PERFORMANCE OF TREE SPECIES UNDER SALINE AND WATERLOGGED SOILS OF TUNGABHADRA COMMAND AREA

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C E R T I F I C A T E

This is to certify that the thesis entitled **"PERFORMANCE OF TREE SPECIES UNDER SALINE AND WATERLOGGED SOILS OF TUNGABHADRA COMMAND AREA"** Submitted by **Mr. VITTAL KULIGOD.**, for the degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE** of the UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis of award of any degree, diploma, associateship, fellowship or other similar titles.

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To my beloved parents and
parents-in-law

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CHAPTER - I

INTRODUCTION

I INTRODUCTION

The ever growing population of our country has opened up new opportunities and obligations to alternate land use planning of salt-affected soils. This has further gained significance due to extra agricultural inputs such as expensive chemical amendments, fertilizers, water and drainage to reclaim these saline and sodic waste lands. These rehabilitative measures are not only cost prohibitive but also time consuming besides the socio-economic status of our farmers. This has led to the alternate management practices in which use of agricultural inputs are phased out. This requirement is very well metout through afforestation programme either by individual farmer or on community basis. In addition, the afforestation programme of salt affected soils have proven bio-ameliorative effects besides providing forest cover, fuel wood, fodder, timber and also preventing soil erosion. Afforestation of any such waste lands thus provides a unique opportunity not only in relcamation but also in improving the bio-productivity of such waste lands with sound benificial effects on natural ecology and environment.

The choice of the tree species in the afforestation programme is largely governed by their ability to withstand

the hostile environment like high salinity, sodicity and water logging. From the research reports, it is quite evident that the tree/horticultural species show marked variations in their abilities to withstand such unfavourable soil conditions. Tolerant tree species may differ in their mechanism which may enable them to overcome high concentrations of salt and ion stresses. Whenever the salinity and waterlogging occur simultaneously, the salinity and aeration stresses are often confounded.

Saline soil conditions, are normally stressful to plants. Firstly, they depress the external water potential making water not readily available to plants (osmotic effect). Secondly, ions such as sodium, chloride and others may upset mineral nutrition or cuase toxicities (specific ion effects). Sodicity i.e. higher ratio of sodium to other cations may have specific ion effects. The osmotic effects of salinity are dealtwith by two mechanisms: absorption of salts from the medium and synthesis of organic solutes and normally by both mechanisms.

Usually most salt tolerant species are halophytes tend to absorb more salts from the medium and sequester them in the vacuoles while, organic compatible solutes serve the osmotic adjustment in the cytoplasm. In case of salt

sensitive plants (glycophytes), they tend to exclude sodium and chloride from the shoots and especially, the leaves. Hence, they have to rely more heavily than halophytes do for the synthesis of organic osmolytes. Disturbances in various aspects of mineral nutrition cause specific ion effects. The most common specific ion effects are saltinduced deficiencies of nutrient elements. Usually, calcium at elevated concentrations mitigate the adverse effects of salinity to plants.

Certain tree species show greater tolerance to saline and sodic conditions as compared to agricultural crops. This attributes exhibited by tree species are best exploited in the afforestation programme all over the world.

The present experiment on evaluation of tree species against soil salinity and shallow water table was laid out with the following objectives.

1. To study the performance of different tree species under saline and shallow water table conditions and
2. To study bio-ameliorative effect of tree species on saline soils

CHAPTER - II

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

In the recent past improved technologies have been developed for cultivation of annual food crops in problematic soils including salt affected and waterlogged soils. Besides, these soils can be chemically ameliorated. However, profitable cultivation of annual food and fibre crops in these soils is doubtful because of their lower production potentiality. Further, these soils may deteriorate again due to cultivation of field crops. On the other hand, trees noted for tolerance to salinity and waterlogging can be profitably grown on such problematic soils without much investments for fuel, wood and fodder. Some of the tree species have been known to ameliorate salt affected soils. So, their potentiality to improve the soils can be exploited.

