. This technique simulates a semi-hydroponic system where the upper layers of cocoa peat medium receive water/ or saline solution only by capillary movement, while the roots are immersed in saturated lower coco peat medium. During capillary movement there is free flow of oxygen owing to constant evapo-transpiration. Observations were recorded for the 20-days-old seedlings. Some growth criteria such as on average emergence percentage, shoot length (cm), root length (cm) as well as dry weight were recorded on the 15th day for four replicas of seedlings.

This technique is highly efficient, repeatable and inexpensive in selecting crop cultivars for salinity tolerance. We present here the salient results on various field and vegetable crops.

High Seedling Emergence (%), Profuse Adventitious Roots observed in salinity tolerant cereal cultivars and hybrids (rice, maize, Figure 3; wheat, and pearl millet, Figure 4). In general with an increase insalinity there was an increase in root elongation/increase in number of lateral roots which function in osmotic adjustment. Crop cultivars selected are well confirmed by the breeders in saline prone areas showing the transfer of technology from lab to the land and vice-versa.

Sufficient research inputs support these findings;

- The scope for enhancing salt tolerance in maize through selection and breeding on the basis of root length. (Khan et al., 2003)
- Nguyen et al. (1997) suggested root characteristics to be associated with water stress tolerance in rice.
- Maiti et al., (1996) reported high genetic variability in maize cultivars (*Zea mays*) for resistance to drought and salinity at the seedling stage.
- Differences in salinity tolerance were found (Manga and Saxena. 1981; Agrawal et al., 1985; Garget al., 1984). Genotypic variability of salinity tolerance is observed and some hybrids were selected for salinity tolerance lines (Maiti, et al., 2009, 2010).
- Maiti et al., 2006 studied genotypic variability in salinity tolerance of rice hybrids and their parents and thereby giving opportunity to the breeders for genetic improvement for salinity tolerance.
- Salicylic Acid could be used as a potential growth regulator to improve salt tolerance in plants (Hussain et al., 2010).
- Maiti et al., 2005 in another study undertook a comparative study on the levels of tolerance to NaCl-salinity of some crop cultivars (sorghum, pearl millet, rice, maize, cotton and sunflower) at early emergence and germination stage.
- Exogenous application of organic chemicals, such as glycine, betaine, proline, or plant growth regulators, or inorganic chemicals to plants under salinity stress (Ashraf et al., 2008).
- Differences among genotypes in yield under stress during flowering and grain-filling were partitioned into differences in yield potential, drought escape, and drought tolerance (Fussel et al., 1991).
- Phenotypic traits related to yield under stress were divided into those reflecting drought escape and those reflecting drought tolerance. (Fussel et al., 1991).
- In the following the responses of few dicotyledon crops such as sunflower, castor (Figure 5) and cotton (Figure 6). The results are shown in brief.
- Increased taproot length & production of profuse lateral roots

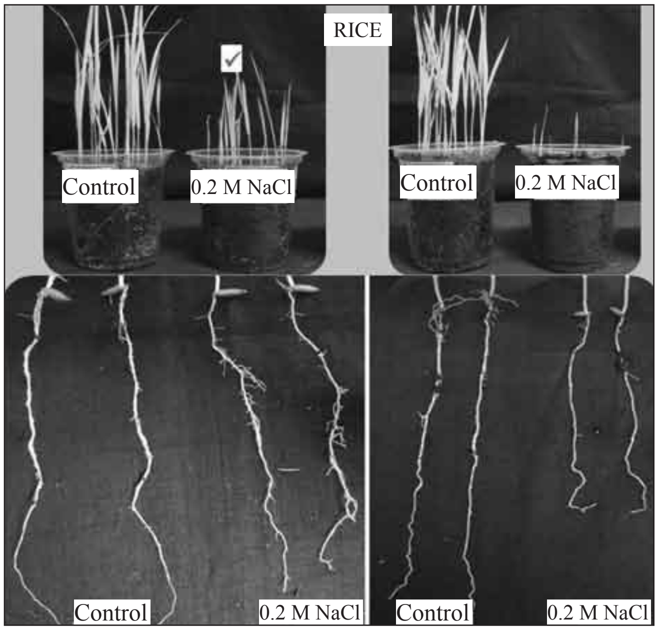
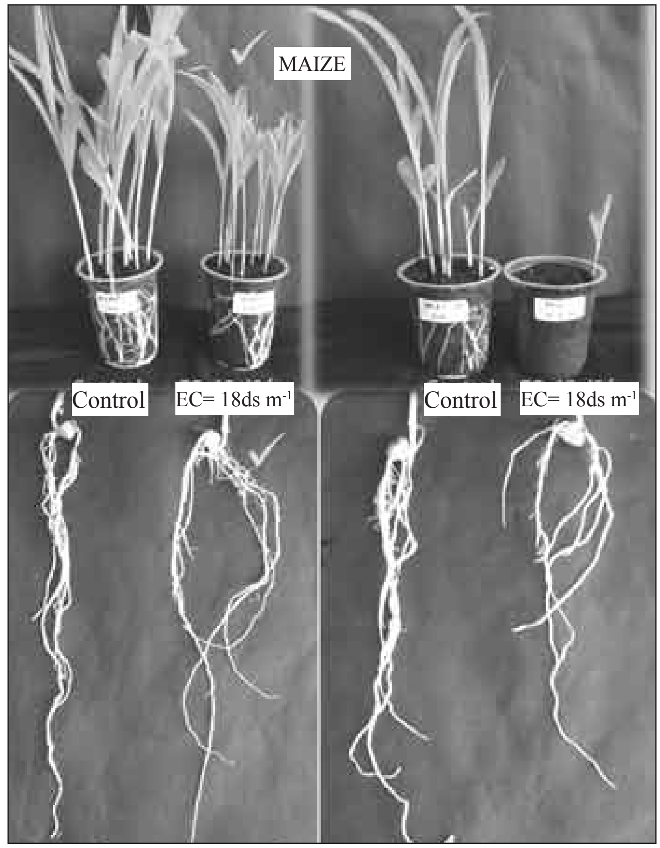


