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Salinity/sodicity tolerance of *Acacia ampliceps* and identification of techniques useful to avoid early stage salt stress

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(Khalid Mahmood)

List of Abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
%	Percent	K	Potassium
BCR	Benefit cost ratio	Kg	Kilogram
C	Carbon	M	Meter
Ca^{2+}	Calcium	M ha	Million hectare
CEC	Cation exchange capacity	Mg^{2+}	Magnesium
Cl^{-}	Chlorides	Na^{1+}	Sodium
cm	Centimeters	No.	Number
CO_3^{2-}	Carbonates	PH	Negative logarithm of hydrogen ion activity
Conc.	Concentration	PHs	pH of saturated soil paste
CRD	Completely randomized design	Ppm	Parts per million
Cu.m	Cubic meter	RCBD	Randomized complete block design
dS m^{-1}	DeciSiemens per meter	Rs.	Pakistani rupees
EC	Electrical conductivity	RSC	Residual sodium carbonate
EC_e	Electrical conductivity of saturated soil extract	SAR	Sodium adsorption ratio
Expt.	Experiment	SO_4^{2-}	Sulphates
Ft	Foot/feet	T	Treatment
g	Grams	t.ha^{-1}	Ton per hectare
g Kg^{-1}	Gram per Kilogram	TSS	Total soluble salts
G.R.	Gypsum requirement	USDA	United State Department of Agriculture
ha	Hectare	Wt.	Weight
HCO_3^{1-}	Bicarbonates	Yr.	Year

LIST OT CONTENTS

4. RESULTS 39

Salinity/sodicity tolerance of *Acacia ampliceps* and identification of techniques useful to avoid early stage salt stress

ABSTRACT:

Soil and water salinity are major problems of present agriculture in the world as well as Pakistan. Salt-affected area has been reported as 6.8 million hectare in the country. There is limitation of resources for reclamation, water in particular. The alternate approach is to use this huge area by growing salt tolerant plants of economical importance. *Acacia ampliceps* is one of the best options because this plant has not only high salt tolerance but is also rapid growing and very good fodder for sheep and goats. Present studies were conducted to find out the tolerance limits against different type of salt stress under specified conditions of the country. Three studies were accomplished with specific objectives. Plants survived in all the salinity (EC_e 10 – 50 dS m^{-1}) and sodicity (SAR 20 – 50) levels. The collected and statistically processed data of two years studies indicated that plant growth parameters (height, stem diameter, number of leaves and branches and canopy volume) and water uptake reduced significantly with increasing levels of salinity (EC_e), sodicity (SAR) and both of these combined. The percent decreases in growth parameters and shoot dry weight were 50 % with the EC_e 50 dS m^{-1} or SAR 50 or EC_e 30 + SAR 40. Sodium concentration in plant leaves highly increased while K^+, Ca^{2+} and Mg^{2+} decreased with increasing levels of stresses. The negative effect of salt stress was due to osmotic effect as well as specific ion toxicity, especially Na^+. The plant was successful to tolerate salinity and sodicity stress through ion selectivity (keeping K^+: Na^+ ratio comparatively wider) and compartmentation. Growing *Acacia ampliceps* improved the soil health through decreasing EC_e and SAR of the soil underneath the plants. Transplantation of plants in pits refilled with silt or silt + compost proved highly helpful in avoiding early stage salt stress and keeping the growth intact. The message for the farmers from the present studies was that they can earn 1176 € (Pakistani Rs.94084) per annum per hectare by growing *Acacia ampliceps* in 4 hectare of salt-affected land supplemented with one hectare of seasonal fodder and rearing 100 heads of sheep and goats in order to improve their livelihood employment at their farms. This will also decrease further aggravation of lands that occurs if salt-affected lands are abandoned.

CHAPTER - 1

INTRODUCTION

Based on the FAO/ UNESCO Soil Map of the World, the total area of saline soils is 397 million hectare while that of sodic soils is 434 million ha, which are not necessarily arable but cover all salt-affected lands at global level. Out of the current 230 million ha of irrigated land, 45 million ha are salt-affected soils (19.5 percent) and of the almost 1,500 million ha of dry land agriculture, 32 million ha are salt-affected (2.1 percent), to varying degrees by human-induced processes (OLDEMAN *et al*., 1991). Salt-affected lands in Pakistan are estimated at about 6.8 million ha (KHAN, 1998). The area having water table within 5 feet or 152 cm has been reported to be 0.314 million ha while area having water table at 10 feet or lesser is 0.633 million ha (ANONYMOUS, 2003). According to earlier estimates, out of 5.8 million ha salt-affected land, 3.16 million ha are within the canal command area (CCA) and 2.64 million ha are outside the CCA, while 2.93 million ha are cultivated (RAFIQ, 1990). Half of salt-affected area is classified as wasteland (QURESHI, 1993) that is uneconomical to reclaim chemically. It was also estimated that there was a net yearly addition of 0.98 to 2.47 tones salts per hectare, through various sources and each year 0.2 to 0.4 % of total arable land was going out of cultivation because of salinity and water logging (SANDHU and QURESHI, 1986).

The annual losses because of salinity under rice-wheat rotation are Rupees (Rs.) 10 billion (QURESHI, 1993) that equals 16.7 million $ or 14.3 million Euro. QAYYUM and MALIK (1988) computed an annual loss of Rs. 20 billion due to salinity in the irrigated area of Indus plain on account of decreased agricultural productivity. According to SANDHU and QURESHI (1986), salinity and water logging have adverse social and economic effects on communities in Pakistan and about 16 million people are directly affected by this menace (QURESHI and BARRETT-LENNARD, 1998). The problem of salinity and sodicity can be tackled through engineering and reclamation approaches. The engineering approach has been used in Pakistan at national level to control salinity by draining the soil through a network of surface and subsurface drains and tube wells. According to Water and Power Development Authority (1997), more than 19000 public tube wells are operating in the country and 11000 km of drains have been constructed.

The number of private tube wells operating only in the province of Punjab is 0.588 million (ANONYMOUS, 2002). One of the biggest drainage projects underway to dispose of saline effluent is the Left Bank Outfall Drain (LBOD), which will cost around 26 billion rupees. However, according to the reports of International Commission on Irrigation and Drainage (1991), it may carry only about one fifth (i.e., 25-30 million tons) of total salt balance of the Indus basin to the sea each year.

Reclamation of the sodic and saline sodic soils cannot be possible by simple leaching (ABROL and BHUMBLA, 1973; GHAFOOR, 1984). Reclamation of these types of soils involves the use of different amendments like gypsum, sulfur, sulfuric acid, scraping of surface salt and use of good quality water etc GHAFOOR *et al.*, 2004). But due to certain limitations like insufficient supply of good quality irrigation water and high cost of amendments, poor farmers cannot use these methods on a large scale. The saline agriculture another approach is based on growing salt tolerant plant species and use of saline waters to utilize salt-affected soils, has been explored to a lesser extent (QURESHI and BARETT-LENNARD, 1998). However, an understanding of the plant responses to various stresses and the mechanisms that make some species/genotypes more tolerant than others is essential.

Naturally there are two groups of plants with respect to their adoptability under saline conditions. The plants may be sensitive to saline environment; the glycophytes, or can tolerate the salinity; the halophytes (MAAS and NIEMAN, 1978). Halophytes represent an interesting group of plants because of very low water potential and high salt concentration (HELLELBUST, 1976). True halophytes accumulate large amount of Na^+ and Cl^- in higher concentration for osmotic adjustment within their tissues to keep the water potential at desired level. Maintenance of plant growth in the presence of such high concentrations of toxic ions depends on the localization of ions in the tissues and efficient partitioning of solutes between vacuole and cytoplasm (FLOWERS *et al.,* 1977). Crops/varieties are available with high salt tolerance (MAAS 1990; QURESHI *et al.,* 1990a; ASLAM *et al.,* 1993 a), but there is a severe reduction in the yield of different agricultural crops when grown on ultra saline soils. Therefore, these are not economical to grow on these lands (ASLAM *et al.,* 1997a). Instead, the development and maintenance of sustainable agro-ecosystems in highly salt-affected lands will be easier and more economical with perennial salt tolerant plant species such as forage shrubs and trees. At present, in Pakistan 4.3 % area is under forests (AHMAD *et al.,* 1996), whereas at least 25% forests are considered essential for the economy of a country. It is worth mentioning that the current annual consumption of fire wood in the country is 19.70 million m^3, whereas annual domestic energy requirements of Pakistan is equivalent to 61.01 million m^3 fuel wood (ANONYMOUS, 1988). Without making planned and consistent efforts, it would be difficult to reduce this gap. The population of the country, on the other hand, is growing so quickly that land and water are unable to sustain it. Further, to overcome the shortage in food demand, farmers prefer to grow farm crops on good lands with fresh good quality water. It appears that considerable scope exists in the choice of trees for forestation on adverse lands both under dry and irrigated conditions. Adopting tree based strategies to productively utilize adverse lands, could help rural economics both directly, through the economically valuable products provided to the local people (especially fire wood and fodder) and indirectly by helping to initiate or advance the ecological rehabilitation and sustainable agro-redevelopment of ecosystem, is need of innovative attention and care.

Trees have many beneficial effects. These include commercial uses of wood for timber, pulp, fuel, fodder, oil etc. Despite this, tree plantations are also made for shelter and shade purposes and to control wind and water erosion (MARCAR *et al.,* 1995). Besides, ability of trees to lower the ground water table has successfully been tried in many countries, in areas having rising ground water table problems (GEORGE *et al.,* 1993; LEFROY and SCOTT, 1994). Tree plantation may cause a continuous decrease in salinity/sodicity hazard (QURESHI *et al.,* 1993b) and improve the physical properties by their root action (ELKINS, 1985).

Acacia ampliceps Maslin from Fabaceae family (known as salt wattle, Jila jila bush and nyalka) is very highly salt tolerant plant from Australian origin. Therefore, in Pakistan it is known as Australian “Kikar”. It is very fast growing plant. Its leaves, flowers and pods can be fed to sheep and goat. It can be mixed with other fodders in order to feed the cattle. This fast growing dense shrub can be used as wind breaks, soil conservation and stabilization of dunes. It enhances reclamation of salt-affected soils through root action and decomposition of organic matter. Its wood is a good fuel that burns well. The wood is hard and tough, hence can be used as posts and small poles (QURESHI and BARRETT-LENNARD, 1998).

The knowledge about its salinity tolerance in the ecology of Pakistan is deficient in many aspects, especially tolerance to sodicity and planting techniques. The present studies have been planned to answer questions that are presently unanswerable on the basis of generated data. The study will address the deficient corners. Proposed investigations will accomplish the following objectives.

1. The tolerance of *Acacia ampliceps* will be assessed and limits will be quantified with respect to salinity, sodicity and their combinations.
2. The effects of growing this plant on long term basis on the soil characteristics, especially salinity parameters will be evaluated. Similarly, long-term effect of salt-affected soil on plant growth will also be investigated.
3. Some useful transplanting techniques will be identified which may help to avoid early stage salinity stress and prove helpful in better growth of this plant.

The information generated through these studies would be helpful not only in understanding the tolerance and adaptive ability of *Acacia ampliceps* to saline/sodic environment but also lead towards the productive use of these lands. Finally it would help in improving rural economics of developing countries with similar land problems.

CHAPTER - 2

REVIEW OF LITERATURE

2.1 Types and extent of salinity

Accumulation of salts on the soils surface is characteristics for arid and semi-arid environments, especially where irrigation is practiced (VOSE, 1983; SANDHU and QURESHI, 1986, MARSCHNER, 1995; QURESHI and BARRETT-LENNARD, 1998). The soils of Pakistan generally contain Ca^{2+}, Mg^{2+} and Na^{+} as the dominant cations in the solution phase. The principal anions are SO_4^{2-}, Cl^{-}, CO_3^{2-} and HCO_3^{-} (SANDHU and QURESHI, 1986). High temperature causes evaporation, which concentrates the soil solution, leading to the precipitation of Ca^{2+} as $CaCO_3$ and to a lesser extent, as $CaSO_4$, while Mg^{2+} may be precipitated as $MgSiO_3$. This causes an increase in the Na^{+}: (Ca^{2+} + Mg^{2+}) ratio of the soil solution. Because of dynamic equilibrium between the solution cations and those present on the exchange complex, more Na^{+} ions are adsorbed by the soil colloids. This results in a steady rise in sodium adsorption ratio (SAR) of the soil solution. As a consequence, saline soils are slowly converted to saline-sodic soils (RICHARDS, 1954; GHAFOOR, 1984).

Saline, saline-sodic and sodic, all the three types of salt-affected soils exist in Pakistan and are 6.8 million ha (KHAN, 1998). However, majority of them are saline-sodic in nature. According to MUHAMMAD (1983) 80 % of salt-affected soils in Punjab and about 60% in Pakistan are saline-sodic. RAFIQ (1990) classified salt-affected soils of Pakistan as slightly saline-sodic or saline-gypsiferous soils (0.7 million ha), porous saline-sodic or saline-gypsiferous (1.9 million ha), severely saline-sodic and saline gypsiferous soils (1.1 million ha) and soils with sodic tube well water (2.3 million ha). Although there is great heterogeneity in salt-affected soils some characteristic of land types in Pakistan can be identified as under: -

1. Cropping (irrigated) lands are with saline-sodic patches. This type covers an area of approximately 3.0 million ha (RAFIQ, 1990).
2. Low-lying moderately salt-affected lands originally used for rice growing, covers about 0.83 million ha (QURESHI *et al.*, 1990a).

3. Salt-affected areas with the associated problem of water logging (water Table within 1 m depth) cover about 1.16 million ha (AHMAD and CHAUDHRY, 1990).

4. High-lying fields within irrigated area are left uncultivated due to water shortage and high salinity.

5. Salt-affected desert areas with sandy soils and no irrigation supplies but saline underground water have a total area of about 11 million ha.

6. Coastal salt-affected area and coastal sands with brackish ground water is another category.

7. Moderately saline un-irrigated and degraded range lands.

8. Waterlogged area (water Table within 0-5 feet depth) is 4.9 million ha (AHMAD and CHAUDHRY, 1988).

2.2 Approaches to tackle the salinity

There are several practicable methods for the reclamation of salt-affected soils.

2.2.1 Reclamation approach

Good internal soil drainage, land leveling and deep ground water are essential pre-requisite for successful reclamation (MUHAMMAD, 1983; HOFFMAN, 1986). The suitable ground water depth depends upon climate, ground water quality and crop to be grown in arid regions with hot climate. Ground water should be well beyond the capillary range (KOVDA *et al.,* 1973). Saline soils can be reclaimed by the application of excess water, which leaches the soluble salts out of the root zone. The quantity of water that must leach through the soil profile to remove soluble salts depends primarily upon the initial soil salinity level, the technique of water application and the type of soil. Water suitable for irrigation is normally considered suitable for soil reclamation (HOFFMAN, 1986).

The process of amelioration of sodic and saline-sodic soils requires removal of Na^+ from the cation exchange sites, usually by adding Ca^{2+} and then leaching the replaced Na^+ out of the root zone with the percolating water. This Ca^{2+} is usually supplied externally through some chemical amendment. Chemical amendments used for the reclamation of saline-sodic/sodic soils, are either soluble Ca^{2+} salts, like $CaC1_2$, gypsum or sparingly soluble ground lime, i.e. $CaCO_3$ (OSTER, 1982; GHAFOOR *et al*., 1992). In calcareous sodic/saline-sodic soils, the native $CaCO_3$ may be solubilized (conversion of $CaCO_3$ to more soluble $CaSO_4$, Ca $(HCO_3)_2$, Ca $(NO_3)_2$ or $CaC1_2$) by treating the soil with some acids (H_2SO_4, HCI, HNO_3) or acid generating materials [sulphur, pyrite (FeS), lime sulphur (CaS), $FeSO_4$, and Al_2 $(SO_4)_3$] (RICHARDS, 1954; AGARWAL *et al.,* 1979; GHAFOOR and MUHAMMAD, 1981; AHMAD et *al.,* 1991; GHAFOOR *et al*., 1986).

In Pakistan, reclamation of impermeable soils by traditional reclamation method is difficult (RAFIQ, 1990), expensive (QURESHI, 1993; QURESHI and BARRETT-LENNARD, 1998), un-economical (RAFIQ, 1975), has limited scope and not sustainable (QURESHI, 1993, QURESHI and BARRETT-LENNARD, 1998). Therefore, other alternatives were also investigated.

2.2.2 Biological approach

Biological approach deals with the cultivation of certain plant species, which are more tolerant to salinity and sodicity than the most of the field crops. The high initial investment to purchase chemical amendment has diverted the attention of many workers towards the rational utilization of sodic/saline-sodic soils, by growing plants tolerant to high concentration of soluble salts and exchangeable sodium (SANDHU and MALIK, 1975; MALIK *et al.,* 1986; SANDHU and QURESHI, 1986; ABROL *et al.,* 1988; AHMAD *et al*., 1989; QURESHI *et al*., 1993a). Lime ($CaCO_3$) occurs at varying depth in most of the sodic/saline-sodic soils of the world (KOVDA *et al.,* 1973) including those of Pakistan (CHOUDHRY, 1972). This Ca^{2+} source does not participate in ion exchange reactions with Na^+ because of its negligible solubility (0.0131 g L^{-1}). The $CaCO_3$ in sodic/saline-sodic soils could be mobilized to release Ca^{2+} through the root action of certain plant species, which are more tolerant to salinity/sodicity than the most of the field crops (QADIR, 1992).

The plant roots release organic compounds and complex energy sources (DORMAAR, 1988) and increase partial pressure of CO_2 (ROBBINS, 1986b, QADIR *et al.,* 1996a), as well as decrease soil pH (QADIR *et al.,* 1996a & b). All these factors combine to increase the dissolution of soil $CaCO_3$ and cause a decrease in soil salinity/sodicity with time (ABROL *et al.,* 1988; AHMAD *et al.,* 1990; QADIR *et al.,* 1996a & b). The probable factors involved in SAR (sodium adsorption ratio) decrease by the root action could be explained as:

1. Release of CO_2 in the root zone as a result of root and microbial respiration,
2. Formation of carbonic acid (H_2CO_3) through dissolution of CO_2 in water,
3. Reaction of H_2CO_3 with the native $CaCO_3$ to form a soluble Ca $(HCO_3)_{2,}$
4. Release of Ca^{2+} ions from Ca $(HCO_3)_{2,}$ and
5. Displacement of exchangeable Na^+ by the Ca^{2+} (ROBBINS, 1986a & b; QADIR *et al .,* 1996a & b).

The plant roots also physically act upon the soil to improve its permeability (ELKINS, 1985). MALIK *et al.,* (1986) found that the root exudates of kallar grass caused coagulation of the dispersed soil matrix and improved soil structure. The roots could also physically act upon the soil like a potential tillage tool (ELKINS, 1985). This physical manipulation of the soil provides channels for the soluble movement through the soil profile. ILYAS (1990) concluded that the root channels can modify the soil profile rapidly even within two years. The above ground parts of the plant provide shade to the host soil, lower the soil temperature, have a mulching effect, decrease evaporation from the soil surface and consequently check upward movement of salts through capillary action (SANDHU and QURESHI, 1986; AHMAD *et al.,* 1991; QURESHI *et al.,* 1993b).

2.3 Utilization of adverse salt-affected waste lands

While soil Stalinization may drastically lower agricultural production, saline and wetlands should not be equated with wastelands. The ability of some plant species to grow in a wide range of stress conditions can put them in a wide range of adaptability and utility when compared with others. It has been established that there are feasible potential roles for halophytes to play in an economic agricultural use of salt-affected wastelands. (O' LEARY *et al.,* 1985; JEFFERIES and PITMAN, 1986; Le HOUEROU, 1986; WATSON *et al.,* 1987; ARONSON, 1989; MARCAR *et al.,* 1993; MALCOLM, 1993; CHOUKR- ALLAH, 1993, 1996; PASTERNAK and NERD, 1996).

Substantial progress has also been made in evaluating halophytes for their potential use as crop plants (LE HOUEROU, 1979, 1986; MALCOLM and POL, 1986, O'LEARY, 1988). Halophytes are plant species with a set of ecological and physiological characteristics allowing them to grow and reproduce in a saline environment. Arbitrarily a salinity of 0.5 % NaCI in soil solution should be tolerated by halophytic plants (GORHAM, 1995). Another promising use of problem soils is the possibility of bringing them under forests. Many tree species such as *Acacia ampliceps, Eucalyptus sargentii, Prosopis* species, *Tamarix* species, *Salvadora persica, Casuarina glauca* etc. have a high degree of salt tolerance and should be used for a forestation of salt-affected soils (PASTERNAK and NERD, 1996).

2.4 General responses of plants to salinity

A large number of studies have been reported regarding the response of plants to saline environment (FLOWERS *et al.,* 1977; MAAS and HOFFMAN, 1977; GREENWAY and MUNNS, 1980; LAUCHLI and EPSTEIN, 1990). Although salinity affects the plants in many ways physiologically, over injury symptoms seldom occur except under extreme salination and these responses vary considerably with the species, growth stage, cultural and climate conditions (MAAS, 1986). Generally, salt-affected plants appear normal although they are stunted and may have dark green leaves, which, in some cases, are thick and are more succulent. Different plant species have different degrees of tolerance to salts in the root medium. In some plant species, for instance in halophytes, salinity sometimes affects growth positively, although except for C_4 species like *Atriplex*, where Na^+ is needed as a micronutrient (FLOWERS and LAUCHLI, 1983). There appears to be no obligate requirement of salts for growth. The optimum growth in many dicotyledonous species occurs in the range of salinity from 100 to 300 mol m^{-3} (FLOWERS *et al.,* 1977). Monocotyledonous halophytes are not stimulated by low to medium salinity and grow more slowly at higher concentrations (LEVITT, 1980) whereas; most of the glycophytes can only survive on low salinity. The typical response of plants to salts in the root medium is the growth inhibition (Maas and HOFFMAN, 1977; MAAS and NIEMAN 1978; ASLAM *et al.,* 1989, FLOWERS *et al.,* 1991). The excessive entry of ions though facilitates the osmotic adjustment within plants but plants have to pay the price in terms of growth retardation (MARSCHNER, 1986). As salt concentration increases above a threshold level, both the rate of growth and the vigour of plant are progressively decreased, shoot growth is more severely affected than root (BERNSTEIN *et al.,* 1955; AYERS and EBERHARD, 1960; MEIRI and POLJAKOFF-MAYBER, 1970; DELANE *et al.,* 1982; WEIMBERG *et al.,* 1984; SHARMA, 1986; LONE, 1988; ASLAM *et al.,* 1991). Plant becomes stunted because of reduced cell division than cell expansion (MAAS and NIEMAN, 1978). However, the reduction of vegetative growth is not always related to reduction in fruit or seed production. A good example is of rice, where yield was reduced because of salinity without an appreciable effect on straw yield (AKBAR and PONNAMPERUMA, 1982; ASLAM *et al.,* 1993c). Conversely, in barley, wheat, cotton and few grasses, seed and fiber production were decreased much less than the vegetative growth (AYERS *et al.,* 1952).

2.5 <u>Salt tolerance</u>

Salt tolerance may be defined as the ability of a plant to grow and complete its life cycle on saline substrate that contain high concentrations of salt, mainly NaCI, but some times also other salts including calcium salts and sulphates (JESCHKE, 1984). The ability of a plant to regulate the influx of salts is one of the major factors determining salt tolerance. The most tolerant species have high internal salt concentrations, suggesting that the ability of cells to tolerate high concentration is as important as the ability to restrict the accumulation of salt (GORHAM, 1996).

Plants are classified into glycophytes; that can tolerate only low concentrations of salts and halophytes; that can tolerate relatively high concentrations of salts (MAAS and NIEMAN, 1978). Halophytes can tolerate salinities of 500 mol m^{-3} NaCl (UNGAR, 1991) while growth of glycophytes is severely limited at concentrations as low as 50 mol m^{-3} NaCl (GORHAM, 1996). There is however, no clear-cut line of demarcation in higher plants between these groups, rather there is a continuous spectrum from sensitive and fairly tolerant (GREENWAY and MUNNS, 1980; WYN JONES, 1981; MAAS, 1986). Salt tolerance involves the expression of a number of genes and the importance of the expression of each may depend upon its interaction with other genes (AKBAR and SENADHIRA, 1985) external salt concentrations, salt type, stages of growth (ASLAM, *et al.,* 1993b), other environmental conditions (HOFFMAN and RAWLINS, 1970 & 1971; BYTNEROWICZ and TAYLOR, 1983; SALIM, 1989), soil physical conditions (PERVEEN *et al.,* 1991) and natural variation within salt-affected field (RICHARD, 1983). Though salt tolerance varies considerably among species, it also depends much on cultural conditions. Many plant, soil, water and environmental factors interact to influence salt tolerance.

2.5.1 Criteria for salt tolerance

Salt tolerance of plants can be assessed in one of the three ways: (1) The ability of a plant to survive in saline conditions (2) The absolute plant growth or yield (3) The relative growth or yield on saline soils compared with that on non-saline soils (NIEMAN and SHANNON, 1976; LAUCHLI, 1984; SHANNON, 1984, 1985 & 1990, MAAS, 1986 & 1990, QURESHI *et. al.* 1990a; ASLAM *et al.,* 1993a).

Plant survival (at higher salinities) an important ecological criterion, is of little interest for an agriculturist, although some workers used it for searching more tolerant plants such as wild relatives of crop plants (SHANNON, 1978). Absolute yield permits the direct estimation of economic returns under specified saline conditions but it also reflects response to many other environmental parameters e.g. climate, soil moisture regime, soil fertility, cultural practices, pest and disease control (HOFFMAN and RAWLINS, 1970; MAAS, 1990; GRATTAN and GRIEVE, 1992; QURESHI and ASLAM, 1988). FURTHERMORE, absolute yield responses do not permit inter-crop comparison because yields for different crops are not expressed in comparable terms (MAAS, 1986). The relative yield, a useful criterion for expression of salt tolerance of different crops (MAAS and HOFFMAN, 1977; MAAS, 1986; RASHID, 1986; QURESHI *et al.,* 1990a; NAWAZ *et al.,* 1986; ASLAM *et al.,* 1993a; NASIM *et al.,* 1993; AKHTAR *et al.,* 1994). It is the yield of a crop grown under saline conditions expressed as a fraction of that achieved under non-saline, but otherwise comparable conditions (MAAS, 1990). Salt tolerance of a crop can be documented with following equations:

$$Y_r = 100 - b\,(ECe - a)$$

Or

$$Y_r = \frac{Y_m}{[1 + (C/C_{50})^p]}$$

Where

Y_r = Relative yield of crop

b = Slope expressed in % per $dS.m^{-1}$

EC_c = Electrical conductivity of the saturated soil extract

a = Salinity threshold expressed in dS m^{-1}

Y_m = Yield of crop under non-saline conditions

C = Average salinity of the root zone

C_{50} = Average salinity of the root zone that reduces yield by 50%

P = An empirical constant

(VAN GENUCHTEN, 1983; MAAS, 1990)

In addition, germination percentage, uptake of Na^+ and Cl^- by root and shoot, root and shoot length, growth characters and grain yield of crop varieties are the various criteria considered for salt tolerance (IKEHASHI and PONNAMPERUMA, 1978; ASHRAF *et al.,* 1986; ASHRAF and MC NEILLY, 1992). However, different salt tolerance criteria could be used for different species depending upon the facilities available and the objectives of the study (QURESHI *et al.,* 1990a; ASLAM *et al.,* 1993a).

2.5.2 Factors affecting salt tolerance

2.5.2.1 *Plant factors*

Different plant species have different degree of salt tolerance. The differences between halophytes and glycophytes and also within glycophytes are good examples of this fact (FLOWERS *et al.,* 1977; GREENWAY and MUNNS, 1980; MAAS, 1990). However, cotton, barely, sugar beet, asparagus, wheat (semi dwarf) and triticale are considered salt tolerant while, rice, bean and sesame are categorized as sensitive crops (MAAS, 1986). Some crops are intermediate; these may be moderately tolerant like sorghum, soybean, rape, guar, oats, rye, and safflower or may be moderately sensitive as corn, sugarcane and sunflower (MAAS, 1986).

Varietals differences, which are common, must be considered for crop tolerance evaluation. Tolerance to salinity varies widely among varieties of wheat (KINGSBURY and EPSTEIN, 1984; SAYED, 1985; QURESHI *et al.,* 1990a) rice (AKBAR *et al.,* 1972; ASLAM *et al.,* 1989; 1993c), cotton (NAWAZ *et al.,* 1986; NAWAZ, 1987), barley (NIAZI *et al.,* 1987, 1992) and eucalyptus (THOMSON, 1988; VANDER-MOEZEL *et al.,* 1991; MARCAR *et al*., 1995). Salinity affects plant growth at all stages of development, and for some crops, sensitivity varies from one growth stage to the other.

Many salt sensitive species germinate in the presence of high salt concentration e.g. corn (MAAS *et al.,* 1983), tomato (KURTH *et al.,* 1986) and rice (MAAS and HOFFMAN, 1977). In contrast, the most salt tolerant crops like cotton (SHANNON and FRANCOIS, 1977; KENT and LAUCHLI, 1985) and sugar beet (MARSCHNER, 1995) are salt sensitive during germination. Similarly, some halophytes whose vegetative growth is often stimulated by salinity do not appear to be salt tolerant during germination (UNGAR, 1978a, JEFFERIES, 1988).

Sorghum, barley, wheat and corn are more sensitive to salinity at early seedling stage than later stages of growth (MAAS *et al.,* 1983, 1986; NAWAZ *et al.,* 1986; RASHID, 1986; ASLAM *et al*., 1988; MAAS and POSS, 1989). Increased tolerance with age has also been observed in asparagus. Seedling stage of rice proved to be the most sensitive while it gains tolerance at tillering and vegetative growth stage (AKITA, 1986; ASLAM *et al.,* 1993b). In maize, salt sensitivity is particularly high at tasseling and low at grain filling (MAAS *et al.,* 1983).

2.5.2.2 Soil factors

Increased frequency of irrigation is required under saline conditions (RHOADES and LOVEDAY, 1990). Excessive irrigation however, can cause poor soil aeration particularly in fine textured or sodic soils. Low oxygen levels have interacted with salinity to affect shoot growth of tomato (AUBERTIN *et al.,* 1968) and wheat (ACEVES *et al.,* 1975; PERVEEN *et al.,* 1991; NAWAZ *et al.,* 1992). Physical conditions of soil also affect salt tolerance of plants. Soil with poor structure or an impermeable layer restrict the root growth as well as influences the distribution of water and salt in soil (MAAS, 1990; MUHAMMAD, 1990).

Another problem in evaluating salt tolerance studies conducted in field may develop from shallow water table and, depending upon the quality of water; plants respond much differently than expected from salinity levels in the soil profile (MAAS and HOFFMAN, 1977).

2.5.2.3 Climatic factors

Climatic conditions like temperature, humidity, and pollution have marked influence on salt tolerance. Many crops seem to be less salt tolerant when grown under hot dry conditions than under cool humid condition. Lower, yields of alfalfa, bean, beet, carrot, cotton, onion, squash, strawberry, clover, salt grass and tomato were observed under salinity at higher temperatures (HOFFMAN and RAWLINS, 1970; MAAS, 1990). Relative humidity also influences the salinity tolerance of plants. Yields of many crops decrease more by salinity as relative humidity decreases. Studies reveal that barley, bean, corn, onion, radish and rice were sensitive to salt at low humidity (HOFFMAN and RAWLINS, 1970; NIEMAN and POULSEN, 1967; MAAS, 1990), whereas high atmospheric humidity tends to increase salt tolerance of some crops (SALIM, 1989). Although high humidity improves growth under salt stress (NIEMAN and POULSEN, 1967), temperature is the dominant factor in plant response to saline conditions. Other studies confirmed that temperature influences salt tolerances to greater degree than relative humidity (HOFFMAN and RAWLINS, 1970).

2.6 Mechanism of salt tolerance (How plants manage to survive under salinity)

Plants manage to survive in saline environments by adopting some mechanisms e.g. morphological, biochemical and anatomical mechanisms, which enable them to survive and grow in the presence of toxic salts (FLOWERS *et al.,* 1977; GREENWAY and MUNNS, 1980; WYN JONES, 1981 and YEO, 1983). In general, plants avoid toxic concentrations of salts either by restricting ion uptake or by compromising with high salt concentration through osmotic adjustment. Some of the important adaptive mechanisms for salt tolerance are discussed as under:

2.6.1 Morphological mechanisms

The most obvious mechanisms of salt tolerance are morphological adaptation e.g. stunted growth. Salinity causes several specific structural changes that disturb plant water balance or status (ROBINSON *et al.,* 1983). These structural changes include fewer and smaller leaves, less number of stomata per unit leaf area, thickening of leaf cuticle and waxiness of leaf surface, reduced differentiation and development of vascular tissues, increased development of tyloses, earlier lignifications of roots, low chlorophyll content, higher elasticity of cell walls, fully developed water storing tissues and increased succulence (WAISEL, 1972; POLJAKOFT-MAYBER, 1975; YEO and FLOWERS, 1984). These responses vary with plant specie and the type of salinity (Maas and NIEMAN, 1978; ASLAM *et al.,* 1993b). Succulence is a typical morphological adoption to high substrate salinity in the most dicotyledonous plants (LONGSTRETH and NOBEL, 1979; LONGSTRETH *et al.,* 1984).

2.6.2 Anatomical mechanisms

The transpiration stream continuously transports salts to plant shoots. Even in halophytes, the amount of transport salts is in excess to that required for turgor maintenance. Excretion of salts through special glands i.e. salt glands is one of the most important mechanisms for salt tolerance (ABDULLAH, 1985; BALL, 1988; GORHAM, 1996).

Salt glands are an effective method of controlling the slat content of leaves. The quantitative contribution of salt glands to the regulation of salt concentrations in leaves has been studied in relatively few species. However, a substantial proportion of the salt entering a leaf of *Leptochloa fusca L*; can be excreted through salt glands (ABDULLAH, 1985; GORHAM, 1987). They may be multicellular organs of highly specialized cells, for example in *Avicennia marina*, or are simple type glands comprising of only two cells. e.g. in kallar grass, *Leptochlo afusca* (WIENEKE *et al.,* 1987). Salt glands are highly selective and may eliminate relatively large quantities of salts by secretion to the leaf surface, where it can be washed off by rain or dew. Secretion as an active process is highly temperature dependent (GORHAM, 1987), and usually Na^+ and Cl^- are secreted in equivalent amounts (GORHAM, 1987; BALL, 1988). The rate of salt secretion is affected by numerous factors, including salt concentration of the growth medium, ions present, light intensity, temperature, oxygen concentration, the presence of metabolic inhibitors and different osmotica (BATANOUNY *et al.,* 1992).

Salt may also be accumulated in bladder cells on the surface of leaf for example, *Atriplex* species and *Mesembryanthemum crystallimum* L. (LUTTGE *et al.,* 1978). These bladder cells may burst or become detached from the leaf, thus reducing the overall salt content of the leaf. Compared with salt-excreting glands, bladder cells in some species are a comparatively short term and limited answer to the accumulation of salt, and are particularly effective in protecting the young expanding leaves (GORHAM, 1996). Evidence for the presence of leaf hair in certain moderately salt tolerant species such as tomato, was also found (MARSCHNER, 1986). FLOWERS *et al.,* (1990) analyzed the content of the salt hairs of the leaves and found it as powerful evidence in support of contention that the secreted salt comes from the hairs.

2.6.3 Escape mechanisms

A saline environment also induces phonological adaptations in plants (WAISEL, 1972). LEVITT (1972) used the terms avoidance and tolerance for specific aspects of the responses of plants to stress. Avoidance involves escaping from the stress. When the salt stress is seasonal, the plants adopt the phonological escape mechanism i.e. they grow and adjust their life cycle according to optimum seasonal conditions. The species enjoying escape mechanisms are called pseudo halophytes (FLOWERS, 1975).

2.6.4 Physiological mechanisms

The ability of plants to regulate the influx of salt is one of the major factors determining salt tolerance. While an important point of regulation of net influx must be the point of initial entry of salts in to roots (i.e. primarily at the *rhizodermis*). In the pathway from the rhizodermis to the xylem, the movement of ions could be controlled by exchange process in the contex (STAPLES and TOENNIESSON, 1984), in forced passage through membranes (and hence selectivity) at the endodermis and by selective xylem loading (GORHAM, 1996). In some species there is an appreciable re-circulation of sodium in the phloem, although this is mainly a feature of salt-sensitive species such as Beans and Lupines (JESCHKE *et al.,* 1987). Young, expanding leaves are supplied with a potassium-rich inorganic solute supply via phloem, while sodium accumulates in older leaves, often replacing potassium accumulated previously. The potassium in older leaves is thus available for re-circulation via phloem to sink tissues (GORHAM, 1996). All the plants are salt excluders with varying degrees of exclusion. In many monocots the accumulation of salts with in the shoots is strictly limited and osmotic adjustment is partially achieved with low molecular weight carbohydrates (ALBERT and POPP, 1978; GORHAM *et al.,* 1980). Several researchers have demonstrated salt tolerance mechanisms based on factors related to growth under saline conditions, including ion accumulation (TAL and SHANOON, 1983), ion exclusion (NOBEL *et al.,* 1984), compatible solute production (WYN JONES *et al.,* 1977; GRUMET and HANSON, 1986), late maturation (BERNAL *et al*., 1974) and pollen sterility (AKBAR *et al.,* 1972; AKBAR and YABUNO, 1977).

2.6.4.1 Ion exclusion/inclusion

Salt tolerance can be achieved by salt exclusion or salt inclusion. Different degrees of exclusion and inclusion, both between Na^+ and Cl^-, and between different parts and organs of plants have been observed. In glycophytes, there is generally an inverse relationship between salt uptake and salt tolerance, i.e. exclusion is the predominant strategy (GREENWAY and MUNNS 1980; GORHAM *et al.,* 1985). In halophytes of the chenopodiaceae, high salt tolerance is mainly due to salt inclusion. The highly salt tolerant species such as kallar grass *(Leptochlo afusea)* is also a salt includer (GORHAM, 1987), although intensive re-translocation of Na^+ and Cl^- from the shoot to the roots and then their release from roots i.e. exclusion can also be observed (BHATTI and WIENEKE, 1984). Ion excluders possess a variety of mechanisms which limits the uptake of saline ions (Na^+ and Cl^-) that reaches the shoot and such plants usually maintain relatively high shoot K^+: Na^+ ratio (GREENWAY and MUNNS, 1980; GORHAM *et al.,* 1980 & 1985; ASLAM *et al.,* 1993). This may be due to very efficient selective absorption of K^+ and limited uptake of Na^+ at xylem level (WOLF *et al.,* 1991).

LAUCHLI (1976) concluded that Na^+ accumulation in the xylem parenchyma cells was due to Na^+ re-absorption from the xylem sap in exchange of K^+ possibly by a Na^+/K^+ exchange process operating at the plasma lemma of the transfer cells (JESCHKE*, et al.,* 1983, JESCHKE, 1984; GORHAM *et al.,* 1985).

In the stele, active transport processes are involved in loading solutes into the xylem stream. This offers another site for selectivity. On the other hand active transport out of the xylem via transfer cells (KRAMER, 1983) may further regulate the proportions and concentrations of different ions supplied to the shoot. Such a mechanism has also been described in maize mesophylls, where sodium is transported through the endodermis of the mesocotyl from the xylem stream in the stele to the cortex (JOHANSON and CHEESEMAN, 1983; JOHANSON *et al.,* 1983).

Restricted import of Na^+ and Cl^- into young leaves is a characteristic for salt tolerance species (BLITS and GALLAGHER, 1990; ROBERTSON and WAINWRIGHT, 1987). The capacity to maintain steep concentration gradients of Na^+ and Cl^- between old and young leaves but not total salt content in the shoot dry matter is important for salt tolerance as has been observed in wheat (GORHAM *et al.,* 1986) and maize (HAJI BAGHERI *et al.,* 1987). High K^+ but low Na^+ concentrations in young leaves and reproductive organs are achieved by a general low xylem import of both K^+ and Na^+ but high phloem import of K^+ from mature leaves (WOLF *et al.,* 1991). The importance of Cl^- partitioning within individual leaves for salt tolerance has been observed in sorghum (BOUSIER and LAUCHLI, 1989) and barley (HUANG and VAN STEVENINCK, 1989).

2.6.4.2 Osmotic adjustment

With a sudden increase in salinity, osmotic adjustment is achieved first by a decrease in tissue water content (Partial dehydration). Salt tolerance and further growth in a saline substrate, requires a net increase in the quantity of osmotically active solutes in the tissue (GORHAM *et al.,* 1985). In genotypes having salt exclusion as major mechanism of salt tolerance, the synthesis of organic acids (K^+, Ca^{2+}, and $NO3^+$) must be increased. However, in genotypes in which salt inclusion is the predominant strategy, osmotic adjustment is achieved by the accumulation of salts (mainly NaCl) in the leaf tissue (FLOWERS, 1988). In natrophyllic species, Na^+ can replace K^+ not only in its function as an osmotically active solute, but to some extent also due to its specific functions in cell metabolism. The different strategies for regulating sodium transport to the shoots have important consequences in pasture plants for animal nutrition and in crop plants in general for salt tolerance (GREENWAY and MUNNS, 1980).

In salt tolerant includers the capacity of the mesophyll vacuoles (in the leaves) to accumulate Na^+ and Cl^- may be vastly increased at high substrate salinity. This occurs by increasing cell size, mainly the vacuole and thereby diluting the accumulated salts and preventing accumulation of Na^+ and Cl^- in the leaf apoplasm and in the cytoplasm (GORHAM *et al.,* 1985; FLOWERS *et al.,* 1986). Osmotic adjustment (in includers) requires accumulation of Na^+ and Cl^- in the leaf cells in the order of 300-500 mM. In the cytoplasm the concentration of inorganic ions has to be kept in the range 100-200 mM (GORHAM *et al.,* 1985).

RAVEN (1985) analysed the cost benefit of turgor regulation with different solutes. These calculations show that 2-4 mol photons of light energy is needed for the accumulation of 1 osmol KCI or NaCl, but 68-78 mol photons is needed for the synthesis of 1 osmol sorbitol or manitol., 70-93 mol photons for 1 osmol proline, and 78-101 mol photons for 1 osmol glycine betaine. The exact amount of photons needed in each case depend on whether the solutes are accumulated is the roots or the shoots, and, for proline and glycine betaine, also on the N source i.e. NH_4^+ or NO_3^-.

2.6.4.3 Compartmentation

Many halophytes regulate turgor by accumulation of NaCl to concentrations higher than that present in the substrate medium (PESSARKLI, 1994). Certain enzymes such as membrane bound ATPase, in the roots are either activated or inhibited in vitro by high salt concentrations, depending upon the salt tolerance of the intact plants, i.e. membrane ATPases of halopytes may be less sensitive to salt than those of glycophytes (LERNER *et al.,* 1983). However, in vitro in many instances enzymes such as malate dehydrogenase and aspartate transaminase of halophytes such as atriplex spongiosa and of glycophtes like *Phaseolus vulgaris* are equally sensitive to high NaCl concentrations (GREENWAY and OSMOND, 1972).

2.6.4.4 Potassium-sodium selectivity

Because of the plants requirement for an adequate amount of K^+, it is fortunate that the plasma membranes of root cortical cells have a high affinity for K^+ over Na^+, even though the degree of selectivity can vary quite drastically among species. This is particularly important in saline-sodic and sodic environments, in which concentrations of Na^+ in the soil solution are of higher magnitude than those of K^+. The high K^+/Na^+ selectivity within plants is maintained, provided that the calcium status in the root is adequate (CARTER, 1983, SUBBARAO *et al.,* 1990) and the roots have a sufficient supply of O_2 (DREW *et al.,* 1988). Despite the plants, high affinity for K^+ over Na^+ the K^+ status in plants is related to the ratio of Na^+/K^+ in the saturated soil extract (DEVITT *et al.,* 1981). Although plants selectively absorb and translocate K^+ in preference to Na^+, the degree of selectivity varies among species as well as among cultivars within a species. (KAFKAFI, 1984).

It has been pointed out by JESCHKE and NASSERY (1981) that K^+: Na^+ selectivity may reside not only in different organs such as root (RAINS and EPSTEIN 1967a). Stem (JACOBY, 1965) or leaves (RAINS and EPSTEIN, 1967b), due different selectivity mechanisms may operate in the same organ. For example, in roots, different tissues such as epidermis (KRAMER *et al.,* 1977), endodermis (NASSERY and BAKER, 1974), Xylem parenchyma (YEO *et al.,* 1977) as well as cortical plasma lemma and tonoplast (JESCHKE, 1979) may have different selectivities for K^+ and Na^+.

Gross selective uptake of K^+ compared with Na^+ can be calculated with the help of formulae (PITMAN, 1976).

$$S\,K^+, Na^+ = \frac{K^+ \text{ conc. in plant}/ K^+ \text{ conc. in solution}}{Na^+ \text{ conc. in plant}/Na^+ \text{ conc. in solution}}$$

or

$$S\,K^+, Na^+ = \frac{K^+/ Na^+ \text{ in plant tissue}}{K^+/Na^+ \text{ in external solution}}$$

During influx of ion across the root, selectivity can be achieved at four membranes i.e. the plasma lemma of the cortical root cells, the tonoplast of the root cells, the plasma lemma of the xylem parenchyma cells (JESCHKE, 1983, 1984; GORHAM *et al.,* 1985) and Plasma lemma of the phloem (GORHAM *et al.,* 1985) JESCHKE (1984) and GORHAM *et al.,* (1985) further pointed out that eight different, but possible related mechanism of K^+/Na^+ selectivity, can be distinguished at these sites.

1. Preference of K^+ during influx (influx selectivity).
2. H^+ dependent $K^+ – Na^+$ exchange at the plasma lemma (effective selectivity).
3. Selective Na^+ accumulation in vacuoles and $Na^+ – K^+$ exchange across the tonoplast.
4. Selectivity during release of K^+ and Na^+ to the xylem vessels.
5. Selective re-absorption of Na^+ from the xylem sap.
6. Selective movement of solutes in phloem.
7. Supply to apical regions and recovery of nutrient from older leaves (GREENWAY and PITMAN, 1965; PATE, 1975; GORHAM *et al.,* 1985) leading to selectivity gradient through the plants.
8. Relationship of phloem xylem pathways to site of meristematic activity.

Although plants show high selectivity of K^+ over Na^+, excessive amounts of K^+ may be detrimental to some plants. RUSH and EPSTEIN (1981) found that the wild tomato species could tolerate 200 mM Na^+, but 200 mM K^+ was toxic. On the other hand, the domestic and more salt sensitive tomato species (*Lycopersicon esculentum* Mill) showed the opposite behaviour, it could tolerate K^+ but not Na^+ at the same concentration. In regard to halophytes, the adverse effects of high K^+/Na^+ at high total salt concentrations have been observed in *Atriplex amunicola*, *Atriplex inflata*, *Atriplex nummularia* and *Vigna radiate* (ASLAM *et al.,* 1988).

2.7 Salt tolerance potential of *Acacia ampliceps* and different forest trees

The salt tolerant forest species found in different studies are *Acacia ampliceps* (salt wattle), *Acacia nilotica*, *Albizzia lebbek*, *Casuarina equisetifolia*, *Ecalyptus camaldulensis*, *Leucaena leucocephala*, *Parkinsonia aculeate*, *prosopis cineraria, Prosopis juliflora, Sesbania bispinosa, Sesbania sesban and Tamarix aphylla* (Qureshi and Barret Lennard 1998).

Acacia ampliceps is tolerant of high saline, sodic and alkaline soils, but intolerant of acid soils and water logging. Researchers from Australia have noted reduced growth at EC_e values of 10 - 15 decisiemens per meter and reduced survival above 20 decisiemens per meter (MARCAR *et al.,* 1995). Some provenances have been reported to survive in nutrient solutions at concentrations in excess of 65 decisiemens per meter

(ASWATHAPPA *et al.,* 1987). In Pakistan 2 years-old plants had 25 and 50 % reductions in dry weight at 17 and 20 decisiemens per meter (calculated from the data of ANSARI *et al.,* 1994). In an adaptation trial on a saline site (EC_e values of 5 - 40 decisiemens per meter) there was 77 - 98 % survival after 2 years, but 3 months of flooding eliminated survivors in three provenances and caused substantial mortality in a fourth (ANSARI *et al.,* 1994).