Literature pertinent to the present investigation are presented in this chapter under following sub-titles.

2.1 Scope and relevance of agroforestry for salt-affected soils

2.2 Dynamics of soil salinity and ground water table

2.3 Relative tolerance of trees to salinity and waterlogging

2.4 Influence of soil salinity and waterlogging on ionic composition of tree tissues

2.5 Bio-amelioration of salt affected soils through tree cover

2.1 Scope and relevance of agro-forestry in salt affected soils

The Usar Land Reclamation Committee (1938) and Yadav (1956) suggested possible use of salt affected soils of North India for growing trees to meet the energy requirement of the rural poor. The land which has lost production potentiality for agricultural crop can successfully be planted with the local hardy trees and grasses. Abrol *et al.* (1973) and Abrol and Bhumbla (1978) have failed to succeed in cultivation of rice and wheat in some salt affected soils of Uttar Pradesh even by adopting the improved cultivation practices. They suggested to use these soils for planting hardy trees for the production of firewood.

Several workers (Yadav, 1975; Yadav and Singh, 1970; Yadav, 1980; Abrol and Sandu, 1981; Sandu and Abrol, 1981 and Abrol, 1982) hold that village panchayat lands affected by salinity/sodicity should be devoted to silvipastoral system because of following reasons a) Production of agricultural crops is neither feasible nor profitable due to prohibitive cost of amendments b) Reclamation of such land is difficult

because of absence of individual property rights c) Possibility of increasing area under forestry and d) Suitability of these lands for social forestry programmes to meet local fuel, fodder, timber and energy needs.

National commission on agriculture (1976) has estimated fuel wood requirment of 2.25 million m^3 by 2000 A.D. The shortage of fuel has been termed as `poor man's energy crisis' because it would further reduce the already intolerably low living standards of rural poor. Another consequence of this inadequate supply of fuel wood relates to burning of agricultural residues and animal dung which otherwise would have been used to restore soil health and fertility. It has been estimated that 68.5 per cent of energy used in Indian households is in the form of firewoods and 64.2 per cent of it is collected from natural sources. By the year 2000 A.D, there may be a short fall of 137 million tonnes of firewood supply. To meet this demand and to avert the major fuel crisis, India requires additional 34 million hectare of land under firewood plantation with annual investments of 5000 crores. The report further says that during the period of 1951-1973, the country has lost a total forest area of 3.4 million hectares, out of which agricultural expansion has claimed 71.5 per cent and river valley projects 11.3 per cent.

According to Wegner (1976), the usual increase in price of petroleum products and associated political and economic dependency on oil exporting countries has generated interest all arround the world in recent years about use of wood and plant bio-mass as source of energy and chemical raw materials. Burning of 60-65 million tonnes of dry dung annualy deprives the farm lands of much needed organic matter and nutrients (Kaul and Menon, 1977).

Firewood is the chief source of warmth and energy for rural inhabitants to cook food (Argel, 1978). Consumption of firewood varies betwen 0.5 to 2.0 cubic metres per person per year (Arnold, 1978).

Spergeon (1979) outlined the need for immediate vigorous plantation drives in developing countries and recommended planting of quick growing, short duration tree species on all types of land producing sufficient bio-mass, land improvment and economic development of backward areas. The present supply of fire wood and timber in our country is far less than its demand and this gap is predicted to widen further (Swaminathan, 1980), Ojeniyi *et al.* (1980), Ojeniyi and Agbede (1980 a,b): Kaul and Gurumurthi (1981) and Goswami (1982) have recommended large scale plantation of short

duration fast growing tree species at close spacing on degraded lands for increasing bio-mass production, soil improvement, minimising floods, moderating droughts and checking siltation of dams. Considering the vast scope that salt affected soils offer for tree plantation, Yadav (1980) stressed the need for generating information on priority for planning agroforestry/silvi-pastoral systems in salt affected soils. Storris (1981) stated that if forest destruction continued at the present pace, there will soon be no need to grow more food since no fuel is left with which to cook it. The auther stressed the urgent need for energy plantation on marginal and problamatic soils to meet the firewood requirements as well as to arrest their further degradation.