Figure 3: Screening of rice (top) and maize (right) hybrids for salinity tolerance by using semi-hydroponic technique. High seedling emergence (%), profuse adventitious roots was observed in salinity tolerant hybrids



under saline condition in tolerant hybrids of cotton, Sunflower for maintaining osmotic adjustments as observed in the case of the monocotyledons cereals.

We also studied the responses of salt tolerant and susceptible cotton cultivars exposed at 35 days with increasing levels of salinity concentration (Figure 7). It is observed similarly to the responses at seedling stage salt tolerant cotton cultivars showed an increase in root length up to 0.2 mNaCl, but the reverse is observed in susceptible ones.

In the following schematic diagrams is outlined the breeding for salinity tolerance (Figure 8)

4.2. Drought resistance

4.2.1. Method

The methodology involves by applying drought cycles in Polyhouse (ranging from 15-20 days) depending on genotypes, evaporative demand & selection pressure and also experiences of the researchers.

Drought resistant varieties of rice, wheat and maize (Figure 9) have shown:

- High percentage of seedling survival
- Deep root system
- Stay green character
- Good recovery after drought period

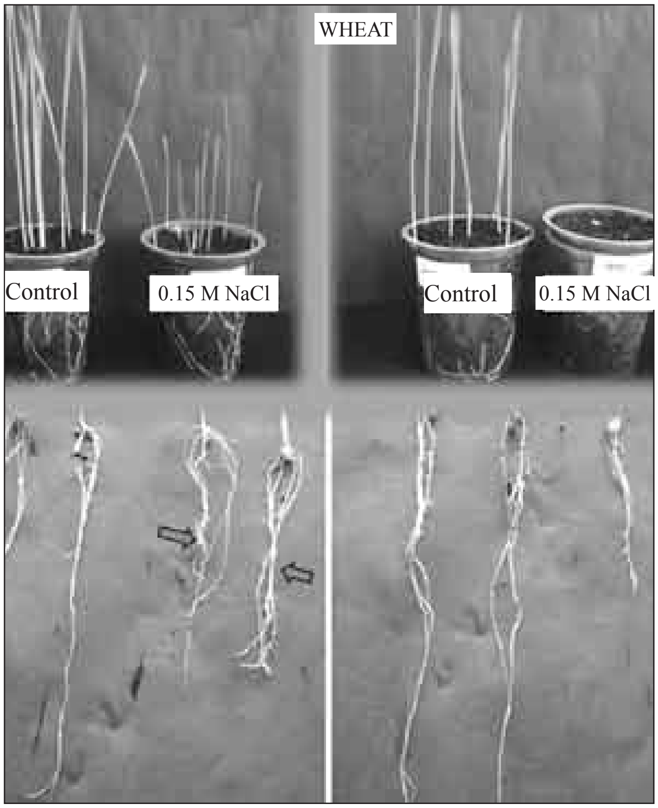
These findings support the findings of various researchers mentioned below.

- Root characteristics, predominantly root depth, are likely to increase plant water uptake, dehydration avoidance mechanisms, and rice resistance to drought effects (Serraj et al., 2009)
- Root length intensity is related to drought resistance (Merril and Rawlins, 1979)
- Low canopy temperature during drought stress is a possible indicator of plant water status and drought avoidance mechanisms (Jones et al., 2009 cited by Henry et al., 2011), such as deep root growth, that allow the plants to continue water uptake and transpiration that cools the leaves.

Drought resistant maize possess deep and inclined robust root system in the form of 'V' occupying less area compared to drought susceptible. This could be used as selection criteria for drought resistance

Schematic root ideotypes (Figure 10 & 11) are put forward which needs to be confirmed by future study.

- Drought tolerant inbred lines showed distinct root system than sensitive, by presenting larger root length, surface area, volume, and greater contribution of roots to total root length (Fernando Rodrigo, et al., 2008).
- Scientists Hamblin and Tennant in the 1987 suggests that rapid rates of root elongation and deepening of roots can be potential parameters plant breeders select for in drought resistance
- Jordan et al., (1983) have shown that deeper rooting would increase crop yield under drought stress.