SHIRAZI *et al.* (2006) investigated the salt tolerance of different species like *Acacia ampliceps, Acacia nilotica, and Acacia stenophylla.* They recorded 60 - 80 % survivals of different species depending upon severity of the salinity hazard. Under very high salinity patches (25 - 30 dS m^{-1}), the performance of *Acacia ampliceps* was found to be very good. Studies of AMER *et al. (2006)* indicated that *Acacia ampliceps* can successfully be grown in the soil having EC_e 21.7 dS m^{-1}. In studies of MARCAR *et al.* (1991) *Acacia ampliceps* and some other species differed in their salt tolerance. Four months old seedlings were treated with 100 (SI), 200 (S2) and 400 (S3) mol m^{-3} NaCl in sand culture. Ranking of species for salt tolerance, based on relative decline in dry weight of shoot, whole plant and nodules under NaCl addition, was in the order *A. ampliceps* > *A. auriculiformis* > *A. mangium.* The greater salt tolerance of *Acacia ampliceps* was associated with relatively low shoot Na^{1+} and Cl^{1-} concentration (dry weight basis).

Acacia nilotica can tolerate moderately saline and sodic conditions as well as soils with a cemented pan. It has a 40 % reduction in growth (dry weight) at an EC_e of about 8 decisiemens per meter (SINGH, 1991). It is relatively tolerant to water logging. In longer term field experiments near Faisalabad it produced more wood per plant than *Prosopis cineraria* on a saline soil, and on a dense saline soil its production was more highly ranked than *Leucaena leucocephala*, *Terminalia arjuna* or *Dalbergia sisoo* (QURESHI *et al.,* 1993). *Albizzia lebbek* tolerates moderate salinity/sodicity and high pH (8.7 - 9.4). *Casuarina equisetifolia* grows in calcareous and slightly alkaline soils, where it withstands salinity but not water logging. In nutrient solution culture, *Casuarina equisetifolia* is reported to have a 25 % reduction in growth with an electrical conductivity of 12 decisiemens per meter (MIYAMOTO, 1996), and survived salinities of 56 decisiemens per meter under drained but not waterlogged conditions (MOEZEL *et* *al.,* 1989). Irrigation with water of electrical conductivity of 9 - 10 decisiemens per meter caused 16 - 18 % decreases in height and stem diameter.

Eucalyptus camaldulensis grows in slightly alkaline soils, where it can withstand some salinity and water logging. The situation regarding the salt and water logging tolerance of the species is confused. This may be because of the enormous variation between provenances. In irrigated sand culture, plant height and stem diameter decreased by 36 and 55 % respectively, when water with an electrical conductivity (EC_w) of 9 - 10 decisiemens per meter was used (compared to control plants irrigated with water of EC_w 1.6 decisiemens per meter; AHMAD, 1987). However, the species has survived in nutrient solutions with electrical conductivities up to 50 decisiemens per meter (drained conditions; MARCAR, 1989) and 42 decisiemens per meter (both drained and waterlogged conditions; MOEZEL *et al.,* 1988). A confused picture also emerges from experiments in the field. On a saline/ waterlogged site in Australia there was a 50 % decrease in canopy volume with an increase in EC_e in the upper 60 centimeters of the soil profile to 5 decisiemens per meter (MARCAR *et al.,* 1994). In one adaptation trial only 13 % of the plants survived for 24 months; this performance was eclipsed by every other genotype in the trial (ANSARI *et al.,* 1994). However, in another adaptation trial the species performed better than 11 other species over seven and a half years (QURESHI *et al.,* 1993b). Fast growth of *Eucalyptus camaldulensis* has been observed on saline land in Satiana Faisalabad, Pakistan.

Leucaena leucocephala grows well on light-textured saline soils that are well drained. However, it is sensitive to water logging. In irrigated sand and gravel cultures, water with electrical conductivities of 9 - 10 decisiemens per meter did not adversely affect growth (AHMAD, 1987). Two field experiments examined the adaptation of the species to saline soils at Faisalabad. The first of these examined the effects on survival of 3 months flooding of the soil surface. Under drained conditions there was 80 - 100 % survival, but under flooded conditions there was no survival (QURESHI *et al.,* 1993b). In a long-term adaptation experiment on a saline sodic soil, *Leucaena* produced 90 kilograms of timber per plant over a seven-and-a- half-year period (QURESHI *et al.,* 1993b). *Parkinsonia aculeata* grows well under conditions of high salinity but is sensitive to waterlogged conditions. *Prosopis cineraria* grow successfully in highly saline and alkaline soils (pH values up to 9.8). *Prosopis juliflora* is an aggressive species that grows under conditions of moderate to high salinity and sodicity, high alkalinity (pH values up to 9.8) and intermittent flooding. It can be quite successful in lowering water tables on dense saline-sodic soils with shallow groundwater. Plantations can be established and/or grown using irrigation with saline groundwater or seawater. Nevertheless 25 % reductions in shoot extension with irrigation water of electrical conductivity 30 decisiemens per meter seem likely (RHODES and FELKER, 1988; MIYAMOTO, 1996). There are reports that production is decreased by about 25 % as the soil pH increases from 8.0 to 10.5 (FAGG and STEWART, 1994).

Sesbania bispinosa can be grown for the reclamation of salt-affected soils. It is adapted to a variety of soil conditions, varying from waterlogged to saline, and from sand to clay. It has a 50 % decrease in growth in soil with an EC_e of 13 decisiemens per meter (SANDHU and HAQ 1981). *Sesbania sesban* can tolerate water logging, salinity and alkalinity (pH value as high as 10). Experiments in which plants were grown in sand cultures irrigated with water of different salinities show that;

- 46 % decreases in stem diameter can be expected at an electrical conductivity of 16 decisiemens per meter (calculated from AHMAD *et al.,* 1985).
- 15-22 % decreases in height and stem diameter can be expected at electrical conductivities of 9 - 10 decisiemens per meter (AHMAD, 1987).

Yokota (2003) reported that among the five investigated species of Acacia, A. Salicina, A. ligulata, A. holosericea, A. mangium and A. ampliceps proved the most tolerant to salinity in terms of mortality, growth and proline accumulation. The level of proline accumulation was not related to the degree of salt toleranc. MEHARI, *et al*. 2005 reported that Acacia nilotica and Acacia tortilis behaved similarly to salinity levels of 150 and mM NaCl in statistical terms, although the former was significantly superior in biomass. In terms of shoot water, there was significant variation. Both species shed their leaves when exposed to salinity. Ramoliyap *et al.* (2004) investigated tolerance of Acacia catechu to mixture of chlorides and sulphates of Na, K, Ca and Mg at EC levels of 4.1, 6.3, 8.2, 10.1 and 12.2 dS m^{-1}. A negative relationship between proportion of seed germination and salt concentration was noticed. Seedling did not emerge when salinity exceeded 10.0 dS m^{-1}. Elongation of stem and root was retarded by increasing stress. Old roots and leaves died continuously. Hamad *et al.* (2006) assessed the field growth of eleven Acacia and three prusopis species in central Saudia Arabia. Stem diameter, plant height and crown diameter were measured. Acacia ampliceps showed the best performance as for as all studied parameters while A. nilotica, A. seyaland and A.salicina shared the second best treatment. Study of Marcar *et al.* (2003) indicated that fast growing salt tolerant trees and shrubs can productively use salt affected land and contributes to its reclamation. The most salt tolerant was the Acacia ampliceps on soil having EC of 21 dS m^{-1}. Surviving trees of other species grew slowly.

Tamarix aphylla can tolerate high levels of salinity and sodicity. It is a common tree of salt-affected wastelands. Studies at the University of Agriculture, Faisalabad show it to be highly tolerant to salinity and water logging (QURESHI *et al.,* 1993b). There are reports of its survival when irrigated with water of electrical conductivity 56 decisiemens per meter (ARONSON, 1989).

2.8 Transplantation techniques as management strategies for growing plants in salt-affected soils

A field study was under taken by GREWAL and ABROL (2006) to examine the growth responses of some management practices in a unified system for plantations of agro-forestry. Techniques like inter-row, planting in shallow depth of soil and deep augering to cross the hard pan were investigated. Plant parameters like plant height, basal diameter etc. indicated that deep auger hole planting was markedly superior to shallow planting. Biomass data after two years also indicated the same trend.

Studies of MEHDI *et al. (2004)* indicated that transplantation of Eucalyptus and Guava sapling after removal of plastic bags (total or partially) used for nursery growing increased survival rate and subsequent plant growth as compared to bag remaining intact.

MINHAS *et al.* (2006) reported that growth of *Acacia nilotica* and *Dalbergia sisoo* saplings planted in irrigation furrows were not affected when irrigated with water of EC_{iw} of 10.5 dS m^{-1}. Special transplantation techniques of saplings have to be adopted for successful survival and growth of different trees.

CHAPTER - 3

MATERIALS AND METHODS

The research work was undertaken at Soil Salinity Research Institute Pindi Bhattian, Punjab, Pakistan and consisted of following three studies,

1. Assessment of tolerance to salinity/sodicity and their combinations by *Acacia ampliceps*.
2. Evaluation of long term effect of saline sodic environment on growth of *Acacia ampliceps* and vice versa.
3. Investigating transplantation techniques to avoid early stage salinity stress.

3.1 Study- 1

ASSESSMENT OF TOLERANCE TO SALINITY/SODICITY AND THEIR COMBINATIONS BY ACACIA AMPLICEPS

This study was conducted to assess the tolerance potential of *Acacia ampliceps* against salinity/sodicity and their combinations. Three experiments were carried out to accomplish this objective.

3.1.1 Experiment – 1: Evaluation of *Acacia ampliceps* for salinity tolerance

The experiment was completed in pots. A normal soil was selected and brought to the wire-house in bulk; soil samples were obtained and analyzed for salinity parameters (EC_e, pH, SAR, cations and anions), calcareousness and texture (Table 3.1).

Soil EC_e levels of 10, 20, 30, 40 and 50 (dS m^{-1}) were developed artificially, in addition to original soil status (for the sake of comparison). A mixture of salts (NaCl, Na_2SO_4, $CaCl_2$ and $MgSO_4$ in ratio of 3:4:2:1) in calculated amounts was added to develop the respective desired EC_e levels. Salts were dissolved in distilled water and sprayed on the soil that was spread in thin layers. Soil was stirred and mixed after each application of the salts. Samples were obtained separately from each soil to ascertain the development of the desired levels. After development of desired levels, the soil was filled in pots.

3.1.2 Experiment – 2: Assessing tolerance potential of *Acacia ampliceps* in sodic environment

The bulk soil of experiment No.1 was also used for developing the sodicity levels. Sodium bicarbonate ($NaHCO_3$) was added to create artificial levels of SAR {10, 20, 30, 40, 50, 60 and 70 $(mmol\ L^{-1})^{1/2}$}, in addition to original soil status (for the sake of comparison). The procedure for development of sodicity was similar as explained in experiment No.1. When whole quantities of salts have been added, the moist soil was covered (air tight) for seven days to complete exchange reactions.

3.1.3 Experiment – 3: Investigating tolerance against combined stresses of salinity and sodicity

The same bulk soil was used as well to develop the following combined levels of EC_e and SAR in addition to original soil status (for the sake of comparison).

Treatment No.	EC_e level ($dS\ m^{-1}$)	SAR level
1	**Original soil (control)**	**Original soil (control)**
2	10	30
3	10	40
4	10	50
5	20	30
6	20	40
7	20	50
8	30	30
9	30	40
10	30	50

The combination of salts as described in experiment No.1 was used to develop desired salinity level. Then sodium bicarbonate ($NaHCO_3$) was applied in different calculated quantities so as to create desired SAR levels within one EC level. Other procedure was similar as already described above. Quadratic equation was used to calculate different amounts of Na^+, Ca^{2+} and Mg^{2+} salts for developments of desired levels of EC_e and SAR.

Standard quadratic formula

$$x = \frac{-b \pm (b^2 - 4ac)^{1/2}}{2a}$$

After putting the values of SAR and subsequent solving, the quadratic formula can be converted to quadratic equation as under:

$$ax^2 + b x + c = 0$$

Where

a	=	coefficient of x^2
b	=	coefficient of x
c	=	constant
x	=	Variable

3.1.4 Methodology

The soil was filled in pots when artificial creation of EC_e, SAR levels and their different combination was completed. The pots were arranged in completely randomized design (CRD) for each experiment separately. There were four repeats of each experiment. Three seedlings of *Acacia ampliceps* of the same age and approximately same height (25 – 30 cm) were transplanted in each pot on September 15, 2004 and irrigated subsequently. Canal water (Analysis presented in Table 3.2) was applied as and when needed by the plants. The survival rate was studied up to the period of one month. However, one seedling was maintained in each pot after 30 days. Fertilizer was applied in solution form. One liter of 1 % urea, TSP (triple super phosphate) and potassium sulphate was applied into each pot one week after transplantation and after every six months. The following observations were recorded after every six months during the period of two years.

a) Survival rate.
b) Plant height.
c) Stem diameter (girth).
d) Number of leaves and branches per plant.
e) Canopy volume of each plant.

Stem diameter of smaller plants was taken by vernier caliper. However, the diameter of bigger plants was indirectly calculated from the circumference (C) that was measured by a measuring tape. The formula for calculation of diameter (D) is as under:

D = C / ¶

The Canopy volume (C.V.) in cubic meter was determined by the following formula:

D1 + D2 / 2 = r

C.V. = ¶ r^2 X h / 4

Where

D1 = Diameter of one side of the plant

D2 = Diameter of the other side of the plant

h = Height of the plant

Young and older leaves of plants were collected after six months from each treatment separately and analyzed for K^+, Na^+, Ca^{2+} and Mg^{2+}. Plants were harvested on September 15, 2006 after completion of two years period. Roots were separated from the soil, giving washing to the soil with distilled water. The oven dry root and shoot weights were recorded separately. The young and older leaves as well as roots were also analyzed for K^+, Na^+, Ca^{2+} and Mg^{2+}.

3.2 Study-2

EVALUATION OF LONGTERM EFFECT OF SALINE SODIC ENVIRONMENT ON GROWTH OF Acacia ampliceps AND VICE VERSA

Impact of salinity/sodicity on the growth of *Acacia ampliceps* was investigated in this study. The probable effect of plant growth on soil improvement was also monitored. For this purpose, plants of different conditions (poor, medium, and good) 12 in each were selected from one-acre block, which were transplanted on September 10, 2001. Classification of any plant into one of the above categories was on the basis of visual parameters like, height, No. of branches, girth and spread (canopy) of the plant. The heights, girth, number of branches per plant and spread of plants (included in different classes as above) were recorded at the initiation of study on March 10, 2005.

Soil samples were obtained up to 150 cm depth at the same time and analyzed for ECe, pH, SAR, cations and anions. The soil analysis data was compared with the original soil analysis recorded at the time of transplantation. Fertilizer in solution form (Two liter per plant of 2 % solution of urea, TSP and potassium sulphate) was applied after one week of the initiation of the experiment. Fifty grams of urea, TSP and potassium sulphate were applied into soil after six months while 100 grams of these fertilizers were also added each year in the month of February. Young and older leaves were also collected for analysis of K^+, Na^+, Ca^{2+} and Mg^{2+}. All the above observations were recorded after every six months during the two years study that ended on September 10, 2006. Correlations of different growth parameters with soil characteristics were worked out so that effect of soil salinity/sodicity on plants and plant growth on soil improvement could be predicted.

3.3 Study-3

INVESTIGATING TRANSPLANTING TECHNIQUES TO AVOID EARLY STAGE SALINITY STRESS

The plants, in general, are comparatively more sensitive during early stage of their growth as compared with later stages when they become older. Therefore, improved transplantation techniques, which help in avoiding early salt stress, may prove more useful in salt-affected soil. Such a probability was investigated in this study. The following transplantation techniques were tested in the selected salt-affected (saline sodic) field.

- T1. Transplantation on the flat field (without any channel, pit or amendment)
- T2. Transplantation in pits (60 x 60 x 60 cm) filled with original soil on the shoulder of a channel (90x60 cm).
- T3. Transplantation in pits (60 x 60 x 60 cm) filled with silt (fresh alluvium) on the shoulder of a channel (90 x 60 cm).
- T4. Transplantation in pits + augering (7.5 cm diameter) down to 150 cm.
- T5. Transplantation in pits + silt + gypsum (ratio 20:1)
- T6. Transplantation in pits + original soil + gypsum (ratio 20:1)
- T7. Transplantation in pits + silt + compost (ratio 20:1)
- T8. Transplantation in pits + original soil + compost (ratio 20:1)

Almost uniform field with respect to salinity parameters was selected. The field was leveled and prepared for transplantation of saplings. Soil samples were obtained and analyzed for EC_e, pH, SAR, cations, anions, calcareousness and texture. The determinations of the experimental soil are presented in Table 3.1. Plants of uniform age and approximately same height were transplanted on September 10, 2004 through the techniques described above and field was irrigated. There were four replications of experiment in Randomized Complete Block Design (RCBD) and 12 plants in each replication. Plant to plant and row-to-row distance was 3 meters. Subsequent irrigations were applied as and when needed, depending upon the season. Fertilizer in solution form (two liter per plant of 2 % solution of urea, TSP and potassium sulphate) was applied after one week of the initiation of the experiment. Fifty grams of urea, TSP and potassium sulphate were applied into soil after six months while 100 grams of these fertilizers were also added each year in the month of February. There was scale insect attack on plants in winter season of 2005 and hostathion (100 ml per 20 lit tank) insecticide was sprayed to control it. Fungus attack was also identified and thiophenate powder (2 grams per liter of water) was used to check its effect. Young and older leaves were collected after every six months for analysis of K^+, Na^+, Ca^{2+} and Mg^{2+}. Composite soil samples were also obtained at the same time and analyzed for EC_e, pH_s, SAR, cations and anions.

The following observations were recorded as well after every six months over a period of two years that was completed on September 11, 2006.

a) Survival rate.
b) Plant height.
c) Stem diameter (girth).
d) Number of leaves and branches per plant.
e) Canopy volume of each plant

3.4 Irrigation waters

Uniform quantity of water was applied to all the pots and plots in the field. Canal water was used to irrigate all the pots and field experiments. However, for field experiments brackish ground water was also used occasionally for irrigation when canal water was not available due to insufficient supply. All these waters were also analyzed in the laboratory for their chemical characteristics (Table 3.2). According to the analysis, canal water had electrical conductivity (EC) 0.28 dS m^{-1}, sodium adsorption ratio (SAR) 0.16 $(mmol\ L^{-1})^{1/2}$ and no residual sodium carbonate (RSC). Laboratory analysis indicated that EC, SAR and RSC of brackish ground water of study -2 were 1.22 dS.m^{-1}, 4.90 $(mmol\ L^{-1})^{1/2}$ and 3.80 $mmol_c\ L^{-1}$ and in study -3 were 1.59 dS m^{-1}, 7.89 $(mmol\ L^{-1})^{1/2}$ and 5.70 $mmol_c\ L^{-1}$ respectively.

3.5 Analytical procedures

3.5.1 Soil analysis

Soil samples were collected from 0-15 cm in all the pot and field experiments after the harvest of each crop. These samples were air dried and passed through 2-mm sieve. Analysis work was carried out in the laboratories of Soil Salinity Research Institute, Pindi Bhattian, Pakistan. Analytical methods of U.S. Salinity Laboratory Staff (1954) were followed or otherwise mentioned. All the calculations were made on oven dried soil weight basis.

Preparation of saturated soil paste

Saturated soil paste was prepared according to Method 2.

Saturation percentage

Saturated soil paste was prepared and saturation percentage was determined by drying the paste in an oven at 105^{o}C to a constant weight (Method 27a).

Particle size analysis

This was done by Bouyoucos hydrometer technique (MOODIE et al., 1959). Dispersion was made with 1 % sodium hexametaphosphate solution and soil texture was determined by using International Textural Triangle.

pH of saturated soil paste

Soil pH of the saturated paste was determined by pH meter having combination electrode after calibrating with buffer solutions of pH 7.0 and 9.0 (Method 21a).

Saturation soil extract

Saturated soil extract was obtained by vacuum pump (Method 3a).

Electrical conductivity of saturation extract

After calibrating the instrument with 0.01 N KCl, the EC_e was measured with (LF-191 Conduktometer) conductivity meter (Method 4b).

Soluble calcium + magnesium

By titration of sample against 0.01N EDTA solution using NH_4Cl + NH_4OH buffer solution and Eriochrome Black T (EBT) indicator (Method 7).

Soluble sodium

It was determined with the help of a flame photometer (Jenway Model PFP-7). The instrument was first standardized with a series of standard solutions of Na using analytical reagent NaCl salt. After this, Na was determined in the saturation extract (Method 10a).

Soluble potassium

It was determined with the help of a flame photometer (Jenway Model PFP-7). The instrument was first standardized with a series of standard solutions of K using analytical reagent KCl salt. After this, K was determined in the saturation extract (Method 11a).

Carbonates

By titration with 0.1N H_2SO_4 using phenolphthalein as an indicator to a colorless end point (Method 82).

Bicarbonates

After carbonate titration, the sample was titrated with 0.1N H_2SO_4 using methyl orange as an indicator to a light pink end point (Method 82).

Chlorides

The same sample, after bicarbonate determination, was titrated against 0.01N silver nitrate solution using potassium chromate as an indicator to a brick red end point (Method 13).

Sulphates

It was determined by the difference method, i.e.

$$SO_4 = TSS - (CO_3 + HCO_3 + Cl)$$

Where all ions being expressed in $mmol_c\ L^{-1}$

Sodium adsorption ratio (SAR)

It was calculated by the following formula:

$$SAR = \frac{Na}{(Ca + Mg / 2)^{1/2}}$$

Where all cations are expressed in $mmol_c\ L^{-1}$ concentration

Calcium carbonates ($CaCO_3$)

It was determined by the calcimeteric method using 6 N HCL solutions. Five g soil sample was treated with 1:1HCl and volume of CO_2 liberated from $CaCO_3$ present in the soil was noted (MOODIE *et al*., 1959).

$$CaCO_3\ (\%) = CO_2 \text{ released (ml) X } (0.00399)/\text{weight of soil sample taken (g)}$$

Organic carbon and organic matter

Organic carbon was determined by titrating the sample containing soil, potassium dichromate and sulphuric acid using ferroin indicator (Method 24). Organic matter was determined by applying following formula:

Organic matter in percent = Organic carbon in percent X 1.72

Total nitrogen

Ten (10) grams of soil was added in 30 ml of concentrated H_2SO_4 and 10 grams of digestion mixture (K_2 SO_4: Fe SO_4: Cu SO_4 = 10: 1: 0.5) and then digesting the material using Kjeldahl's digestion tubes, cooled and volume was made to 250 ml. An aliquot of 10 ml was taken from it for distillation of ammonia, into a receiver containing 4 % boric acid solution and mixed indicator (bromocresol green and methyl red). Sodium hydroxide was added to the distillation flask to make the contents alkaline. After distillation, the material in the receiver was titrated against standard N/10 H_2SO_4 by Gunning and Hibbard's method of H_2SO_4 digestion and distillation with micro Kjeldahl's apparatus (JACKSON, 1962).

Available phosphorus

Oleson's method was followed to determine the available phosphorus contents in the soil using $NaHCO_3$ solution as extracting agent. Standard stock P solution was prepared by dissolving exactly 0.439 g potassium dihydrogen orthophosphate (KH_2PO_4) analytical grade in ½ litre distilled water. Then 25 ml 7 N H_2SO_4 were added and volume was made one litre to get 100 ppm P standard stock solution. Soil sample of 2.5 g was weighed and 50 ml Oleson's reagent (0.5 M $NaHCO_3$, pH = 8.5) was added and this suspension was shaken for 30 minutes and filtered. Five ml of the filtrate was used to develop colour and then reading was noted using Spectrophotometer (TANDON, 2001).

3.5.2 Water analysis

For water analysis, all the methods used were same as in soil analysis except RSC.

Residual sodium carbonate (RSC)

RSC of irrigation water was determined by the following formula (EATON, 1950):

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

Where all ions are expressed in $mmol_c\,L^{-1}$ concentration

3.5.3 Plant analysis

Wet digestion

Dried plant sample of 1.0 g was transferred to 50 ml beaker and 20 ml concentrated HNO_3 was added to it. This beaker was covered with a watch glass until the completion of initial reactions. Then these contents were heated until solid particles have nearly dissolved, cooled and 10 ml of perchloric acid were added to the same beaker. Then this was again heated till the volume is reduced to approximately 3 ml. The contents were cooled and transferred to 100 ml volumetric flask and volume was prepared. This solution was used for all subsequent determinations (Method 54 a).

Potassium

Atomic absorption spectrophotometer was used to determine the total potassium concentration in plants samples (Method 58 a).

Sodium

Atomic absorption spectrophotometer was used to determine the total sodium concentration in plants samples (Method 57 a).

Calcium

Atomic absorption spectrophotometer was used to determine the total calcium concentration in plants samples (Method 55 a).

Magnesium

Atomic absorption spectrophotometer was used to determine the total magnesium concentration in plants samples (Method 56).

3.5.4 Statistical analysis

The data collected about soils and crops were subjected to analysis of variance (ANOVA) [STEEL and TORRIE, 1980). Individual comparisons between treatments were made according to Duncan's Multiple Range Test (DMR Test). Mean and Standard Deviations (SD) were computed for data of study -2. Correlation Coefficients (R^2) were also worked out and correlation equations were developed for prediction of variations.

Table 3.1: Original soil analysis of three studies (pot and field experiments)

Sr. No.	Determinations	Unit	Study -1 Pot Experiment	Study - 2 Field Experiment	Study - 3 Field Experiment
1	Saturation percentage	%	35.70	40.75	38.53
2	pH_s	-	8.19	9.49	10.12
3	EC_e	$dS\ m^{-1}$	1.70	15.00	23.21
4	CO_3^{2-}	$mmol_c\ L^{-1}$	-	1.16	21.54
5	HCO_3^{1-}	$mmol_c\ L^{-1}$	5.00	23.83	16.47
6	Cl^{1-}	$mmol_c\ L^{-1}$	4.50	158	256
7	SO_4^{2-}	$mmol_c\ L^{-1}$	7.50	6.33	9.95
8	$Ca^{2+} + Mg^{2+}$	$mmol_c\ L^{-1}$	3.20	4.32	3.11
9	Na^{1+}	$mmol_c\ L^{-1}$	13.80	183	299
10	K^{1+}	$mmol_c\ L^{-1}$	0.36	0.52	0.54
11	SAR	$(mmol\ L^{-1})^{1/2}$	10.95	124	240
12	Sand	%	68.00	55.15	59.17
13	Silt	%	15.00	21.25	20.36
14	Clay	%	17.00	23.60	20.47
15	Textural class	-	Sandy loam	Sandy clay loam	Sandy clay loam
16	$CaCO_3$	%	4.80	5.13	5.52
17	Organic carbon	%	0.18	0.12	0.10
18	Organic matter	%	0.35	0.26	0.17
19	Total Nitrogen	%	0.02	0.01	0.01
20	Available phosphorus	$mg\ kg^{-1}$	7.18	5.12	5.00

Table 3.2: Analysis of irrigation water used for experiments

Sr. No.	Determinations	Unit	Study 1 Pot Experiment Canal water	Study 2 Field Experiment Brackish ground water	Study 3 Field Experiment Brackish ground water
1	Electrical conductivity (EC)	$dS\ m^{-1}$	0.28	1.22	1.59
2	Total soluble salts (TSS)	$mmol_c\ L^{-1}$	2.80	12.20	15.90
3	pH	-	7.42	8.00	8.24
4	Carbonates (CO_3^{2-})	$mmol_c\ L^{-1}$	Nil	Nil	Nil
5	Bicarbonates (HCO_3^{1-})	$mmol_c\ L^{-1}$	1.48	8.50	10.00
6	Chlorides (Cl^{1-})	$mmol_c\ L^{-1}$	1.00	1.16	2.52
7	Sulphates (SO_4^{2-})	$mmol_c\ L^{-1}$	0.32	2.54	3.38
8	Calcium + magnesium ($Ca^{2+} + Mg^{2+}$)	$mmol_c\ L^{-1}$	2.62	4.70	4.30
9	Sodium (Na^{1+})	$mmol_c\ L^{-1}$	0.18	7.50	11.60
10	Sodium adsorption ratio (SAR)	$(mmol\ L^{-1})^{1/2}$	0.16	4.90	7.89
11	Residual sodium carbonate (RSC)	$mmol_c\ L^{-1}$	Nil	3.80	5.70

Table 3.3: Analysis of compost used in the experiment

Sr. No.	Determinations	Unit	Compost
1	pH (1:1)	-	7.60
2	EC (1:1)	$dS\ m^{-1}$	6.44
3	Organic matter	%	47.50
4	Organic carbon	%	27.60
5	Total nitrogen	%	2.23
6	C/N ratio	-	12.38
7	Calcium	$g\ kg^{-1}$	18.10
8	Magnesium	$g\ kg^{-1}$	6.22
9	Potassium	$g\ kg^{-1}$	14.15
10	Available Phosphorus	$g\ kg^{-1}$	15.30
11	Chlorides	$g\ kg^{-1}$	6.12

CHAPTER - 4

RESULTS

These investigations consisted of following three studies; each had specified objective, treatments and methodology.

1. Assessment of tolerance to salinity/sodicity and their combinations by *Acacia ampliceps*
2. Evaluation of long term effect of saline sodic environment on growth of *Acacia ampliceps* and vice versa
3. Investigating transplantation techniques to avoid early stage salinity stress

Study -1 comprised of three experiments, which were conducted in pots. Study -2 and study -3 were conducted under field conditions. All the studies were inter-related and associated to each other so that precise, refined and comprehensive information be generated that could be used for making recommendations to the farmers. The results of each experiment are being presented here after:

4.1 Study-1

ASSESSMENT OF TOLERANCE TO SALINITY/SODICITY AND THEIR COMBINATIONS BY Acacia ampliceps

4.1.1 Experiment -1: Evaluation of *Acacia ampliceps* for salinity tolerance

4.1.1.1 Plant growth parameters

Data on salinity parameter of *Acacia ampliceps* indicated that the plant could survive up to soil EC_e of 50 dS m^{-1}. Plant did not die in any of the salinity levels (10, 20, 30, 40 and 50 dS m^{-1}). The effect on growth parameter is being presented as under: -

4.1.1.1.1 Plant height

The comparative data for different salinity levels revealed a significant decrease in height of plants. The appreciable suppressing effect on this parameter started from EC_e 30 dS m^{-1} as assessed after six months. The negative effects of soil salinity progressively penetrated and during the second year significantly short stature plants were obtained even with level of EC_e 10 dS m^{-1}. At this stage, each consecutive level resulted in significantly decreasing effect in respect of plant height. The over all values of this plant character after two years were decreased by 36, 56, 80, 124 and 165 cm respectively for EC_e 10, 20, 30, 40 and 50 dS m^{-1} with respective decrement of 13, 20, 29, 45 and 60 % over control (Table 4.1).

4.1.1.1.2 Stem diameter (girth)

Soil salinity effect was not only observed on plant height but also the thickening was depressed significantly (Table 4.2). An appreciable negative impact started from the level of EC_e 20 dS m^{-1} in the first year and from 10 dS m^{-1} in the second year. Each level caused statistically measurable reduction. The stem girth was increased from 0.28 cm to 2.59 cm in control plants during study of two years. However, increase in stem diameter was checked due to saline environment and 8, 17, 26, 42 and 57 % decreased over control was recorded in EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} respectively.

4.1.1.1.3 Number of leaves

Leaf bearing of plants was also affected inversely with increasing salinity levels (Table 4.3). Number of leaves increased from 26 (at transplantation time) to 583 in control after two years that were restricted to 544, 489, 429, 348 and 209 due to respective levels of EC_e 10, 20, 30, 40 and 50 dS m^{-1}. Thus, these saline conditions caused decrease of 7, 17, 27, 43 and 68 % over control. Initially, effect of 20 dS m^{-1} was found to be significant but in the second year impact of even 10 dS m^{-1} was assessed as appreciable in statistical terms. A significant and consecutive decrease with each level of salinity was recorded in the later year.

4.1.1.1.4 Number of branches

Branching is also phenomenon of plant growth, which was clearly affected under saline soil medium. The single trunk branched in to 45 in control plants growing in normal conditions, which was reduced by 16, 30, 48, 68 and 77 % in EC_e 10, 20, 30, 40 and 50 dS m^{-1} respectively (Table 4.4). The level of 30 dS m^{-1} proved negative significantly during observation of six month old plants while effect of 20 dS m^{-1} became prominent after one year whereas only 10 dS m^{-1} produced similar results in the second year.

4.1.1.1.5 Canopy volume

There was nominal canopy volume of the plants at the time of transplantation that consistently and gradually increased and reached to 5.27 m^3 after two years in control plants with no stress of salinity (Table 4.5). However, even the first level of salinity (10 dS m^{-1}), this parameter was decreased significantly. Each increasing level was differentiated causing measurable reductions. The recorded end values were 5.27, 4.68, 4.13, 3.81, 2.25 and 1.07 m^3 with salinity levels of control, 10, 20, 30, 40 and 50 dS m^{-1}.

4.1.1.1.6 Plant shoot weight

This parameter was only recorded in pot study because plants could be cut, dried and weighed. Total biomass (fresh and dry) was significantly decreased with each consecutively increasing level of salinity indicating the suppressing of growth under saline environment (Table 4.6). The percentage decrease in dry weight was recorded to be 5, 6, 16, 37 and 52 over control with respective EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1}. An interesting phenomenon observed was consecutively decreasing moisture percentage in plants indicating the depressing effects of salinity in water uptake by plants, although these were constantly irrigated uniformly.

4.1.1.1.7 Plant root weight

The effect and pattern of variation of root weight was exactly similar as recorded in shoot weight and described in the earlier sections. The decreased in mass of root (after two years) and water uptake was assessed to be significantly and each salinity level was differentiated statistically (Table 4.7). The decrease was 15, 22, 29, 46 and 60 % over control respectively with EC_e 10, 20, 30, 40 and 50 dS m^{-1}.

4.1.1.2 Soil characteristics (soil salinity parameters)

Soil analysis after two years indicated that a slight decrease occurred in EC_e as compared with the initially created level (Appendix 1). For examples recorded EC_e was 9.21 dS m^{-1} where level of 10 dS m^{-1} was artificially synthesized. Similarly, it was found to be 46.69 dS m^{-1} against starting level of 50 dS m^{-1}. The pH remained almost unchanged. The values of SAR and cations (Ca + Mg and Na) were corresponding with soil EC_e i.e. these were found to be more where created EC_e was of higher level. Thus, plants remained growing throughout under the desired levels of salinity stress.

4.1.1.3 Plant leaf compositions

4.1.1.3.1 Sodium contents

Sodium concentration in older leaves increased with increasing levels of salinity as well as age of plants. Maximum values were recorded in plants growing in soil EC_e of 50 dS m^{-1} that steadily increased as well with growth of plants. The values were gradually enhancing and magnitudes of 15.22, 17.30, 18.24 and 19.45 g kg^{-1} were recorded in leaves of six months, one year, one and a half year and two years respectively (Table 4.8 and 4.9). Minimum values were observed in control (no stress) while other levels of salinity were having intermediate quantum of Na. Younger leaves depicted exactly similar trend but were having almost half numerical values compared with older ones.

4.1.1.3.2 Potassium contents

The variation pattern of K contents was similar in older and younger leaves whereas determined values were higher in younger leaves compared with older. However, K concentration was decreasing with corresponding increased in EC_e but increasing with increasing age of plants (Table 4.10 and 4.11). Maximum values were recorded in leaves of non-stressed plants (T1 control) while K concentrated to minimum in highly stressed plants (EC_e 50 dS m^{-1}).

4.1.1.3.3 Potassium to sodium ratio (K: Na)

More values of K: Na were recorded in control plants which were still higher in younger leaves. The increasing salinity levels decreased it appreciably in both type of leaves (older and younger) but numerical values were more in younger ones. Thus, plants sequestered excess Na into older leaves to control the negative effects on growing tissues up to certain extent.

4.1.1.3.4 Calcium contents

A slight increased in Ca contents of old and younger leaves were recorded, as the plants grew older (Table 4.12 and 4.13). The value was 13.42 g kg^{-1} in six months old plants growing under unstressed conditions (control) that increased to 15.56 g kg^{-1} in older leaves of two years age. Salinity stress affected drastically the Ca concentration in both type of leaves. The contents of 13.42 g kg^{-1} in older leaves of six months plants decreased to 4.22 g kg^{-1} with EC_e level of 50 dS m^{-1}. There was a consistent and corresponding depressing effect with each increasing level of salinity. All the treatments were differentiated statistically. Same trend was noticed in all the four observations during two years period. Variations followed exactly similar pattern with pronouncedly lower values.

4.1.1.3.5 Magnesium contents

The Mg concentrations in older and younger leaves were depicting the same style of variations as reported already for Ca. However, the values were almost half of Ca (Table

4.14 and 4.15). For example, the mean value of Mg was 7.05 g kg^{-1} in older leaves of six months old plants growing in control pots as against corresponding value of 13.42 g kg^{-1} for Ca. The effect of age of plants was almost negligible as indicated by consistent values during all the four observations. Values of Mg were the least among the four cations (Na, Ca, K and Mg).

4.1.1.4 Plant root composition

The root Na contents increased significantly with increasing levels of salinity whereas K, Ca, Mg and K/Na ratio decreased appreciably. All the salinity levels (10, 20, 30, 40 and 50 dS m^{-1}) were different statistically in case of Na and K (Table 4.16). The consecutive levels were non-significant in case of Ca contents. EC_e levels of 10 and 20 dS m^{-1} were at par in respect of Mg. Similarly, 30 and 40 dS m^{-1} was alike. No statistical difference in Mg values was recorded for EC_e 40 and 50 dS m^{-1}. The K: Na decreased progressively and was calculated to be only 0.40 in the highest level as against 2.44 for the control plant roots.

4.1.2 Experiment – 2: Assessing tolerance potential of *Acacia ampliceps* in sodic environment

4.1.2.1 Plant growth parameters

The plants could not survive in SAR 60 and 70 while growth was suppressed to various degrees under other levels. Effects on different parameters are presented as under: -

4.1.2.1.1 Plant height

Increased in plant height was checked due to sodicity levels but statistical difference only occurred with SAR of 50 in six months plants (Table 4.17). After next six months more (one year old plants) the last two levels became prominent. The effects were more pronounced in the second year and each level differentiated significantly. Thus, sodicity penetrated with time. The over all decrease in two years were found to be 18, 32, 51 and 86 % over control for SAR 20, 30, 40 and 50 respectively. Hence, there was nominal increase of plant height during two years growth period under highest sodicity level SAR 50.

4.1.2.1.2 Stem diameter (girth)

The thinner plants at the time of transplantation become gradually thicker and stem diameter grew by 2.30 cm during two years (Table 4.18) in the absence of any stress (control). However, sodicity hindered the increase in stem diameter that became significant within six months due to SAR 50, after one year with SAR 40 and 50 and in all the SAR levels during the second year. The stem diameter of 2.60 cm attained after two years in control plants was restricted to only 0.76 cm by the level of SAR 50. The value of this parameter was 0.25 cm initially at the time of transplantation. The decrease in stem diameter was recorded as 13, 25, 43 and 78 % with respective SAR levels of 20, 30, 40 and 50.

4.1.2.1.3Number of leaves

The number of leaves is a sign of a healthy plant that steadily increased from 29 (initial) to 578 in non-stressed plants during two years but there were restricted to only 112 with SAR 50 (Table 4.19). Penetration of sodicity effect was found to be significant for SAR 40 and 50 in the first year and all levels during the second year. The decrease in total leaves was investigated as 8, 20, 48 and 85 % under sodic conditions measured with SAR 20, 30, 40 and 50 respectively. Thus, SAR 40 caused about 48 % reduction, which is very closer to 50 % that is considered least economical in salt tolerant studies.

4.1.2.1.4 Number of branches

The single stem branched into 47 during two years without any stress. The effects of sodicity proved highly negative and highest level of SAR (50) retarded to only 7 branches (Table 4.20). Such effects were assessed to be significant just after six months even with SAR 20 but SAR 50 was highly pronounced. The effects of different levels were overcome in one-year plant but SAR 50 still remained significant. All the levels were statistically differentiated in the last year. The reduction was evaluated as 30, 48, 63 and 87 % with corresponding levels of SAR 20, 30, 40 and 50.

4.1.2.1.5 Canopy volume

The spread of plant, as measured through canopy volume, was significantly checked by each level of sodicity (Table 4.21). The negative effect increased with enhancing quantum. It started from the beginning of experiment and persisted like this to the end because same trend was observed during all the four six monthly observations. The nominal canopy volume (0.005 m^3) at transplantation time, increased to 5.22 m^3 in the absence of any stress that was restricted just to 0.49 m^3 in the highest SAR (50). The over all decrements were found to be 15, 38, 77 and 90 % for respective SAR levels of 20, 30, 40 and 50.

4.1.2.1.6 Shoot weight

Biomass and shoot weight of plants is the result of many factors and over all measurement of growth. The total fresh biomass was harvested as 2460 g $plant^{-1}$ in control, which was just 549 g $plant^{-1}$ in the highest sodicity level. There was corresponding decreased as SAR was elevated. The recorded dry weight was 1009 g $plant^{-1}$ in control pots that was reduced to 976, 824, 473 and 303 g $plant^{-1}$ with progressive sodicity levels of SAR 20,30,40 and 50 (Table 4.22). These decreases were measurable significantly and each level was differentiated. The loss in fresh mass was also maximum in control plants indicating less water uptake under sodic environment. The detrimental effect of SAR levels was calculated to be 3, 18, 53 and 70 % on the basis of loss in dry mass during two years.

4.1.2.1.7 Root weight

Not only shoot was affected negatively under sodic conditions but also root development was also restricted significantly. Each SAR level suppressed it appreciably. The recorded dry mass of 243 g $plant^{-1}$ under normal conditions was restricted as only 83 g $plant^{-1}$ in the highest sodicity (Table 4.23). The reduction was recorded as 20, 34, 52 and 66 % with respective levels of SAR 20, 30, 40 and 50. The reduction in root mass was more than shoot magnitude with the first two levels (20 and 30 SAR). Moisture percentage was more in unstressed or less stressed plants compared with plant growing in highly sodic environment.

4.1.2.2 Soil characteristics (soil salinity parameters)

Soil analysis after harvesting and uprooting of plants indicated that end SAR values remained very closer to those created before transplantation of plants. Thus, plants remained growing and faced the stressed conditions as was targeted under the scope of the experiments (Appendix -2). Hence, the sodicity tolerance evaluation was almost correct, as no significant changes occurred afterwards. For example, created soil SAR level of 50 was having 47.73 even after two years.

4.1.2.3 Plant leaf composition

4.1.2.3.1 Sodium contents

Leaf constitution of Na was minimum in control plants of younger leaves while in older leaves it was slightly more. The age of plants caused a little bit increase (Table 4.24). Progressively increasing sodicity levels increased Na contents of old as well as younger leaves. Each level was found to be significant with the subsequent consecutive level.

Sodium contents of leaves in last sodicity level were many times high during all the four observations in four years. For example, Na magnitude was 3.94 g kg^{-1} after six months that was analyzed as 4.83 g kg^{-1} in older leaves of two years old plants grown in control plants but its recorded value of 19.43 g kg^{-1} after six months increased to 24.53 g kg^{-1} during two years under highest level of SAR 50. The values of this parameter were found to be slightly higher than saline conditions under experiment-1. Younger leaves behaved just like older leaves but with lesser values (Table 4.25).

4.1.2.3.2 Potassium contents

There was comparatively little change with age of plants in K contents of older and younger leaves (Table 4.26). However, each increasing sodicity level reduced K contents in leaves significantly. The reduction of about 4 – 5 g kg^{-1} K in leaves with highest sodicity levels was observed during different samplings. For example K contents after one year were decreased from 13.06 (control) to 9.05 g kg^{-1} (highest level) while after two years from 14.54 (control) to 9.34 (SAR 50) g kg^{-1}. The values in younger leaves were estimated to be higher with the same trend of variation (Table 4.27).

4.1.2.3.3 Potassium to sodium ratio (K:Na)

This ratio had more values under control condition. The numerical quantum was higher in younger leaves in comparison to older ones. The increasing levels of sodicity shattered this ratio and plants could not maintain it because lesser values were observed with progressively increase in SAR. The value of 3.01 (control) decreased to 0.38 (SAR 50) in older leaves while it was cut short to 1.32 from 6.05 (control) with the highest SAR value in younger leaves (Table 4.26 and 4.27).

4.1.2.3.4 Calcium contents

Each of the ascending SAR decreased leaves Ca contents significantly. The observation was true in older and younger leaves as well as for all the four samplings during two years study (Table 4.28 and 4.29). The age of plants indicated a slightly increasing effect. For example Ca contents increased to 15.76 from initial values of 13.64 g kg^{-1} in leaves of unstressed plants while recorded as 4.26 after two years as against initial 3.31 g kg^{-1} in the older leaves of plants growing under highest sodic environment (SAR 50). Recorded values for all the four observations and sodicity levels were lesser in younger leaves.

4.1.2.3.5 Magnesium contents

The parameter exactly followed the pattern of variation for sodicity level as was observed for Ca in the above section. However, the quantitative contents were measurably lower than Ca, rather almost half under most of the observations. Very slight difference was recorded with age and the Ca contents remained consistent (Table4.30 and 4.31).

4.1.2.4 Plant root composition

Under normal conditions the root Ca concentration was the maximum (12.04 g kg^{-1}) closely followed by K (11.25 g kg^{-1}) and Mg with lesser values (6.74 g kg^{-1}) (Table 4.32). Sodium contents were the least (4.85 g kg^{-1}). However, soil sodicity stress totally changed this pattern. Sodium constituent became the largest among all the four determined cations that increased correspondingly with increasing sodicity levels while all the other three cations decreased significantly. Each level was differentiated in case of K and its contents decreased from 11.25 g kg^{-1} (control) to 5.03 g kg^{-1} with highest level of SAR (50). Root Ca contents decreased from 12.04 g kg^{-1} (control) to only 2.82 g kg^{-1} while Mg was restrict to just 1.82 g kg^{-1}. The K: Na ratio also decreased. Its calculated values were 2.32, 0.99, 0.56, 0.36 and 0.26 in control and respective levels of SAR 20, 30, 40 and 50.

4.1.3 Experiment -3: Investigating tolerance against combined stresses of salinity and sodicity

Major category of salt-affected soil in Pakistan is saline sodic in which both stresses (salinity and sodicity) are combined together. Scanty information is available in world literature on tolerance of plants for combined salinity sodicity. This experiment was conducted to generate information in this deficient field. Results of this experiment are as under:

4.1.3.1 Plant growth parameters

4.1.3.1.1 Plant height

Data of six months plants indicated that combination of soil EC_e up to 20 dS m^{-1} and SAR up to 40 did not affected the plants height significantly compared with control although depressing effect was there. However, these impacts penetrated with time and level of EC_e 10 dS m^{-1} + SAR 40 became appreciable statistically after one year (Table 4.33). Further penetration was recorded with increasing age of plants and all the levels were differentiated after one and a half year that persisted to the end of the study. The height of plants was 310 cm after two years in unstressed plants, which was just 133 cm under the highest level (EC_e 30 dS m^{-1} + SAR 50). The respective percent decreases were 16, 23, 29, 29, 36, 48, 44, 55 and 64 for combinations of EC_e dS m^{-1} + SAR: 10 + 30, 10 + 40, 10 + 50, 20 + 30, 20 + 40, 20 + 50, 30 + 30, 30 + 40 and 30 + 50. Increasing levels of sodicity at the same level of salinity also revealed negative effect and plant height was restricted to lesser values.

4.1.3.1.2 Stem diameter (girth)

The thickening of plants was also suppressed with combined stress of salinity and sodicity. Stem diameter was recorded to be 2.61 cm after two years in unstressed plants, which was restricted to 1.42 cm in the highest combination of salinity and sodicity (EC_e 30 dS m^{-1} + SAR 50). The initial level (10 + 30) did not prove detrimental significantly up to one-year growth of plants but became measurable after one and a half year persisting to the end of investigation. The effect of other combinations was variable; some of these significant and other non-significant during all the four sampling and observations intervals. However, the general trends of the data indicated that effects of salinity and sodicity penetrated with time (age of plants) as well as increasing levels of stresses. The range of decrease in stem diameter was from 11 to 51 % (Table 4.34).

4.1.3.1.3 Number of leaves

Under normal conditions (control) leaf bearing increased with age of plants and 587 leaves per plants were counted after two years. However, it was depressed significantly under saline sodic soil medium, the extent of negative effect depended upon severity of stresses. The number of leaves was limited to only 194 per plant in the highest level (EC_e 30 dS m^{-1} + SAR 50) for the same age of plants (Table 4.35). The effect of all the levels was significant compared with control after six months while similar among selves. However, treatment impacts increased with time but after one and half year started diluting again. The decrease in number of leaves per plant ranged from 10 to 65 %, being very much pronounced with higher levels (EC_e + SAR = 20+50, 30+30, 30+40 and 30+50).