In China, Zang *et al.* (1983) has emphasised the need for combined agro-eco-system having trees, grasses and crops in degraded soils for ecological stability. While in Rajasthan, Gupta and Menon (1982) have found growing of trees more economical compared to annual field crops in marginal agricultural lands.

The situation for fuel and wood based industries is very precarious as fuel wood dominates as source of energy. The requirement of fuel wood is increasing and estimated

consumption by 2005 AD is 247 and 69 million tonnes for rural and urban population, respectively. Owing to scarcity of fuelwood, animal dung is being burnt as a fuel. Annually 60-80 million tonnes of dry dung (300-400 million tonnes wet dung) is being utilized as fuel (Khoshoo, 1986).

In addition, the trees have many other benefits. They help in significant economic development (Westoboy, 1962; Brown, 1967 and Pant, 1980). Trees influence the environment (Kittredge, 1948; FAO, 1962; Singh, 1976 and Tejwani, 1979), help in soil stabilization (Lundgren, 1978 and Rice, 1978), prevent soil erosion (Anderson *et al.*, 1976; Bruning, 1977 and Kenkel, 1978), Control water run-off in catchment areas (Kenkel, 1974; Ghosh, 1978; Tejwani, 1977; Ghosh and Rao, 1979), provide shelter from wind and heat (Payne, 1968) and against sand and dust storms (Musa, 1977).

The forest tree species are indispensible to conserve the soil and to arrest further degradation. No one disputes the beneficial effects of trees on deteriorating environmental conditions. Further, forest is the prime source of much needed timber, fuel and fodder and many other products besides purifying air.

2.2 Dynamics of soil salinity and ground water table

Development of saline soil conditions in river valley projects is mainly due to high water table which is brought about by excessive irrigation or seepage from canals. Accumulation of salts on the surface by capillary upward movement of salts along with water and their deposition are most prominant features. Inadequate drainage and impermeable layer at lower depths are responsible factors for deterioration of black soils and build up of water table. The ground water is polluted depending upon soil types, rise of water table, seepage and other hydrological characteristics. The water flowing or passing through the basic magnetic rock such as basalt, denite etc., are more saline as basic minerals are less stable and more soluble than their acid counterparts (Raghav Rao, 1967). Development of soil salinity and alkalinity due to rising water table in alluvial and clay loam soils of Rajastan and Chambal command were reported by Mishra and Singh (1968) and Dayal *et al.* (1968). The rise in water table in both the command areas was because of seepage from unlined canals. Uppal (1967) reported on the basis of ground water survey that regular increase in water table proceeds with time till dynamic equilibrium is reached.

Mehta *et al.* (1968) and Gupta (1979) noticed considerable adverse effects on soil physical and chemical properties due to shallow and poor quality ground water. Periodical observations of piezometers and soil salinity in Mula command area by Patil *et al.* (1982) indicated that the water table increased by 13.5 per cent with 4.6 per cent increase in pH and 48.2 per cent increase in EC of ground waters within 3 years. These observations were made at 50m away from the canal which had 5m high embankment and water in canal maintained a head of about 3 m when canal was flowing in its full capacity. In Sonepat district of Haryana, Gupta and Khosla (1982) observed higher salinity of shallow ground waters where as, the salinity was much lesser where ground water table was deeper. The electrical conductivity of ground water increased from 12 dSm^{-1} in rainy season to 36 dSm^{-1} in summer. The soil salinity increased with shallow water table while decreased where ground water table went deeper.