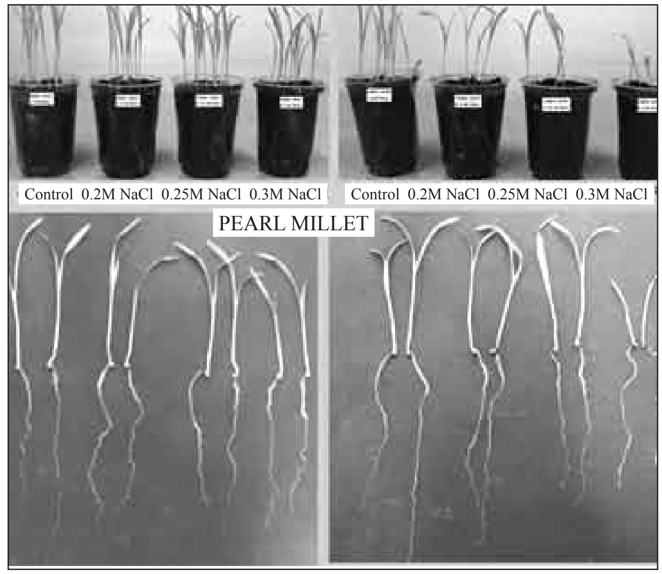


Figure 4: Screening of wheat (Left)varieties and pearl millet (top) hybrids for salinity tolerance by using semi-hydroponic technique. High Seedling Emergence (%), profuse adventitious roots was observed in salinity tolerant entries

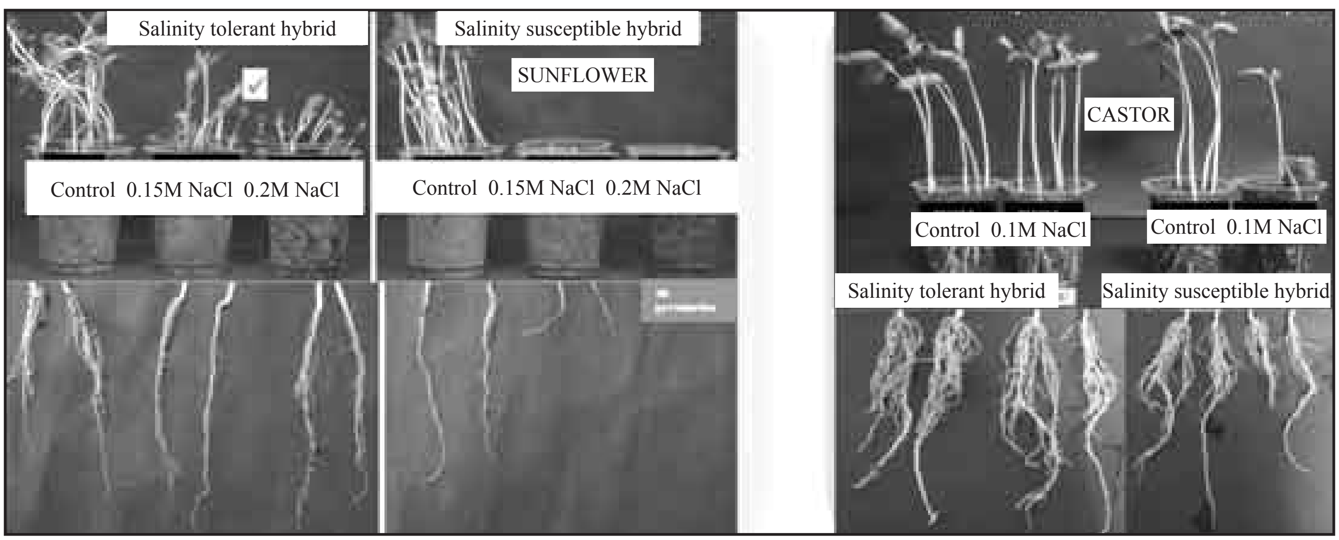


Figure 5: Screening of sunflower and castor lines for salinity tolerance by using semi-hydroponic technique. High Seedling Emergence (%), increased taproot length & Production of profuse lateral roots under saline condition in tolerant hybrid

- Scientists found that the terminal drought tolerant lines do have a relatively more profuse rooting in the deeper layers than the sensitive lines (Vadez et al., 2005).
- This Technique is simple & well confirmed in the field.
- Well Accepted by Plant Breeders of Field & Vegetable Crops

Brick chamber is considered as efficient technique in studying root systems of both drought resistant and susceptible crop cultivars. Drought tolerant cultivars possess profuse and deep root system compared to the susceptible ones (Figure 12).

4.2.2. Mechanisms for adaptation to drought

- Drought resistant hybrid showing Increased root length and inclined lateral roots (robust root system) under drought condition