4.1.3.1.4 Number of branches

Single trunk of plants at transplantation brought 15, 20, 27and 45 branches after six months, one year, one and half year and two years respectively under control conditions. Branching was delayed and decreased when plants were exposed to saline sodic conditions. It was just half of control with initial two saline sodic levels (10 + 30 and 10 + 40) and about one fourth in the last two levels (30 + 40 and 30 + 50) after six months. All the levels differentiated significantly after two years in respect of branching. The recorded number of branches at the end of two years study was only 12 under the saline sodic level of EC_e 30 dS m^{-1} + SAR 50 as against 45 in unstressed plants (Table 4.36). The calculated percent decreases varied from 14 to 75.

4.1.3.1.5 Canopy volume

The spread of plants was rapid and tremendous that reached to 5.30 m^3 during two years under normal conditions without any salinity and sodicity. It was decreased appreciably with different stress levels. The negative effects started from the start and persisted to the last. However, penetration was extended with time and overall decreases ranged from 11 to as high as 82 % (Table 4.37). The last value with highest level (EC_e 30 dS m^{-1} + SAR 50) was just 0.95 m^3 as against 5.30 m^3 in control. Negative effects of various levels of sodicity combined with quantum of salinity were clearly apparent.

4.1.3.1.6 Shoot weight

Total biomass (shoot + root) is the end result of different growth parameters. It was inversely affected by quantum of salinity and sodicity. Differences among the treatments were statistically significant except T4 (EC_e 10 dS m^{-1} + SAR 50) and T5 (20+30) as well as T7 (20+50) and T8 (30+30), which were similar (Table 4.38). Dry shoot mass was also differentiated measurably in statistical terms except T7 and T8 that were alike. Recorded mass was found to be maximum (1028 g $plant^{-1}$) in unstressed plants while its value was just 168 g. in the highest stress level (EC_e 30 dS m^{-1} + SAR 50). Decrease in various treatments ranged from 66 % in different magnitude of combined salinity and sodicity. Moisture % was maximum in control plants and decreased with increasing levels of stress indicating less succulency under saline sodic environment.

4.1.3.1.7 Root weight

The trends of variations of root weight and moisture contents in roots were almost similar to shoot weight. There were 121 g $plant^{-1}$ roots in control and just 21 g in the highest stress level (EC_e 30 dS m^{-1} + SAR 50). Negative effect of lower levels were lesser and directly related to the quantity of salts + Na in rhizosphere. The values of decrease varied from 17 to 61 %. Moisture % in roots ranged from 34 to 19 (Table 4.39).

4.1.3.2 Soil characteristics (soil salinity/sodicity parameters)

Soil analysis after two years (at the termination of study) indicated that soil EC_e and SAR were still very closer to the created levels of these parameters. Soil pH was corresponding with EC_e and SAR. Hence, plants remained stressed throughout their growth period as was required under the research plan. So, the derived results were valid (Appendix 3).

4.1.3.3 Plant leaf composition

4.1.3.3.1 Sodium contents

The contents of Na increased a little bit with increasing age of plants in older as well as younger leaves of unstressed plants (Table 4.40 and 4.41). The combined stresses of salinity and sodicity increased Na in leaves. The increasing effect was corresponding with the quantum of stresses. The values of this parameter were clearly more at all the levels in older leaves compared younger ones. The numerical values were 3.73 and 4.80 g kg^{-1} in older leaves after six months and two years respectively whereas corresponding values in younger leaves were estimated as 2.62 and 2.93 g kg^{-1}. These quantities increased to 16.22 and 21.56 g kg^{-1} of older leaves of plants having age of six months and two years while respective values were 6.90 and 8.14 g kg^{-1} in younger leaves. Thus, age differences depicted wider differences in older leaves.

4.1.3.3.2 Potassium contents

In contrast to Na the contents of this constituent decreased significantly with increasing magnitude of both stresses (salinity and sodicity). The value of 12.14 g kg^{-1} (unstressed plants) was restricted to 6.20 g kg^{-1} with the highest level (EC_e 30 dS m^{-1} + SAR 50) in leaves of six months old plants whereas respective values in younger leaves of same age were 13.90 and 9.84 g kg^{-1} (Table 4.42 and 4.43). The K contents of younger leaves were greater than older whether the plants were stressed or not or these may be of any age. The comparison could be made from the respective figures of 14.66 and 8.24 g kg^{-1} in older leaves of two years unstressed plants those growing in the highest level (EC_e 30 + SAR 50). The values in younger leaves were 18.03 and 11.83 g kg^{-1} if the plants were stressed or growing in the highest level respectively. The differences were significant among most of the treatments, impact being more pronounced in the higher stressed level.

4.1.3.3.3 Potassium to sodium ratio (K:Na)

Younger leaves are the active seats of most of the metabolic reactions and K is an integral part of many of these processes. The metabolism leads to growth and formation of protoplasm. The higher K: Na ratio is important for normal reactions. The ratio was observed to be 6.15 in younger leaves and 3.05 in older leaves of plants without any stress (Table 4.42 and 4.43). However, it decreased with increasing quantum of stresses and was just 0.38 in older leaves but 1.45 in younger leaves of two years plants growing under highest stresses (EC_e 30 dS m^{-1} + SAR 50). Intermediate values were calculated for slight to moderate stresses that changed correspondingly with the quantum of salinity and sodicity.

4.1.3.3.4 Calcium contents

Calcium contents of older and younger leaves slightly increased with age of unstressed plants (Table 4.44 and 4.45). The recorded values were 13.61 and 15.65 g kg^{-1} in older leaves and 8.64 and 10.45 g kg^{-1} in younger leaves of six months and two years plants respectively. Nevertheless, these were restricted to 2.70 and 3.16 g kg^{-1} in older leaves of six months and two years when plants were stressed with the highest level (EC_e 30 dS m^{-1} + SAR 50). The numerical values in younger leaves with this level of stress were still a little bit lesser. The negative effect of combined stressed of salinity and sodicity regarding Ca uptake was significant and elevating as the levels increased. The differences between older and younger leaves were evaluated to be very wide. Relatively high values in older leaves indicated that excess Ca was being pushed into older tissues.

4.1.3.3.5 Magnesium contents

The contents of Mg in leaves (old and young) were slightly increasing with age, and significantly decreasing with increasing levels of salinity + sodicity. The quantum of this parameters in younger leaves was lesser whether the plants were stressed or not or what was the level of created salinity + sodicity (Table 4.46 and 4.47). The differences within treatments were either significant or at par depending upon the magnitude of partition. Variations were wider when the levels were higher but lesser where upon created differences were lower. The initial contents of 7.64 g kg^{-1} in older leaves of six months plants decreased to only 1.32 g kg^{-1} in the highest level of stress while respective values in younger leaves were determined as 6.41 and 1.04 g kg^{-1}. Similarly, Mg contents of 8.01 g kg^{-1} in older leaves of two years plants reduced to 1.03 g kg^{-1} while the corresponding values in younger leaves were 6.74 and 0.72 g kg^{-1}.

4.1.3.4 Plant root composition

When the plants were not stressed, the contents of K and Ca were almost comparable but more than Na as well as Mg (Table 4.48). The stressed conditions caused significant increased in Na but decreased K, Ca, Mg and K: Na. Sodium increased from 4.71 g kg^{-1} (control) to 16.13 g kg^{-1} with the highest level of salinity + sodicity (EC_e 30 dS m^{-1} + SAR 50). Decrease in K contents was from 11.36 to 5.33 g kg^{-1} with the same level. Calcium contents were 12.45 and 2.51 g kg^{-1} in control and the highest level respectively. Respective values for Mg were determined as 6.26 and 1.16 g kg^{-1}. The corresponding values of K: Na were 2.40 and 0.33. The effects of lower levels were lesser and higher levels were more pronounced. Thus, stressing of plants with salinity + sodicity changed composition of roots.

4.2 Study-2

<u>EVALUATION OF LONGTERM EFFECT OF SALINE SODIC ENVIRONMENT ON GROWTH OF Acacia ampliceps AND VICE VERSA</u>

The objective of this study was to correlate the growth of *Acacia ampliceps* with soil properties. Plants were transplanted in different levels of salinity/sodicity 3.5 years earlier of data recording. Plants of various conditions of growth (poor, medium and good) were selected to record observations on growth, soil characteristics and ion uptake. The results are presented as under: -

4.2.1 Plant growth parameters

4.2.1.1 Plant height

Consistent 6 monthly observations (when the plants attained 3.5, 4.0, 4.5 and 5.0 years age) indicated that height of poor plant was lesser than medium and good condition plants (Table 4.49a). This growth parameter was found to be maximum in plants selected in good condition. The last observation indicated that height of medium and good plants was recorded as 36 % and 81 % more respectively than poor plants. These data also indicated that effects of salinity/sodicity persisted to the last observation (after two years when plants were of five years) and initial differences were kept to the end of study.

4.2.1.2 Stem diameter (girth)

This parameter was recorded to be minimum in poor conditioned plants followed by medium and good plants in the increasing order (Table 4.49b). A reverse relationship between salinity characteristics (soil EC_e, pH and SAR) and stem girth was found that existed to the last indicating permanently negative effects of salt stress. On the average, the assessed values of plant's girth after five years were 54 % more in medium plant over poor and 50 % lesser than plants having good condition.

4.2.1.3 Canopy volume

The differences in canopy volume among poor, medium and good conditioned plants were wider than plant height and stem diameter (Table 4.49c). This indicated that spread of plant was affected more than its height and girth when plants were transplanted in the soil varying widely in soil salinity characteristics.

4.2.1.4 Number of branches

The branching of plants was affected negatively under saline sodic environment (Table 4.49d). The magnitude of negative effect was directly related to levels of salinity/sodicity due to which condition of plants was translated into poor, medium and good. The detrimental effect persisted to the whole growth period. However, differences in number of initial branches and after two years were closer in poor plants and wider in medium and good plants.

4.2.2 Soil characteristics (soil salinity/ sodicity parameters)

4.2.2.1 Soil ECe

Analysis before transplantation (September, 2001) indicated that soil profile up to 150 cm was having very high EC_e that decreased with increasing soil depth (Table 4.50). Salt contents were the highest where plant condition was found as the poor after 3.5 years (March, 2005). The EC_e value was moderate or the least where plant conditioned was medium or good respectively. The later analysis (September, 2005, March, 2006 and September, 2006) revealed that the recorded differences persisted to the last and kept the plant condition as such through out the study period. However, the numerical values constantly decreased indicating positive effect of growing *Acacia ampliceps* plants.

4.2.2.2 Soil pH

Very high values of pH through out the soil profile were determined in experimental site before transplantation of plants (September, 2001). Comparatively low medium and high magnitudes of pH were translated into good, medium and poor conditioned plants during growth period of 5 years (Table 4.51). The initial differences persisted to the last although there was substantive decrease in the values of this very important soil characteristic. However, initial differences in plant growth could not be removed and poor as well as medium plant remained with same condition due to comparatively high pH. The calculated standard deviation (S.D.) value indicated a little variation of the recorded data.

4.2.2.3 Soil cations

Differences of Ca + Mg in soil were not very wider through out the profile before transplantation of plants (Appendix 4). However, the values of these cations increased as the plant grew larger with passage of time and differences of Ca + Mg becomes clearer. The contents were determined as the highest where plant condition was good whereas these were lowest in the growing sites of poor plants. This observation was true up to 150 cm soil depth indicating very deep and positive effects of growing plants in soil amelioration.

Sodium, the cation directly related to sodicity, was very high before plantation of *Acacia ampliceps* (Appendix 5). The sites that caused poor growth of plants later on were especially having higher values of Na as compared to soil of medium and fast growing (good conditioned plants). Such differences were recorded in the whole soil profile up to 150 cm depth. A continuous reduction in soil Na was observed as the plant growth proceeded at the entire site and through out the profile. However, differences among plant size could not patch up and persisted to the end of experiment. Potash is cations related more to soil fertility than sodicity. The soil surface (0 – 15 cm) analysis indicated that much difference did not exist among various sites (Appendix 6). The effects of plant growth on soil K were not too much and just slightly high values were determined in later sampling.

4.2.2.4 Soil anions

The determination of anion in the experimental site revealed that the soil was chloride dominant with very high value ranging from 114 (with good plant) to 197 $mmol_c\ L^{-1}$ (poor plant). The standard deviation (S.D.) value was also high (Appendix 7). The plant growth proceeding coupled with leaching caused very high reduction in chloride but site differences yet persisted and the soil still remained chloride dominant.

Bicarbonate was the anion with next higher magnitude that was reduced to almost half in poor plant sites and the reduction was still more in medium and good plants during five years growth. Carbonates were also present in significant quantities that were decreased to half in good plant after five years and by 38 % in medium and poor plants.

Sulphates were determined to be minimum among all the anions that increased as the plant grow more and more. This observation was in contrast to other anions, which reduced with passage of time.

4.2.2.5 Soil SAR

Soil SAR is the single parameter mostly used to determine the gravity of sodicity. Pre and post plantation analysis indicated that it was very high in the experimental sites, as against its critical value of 13 $(mmol\ L^{-1})^{1/2}$. Very clear differences in SAR existed that was later on translated into poor (highest SAR), medium (intermediate SAR values) and good (lesser SAR) growth of plants (Table 4.52). The values were highest in surface layer (0-15 cm), decreased with increasing soil depths and recorded to be minimum in last investigated depth (120- 150 cm) at all the plant sites. A consistent decrease was also recorded in the entire plantation sites as well as soil depths, as the plant growth proceeded with lapse of time. Almost 100 (mmol L^{-1})$^{1/2}$ decrease was noticed in surface 0 -15 cm depth. The reduction was the least in the last sampling depth (120-150 cm) indicating soil surface or near to the surface impact of plant growth. The values of SAR remained still higher in all plant sites than the critical limit (SAR 13).

4.2.3 Plant leaf composition

4.2.3.1 Potassium contents

Leaf K contents of *Acacia ampliceps* were found to be least in all the four observations (after 3.5, 4.0, 4.5 and 5 years plant age) on the sites having highest soil salinity/sodicity parameters (EC_e, SAR and pH) that resulted in poor growth of plants (Table 4.53). Maximum values of K constituent were recorded in leaves of good condition plants while moderate values were determined for plants of medium health. These differences were consistent through out the study period. Potash composition of older leaves was lesser than younger leaves but the similar trend of variation (as was noticed for older leaves) was revealed (Table 4.54).

4.2.3.2 Sodium contents

The leaf (older and younger) composition indicated that Na contents were in contrast to K. These were found to be highest in leaves obtained from poor conditioned plants that were growing in highest levels of salinity/sodicity (Table 4.55). Minimum values were investigated in good plants. This also revealed the negative effects of Na uptake are depicted in plant growth. Values of this parameter increased a little in later observations but the trend did not change. The Na contents of younger leaves (Table 4.56) were lesser than older leaves. The higher contents of older leaves depicted the accumulation of Na and a physiological mechanism to keep the growing tissues free of Na.

4.2.3.3 Potassium to sodium ratio (K:Na)

The calculation of K: Na ratio in leave tissues is also important parameter and indicates ions selectivity while plants are up taking different cations during growth. The computed values of K: Na were lesser in poor plant for older (1.15) and younger leaves (3.47) as compared to medium (2.04 and 4.93) and good (2.81 and 6.73) conditioned plants (Table 4.55 and 4.56). The over all values of this ratio were higher in younger leaves than older leaves. Thus, it was clear that excessive Na was sequestered into older leaves that brought the ratio closer while more K (performing beneficial functions) than Na was concentrated into the younger leaves which were the active seat of all the metabolic activities.

4.2.3.4 Calcium contents

The trends of variation in calcium contents of leaves were found to be just like potash. The values of older leaves were also closer to these recorded for potassium (Table 4.57). However, Ca contents of younger leaves were far lesser than the older ones (Table 4.58). It can be concluded that excessive Ca was sequestered into older leaves. The investigated Ca contents at different time intervals were found to be lowest (ranged from 11.24 to 12.63 g kg^{-1}) from the sites having highest salinity/sodicity levels and poor plant condition. The values were highest (15.16 to 17.34 g kg^{-1}) in good conditioned plants. The bad effects of saline/sodic environment could not be overcome fully by plants even in five years of growth.

4.2.3.5 Magnesium contents

Like K and Ca, the Mg contents were also higher (6.43 – 6.81 g kg^{-1}) in good plants that were growing in comparatively less saline environment as compared to poor plant (4.80 – 5.14 g kg^{-1}) standing in high salinity (Table 4.59). No clear-cut differences were found in magnitude of leaf Mg at all the four sampling intervals. Similarly, there were no significant differences among the studied plant leaves, might be old or young (Table 4.60). This indicated that *Acacia ampliceps* exercise a strong control on Mg uptake and its contents are almost fixed although plants may be growing under any environment.

4.3 <u>Study-3</u>

<u>INVESTIGATING TRANSPLANTING TECHNIQUES TO AVOID EARLY STAGE SALINITY STRESS</u>

The objective of this study was to identify and devise such transplantation techniques that prove helpful to avoid early stage salinity stress when the plants are relatively more sensitive. The results of these investigations are as under: -

4.3.1 Plant crowth parameters

4.3.1.1 Plant height

Height was greatly checked in control plants and very slightly increase (from 28 to 63 cm) was recorded in two years as compared with other transplantation techniques. Plantation in pits filled with silt + compost was investigated as the best technique causing maximum height (508 cm) of plants after two years that indicated its effectiveness in controlling bad effects of salinity/sodicity (Table 4.61). Transplantation in pits filled from silt coupled with deep augering was the next better treatment. All the other treatments were also found useful that revealed significant differences over control during all the measurements in two years. Hence, it was noticed that these techniques were beneficial in controlling early stage stress of salinity/sodicity. However, filling the pits with original soil was not found to be very good, although even this remained superior over control. An increase of 211 to 1271 % in plant height over control was observed under various treatments.

4.3.1.2 Stem diameter (girth)

A good growth is translated slowly and gradually into girth of plants (stem diameter). Very little difference in stem diameter (0.51 cm) was observed during two years investigation in control plots. Thus, soil salinity/sodicity suppressed the increase in stem diameter when the plants were transplanted without any improved techniques (control) (Table 4.62). All the investigated plantation strategies proved significantly superior over control. However, the best technology found in this experimentation was filling of plant pits with silt + compost. An increase of 11.09 cm in stem diameter was recorded due to this treatment. The significance of this difference sustained through out except the first observation after six months. Silt + augering was the next significant technique of transplantation.

4.3.1.3 Number of leaves

Leaves are the seats of photosynthesis where carbohydrates are synthesized that contribute a lot in growth of plants. The data (Table 4.63) revealed that number of leaves per plant kept increasing even in control plots during the whole study period, although the numerical values were far lesser than all the transplantation techniques. For example, it was recorded to be 301 after two years as against 4535 in the best treatment (filling of pit with silt + compost). The second best treatment found through these investigations was augering down of soil to 150 cm coupled with filling of pit with silt alone. Each treatment was significantly different than the other and there descending order in respect of this parameter was T7 > T4 > T3 > T8 > T5 > T6 > T2 and T1. Thus, all the techniques proved successful in controlling the bad effects of saline/ sodic environment partially are almost fully.

4.3.1.4 Number of branches

There was only single trunk with no side branches when the plants were transplanted. The branching of plants proceeded slowly but consistently that reached to 14 after two years in control plants while 156 branches were counted in the best treatment as result of filling the pits with silt + compost (Table 4.64). The transplantation technique, deep augering + filling of pits with silt alone (T4) was assessed as the second best causing 121 branches of plants on the average. All the techniques proved superior to control statistically. Superiority of better treatment was significant over inferior ones in all the four observation intervals. In general, using the original salt-affected soil alone for filling of pits are its combination with gypsum or compost was comparatively less effective whereas silt alone or its various combinations were highly beneficial in avoiding early stage bad effects of saline/ sodic soil environment.

4.3.1.5 Canopy volume

Canopy volume was almost negligible when the plants were transplanted. The magnitude of plant growth in two years indicated the rapid growing character of *Acacia ampliceps*. The canopy volume of 0.62 (control plants) to 35.6 m^3 (silt + compost) was recorded after two years (Table 4.65), which revealed very large variation due to impact of experimental treatments. Significant effects among various transplantation techniques were generally better due to silt additions above or its various combinations. Filling of pits with the same soil (salt-affected) alone or combining it with gypsum, or compost proved inferior. The success of good treatments could be measured by the spread of plants into 35.6 m^3 volume that was just like a big bush although the soil was totally barren due to very high salinity and sodicity at the time of transplantation.

4.3.2 Soil characteristics (soil salinity/ sodicity parameters)

4.3.2.1 Soil EC_e and total soluble salts (TSS)

There were very high values of soil EC_e (22.85 to 23.41 dS m^{-1}) and TSS (290 to 308 $mmol_c$ L^{-1}) when plants were transplanted in salt-affected soil. As the plant growth proceeded in two experimental years, the soil EC_e and TSS decreased progressively. However, the quantum of decrease depended upon the effectiveness of transplantation techniques and the material used for filling the pits of plants (Table 4.66 and Appendix 15). The end values were recorded as 9.53 dS m^{-1} in the best treatment (silt + compost) as against 17.62 dS m^{-1} in control. Reduction of EC_e and salts in all the treatments was significant compared with control except filling of pits with the original soil again that was noticed at par with control. The plant root activities coupled with leaching of salts and organic matter decay as well as different materials used in filling of pits caused decreasing of salts and impact of treatments in the decreasing order was found as; silt +

compost, silt + augering, silt alone, original soil + compost, silt + gypsum, original soil + gypsum, original soil and control with respective end values of 9.53, 11.63, 12.51, 13.06, 13.34, 14.04, 16.34 and 17.62 dS m^{-1}.

4.3.2.2 Soil pH

The pH of the experimental soil was very high (slightly lower or higher than 10) at the time of transplantation of *Acacia ampliceps* plants. As result of plant growth and associated factors (field operations, plant root activities, organic matter decomposition, irrigation etc.) this parameters started decreasing, as the first determination after six months indicated (Table 4.67). However, the treatment differences were not very conspicuous at this stage and a statistical equality was observed. The continuous decrease persisted and the differences became significant after one year. The best treatment in this regard at this time and thereafter was silt + compost. The pH values reached here to 8.7 within two years as against 9.45 in the control plots. Thus, plant was benefited from soil treatment and soil was improved due to plant growth. All the other treatments were at par but still superior to control as well as filling of pits with original soil again. The later two treatments proved similar but the most inferior.

4.3.2.3 Soil SAR and cations

A slow, gradual but consistent increase in water soluble Ca + Mg of soil was observed (Appendix 8) that was more in its magnitude under better treatments but lesser in control and filling the pits with original soil. In contrast, very large decreased in Na values were recorded constantly (Appendix 9). The decrease in two years ranged from 82 to 193 $mmol_c$ L^{-1}. Resultantly, a clear and extensive decrease of 83 to 171 $(mmol\ L^{-1})^{1/2}$ in SAR was determine after two years that was having very high values (237 to 246) at the time of transplantation (Table 4.68). The impact of treatments in reduction of SAR was assessed as significant. In the best treatments (silt + compost) it was decreased from 239 to only 68 as against control where it reached to 159 starting from 242. Other treatments were moderate in positive effect but all were better significantly over control and filling of pits with same field (salt-affected) soil. A constant decrease was recorded through out the study period. There were very slight differences in soluble K contents of soil either due to treatments effect or passage of time with proceeding of plants growth. The nominal differences were evaluated as non-significant (Appendix 10).

4.3.2.4 Soil anions

An appreciable amount of soil carbonates was observed at the time of transplantation. Carbonate contents decreased later on due to treatment effects as well as plant growth (Appendix 11). The differences among treatments proved significant during first year and became non-significant in the second year. Maximum reduction occurred in silt + compost (from 22.90 to 14.08 $mmol_c\ L^{-1}$) whereas minimum change was observed in control (from 20.34 to 17.06 $mmol_c\ L^{-1}$).

Values of bicarbonate were lesser than carbonates (Appendix 12). Slight decrease in magnitude up to one and half year remained non-significant statistically. Significant differences could only occur after two years (last observations). At this time, all the treatments proved similar among themselves but superior to control as well as filling of pits with original soil. The recorded values decreased from 17.30 to 10.44 $mmol_c\ L^{-1}$ in treatment of silt + compost that was assessed as the best in this regard.

Chlorides quantities were very high at transplantation time that decreased rapidly due to treatments impact as well as growth of plants. Treatment differences were narrow at early stage and became wider after one year that expanded still further in the next year (Appendix 14). Maximum reduction was recorded in silt + compost treatment (from 257 to 70 $mmol_c\ L^{-1}$) against minimum in control (from 256 to 181 $mmol_c\ L^{-1}$).

Highly contrasting trend was observed in case of sulphates. The values were the least among all the soil anions that increased due to treatment effects as well as plant growth (Appendix 13). The recorded results were non-significant during first year and statistically appreciable in the second year. Sulphates were maximum in silt + compost treatments (20.78 $mmol_c\ L^{-1}$) and minimum in control (13.45 $mmol_c\ L^{-1}$) at termination of study.

4.3.3 Plant leaf composition

4.3.3.1 Sodium contents

The treatment of the experiment helped in controlling Na uptake by plants and values of this constituent in leaves (Table 4.69) were significantly lower than control during all the four observations (after six months, one year, one and a half year and two years). The minimum values (2.64, 2.81, 3.14 and 3.45 g kg^{-1}) were recorded in the treatment of silt + compost as against control with maximum amounts (7.12, 7.65, 8.43 and 9.05 g kg^{-1}). Exactly similar trend was found between older and younger leaves (Table 4.70). However, values were far lesser in younger leaves compared with older leaves.

4.3.3.2 Potassium contents

The pattern of K variation was opposite to Na as noticed in the earlier section. Different treatments caused variable increases in K contents of old and young leaves (Table 4.71).Best treatments with maximum values in old leaves (19.33, 19.91, 21.15 and 22.02 g kg^{-1} after six months, one year, one and a half year and two years respectively) were found to be silt + compost. Quantum of K in younger leaves (Table 4.72) was lesser than the older but impact of treatment was similar. Plant growth exerted positive effect on K uptake and leaf contents (old and younger) of this nutrient enhanced with increasing age of *Acacia ampliceps.*

4.3.3.3 Potassium to sodium ratio (K: Na)

This very important ratio was found to be narrower in control plots and less effective treatments (filling of pits with same soil + gypsum etc.) and wider in treatment performed well (silt + compost, original soil + compost and silt + augering etc.) (Table 4.71 and 4.72). This indicated that transplantation techniques helped a lot in uptake of K compared Na i.e. ion selectivity. The values recorded in younger leaves were greater than respective magnitude in older leaves, which revealed active roll and higher concentration of K in the young tissues. The speedy metabolic processes contributed in more and rapid growth.

4.3.3.4 Calcium contents

Data on Ca depicted exactly same trend of dynamism, which was observed and described for K under the above section. Experimental treatments as well as plant growth affected positively and indicated increased values (Table 4.73) in older and younger leaves. Nevertheless, the determined quantities in younger leaves were far lesser when compared with older leave. For example in the most affective treatments the respective values for older leaves of six months, one year, one and a half year and two years were 21.60, 22.52, 23.24 and 24.53 g kg^{-1} as against 13.64, 14.31, 14.70 and 15.33 g kg^{-1} in younger leaves (Table 4.74). Treatment differences were found to be significant statistically.

4.3.3.5 Magnesium contents

Significant differences in Mg contents of leaves (older and younger) as result of imposing transplantation techniques were noted (Table 4.75 and 4.76) while plant growth did not affect very clearly. Relative values were lesser in younger leaves. The effectiveness of silt + compost was recorded as the highest. There was statistical equality between control and filling of pits with the original soil again while these were inferior to all other techniques.

Table 4.1: Effect of salinity on plant height (cm) of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e (dS m^{-1})	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	31	58 AB	131 A	199 A	306 A	275	-	-
10	31	62 A	118 A	181 B	270 B	239	36	13
20	29	46 ABC	130 A	161 C	248 C	219	56	20
30	29	41 C	118 A	129 D	224 D	195	80	29
40	35	40 C	91 B	115 E	186 E	151	124	45
50	36	43 BC	74 B	88 F	146 F	110	165	60

Table 4.2: Effect of salinity on stem diameter (cm) of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e (dS m^{-1})	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.28	0.95 A	1.57 A	1.91 A	2.59 A	2.31	-	-
10	0.30	0.86 AB	1.55 A	1.80 B	2.42 B	2.12	0.19	8
20	0.27	0.74 BC	1.48 BC	1.76 B	2.18 C	1.91	0.40	17
30	0.26	0.53 D	1.35 C	1.54 C	1.98 D	1.72	0.59	26
40	0.32	0.56 CD	1.13 D	1.23 D	1.66 E	1.34	0.97	42
50	0.29	0.44 D	0.76 E	0.93 E	1.28 F	0.99	1.32	57

Table 4.3: Effect of salinity on number of leaves plant^{-1} of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e (dS m^{-1})	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	26	134 A	251 A	357 A	583 A	557	-	-
10	28	110 A	247 A	322 B	544 B	516	41	7
20	26	69 B	161 B	275 C	489 C	463	94	17
30	25	56 B	107 C	200 D	429 D	404	153	27
40	32	58 B	105 C	156 E	348 E	316	241	43
50	28	42 B	77 C	97 F	209 F	181	376	68

Table 4.4: Effect of salinity on number of branches plant^{-1} of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e (dS m^{-1})	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	1	7 A	11 A	26 A	45 A	44	-	-
10	1	6 AB	11 A	22 B	38 B	37	7	16
20	1	4 ABC	7 BC	18 C	32 C	31	13	30
30	1	2 BC	4 C	11 D	24 D	23	21	48
40	1	3 ABC	5 C	9 E	15 E	14	30	68
50	1	1 C	5 C	8 F	11 F	10	34	77

Table 4.5: Effect of salinity on canopy volume (m^3) of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e ($dS\ m^{-1}$)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.005	0.035 A	0.075 A	1.49 A	5.27 A	5.26	-	-
10	0.005	0.024 B	0.044 B	1.31 B	4.68 B	4.67	0.59	11
20	0.005	0.018 C	0.032 C	1.12 C	4.13 C	4.12	1.14	22
30	0.005	0.010 D	0.020 D	1.06 CD	3.81 D	3.80	1.46	28
40	0.005	0.007 E	0.012 E	0.96 D	2.25 E	2.24	3.02	57
50	0.005	0.006 E	0.007 F	0.75 E	1.07 F	1.06	4.24	80

Table 4.6: Effect of salinity on shoot weight (g $Plant^{-1}$) of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e ($dS\ m^{-1}$)	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry shoot weight over control	Decrease in dry shoot weight over control (%)
Control	2458 A	2108 A	1003 A	1105	52	-	-
10	2161 B	1879 B	950 B	929	49	53	5
20	1929 C	1685 C	943 C	742	44	60	6
30	1671 D	1454 D	844 D	610	42	159	16
40	1222 E	1060 E	632 E	428	40	371	37
50	884 F	767 F	486 F	281	37	517	52

Table 4.7: Effect of salinity on root weight (g $Plant^{-1}$) of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e ($dS\ m^{-1}$)	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry root weight over control	Decrease in dry root weight over control (%)
Control	2458 A	350 A	235 A	115	33	-	-
10	2161 B	282 B	200 B	82	29	35	15
20	1929 C	244 C	184 C	60	25	51	22
30	1671 D	217 D	167 D	50	23	68	29
40	1222 E	162 E	126 E	36	22	109	46
50	884 F	117 F	93 F	24	20	142	60

Table 4.8: Na^+ ($g\ kg^{-1}$) concentration in older leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	3.83 F	4.41 F	4.73 F	5.05 F
10	5.15 E	6.04 E	7.16 E	7.92 E
20	6.50 D	7.32 D	8.45 D	9.61 D
30	8.33 C	9.72 C	10.75 C	11.53 C
40	11.84 B	13.10 B	13.62 B	14.16 B
50	15.22 A	17.30 A	18.24 A	19.45 A

Table 4.9: Na^+ ($g\ kg^{-1}$) concentration in younger leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	2.31 F	2.65 F	2.56 E	2.60 E
10	3.24 E	3.33 E	3.50 D	3.56 D
20	3.81 D	3.62 D	3.86 D	4.04 D
30	5.23 C	5.03 C	5.60 C	6.12 C
40	6.05 B	6.45 B	6.72 B	7.26 B
50	7.03 A	7.63 A	8.04 A	8.41 A

Table 4.10: K^+ ($g\ kg^{-1}$) concentration in older leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years	K: Na ratio after two years
Control	12.23 A	12.60 A	13.54 A	14.15 A	2.80
10	11.92 B	12.16 B	12.63 B	12.82 B	1.62
20	9.64 C	10.22 C	11.05 C	11.53 C	1.20
30	9.14 D	9.45 D	10.43 D	10.82 D	0.94
40	8.22 E	8.08 E	8.62 E	8.66 E	0.61
50	7.61 F	7.26 F	7.55 F	7.74 F	0.40

Table 4.11: K^+ (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years	K : Na ratio after two years
Control	14.03 A	14.71 A	15.64 A	17.04 A	6.55
10	13.41 B	13.56 B	13.82 B	14.51 B	4.07
20	12.23 C	12.44 C	12.55 C	12.92 C	3.20
30	11.94 C	11.41 D	11.56 D	12.05 D	1.97
40	11.31 D	11.17 E	11.24 DE	11.60 E	1.60
50	10.93 E	10.52 F	10.70 E	11.07 F	1.32

Table 4.12: Ca^{2+} (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	13.42 A	13.84 A	14.05 A	15.56 A
10	10.24 B	11.05 B	11.32 B	12.24 B
20	8.71 C	9.63 C	9.40 C	10.72 C
30	7.04 D	7.20 D	7.31 D	7.93 D
40	5.80 E	6.52 E	6.94 D	7.25 E
50	4.22 F	4.61 F	5.06 E	5.43 F

Table 4.13: Ca^{2+} (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	8.74 A	9.45 A	9.63 A	10.56 A
10	6.92 B	7.40 B	7.51 B	8.04 B
20	5.70 C	6.05 C	6.04 C	6.63 C
30	4.90 D	5.12 D	5.02 D	5.45 D
40	3.83 E	4.54 E	4.72 D	4.95 D
50	2.74 F	3.45 F	3.57 E	3.86 E

Table 4.14: Mg^{2+} ($g\ kg^{-1}$) concentration in older leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	7.05 A	7.13 A	6.92 A	7.24 A
10	5.72 B	5.90 B	5.71 B	6.03 B
20	4.91 C	4.94 C	4.85 C	5.15 C
30	4.12 D	3.91 D	3.82 D	3.64 D
40	3.34 E	3.02 E	3.10 E	2.92 E
50	2.52 F	2.21 F	2.04 F	2.23 F

Table 4.15: Mg^{2+} ($g\ kg^{-1}$) concentration in younger leaves of *Acacia ampliceps* (Expt. -1)

Salinity levels EC_e ($dS\ m^{-1}$)	After six months	After one year	After one and a half year	After two years
Control	6.23 A	6.44 A	6.15 A	6.36 A
10	5.40 B	5.51 B	5.73 B	5.52 B
20	4.05 C	4.12 C	3.94 C	4.23 C
30	3.72 D	3.40 D	3.42 D	3.15 D
40	2.93 E	2.94 E	2.73 E	2.61 E
50	1.95 F	1.84 F	1.82 F	1.76 F

Table 4.16: Concentration of various ions ($g\ kg^{-1}$) in roots of *Acacia ampliceps* (Expt. -1, Study -1)

Salinity levels EC_e ($dS\ m^{-1}$)	Na^{1+}	K^{1+}	Ca^{2+}	Mg^{2+}	K: Na ratio
Control	4.52 F	11.04 A	12.21 A	6.45 A	2.44
10	6.84 E	10.22 B	9.63 B	4.93 B	1.49
20	8.26 D	8.63 C	7.85 BC	4.40 B	1.04
30	9.61 C	7.65 D	6.20 CD	3.54 C	0.80
40	12.30 B	7.05 E	4.72 DE	2.81 CD	0.57
50	15.24 A	6.13 F	3.61 E	2.22 D	0.40

Table 4.17: Effect of sodicity on plant height (cm) of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	30	60 A	135 A	193 A	296 A	266	-	-
20	30	59 A	128 AB	168 B	247 B	217	49	18
30	32	56 A	122 AB	151 C	214 C	182	84	32
40	32	50 A	112 B	131 D	163 D	131	135	51
50	32	39 B	48 C	56 E	68 E	36	230	86

Table 4.18: Effect of sodicity on stem diameter (cm) of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.30	0.89 A	1.55 A	2.06 A	2.60 A	2.30	-	-
20	0.30	0.86 A	1.51 A	1.78 B	2.31 B	2.01	0.29	13
30	0.27	0.80 A	1.46 A	1.67 C	1.99 C	1.72	0.58	25
40	0.26	0.74 A	1.28 B	1.38 D	1.58 D	132	0.98	43
50	0.25	0.32 B	0.56 C	0.64 E	0.76 E	0.51	1.79	78

Table 4.19: Effect of sodicity on number of leaves plant^{-1}of *Acacia ampliceps* (Experiment -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	29	133 A	270 A	343 A	578 A	549	-	-
20	31	130 A	267 A	305 B	535 B	504	45	8
30	29	103 AB	265 A	289 C	466 C	437	112	20
40	27	89 B	175 B	224 D	315 D	288	261	48
50	28	36 C	48 C	70 E	112 E	84	465	85

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.20: Effect of sodicity on number of branches plant^{-1} of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	1	12 A	18 A	27 A	47 A	46	-	-
20	1	8 B	16 A	20 B	33 B	32	14	30
30	1	9 B	13 A	17 C	24 C	24	22	48
40	1	8 B	13 A	16 C	18 D	17	29	63
50	1	2 C	5 B	6 D	7 E	6	40	87

Table 4.21: Effect of sodicity on canopy volume (m^3) of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.005	0.031 A	0.077 A	1.38 A	5.22 A	5.21	-	-
20	0.005	0.022 B	0.054 B	1.21 B	4.45 B	4.44	0.77	15
30	0.005	0.014 C	0.030 C	1.04 C	3.25 C	3.24	1.97	38
40	0.005	0.010 C	0.025 D	0.79 D	1.23 D	1.22	3.99	77
50	0.005	0.007 D	0.10 E	0.32 E	0.50 E	0.49	4.72	90

Table 4.22: Effect of sodicity on shoot weight (g Plant^{-1}) of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR (mmol L^{-1})$^{1/2}$	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry shoot weight over control	Decrease in dry shoot weight over control (%)
Control	2460 A	2101 A	1009 A	1092	52	-	-
20	2042 B	1773 B	976 B	797	45	33	3
30	1583 C	1375 C	824 C	551	40	185	18
40	879 D	732 D	473 D	259	35	536	53
50	549 E	448 E	303 E	145	32	706	70

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.23: Effect of sodicity on root weight (g $Plant^{-1}$) of *Acacia ampliceps* (Expt. -2, Study -1)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry root weight over control	Decrease in dry root weight over control (%)
Control	2460 A	359 A	243 A	116	32	-	-
20	2042 B	269 B	194 B	75	28	49	20
30	1583 C	207 C	160 C	47	23	83	34
40	879 D	147 D	116 D	31	21	127	52
50	549 E	101 E	83 E	18	18	160	66

Table 4.24: Na^+ (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	3.94 E	4.25 E	4.60 E	4.83 E
20	7.72 D	9.36 D	11.23 D	11.80 D
30	12.34 C	14.30 C	15.04 C	16.11 C
40	15.62 B	18.66 B	19.83 B	21.06 B
50	19.43 A	22.91 A	23.85 A	24.53 A

Table 4.25: Na^+ (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	2.53 E	2.61 E	2.65 E	2.74 E
20	4.03 D	4.26 D	4.51 D	4.90 D
30	5.51 C	6.07 C	6.24 C	6.53 C
40	6.33 B	7.24 B	7.60 B	8.16 B
50	7.64 A	8.12 A	8.63 A	9.05 A

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.26: K^+ (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years	K: Na ratio After two years
Control	12.42 A	13.06 A	13.70 A	14.54 A	3.01
20	11.10 B	11.82 B	12.53 B	13.04 B	1.10
30	9.22 C	10.20 C	11.06 C	11.42 C	0.71
40	8.53 D	9.62 D	10.33 D	10.80 D	0.51
50	7.94 E	9.05 E	9.21 E	9.34 E	0.38

Table 4.27: K^+ (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years	K: Na ratio After two years
Control	13.71 A	14.63 A	16.44 A	16.57 A	6.05
20	13.03 B	13.74 B	14.82B	15.53 B	3.17
30	12.05 C	12.41 C	13.50 C	13.81 C	2.11
40	11.43 D	11.94 D	12.36 D	12.63 D	1.55
50	10.84 E	11.42 E	11.53 E	11.92 E	1.32

Table 4.28: Ca^{2+} (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	13.64 A	13.92 A	14.25 A	15.76 A
20	8.30 B	8.51 B	8.53 B	9.07 B
30	5.92 C	6.34 C	6.74 C	7.14 C
40	4.82 D	5.30 D	5.41 D	5.95 D
50	3.31 E	3.63 E	3.65 E	4.26 E

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.29: Ca^{2+} (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	8.92 A	9.44 A	9.85 A	10.56 A
20	5.32 B	5.24 B	5.56 B	5.68 B
30	4.01 C	4.20 C	4.75 C	4.84 C
40	3.66 C	3.64 D	3.82 D	4.03 D
50	2.45 D	2.73 E	2.82 E	3.16 E

Table 4.30: Mg^{2+} (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	7.35 A	7.52 A	7.23 A	7.50 A
20	5.04 B	5.63 B	5.71 B	5.42 B
30	3.85 C	3.61 C	3.45 C	3.36 C
40	2.93 D	2.53 D	2.41 D	2.27 D
50	2.06 E	1.92 E	2.05 E	1.84 E

Table 4.31: Mg^{2+} (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	After six months	After one year	After one and a half year	After two years
Control	6.11 A	6.45 A	6.53 A	6.34 A
20	4.30 B	4.53 B	4.21 B	4.62 B
30	3.04 C	2.91 C	3.05 C	2.75 C
40	2.16 D	2.27 D	1.86 D	1.74 D
50	1.51 E	1.54 E	1.33 E	1.16 E

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.32: Concentration of various ions (g kg^{-1}) in roots of *Acacia ampliceps* (Expt. -2)

Sodicity levels SAR (mmol $L^{-1})^{1/2}$	Na^{1+}	K^{1+}	Ca^{2+}	Mg^{2+}	K: Na ratio
Control	4.85 F	11.25 A	12.04 A	6.74 A	2.32
20	9.63 D	9.61 B	8.24 B	4.05 B	0.99
30	12.81 C	7.22 C	6.53 BC	3.11 C	0.56
40	16.64 B	5.94 D	4.91 C	2.30 CD	0.36
50	19.43 A	5.03 E	2.82 D	1.82 D	0.26

Note: Plants could not survive in SAR of 60 & 70 (T6 & T7)

Table 4.33: Effect of salinity and sodicity on plant height (cm) of *Acacia ampliceps*
(Experiment -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	30	75 A	138 A	200 A	310 A	280	-	-
10 + 30	31	56 ABC	132 AB	190 B	265 B	234	46	16
10 + 40	31	63 ABC	136 A	173 C	247 C	216	64	23
10 + 50	30	65 AB	134 AB	162 D	229 D	199	81	29
20 + 30	29	60 ABC	132 AB	154 E	228 D	199	81	29
20 + 40	30	61 ABC	114 CD	146 FG	210 E	180	100	36
20 + 50	29	52 BC	110 CD	140 GH	176 G	147	133	48
30 + 30	30	51 BC	97 D	149 EF	188 F	158	122	44
30 + 40	29	44 C	98 D	133 H	156 H	127	153	55
30 + 50	32	46 C	97 D	118 I	133 I	100	180	64

Table 4.34: Effect of salinity and sodicity on stem diameter (cm) of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e+ SAR)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.30	0.98 A	1.65 A	2.16 A	2.61 A	2.31	-	-
10 + 30	0.29	0.83 ABC	1.53 AB	1.88 B	2.34 B	2.05	0.26	11
10 + 40	0.28	0.78 BCD	1.66 A	1.79 BC	2.24 C	1.96	0.35	15
10 + 50	0.30	0.87 AB	1.64 A	1.73 C	2.11 DE	1.81	0.50	22
20 + 30	0.29	0.65 CD	1.39 BCD	1.81 BC	2.15 D	1.86	0.45	19
20 + 40	0.30	0.69 CDE	1.33 BCD	1.72 C	2.09 E	1.79	0.52	23
20 + 50	0.29	0.63 DE	1.27 CDE	1.63 D	1.93 F	1.64	0.67	29
30 + 30	0.30	0.59 E	1.17 DE	1.44 E	2.06 E	1.76	0.55	24
30 + 40	0.30	0.66 CDE	1.14 DE	1.37 E	1.74 G	1.44	0.87	38
30 + 50	0.29	0.54 E	1.10 E	1.18 F	1.42 H	1.13	1.18	51

Table 4.35: Effect of salinity and sodicity on number of leaves plant^{-1} of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e+ SAR)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	29	190 A	342 A	372 A	587 A	558	-	-
10 + 30	30	127 B	240 B	341 B	534 AB	504	54	10
10 + 40	29	112 B	230 B	335 B	522 ABC	493	65	12
10 + 50	28	86 B	223 B	307 C	460 BCD	432	126	23
20 + 30	28	77 B	203 B	301 C	469 BCD	441	117	21
20 + 40	30	70 B	190 BC	263 D	429 BCD	399	159	28
20 + 50	28	65 B	139 CD	234 E	364 DE	336	222	40
30 + 30	30	73 B	114 D	226 E	380 CDE	350	208	37
30 + 40	28	70 B	114 D	163 F	309 EF	281	277	50
30 + 50	30	70 B	96 D	117 G	224 F	194	364	65

Table 4.36: Effect of salinity and sodicity on number of branches plant^{-1} of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	1	15 A	20 A	27 A	45 A	44	-	-
10 + 30	1	7 B	16 AB	23 B	39 B	38	6	14
10 + 40	1	7 B	15 AB	19 C	36 C	37	7	16
10 + 50	1	5 B	11 B	16 D	29 E	28	16	36
20 + 30	1	5 B	10 B	15 DE	32 D	30	14	32
20 + 40	1	8 B	12 B	13 EF	26 F	25	19	43
20 + 50	1	5 B	11 B	13 EF	20 G	19	25	57
30 + 30	1	6 B	9 B	12 F	16 H	15	29	66
30 + 40	1	4 B	9 B	10 G	14 I	13	31	70
30 + 50	1	4 B	9 B	10 G	12 J	11	33	75

Table 4.37: Effect of salinity and sodicity on canopy volume (m^3) of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Decrease over control (%)
Control	0.005	0.042 A	0.100 A	1.51 A	5.30 A	5.29	-	-
10 + 30	0.005	0.022 B	0.049 B	1.41 B	4.70 B	4.69	0.60	11
10 + 40	0.005	0.020 B	0.047 B	1.33 C	4.22 C	4.21	1.08	20
10 + 50	0.005	0.019 B	0.042 C	1.17 D	3.68 D	3.67	1.62	31
20 + 30	0.005	0.016 C	0.029 D	1.05 E	3.73 D	3.72	1.57	30
20 + 40	0.005	0.010 D	0.024 E	0.95 F	3.24 E	3.23	2.06	39
20 + 50	0.005	0.009 D	0.017 F	0.75 E	2.47 F	2.46	2.83	54
30 + 30	0.005	0.006 E	0.011 G	0.53 H	2.52 F	2.51	2.78	53
30 + 40	0.005	0.005 E	0.008 GH	0.45 I	1.43 G	1.43	3.86	73
30 + 50	0.005	0.005 E	0.007 H	0.34 J	0.95 H	0.94	4.35	82

Table 4.38: Effect of salinity and sodicity on shoot weight (g Plant^{-1}) of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry shoot weight over control	Decrease in dry shoot weight over control (%)
Control	2458 A	2105 A	1028 A	1077	51	-	-
10 + 30	2126 B	1850 B	962 B	888	48	66	6
10 + 40	1963 C	1709 C	906 C	803	47	122	12
10 + 50	1753 D	1522 E	851 E	671	44	177	17
20 + 30	1816 D	1580 D	884 D	696	44	144	14
20 + 40	1560 E	1354 F	787 F	567	42	241	23
20 + 50	1230 F	1064 G	660 G	404	38	368	36
30 + 30	1258 F	1086 G	662 G	424	39	366	36
30 + 40	933 G	807 H	513 H	294	36	515	50
30 + 50	625 H	513 I	345 I	168	33	683	66