Tomar and Gupta (1985) observed the fluctuation of water table from 10-140 cm from surface on yearly cycle. The salinity of ground waters did vary from 2 to 46 dSm^{-1} . The lower salinity coincided with monsoon because of dilution effect while, in summer months, the salinity of water was highest. In Swiss Rhone Valley, Layanchy and Musy (1990)

observed that shallow water table was the main cause for accumulation of salts in surface through capillery fringe. The strong mean summer water deficit (300mm) was equilibrated by capillary rise from water table which varied between 110-230 cm from surface. From Shanding province of China, Wen-rui You (1990) reported that ground water salt concentration ranged between 5-30g/l and even upto 50-150g/l. The slope of ground water was only 1/1000 indicating no lateral free flow of water. The ground water table varied from 1 to 2 m in an yearly cycle depending on precipitation and evaporation. Through the capillary upward movement of ground water at a speed of 2-3 mm day^{-1}, the salts were accumulated in summer till they are again leached down after onset of monsoon rains. The observation made on waterlogging through seepage in Barna command area by Kool (1993) revealed that the annual rate of rise in water table ranged between 0-25 cm depending on distance from the canal. The water seepage from canal was 1.389 cummec/Mm^2. The rise and fall of water table followed opening and closure of canals.

2.3 Relative tolerance of trees to soil salinity and waterlogging

The tolerance of tree species to soil salinity and flooding is emphasised by many workers in India and abroad.

The forest species differ in their tolerance to salt stress. Flooding of tree seedlings causes serious injury to some trees. Under saline conditions, generally, salt and waterlogging impart the combined stress on growing plant. The tree species differing in their ability to tolerate salt and waterlogging stresses adopt physiological and morphological mechanism to overcome and survive. Griffith (1945) recommonded planting of promising *Acacia arabica, Prosopis juliflora* and *P. spicigera* to Kallar soils of Punjab with impervious layer of *kankar* at depth of 5 to 10 feet and pH values ranging from 8.10 to 10.22. While, Bhargava (1951) reported that species such as *Acacia arabica, Prosopis juliflora* and *Azadirachta indica* were better suited to afforest saline and alkali soils of Madhya Pradesh compared to *Dalbergia sissoo, Tamarix* sp., *Casuarina equisetifolia, Tarminalia arjuna, Bombax malabaricum* and *Anogeissus* sp.

Parkar (1950) found that dogwood was severely injured or killed within a week, but red, white, and overcup oak survived for several weeks after flooding of soil. Hunt (1951) observed that loblolly pine seedlings survived in saturated soil for ten months with no visible injury to tops, though the roots were severely injured. In the experiments conducted by Kramer (1951), yellow poplar showed yellowing and

death of lower leaves which might be due to the uptake and accumulation of toxic compounds by dead roots from flooded soil.

The species such as *Picea pungens* (blue spruce), *Psuedalsuga menziesii* (Douglas fir); *Juglands nigra* (black walnat), *Tilia cordata* (Linden), *Burberis thunbergii* (barberry), *Euonymus alatus* (euonymus) *Rosa multiflora (multiflora* rose), *Spiraca Vanhouttii* (Spiraca) and *Salix perpurea* (blue willow) showed little tolerance while, rate of growth of *Tamarix pentandra (tamarix)* and *Fraxinus pennsylvania* (green ash) was higher in all the salt treated plots than in control. Black locust, honey locust, Russian olive squash bush and tamarix survived at 10000 ppm of salt concentration in irrigation water. Members of pinaceae were not tolerant. Whereas, golden willow of salicaceae family was considered as moderately tolerant (Monk and Peterson, 1956) to salinity.