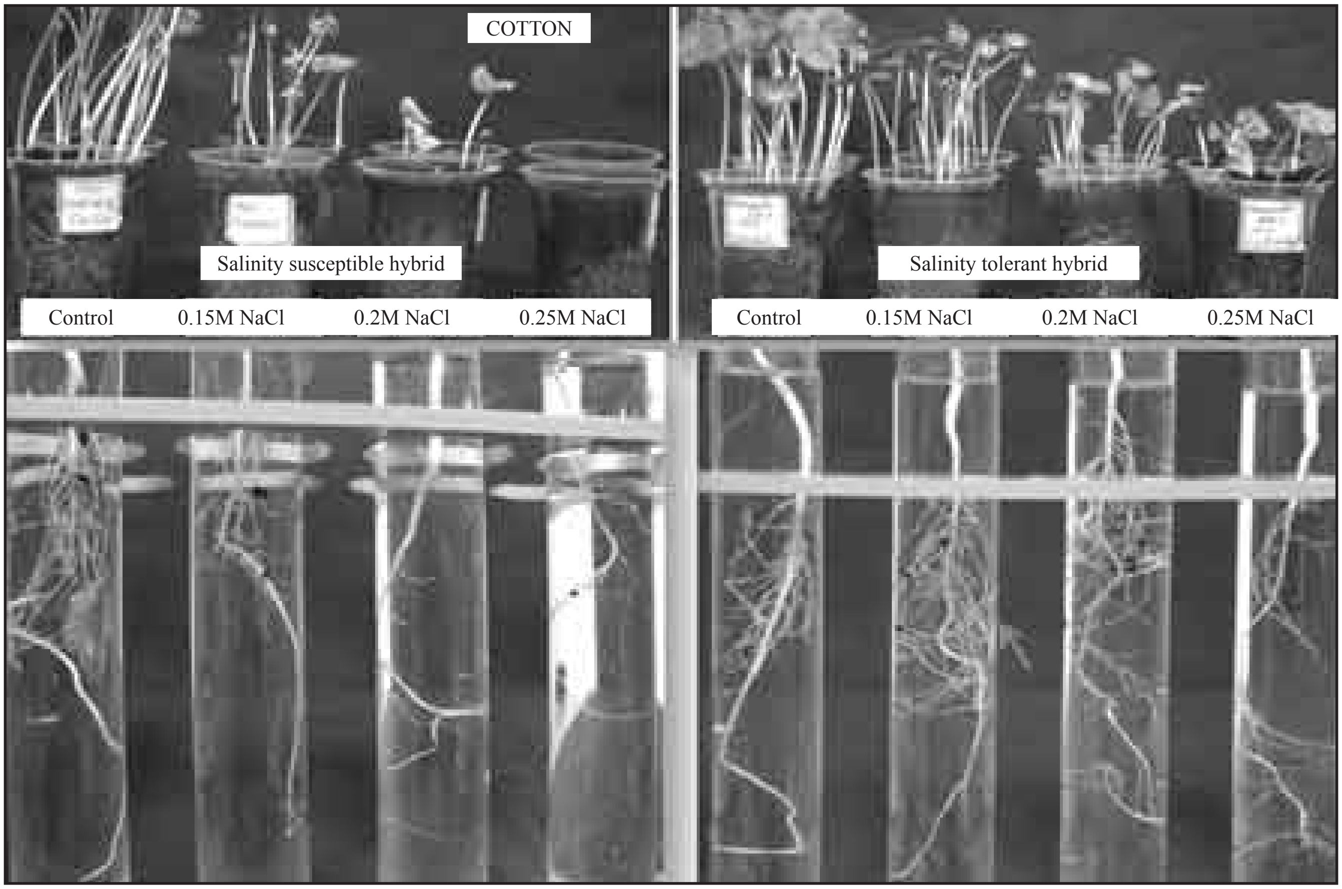


Figure 6: Screening of cotton lines for salinity tolerance by using semi-hydroponic technique. High emergence % and seedling vigour under Saline Condition is observed in salinity tolerant hybrid. Increased taproot length & production of profuse lateral roots under saline condition in tolerant hybrid

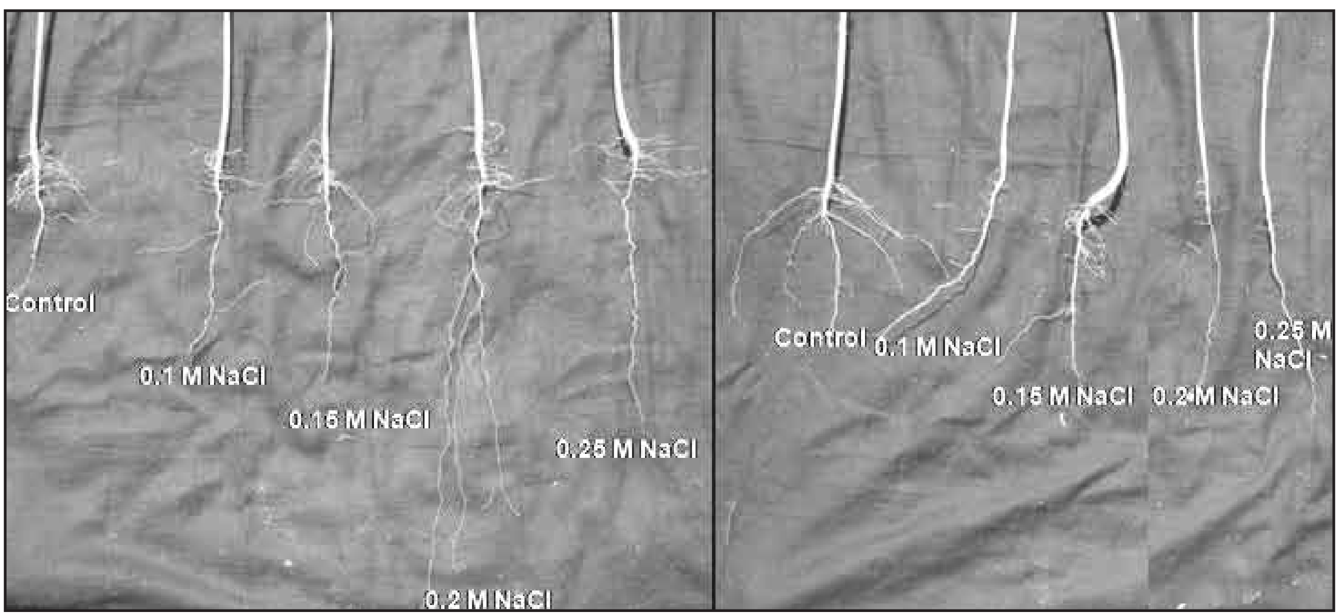
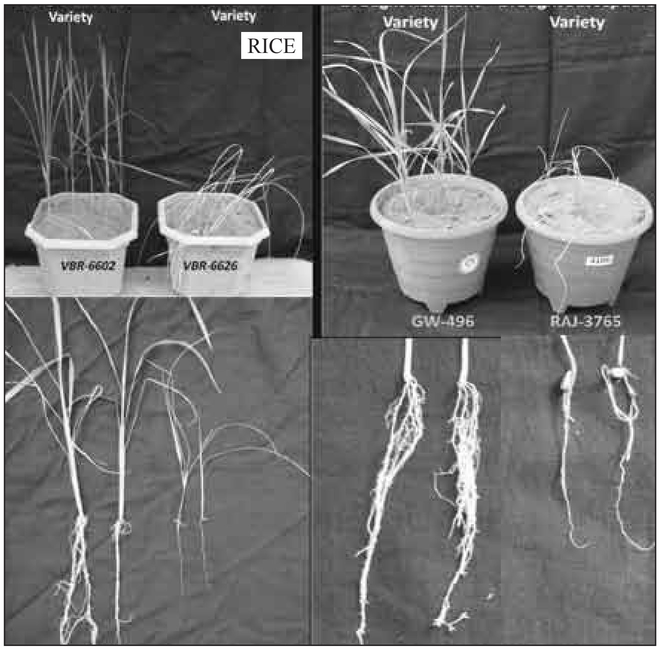