Table 4.39: Effect of salinity and sodicity on root weight (g Plant^{-1}) of *Acacia ampliceps* (Experiment -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	Total Biomass	Fresh weight	Dry weight	Loss in weight	Moisture %	Decrease in dry root weight over control	Decrease in dry root weight over control (%)
Control	2458 A	354 A	233 A	121	34	-	-
10 + 30	2126 B	276 B	193 B	83	30	40	17
10 + 40	1963 C	254 C	184 C	70	28	49	21
10 + 50	1753 D	231 D	167 D	64	28	66	28
20 + 30	1816 D	237 D	168 D	69	29	65	28
20 + 40	1560 E	206 E	152 E	54	26	81	35
20 + 50	1230 F	166 F	128 F	38	23	105	45
30 + 30	1258 F	172 F	131 F	41	24	102	44
30 + 40	933 G	127 G	102 G	25	20	131	56
30 + 50	625 H	112 H	91 H	21	19	142	61

Table 4.40: Na^+ ($g\ kg^{-1}$) concentration in older leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	3.73 H	4.25 H	4.53 H	4.80 H
10 + 30	5.03 G	6.31 G	7.60 G	8.52 G
10 + 40	6.21 F	8.40 F	9.32 F	11.24 F
10 + 50	7.26 E	9.82 E	11.41 DE	12.63 D
20 + 30	7.54 DE	9.94 E	10.90 E	12.03 E
20 + 40	7.92 CD	10.22 E	11.83 D	13.10 D
20 + 50	8.45 C	12.40 C	13.44 C	14.26 C
30 + 30	7.84 DE	11.72 D	12.90 C	13.74 C
30 + 40	12.80 B	15.85 B	16.74 B	17.50 B
30 + 50	16.22 A	19.40 A	20.63 A	21.56 A

Table 4.41: Na^+ ($g\ kg^{-1}$) concentration in younger leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	2.62 G	2.84 I	2.66 F	2.93 F
10 + 30	3.41 F	3.27 H	3.72 E	4.04 E
10 + 40	3.83 E	3.74 G	3.90 E	4.43 E
10 + 50	4.60 D	4.82 E	5.36 D	6.15 CD
20 + 30	4.05 E	4.40 F	5.07 D	5.72 D
20 + 40	4.83 D	4.86 E	5.54 D	6.23 CD
20 + 50	5.42 C	6.11 C	6.45 BC	6.92 B
30 + 30	5.40 C	5.44 D	6.14 C	6.60 BC
30 + 40	6.06 B	6.51 B	6.83 B	7.06 B
30 + 50	6.90 A	7.36 A	7.62 A	8.14 A

Table 4.42: K^+ (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years	K: Na ratio after two years
Control	12.14A	12.63 A	13.45 A	14.66 A	3.06
10 + 30	11.43 B	12.06 B	12.60 B	13.24 B	1.55
10 + 40	10.82 C	11.05 C	11.26 C	12.23 C	1.09
10 + 50	9.64 E	10.61 D	11.03 CD	11.46 D	0.90
20 + 30	10.45 D	10.84 C	11.36 C	11.90 CD	0.99
20 + 40	9.06 F	9.44 E	10.53 DE	11.4 D	0.87
20 + 50	8.04 G	8.52 G	9.33 F	10.26 E	0.72
30 + 30	9.42 E	9.07 F	10.46 E	11.05 DE	0.80
30 + 40	7.34 H	6.91 H	7.73 G	8.94 F	0.51
30 + 50	6.20 I	6.16 I	7.05 H	8.24 G	0.38

Table 4.43: K^+ (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years	K: Na ratio after two years
Control	13.90 A	14.52 A	16.24 A	18.03 A	6.15
10 + 30	13.23 B	13.64 B	15.43 B	16.55 B	4.10
10 + 40	12.80 C	13.25 C	15.04 BC	16.07 BC	3.63
10 + 50	12.03 E	12.42 DE	14.24 DE	15.33 CDE	2.49
20 + 30	12.31 D	12.73 D	14.60 CD	15.81BCD	2.76
20 + 40	11.84 E	12.25 E	14.06 EF	15.22 DE	2.44
20 + 50	11.13 G	11.44 F	13.14 G	14.46 F	2.08
30 + 30	11.40 F	11.53 F	13.62 FG	14.65 EF	2.22
30 + 40	10.47 H	11.08 G	12.33 H	13.05 G	1.85
30 + 50	9.84 I	10.34 H	11.06 I	11.83 H	1.45

Table 4.44: Ca^{2+} ($g\ kg^{-1}$) concentration in older leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	13.61 A	14.04 A	14.21 A	15.65 A
10 + 30	8.60 B	8.81 B	9.12 B	9.74 B
10 + 40	7.13 C	7.64 C	7.55 C	8.16 C
10 + 50	5.82 E	6.10 E	6.21 D	6.73 E
20 + 30	6.55 D	6.93 D	7.04 C	7.40 D
20 + 40	5.11 F	5.72 E	5.61 E	6.13 F
20 + 50	4.34 G	4.45 FG	4.93 F	5.26 G
30 + 30	4.81 FG	4.86 F	5.24 EF	5.45 G
30 + 40	3.66 H	4.05 G	4.13 G	4.30 H
30 + 50	2.70 I	2.72 H	3.05 H	3.16 I

Table 4.45: Ca^{2+} ($g\ kg^{-1}$) concentration in younger leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	8.64 A	9.25 A	9.71 A	10.45 A
10 + 30	6.10 B	6.41 B	6.52 B	7.06 B
10 + 40	5.33 C	5.74 C	5.91 C	6.23 C
10 + 50	4.60 D	4.81 D	4.86 D	5.04 D
20 + 30	4.62 D	5.01 D	4.93 D	5.25 D
20 + 40	3.90 E	4.30 E	4.32 E	4.40 E
20 + 50	3.12 F	3.53 F	3.45 FG	3.66 FG
30 + 30	3.32 F	3.36 F	3.62 F	4.05 EF
30 + 40	2.63 G	2.90 G	3.05 G	3.44 GH
30 + 50	2.05 H	2.41 H	2.52 H	2.93 H

Table 4.46: Mg^{2+} (g kg^{-1}) concentration in older leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	7.64 A	7.92 A	7.73 A	8.01A
10 + 30	4.50 B	4.74 B	5.02 B	4.83 B
10 + 40	3.83 C	3.61 C	3.45 C	3.52 C
10 + 50	3.42 D	3.20 D	3.31 C	3.06 D
20 + 30	3.54 CD	3.63 C	3.42 C	3.70 C
20 + 40	3.02 E	2.75 E	2.54 D	2.56 E
20 + 50	2.31 F	2.06 FG	1.97 E	1.73 F
30 + 30	2.31 F	2.20 F	2.12 E	1.94 F
30 + 40	1.94 G	1.72 G	1.81 E	1.64 F
30 + 50	1.32 H	1.25 H	1.22 F	1.03 G

Table 4.47: Mg^{2+} (g kg^{-1}) concentration in younger leaves of *Acacia ampliceps* (Expt. -3)

Salinity + sodicity levels (EC_e + SAR)	After six months	After one year	After one and a half year	After two years
Control	6.41 A	6.54 A	6.23 A	6.74 A
10 + 30	4.03 B	4.42 B	4.55 B	4.33 B
10 + 40	3.31 C	3.43 C	3.04 C	3.21 C
10 + 50	2.91 D	2.60 D	2.42 D	2.76 D
20 + 30	3.14 CD	3.22 C	2.91 C	3.34 C
20 + 40	2.43 E	2.12 E	1.90 E	1.93 E
20 + 50	1.84 G	1.72 EF	1.41 F	1.65 E
30 + 30	2.12 F	2.11 E	1.93 E	1.84 E
30 + 40	1.56 H	1.46 FG	1.27 F	1.03 F
30 + 50	1.04 I	1.07 G	0.81 G	0.72 G

Table 4.48: Concentration of various ions (g kg^{-1}) in roots of *Acacia ampliceps* (Expt. -3, Study -1)

Salinity + sodicity levels (EC_e + SAR)	Na^{1+}	K^{1+}	Ca^{2+}	Mg^{2+}	K: Na ratio
Control	4.73 I	11.36 A	12.45 A	6.26 A	2.40
10 + 30	7.85 H	10.41 B	8.92 B	3.94 B	1.33
10 + 40	9.11 G	9.73 BC	8.06 BC	3.82 BC	1.07
10 + 50	11.23 E	8.55 DE	6.80 CD	3.33 CDE	0.76
20 + 30	10.51 F	9.06 CD	7.23 CD	3.40 BCD	0.86
20 + 40	11.75 DE	8.21 EF	6.51 CD	2.94 DEF	0.70
20 + 50	12.53 C	7.53 F	5.90 D	2.61 F	0.60
30 + 30	12.24 CD	7.84 EF	5.91 D	2.83 EF	0.64
30 + 40	13.61 B	6.56 G	4.33 E	1.75 G	0.48
30 + 50	16.13 A	5.33 H	2.51 F	1.16 H	0.33

Table 4.49: Growth assessment of *Acacia ampliceps* in relation to visual plant condition in study -2

a) Plant height (m)

Plant Condition	After 3.5 years March, 2005	After 4 years Sep., 2005	After 4.5 years March, 2006	After 5 years Sep., 2006
Poor	3.82 ± 0.27	4.06 ± 0.23	4.60 ± 0.22	4.71 ± 0.19
Medium	4.80 ± 0.22	4.99 ± 0.22	5.63 ± 0.09	6.40 ± 0.08
Good	6.14 ± 0.37	6.43 ± 0.34	7.25 ± 0.22	8.53 ± 0.22

b) Stem diameter (cm)

Poor	9.15 ± 1.59	10.11 ± 1.41	11.55 ± 0.93	12.67 ± 0.44
Medium	14.80 ± 2.05	15.92 ± 2.13	18.08 ± 1.00	22.02 ± 1.52
Good	24.60 ± 3.92	25.39 ± 3.96	33.96 ± 1.65	44.00 ± 1.06

c) Canopy volume (m^3)

Poor	8.94 ± 1.07	9.36 ± 1.04	11.21 ± 0.47	11.50 ± 0.43
Medium	33.70 ± 4.01	35.78 ± 3.69	38.84 ± 2.41	49.43 ± 2.45
Good	79.86 ± 6.99	84.24 ± 6.09	90.59 ± 4.83	113.93 ± 4.95

d) Number of branches $plant^{-1}$

Poor	32.25 ± 8.65	36.50 ± 7.89	45.75 ± 6.75	49.00 ± 4.16
Medium	73.00 ± 9.63	79.25 ± 9.39	91.75 ± 6.75	111.75 ± 4.03
Good	134.75 ± 11.44	145.25 ± 9.57	167.75 ± 8.88	194.25 ± 9.03

All values are average of 12 observations.

Table 4.50: Changes in soil EC_e (dS m^{-1}) in relation to plant growth at various depths in study -2

Plant Condition	Before plantation Sep., 2001	After 3.5 years March, 2005	After 4 years Sep., 2005	After 4.5 years March, 2006	After 5 years Sep., 2006
0-15 cm					
Poor	18.29 ± 0.94	12.45 ± 0.93	10.11 ± 0.70	8.88 ± 0.69	7.56 ± 0.53
Medium	14.44 ± 0.83	7.27 ± 0.71	6.45 ± 0.65	5.67 ± 0.23	5.18 ± 0.09
Good	12.29 ± 0.48	6.78 ± 0.35	5.79 ± 0.19	5.06 ± 0.05	4.37 ± 0.12
15-30 cm					
Poor	16.08 ± 0.88	10.98 ± 0.57	8.76 ± 0.43	7.83 ± 0.47	6.51 ± 0.21
Medium	12.33 ± 0.87	7.29 ± 0.48	6.30 ± 0.37	5.47 ± 0.32	4.92 ± 0.17
Good	10.43 ± 0.46	6.46 ± 0.27	5.74 ± 0.29	4.91 ± 0.34	4.26 ± 0.19
30-60 cm					
Poor	15.74 ± 0.87	10.66 ± 0.46	8.70 ± 0.33	7.40 ± 0.28	6.33 ± 0.20
Medium	12.03 ± 0.80	6.58 ± 0.21	6.24 ± 0.27	5.20 ± 0.36	4.88 ± 0.14
Good	10.14 ± 0.39	6.32 ± 0.25	5.40 ± 0.32	4.52 ± 0.22	4.22 ± 0.12
60-90 cm					
Poor	15.33 ± 0.71	9.79 ± 0.26	8.43 ± 0.29	7.12 ± 0.24	6.31 ± 0.20
Medium	11.70 ± 0.78	6.41 ± 0.12	6.05 ± 0.18	5.10 ± 0.32	4.83 ± 0.22
Good	9.83 ± 0.40	6.10 ± 0.13	5.22 ± 0.21	4.34 ± 0.23	4.18 ± 0.18
90-120 cm					
Poor	11.59 ± 0.75	9.22 ± 0.13	8.26 ± 0.22	6.90 ± 0.17	6.22 ± 0.09
Medium	8.64 ± 0.54	6.24 ± 0.12	5.96 ± 0.19	5.02 ± 0.24	4.80 ± 0.13
Good	7.96 ± 0.12	5.93 ± 0.11	5.14 ± 0.20	4.24 ± 0.18	4.06 ± 0.13
120-150 cm					
Poor	8.81 ± 0.41	8.37 ± 0.16	8.12 ± 0.18	6.77 ± 0.14	6.14 ± 0.05
Medium	6.31 ± 0.19	6.08 ± 0.10	5.62 ± 0.14	5.00 ± 0.17	4.66 ± 0.11
Good	5.77 ± 0.40	5.74 ± 0.11	5.04 ± 0.15	4.18 ± 0.19	3.95 ± 0.11

All values are average of 12 observations.

Table 4.51: Changes in soil pH in relation to plant growth at various depths in study-2

Plant Condition	Before plantation Sep., 2001	After 3.5 years March, 2005	After 4 years Sep., 2005	After 4.5 years March, 2006	After 5 years Sep., 2006
0-15 cm					
Poor	9.6 ± 0.10	9.5 ± 0.15	9.1 ± 0.07	8.9 ± 0.10	8.8 ± 0.05
Medium	9.4 ± 0.17	8.8 ± 0.14	8.7 ± 0.09	8.7 ± 0.08	8.6 ± 0.08
Good	9.3 ± 0.14	8.8 ± 0.08	8.6 ± 0.04	8.6 ± 0.02	8.5 ± 0.04
15-30 cm					
Poor	9.7 ± 0.07	9.6 ± 0.11	9.2 ± 0.12	9.0 ± 0.16	8.9 ± 0.05
Medium	9.5 ± 0.10	9.2 ± 0.52	8.9 ± 0.16	8.9 ± 0.13	8.7 ± 0.08
Good	9.3 ± 0.08	8.9 ± 0.08	8.7 ± 0.10	8.6 ± 0.1.9	8.6 ± 0.06
30-60 cm					
Poor	9.7 ± 0.09	9.5 ± 0.07	9.2 ± 0.11	9.0 ± 0.10	8.8 ± 0.06
Medium	9.6 ± 0.12	8.8 ± 0.16	8.8 ± 0.14	8.7 ± 0.09	8.7 ± 0.11
Good	9.3 ± 0.07	8.7 ± 0.06	8.7 ± 0.10	8.6 ± 0.11	8.5 ± 0.05
60-90 cm					
Poor	9.6 ± 0.14	9.3 ± 0.10	9.1 ± 0.12	8.9 ± 0.09	8.8 ± 0.10
Medium	9.4 ± 0.10	8.7 ± 0.04	8.8 ± 0.08	8.7 ± 0.11	8.7 ± 0.14
Good	9.2 ± 0.07	8.6 ± 0.06	8.6 ± 0.09	8.6 ± 0.10	8.5 ± 0.06
90-120 cm					
Poor	9.4 ± 0.12	9.2 ± 0.19	9.1 ± 0.14	8.9 ± 0.12	8.8 ± 0.10
Medium	9.0 ± 0.11	8.6 ± 0.15	8.7 ± 0.11	8.7 ± 0.10	8.6 ± 0.15
Good	8.9 ± 0.20	8.5 ± 0.06	8.5 ± 0.08	8.5 ± 0.09	8.5 ± 0.06
120-150 cm					
Poor	9.2 ± 0.09	9.1 ± 0.14	9.0 ± 0.12	8.8 ± 0.11	8.8 ± 0.08
Medium	8.7 ± 0.17	8.6 ± 0.11	8.6 ± 0.09	8.6 ± 0.08	8.6 ± 0.11
Good	8.6 ± 0.07	8.5 ± 0.03	8.5 ± 0.10	8.5 ± 0.06	8.4 ± 0.04

All values are average of 12 observations.

Table 4.52: Changes in soil SAR $(mmol\ L^{-1})^{1/2}$ in relation to plant growth at various depths in study -2

Plant Condition	Before plantation Sep., 2001	After 3.5 years March, 2005	After 4 years Sep., 2005	After 4.5 years March, 2006	After 5 years Sep., 2006
0-15 cm					
Poor	146 ± 6.38	117 ± 8.28	83 ± 5.77	63 ± 6.32	50 ± 5.06
Medium	124 ± 5.85	48 ± 5.19	39 ± 4.28	31 ± 2.15	28 ± 0.81
Good	102 ± 4.71	43 ± 1.17	34 ± 1.06	26 ± 0.13	20 ± 0.94
15-30 cm					
Poor	143 ± 8.59	100 ± 7.87	62 ± 5.80	54 ± 5.12	42 ± 1.71
Medium	111 ± 5.55	48 ± 4.71	39 ± 4.92	31 ± 3.64	27 ± 1.34
Good	94 ± 6.52	42 ± 0.89	30 ± 1.63	25 ± 2.10	20 ± 1.02
30-60 cm					
Poor	135 ± 7.08	93 ± 5.36	61 ± 5.06	50 ± 4.68	40 ± 1.83
Medium	106 ± 5.23	42 ± 2.78	37 ± 3.76	29 ± 2.87	26 ± 1.15
Good	91 ± 5.93	40 ± 1.23	28 ± 2.00	22 ± 1.69	20 ± 0.89
60-90 cm					
Poor	124 ± 4.68	83 ± 2.81	58 ± 4.15	47 ± 4.28	40 ± 1.78
Medium	97 ± 5.35	39 ± 1.39	34 ± 2.35	28 ± 3.20	25 ± 1.60
Good	83 ± 5.48	37 ± 1.47	27 ± 3.01	21 ± 1.94	20 ± 1.22
90-120 cm					
Poor	90 ± 7.17	76 ± 1.97	56 ± 2.56	45 ± 3.51	39 ± 0.27
Medium	66 ± 4.51	37 ± 0.71	33 ± 1.65	28 ± 2.14	24 ± 0.83
Good	62 ± 1.26	35 ± 1.15	26 ± 2.16	20 ± 1.78	19 ± 1.03
120-150 cm					
Poor	78 ± 1.60	67 ± 1.74	55 ± 3.85	44 ± 4.23	38 ± 0.67
Medium	45 ± 2.00	36 ± 0.63	31 ± 1.44	27 ± 1.67	23 ± 0.92
Good	42 ± 3.66	33 ± 0.70	27 ± 1.10	19 ± 0.84	18 ± 0.96

All values are average of 12 observations.

Table 4.53: Potassium concentration (g kg^{-1}) in older leaves in study -2

Plant Condition	After 3.5 years March, 2005	After 4 years Sep., 2005	After 4.5 years March, 2006	After 5 years Sep., 2006	K: Na ratio after 5 years
Poor	9.04 ± 0.31	9.23 ± 0.43	9.35 ± 0.33	9.51 ± 0.45	1.15
Medium	12.42 ± 0.46	13.17 ± 0.25	13.61 ± 0.30	14.42 ± 0.34	2.04
Good	14.50 ± 0.41	15.73 ± 0.50	15.64 ± 0.43	15.92 ± 0.52	2.81

Table 4.54: Potassium concentration (g kg^{-1}) in younger leaves in study -2

Poor	11.93 ± 0.52	12.60 ± 0.31	12.34 ± 0.40	13.06 ± 0.31	3.47
Medium	15.44 ± 0.41	15.53 ± 0.40	15.56 ± 0.36	16.63 ± 0.52	4.93
Good	16.90 ± 0.56	18.16 ± 0.68	17.80 ± 0.53	19.05 ± 0.75	6.73

Table 4.55: Sodium concentration (g kg^{-1}) in older leaves in study -2

Plant Condition	After 3.5 years	After 4 years	After 4.5 years	After 5 years
Poor	6.73 ± 0.40	7.44 ± 0.52	7.18 ± 0.43	8.26 ± 0.55
Medium	5.45 ± 0.35	6.14 ± 0.40	6.37 ± 0.36	7.06 ± 0.33
Good	4.54 ± 0.41	5.46 ± 0.39	5.05 ± 0.43	5.66 ± 0.40

Table 4.56: Sodium concentration (g kg^{-1}) in younger leaves in study -2

Poor	2.82 ± 0.23	3.54 ± 0.32	3.73 ± 0.24	3.76 ± 0.21
Medium	2.65 ± 0.18	2.92 ± 0.20	3.06 ± 0.26	3.37 ± 0.24
Good	2.43 ± 0.16	2.55 ± 0.14	2.64 ± 0.20	2.83 ± 0.22

All values are average of 12 observations.

Table 4.57: Calcium concentration (g kg^{-1}) in older leaves in study -2

Plant Condition	After 3.5 years	After 4 years	After 4.5 years	After 5 years
Poor	11.24 ± 0.34	11.72 ± 0.48	11.91 ± 0.50	12.63 ± 0.45
Medium	13.04 ± 0.56	13.92 ± 0.45	14.45 ± 0.38	15.06 ± 0.54
Good	15.16 ± 0.46	16.05 ± 0.54	16.64 ± 0.47	17.34 ± 0.50

Table 4.58: Calcium concentration (g kg^{-1}) in younger leaves in study -2

Poor	5.63 ± 0.32	5.91 ± 0.36	6.05 ± 0.24	6.43 ± 0.34
Medium	7.16 ± 0.44	7.65 ± 0.41	7.93 ± 0.34	8.25 ± 0.38
Good	8.73 ± 0.52	9.54 ± 0.56	9.92 ± 0.55	10.74 ± 0.53

Table 4.59: Magnesium concentration (g kg^{-1}) in older leaves in study -2

Plant Condition	After 3.5 years	After 4 years	After 4.5 years	After 5 years
Poor	4.80 ± 0.24	5.14 ± 0.35	4.83 ± 0.20	5.24 ± 0.25
Medium	5.61 ± 0.30	5.62 ± 0.26	5.51 ± 0.31	5.82 ± 0.33
Good	6.43 ± 0.34	6.81 ± 0.33	6.62 ± 0.40	6.70 ± 0.37

Table 4.60: Magnesium concentration (g kg^{-1}) in younger leaves in study -2

Poor	4.12 ± 0.20	4.26 ± 0.33	4.03 ± 0.25	4.14 ± 0.25
Medium	4.90 ± 0.28	4.85 ± 0.24	5.06 ± 0.22	5.16 ± 0.34
Good	5.41 ± 0.23	5.43 ± 0.29	5.60 ± 0.24	5.52 ± 0.28

All values are average of 12 observations.

Table 4.61: Effect of transplantation techniques on plant height (cm) in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	28.0	31.0 F	34 H	42 H	63 H	35	-	-
T2- Transplantation in pit filled with original soil	28.1	45.3 E	62 G	90 G	137 G	109	74	211
T3- Transplantation in pit filled with silt	28.5	91.3 A	186 C	281 C	381 C	353	318	909
T4- Transplantation in pit filled with silt + augering	27.9	78.0 C	207 B	291 B	410 B	382	347	991
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	28.2	79.7 BC	170 D	240 E	331 E	303	268	766
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	28.3	85.3 AB	105 F	176 F	294 F	266	231	660
T7- Transplantation in pit filled with silt + compost (20 : 1)	27.9	90.3 A	260 A	365 A	508 A	480	445	1271
T8- Transplantation in pit filled with original soil + Compost (20:1)	28.5	72.7 D	152 E	255 D	363 D	334	299	854

Table 4.62: Effect of transplantation techniques on stem diameter (cm) in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	0.20	0.32 D	0.40 H	0.54 H	0.71 H	0.51	-	-
T2- Transplantation in pit filled with original soil	0.20	0.63 C	0.86 G	1.29 G	1.91 G	1.71	1.20	235
T3- Transplantation in pit filled with silt	0.19	1.93 A	5.12 C	6.14 C	7.45 C	7.26	6.75	1324
T4- Transplantation in pit filled with silt + augering	0.21	1.66 B	5.40 B	6.31 B	7.86 B	7.65	7.14	1400
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	0.20	1.64 B	4.46 E	5.11 E	6.27 E	6.07	5.56	1090
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	0.22	1.93 A	2.72 F	3.44 F	4.55 F	4.33	3.82	749
T7- Transplantation in pit filled with silt + compost (20 : 1)	0.19	2.18 A	7.10 A	8.76 A	11.28A	11.09	10.58	2074
T8- Transplantation in pit filled with original soil + Compost (20:1)	0.21	1.61 B	4.82 D	5.39 D	6.59 D	6.38	5.87	1151

All values are average of 48 observations.

Table 4.63: Effect of transplantation techniques on number of leaves plant^{-1} in study -3

Treatments	At trans plant ation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	30	17 C	94 H	190 H	301 H	271	-	-
T2- Transplantation in pit filled with original soil	29	53 C	265 G	475 G	630 G	601	330	122
T3- Transplantation in pit filled with silt	30	607 A	1427 C	2228 C	3035 C	3005	2734	1009
T4- Transplantation in pit filled with silt + augering	28	400 B	1514 B	2345 B	3239 B	3211	2940	1085
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	29	366 B	924 E	2015 E	2541 E	2512	2241	827
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	30	605 A	903 F	1619 F	2135 F	2105	1834	677
T7- Transplantation in pit filled with silt + compost (20 : 1)	29	620 A	1955 A	3452 A	4535 A	4506	4235	1563
T8- Transplantation in pit filled with original soil + Compost (20:1)	30	343 B	1043 D	2137 D	2769 D	2739	2468	911

Table 4.64: Effect of transplantation techniques on number of branches plant^{-1} in study -3

Treatments	At trans plant ation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	1	3 E	5 G	10 H	14 G	13	-	-
T2- Transplantation in pit filled with original soil	1	6 D	13 F	31 G	41 F	40	27	208
T3- Transplantation in pit filled with silt	1	13 AB	32 B	58 C	96 C	95	82	631
T4- Transplantation in pit filled with silt + augering	1	10 C	35 B	65 B	121 B	120	107	823
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	1	11 BC	24 D	47 E	61 D	60	47	362
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	1	13 AB	20 E	43 F	49 E	48	35	269
T7- Transplantation in pit filled with silt + compost (20 : 1)	1	14 A	48 A	85 A	156 A	155	142	1092
T8- Transplantation in pit filled with original soil + Compost (20:1)	1	11 BC	28 C	53 D	66 D	65	52	400

All values are average of 48 observations.

Table 4.65: Effect of transplantation techniques on canopy volume (m^3) $plant^{-1}$ in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	0.005	0.006 H	0.01 H	0.33 H	0.62 H	0.61	-	-
T2- Transplantation in pit filled with original soil	0.005	0.032 G	0.42 G	1.19 G	2.32 G	2.31	1.70	279
T3- Transplantation in pit filled with silt	0.005	0.517 B	7.10 C	14.48 C	23.67 C	23.66	23.05	3779
T4- Transplantation in pit filled with silt + augering	0.005	0.418 E	7.56 B	15.18 B	28.59 B	28.58	27.97	4585
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	0.005	0.449 D	4.75 E	10.25 E	16.23 E	16.22	15.61	2559
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	0.005	0.483 C	3.87 F	8.71 F	12.49 F	12.48	11.87	1946
T7- Transplantation in pit filled with silt + compost (20 : 1)	0.005	0.560 A	10.40 A	19.64 A	35.60 A	35.59	34.98	5734
T8- Transplantation in pit filled with original soil + Compost (20:1)	0.005	0.374 F	6.14 D	12.01 D	19.53 D	19.52	18.91	3100

Table 4.66: Impact of transplantation techniques on soil EC_e (dS m^{-1}) in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	23.18	21.10 A	19.96 A	18.84 A	17.62 A	5.56	-	-
T2- Transplantation in pit filled with original soil	22.85	21.21 A	19.90 A	17.90 B	16.34 A	6.51	0.95	17
T3- Transplantation in pit filled with silt	23.26	19.30 B	18.30 CD	15.73 E	12.51 BC	10.75	5.19	93
T4- Transplantation in pit filled with silt + augering	23.32	19.47 B	18.26 CD	15.25 F	11.63 CD	11.69	6.13	110
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	23.39	19.34 B	18.42 CD	15.93 DE	13.34 BC	10.05	4.49	80
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	22.91	19.39 B	19.50 AB	16.55 C	14.04 B	8.87	3.31	60
T7- Transplantation in pit filled with silt + compost (20 : 1)	23.36	19.00 B	17.76 D	14.52 G	9.53 D	13.83	8.27	149
T8- Transplantation in pit filled with original soil + Compost (20:1)	23.41	19.14 B	19.00 BC	16.00 D	13.06 BC	10.35	4.79	86

All values are average of 48 observations

Table 4.67: Impact of transplantation techniques on soil pH value in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	10.16	9.73	9.72 A	9.58 A	9.45 A	0.71	-	-
T2- Transplantation in pit filled with original soil	10.06	9.70	9.64 AB	9.49 A	9.28 B	0.78	0.07	10
T3- Transplantation in pit filled with silt	10.10	9.48	9.44 AB	9.28 B	9.06 C	1.04	0.33	46
T4- Transplantation in pit filled with silt + augering	10.07	9.48	9.48 AB	9.24 B	9.00 C	1.07	0.36	51
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	10.11	9.54	9.40 AB	9.27 B	9.05 C	1.06	0.35	49
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	10.25	9.63	9.52 AB	9.30 B	9.11 C	1.14	0.43	61
T7- Transplantation in pit filled with silt + compost (20 : 1)	10.23	9.42	9.31B	9.02 C	8.70 D	1.53	0.82	115
T8- Transplantation in pit filled with original soil + Compost (20:1)	10.15	9.55 N.S.	9.43 AB	9.29 B	9.08 C	1.07	0.36	51

Table 4.68: Impact of transplantation techniques on soil SAR (mmol $L^{-1})^{1/2}$ in study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	242	200 A	185 A	171 A	159 A	83	-	-
T2- Transplantation in pit filled with original soil	237	204 A	183 A	161 B	144 B	93	10	12
T3- Transplantation in pit filled with silt	238	176 BC	158 CD	133 E	97 DE	141	58	70
T4- Transplantation in pit filled with silt + augering	240	178 BC	158 CD	126 F	89 E	151	68	82
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	246	181 BC	166 BC	138 D	107 CD	139	56	67
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	238	184 B	183 A	150 C	120 C	118	35	42
T7- Transplantation in pit filled with silt + compost (20 : 1)	239	168 C	154 D	117 G	68 F	171	88	106
T8- Transplantation in pit filled with original soil + Compost (20:1)	239	178 BC	170 B	138 D	106 D	133	50	60

All values are average of 48 observations

Table 4.69: Sodium concentration (g kg^{-1}) in older leaves of *Acacia ampliceps* in study 3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	7.12 A	7.65 A	8.43 A	9.05 A
T2- Transplantation in pit filled with original soil	6.63 B	7.04 B	7.46 B	7.92 B
T3- Transplantation in pit filled with silt	4.25 C	4.83 C	5.61 C	5.73 C
T4- Transplantation in pit filled with silt + augering	4.22 C	4.71 CD	5.44 C	5.46 CD
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	3.60 D	3.84 E	4.41 E	4.91 D
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	4.32 C	4.45 D	5.05 D	5.43 CD
T7- Transplantation in pit filled with silt + compost (20 : 1)	2.64 E	2.81 G	3.14 F	3.45 E
T8- Transplantation in pit filled with original soil + Compost (20:1)	3.51 D	3.43 F	4.55 E	5.40 CD

Table 4.70: Sodium concentration (g kg^{-1}) in younger leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	3.32 A	3.61 A	3.53 A	3.65 A
T2- Transplantation in pit filled with original soil	2.81 B	3.20 B	3.17 B	3.14 A
T3- Transplantation in pit filled with silt	1.64 D	2.05 CD	2.33 CD	2.21 B
T4- Transplantation in pit filled with silt + augering	1.60 D	1.83 DE	2.52 D	2.05 B
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	1.43EF	1.64 EF	1.81 E	1.93 B
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	1.93 C	2.24 C	2.54 C	2.42 B
T7- Transplantation in pit filled with silt + compost (20 : 1)	1.05 G	1.14 G	1.22 F	1.24 C
T8- Transplantation in pit filled with original soil + Compost (20:1)	1.32 F	1.45 F	1.63 E	2.20 B

All values are average of 48 observations.

Table 4.71: Potassium concentration (g kg^{-1}) in older leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years	K: Na ratio after two years
T1- Control (flat sowing)	8.32 F	8.05 G	8.73 F	9.54 E	1.05
T2- Transplantation in pit filled with original soil	8.61 F	8.64 F	8.35 F	9.62 E	1.21
T3- Transplantation in pit filled with silt	13.15 C	13.42 C	13.73 C	14.45 C	2.52
T4- Transplantation in pit filled with silt + augering	13.53 C	13.57 C	14.05 C	14.61 C	2.67
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	11.14 D	11.45 D	12.15 D	12.44 D	2.53
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	10.16 E	10.66 E	11.13 E	11.73 D	2.16
T7- Transplantation in pit filled with silt + compost (20 : 1)	19.33 A	19.91 A	21.15 A	22.02 A	6.38
T8- Transplantation in pit filled with original soil + Compost (20:1)	16.10 B	16.46 B	17.05 B	16.80 B	3.11

Table 4.72: Potassium concentration (g kg^{-1}) in younger leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years	K: Na ratio after two years
T1- Control (flat sowing)	10.34 E	10.16 F	11.43 G	11.26 F	3.08
T2- Transplantation in pit filled with original soil	10.51 E	10.66 F	11.60 G	11.65 F	3.71
T3- Transplantation in pit filled with silt	14.33 C	14.75 C	15.14 D	16.42 C	7.43
T4- Transplantation in pit filled with silt + augering	14.50 C	14.83 C	15.46 C	17.01 B	8.30
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	12.24 D	12.55 D	12.81 E	13.36 D	6.92
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	11.80 D	12.07 E	12.25 F	12.27 E	5.07
T7- Transplantation in pit filled with silt + compost (20 : 1)	19.41 A	20.05 A	21.42 A	22.24 A	17.93
T8- Transplantation in pit filled with original soil + Compost (20:1)	16.63 B	16.94 B	17.26 B	17.18 B	7.81

All values are average of 48 observations.

Table 4.73: Calcium concentration (g kg^{-1}) in older leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	9.62 F	10.13 C	10.21 D	11.06 D
T2- Transplantation in pit filled with original soil	11.04 E	11.45 C	11.63 D	12.21 D
T3- Transplantation in pit filled with silt	18.72 C	19.11 B	19.23 C	20.74 C
T4- Transplantation in pit filled with silt + augering	18.63 CD	19.24 B	19.65 C	21.26 C
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	20.56 B	21.53 A	22.04 AB	23.14 AB
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	17.81 B	18.65 B	19.21 C	21.02 C
T7- Transplantation in pit filled with silt + compost (20 : 1)	21.60 A	22.52 A	23.24 A	24.53 A
T8- Transplantation in pit filled with original soil + Compost (20:1)	19.22 C	19.93 B	21.11 B	21.64 BC

Table 4.74: Calcium concentration (g kg^{-1}) in younger leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	4.54 D	4.92 D	5.16 D	6.05 D
T2- Transplantation in pit filled with original soil	4.71 D	5.34 D	5.43 D	6.41 D
T3- Transplantation in pit filled with silt	10.92 C	11.43 C	11.75 C	12.21 C
T4- Transplantation in pit filled with silt + augering	11.04 C	11.41 C	11.92 C	12.53 C
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	12.41 B	12.90B	13.24 B	14.06 AB
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	11.92 BC	12.34 BC	12.87 BC	13.32 BC
T7- Transplantation in pit filled with silt + compost (20 : 1)	13.64 A	14.31 A	14.70 A	15.33 A
T8- Transplantation in pit filled with original soil + Compost (20:1)	11.90 BC	12.43 BC	13.04 BC	13.51 BC

All values are average of 48 observations.

Table 4.75: Magnesium concentration (g kg^{-1}) in older leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	4.41 D	4.63 D	4.42 D	4.54 C
T2- Transplantation in pit filled with original soil	4.93 D	4.82 D	4.70 D	4.81 C
T3- Transplantation in pit filled with silt	9.15 BC	9.31 BC	8.92 BC	9.21 B
T4- Transplantation in pit filled with silt + augering	8.81 BC	8.86 BC	9.01 BC	8.93 B
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	9.42 B	9.74 B	9.83 B	9.91 B
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	8.25 C	8.43 C	8.61 C	8.95 B
T7- Transplantation in pit filled with silt + compost (20 : 1)	11.21 A	11.43 A	11.44 A	11.32 A
T8- Transplantation in pit filled with original soil + Compost (20:1)	9.03 BC	9.24 BC	9.46 BC	9.44 B

Table 4.76: Magnesium concentration (g kg^{-1}) in younger leaves of *Acacia ampliceps* in study -3

Treatments	After six months	After one year	After one and a half year	After two years
T1- Control (flat sowing)	3.63 C	3.31 C	3.75 C	3.62 C
T2- Transplantation in pit filled with original soil	3.51 C	3.82 C	3.60 C	3.73 C
T3- Transplantation in pit filled with silt	7.83 B	7.81 B	8.14 B	8.26 B
T4- Transplantation in pit filled with silt + augering	8.01 B	8.20 B	7.92 B	8.34 B
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	8.52 AB	8.83 AB	8.81 AB	8.51 AB
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	7.92 B	7.96 B	8.11 B	8.05 B
T7- Transplantation in pit filled with silt + compost (20 : 1)	9.20 A	9.64 A	9.73 A	9.44 A
T8- Transplantation in pit filled with original soil + Compost (20:1)	7.91 B	8.27 B	8.06 B	7.95 B

All values are average of 48 observations.

CHAPTER - 5

DISCUSSION

Soil salinity and sodicity are conspicuous problems of agriculture in the whole world. Soil and water salinity constraint is spread in all the continents except Antarctica. Arid and semi-arid regions are especially victim of it. Pakistan faces this menace in an area of 6.8 million ha. A severe curtailment in crop yields and farmer's income, unemployment, wide spread poverty, shrinkage of land and water resources and salt pollution is the major outcomes with a clear threat to socio-economic system of rural communities. Reclamation of salt-affected soils and their utilization at the prevailing status are two parallel approaches used to tackle these constraints. The former requires amendments, water and machinery that need money not affordable by farmers, especially small holders. Under such situation the latter approach is preferable. Farmers can get some thing and control further soil deterioration. Salt tolerant plants are selected to match with the prevailing conditions but these should be of economic importance and preferably meet food or fodder requirements of the farmers.

Acacia ampliceps is a plant reported to have very high salt tolerance, rapid growing and a very good fodder, for goats and sheep in particular. World literature indicates its tolerance to salinity alone under specific soil and climatic conditions that are contrary to those prevailing in Pakistan. Almost nothing is available on behavior of this plant under sodicity (SAR > 13) alone and its combination with salinity ($EC_e > 4.0$ dS m^1). Thus, a wide gap existed between information already available and that is required to fit in the conditions dominantly prevailing in Pakistan. (More than 85 % soils face combined stresses in Punjab Province and 65 % in the country). Hence, this research work was under taken to make available the deficient data so that the farming community can be guided most appropriately. Following three studies were conducted (First one in pots and other two in the field).

1. Assessment of tolerance to salinity/sodicity and their combinations by *Acacia ampliceps.*
2. Evaluation of long term effect of saline sodic environment on growth of *Acacia ampliceps* and vice versa.
3. Investigating transplantation techniques to avoid early stage salinity stress.

Results of each study have been presented in chapter 4. The causes of variations recorded as well as logic and viewpoints of different researchers of the world are being discussed under the following main titles. However, new visualizations with the support of data and information generated through current investigation are also presented.

1. Tolerance of *Acacia ampliceps* to soil salinity
2. Tolerance of *Acacia ampliceps* to soil sodicity
3. Combined soil salinity and sodicity tolerance of *Acacia ampliceps*
4. Correlation of soil and plant parameters
5. Impact of growing *Acacia ampliceps* on soil improvement
6. Leaf compositions of *Acacia ampliceps* under various levels of salinity/sodicity
7. Physiological basis of salt tolerance of *Acacia ampliceps*
8. Appropriate transplantation techniques for *Acacia ampliceps* saplings
9. Economics and adaptability of evolved techniques.

5.1 Tolerance of *Acacia ampliceps* to soil salinity

Salt tolerance may be defined as the ability of a plant to grow and complete its life cycle on saline substrate that contains concentrations of salts (JESCHKE, 1984). The ability of a plant to regulate the influx of salts is one of the major factors determining salt tolerance (GORHAM, 1996). Many plant, soil, water and environmental factors as well as genetic makeup interact to express salt tolerance.

5.1.1 Effect on growth parameters

The growth of a plant is depicted through increase in plant height, girth (stem diameter), bearing of new leaves, number of branches and the plant spread (canopy volume). If increase in any of these parameters is measured it will indicate net difference in growth. Experiment -1 of study -1, was conducted to assess the tolerance of *Acacia ampliceps* under different levels of soil salinity (quantity of soluble salts in soil solution). Experimental data indicated that increase in plant height was significantly checked over two years (Table 4.1) by salinity of various degrees. Plants could neither be thickened normally (Table 4.2) nor brought new leaves (Table 4.3) or branches (Table 4.4), as in case of plants growing without any stress. Resultantly, plant could not spread properly (Table 4.5). A cut of 13 to 60 % in plant height, 8 to 57 % in stem diameter, 7 to 68 % in leaf bearing, and 16 to 77 % in number of branches and 11 to 80 % in canopy volume

(Table 5.1 and Figure 5.1 – 5.5) was recorded in the recorded data referred above due to various levels of soil salinity (from 10 to 50 dS m^{-1}). The effects of initial levels were lesser that aggravated with increase in salt contents. The EC_e level of 40 dS m^{-1} was the critical one that caused almost 50 % reduction in studied growth parameters. Fifty percent reduction level is generally considered as the last economical one with minimum affordable rewards. Hence, 50 % salinity tolerance level of *Acacia ampliceps* was found to be 40 dS m^{-1} under prevailing conditions of the investigations (Appendix 16). *Acacia ampliceps* has been reported to be highly tolerant to salinity in other parts of the world as well. MARCAR *et al.* (1995) reported that this plant is tolerant to highly saline, sodic and alkaline soils but intolerant to acid soils and water logging. A reduction in growth starts at EC_e values of 10 to 15 dS m^{-1}. The plant survived in nutrient solutions having salt concentrations up to 65 dS m^{-1} (ASWATHAPPA *et al*., 1987). SHARAZI *et al.* (2006) observed that under very high salinity patches (25 to 30 dS m^{-1}) performance of *Acacia ampliceps* was very good. While studies of AMER *et al*. (2006) indicated that this plant can successfully be grown in the soil having EC_e 21.7 dS m^{-1}.

Soil salinity acts like drought on plants, preventing roots from performing their osmotic activity where water and nutrients move from an area of low concentration to high concentration. High salinity creates high levels of salts in the rhizosphere and increases the osmotic pressure around the roots that is higher than the internal osmotic pressure. Hence, water and nutrients cannot enter the roots and translocated subsequently into growing parts. Therefore, the growth is checked and increase in growth parameters is retarded. The data of present studies on moisture percentage in shoots and roots of *Acacia ampliceps* (Table 4.6 and 4.7) also supported this hypothesis. The moisture clearly decreased appreciably in roots and shoots with increasing salinity levels. Although salinity affects the plants in many ways (especially physiologically) but over injury symptoms seldom occur except under extreme salination (GREEN WAY and MUNNS, 1980 and LAUCHLI and EPSTEIN, 1990). However, response to salinity varies considerably depending upon the species itself, growth stage, cultural and climatic and conditions (MAAS, 1986). Generally, salt affected plants are stunted, as a significant decrease in plant height has been observed in this study also. Salt concentration in tissues over the threshold level decreases the rate of growth (WEIMBERG *et al*., 1984;

SHARMA, 1986; LONE, 1988 and ASLAM *et al.*, 1991). Plant becomes stunted because of reduced cell division than cell expansion (MAAS and NIEMAN, 1978).

The growth of a plant is also directly related to the amount of water transpired. However, if water uptake is reduced considerably due to increase in osmotic pressure under saline environment, the transpiration rate will also be decreased accordingly resulting in decrease of plant growth that was measured through clear reduction in growth parameters like height, number of leaves and branches, stem diameter and canopy volume.

5.1.2 Effect on shoots and root weight

Shoot weight is the end product of plant growth while roots are growing in soil and directly facing the rhizosphere stress, if any. At the same time roots also receive photosynthates from the shoot, especially leaves. These are also absorbing water and nutrients from the soil solution and translocating these to the upper parts of the plants. Xylem and phloem tissues play their part in this regard. Soil salinity stress disturbs the whole system of translocation as well as root development. Hence, growth, shoot weight and root development are water related. It has been observed under previous section (5.1.1) that all the growth parameters (plant height, stem diameter, leaf bearing, branched and canopy volume) were affected negatively with increasing levels of salinity (Table 4.1 - 4.5). Hence, net growth was checked that also resulted in decreased dry shoot weight (Table 4.6). The recorded reductions were 5, 6, 16, 37 and 52 % with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} (Table 5.1). Thus, the highest salinity level (50 dS m^{-1}) caused just slightly more than the critical reduction of 50 %. Therefore, it can be concluded that *Acacia ampliceps* can tolerate 50 dS m^{-1} salinity level with reduction of almost 50 % in shoot weight. Roots were directly growing in the salinity stress, therefore were severely suppressed for their development. A decrease of 60 % was recorded in root dry weight for the same level (50 dS m^{-1}). The root weight was reduced by 15, 20, 29 and 46 % for rest of the respective levels with EC_e values of 10, 20, 30 and 40 dS m^1(Table 5.1 and Figure 5.6 - 5.7). All these decreases were more than the corresponding magnitude for the shoot weight. This finding of the present study is in contrast to reports of old research workers (BERSTEIN *et al.*, 1955; AYERS and EBERHARD, 1960; MEIRI and PALJAKOFF-MAYBER, 1975; DELANE *et al.*, 1980; WEIMBERG *et al.*, 1984; SHARMA, 1986; LONE, 1988 and ASLAM *et al.*, 1991) who claimed that shoot growth is more severely affected than root. However, there is also possibility that opposite behaviour would have found in *Acacia ampliceps* in particular. Salt tolerance of crops is also documented in terms of relative yield. The equation of MASS (1990) is used for this purpose that is:

$$Y_r = 100 - b (EC_e - a) \quad \text{(detailed in review chapter)}$$

Using this equation, relative yield of *Acacia ampliceps* were calculated as 96, 88, 71 and 56 for salinity levels of 20, 30, 40 and 50 dS m^{-1}. Salt tolerance study of ANSARI *et al*. (1994) indicated 25 and 50 % reductions in dry weight at EC_e 17 and 20 dS m^{-1} while SINGH (1991), reported 50 % decrease in dry shoot weight at 8 dS m^{-1}. These differences may be due to variations in soil texture, drainage and prevailing climate. AMER *et al*. (2006) ranked different species on the basis of salinity tolerance as *Acacia ampliceps* > *Acacia amiculiformis* >*Acacia mangium* after his salt tolerance studies. The physiological basis of salt tolerance has been discussed in a separate section.

5.2 Tolerance of *Acacia ampliceps* to soil sodicity

5.2.1 Impact on growth parameters

Sodicity is characterized by excessive amount of sodium in soil solution and clay particle complex. Sodicity affects the plants in three ways; Specific ion effect, nutritional imbalance (especially Ca, K and S) in plants and clay dispersion. Excessive Na in the soil disperses the soil granules, pores are closed / reduced in size or number, water infiltration and hydraulic conductivity is decreased, soil becomes very hard, root penetration is highly checked, root development retarded, roots suffer from air deficit and resultantly water as well as nutrients uptake is severely cut down. Thus, sodicity imposes more threat to plant growth than salinity. Functions of K, Ca and S are very vital in plants but excessive amount of Na is a big constraint for normal metabolic functions. On one way , Na reduces chances of uptake of essential elements while on the other way the lesser amount of nutrients absorbed can not perform exact and balanced role due to overwhelming quantities of Na every where within tissues. Thus, plant growth is either checked fully or partially, depending on the level of Na being faced by the plants. However, it will also depend upon the nature of plant itself because certain plants have developed mechanism either to avoid sodicity or tolerate it. Some of the physiological basis of salt tolerance in *Acacia ampliceps* has been discussed in separate section (5.7.2).