In a review article, Khan (1962) reported that amongst babul, shisham and neem, babul exibited fairly good stand in the early stage but died out when their roots struck the *kankar* pan. In an experiment conducted at Avadh, Uttar Pradesh, with heavy efforescence of salts due to restricted

drainage in vicinity of canal, *Acacia arabica, Azadirachta indica, Albizzia sp. Butea monosparma, Dalbergia sissoo, Madhuca latifolia, Prosopis juliflora, Tamarindus indica* etc. were tried for their tolerance to soil salinity. Amongst these species *Prosopis juliflora, Azadirachta indica* and *Albizzia procera* appeared to be more promising. Similarly, in Sourthern Doad experiment *Prosopis juliflora, Pongamia pinnata, T. arjuna* gave best results while, amongst irrigated plantations *A. indica, T. indica, and A. procera* showed the best performance.

According to Pande (1965) *A. arabica, A. catechu, A. procera, A. indica, B. monosperma, C. religiosa, D. Sissoo, M. latifolia, P. juliflora, T. indica* and *T. Balerica* planted in usar land at Kukrail, Uttar Pradesh, the species such as *A. arabica, P. juliflora, A. nilotica* and *A. procera* showed comparatively better performance.

In Kuwait and Sudan, *Eucalyptus camaldulensis* proved to be the most promising species in arid and saline lands. Other species of *Eucalyptus* found tolerant in such conditons were *E. microtheca* and *E. tereticornis* in Sudan and *E. gamphocephala* and *E. obtusa* in Kuwait (Singh, 1965). In an experiment conducted by Karchan (1966) in Rift valley, Israel

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on soils rich in $CaCO_3$ and containing higher levels of soluble salts of chlorides and sulphates with pH 7.6 to 8.1, *E. camaldulensis* showed very high level of salt tolerance where as *Tamarix mannifera* was better for solonchak soils. In another experiment by same author under saline water irrigation in French Sahara, *E. camaldulensis, A. eburnia, casuarina torulosa* and *Cupressus scmpervirons* and various *Tamarix* species expressed better salt tolerance. In Negeve region of Isreal, *E. Camaldulensis* and *Pinus halepensis* were found to be the most tolerant on chloride solonchak soil having ECe between 12-17 dSm^{-1} in upper 30cm depth and about 22 dSm^{-1} below this depth and pH between 7.0 - 8.2 (Binder-Barghava and Ramati, 1967). Kaushik *et al.* (1969) found *Eucalyptus* hybrid to grow satisfactorily on soils having pH lower than 9 and soluble salts upto 0.3% in Haryana and Punjab, however, the species failed to grow on soils having pH more than 10 and soluble salts above 0.7 per cent and sub soil *kankar* layer.

Yadav and Singh (1970) in their investigation in Vrijabhumi Forest Division of UP found that all planted species failed to grow in soils having pH more than 10 and soluble salt above 3.42 per cent in the top and above 1.14 per cent salt in sub soil with cemented bed of *Kankar* nodules.

Safe limit for *Prosopis juliflora* was found to be upto 0.54 per cent with pH upto 9.5, though the species would tolerate soluble salt content upto 1 per cent and pH upto 10. *Acacia nilotica* grew satisfactorily on soil having pH below 9 and soluble salt content below 0.3 per cent. *Azadirachta indica, Butea monosperma, Dalbergia sissoo, Pongamia pinnata* and *Terminalia arjuna* were found to grow on soils which were almost free of salt in surface 60 cm depth but had pH values 9.8 and soluble salts up to 0.45 per cent in sub-soil. Out of the species studied, auther reported that *Albizzia lebbek* and *Alianthus excelsa* were least tolerant to salinity and alkali status and require comparatively better structured soils.

Observations of a pot culture experiment by Bernstein *et al.* (1972) showed species like bougainvillea, Natal plum and rosemary were affected little by soil salinity of 8 dSm^{-1} where as, sensitive species like jasmine, guava, holly and rose were severaly damaged or killed at ECe of 4 dSm^{-1}. All the individual plants of *D. Sissoo, A. procera, A. nilotica* and *Salyx tetrasperma* died when planted in a field with pH 10.4 and electrical conductivity of 1.5 dSm^{-1} while, *P. juliflora, T. articuleata, E. tereticornis* did well in the experiment conducted by Mohindra (1973) in Punjab. An investigation carried out at CSSRI, Karnal by Yadav (1973)

indicated that *A. lebbek* and *T. arjuna* had registered poor performance while, *P. juliflora, Eucalyptus* hybrid, and *A. arabica* performed better,furhter their height was enhanced by fertilizer application in alkali soils with pH above 10 and EC ranging from 0.45 to 1.75 dSm^{-1}.