Figure 7: Response of salinity tolerant cotton hybrid to salinity stress at adult stage (35 days). In spite of gradual accumulation of salt in the soil (applied 8 times) showing root elongation for osmotic adjustments. Production of profuse lateral roots & increased tap root length in salinity tolerant hybrid was observed.



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Preliminary screening of pipeline hybrids and parents

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Novel techniques-semi-hydroponics

↓

Selectionof hybrids and parents

↓

MASS SCREENING UNDER MEDIUM TO HIGH SALINITY STRESS

↓

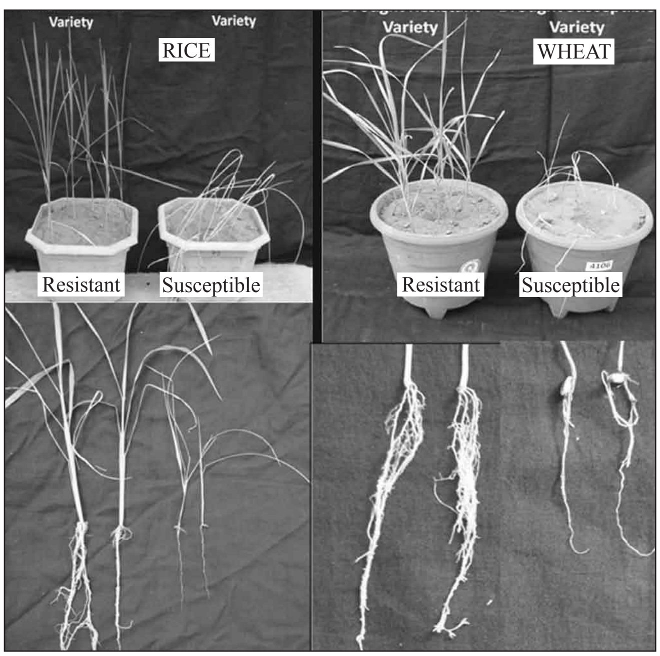
Salinity tolerant hybrids need to be tested under salinity prone areas

↓ ↓

Materials to Breeders
1. Testing of selected salinity tolerant hybrids for adoption in MLTs in saline areas
2. Utilization of selected tolerants in the crossing programme

Materials to Biotechnologist
1. Marked Assisted Selection
2. Molecular breeding and transenic research

Figure 8: Schematic representation of developing lines for salinity tolerance



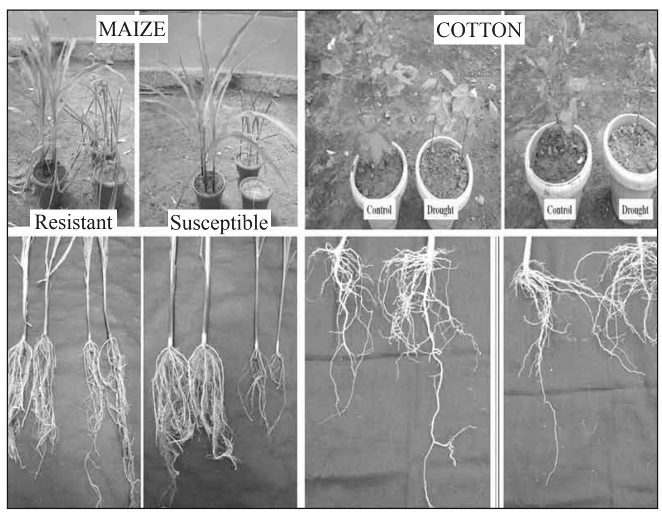


Figure 9: Salinity tolerant cotton hybrid to salinity stress at 35 days. In spite of gradual accumulation of salt in the soil (applied 8 times) showing root elongation for osmotic adjustments. Profuse lateral roots & tall tap root in salinity tolerant hybrid.

• Thick leaves with compactly arranged palisade tissue reduce transpiration (Figure 14 a). The resistant line showed tightly arranged mesophyll cells in flag leaves, fully developed vascular bundles and some closed stomata (Gui-lian et al., 2009)

• Selection on the basis of yield through multilocation testing under optimal input conditions will perform better under low input environment by virtue of their high yield potential. Byrne et al., (1995)

• Use of secondary traits, in addition to grain yield, as selection criteria for tolerance to different abiotic stresses have been suggested (Banziger et al., 1997).