The data of investigations on sodicity (Table 4.17 - 4.21) indicated that plant growth parameters were more negatively affected to various degrees as compared to sodicity quantum up to SAR 50 while plants could not survive and grow in levels of SAR 60 and 70. The reductions in plant height were 18, 32, 51 and 86 % at respective levels of SAR 20, 30, 40 and 50. Stem diameter reduced from 13 to 78 %. The number of leaves decreased from 8 to 85 % while observed decrements were 30 to 87 % in case of branching. Canopy volume was cut short by 15 to 90 % (Table 5.2 and Figure 5.8 -5.12). The reasons presented in earlier part of this section indicated why and how these reductions occurred. These data indicates that recorded reductions were lesser when compared with many other plants. Reduction of almost 50 % occurred at SAR 50. Hence, this plant denoted very good tolerance of sodicity as well.

Another fact observed during comparison of salinity and sodicity was that effects of sodicity were more pronounced because impact of the later was far reaching. It did not only affect the plants directly but also deteriorated physical properties of the soil that were urgent requirements of normal growth. Research works of MASS (1990) and MUHAMMAD (1990) indicated that physical conditions of soil also affected salt tolerance and root growth. The poor soil aeration in sodic soil after irrigations caused less shoot growth (NAWAZ *et at*., 1992 and PERVEEN *et at*., 1991).

5.2.2 Effect of sodicity on root and shoot weight

It is clearly understandable that suppression of growth will ultimately be translated into reduction of root and shoot weight. Thus, the observation of the section 5.2.1 leads to the expectation of less mass of plant dry matter. Such results, in fact were recorded. There was decrease of 3, 18, 53 and 70 % over control (non-sodic) in shoot weight with SAR levels of 20, 30, 40 and 50 while respective cut short was 20, 34, 52 and 66 % (Table 5.2) in case of root dry weight. When these reductions were compared with the same levels of salinity, it was noticed that losses were more in case of sodicity indicating higher negative impact of the latter. Mass formation in plant is the product of several metabolic processes. The plant nitrogen is hydrogenised, synthesized into amino acids, proteins, cellulose and chain compounds of unbreakable nature like lignin. But if the synthesis process is slowed down or stopped totally the mass of plant measured, as dry matter will ultimately be lessened corresponding with the quantum of sodicity stress. That is why, total stoppage of such reactions resulted in death of plant, as was observed in SAR 60 and 70 where plants could not survive beyond a few days. However, plants indicated almost 50 % reduction at SAR 40 that was fairly good tolerance against more destructive stress. *Acacia ampliceps* has been reported to be tolerant of highly saline sodic and alkaline soil but intolerant to acid soils and water logging (MARCAR *et at*., 1995).

5.3 Combined soil salinity and sodicity tolerance of *Acacia ampliceps*

5.3.1 Impact on growth parameters

When salinity and sodicity are combined together, the plant suffers more than salinity but the effects are diluted when compared with sole sodicity. The specific ion effect of excessive Na is not present when plants are growing in saline environment rather only osmotic impact is faced. However, the sole negative effect of sodicity may be lessened either due to help in balancing the ionic concentrations within the plant or better physical properties of the saline sodic soil as compared to sodic one that presents worst physical condition. If the plant growth data of present study are adjudged carefully, the above reasons can be found true. The reduction in plant growth parameters (height, girth, number of leaves, branches and canopy volume) due to combined salinity and sodicity (Table 4.33 - 4.39 and Figure 5.15 – 5.19) were more at similar levels of salinity alone (Table 4.1 - 4.5) but lesser than same levels of sodicity (Table 4.17 - 4.21). The decreases for various combinations of salinity and sodicity were 16 - 64, 11 - 51, 10 - 65, 14 - 75 and 11 – 82 % in plant height, stem diameter, number of leaves, number of branches and canopy volume respectively (Table 5.3). In, general, EC_e + SAR (20 dS m^{-1} + 50 or 30 dS m^{-1} + 40) were the combined levels causing approximately 50 % growth decrease. Either higher level of EC_e with lesser SAR or lesser level of salinity with more SAR proved pronouncedly detrimental. No previous reference could be found on the effect of combined salinity and sodicity that could be quoted here.

5.3.2 Effect on root and shoot weight

Reduction in dry shoot weight ranged from 6 to 66 % for various combinations of salinity and sodicity whereas decreases in dry root weight were recorded from 17 to 61 % (Table 5.3). The roots were directly growing in different quanta of saline sodic environment. Therefore, such reductions were expected. However, these were lesser than many other plants at the similar levels that indicated the ability of *Acacia ampliceps* roots to withstand high levels of salinity + sodicity. Similarly, shoot dry weight was suppressed but its reduction magnitude was lesser than many other plants at these investigated levels indicating its high tolerance for salinity + sodicity. The growth reduction of various parameters was translated into corresponding overall decrease of shoot and root development. Hence, lesser dry weights were received over control after two years. More detailed reasons have been discussed in earlier sections. The soluble salts and Na concentration in the soil checked the water and nutrient uptake while metabolic reactions within plant were negatively affected due to saline sodic rhizosphere environment.

5.4 <u>Correlation of soil and plant growth parameters</u>

Discussion of all the previous sections indicated that soil salinity/sodicity parameters (EC_e and SAR) were correlated with plant growth parameters like height, stem diameter, new leaf bearing, number of branches and canopy volume (spread of the plant). The increase in EC_e or SAR or both (combined) resulted in checking of all the growth characters that resulted ultimately in tremendous decrease of root and shoot weights. However, a precise statistical treatment was also employed to workout exact correlation coefficient, finding their significance and computing equations to predict relations among different soil and plant growth parameters. The outcome of these efforts has been presented in figures 5.1 to 5.66. These figures also indicate the relationship between single soil characters with one plant parameter. The developed equations can also be used for prediction of any plant growth parameters quantum correlated with magnitude of soil EC_e or SAR or both combined. Such correlations equations for *Acacia ampliceps* were not already available in literature, especially for SAR and EC_e + SAR.

The correlation coefficients (R^2) values and test of significance revealed that all the plant characters were highly correlated with soil EC_e, SAR and EC_e + SAR (Table 5.1). This correlation was negative indicating that increase in EC_e or SAR will result in decrease of plant growth parameters.

Field data of study-2 (Table 4.49) also supported the correlations developed from pot study (referred above); it was observed that plants were poor in growth where soil salinity + sodicity were high. The medium condition was correlated with moderate salinity/ sodicity values whereas good condition plants were found on sites that were having slight problem. These observations were started with plants of 3.5 years and continued when plants became of 5 years age. Thus, the observed correlation persisted so long although values of soil parameters decreased consistently (Table 4.50 – 4.52 and Figure 5.67–5.78) with the age of plants (and under influence of other factors being discussed in a subsequent section) but the original growth differences could not be covered up later on. NASIM (1998) also reported that soil SAR and pH had significantly negative correlation with all the growth parameters of *Eucalyptus camaldulensis*.

5.5 Impact of growing *Acacia ampliceps* on soil improvement

Growing of any plant or crop in salt affected lands also improves soil conditions. The impaired physical properties are regenerated. Infiltration rate, permeability, bulk density, porosity and hydraulic conductivity significantly become better. Resultantly, leaching of salts is eased and removal of salts occurs. The causes of these betterment are addition of organic matter from plant residues, subsequent and consistent decomposition of the added organic matter, release of organic acids and acid forming materials, replacement of Na from the clay complex by produced H and Ca ions (through reaction of organic acids with $CaCO_3$ of calcareous soil), root action enhances microbial activity, soil granulation and opening as well as widening of closed pores (in case of dispersed soil). Thus, long term effect of planting and cropping is highly positive. Soils are gradually improved in chemical and physical characteristics. Data of study- 2 also revealed such effects (Table 4.50-4.52 and Figure 5.67–5.78). Soil EC_e, pH and SAR all decreased consistently for 5 years. The values recorded at the time of starting this study (Plants of 3.5 years age) were far lesser than that when the plants were transplanted. The trend of decrease continued consistently in the next 1.5 years unless plants became of 5 years and the study was terminated. The starting EC_e (0-15 cm) was 18.29, 14.44 and 12.29 dS m^{-1} in case of poor, medium and good plants that was decreased to 7.56, 5.18 and 4.37 dS m^{-1} after 5 years. Hence, respective percent decreases for EC_e were 59, 64 and 65. The observed decreases in case of soil SAR were 66, 77 and 80 % under the canopy of poor, medium and good conditioned plants. This also supported the hypothesis laid out in the beginning of this section because there was more plant residue in medium and good plants that caused higher soil improvement. The positive effect penetrated in the down profile up to 150 cm. However, the impact was decreasing with depth. Results of study-3 (Table 4.66 - 4.68) also favoured of the above claim. Plants were transplanted in pits filled with same soil and the silt (alluvium) alone or coupled with gypsum or compost. Plants grew stronger and stout where a temporary relief was provided. When the original soil with very high salinity /sodicity parameters was sampled under the canopy of plants and analyzed, a decrease of 17 – 149 % in EC_e, 10 – 115 % in pH and 12 – 106 % in SAR were recorded for different treatments that affected the plant growth variably. The noticed differences were corresponding to the plant growth conditions. NASIM (1998) obtained similar results for *Eucalyptus* plants. SANDHU and HAQ (1981) claimed that *Sesbania bispinosa* could be grown for the reclamation of salt affected soils.

5.6 Leaf and root composition of *Acacia ampliceps* under various levels of salinity/sodicity

When the salinity or sodicity occurs in the soil, the root environment totally changes. There are two types of effects:

1. The osmotic pressure around the roots increases in proportion to the salt contents. Many times the outer osmotic pressure becomes more than that in the roots. The result is reduced uptake of water by the plants.

2. The balance of different ions in the rhizosphere is highly disturbed. There is excess of Na in case of sodicity. This changes the ion uptake pattern of the plant. Thus, some unwanted ions enter to plant in undesired quantities whereas the uptake of essential ions like K is reduced. The data on leaf composition in different experiments of the present studies indicated the following facts.

i. Sodium contents of older leaves were more than younger one and increased with increasing levels of salinity (EC_e), sodicity (SAR) and their combination (EC_e +SAR). Impact of SAR alone was greater. The values of this parameter were higher in poor conditioned plants as compared to plants with good growth. Quantity of Na in roots also increased with increasing EC_e, SAR and EC_e + SAR levels.

ii. Potassium contents of older leaves were estimated on lower side compared with younger leaves that decreased with increasing magnitude of EC_e, SAR and EC_e + SAR. Healthy plants were containing more K in their leaves. There was decrease in K concentration in roots but with lesser quantum.

iii. Concentration of Ca was higher in older leaves and significantly decreased with an increase of EC_e, SAR and EC_e + SAR. Similar was the trend in roots. Plant health and growth was related with more Ca contents.

iv. There was a decrease in Mg contents of leaves and roots with increasing stress of any type of salt. Older and younger leaves did not vary much.

v. The ratio of K: Na was more in leaves and roots without stress but change in salt contents of rhizosphere narrowed down this important parameter.

Plants having salt tolerance in their genetic make up exercise ion selectivity even under saline/sodic environment while sensitive plants allow free entry and suffer after influx of undesired ions. Concentration of Na in soil solution more than K affects the plant uptake under saline sodic or sodic environment. The high K/Na selectivity is maintained provided Ca is adequate (CARTER, 1983 and SUBBORAO *et al.,* 1990). Despite plant's high affinity for K over Na, the K status in plants is related to the ratio of Na/K in the saturated soil extract (DEVITT *et al.,* 1981). When different EC_e, SAR and EC_e + SAR were correlated with leaf and root ion concentration, these were found significant. The correlations of salinity/sodicity parameters were positive with leaf and root Na but negative in case of K, Ca, Mg and K: Na ratio (Table 5.8 - 5.10 and Figure 5.22 – 5.66). It may be pointed out that plant Na is not correlated with soil EC_e and SAR when the soil levels of these parameters are low but these are highly correlated when the values exceed a level particular for a plant. Hence, a plant up to a specified limit can exert ion selectivity. Above this limit, this character of plant is lost and Na can enter the roots freely.

5.7 <u>Physiological basis of salt tolerance of *Acacia ampliceps*</u>

There are two different aspects of physiological basis in salt tolerant studies; how the salinity/sodicity affects the plants (mechanism of salt stress) and through what physiological ways the plants manage to survive and tolerate (mechanism of salt tolerant). The mechanism of salt stress is mostly common in almost all the plants while mechanism of salt tolerant vary from plant to plant. These two mechanisms, with reference to *Acacia ampliceps*, are being discussed separately on the basis of collected data in these investigations.

5.7.1 Mechanism of salt stress in *Acacia ampliceps*

Generally four major mechanisms of salt stress are found in plants. These are reduction in uptake of water and nutrients, specific ion effect, imbalanced nutrition and indirect effects through soil (retarded root development, root aeration, ponding of water, hardness of soil etc.). Still other effects like breaking of plasma membrane of root and ultra structures within the cells even changes in DNA can occur. However, recorded data proved two types of physiological mechanisms while data on other aspects were not part of the planned studies.

5.7.1.1 Osmotic effect

Water could not enter the roots and translocated through xylem tissues to the upper parts. Resultantly, the water contents in the roots and shoot were recorded to be lesser in stressed plants compared with unstressed (control) when the plants were harvested after two years. Moisture percentage of shoot decreased from 52 to 37 when soil EC_e level was increased to 50 dS m^{-1} (Table 4.6) whereas, it was suppressed to 20 % for the same level in roots against 33 % in the absence of any stress (Table 4.7). The same level of SAR (50) decreased moisture from 52 (shoot) and 32 (root) to 32 and 18 % respectively (Table 4.22 and 4.23). Although uniform irrigations were applied in all the treatments yet lesser moisture contents were present in stressed plants. This indicated physiological unavailability of water to the plants. The osmotic stress reduced leaf growth and root development and decreased stomatal conductance and thereby photosynthesis (MUNNS, 1993). The rate at which new leaves are produced depends largely on the water potential of the soil solution. ROBINSON *et al*. (1983) reported that salinity causes several specific structural changes that disturb plant water balance.

5.7.1.2 Specific ion effect

The restricted water uptake also retards ion uptake by plants but at the same time there is increase in Na absorption under saline or sodic environment. Thus, there is deficit for essential ions within the plant but simultaneously excess of unwanted ions especially Na occurs. Hence, there is damage to various parts and processes within the plants. However, the severity of the salt damage to plants depends upon the amount and duration of exposure and the concentration of salt. The data discussed under section on leaf and root composition clearly indicated that K, Ca and Mg decreased in the plant tissue while Na alarmingly increased with increasing levels of salinity and sodicity (Figure 5.22 - 5.66). Continued transport of salt into transpiring leaves over a longer period of time eventually results in very high Na and Cl concentrations. In acute case, the leaves may die. The scenesis of old leaves is also common when excess Na is being pushed in leaves of certain plants like *Acacia ampliceps*.

5.7.2 Mechanism of salt tolerance in Acacia ampliceps

The survival of plants in salt stressed environment is classified into avoidance and tolerance. Avoidance involves escaping from the stress. Plants exercising avoidance adjust their life cycle and try to complete it in short period under stressed conditions. Such a mechanism was not observed in *Acacia ampliceps* during these studies. Salt tolerance denotes as the ability of plant to grow and complete normal life cycle on saline substrate that contains high concentration of salts, mainly NaCl but some times also other salts including calcium and sulphates (JESCHKE, 1984). The salt tolerance may be through morphological, anatomical or physiological mechanisms. The first two were not planned to investigate but collected data cleared some aspects of the physiological mechanisms in *Acacia ampliceps*. The ability of a plant to regulate the influx of salts is one of the major mechanisms (GORHAM, 1996) and is called physiological mechanism that totally depends upon the genetic make up of a plant. The identified physiological mechanisms on the basis of collected data are described as under:-

5.7.2.1 Ion selectivity

One of the major physiological mechanisms is ion selectivity during absorption from the soil solution; nevertheless ion selectivity may also be exercised after influx at plasmalemma of the cortical root cells, tonoplast of the root cells, the plasmalemma of the xylem parenchyma cells and plasmalemma of the phloems (JESCHKE, 1983, 1984 and GORHAM *et al.,* 1985). Although plants having salt tolerance selectively absorb and translocate K in preference to Na, the degree of selectivities varies among species (KAFKAFI, 1984), but will also be related to the ratio of Na to K in the saturated soil extract (DEVITT *et al.,* 1981). The data of present investigation indicated that *Acacia ampliceps* has adopted ion selectivity as mechanism of salt tolerance. The values of K/Na ratio, although decreased with increasing level of salinity/sodicity but these were fair at even EC_e 50 dS m^{-1} or SAR 50 in younger leaves (Table 4.10, 4.26 and 4.42). However, in older leaves, these values were lesser indicating that more Na was pushed and concentrated in them. However, when the stresses became too severe (levels 40 and 50 of EC_e or SAR) the ion selectivity mechanism was shattered and the control of plant was lost while the K: Na values became lesser than unity.

Another fact observed in the plant under investigation was that it had very good control in absorption of Ca and Mg. Very less impact of different stresses was observed on uptake of these ions from the soil solution. This character also helped in maintaining K: Na because there are reports in literature that high K: Na selectivity in plant will be found if Ca status in the roots is adequate (CARTER, 1983; SUBBARAO *et al*., 1990).

5.7.2.2 Compartmentation

Compartmentation means concentration of unwanted ions into different organs of the plants. For example, it may be held in roots, pushed into vacuoles of cells, or older leaves. *Acacia ampliceps* exercise the mechanism of sequestering Na ions into older leaves and keeping the younger leaves (the active centers) free of concentrations that are negative or toxic to plant (Tables 4.8, 4.9, 4.24, 4.25, 4.40 and 4.41). The Na concentration of roots (Table 4.16, 4.32 and 4.48) was almost similar to older leaves but significantly lesser than younger leaves. These comparisons clearly indicated that the mechanism of compartmentation was there in *Acacia ampliceps*. MUNNS, 2002 reported that high concentration of Na in leaves up to 100 mM did not severely affect the normal functioning of leaves above which death of leaves may occur. Less number of leaves was observed (Table 4.3, 4.19 and 4.35) at higher levels of salts in the soil indicating scenesis of older leaves that were leaving (felling) the plants and removing excess salts.

5.8 Appropriate transplantation techniques for *Acacia ampliceps* saplings

The environment of soil where the young plants are to be transplanted is very harsh when there are high levels of salinity or sodicity or both combine together. The saplings are not hardy to withstand such hard conditions of rhizosphere and it becomes very difficult for them to establish there. Therefore, it is appreciable if some techniques be adopted that can provide some relief to the young seedling until they become hard and bring in the tolerance against salinity and sodicity. The best strategy may be digging out the original salt affected soil and filling the pit with good soil or silt alone or mixed with some amendment (gypsum or compost). This may provide the relief to the young plants. The roots will neither meet suddenly the hard conditions nor do they suffer osmotic effects and aeration. Roots can also develop well. Such effects were observed in this investigation. Many plants could not survive the saline sodic environment of the salt affected field when these were transplanted in the prevailing condition without any improved technique. However, when improved techniques were used during transplantation, very good growth data was recorded (Table 5.5, Figure 5.109 and 5.110) whereas no positive effect of filling the pit with the same soil was observed. The combination of original soil with gypsum or compost was also inferior. Whereas, filling of pit with silt alone or combined with compost remained as the best strategies. Silt (fresh alluvium soil) is the material that has low exchange capacity; therefore, less chances of dispersion with excessive Na and the pores are kept opened for root development. The rate of penetration of negative effect of surrounding salts was found to be slow. Its mixing with compost further improved the positive effects by providing nutrients and H to neutralize Na effects. That is why the plants became bushes within two years (see the photographs). The later negative effects could not harm the plants. Application of compost alone or gypsum was not comparable with the combination with silt because these could not provide the buffer zone for longer periods. The improved transplantation techniques for plants other than *Acacia ampliceps* also proved useful (GREWAL and ABROL, 2006; MEHDI *et al*., 2004; MINHAS *et al*., 2006).

5.9 Economics and adaptability of evolved technologies

Strongly salt-affected soils are usually left uncultivated that become barren with passage of time because there is further degradation under this situation. Farmers are not receiving anything from these lands. If they plant 4 hectares of *Acacia ampliceps* as perennial bush and one hectare of seasonal fodder (Alfalfa, sesbania, maize + pearl millet + small millet) to supplement feeding, they can rear 100 heads of goats successfully (ASLAM *et al*., 2006). This can bring the owner an additional annual income from salt-affected land that was to be kept fallow and barren (Table 5.4). This is very attractive income for the farmers. This also denotes the practical importance of the investigation and chances of its adaptability. Hence, it is quite clear that the investigated techniques has direct relevance to the farming community and can safely be recommended for management of salt-affected lands with significant envisaged income.

Table 5.1: Percent decrease of growth parameters over control after two years due to salinity (Expt. – 1, Study – 1)

Salinity levels EC_e ($dS\ m^{-1}$)	Plant Height	Stem Diameter	No. of Leaves $Plant^{-1}$	No. of Branches $Plant^{-1}$	Canopy Volume	Shoot Weight	Root Weight
Control	-	-	-	-	-	-	-
10	13	8	7	16	11	5	15
20	20	17	17	30	22	6	22
30	29	26	27	48	28	16	29
40	45	42	43	68	57	37	46
50	60	57	68	77	80	52	60

Table 5.2: Percent decrease of growth parameters over control after two years due to sodicity (Expt. – 2, Study – 1)

Sodicity levels SAR $(mmol\ L^{-1})^{1/2}$	Plant Height	Stem Diameter	No. of Leaves $Plant^{-1}$	No. of Branches $Plant^{-1}$	Canopy Volume	Shoot Weight	Root Weight
Control	-	-	-	-	-	-	-
20	18	13	8	30	15	3	20
30	32	25	20	48	38	18	34
40	51	43	48	63	77	53	52
50	86	78	85	87	90	70	66

Table 5.3: Percent decrease of growth parameters over control after two years due to salinity + sodicity (Expt. – 3, Study – 1)

Salinity + sodicity levels (EC_e + SAR)	Plant Height	Stem Diameter	No. of Leaves $Plant^{-1}$	No. of Branches $Plant^{-1}$	Canopy Volume	Shoot Weight	Root Weight
Control	-	-	-	-	-	-	-
10 + 30	16	11	10	14	11	6	17
10 + 40	23	15	12	16	20	12	21
10 + 50	29	22	23	36	31	17	28
20 + 30	29	19	21	32	30	14	28
20 + 40	36	23	28	43	39	23	35
20 + 50	48	29	40	57	54	36	45
30 + 30	44	24	37	66	53	36	44
30 + 40	55	38	50	70	73	50	56
30 + 50	64	51	65	75	82	66	61

Table 5.4: Economic calculations of growing *Acacia ampliceps* on 4 hectares salt-affected land and rearing goats (100 heads)

Sr. No.	Item/operation	Price in Rupees	Price in Euro (€)
1	Land leveling, Cultivation, Making of furrows and pits	31000.00	387.50
2	Filling of pits with silt, compost and gypsum etc.	25000.00	312.50
3	Irrigation, water charges, fertilizer, weeding and fungicide for 5 years (156.25 € per annum)	62500.00	781.25
4	Price of seasonal fodders (one ha) to supplement feeding for 5 years	200000.00	2500.00
5	Sub total (Cost of fodder production for 100 heads for 5 years)	**318500.00**	**3981.25**
6	Price of 100 head of goats (6 months aged)	350000.00	4375.00
7	Construction of sheds and structures	150000.00	1875.00
8	Labour, medicines and other care (5 years)	700000.00	8750.00
9	Sub total (Total costs)	**1518500.00**	**18981.25**
10	Income from selling of goats (after five years)	3400000.00	42500.00
11	Net income for 5 years from 4 ha	**1881500.00**	**23518.75**
12	Annual net income from 4 ha	376300.00	4703.75
13	Annual income from one ha salt-affected land	**94080.00**	**1175.94**

Note: Cost of depreciation and interest were not included in these calculations.

Table 5.5: Percent increase of growth parameters over control after two years due to various transplantation techniques in study -3

Treatments	Plant Height	Stem Diameter	No. of Leaves Plant^{-1}	No. of Branches Plant^{-1}	Canopy Volume
T1- Control (flat sowing)	-	-	-	-	-
T2- Transplantation in pit filled with original soil	211	235	122	208	279
T3- Transplantation in pit filled with silt	909	1324	1009	631	3779
T4- Transplantation in pit filled with silt + augering	991	1400	1085	823	4585
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	766	1090	827	362	2559
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	660	749	677	269	1946
T7- Transplantation in pit filled with silt + compost (20 : 1)	1271	2074	1563	1092	5734
T8- Transplantation in pit filled with original soil + Compost (20:1)	854	1151	911	400	3100

Table 5.6: Percent decrease in soil characteristics over control after two years due to various transplantation techniques in study -3

Treatments	Soil EC_e (dS m^{-1})	Soil pH	Soil SAR (mmol L^{-1})$^{1/2}$
T1- Control (flat sowing)	-	-	-
T2- Transplantation in pit filled with original soil	17	10	12
T3- Transplantation in pit filled with silt	93	46	70
T4- Transplantation in pit filled with silt + augering	110	51	82
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	80	49	67
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	60	61	42
T7- Transplantation in pit filled with silt + compost (20 : 1)	149	115	106
T8- Transplantation in pit filled with original soil + Compost (20:1)	86	51	60

Table 5.7: Correlation coefficient (R^2) between soil characteristics and growth parameters of *Acacia ampliceps* after two years in study -1

	Plant Height	Stem Diameter	No. of Leaves	No. of Branches	Canopy Volume	Shoot Weight	Root Weight
Soil ECe ($dS\ m^{-1}$)	-0.9885 **	-0.9842 **	-0.9570 **	-0.9928 **	-0.9434 **	-0.9010 **	-0.9772 **
Soil SAR ($mmol\ L^{-1})^{1/2}$	-0.9625 **	-0.9513 **	-0.9264 **	-0.9778 **	-0.9773 **	-0.9369 **	-0.9936 **
Soil EC_e + SAR	-0.9546 **	-0.8564 **	-0.9504 **	-0.9705 **	-0.9709 **	-0.9212 **	-0.9592 **

Table 5.8: Correlation coefficient (R^2) between soil characteristics and older leaves composition of *Acacia ampliceps* after two years in study -1

	Na	K	Ca	Mg	K: Na ratio
Soil ECe ($dS\ m^{-1}$)	+0.9598 **	-0.9862 **	-0.9593 **	-0.9830 **	-0.8674 *
Soil SAR ($mmo\ L^{-1})^{1/2}$	+0.9812 **	-0.9810 **	-0.8470 *	-0.9322 **	-0.8185 *
Soil EC_e + SAR	+0.8729 **	-0.8965 **	-0.7812 *	-0.7797 *	-0.6497 *

Table 5.9: Correlation coefficient (R^2) between soil characteristics and younger leaves composition of *Acacia ampliceps* after two years in study -1

	Na	K	Ca	Mg	K: Na ratio
Soil ECe ($dS\ m^{-1}$)	+0.9805 **	-0.8740 **	-0.9309 **	-0.9845 **	-0.8672 **
Soil SAR ($mmol\ L^{-1})^{1/2}$	+0.9766 **	-0.9820 **	-0.7909 *	-0.9528 **	-0.8091 **
Soil EC_e + SAR	+0.8999 **	-0.8977 **	-0.8047 **	-0.8320 **	-0.7794 *

Table 5.10: Correlation coefficient (R^2) between soil characteristics and root composition of *Acacia ampliceps* after two years in study -1

	Na	K	Ca	Mg	K: Na ratio
Soil ECe ($dS\ m^{-1}$)	+0.9802 **	-0.9799 **	-0.9743 **	-0.9646 **	-0.8680 *
Soil SAR ($mmol\ L^{-1})^{1/2}$	+0.9888 **	-0.9712 **	-0.9614 **	-0.8743 **	-0.8794 *
Soil EC_e + SAR	+0.8958 **	-0.9376 **	-0.8680 **	-0.8354 **	-0.7136 *

Table 5.11: Correlation coefficient (R^2) between soil characteristics and growth parameters of *Acacia ampliceps* in study -2

	Plant Height	Stem Diameter	No. of Branches	Canopy Volume
Soil EC_e ($dS\ m^{-1}$)	-0.7113 **	-0.5891 *	-0.6669 *	-0.5777 *
Soil pH	-0.6025 *	-0.6669 *	-0.5669 *	-0.5854 *
Soil SAR ($mmol\ L^{-1})^{1/2}$	-0.6160 *	-0.5686 *	-0.5868 *	-0.5812 *

Table 5.12: Correlation coefficient (R^2) between soil characteristics and older leaves composition of *Acacia ampliceps* in study -2

	Na	K	Ca	Mg	K: Na ratio
Soil EC_e ($dS\ m^{-1}$)	+0.1973 NS	-0.7632 **	-0.7896 **	-0.6054 *	-0.5875 *
Soil pH	+0.1326 NS	-0.6912 **	-0.6832 *	-0.5373 *	-0.5640 *
Soil SAR ($mmol\ L^{-1})^{1/2}$	+0.1699 NS	-0.6846 **	-0.7090 **	-0.5740 *	-0.5682 *

Table 5.13: Correlation coefficient (R^2) between soil characteristics and younger leaves composition of *Acacia ampliceps* in study -2

	Na	K	Ca	Mg	K: Na ratio
Soil EC_e ($dS\ m^{-1}$)	+0.0779 NS	-0.7685 **	-0.7322 **	-0.6854 **	-0.6294 *
Soil pH	+0.0284 NS	-0.6860 **	-0.6326 *	-0.5542 *	-0.6331 *
Soil SAR ($mmol\ L^{-1})^{1/2}$	+0.0492 NS	-0.6907 **	-0.6514 *	-0.6073 *	-0.6683 *

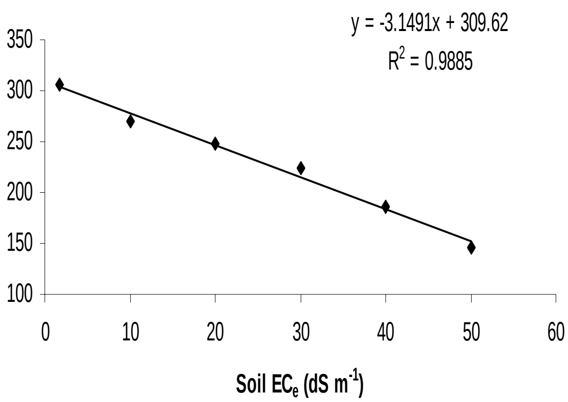


Figure 5.1: Correlation between soil EC_e and plant height (cm) after two years in study -1

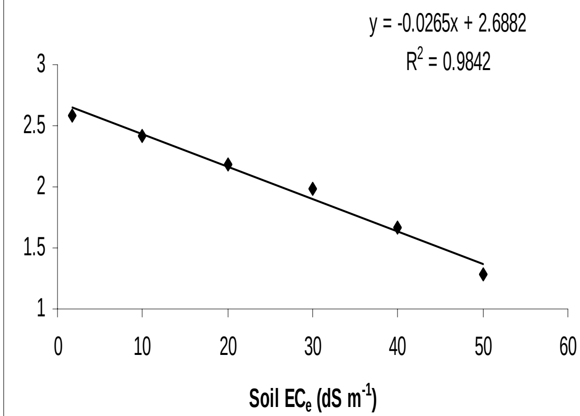


Figure 5.2: Correlation between soil EC_e and stem diameter (cm) after two years in study -1

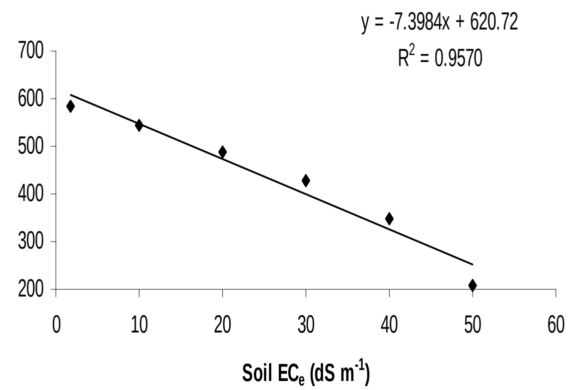


Figure 5.3: Correlation between soil EC_e and No. of leaves $plant^{-1}$ after two years in study -1

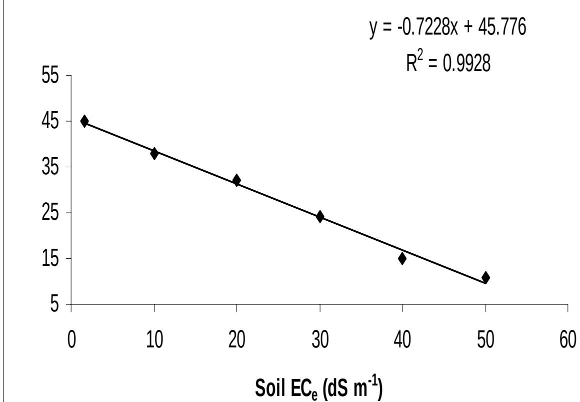


Figure 5.4: Correlation between soil EC_e and No. of branches $plant^{-1}$ after two years in study -1

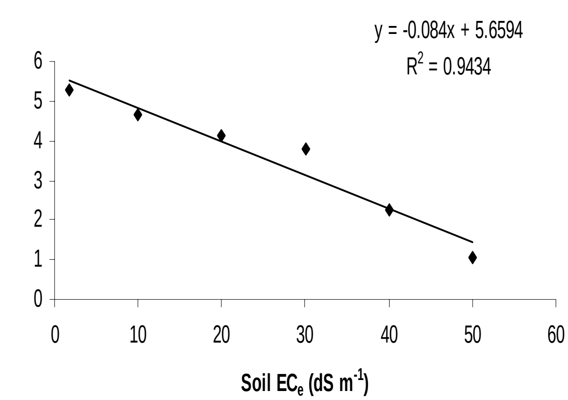


Figure 5.5: Correlation between soil EC_e and canopy volume(m^3) after two years in study -1

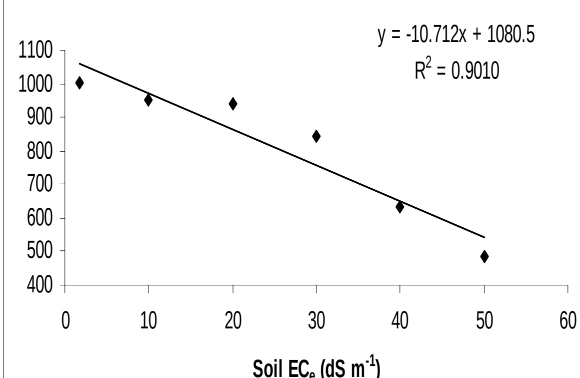


Figure 5.6: Correlation between soil EC_e and oven dry shoot wt. (g $plant^{-1}$) after two years in study -1

Figure 5.7: Correlation between soil EC_e and oven dry root wt. (g plant^{-1}) after two years in study -1

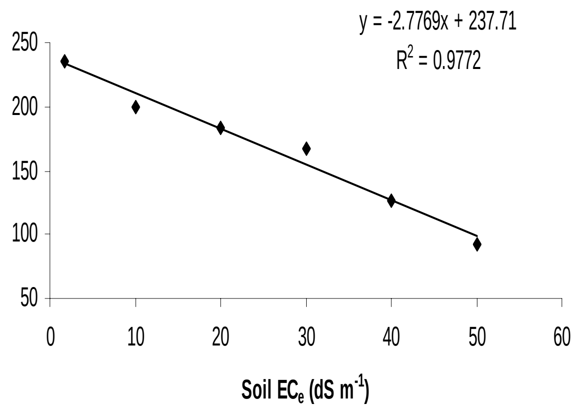


Figure 5.8: Correlation between soil SAR and plant height (cm) after two years in study -1

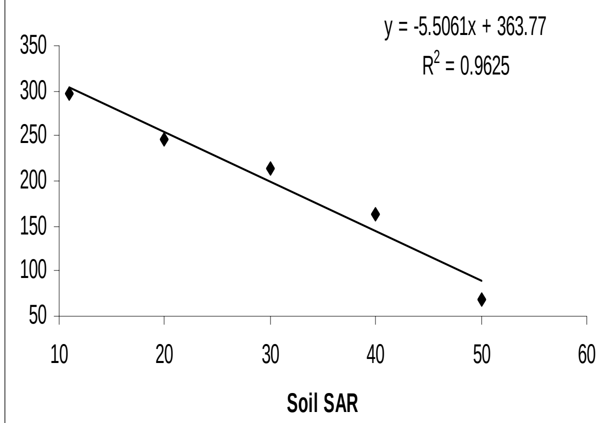


Figure 5.9: Correlation between soil SAR and stem diameter (cm) after two years in study -1

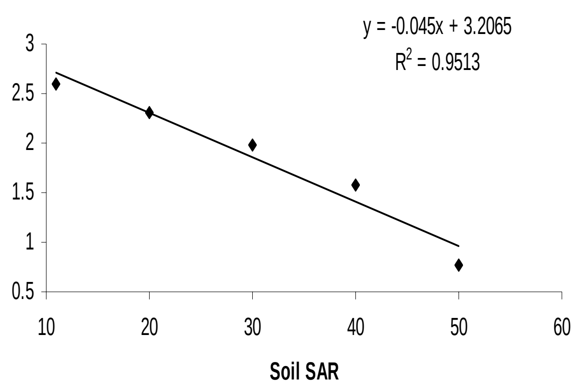


Figure 5.10: Correlation between soil SAR and No. of leaves plant^{-1}after two years in study -1

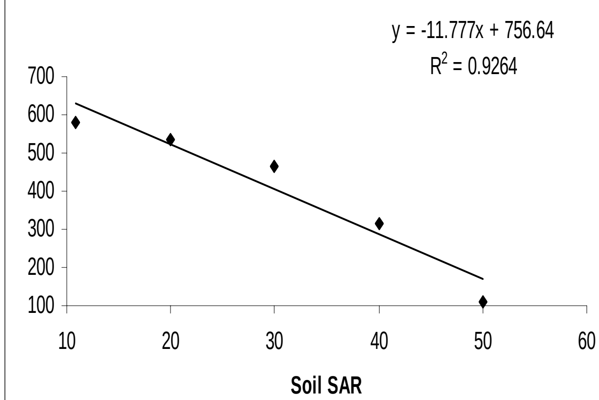


Figure 5.11: Correlation between soil SAR and No. of branches plant^{-1} after two years in study -1

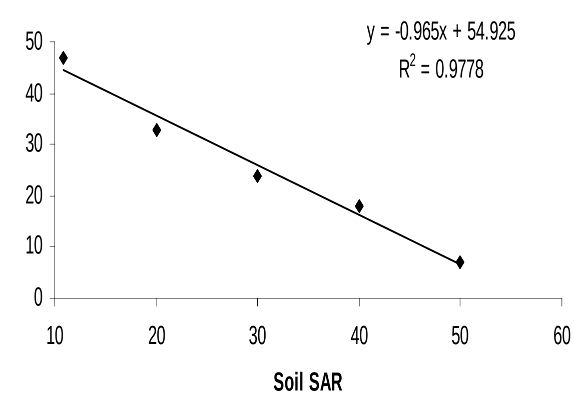


Figure 5.12: Correlation between soil SAR and canopy volume(m^3) after two years in study -1

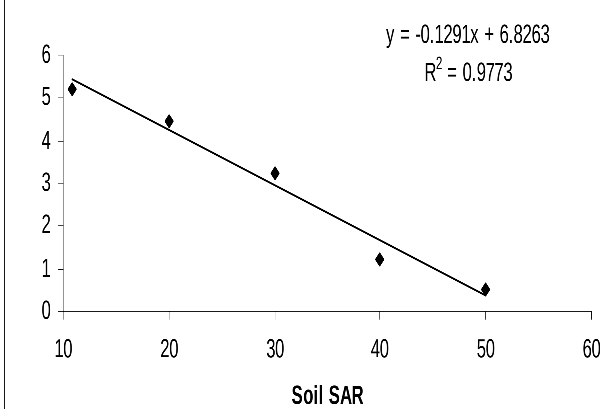


Figure 5.13: Correlation between soil SAR and oven dry shoot wt. (g plant^{-1}) after two years in study -1

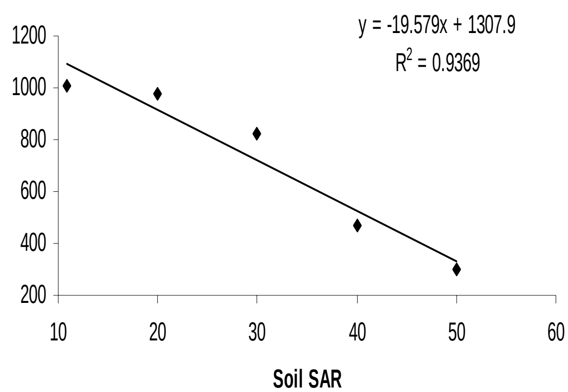


Figure 5.14: Correlation between soil SAR and oven dry root wt. (g plant^{-1}) after two years in study -1

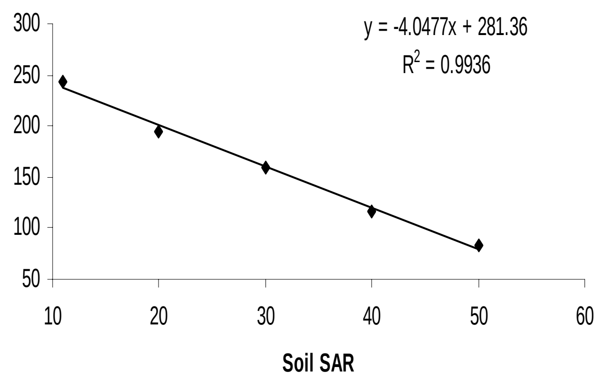


Figure 5.15: Correlation between soil EC_e + SAR and plant height (cm) after two years in study -1

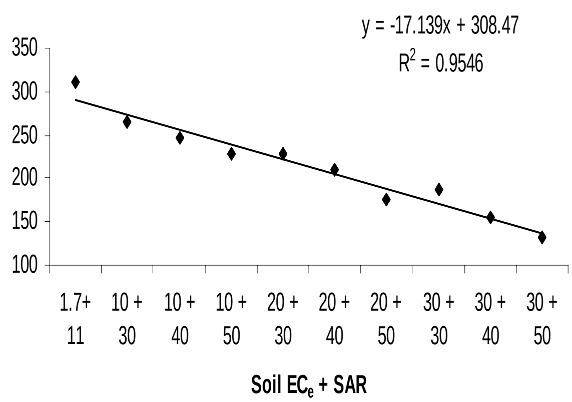


Figure 5.16: Correlation between soil EC_e + SAR and stem diameter (cm) after two years in study -1

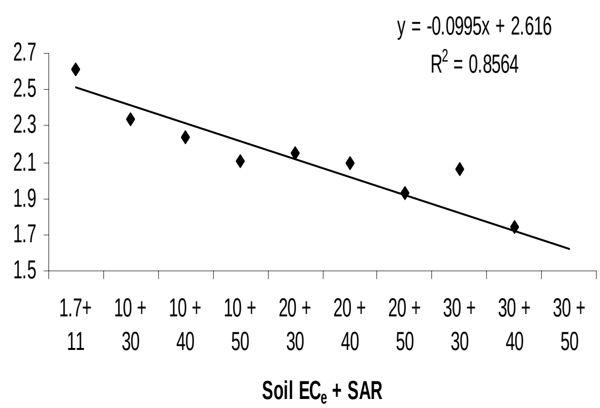


Figure 5.17: Correlation between soil EC_e + SAR and No. of leaves plant^{-1}after two years in study -1

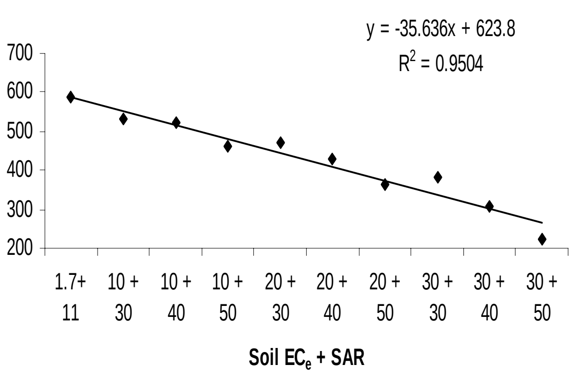


Figure 5.18: Correlation between soil EC_e + SAR and No. of branches plant^{-1}after two years in study -1

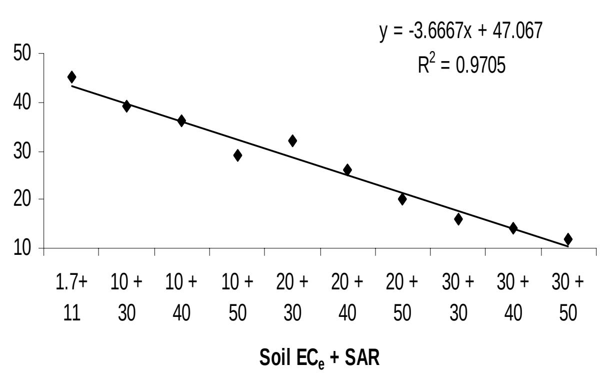


Figure 5.19: Correlation between soil EC_e + SAR and canopy volume (m^3) after two years in study -1

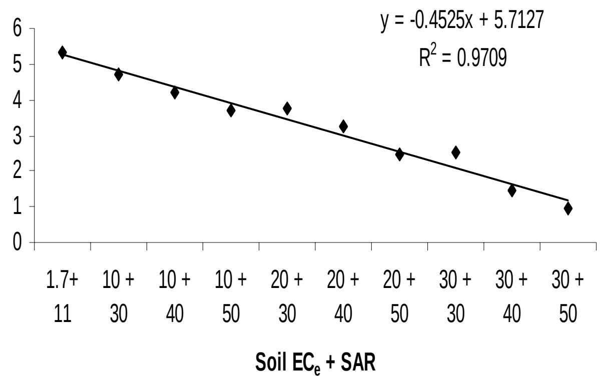


Figure 5.20: Correlation between soil EC_e + SAR and oven dry shoot wt. (g $plant^{-1}$) after two years in study -1

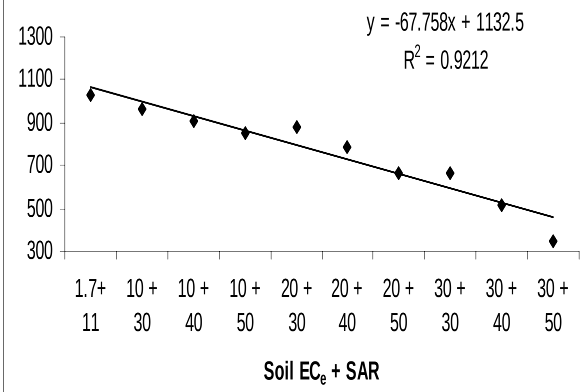


Figure 5.21: Correlation between soil EC_e + SAR and oven dry root wt. (g $plant^{-1}$) after two years in study -1

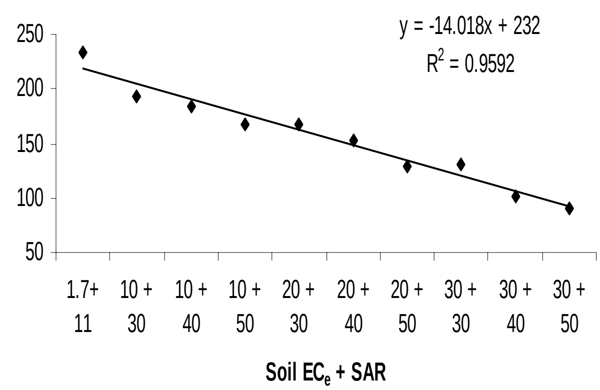


Figure 5.22: Correlation between soil EC_e and Na conc. (g kg^{-1}) in older leaves after two years in study -1

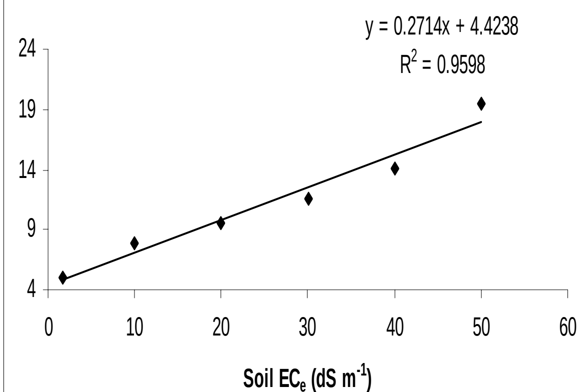


Figure 5.23: Correlation between soil EC_e and K conc. (g kg^{-1}) in older leaves after two years in study -1