Amongst *Eucalyptus* hybrid, *P. juliflora* and *A. arabica*, Yadav (1977) emphasised suitability of *Eucalyptus* hybrid and *P. juliflora* for salt affected soils because of their faster growth and higher bio-mass yield. Migunova (1976) working in South Ukrain has reported that *Tamarix remosissima* and *T. tetrandra* to be able to root successfully in horizons that contained salts upto 6 per cent including above 3 per cent sulphates and 1 per cent chlorides while, in North Eastern Russia, Zelenin (1976) found *Ailanthus altissima* to be promising species in dry and saline conditions. A green-house experiment conducted by Pereira and Kozlowski (1977) established that *Salix nigra* and *E. Camaldulensis* were tolerant without leaf senescence whereas, *Populus deltoids* and *E. globulus* suffered much due to flooding for 37 days.

Frankois and Clark (1978) identified *Leucophyllum fruliscens, syzygium peniculatum* to be highly tolerant and *Pinus halepensis, Chamacrops humilis, Raphiolepis indica* and

P. thunbergiana as moderately tolerant species on the basis of irrigation for more than two years with water containing 0,2, or 4 g/l of NaCl and $CaCl_2$ (50/50 by weight). Brown (1978) found *Alnus glutinosa, Hippophae rhamnoides, Populus* sp., *Salyx purpurea* and *S. ruberns* to be highly tolerant to salts. The decrease in yield of grape fruit was 13.5 per cent per unit increase of dS m^{-1} in soil-saturation extract above a threshold value of 1.2 dS/m. This corresponded to 1.45 per cent yield reduction for each one meq/l increase in chloride concentration above threshold value of 4.5 meq/l (Biclorai *et al.*, 1978). Shaybany and Kashirad (1978) observed significant reduction in shoot and root dry matter, leaf number and area and stem length with increase in salt concentration of irrigation water. Garg and Khanduja (1979) in their studies found *A. nilotica* to grow well in soil with pH 9.4 to 9.6. In general, *A. arabica, Bacihinia diphylla, Callystemon phoeniceus, cassia siamea, Pongamia glabra* and *Terminalia arjuna* established at soil pH ranging from 9.6 to 9.8. Yadav (1980) showed that *P. juliflora, E. hybrid,* and *A. nilotica* could be grown in calcarious sodic soils by treating the soil of planting pit with amendements. Among fast growing exotic species, *Leucaena leucocephala* (varities K8 and Fiji) recorded good growth in moderate to heavy usar soils at

Kukrail (Lohani, 1979). Tomar and Yadav (1980) from a study using saline water (EC 2, 4, 6, 8 and 8 dSm^{-1} and SAR 5, 15 and 30) inferred that EC 8-10 dSm^{-1} and SAR up to 30 could be used in case of *A nilotica, P. pinnata,* and *P. juliflora* while, waters of EC 4-6 dSm^{-1} and SAR 15 could be used in case of *A. tortilis, A. lebback, A. indica, Lowsonia glauca* and *P*arkinsonia aculeata and waters of EC less than 2 dSm^{-1} in case of *Eucalyptus* hybrid to establish and grow.