• Drought resistant hybrids showing high percentage of

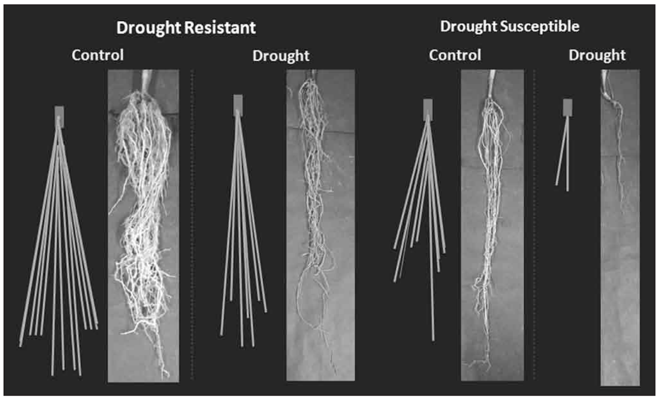


Figure 10: Inclined deep rooting & robust root system are the characters of drought resistance. Profuse & deep Root system in control could be an indicator for drought resistance

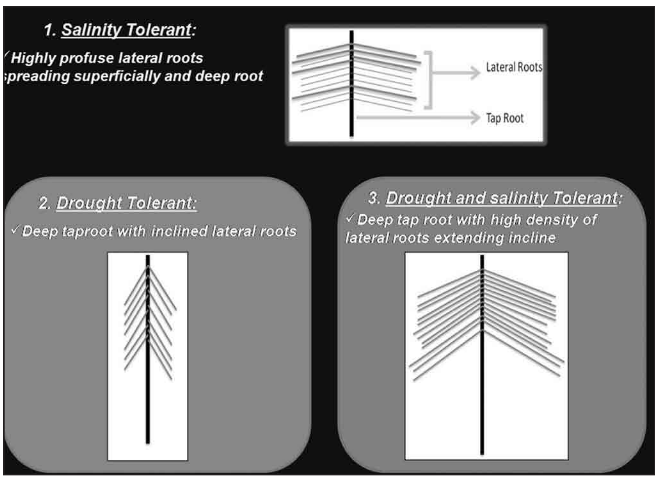


Figure 10: Root ideotypes for salinity and drought resistance in dicots

Root study in brick chamber at flowering stage under control condition

Figure 12: Drought resistant Maize has deep and inclined robust root system. This could be used as selection criteria for drought resistance

stomatalclosure in drought condition to minimize the loss of transpiration.

- Stout petiole – thick cuticle, more number of compactly arranged Collenchyma layers offers thickness in drought resistant hybrids (Figure 13a &b)

Activation of Stress Response Genes by Signal Perception and Transduction

- Abiotic stresses such as salinity, drought, cold, and heat are believed to activate receptors, probably located in the plasma membrane.
- These receptors transduce this perception via pathway intermediates (e.g. protein kinases or phosphatases) to transcription factor proteins.
- Transcription factors in the nucleus activate genes that are important for recovery from stress by binding to specific promoter regions of these responsive genes.

4.3. Heat tolerance

Seeds sown in soil and seedlings have grown up to 10 days. Seedlings exposed to heat stress. In case of cotton high percentage (80-90%) of seedling survival was observed after completion of 25 days under 42-45^{0}C temperature (Figure 14). At flowering high percentage of pollen viability was observed in heat tolerant cotton cultivars.

The heat stress considerably reduced anther dehiscence and pollen fertility rate in sensitive, whereas, its effects were much smaller in tolerant (Yun-Ying Cao et al., 2008).

4.4. Flooding Tolerance

Seedlings were grown normally up to 30 days. After 30 days continuous flooding stress for 10 days were given (stems were Submerged up to 4 cm). Experiment was terminated after 40 days and observed percentage of seedling survival, shoot length, and tap root length, number of lateral roots and number of newly formed roots on the submerged portion of stem.

In flooding susceptible hybrids, growth rate was drastically reduced and survival of seedling was less compared to tolerant hybrids. Flooding tolerant hybrids showing the formation of roots on the submerged portion of the stem (equal to the water level) under flooding condition and observe oxygen from its environment. This is an escape mechanism in most of the hydrophytic plant communities

For extreme flooding stress cotton seedlings were grown normally up to 20 days in big size plastic pots (diameter 30 cm and length 40 cm) from the date of emergence. After that Continuous 30 days period of flooding stress is given at 20 days old cotton seedlings. Growth of the flooding susceptible hybrids were drastically reduced compared to tolerant hybrids. Root system and lower portion of the stem was highly damaged

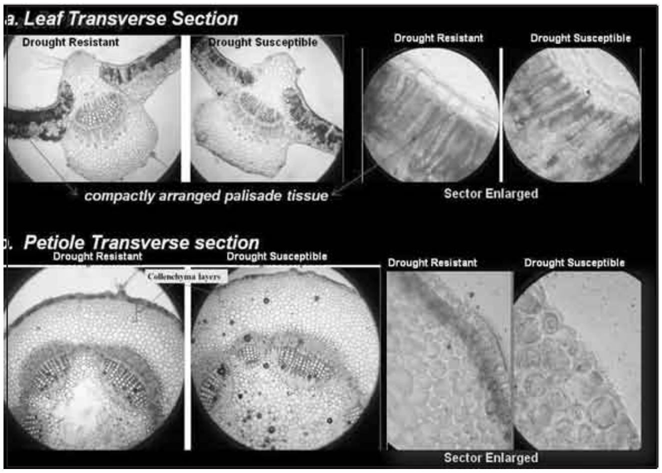


Figure 13a: Compactly arranged palisade tissue was observed in drought resistant cotton hybrids
b: More number of compactly arranged collenchyma layers in drought resistant hybrids offer thickness in drought resistant hybrids