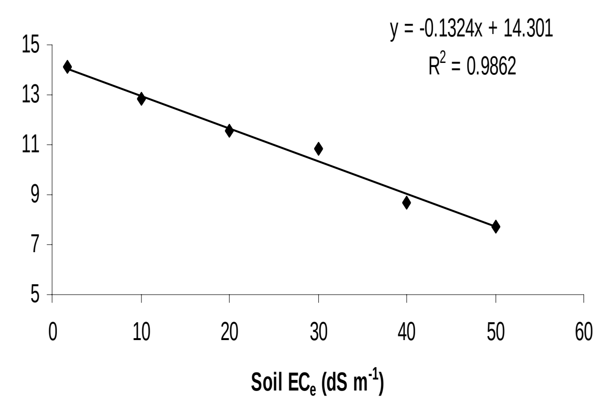


Figure 5.24: Correlation between soil EC_e and Ca conc. (g kg^{-1}) in older leaves after two years in study -1

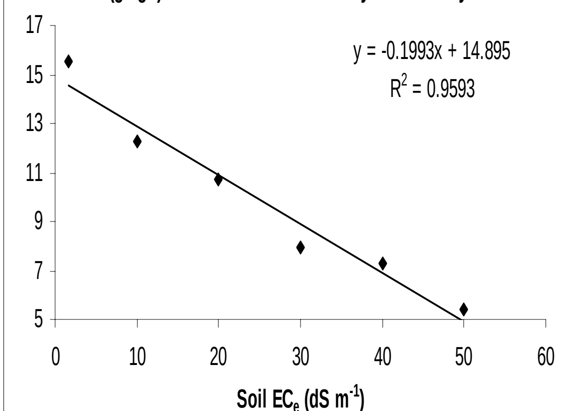


Figure 5.25: Correlation between soil EC_e and Mg conc. (g kg^{-1}) in older leaves after two years in study -1

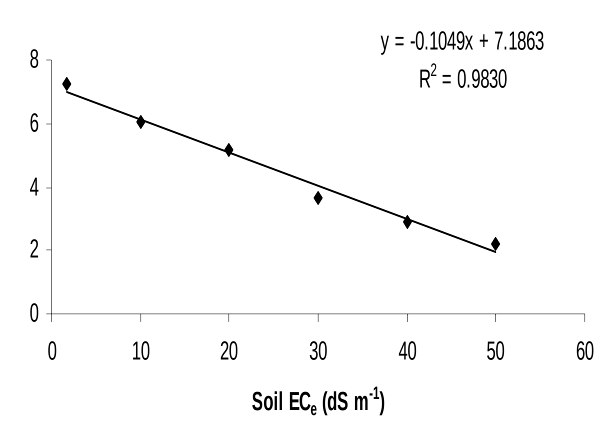


Figure 5.26: Correlation between soil EC_e and K/Na ratio in older leaves after two years in study -1

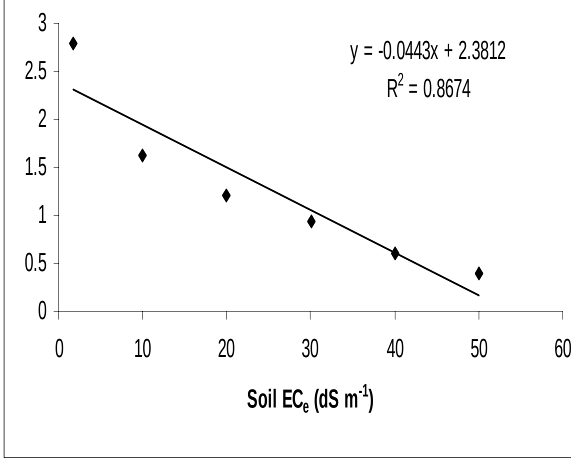


Figure 5.27: Correlation between soil SAR and Na conc. (g kg^{-1}) in older leaves after two years in study -1

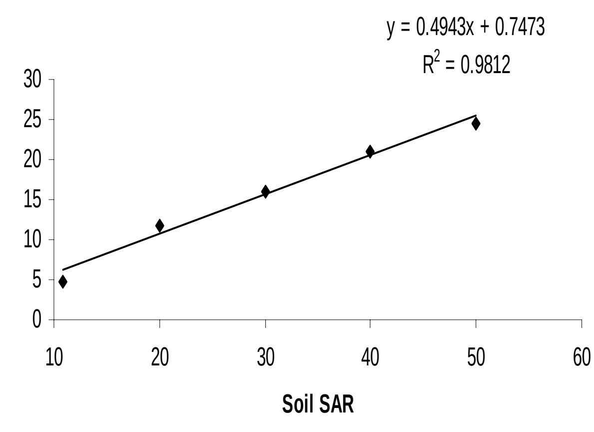


Figure 5.28: Correlation between soil SAR and K conc. (g kg-1) in older leaves after two years in study -1

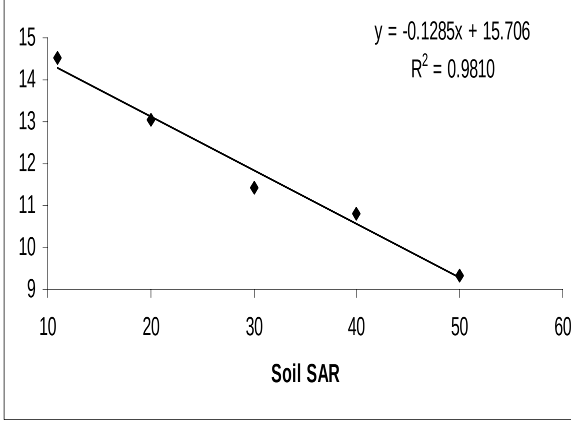


Figure 5.29: Correlation between soil SAR and Ca conc. (g kg^{-1}) in older leaves after two years in study -1

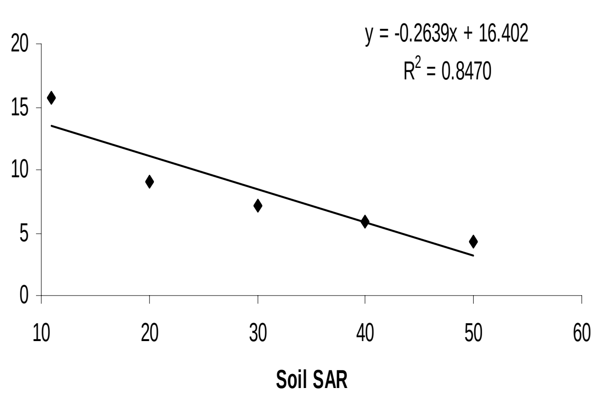


Figure 5.30: Correlation between soil SAR and Mg conc. (g kg^{-1}) in older leaves after two years in study -1

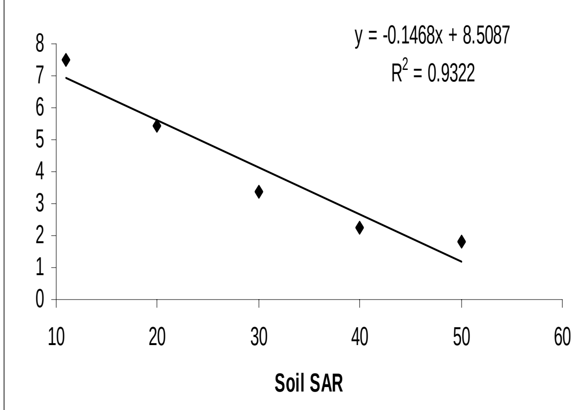


Figure 5.31: Correlation between soil SAR and K/Na ratio in older leaves after two years in study -1

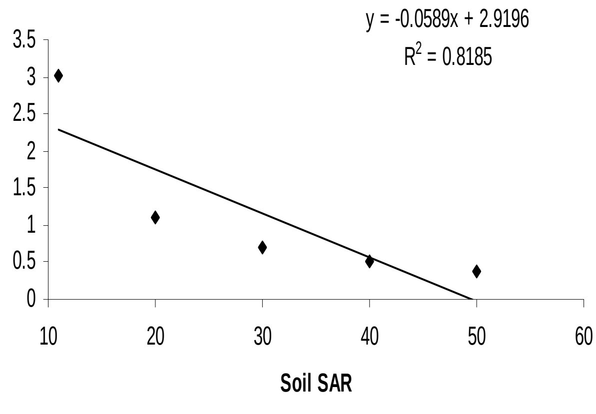


Figure 5.32: Correlation between soil EC_e + SAR and Na conc. (g kg^{-1}) in older leaves after two years in study -1

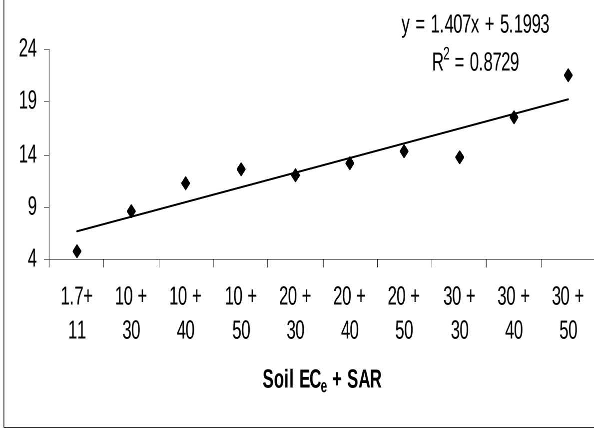


Figure 5.33: Correlation between soil EC_e + SAR and K conc. (g kg^{-1}) in older leaves after two years in study -1

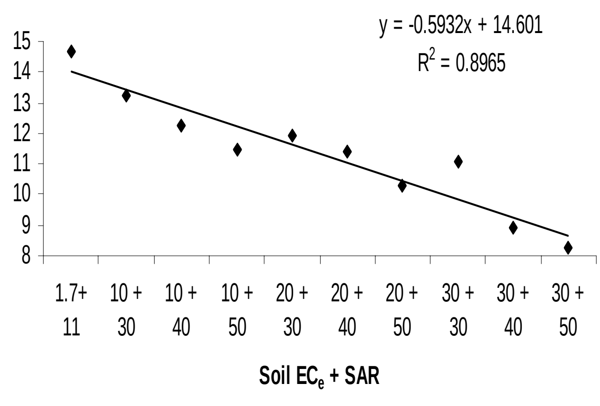


Figure 5.34: Correlation between soil EC_e + SAR and Ca conc. (g kg^{-1}) in older leaves after two years in study -1

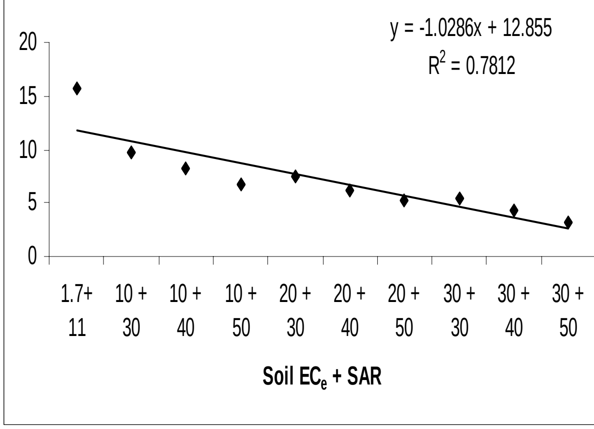


Figure 5.35: Correlation between soil EC_e + SAR and Mg conc.(g kg^{-1}) in older leaves after two years in study -1

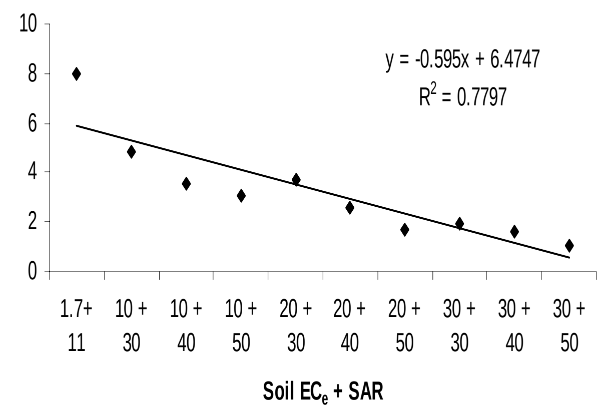


Figure 5.36: Correlation between soil EC_e + SAR and K/Na ratio in older leaves after two years in study -1

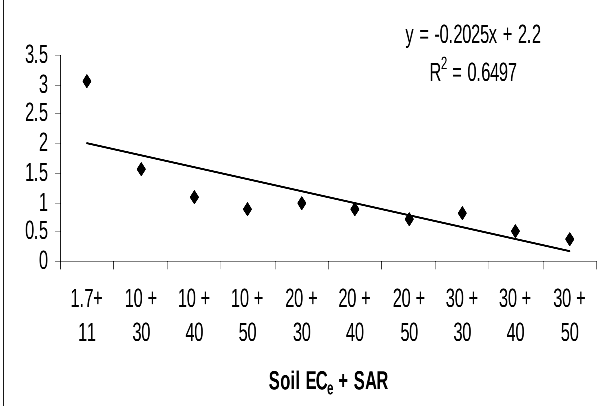


Figure 5.37: Correlation between soil EC_e and Na conc. ($g\ kg^{-1}$) in roots after two years in study -1

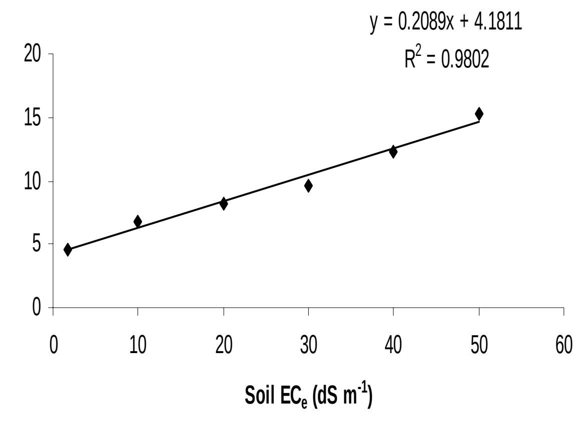


Figure 5.38: Correlation between soil EC_e and K conc. ($g\ kg^{-1}$) in roots after two years in study -1

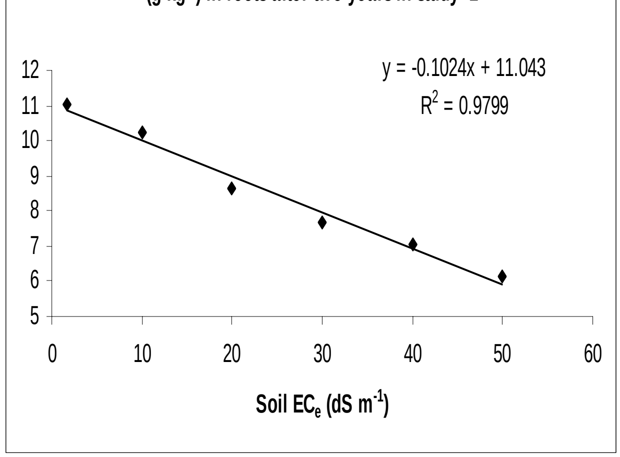


Figure 5.39: Correlation between soil EC_e and Ca conc. ($g\ kg^{-1}$) in roots after two years in study -1

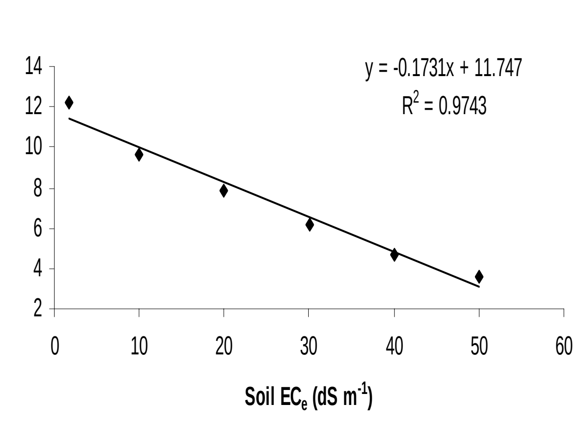


Figure 5.40: Correlation between soil EC_e and Mg conc. ($g\ kg^{-1}$) in roots after two years in study -1

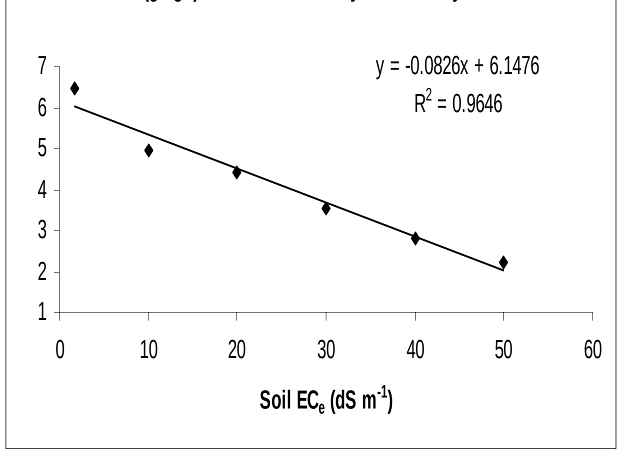


Figure 5.41: Correlation between soil EC_e and K/Na ratio in roots after two years in study -1

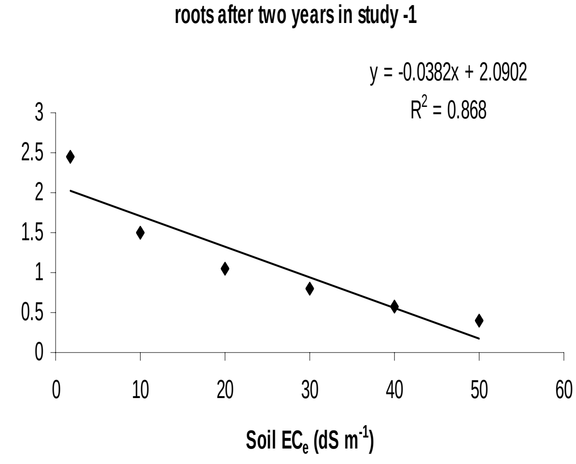
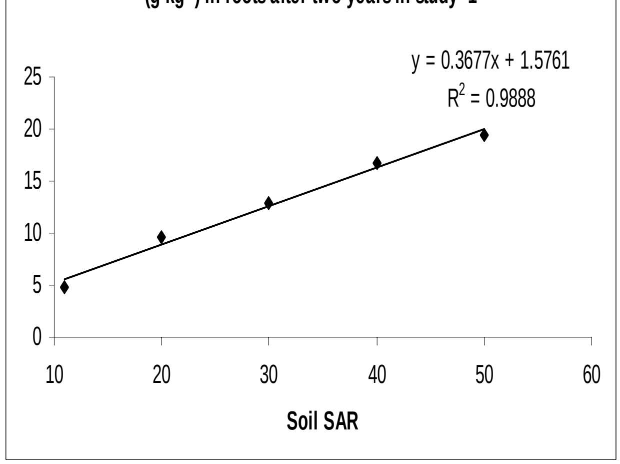


Figure 5.42: Correlation between soil SAR and Na conc. ($g\ kg^{-1}$) in roots after two years in study -1



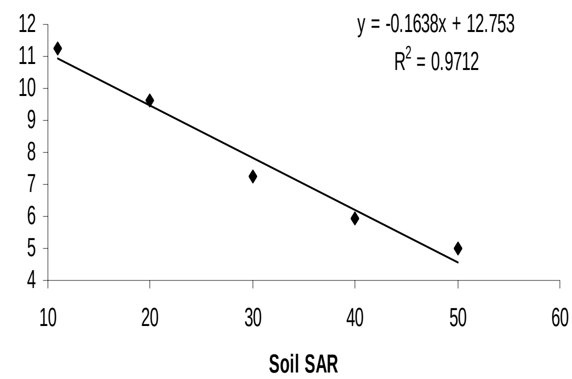


Figure 5.43: Correlation between soil SAR and K conc. (g kg^{-1}) in roots after two years in study -1

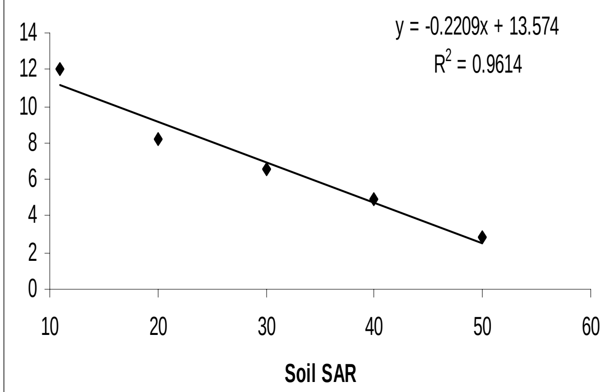


Figure 5.44: Correlation between soil SAR and Ca conc. (g kg^{-1}) in roots after two years in study -1

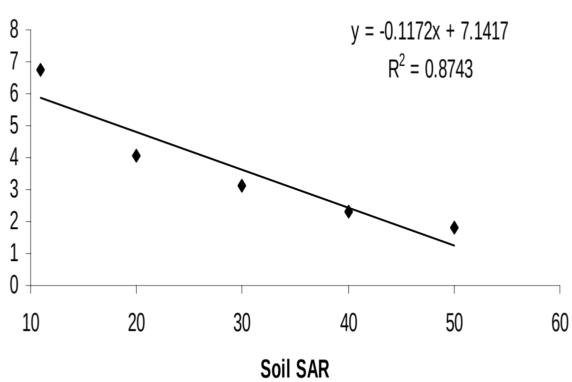


Figure 5.45: Correlation between soil SAR and Mg conc. (g kg^{-1}) in roots after two years in study -1

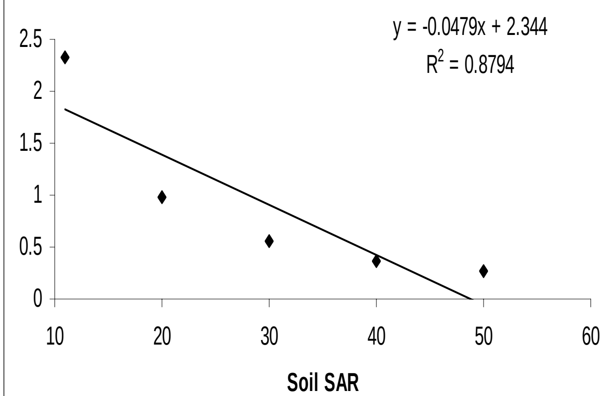


Figure 5.46: Correlation between soil SAR and K/Na ratio in roots after two years in study -1

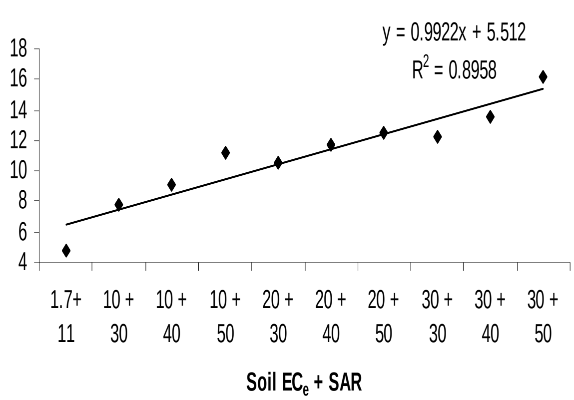


Figure 5.47: Correlation between soil EC_e + SAR and Na conc.(g kg^{-1}) in roots after two years in study -1

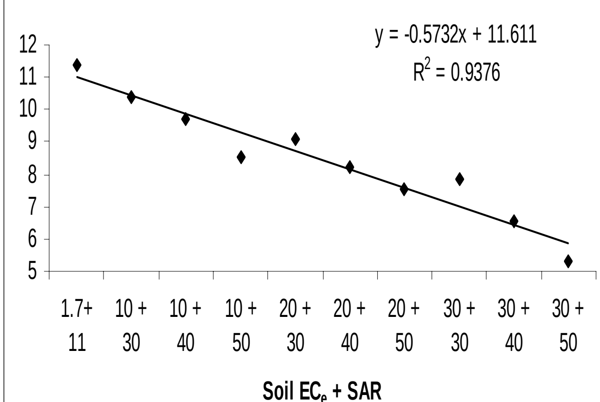


Figure 5.48: Correlation between soil EC_e + SAR and K conc.(g kg^{-1}) in roots after two years in study -1

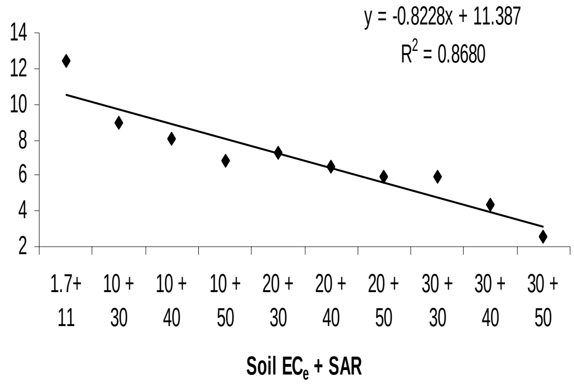


Figure 5.49: Correlation between soil EC_e + SAR and Ca conc. (g kg^{-1}) in roots after two years in study -1

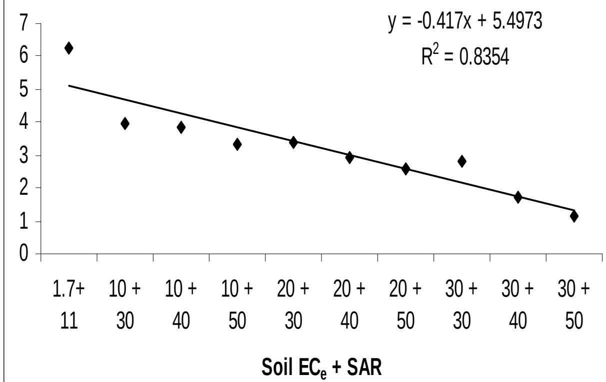


Figure 5.50: Correlation between soil EC_e + SAR and Mg conc. (g kg^{-1}) in roots after two in study -1

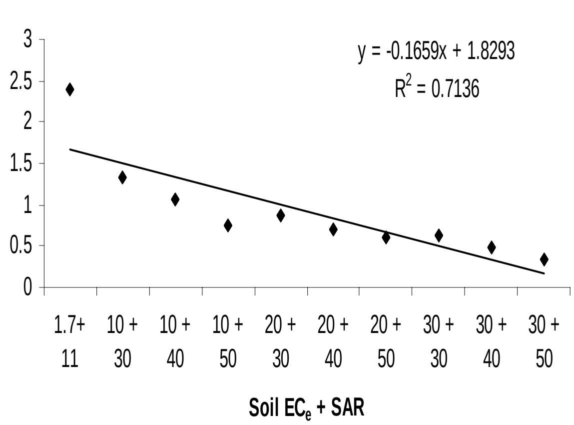


Figure 5.51: Correlation between soil EC_e + SAR and K/Na ratio in roots after two years in study -1

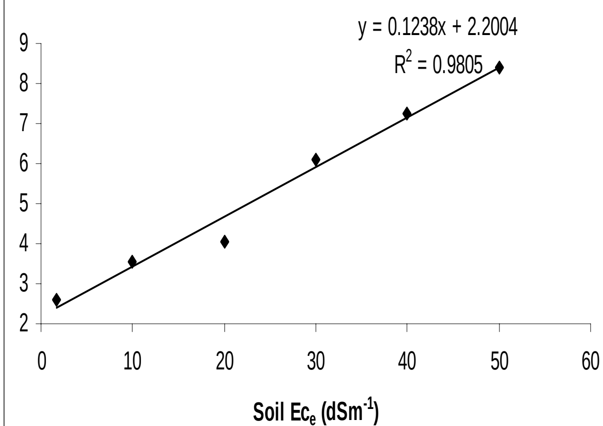


Figure 5.52: Correlation between soil EC_e and Na conc. in younger leaves after two years in study -1

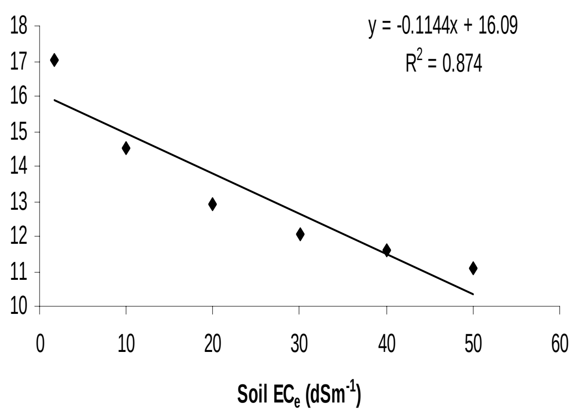


Figure 5.53: Correlation between soil EC_e and K conc. in younger leaves after two years in study -1

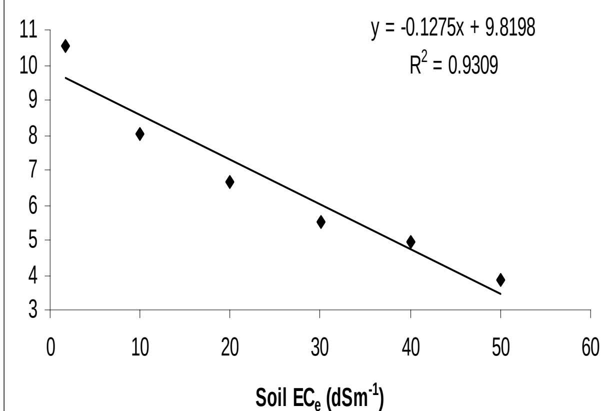


Figure 5.54: Correlation between soil EC_e and Ca conc. in younger leaves after two years in study -1

Figure 5.55: Correlation between soil EC_e and Mg conc. in younger leaves after two years in study -1

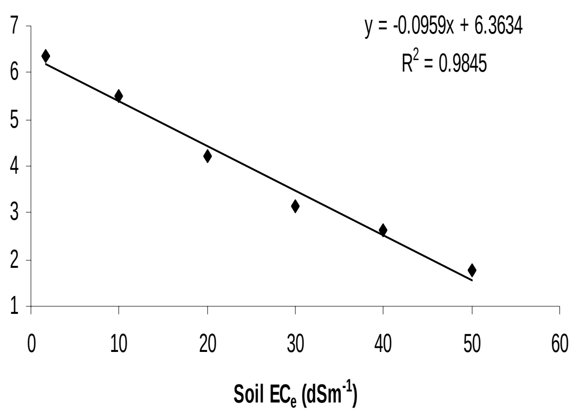


Figure 5.56: Correlation between soil EC_e and K/Na ratio in younger leaves after two years in study -1

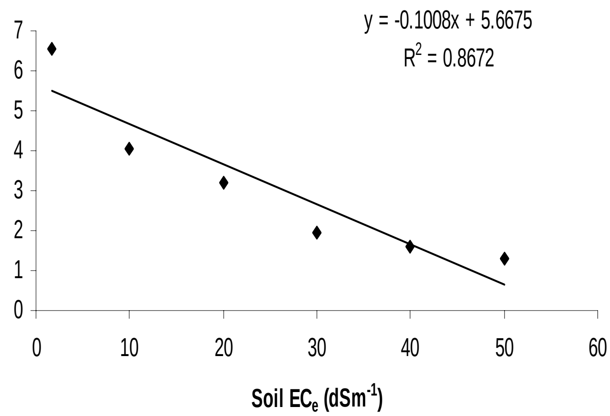


Figure 5.57: Correlation between soil SAR and Na conc. in younger leaves after two years in study -1

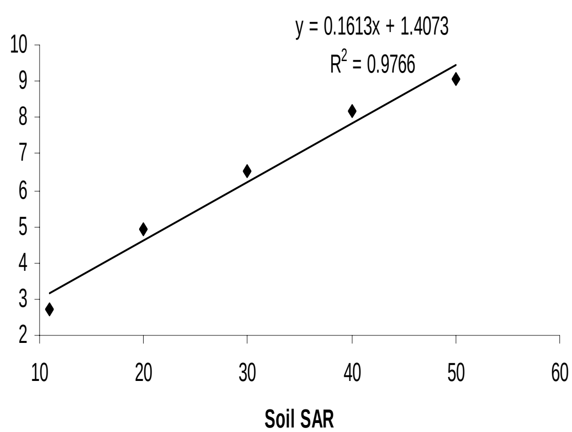


Figure 5.58: Correlation between soil SAR and K conc. in younger leaves after two years in study -1

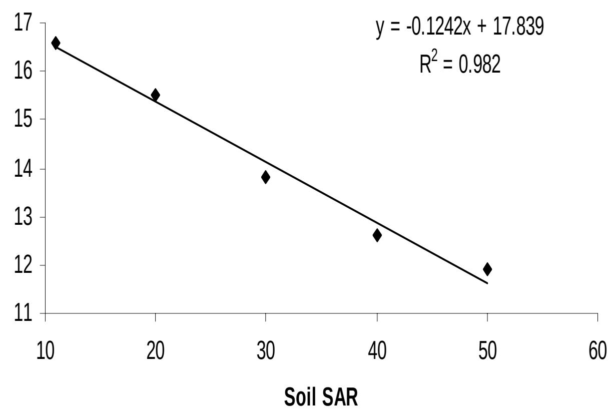


Figure 5.59: Correlation between soil SAR and Ca conc. in younger leaves after two years in study -1

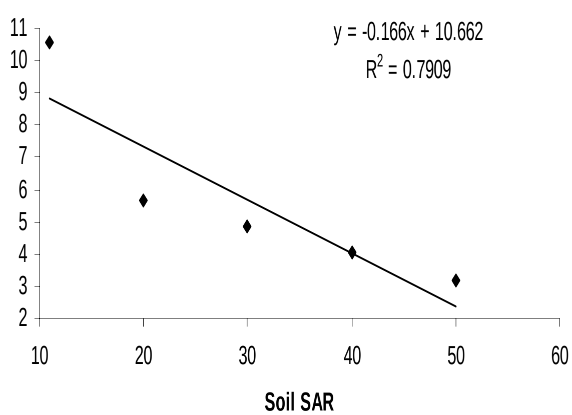


Figure 5.60: Correlation between soil SAR and Mg conc. in younger leaves after two years in study -1

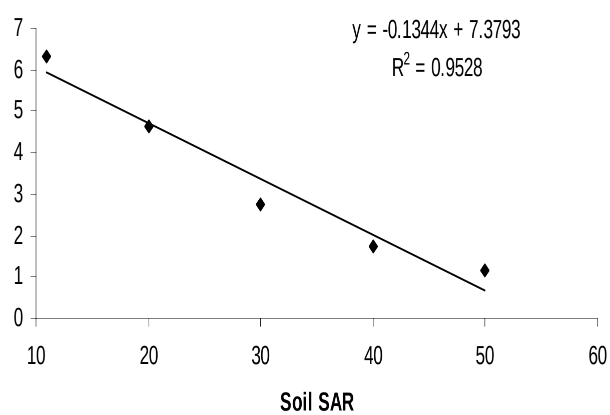


Figure 5.61:Correlation between soil SAR and K/Na ratio in younger leaves after two years in study -1

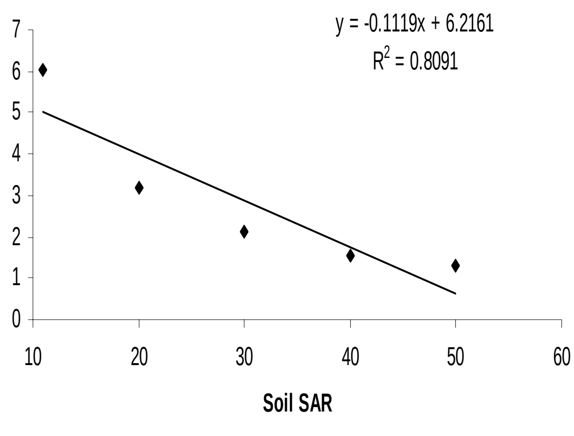


Figure 5.62: Correlation between soil EC_e + SAR and Na conc. in younger leaves after two years in study -1

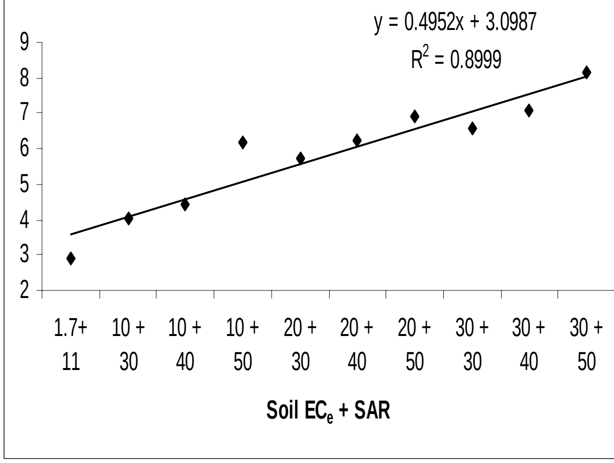


Figure 5.63: Correlation between soil EC_e + SAR and K conc. in younger leaves after two years in study -1

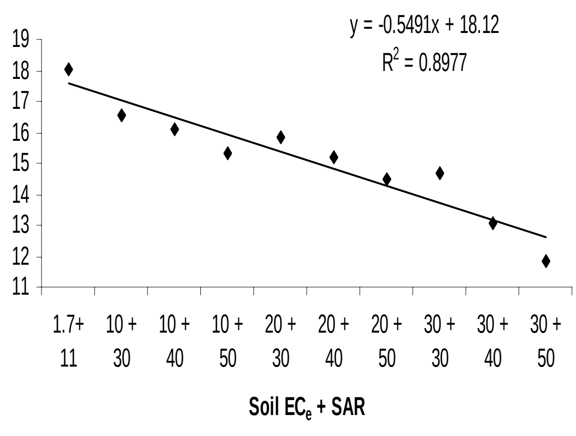


Figure 5.64: Correlation between soil EC_e + SAR and Ca conc. in younger leaves after two years in study -1

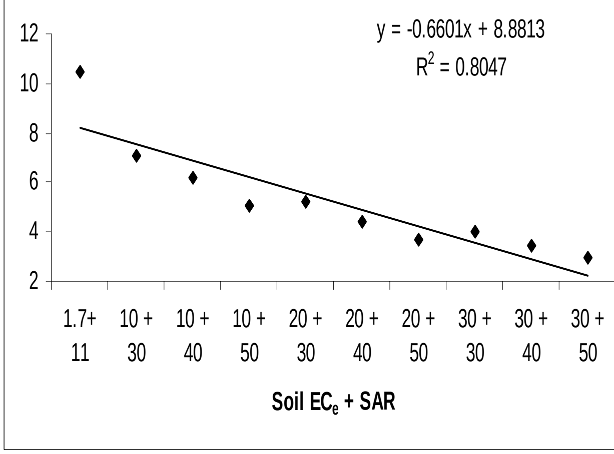


Figure 5.65: Correlation between soil EC_e + SAR and Mg conc. in younger leaves after two years in study -1

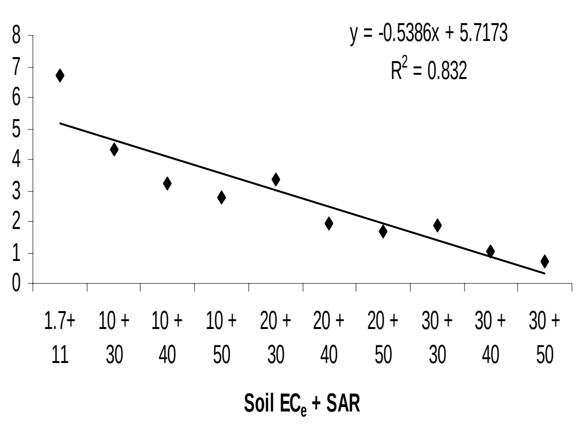


Figure 5.66: Correlation between soil EC_e + SAR and K/Na ratio in younger leaves after two years in study -1

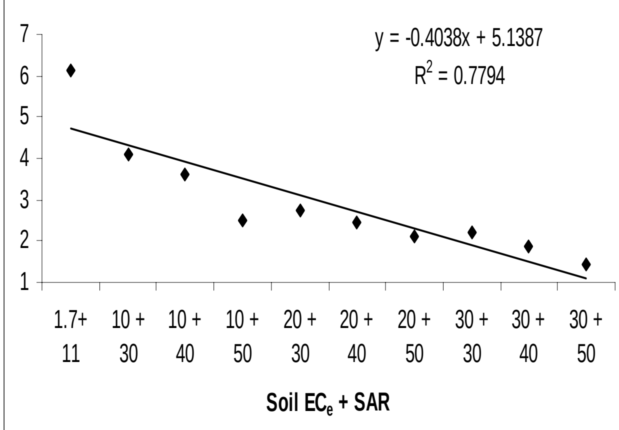


Figure 5.67: Correlation between Soil EC_e and plant height (m) in study - 2

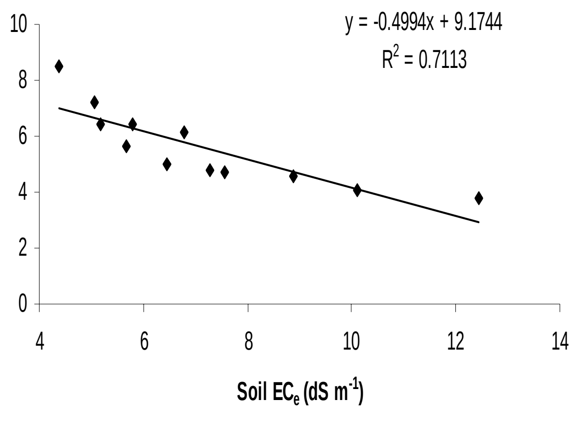


Figure 5.68: Correlation between Soil EC_e and Stem diameter (cm) in study - 2

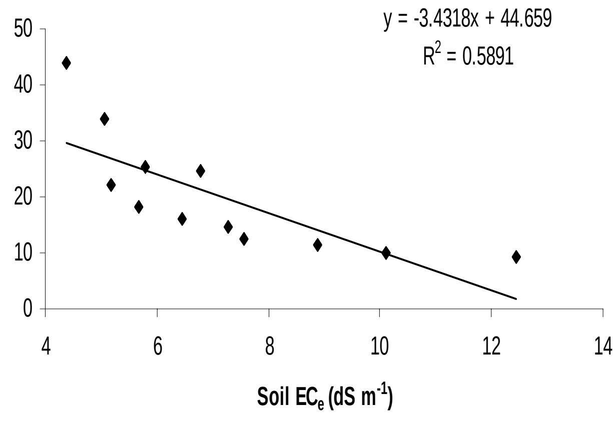


Figure 5.69: Correlation between Soil EC_e and No. of branches $plant^{-1}$ in study - 2

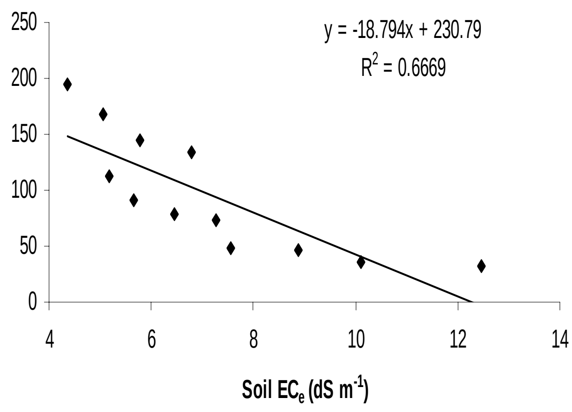


Figure 5.70: Correlation between Soil EC_e and canopy volume (m^3) in study - 2

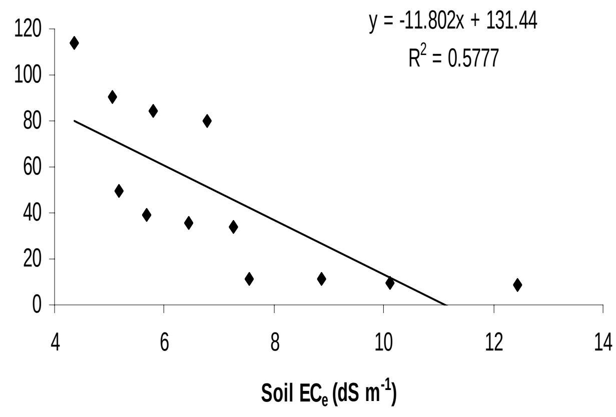


Figure 5.71: Correlation between soil pH and plant height (cm) in study - 2

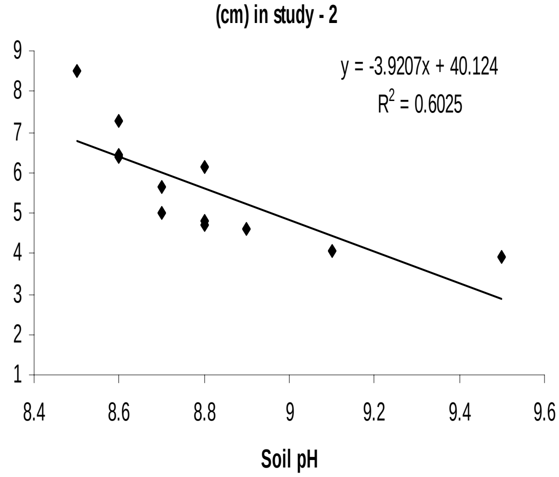


Figure 5.72: Correlation between soil pH and stem diameter (cm) in study - 2

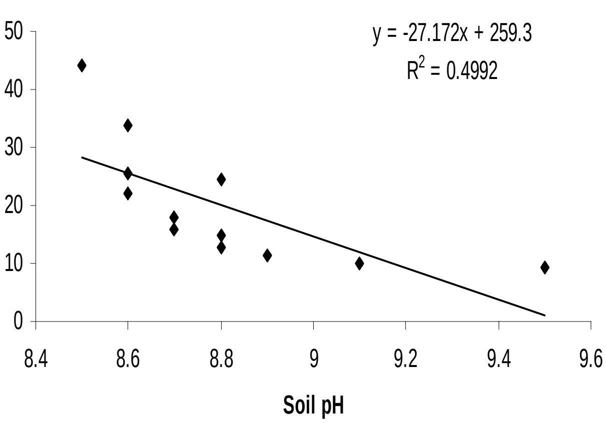


Figure 5.73: Correlation between soil pH and No. of branches plant^{-1} in study - 2

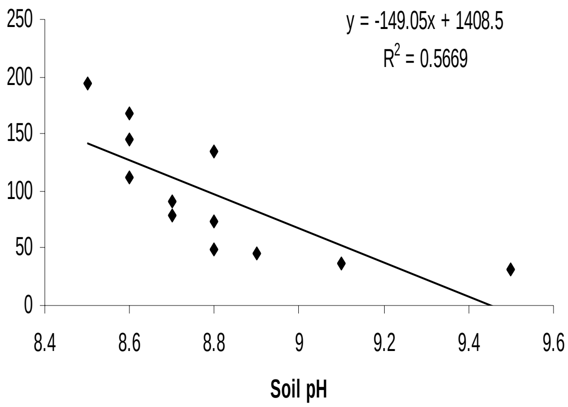


Figure 5.74: Correlation between soil pH and canopy volume (m^3) in study - 2

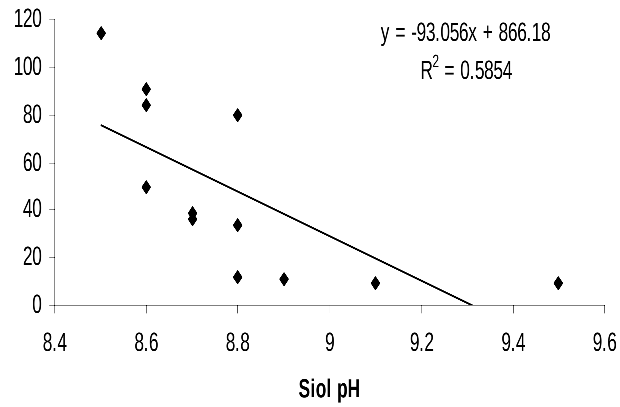


Figure 5.75: Correlation between soil SAR and plant height (cm) in study - 2

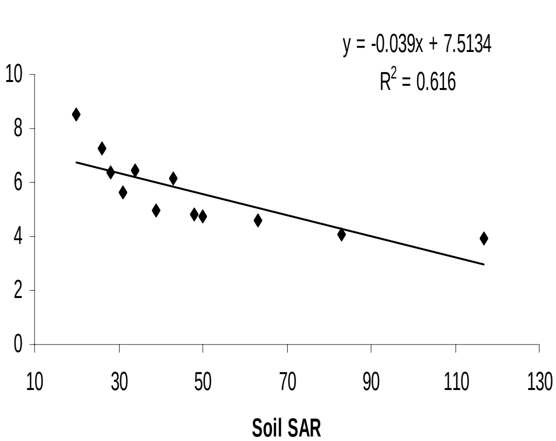


Figure 5.76: Correlation between soil SAR and stem diameter (cm) in study - 2

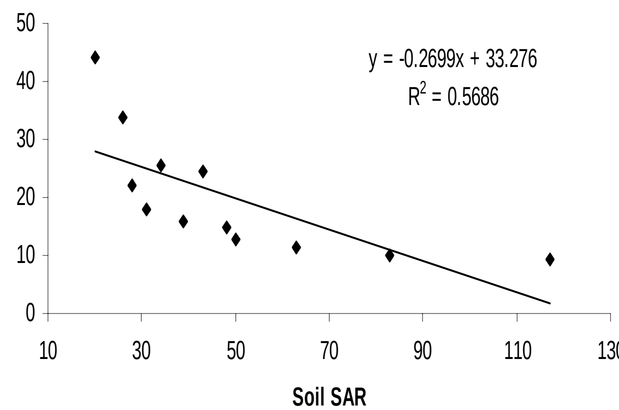


Figure 5.77: Correlation between soil SAR and No. of branches plant^{-1} in study - 2

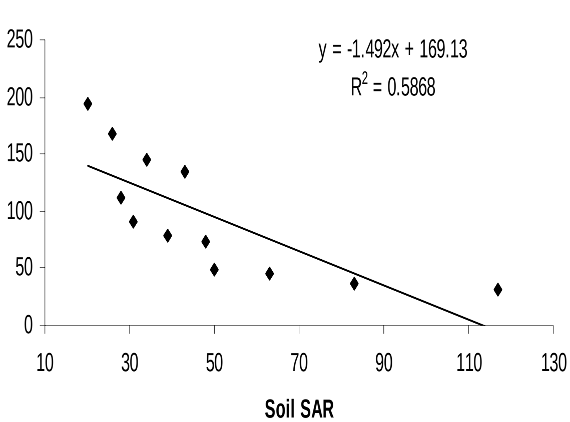


Figure 5.78: Correlation between soil SAR and canopy volume (m^3) in study - 2

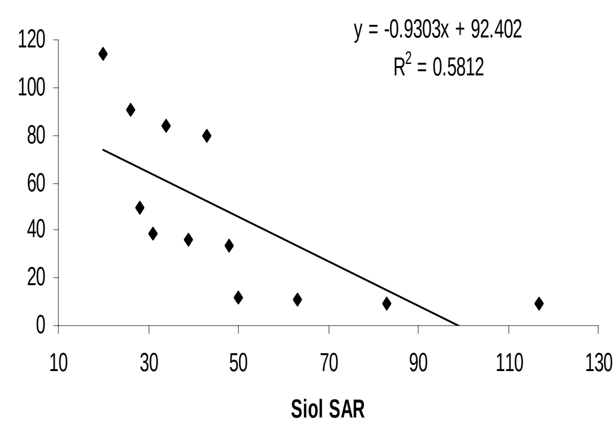


Figure 5.79: Correlation between soil EC_e and Na conc. ($g\ kg^{-1}$) in older leaves in study - 2

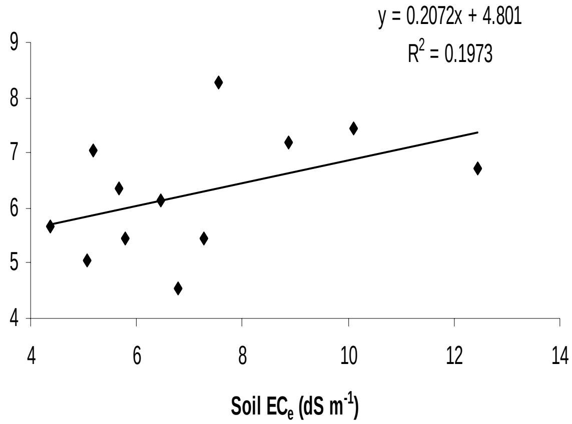


Figure 5.80: Correlation between soil EC_e and K conc. ($g\ kg^{-1}$) in older leaves in study - 2

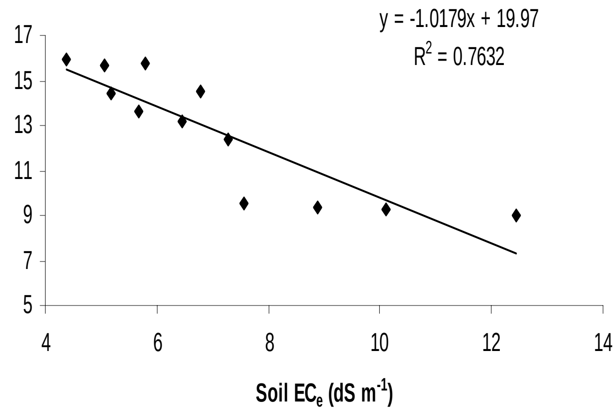


Figure 5.81: Correlation between soil EC_e and Ca conc. ($g\ kg^{-1}$) in older leaves in study - 2

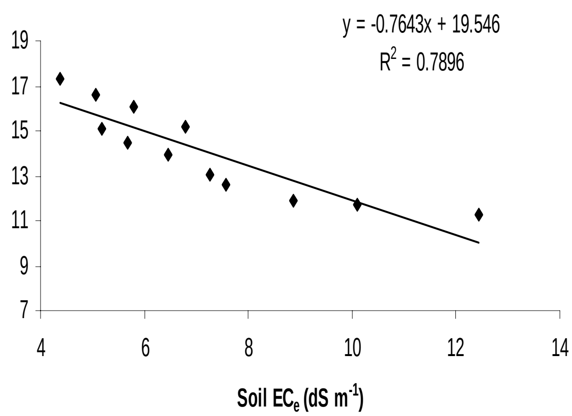


Figure 5.82: Correlation between soil EC_e and Mg conc. (g kg-1) in older leaves in study - 2

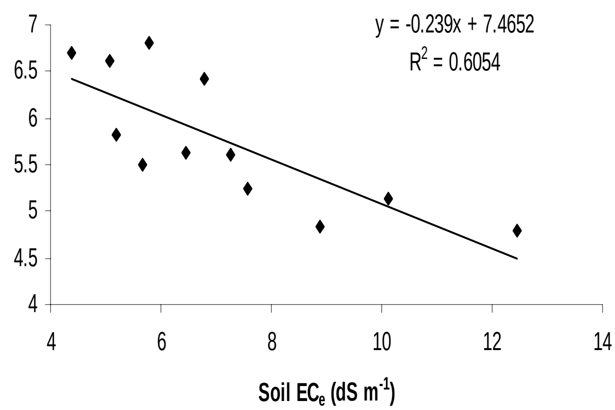


Figure 5.83: Correlation between soil EC_e and K/Na ratio in older leaves in study - 2

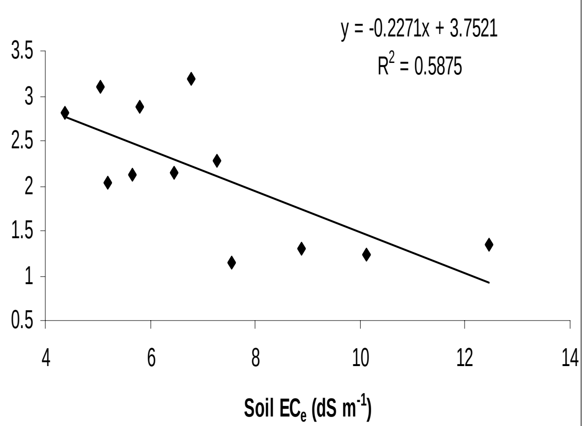


Figure 5.84: Correlation between soil pH and Na conc. ($g\ kg^{-1}$) in older leaves in study - 2

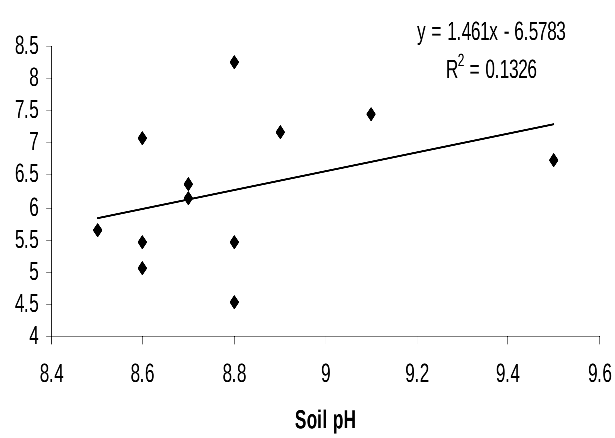


Figure 5.85: Correlation between soil pH and K conc. (g kg^{-1}) in older leaves in study - 2

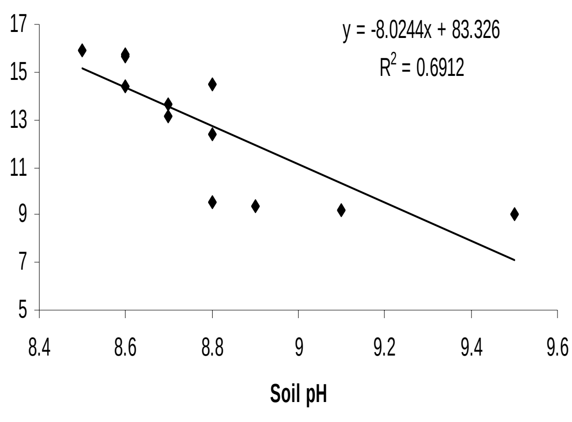


Figure 5.86: Correlation between soil pH and Ca conc. (g kg^{-1}) in older leaves in study - 2

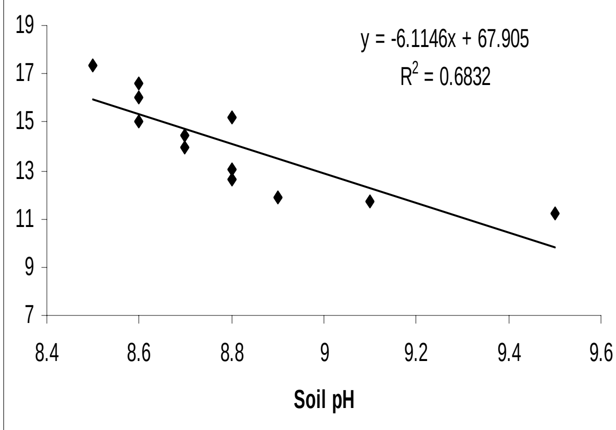


Figure 5.87: Correlation between soil pH and Mg conc. (g kg^{-1}) in older leaves in study - 2

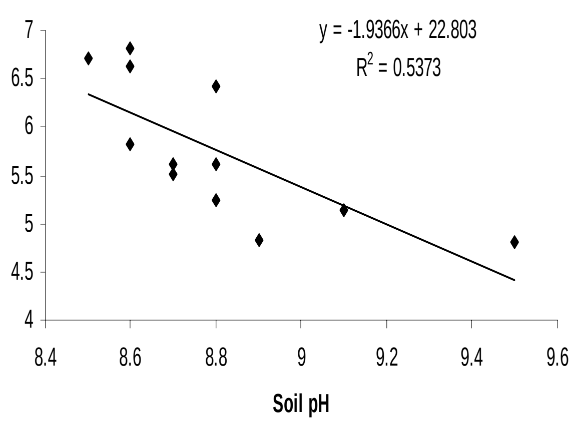


Figure 5.88: Correlation between soil pH and K/Na ratio in older leaves in study - 2

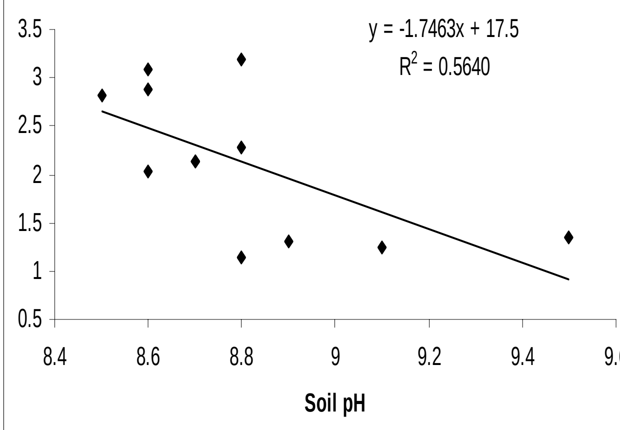


Figure 5.89: Correlation between soil SAR and Na conc. (g kg^{-1}) in older leaves in study - 2

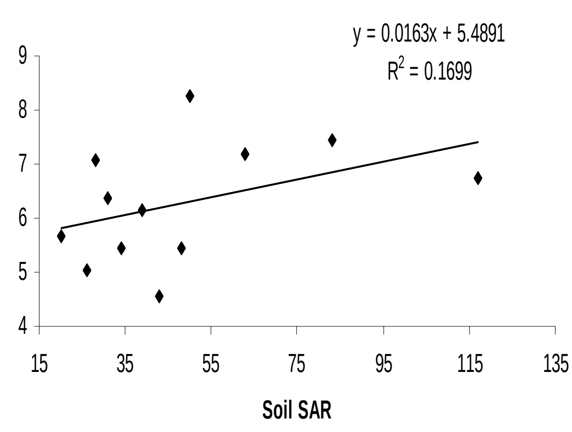


Figure 5.90: Correlation between soil SAR and K conc. (g kg^{-1}) in older leaves in study - 2

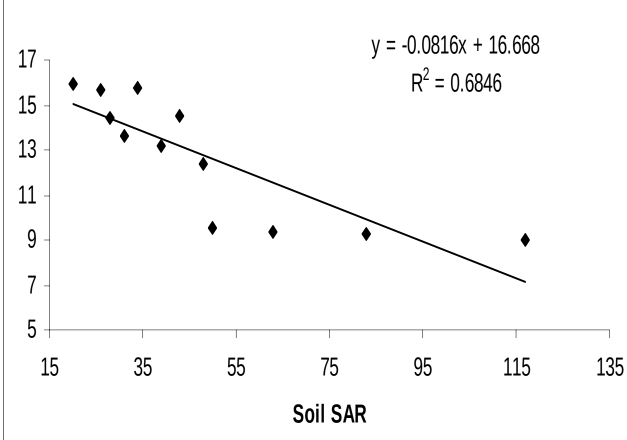


Figure 5.91: Correlation between soil SAR and Ca conc. (g kg^{-1}) in older leaves in study - 2

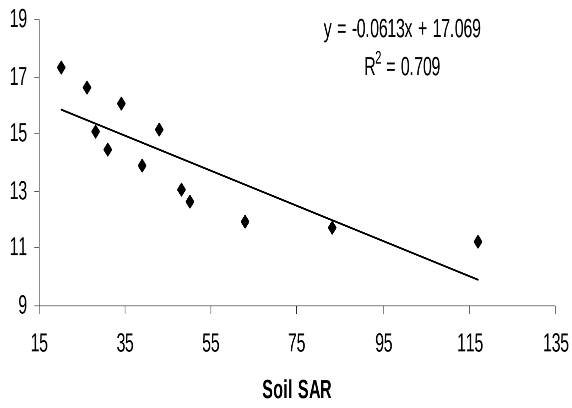


Figure 5.92: Correlation between soil SAR and Mg conc. (g kg^{-1}) in older leaves in study - 2

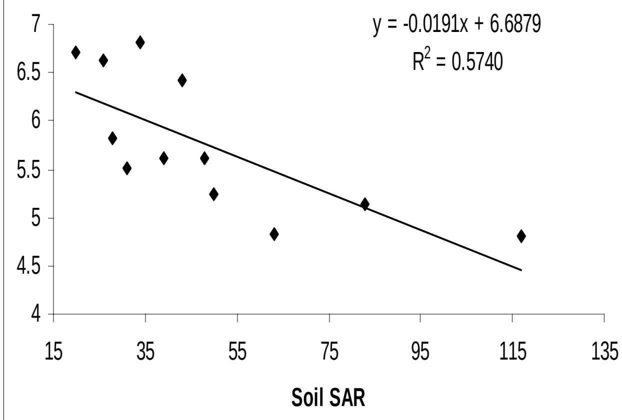


Figure 5.93: Correlation between soil SAR and K/Na ratio in older leaves in study - 2

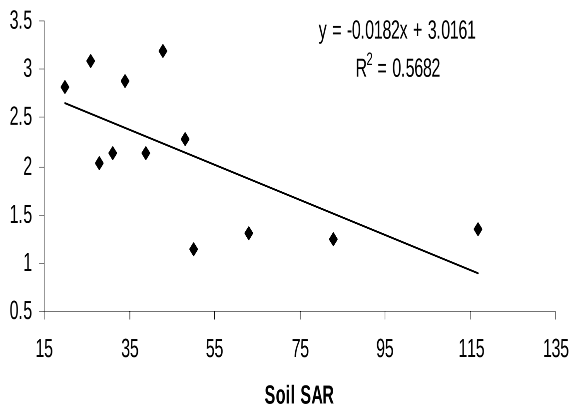


Figure 5.94: Correlation between soil EC_e and Na conc. (g kg^{-1}) in younger leaves in study - 2

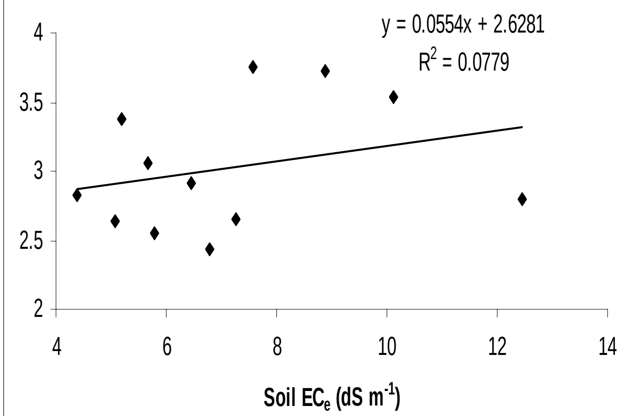


Figure 5.95: Correlation between soil EC_e and K conc. (g kg^{-1}) in younger leaves in study - 2

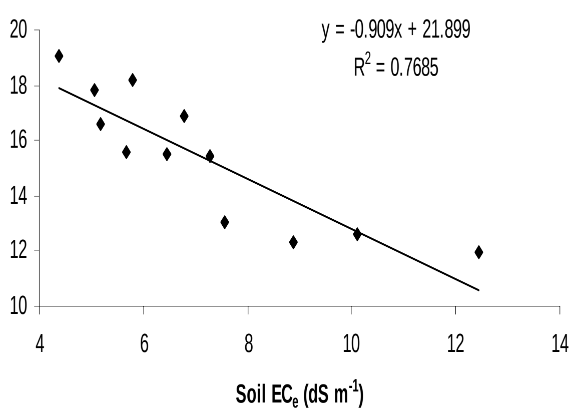


Figure 5.96: Correlation between soil EC_e and Ca conc. (g kg^{-1}) in younger leaves in study - 2

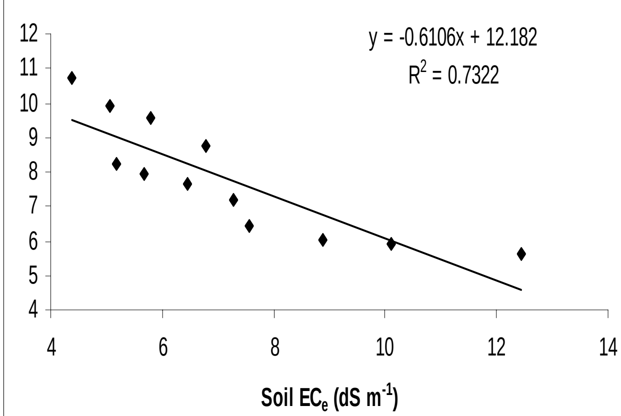


Figure 5.97: Correlation between soil EC_e and Mg conc. ($g\ kg^{-1}$) in younger leaves in study - 2

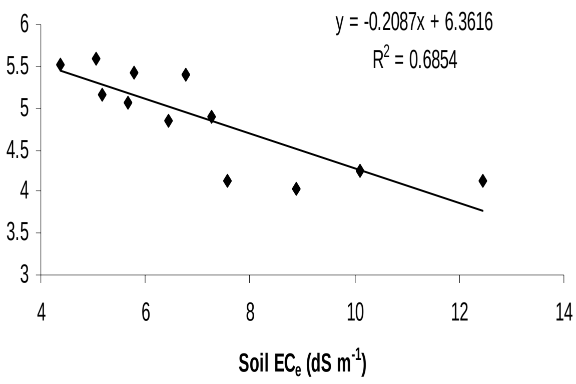


Figure 5.98: Correlation between soil EC_e and K/Na ratio in younger leaves in study - 2

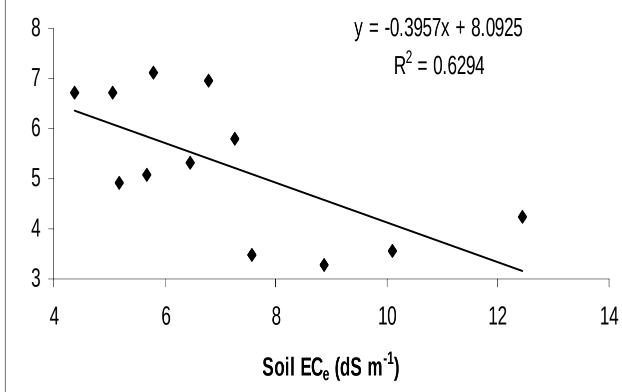


Figure 5.99: Correlation between soil pH and Na conc. ($g\ kg^{-1}$) in younger leaves in study - 2

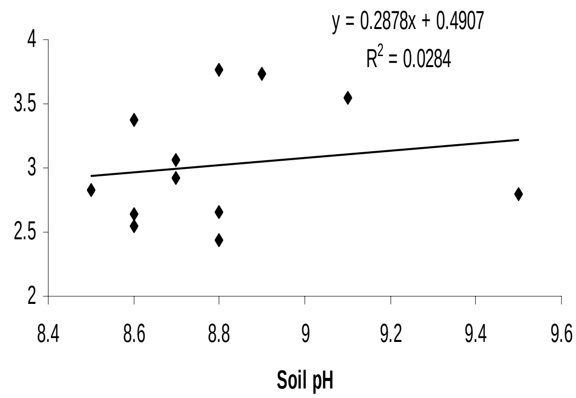


Figure 5.100: Correlation between soil pH and K conc. ($g\ kg^{-1}$) in younger leaves in study - 2

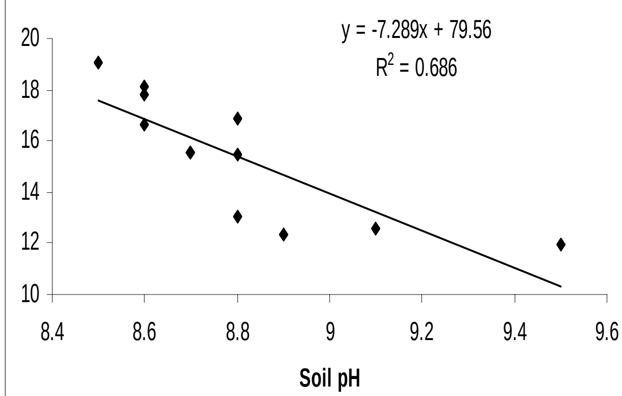


Figure 5.101: Correlation between soil pH and Ca conc. ($g\ kg^{-1}$) in younger leaves in study - 2

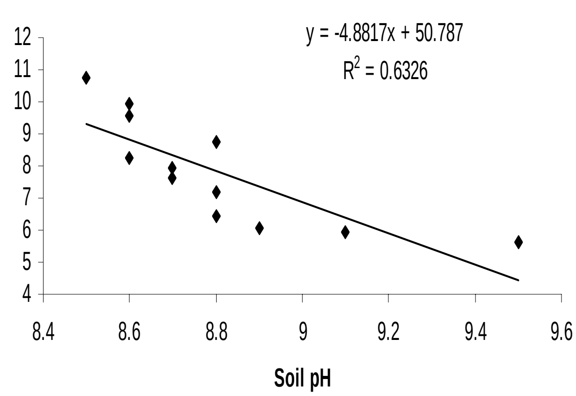


Figure 5.102: Correlation between soil pH and Mg conc. ($g\ kg^{-1}$) in younger leaves in study - 2

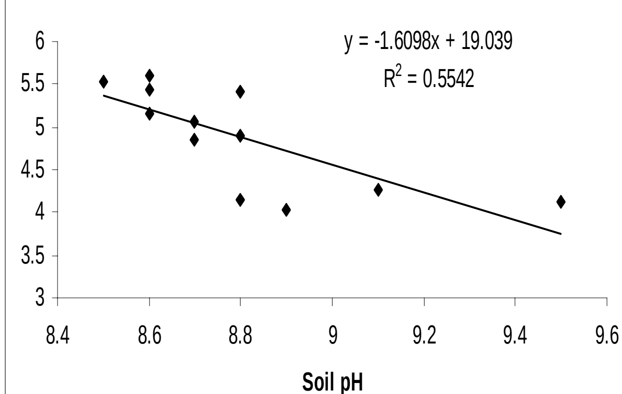


Figure 5.103: Correlation between soil pH and K/ Na ratio in younger leaves in study - 2

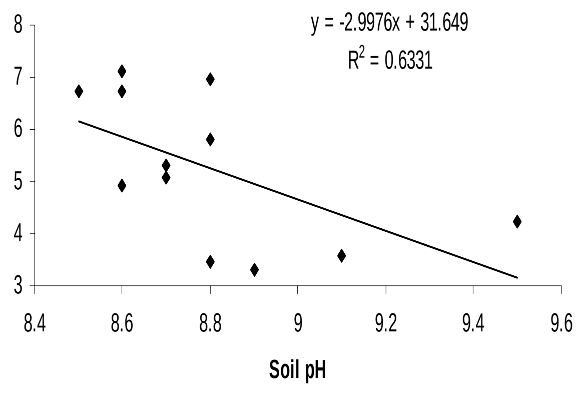


Figure 5.104: Correlation between soil SAR and Na conc. (g kg^{-1}) in younger leaves in study - 2

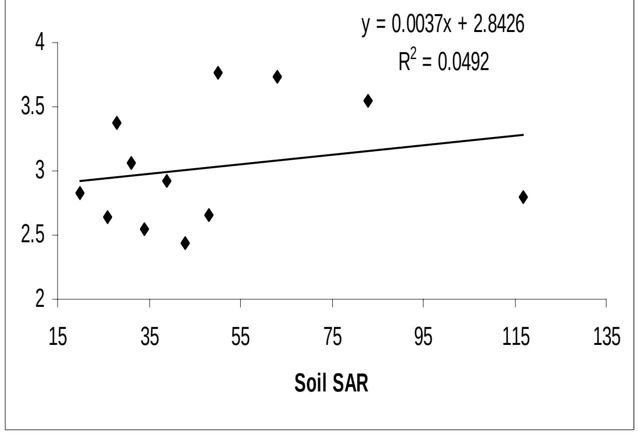


Figure 5.105: Correlation between soil SAR and K conc. (g kg^{-1}) in younger leaves in study - 2

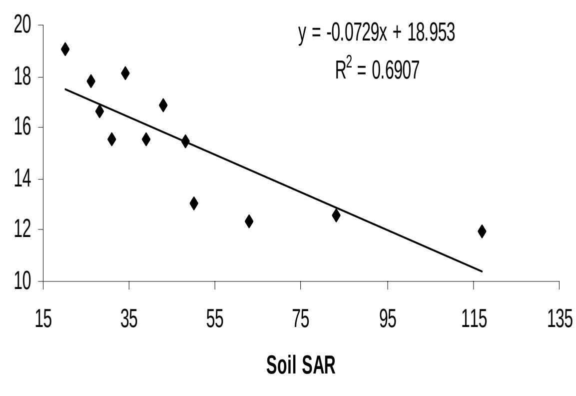


Figure 5.106: Correlation between soil SAR and Ca conc. (g kg^{-1}) in younger leaves in study - 2

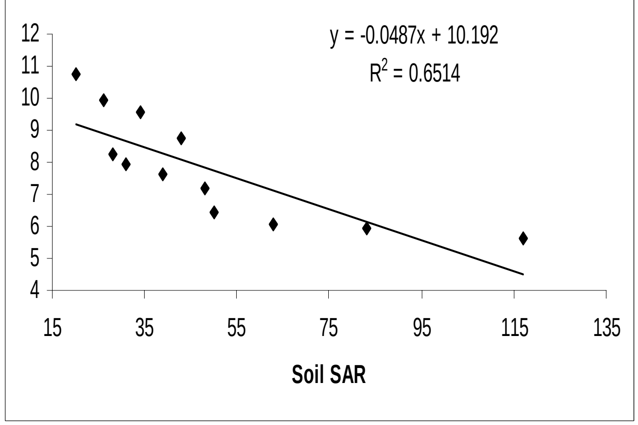


Figure 5.107: Correlation between soil SAR and Mg conc. (g kg-1) in younger leaves in study - 2

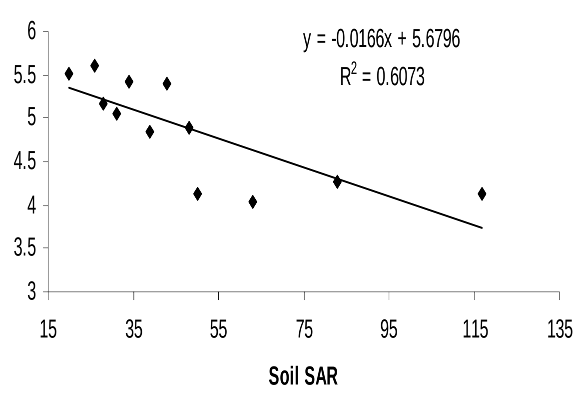


Figure 5.108: Correlation between soil SAR and K/Na ratio in younger leaves in study - 2

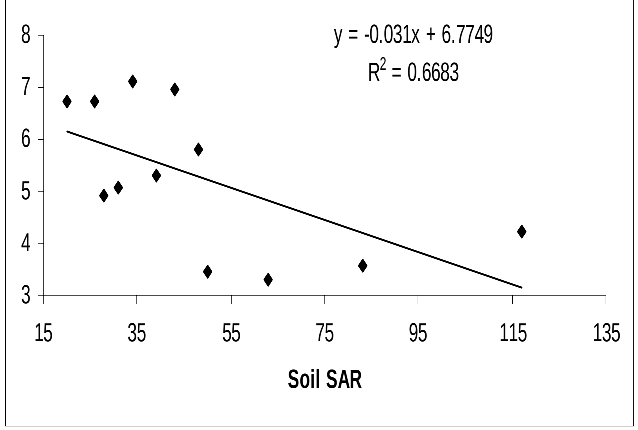


Figure 5.109: Percent increase over control in growth parameters of *Acacia ampliceps* due to transplantation techniques in study-3

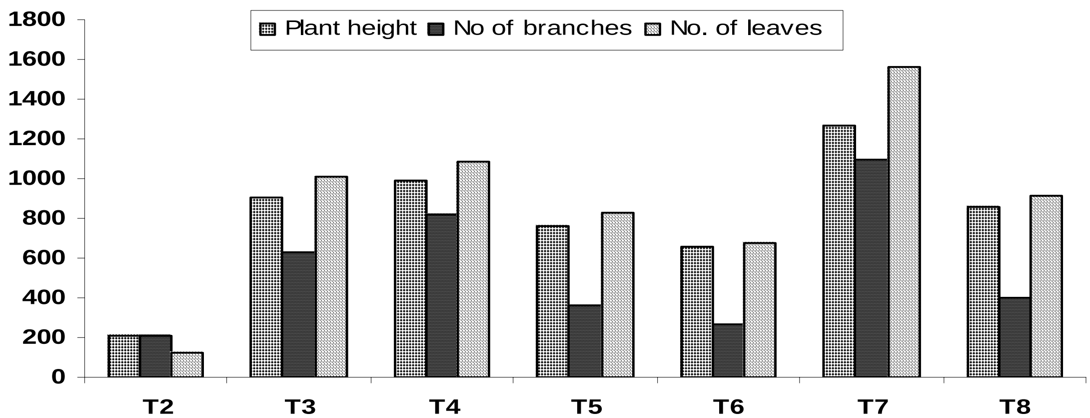


Figure 5.110: Percent increase over control in growth parameters of *Acacia ampliceps* due to transplantation techniques in study-3

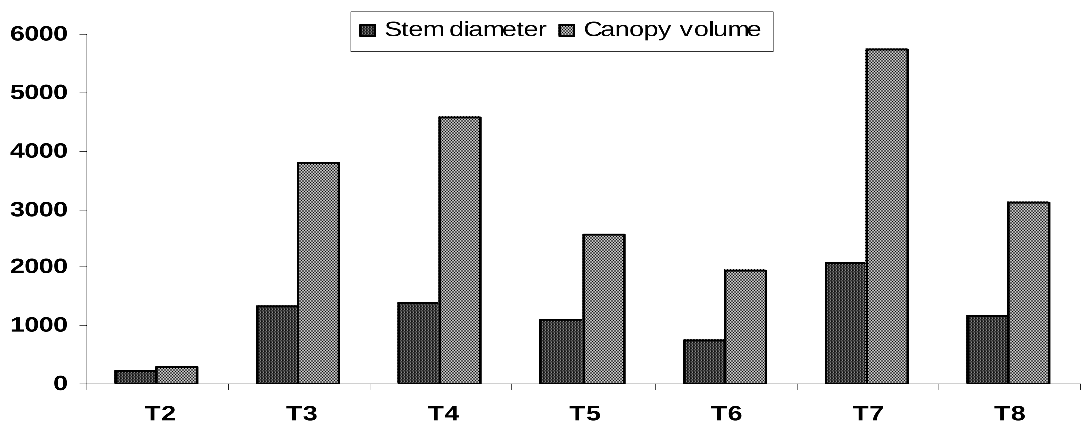
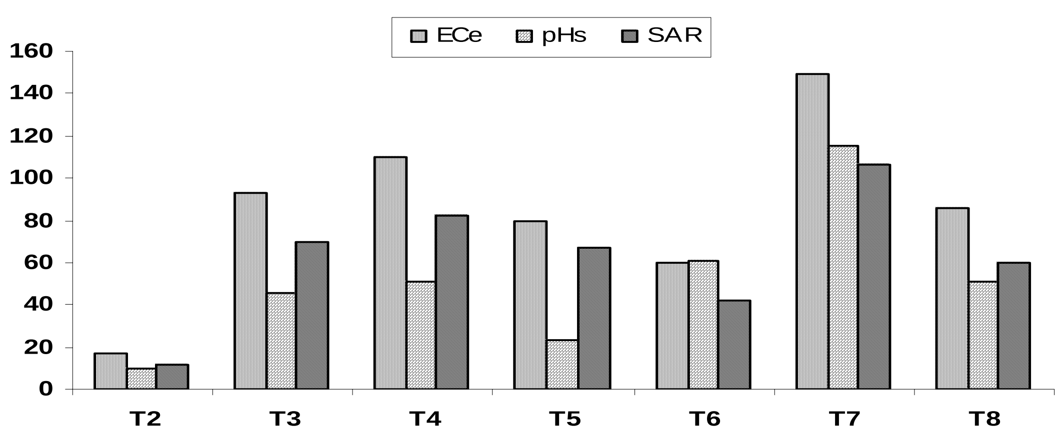


Figure 5.111: Percent decrease over control in soil characteristics after two years due to transplantation techniques in study-3



CHAPTER - 6

SUMMARY AND CONCLUSIONS

One of the major problems of world's agriculture is wide spread soil salinity and sodicity coupled with brackishness of irrigation water. Arid and semi-arid regions are the special victims. Pakistan faces this menace in area of 6.8 million hectare which is about 26 % of the total cropped area. Soil and water salinity and sodicity ultimately results in severe curtailment of crop yield, farmer's income and employment that gives rise to increasing poverty, shrinkage of land as well as water resources and salt pollution.

Salt-affected soils can either be rehabilitated or can be utilized at the prevailing status. The later approach requires less input, but availability of salt tolerance species is a pre-requisite. The selection of species must address economic importance. *Acacia ampliceps* is a plant reported to have very high salt tolerance, rapid growth and a very good fodder for goats and sheep. World literature indicates its tolerance to salinity alone under specific soil and climatic conditions that are mostly contrary to those prevailing in Pakistan. Very little research is available on its behaviour under sodicity and almost none when salinity and sodicity combine together. Thus, a wide gap exists between the information required and already available. In Pakistan more than 85 % salt-affected soils face combined stress in the Punjab province and 65 % in the country. Therefore, this research work was conducted to make available deficient data and information in order to guide the farming community most appropriately. The abroad objectives of study were:

1. To assess the tolerance limits of *Acacia ampliceps* for salinity, sodicity and their combinations.

2. To monitor the long-term effect of growing *Acacia ampliceps* on soil characteristics, especially salinity parameters.

3. To identify some useful plant transplantation techniques that may be helpful to avoid early stage salt stress and beneficial for better plant growth.

6.1 Study-1: Assessment of tolerance salinity / sodicity and their combinations by *Acacia ampliceps*

This study was conducted to assess tolerance potential of *Acacia ampliceps* against salinity/ sodicity alone and combined and consisted of three pot experiments.

6.1.1 Experiment -1: Evaluation of *Acacia ampliceps* for salinity tolerance

A normal soil was selected, brought to the wire house and EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} were developed using mixture of salts (NaCl, Na_2SO_4, $CaCl_2$ and $MgSO_4$ in ratio of 3:4:2:1) in calculated amount. The soil was filled in pots after testing and ascertaining the creation of desired EC_e levels that were arranged in completely randomize design (CRD). Three seedlings of the plant were transplanted in each pot on September 15, 2004, irrigated subsequently and studied for two years. The survival rate was recorded after one month and only one plant per pot was maintained. All the plants survived in the created salinity levels. Subsequently, observation on plant height, stem diameter, number of leaves and branches per plant and canopy volume were recorded six monthly. Young and older leaves were also collected simultaneously and analyzed for K^+, Na^+, Ca^{2+} and Mg^{2+} concentrations. Plants were harvested on September 15, 2006 after completion of two years period. The oven dry root and shoot weight were recorded separately. The roots were also analyzed for K^+, Na^+, Ca^{2+} and Mg^{2+} concentrations.

6.1.2 Experiment -2: Assessing tolerance potential of *Acacia ampliceps* in sodic environment

Sodicity (SAR) levels of 20, 30, 40, 50, 60 and 70 were established using $NaHCO_3$ in addition to control (original soil status for the sake of comparison). The procedure for the development of sodicity, maintenance of plants and recording of different data were similar to experiment-1.

6.1.3 Experiment-3: Investigating tolerance against combined stresses of salinity and sodicity

The same bulk soil was used for this experiment as that for experiment 1 and 2. The levels of SAR 30, 40 and 50 were created within each salinity level of 10, 20 and 30 dS m^{-1}. Including original soil as control there were 10 treatments in different combinations repeated thrice in CRD design. Same salts were used for developing the EC_e levels as in case of experiment 1, while $NaHCO_3$ was applied to create sodicity (SAR), other methodology was similar as described for experiment-1.

6.2 Study-2: Evaluation of long-term effect of saline sodic environment on growth of *Acacia ampliceps* and vice versa

This study was accomplished to evaluate the long-term effect of salinity/sodicity on growth of *Acacia ampliceps* as well as monitoring soil improvement due to plant growth. For this purpose, 12 plants of different growth conditions (poor, medium and good) were selected on March 10, 2005 from block of one acre that was transplanted on September 10, 2001. Thus, the plants had attained age of 3.5 years at that time. Classification of plants into poor, medium and good was on the basis of visual parameters like height, number of branches, girth and spread. These parameters were then measured and recorded. Soil samples were obtained up to 150 cm depth and analysed for EC_e, pH and SAR. Three more similar observations were recorded after every six months. At the same time plant leaves samples were also collected and analysed for K^+, Na^+, Ca^{2+} and Mg^{2+} concentrations. This study was completed on September 10, 2006. Correlations of different growth parameters with soil characteristics were worked out.

6.3 Study-3: Investigating transplantation techniques to avoid early stage salinity stress

This study was conducted to assess the effect of temporary relief through transplantation techniques at early stage when plants are more sensitive to salinity stress. The following transplantation techniques were tested.

- T1. Transplantation on the flat field (without any channel, pit or amendment)
- T2. Transplantation in pits (60 x 60 x 60 cm) filled with original soil on the shoulder of a channel (90x60 cm)
- T3. Transplantation in pits (60 x 60 x 60 cm) filled with silt (fresh alluvium) on the shoulder of a channel (90 x 60 cm)
- T4. Transplantation in pits + augering (7.5 cm diameter) down to 150 cm.
- T5. Transplantation in pits + silt + gypsum (ratio 20:1)
- T6. Transplantation in pits + original soil + gypsum (ratio 20:1)
- T7. Transplantation in pits + silt + compost (ratio 20:1)
- T8. Transplantation in pits + original soil + compost (ratio 20:1)

The selected field was leveled and prepared for transplantation of saplings. Pre-transplantation soil analysis was completed for EC_e, pH, SAR, cations, anions, calcareousness and texture. Channels and pits were made and refilled with combination of different materials per treatments. Seedlings of almost uniform age and size were transplanted in randomized complete block design having four replications, including 12 plants in each of replicate. Plant growth parameters were recorded six monthly along with simultaneous soil analysis. Leaf analysis was also conducted for concentrations of K^+, Na^+, Ca^{2+} and Mg^{2+} biannually for two years and experiment was completed on September 11, 2006.

All the collected data were processed statistically through analysis of variance, correlation coefficient and calculation of means and standard deviation. Correlation equations were developed for prediction of variations. On the basis of results following facts were found:-

1. *Acacia ampliceps* survived all the investigated salinity (EC_e 10 – 50 dS m^{-1}) and sodicity (SAR 20 – 50) levels except SAR 60 and 70 (mmol $L^{-1})^{1/2}$ where the mortality of plants occurred. No mortality was observed when combined effects of salinity (EC_e 10 – 30 dS m^{-1}) and sodicity (SAR 30 - 50) were tested at various levels.
2. Salinity and sodicity levels as well as different combinations retarded the plant growth depending upon their severity. There was corresponding decreased in plant growth parameters (height, stem diameter, number of leaves and branches and canopy volume) with increasing levels of various stresses. Even increasing age of plants (up to 2 years) could not control the negative effects.
3. Height of *Acacia ampliceps* decreased by 13, 20, 29, 45 and 60 % over control with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} whereas decreases were 18, 32, 51 and 86 % over control with SAR levels of 20, 30, 40 and 50 (mmol $L^{-1})^{1/2}$. The decrease in this parameter due to various combinations of EC_e and SAR ranged from 16 to 64 % depending upon severity of EC_e or SAR.
4. Stem diameter of the plant was cut short by 8, 17, 26, 42 and 57 % over control with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} respectively whereas respective decreases were 13, 25, 43 and 78 % with SAR 20, 30, 40 and 50. Decrease values vary from 11

to 51 % with various combinations of salinity and sodicity. Maximum decrease was recorded with the combined level of EC_e 30 + SAR 50.

5. Leaf bearing was also affected negatively in various stresses. A consistent fall of older leaves was also recorded. Resultantly, number of leaves plant^{-1} was lesser by 7, 17, 27, 43 and 68 % with respective EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1}. Effect of sodicity was recorded to be more pronounced and number of leaves plant^{-1} remained 8, 20, 48 and 85 % lesser than control with SAR levels of 20, 30, 40 and 50 (mmol L^{-1})$^{1/2}$. Combined effect of salinity and sodicity also decreased number of leaves plant^{-1}. The minimum values were recorded with combination of ECe 10 + SAR 30 while maximum decrease was observed with ECe 30 + SAR 50 with a value of 65 %.
6. The number of branches plant^{-1} also decreased like number of leaves plant^{-1}. There was a cut short of 16, 30, 48, 68 and 77 % with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} respectively. The decrement were observed as 30, 48, 63 and 87 % over control with SAR corresponding levels of 20, 30, 40 and 50 (mmol L^{-1})$^{1/2}$. The decrease with combined salinity and sodicity was 14 % (minimum with EC_e 10 + SAR 30) to 75 % (maximum with EC_e 30 + SAR 50). The effect of other levels was recorded to be in between these values.
7. The spread of plants was also suppressed. There was a decrease of 11, 22, 28, 57 and 80 % with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1} while the decrease values were recorded as 15, 38, 77 and 90 % with SAR levels of 20, 30, 40 and 50 (mmol L^{-1})$^{1/2}$. The variation of decreases was from 11 to 82 % when salinity and sodicity were combined together.
8. 5, 6, 16, 37 and 52 % with ECe levels of 10, 20, 30, 40 and 50 dS m-1 lost the shoot dry weight. Thus, the highest-level caused 52 % decreased, which is very nearer to the critical value of 50 % (allowed in salt tolerant studies). The relative yield as proposed by MASS (1990) was calculated as 96, 88, 71 and 56 % for salinity levels of 20, 30, 40 and 50 dS m^{-1}. This also denoted that the loss with the highest tested level of salinity was almost 50 % that indicated very high salinity tolerant of this plant. The loss of root dry weight for same levels was also observed as 15, 22, 29, 46

and 60 % with EC_e levels of 10, 20, 30, 40 and 50 dS m^{-1}. Hence, roots were affected slightly more than the shoot.

9. Effect of sodicity was recorded higher than salinity, especially at the equivalent higher level (SAR 40 and 50). The decrease in dry shoot weight was 3, 18, 53 and 70 % with SAR 20, 30, 40 and 50 (mmol $L^{-1})^{1/2}$. Similarly cut in dry root weight was 20, 34, 52 and 66 % with the same values of SAR. Therefore, 40 SAR was the level causing almost 50 % losses in weight. This level can be taken as critical level for 50 % decrease.
10. There was a decrease of 6 to 66 % in dry shoot weight and 17 to 61 % in dry root weight with various combined levels of EC_e + SAR. Minimum values were recorded with EC_e 10 + SAR 30 while maximum decrease occurred with EC_e 30 + SAR 50. The level of 50 % decrease was found to be EC_e 30 + SAR 40 that could be taken as the critical level.
11. Field results of study-2 supported the findings of above mentioned pot experiments. The measured growth parameters of poor conditioned plants were related to the higher EC_e and SAR of the soil. The values of EC_e + SAR were recorded as the maximum under the canopy of poor plants whereas; moderately growing plants were having intermediate values. Minimum values were recorded under the good conditioned plants.
12. The correlation between plant growth parameters and soil EC_e and SAR also supported the above findings. There was a direct but negative correlation between growth and soil salinity and sodicity. The values of most of the correlation coefficient (R^2) were evaluated as significant.
13. The data on leaf and root composition in different experiments indicated that Na^+ contents of older as well as younger leaves increased with increasing levels of salinity and sodicity and their combinations. Impact of sodicity alone was greater. There was higher concentration in the older leaves. Quantity of Na^+ in roots also increased. Potassium contents decreased with increasing magnitude of various stresses, concentrations in older leaves remained on lower side. Concentration of Ca^{2+} was higher in older leaves and significantly decreases with increasing EC_e, SAR and EC_e + SAR. Similar was the trend in roots. There was a decrease in Mg^{2+} contents of

leaves and roots with increasing stress of any type. Older and younger leaves did not vary much. The ratio of K^+: Na^+ was wider in leaves and roots without any stress but higher concentrations of the salts in the rhizosphere narrowed down this important parameter.