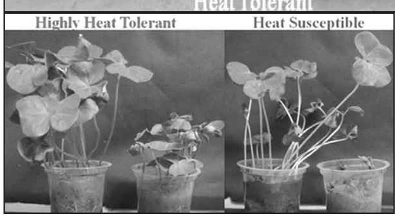


Figure 14: Screening Cotton Hybrids for Heat tolerance at Seedling Stage. High Percentage seedling survival in heat tolerant cultivars

in flooding susceptible hybrids. The same procedure was applied for maize (Continuous flooding for 30-40) days. Higher number of brace roots and aerenchyma formation in roots was observed in case of flooding tolerant cultivars (Figure 15)

Selection Criteria

- High percentage of survival under flooding condition
- Formation of aerenchyma in the root cortical cells.
- Production of roots on submerged portion of the stem

Adaptations to Flooding Stress

- Production of Fleshy roots on the submerged portion of the stem in Flooding tolerant hybrids of cotton
- Formation of Brace Roots in tolerant maize lines
- Formation of aerenchyma in the root cortical cells & facilitates the movement of oxygen for root metabolism.

4.5. Cold tolerance

Seeds are sown in cold conditions (8-10 °C). Temperature was recorded daily at 3 intervals throughout the experiment and counted number of seeds emerged and calculated emergence (%).

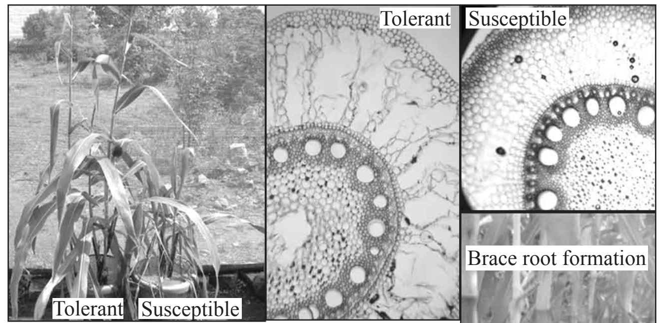


Figure 15: Screening for Flooding Tolerance in Maize. Higher number of brace roots and aerenchyma formation in roots was observed inflooding tolerant cultivars

High percentage of seedling emergence under Cold (8-10 °C) in tolerant hybrids (Figure 16)

5. Relevance of These Screening Techniques in Crop Improvement

Selection for abiotic stresses often faces the problem of improper phenotyping. In crop improvement, higher efficiency of selection is most crucial to develop high yielding abiotic stress tolerant genotypes. Root based screening methods described above are very simple techniques that can be performed on a large number of genotypes within a very short time. This provides opportunities for screening more segregation populations within a very short timeframe. This will allow breeder to perform selection at proper stage. Moreover these methods are very cheap, economic, easy to replicate and can be applied to any crop species.

Perhaps more important applications of these screening strategies are in developing genotypes with multiple abiotic stress resistance. In practice, drought stress is often associated with heat stress, while salinity stress reduces water availability and may impart physiological drought conditions in the field. Since development of effective design for creation of multiple abiotic stresses is very difficult and sometimes practically impossible the above mentioned screening techniques can be simply used to identify candidate genotypes from large germplasm set or segregating population. Once a smaller subset with desired root distribution, suitable anatomical features and crop stand are identified, further in depth research works can be initiated for shortlisting a few genotypes as donor genotypes in transferring multiple stress tolerance to desired high yielding lines and hybrids.

6. Future Lines of Research

- Exploring Genotypic variability for Abiotic stress tolerance
- More emphasis need to be given on root studies in case of

Response of cotton and maize hybrids to cold temperature- showing variability in emergence
High percentage of seedling emergence under cold (8-10 ^{0}C) in tolerant hybrid

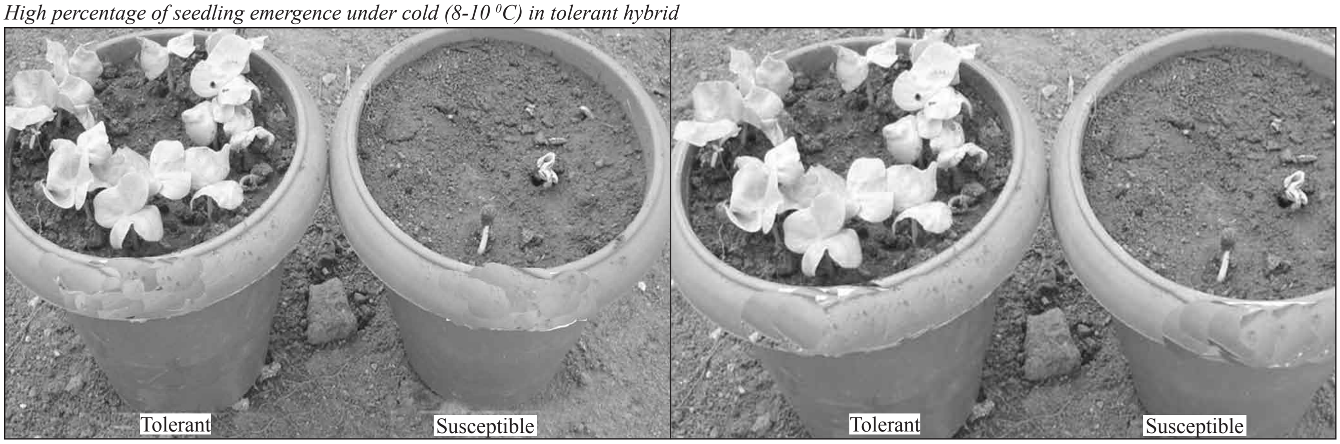


Figure 16: Screening for Cotton & Maize Hybrids for Cold Tolerance

Salinity & Drought Tolerance

- Utilization of selected lines n breeding programme
- Evaluating progeny by standard methods
- Conforming the tolerance under stress in field conditions
- Transgenic crop breeding for abiotic stress tolerance (Biotechnologist)

7. Related References

Ashraf, M. Athar, H.R., Harris P.J.C., Kwon, T.R., 2008. Some Prospective Strategies for Improving Crop Salt Tolerance. Advances in Agronomy 97, 45-110.

Byrne, P.F., Bolanos, J., Edmeades ,G.O., Eaton, D.L., 1995. Grains from selection under drought verses multi-location testing in related tropical maize populations. Crop Science 35, 63-69.

Fernando Rodrigo De O.C., Frederico Ozanan M.D., Antonio Carlos D.O., Angela Maria S., Epaulo Cesar, M., 2008. Morphological attributes of root system of maize genotypes contrasting in drought tolerance due to phosphorus stress. Revista Brasileira de Milho e Sorgo, 7(2), 113-127.

Fussell, L.K., Bidinger F.R., Bieler. P., 1991. Crop physiology and breeding for drought tolerance: research and development. Field Crops Research 27(3), 183-199.

Gui-lian, Z., Li-yun, C., Shun-tang, Z., Hua, Z., Guo-hua, L., 2009 Effects of High Temperature Stress on Microscopic and Ultrastructural Characteristics of Mesophyll Cells in Flag Leaves of Rice. Rice Science 16(1), 65-71.

Henry, A., Gowda, V.R.P., Torres, R.O., McNally, K.L., Serraj, R., 2011. Variation in root system architecture and drought response in rice (*Oryza sativa* L.): Phenotyping of the OryzaSNP panel in rainfed lowland fields. Field Crops Research 120, 205-214.

Jordan, W.R., Dugas Jr. W.A., Shouse, 1983. Strategies for Crop Improvement for Drought-Prone Regions. Agricultural Water Management 7, 281-289.

Hussain, K., Nawaz, K., Majeed, A., Khan, F., Lin, F., Ghani, A., Raza, G., Afghan, S., Zia-ul-Hussnain, S., Ali. K., Shahzad, A., Alleviation of salinity effects by exogenous applications of salicylic acid in pearl millet (*Pennisetum glaucum* (L.) R. Br.) seedlings. African Journal of Biotechnology 9(50): 8602-8607.

Khan, A.A., Rao, S.A., McNeilly, T., 2003. Assessment of salinity tolerance based upon seedling root growth response functions in maize (*Zea mays* L.). Euphytica, 131, 81-89.

Maiti, R.K., Pawar, R., Rodriguez, H.G., Rajkumar, P. Vidyasagar, Macro Vinicio Gomez meza .2009. Salt tolerance of pipeline Bt-cotton (*Gossypium hirsutum*) hybrids subjected to NaCl stress International Journal of Agriculture, Environment and Biotechnology 2(2), 125-132.

Maiti, R.K., Amaya, L.E.D., Cardena, S.I., Dimas, A.O., Rosa-Ibbara, M.D.L., Castillo, H.D.L., 1996. Genotypic variability in maize cultivars (*Zea mays* L.) for resistance to drought and salinity at the seedling stage. Journal of Plant Physiology 148, 741-744.

Merrill, S.D., Rawlins, S.L., 1979. Distribution and Growth of Sorghum Roots in Response to Irrigation Frequency. Agronomy Journal 71, 738-745.

Nguyen, H.T., Babu, R.C., Blum, A., 1997. Breeding for drought resistance in rice physiology and molecular genetics considerations. Crop Science 37, 1426-1434.

Maiti, R.K., 2010. A Novel Technique for Evaluating and Selecting Crop Cultivars for Salinity Tolerance: its Progress. International Journal of Bio-resource and Stress Management 1(1), 51-53.

Serraj, R., Kumar, A., McNally, K.L., Slamet-Loedin, I., Bruskiewich, R., Mauleon, R., Cairns, J., Hijmans, R.J., 2009. Improvement of drought resistance in rice. Advances in Agronomy 103, 41-98.

Vadez, V., Kashiwagi, J., Krishnamurthy, L., Serraj, R., Sharma, K.K., Devi, J., Bhatnagar-Mathur, P., Hoisington, D., Chandra, .S, Gaur, P.M., Nigam, S.N., Rupakula, A., Upadhyaya, H.D., Hash, C.T., Rizvi, S.M.H., 2005. Recent advances in drought research at ICRISAT: Using root traits and rd29a:DREB1A to increase water use and water use efficiency in drought-prone areas. Poster presented at the International drought II conference, Rome 24-28 September, 2005.

Yun-Ying, C., Hua, D., Li-Nian, Y., Zhi-Qing, W., Jian-Chang, Y., 2008. Effect of Heat Stress During Meiosis on Grain Yield of Rice Cultivars Differing in Heat Tolerance and its Physiological Mechanism. Acta Agronomica Sinica 34(12), 2134-2142.