14. The negative effects of salts in *Acacia ampliceps* were found due to osmotic effect and specific ions toxicity. The recorded significant reduction in moisture contents of shoot and roots indicated that plants could not uptake water when salinity or sodicity or levels of both (combined) increased. The decrease was observed as 15 % in shoot and 13 % in roots with the EC_e level of 50 dS m^{-1}. The same level of SAR decreased moisture contents of shoot by 20 % and that of roots by 14 %. There was a very high increase of Na^+ absorption that could cause damage to various internal parts of the plants and metabolic processes.
15. Two mechanisms of salt tolerance in *Acacia ampliceps* were observed through the collected data. These mechanisms were; ion selectivity and compartmentation. The plants exercise selectivity during ion uptake and put control on very high absorption of Na^+ and keeping partially consistence uptake of K^+, Ca^{2+} and Mg^{2+}. This exercise was more effective at the lower level of stresses but lost partially when the magnitude of stresses was very high. Thus, K^+: Na^+ ratio was more than unity up to the level of 40 EC_e or 50 SAR. Clearly higher concentration of Na^+ was recorded in older leaves which indicated that excessive salts were being sequested into older leaves. A consistent leaf senescence proved that the plant was getting rid of salts in this manner, although it is evergreen.
16. The growth of plants also improved soil condition and EC_e and SAR decreased significantly in the soil underneath the plants due to decay of plant litter and leaching subsequent of salts.
17. The improved transplantation techniques helped a lot to withstand early stage salinity/ sodicity stress when the plants were more sensitive. The growth parameters were manifold on higher side when these were transplanted in pits filled with silt or silt + compost.
18. The correlation equations were also developed for prediction of effects of salinity or sodicity, salient ones are as under: -

1.	Soil EC_e and plant height:	y =	-3.1491	x	+ 309.62
2.	Soil EC_e and stem diameter:	y =	-0.0265	x	+ 2.6882
3.	Soil EC_e and number of leaves:	y =	-7.3984	x	+ 620.72
4.	Soil EC_e and number of branches:	y =	-0.7228	x	+ 45.776
5.	Soil EC_e and canopy volume:	y =	-0.0840	x	+ 5.6594
6.	Soil EC_e and shoot dry weight:	y =	-10.712	x	+ 1080.5
7.	Soil EC_e and root dry weight:	y =	-2.7769	x	+ 237.71
8.	Soil SAR and plant height:	y =	-5.5061	x	+ 363.77
9	Soil SAR and stem diameter:	y =	-0.0450	x	+ 3.2065
10.	Soil SAR and number of leaves:	y =	-11.777	x	+ 756.64
11.	Soil SAR and number of branches:	y =	-0.9650	x	+ 54.925
12.	Soil SAR and canopy volume:	y =	-0.1291	x	+ 6.8263
13.	Soil SAR and shoot dry weight:	y =	-19.579	x	+ 1307.9
14.	Soil SAR and root dry weight:	y =	-4.0477	x	+ 281.36

x = soil parameter under consideration

y = plant parameter under consideration

6.4 Conclusions

Following conclusions could be drawn from the completed research studies: -

► *Acacia ampliceps* is a highly salt tolerant plant that indicated 50 % decrease in growth parameters and shoot dry weight with EC_e of 50 dS m^{-1}, SAR of 40 (mmol $L^{-1})^{1/2}$ and EC_e + SAR of 30 + 40

► Plant growth parameters (height, stem diameter, number of leaves and branches and canopy volume) and water uptake reduced significantly with increasing levels of salinity (EC_e), sodicity (SAR) and both of these combined. Sodium uptake highly increased while K^+, Ca^{2+} and Mg^{2+} decreased with increasing levels of stresses.

► The negative effect of salt stress was due to osmotic effect as well as specific ion toxicity, especially Na^+. The plant was successful to tolerate salinity and sodicity stress through ion selectivity (keeping K^+: Na^+ ratio comparatively wider) and compartmentation.

- Growing *Acacia ampliceps* improved the soil health through decreasing EC_e and SAR of the soil underneath the plants.
- Transplantation of plants in pits refilled with silt or silt + compost proved highly helpful in avoiding early stage stress and keeping the growth intact.

6.5 Recommendations for the farmers

Farmers can use their strongly salt-affected lands for growing of *Acacia ampliceps* through making channels of 90 cm wide and 60 cm deep, digging the pits 60 cm wide and 60 cm deep , refilling these with silt or silt + compost (20:1 ratio) without any growth losses and with ultimate improvement in soil health. If they grow 4 hectare of this plant and supplement with one hectare of seasonal fodder (alfalfa, sesbania, maize + pearl millet + small millet) they can rear 100 heads of sheep or goats and can earn 1176 € (Pakistani Rs.94084) per annum/hectare.

6.6 Future lines of action

Further investigations will be needed to generate information for salt-affected soil varying in texture as well as when the plants are irrigated with saline sodic water continuously.

CHAPTER - 7

ZUSAMMENFASSUNG UND SCHLUSSFOLGERUNGEN

Eines der Hauptprobleme in der weltweiten Landwirtschaft ist die weit verbreitete Boden-Versalzung (Sodagehalte) verbunden mit der Nutzung von Brackwasser zur Bewässerung. Aride und semiaride Regionen sind besonders betroffen. Pakistan ist auf einer Fläche von 6,8million ha bedroht und das entspricht ca. 26 % der zu bewirtschaftenden Fläche. Boden- und Wasserversalzung vermindern erheblich die Ernten und das Einkommen der Landwirte. Dies führt zu Armut und der weiteren Einschränkung des nutzbaren Landes sowie der Wasservorräte.

Versalzene Böden können entweder verbessert oder unter den vorherrschenden Bedingungen genutzt werden. Letzteres erfordert einen geringeren Aufwand, setzt aber die Salztoleranz von anzubauenden Arten voraus. Die Selektion von Arten ist deshalb von ökonomischer Bedeutung. Von *Acacia ampliceps* wird berichtet, dass sie eine sehr hohe Salztoleranz aufweist, schnell wächst und ein gutes Futter für Ziegen und Schafe ist. In der weltweiten Literatur gibt es Angaben zur Salztoleranz unter spezifischen Boden- und Klimabedingungen, die meist gegensätzlich zu denen in Pakistan sind. Nur wenige Untersuchungen über das Verhalten von *Acacia ampliceps* liegen bei sodahaltigen Böden vor und so gut wie keine, wenn sodahaltige Verhältnisse mit anderen Salzen kombiniert sind. Deshalb besteht eine große Differenz zwischen Informationen, die noch notwendig sind, und anderen, die bereits vorhanden sind. In der Provinz Punjab in Pakistan weisen mehr als 85 % der salzbeeinflussten Böden diesen Kombinationsstress auf, im ganzen Land sind es 65 %. Diese Forschungsarbeiten wurden durchgeführt um fehlende Daten und Ergebnisse zu gewinnen, um dann die Gemeinschaft der Landwirte optimal auszuleiten. Die Ziele der Untersuchungen waren:

1) Festlegung der Toleranzgrenzen von *Acacia ampliceps* hinsichtlich Salz- und Sodagehalt bzw. der Kombination aus beiden.

2) Auswertung des Langzeiteffektes beim Wuchs von *Acacia ampliceps*, hauptsächlich unter Salzeinfluss.

3) Erkennung von nutzbaren Pflanzentechniken, die frühzeitig den Salzstress vermeiden und damit für ein besseres Wachstum sorgen.

7.1 Studie 1: Festlegung der Salz-/Sodatoleranz und deren Kombination auf *Acacia ampliceps*

Diese Studie bestand aus drei Gefäßversuchen

7.1.1 Experiment 1: Bewertung der Salztoleranz auf *Acacia ampliceps*

Es wurde ein normaler Boden ausgewählt, in dem kalkulierte Mengen von Salzen (NaCl, Na_2SO_4, $CaCl_2$ und $MgSO_4$ im Mischungsverhältnis von 3 : 4 : 2 :1 mit Leitfähigkeiten (ECe) von 10, 20, 30, 40 und 50 dSm^{-1} eingebracht wurden. Der Gefäßversuch befand sich in einem Draht-Gewächshaus. Der Boden wurde in die Töpfe gefüllt, nachdem die gewünschten Leitfähigkeiten eingestellt waren. Die Aufstellung der Gefäße erfolgte vollständig randomisiert (CRD). In jedes Gefäß pflanzte man am 15. September 2004 drei Keimpflanzen, bewässerte und beobachtete diese über 2 Jahre. Die Überlebensrate wurde nach einem Monat registriert und es verblieb nur eine Pflanze pro Gefäß. Alle Pflanzen überlebten in den festgelegten Salzstufen. Alle 6 Monate erfolgte die Erfassung des Höhenwachstums, des Stammdurchmessers, die Anzahl der Blätter und Zweige und der Überdeckungsbereich (Pflanzenkrone) pro Pflanze. Junge und alte Blätter wurden gleichzeitig gesammelt und die K^+, Na^+, Ca^{2+} und Mg^{2+} - Gehalte untersucht. Nach einer zweijährigen Periode erfolgte die Ernte der Pflanzen am 15. September 2006. Die Trockengewichte der Wurzeln und Sprosse hielt man getrennt fest. Die Analyse der K^+, Na^+, Ca^{2+} und Mg^{2+} - Gehalte in den Wurzeln, war auch Bestandteil der Untersuchungen:

7.1.2 Experiment 2: Bewertung der Toleranz von *Acacia ampliceps* gegenüber Sodaböden

Im Vergleich zu unbehandelten Böden wurden Sodagehalte (SAR) von 20, 30, 40, 50, 60 und 70 % unter Nutzung von $NaHCO_3$ eingestellt. Die Einstellung des Sodagehaltes / Soda-Adsorptions-Rate, die Einbringung der Pflanzen und die Auswertung der Ergebnisse erfolgte wie im 1. Experiment.

7.1.3 Experiment 3: Untersuchung zur Toleranz bei einem kombinierten Salz- und Sodastress

Bei diesem Experiment wurde ebenfalls der gleiche Ausgangsboden wie bei den beiden zuvor beschriebenen Versuchen benutzt. Die Sodagehalte (SAR) von 30, 40 und 50 (mmol $L^{-1})^{1/2}$ fanden sich in jeder Leitfähigkeitsstufe von 10, 20 und 30 dSm^{-1} wieder. Einschließlich der Kontrolle ergaben sich somit 10 Behandlungen in dreifacher Wiederholung und zwar vollständig randomisiert. Für die Einstellung der Leitfähigkeitsstufen fand die selbe Salzsorte Verwendung wie im 1. Experiment, ebenso verwendete man $NaHCO_3$ für die Soda-Abstufungen. Ansonsten erfolgten alle Maßnahmen wie in Experiment 1.

7.2 Auswertung des Langzeiteffektes auf das Wachstum von *Acacia ampliceps* bei salz- und sodahaltigen Bedingungen

Der Versuch wurde durchgeführt, um den Langzeiteffekt auf das Wachstum von *Acacia ampliceps* bei Salz- und Sodagehalten sowie Auswirkungen auf die Bodenverbesserung zu untersuchen. Zu diesem Zweck wählte man 12 Pflanzen unterschiedlichen Wuchsverhaltens am 10. März 2005 aus einer Fläche von 4.047 m² (acre) aus. Die Pflanzung war am 10. September 2001 erfolgt. Somit wiesen die Pflanzen bei der Ernte ein Alter von 3,5 Jahren auf. Die Klassifikation der Pflanzen in schlecht, mittelmäßig und gut erfolgte nach Aussehen und Parametern Höhe, Anzahl der Zweige, Stammumfang und Deckungsumfang (Pflanzendach). Bei diesen Parametern erfolgte die Messung und Auswertung. Bodenproben wurden bis zu einer Tiefe von 150 cm entnommen und auf Leitfähigkeit, pH-Wert und Natriumgehalt (SAR) untersucht. Drei weitere vergleichbare Untersuchungen erfolgten alle 6 Monate. Zur gleichen Zeit fand die Sammlung von Blättern und deren Analyse auf K^+, Na^+, Ca^{2+} und Mg^{2+} statt. Am 10. September 2006 war der Versuch vervollständigt. Die Korrelationen zwischen verschiedenen Wachstumsparametern und Bodencharakteristika wurden ausgearbeitet.

7.3 Studie 3: Untersuchung über Pflanzentechniken zur frühzeitigen Vermeidung des Salzstresses

Die Untersuchungen wurden durchgeführt um Auswirkungen von Pflanzentechniken zu einem frühen Zeitpunkt zu erkennen, an dem die Pflanzen noch besonders empfindlich auf einen Salzstress reagieren. Die folgenden Pflanzentechniken wurden geprüft:

T 1 Pflanzung in ein flaches Feld (ohne Gräben, Pflanzgruben oder Zusätze)

T 2 Pflanzung in Pflanzgruben (60 x 60 x 60 cm), aufgefüllt mit Originalboden auf dem Kanaldamm (90 x 60 m)

T 3 Pflanzung in Pflanzgruben (60 x 60 x 60 cm), aufgefüllt mit Schlick (junges Alluvium) auf dem Kanaldamm

T 4 Pflanzung in eine Pflanzgrube mit einem Bohrloch (7,5 cm Durchmesser) bis zu 150 cm Tiefe

T 5 Pflanzung in Pflanzgruben mit Schlick und Gips (Verhältnis 20 : 1)

T 6 Pflanzung in Pflanzgruben mit Originalboden und Gips (Verhältnis 20 : 1)

T 7 Pflanzung in Pflanzgruben mit Schlick und Kompost (Verhältnis 20 : 1)

T 8 Pflanzung in Pflanzgruben mit Originalboden und Kompost (Verhältnis 20 : 1)

Das ausgewählte Feld wurde nivelliert und für die Pflanzung der Bäume vorbereitet. Vor der Pflanzung erfolgte die Vervollständigung der Bodenproben für die Analyse der Leitfähigkeit (ECe) des pH-Wertes, der Natriumsadsorptionsrate (SAR), der Kationen und Anioden, des Kalkgehaltes und der Bodenstruktur. Gräben wurden gezogen und die Pflanzlöcher mit den o.g. Mischungen gefüllt. Es erfolgte die Pflanzung von Sämlingen gleichen Alters und gleicher Größe in einem randomisierten Versuch mit 4-facher Wiederholung mit jeweils 12 Pflanzen. Wuchsparameter wurden gleichzeitig mit Bodenanalysen alle 6 Monate festgehalten. Blattanalysen zur Bestimmung der K^+, Na^+, Ca^{2+} und Mg^{2+} - Konzentrationen erfolgte ebenfalls 2 mal jährlich im Zeitraum von 2 Jahren; der Versuch wurde am 11. September 2006 abgeschlossen.

Für alle gesammelten Daten erfolgte die statistische Auswertung (Varianzanalyse, Korrelationen, Mittelwerte und Standard-Abweichungen)

Aufgrund der Ergebnisse konnten folgende Erkenntnisse gewonnen werden:

1. Acacia ampliceps überlebte alle untersuchten Leitfähigkeitsstufen (Ece 10-50 dSm^{-1}) und alle Sodagehalte (SAR 20-50) mit Ausnahme der Stufen SAR 60 u. 70 (mmol $L^{-1})^{½}$. Keine Verluste waren zu verzeichnen wenn Leitfähigkeiten (Ece 10 - 30 dSm^{-1}) und Sodagehalte (SAR 30 - 50) gemischt untersucht wurden.

2. Salz- und Sodagehalte einschließlich verschiedener Mischungsverhältnisse verzögerten das Pflanzwachstum. Zwischen dem Minderwuchs (Höhe, Stammdurchmesser, Größe der Blattkrone, Anzahl der Blätter und Zweige) und dem Anstieg der verschiedenen Salzstufen gab es eine Beziehung. Auch das zunehmende Alter (bis zu 2 Jahren) konnte die negativen Effekte nicht ausgleichen.

3. Die Wuchshöhe von *Acacia ampliceps* fiel zwischen 13, 20, 29, 45 und 60 % zur Kontrolle bei Leitfähigkeitsstufen (ECe) von 10, 20, 30, 40 und 50 dSm^{-1} aus. Bei Sodagehalten (SAR) von 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ betrugen die Wuchsverluste 18, 32, 51 und 86 % zur Kontrolle. Bei verschiedenen Mischungen zwischen ECe und SAR lagen die Werte zwischen 16 - 64 % je nach Konzentration.

4. Der Stammdurchmesser der Pflanzen verringerte sich um 8, 17, 26, 42 und 57 % im Vergleich zur unbehandelten Variante bei ECe-Stufen von 10, 20, 30, 40 und 50 dSm^{-1}. Bei SAR-Gehalten von 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ betrugen die Werte beachtenswerte 13, 25, 43 und 78 %. Bei den Salzmischungen variierten die Ergebnisse zwischen 11 und 51 %. Die geringste Wuchsleistung trat bei der Salzmischung ECe 30 + SAR 50 auf.

5. Die Blattentwicklung war ebenfalls bei verschiedenen Salzintensitätsstufen negativ. Ein gleichmäßiges Abfallen älterer Blätter war vorhanden. Bei ECe – Stufen von 10, 20, 30, 40 und 50 dSm^{-1} verringerte sich die Blattanzahl um 7, 17, 27, 43 und 68 %. Noch ausgeprägter war das Verhältnis bei den Sodagehalten. Bei SAR Stufen von 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ verringerten sich die Blätter um 8, 20, 48 und 85 % im Vergleich zur unbehandelten Kontrolle. Auch bei der Mischung der Salze verringerte sich die Anzahl der Blätter. Die geringsten Verluste traten bei der Kombination ECe 10 und SAR 30 und die größten bei ECe 30 + SAR 50 mit 65 % auf.

6. Die Anzahl der Zweige pro Pflanze nahm genauso wie die Anzahl der Blätter ab. Bei ECe-Stufen von 10, 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ betrugen die Abnahmen 16, 30, 48, 68 und 77 %. Bei den SAR-Stufen von 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ ergaben sich Werte von 30, 48, 63 und 87 % zur Kontrolle. Bei den Salzmischungen betrugen die Abnahmen zwischen 14 % (ECe 10 + SAR 30) und 75 % (ECe 30 + SAR 50).

7. Die Ausdehnung der Pflanzen wurde ebenfalls unterdrückt. Bei ECe von 10, 20, 30, 40 und 50 dSm^{-1} betrug die Verminderung 11, 22, 28, 57 und 80 %; bei SAR mit 20, 30, 40 und 50 (mmol $L^{-1})^{½}$ 15, 38, 77 und 90 %. Bei Mischung der Salze schwankten die Werte zwischen 11 und 82 %.

8. Bei ECe von 10, 20, 30, 40 und 50 dSm^{-1} ergaben sich beim Trockengewicht der Sprosse Einbußen von 5, 6, 16, 37 und 52 %. Damit verursacht die höchste Stufe einen Wert von 52 %, der sehr dicht zur kritischen Grenze von 50 % liegt (welche in derartigen Salztoleranzuntersuchungen erlaubt ist). Der relative Ertrag, wie von MASS (1990) vorgeschlagen, wurde mit 96, 88, 71 und 56 % für die Salzstufen 20, 30, 40 und 50 dSm^{-1} berechnet. Die höchste untersuchte Stufe mit einem Verlust von ca. 50 % zeigt die hohe Salztoleranz dieser Pflanze an. Die Verluste des Wurzeltrockengewichtes betrugen 15, 22, 29, 46 und 60 % bei ECe von 10, 20, 30, 40 und 50 dSm^{-1}. Wurzeln werden demnach stärker geschädigt als Sprosse.

9. Die Auswirkungen von Soda stellten sich als stärker heraus insbesondere bei dem höheren Stufen (SAR 40 + 50). Die Minderung der Sprosstrockengewichte betrug 3, 18, 53 und 70 % bei SAR 20, 30, 40 und 50 (mmol $L^{-1})^{½}$. In gleicher Weise fielen die Wurzeltrockengewichte um 20, 34, 52 und 66 % bei den selben Werten für SAR. Somit verursacht ein SAR 40 schon ein Gewichtsverlust von 50 %, womit eine kritische Grenze erreicht wurde.

10. Es ergab sich eine Verminderung des Sprosstrockengewichtes von 6 – 66 % und des Wurzeltrockengewichtes von 17 – 61 % bei verschiedenen Mischungsstufen von ECe + SAR. Die Minimumgehalte lagen bei ECe 10 + SAR 30 und die Maxima bei ECe 30 + SAR 50. Der kritische Wert mit einem Abfall von 50 % stellte sich bei ECe 30 + SAR 40 ein.

11. Die Feldergebnisse der 2. Studie bestätigen die Aussagen der zuvor dargelegten Erkenntnisse aus den Gefäßversuchen. Die gemessenen Wuchsparameter der schlechteren Pflanzengruppe standen in Relation zu den höheren ECe und SAR des Bodens. Unter den Pflanzenkronen der schlechteren Pflanzen fand sich das Maximum an ECe und SAR, unter der mittleren Pflanzengruppe ergaben sich auch mittlere Werte und unter den gutwüchsigen Pflanzen lagen die Werte im Minimum.

12. Die Korrelation zwischen den Wuchsparametern und den ECe und SAR Stufen ergab das obige Bild. Die Korrelation zwischen Wachstum und Bodenversalzung war direkt und zwar negativ. Die meisten Korrelationen waren statistisch signifikant.

13. Die Ergebnisse aus Blättern und Wurzeln verschiedener Versuche zeigte einen steigenden Na^+-Gehalt sowohl bei älteren als auch jüngeren Blättern mit steigenden Salzgehalten (einzeln und gemischt) an. Der Einfluss von Soda (allein) war größer. Es ergab sich eine höhere Konzentration in den älteren Blättern. Der Natriumgehalt in den Wurzeln stieg ebenfalls an. Die Kaliumgehalte verringerten sich in einer Vielzahl von Anwendungsstufen, wobei die älteren Blätter im unteren Bereich lagen. Die Gehalte von Ca^{2+} waren in älteren Blättern höher und fielen signifikant mit der Erhöhung von ECe, SAR und ECe + SAR ab. Der Trend in den Wurzeln war gleich. Es ergab sich eine Verringerung des Mg^{2+} - Gehaltes in den Blättern und Wurzeln bei jeder höheren Behandlungsstufe (Versalzung). Ältere und jüngere Blätter variierten nicht besonders stark. Das Verhältnis von K^+ : Na^+ war in Blättern und Wurzeln von Pflanzen ohne jeglichen Salzstress weit, es verringerte sich jedoch bei höheren Salzkonzentrationen in der Rhizosphäre.

14. Der negative Einfluss von Salzen auf *Acacia ampliceps* fand sich auch in einem osmotischen Effekt und einer speziellen Ionen-Toxizität. Die festgestellte signifikante Verringerung des Wassergehaltes in Spross und Wurzeln zeigte an, dass die Pflanzen bei bestimmten (höheren) Salzgehalten (Einzelsalze oder in Mischungen) kein Wasser mehr aufnehmen konnten. Die Feuchtigkeitsabnahme von 15 % bei Sprossen und 13 % bei Wurzeln wurde bei einer ECe-Stufe von 50 dSm^{-1} beobachtet. Bei der selben Stufe von SAR fiel der Wassergehalt bei Sprossen um 20 % und in den

Wurzeln um 14 %. Dort ergab sich eine sehr starke Aufnahme von Na^{+}, die zu Schädigungen innerhalb der Pflanze führen könnte.

15. Zwei Wirkungen zur Salztoleranz von *Acacia ampliceps* konnten aus den gesammelten Daten erkannt werden. Diese Mechanismen waren: Ionen-Selektivität und –Einkapselung. Die Pflanzen führten eine Auswahl der Ionen durch und zwar mit einer sehr hohen Menge von Na^{+} und einer gleichmäßigen Aufnahme von K^{+}, Ca^{2+} und Mg^{2+}. Dieses Verhalten war bei den unteren Salzgehalten besonders wirkungsvoll und ließ teilweise bei den höheren Stufen nach. Dennoch war das K^{+} : Na^{+} - Verhältnis nahezu einheitlich bis zu einer Stufe von 40 ECe oder 50 SAR. Da sich höhere Na^{+}-Gehalte in älteren Blättern nachweisen ließen, kann dort auf eine Ablagerung von Salzen geschlossen werden, auch wenn die Blätter dabei grün blieben.
16. Das Pflanzenwachstum wirkt sich auch auf die Bodenbedingungen aus. ECe und SAR fielen signifikant im Unterboden der Pflanzen ab und zwar in Verbindung mit dem Laubzerfall und dem Auswaschen von Salzen.
17. Die erprobten Pflanztechniken halfen erheblich einem frühzeitigen Salzstress zu widerstehen, wenn die Pflanzen noch besonders empfindlich waren. Die Wuchsparameter waren mannigfach höher, wenn in Pflanzgruben mit Schlick oder Schlick und Kompost gepflanzt wurde.
18. Folgende Korrelationen ergaben sich:

1.	Boden ECe (Leitfähigkeit) und Wuchshöhe	y = -3.1491 x + 309.62
2.	Boden ECe (Leitfähigkeit) und Stammdurchmesser	y = -0.0265 x + 2.6882
3.	Boden ECe (Leitfähigkeit) und Anzahl der Blätter	y = -7.3984 x + 620.72
4.	Boden ECe (Leitfähigkeit) und Anzahl der Zweige	y = -0.7228 x + 45.776
5.	Boden ECe (Leitfähigkeit) und Blattkrone	y = -0.0840 x + 5.6594
6.	Boden ECe (Leitfähigkeit) und Sprosstrockengew.	y = -10.712x + 1080.5
7.	Boden ECe (Leitfähigkeit) und Wurzeltrockengew.	y = -2.7769 x + 237.71
8.	Boden SAR (Sodagehalt) und Wuchshöhe	y = -5.5061 x + 363.77
9.	Boden SAR (Sodagehalt) und Wuchshöhe	y = -0.0450 x + 3.2065
10.	Boden SAR (Sodagehalt) und Wuchshöhe	y = -11.777 x + 756.64
11.	Boden SAR (Sodagehalt) und Wuchshöhe	y = -0.9650 x + 54.925

12. Boden SAR (Sodagehalt) und Wuchshöhe y = -0.1291 x + 6.8263

13. Boden SAR (Sodagehalt) und Wuchshöhe y = -19.579 x + 1307.9

14. Boden SAR (Sodagehalt) und Wuchshöhe y = -4.0477 x + 281.36

X = Berücksichtigung der Bodenparameter

Y = Berücksichtigung der Pflanzenparameter

7.4 Schlussfolgerungen

Folgende Schlussfolgerungen lassen sich von der gesamten Untersuchung ableiten:

- *Acacia ampliceps* ist eine stark salztolerante Pflanze, die Wachstums- und Gewichtseinbußen erst bei ECe von $50 dSm^{-1}$, SAR von 40 $(mmol\ L^{-1})^{1/2}$ und der Mischung von ECe + SAR bei 30 + 40 aufweist.
- Wuchsparameter (Höhe, Stammdurchmesser, Anzahl der Blätter und Zweige, Blattkrone) und Wasseraufnahme werden signifikant mit dem Anstieg der Leitfähigkeit (ECe) und dem Sodagehalt (SAR) bzw. Mischungen daraus, reduziert. Die Natriumaufnahme steigt stark an, während K^+, Ca^{2+} und Mg^{2+}- Gehalte bei steigendem Stress (Salzgehalten) abnehmen.
- Der negative Einfluss des Salzstresses ergab sich aus osmotischen Effekten ebenso wie aus der Ionengiftigkeit, insbesondere des Natriums. Die Pflanze konnte Salz- bzw. Sodagehalte durch Ionenselektivität (Erhaltung eines relativ weiten $K^+ : Na^+$ Verhältnisses) und Einkapselung von Ionen tolerieren.
- Durch den Anbau von *Acacia ampliceps* tritt eine Bodenverbesserung durch Verminderung der ECe und SAR unterhalb der Pflanzen ein.
- Die Einbringung der Pflanzen in Pflanzgruben mit einer Schlick- bzw. Schlick / Kompost – Füllung sorgt für einen guten Wuchs und ist hilfreich im frühen Versalzungsstadien.

7.5 Empfehlung für Landwirte

Landwirte können ihr stark versalzenes Land für den Anbau von *Acacia ampliceps* nutzen, wenn sie Gräben mit einer Breite von 90 cm und einer Tiefe von 60 cm ziehen, Pflanzgruben von 60 cm Seitenlänge und 60 cm Tiefe ausheben und diese mit Schlick oder Schlick + Kompost (Verhältnis 20 : 1) verfüllen. Es gibt keine Wuchsverluste und eine erhebliche Bodenverbesserung. Wenn sie 4 ha mit dieser Pflanze anbauen und 1 ha saisonaler Futterpflanzen (Luzerne, Sesbania, Mais, Perlhirse + kleine Hirse) hinzunehmen, können sie 100 Schafe oder Ziegen aufziehen und 1.176 € (Pakistani Repies 94.084) pro Jahr und ha verdienen.

7.6 Zukünftige Maßnahmen

Weitere Untersuchungen sind auf salzbeeinflussten Böden mit unterschiedlicher Bodenstruktur notwendig. Ebenso wenn die Pflanzen kontinuierlich mit salz-/sodahaltigem Wasser bewässert werden.

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Appendix 1: Soil analysis after two years of Experiment -1 in Study -1

Salinity levels EC_e ($dS\ m^{-1}$)	EC_e ($dS\ m^{-1}$)	pH	SAR ($mmol\ L^{-1})^{1/2}$	$Ca^{2+} + Mg^{2+}$ ($mmol_c\ L^{-1}$)	Na^+ ($mmol_c L^{-1}$)
Control	1.66 F	8.15 C	8.82 F	4.56 F	13.31 F
10	9.21 E	8.31 A	13.53 E	46.33 E	65.11 E
20	17.45 D	8.29 A	15.71 D	107.44 D	115.20 D
30	28.07 C	8.22 B	18.62 C	193.83 C	183.26 C
40	37.17 B	8.23 B	21.16 B	269.96 B	245.78 B
50	46.69 A	8.21 B	23.41 A	347.25 A	308.56 A

Appendix 2: Soil analysis after two years of Experiment -2 in Study -1

Sodicity levels SAR ($mmol\ L^{-1})^{1/2}$	EC_e ($dS\ m^{-1}$)	pH	SAR ($mmol\ L^{-1})^{1/2}$	$Ca^{2+} + Mg^{2+}$ ($mmol_c\ L^{-1}$)	Na^+ ($mmol_c L^{-1}$)
Control	1.59 E	8.16 E	8.33 E	4.39 A	12.35 E
20	2.10 D	8.39 D	17.62 D	2.60 B	19.99 D
30	2.69 C	8.66 C	27.39 C	2.03 C	27.61 C
40	3.24 B	9.10 B	37.85 B	1.66 D	34.53 B
50	3.97A	9.45 A	47.73 A	1.58 E	42.50 A

Appendix 3: Soil analysis after two years of Experiment -3 in Study -1

Salinity + sodicity levels (EC_e + SAR)	**EC_e (dSm^{-1})**	**pH**	**SAR ($mmol\ L^{-1})^{1/2}$**	**Ca^{2+} + Mg^{2+} ($mmol_c\ L^{-1}$)**	**Na^+ ($mmol_c L^{-1}$)**
Control	1.64 D	8.16 I	8.45 D	4.43 J	12.59 I
10 + 30	8.88 C	8.55 F	26.76 C	20.56 G	85.83 H
10 + 40	8.86 C	8.92 C	37.07 B	12.65 H	93.12 GH
10 + 50	8.81 C	9.20 A	45.96 A	9.06 I	97.80 G
20 + 30	17.28 B	8.50 G	26.67 C	67.20 D	154.49 F
20 + 40	17.52 B	8.85 D	36.57 B	47.20 E	177.64 E
20 + 50	17.40 B	9.08 B	46.44 A	33.30 F	189.55 D
30 + 30	27.13 A	8.41 H	26.76 C	142.00 A	225.46 C
30 + 40	27.15 A	8.69 E	36.86 B	103.19 B	264.74 B
30 + 50	27.61 A	8.82 D	45.78 A	81.45 C	292.25 A

Appendix 4: Changes in water soluble $Ca^{2+} + Mg^{2+}$ ($mmol_c L^{-1}$) in relation to plant growth in Study -2 at various depths

Plant Condition	Before plantation Sep.,2001	After 3.5 years March,2005	After 4 years Sep.,2005	After 4.5 years March,2006	After 5 years Sep.,2006
0-15 cm					
Poor	4.89 ± 0.25	3.23 ± 0.32	4.04 ± 0.10	5.03 ± 0.47	5.45 ± 0.30
Medium	3.94 ± 0.25	5.37 ± 0.62	5.98 ± 0.23	6.58 ± 0.18	6.76 ± 0.14
Good	4.12 ± 0.07	5.36 ± 0.64	6.18 ± 0.43	7.07 ± 0.32	7.43 ± 0.22
15-30 cm					
Poor	3.90 ± 0.09	3.40 ± 0.27	5.16 ± 0.35	5.22 ± 0.40	5.50 ± 0.26
Medium	3.59 ± 0.28	5.34 ± 0.45	6.06 ± 0.41	6.34 ± 0.36	6.81 ± 0.14
Good	3.39 ± 0.40	5.37 ± 0.58	7.25 ± 0.47	7.44 ± 0.51	7.58 ± 0.14
30-60 cm					
Poor	4.14 ± 0.11	3.63 ± 0.20	5.35 ± 0.34	5.40 ± 0.39	5.58 ± 0.24
Medium	3.70 ± 0.33	5.64 ± 0.50	6.42 ± 0.46	6.60 ± 0.52	6.90 ± 0.16
Good	3.46 ± 0.32	5.66 ± 0.55	7.34 ± 0.39	7.53 ± 0.47	7.73 ± 0.14
60-90 cm					
Poor	4.60 ± 0.15	3.78 ± 0.13	5.40 ± 0.43	5.42 ± 0.32	5.57 ± 0.22
Medium	4.12 ± 0.19	6.10 ± 0.29	6.64 ± 0.38	6.82 ± 0.41	7.06 ± 0.10
Good	3.85 ± 0.29	6.02 ± 0.42	7.50 ± 0.51	7.56 ± 0.35	7.75 ± 0.11
90-120 cm					
Poor	4.63 ± 0.22	4.00 ± 0.13	5.42 ± 0.36	5.48 ± 0.33	5.65 ± 0.17
Medium	4.44 ± 0.13	6.32 ± 0.21	6.70 ± 0.41	6.86 ± 0.29	7.14 ± 0.06
Good	4.17 ± 0.06	6.25 ± 0.37	7.52 ± 0.33	7.68 ± 0.24	7.82 ± 0.11
120-150 cm					
Poor	3.46 ± 0.23	4.16 ± 0.07	5.48 ± 0.28	5.56 ± 0.27	5.71 ± 0.16
Medium	4.60 ± 0.14	6.45 ± 0.20	6.82 ± 0.31	6.92 ± 0.21	7.22 ± 0.05
Good	4.31 ± 0.22	6.47 ± 0.25	7.60 ± 0.26	7.74 ± 0.32	7.86 ± 0.11

All values are average of 12 observations.

Appendix 5: Changes in water soluble Na^+($mmol_c L^{-1}$) in relation to plant growth in Study -2 at various depths

Plant Condition	Before plantation Sep.,2001	After 3.5 years March,2005	After 4 years Sep.,2005	After 4.5 years March,2006	After 5 years Sep.,2006
0-15 cm					
Poor	228 ± 12.13	149 ± 11.42	118 ± 9.00	99 ± 8.65	82 ± 7.62
Medium	173 ± 12.06	78 ± 9.68	67 ± 7.86	56 ± 3.22	51 ± 1.07
Good	146 ± 6.56	71 ± 3.52	59 ± 2.03	50 ± 0.91	39 ± 1.60
15-30 cm					
Poor	200 ± 13.38	130 ± 7.89	100 ± 8.34	87 ± 7.12	69 ± 2.23
Medium	149 ± 10.99	79 ± 6.36	67 ± 5.66	55 ± 3.42	49 ± 2.41
Good	122 ± 5.10	69 ± 2.67	58 ± 3.52	48 ± 2.10	40 ± 2.09
30-60 cm					
Poor	194 ± 12.64	125 ± 5.44	99 ± 7.42	81 ± 5.68	67 ± 2.94
Medium	145 ± 11.30	70 ± 2.58	66 ± 4.73	53 ± 3.02	48 ± 1.79
Good	120 ± 5.11	67 ± 2.69	54 ± 2.95	43 ± 2.32	38 ± 1.52
60-90 cm					
Poor	187 ± 10.18	114 ± 2.81	95 ± 5.61	77 ± 4.74	67 ± 2.24
Medium	139 ± 10.03	67 ± 1.64	63 ± 3.11	52 ± 2.36	47 ± 2.99
Good	115 ± 4.98	64 ± 1.39	52 ± 2.66	40 ± 2.51	39 ± 2.28
90-120 cm					
Poor	138 ± 10.58	107 ± 1.50	92 ± 6.22	74 ± 3.87	66 ± 0.84
Medium	99 ± 7.54	66 ± 1.06	61 ± 3.24	51 ± 3.20	46 ± 1.58
Good	90 ± 1.80	62 ± 2.50	51 ± 3.00	39 ± 2.42	37 ± 1.91
120-150 cm					
Poor	103 ± 4.15	96 ± 2.56	91 ± 5.69	72 ± 4.13	65 ± 0.45
Medium	69 ± 2.74	64 ± 1.12	58 ± 4.10	51 ± 2.78	45 ± 1.74
Good	62 ± 4.97	59 ± 1.28	52 ± 2.84	38 ± 1.92	36 ± 1.80

All values are average of 12 observations.

Appendix 6: Changes in water soluble K^{+} ($mmol_c\ L^{-1}$) in relation to plant growth in Study -2 (0 – 15 cm) depth

Plant Condition	Before plantation Sep.,2001	After 3.5 years March,2005	After 4 years Sep.,2005	After 4.5 years March,2006	After 5 years Sep.,2006
Poor	0.55 ± 0.06	0.55 ± 0.06	0.54 ± 0.04	0.58 ± 0.03	0.57 ± 0.03
Medium	0.51 ± 0.10	0.55 ± 0.05	0.53 ± 0.05	0.49 ± 0.02	0.53 ± 0.03
Good	0.48 ± 0.05	0.49 ± 0.01	0.50 ± 0.05	0.50 ± 0.03	0.52 ± 0.03

Appendix 7: Changes in water soluble anions ($mmol_c\ L^{-1}$) in relation to plant growth in Study -2 (0 – 15 cm) depth

a) CO_3^{2-}

Plant Condition	Before plantation Sep.,2001	After 3.5 years March,2005	After 4 years Sep.,2005	After 4.5 years March,2006	After 5 years Sep.,2006
Poor	8.12 ± 0.23	6.19 ± 0.28	5.59 ± 0.32	5.09 ± 0.31	5.10 ± 0.36
Medium	8.16 ± 0.20	7.48 ± 0.31	5.84 ± 0.27	6.38 ± 0.27	5.02 ± 0.25
Good	8.22 ± 0.31	6.59 ± 0.27	5.22 ± 0.18	5.05 ± 0.17	4.12 ± 0.21

b)HCO_3^{1-}

Poor	23.74 ± 0.28	16.93 ± 0.20	14.72 ± 0.31	13.01 ± 0.35	12.23 ± 0.31
Medium	23.90 ± 0.33	14.24 ± 0.48	12.64 ± 0.28	11.11 ± 0.24	10.46 ± 0.37
Good	23.85 ± 0.24	12.65 ± 0.43	10.29 ± 0.21	8.58 ± 0.36	7.97 ± 0.39

c) Cl^{1-}

Poor	197 ± 12.32	125 ± 12.17	94 ± 8.95	82 ± 8.52	63 ± 7.34
Medium	142 ± 12.12	58 ± 10.39	47 ± 8.35	37 ± 2.83	31 ± 0.79
Good	114 ± 06.70	50 ± 03.64	38 ± 2.45	31 ± 0.68	22 ± 2.75

d) SO_4^{2-}

Poor	5.76 ± 0.47	6.70 ± 0.36	8.48 ± 0.75	9.36 ± 0.50	10.65 ± 0.60
Medium	6.54 ± 0.26	11.45 ± 0.64	12.34 ± 0.73	12.78 ± 0.73	13.29 ± 0.70
Good	6.56 ± 0.22	13.65 ± 0.74	14.07 ± 0.63	14.16 ± 0.82	14.69 ± 0.43

Appendix 8: Impact of transplantation techniques on water soluble $Ca^{2+} + Mg^{2+}$ ($mmol_c L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	3.10	3.64 ABC	3.71 CD	3.75 E	3.80 D	0.70	-	-
T2- Transplantation in pit filled with original soil	3.00	3.60 BC	3.77 CD	3.88 E	3.96 CD	0.96	0.26	37
T3- Transplantation in pit filled with silt	3.19	3.79 AB	4.12 A	4.30 BC	4.62 AB	1.43	0.73	104
T4- Transplantation in pit filled with silt + augering	3.17	3.81 AB	4.08 AB	4.36 B	4.73 AB	1.56	0.86	122
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	3.00	3.68 ABC	3.83 C	4.12 D	4.42 BC	1.42	0.72	103
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	3.04	3.54 C	3.60 D	3.80 E	4.15 BCD	1.11	0.41	59
T7- Transplantation in pit filled with silt + compost (20 : 1)	3.18	3.84 A	4.15 A	4.55 A	5.11 A	1.93	1.23	176
T8- Transplantation in pit filled with original soil + Compost (20:1)	3.22	3.66 ABC	3.90 BC	4.17 CD	4.34 BCD	1.12	0.42	60

Appendix 9: Impact of transplantation techniques on water soluble Na^{+} ($mmol_c L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	301	270 A	251 A	234 A	219 A	82	-	-
T2- Transplantation in pit filled with original soil	291	273 A	250 A	224 B	202 A	89	7	9
T3- Transplantation in pit filled with silt	300	243 B	227 CD	195 E	148 BC	152	70	85
T4- Transplantation in pit filled with silt + augering	302	245 B	226 CD	185 F	137 C	165	83	101
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	301	245 B	229 CD	198 DE	159 BC	142	60	73
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	293	244 B	246 AB	207 C	172 B	121	39	48
T7- Transplantation in pit filled with silt + compost (20 : 1)	302	233 B	222 D	176 G	109 D	193	111	135
T8- Transplantation in pit filled with original soil + Compost (20:1)	303	240 B	237 BC	199 D	156 BC	147	65	79

All values are average of 48 observations

Appendix 10: Impact of transplantation techniques on water soluble K^+ ($mmol_c\ L^{-1}$) in Study -3

Treatments	At transp lantati on time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	0.55	0.56	0.55	0.54	0.56	0.01	-	-
T2- Transplantation in pit filled with original soil	0.55	0.56	0.58	0.59	0.57	0.02	0.01	100
T3- Transplantation in pit filled with silt	0.51	0.54	0.55	0.55	0.53	0.02	0.01	100
T4- Transplantation in pit filled with silt + augering	0.54	0.58	0.58	0.57	0.57	0.03	0.02	200
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	0.49	0.54	0.49	0.53	0.54	0.05	0.04	400
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	0.51	0.57	0.55	0.56	0.55	0.04	0.03	300
T7- Transplantation in pit filled with silt + compost (20 : 1)	0.64	0.60	0.58	0.59	0.58	0.06	0.05	500
T8- Transplantation in pit filled with original soil + Compost (20:1)	0.52	0.53 N.S.	0.55 N.S.	0.58 N.S.	0.56 N.S.	0.04	0.03	300

Appendix 11: Impact of transplantation techniques on water soluble CO_3^{2-} ($mmol_c\ L^{-1}$) in Study -3

Treatments	At transp lantati on time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	20.34	19.21 BC	18.32 D	17.39	17.06	3.28	-	-
T2- Transplantation in pit filled with original soil	21.15	19.35 BC	19.03 CD	17.82	17.14	4.01	0.73	22
T3- Transplantation in pit filled with silt	21.60	20.90 AB	20.15 ABC	17.23	15.10	6.50	3.22	98
T4- Transplantation in pit filled with silt + augering	22.54	21.28 A	20.84 AB	16.87	14.32	8.22	4.94	151
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	20.68	18.86 C	18.08 D	16.10	15.23	5.51	2.23	68
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	21.42	18.95 C	18.23 D	16.26	15.17	6.25	2.93	89
T7- Transplantation in pit filled with silt + compost (20 : 1)	22.90	21.75 A	21.31 A	17.13	14.08	8.82	5.54	169
T8- Transplantation in pit filled with original soil + Compost (20:1)	22.69	20.32 ABC	19.58 BCD	16.86 N.S.	14.58 N.S.	8.11	4.83	147

All values are average of 48 observations

Appendix 12: Impact of transplantation techniques on water soluble HCO_3^- ($mmol_c L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	17.52	16.24	15.06	14.57	14.16 A	3.36	-	-
T2- Transplantation in pit filled with original soil	17.20	16.16	15.02	14.34	13.62 AB	3.58	0.22	7
T3- Transplantation in pit filled with silt	16.40	14.95	14.04	12.82	11.21 C	5.19	1.83	54
T4- Transplantation in pit filled with silt + augering	16.32	15.72	15.13	13.16	11.10 C	5.22	1.86	55
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	15.96	15.53	14.87	12.23	11.40 BC	4.56	1.20	36
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	16.71	15.75	14.34	12.47	10.92 C	5.79	2.43	72
T7- Transplantation in pit filled with silt + compost (20 : 1)	17.30	16.97	15.24	12.68	10.44 C	6.86	3.50	104
T8- Transplantation in pit filled with original soil + Compost (20:1)	16.39	14.76 N.S.	14.69 N.S.	13.15 N.S.	10.86 C	5.53	2.17	65

Appendix 13: Impact of transplantation techniques on water soluble Cl^- ($mmol_c L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	256	228 A	212 A	196 A	181 A	75	-	-
T2- Transplantation in pit filled with original soil	248	229 A	209 A	184 B	164 A	84	9	12
T3- Transplantation in pit filled with silt	258	198 B	187 CDE	155 E	109 BC	149	74	99
T4- Transplantation in pit filled with silt + augering	257	200 B	184 DE	146 F	99 CD	158	83	111
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	260	203 B	190 CD	160 D	122 BC	138	63	84
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	249	202 B	207 AB	168 C	131 B	118	43	57
T7- Transplantation in pit filled with silt + compost (20 : 1)	257	186 B	178 E	136 G	70 D	187	112	149
T8- Transplantation in pit filled with original soil + Compost (20:1)	259	197 B	190 CD	159 D	118 BC	141	66	88

All values are average of 48 observations

Appendix 14: Impact of transplantation techniques on water soluble SO_4^{2-} ($mmol_c\ L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Increase in two years	Difference over control	Increase over control %
T1- Control (flat sowing)	10.42	11.75	11.62	12.18 B	13.45 C	3.03	-	-
T2- Transplantation in pit filled with original soil	9.86	12.64	12.79	13.75 B	13.66 C	3.80	0.77	25
T3- Transplantation in pit filled with silt	9.75	13.51	13.16	16.40 A	19.54 AB	9.79	6.76	223
T4- Transplantation in pit filled with silt + augering	9.66	13.42	13.30	16.38 A	19.71 AB	10.05	7.02	232
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	10.00	12.70	12.45	15.96 A	18.18 B	8.18	5.15	170
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	9.80	12.86	12.33	16.10 A	18.85 AB	9.05	6.02	199
T7- Transplantation in pit filled with silt + compost (20 : 1)	10.10	13.47	13.44	17.28 A	20.78 A	10.68	7.65	252
T8- Transplantation in pit filled with original soil + Compost (20:1)	10.01	12.73 N.S.	12.75 N.S.	15.60 A	18.94 AB	8.93	5.90	195

Appendix 15: Impact of transplantation techniques on TSS ($mmol_c\ L^{-1}$) in Study -3

Treatments	At transplantation time	After six months	After one year	After one and a half year	After two years	Decrease in two years	Difference over control	Decrease over control %
T1- Control (flat sowing)	305	275 A	257 A	240 A	225 A	80	-	-
T2- Transplantation in pit filled with original soil	296	277 A	257 A	230 B	208 A	88	8	10
T3- Transplantation in pit filled with silt	306	247 B	234 CD	201 E	155 BC	151	71	89
T4- Transplantation in pit filled with silt + augering	306	251 B	234 CD	192 F	144 CD	162	82	102
T5- Transplantation in pit filled with silt + gypsum (20 : 1)	307	250 B	236 CD	204 DE	166 BC	141	61	76
T6- Transplantation in pit filled with original soil + gypsum (20 : 1)	297	249 B	252 AB	213 C	176 B	121	41	51
T7- Transplantation in pit filled with silt + compost (20 : 1)	307	238 B	228 D	183 G	116 D	191	111	139
T8- Transplantation in pit filled with original soil + Compost (20:1)	308	245 B	243 BC	205 D	163 BC	145	65	81

All values are average of 48 observations

Appendix 16: Climatic data of Soil Salinity Research Institute, Pindi Bhattian, Punjab, Pakistan (July, 2004 - September, 2006)

Month	Temperature (C^0) (Minimum)	Temperature (C^0) (Maximum)	Rainfall (mm)
July, 2004	24.93	38.06	50
August, 2004	23.48	36.48	59
September, 2004	21.90	36.43	17
October, 2004	18.12	29.48	06
November, 2004	10.56	18.33	-
December, 2004	09.38	15.93	30
January, 2005	06.09	09.87	25
February, 2005	02.78	11.53	70
March, 2005	11.25	26.61	32
April, 2005	14.30	34.06	11
May, 2005	18.29	39.19	20
June, 2005	24.80	36.00	67
July, 2005	23.90	38.80	141
August, 2005	27.74	39.51	107
September, 2005	20.08	37.36	39
October, 2005	15.00	31.67	10
November, 2005	09.23	26.50	-
December, 2005	12.12	22.93	-
January, 2006	02.45	18.87	Traces
February, 2006	08.57	28.50	16
March, 2006	12.22	28.32	29
April, 2006	21.46	34.83	-
May, 2006	24.51	41.58	50
June, 2006	22.03	39.30	74
July, 2006	23.89	37.76	35
August, 2006	23.50	36.58	24
September, 2006	21.51	35.62	13

LIST OT TABLES

LIST OT FIGURES

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