In a sand culture pot experiment Felkar *et al.* (1981) observed the growth of *Prosopis glandulosa* var, toreyana, *P. velutina, P. articulate, P. chilensis, P. pallida* and *P. tamarugo* var, tamarugo at 6000 mg/l salinity in irrigation water with no reduction. However, *P. velutina, P. Chilensis* and *P. glandulora* did put-on little growth at 18,000 mg/l salinity. Successful growth of *Eucalyptus* hybrid was obtained by Yadav and Tomar (1981) on light textured soil having ECe upto 8.5 dSm^{-1}, pH up 9.4 and SAR 60. The adverse effect of soil salinity on *Eucalyptus* was minimised by soil application of FYM. In a highly deteriorated saline-alkali soil, Sandu and Abrol (1981) found *E. tereticornis* to be more promising than *A.nilotica* when planted in pits with gypsum + FYM. In contrast, Abrol and Sandu (1981) observed 37 per cent establishment of 6 months old *A. nilotica* compared to no

establishment of *E. tereticornis* in saline-alkali soils of Karnal.

An experiment conducted at CSSRI, Karnal, established that *A. lebbeck* could be grown satisfactorily on a soil having ECe of about 7.0 dSm^{-1} and SAR of about 40 (Tomar and Yadav,1982). However, no increase in height was noted when irrigated with water of 5 and 10 dSm^{-1} in *A. lebbeck* from 120 to 280 days of growth

Based on height, survival per cent fresh and dry weight of plants irrigated with saline water, El-Lakany and Laurd (1982) classifed *Casuarina glauca, C. obesa, C. equisetifolia* var. *stricta, C. liltoralis* and *c. torulosa* and as medium tolerant and *C. decaisneana* as most sensitive species to salinity. Winter and Lauchli (1982) recorded salt-induced growth reduction of 30 and 47 per cent at 50 and 100 m Mol NaCl concentration of water, respectively in *Trifolium alexandrium.* This species was found superior to *T. pratense* in tolerating salinity. Jain and Muthana (1982) were able to use water having salinity 9.0 dSm^{-1} to raise the seedlings of *P. juliflora* and *Tamarix articulata.* But water of salinity not more than 6.0 dSm^{-1} was found suitable to grow *Eucalyptus* hybrid and *Dichrostachys glomerata.* The other

species like *Colophospermum mopane, Cassia siamia* and *Acacia aneura* could not tolerate even slight salinity in irrigation water. Gill and Abrol (1983) revealed the promising growth of *C. equisetifolia* on highly sodic soils. In a study carried out in earthen pots using saline water, Jain and Muthana (1983) observed that *P. juliflora* successfully established and grew with water having Ec upto 9.0 dSm^{-1} right from germination. Low salinity water (EC 0.6 dSm^{-1}) could only be used for irrigation at early stage of *Acacia tortilis, Dichrostycha glomerata, Leucaena leucocephala, Colophosphermum mopane* and *Cassia siamea*. Jain *et al.* (1983 a & b) observed higher mortality and retarded growth and collar diameter of *Dichrostachys glomerata* and *Tamarix articulata* when irrigated with water of high salinity (9.0 dSm^{-1}). Similarly growth and survival of *Eucalyptus* hybrid was adversely affected when irrigated with water of 6 dSm^{-1} while, *Cassia siamea* was unaffected with water of 2.7 dSm^{-1}. The species such as *Prosopis juliflora, A aneura* and *Chenopodium* sp., in contrast, recorded good growth even with waters of 9.0 dSm^{-1}. Tomar and Yadav (1983) noted growth of *Eucalyptus* hybrid without reduction in height and stem diameter when irrigated with water of EC 15 dSm^{-1} provided soil salinity build up remained less than 15 dSm^{-1}. *Casuarina equisetifolia* was the

most tolerant of the 11 *Casuarina* species tried for tolerance against soil salinity (Clements *et al.*, 1983).

Data recorded by Tang and Kozlowski (1984) through a systematic experimentation indicated that eight months old seedlings of *Ulmus americana, Frasinus pennsylvania, Melaleuca quicquenervia* and *E. camaldulensis* exhibited greater tolerance to combined effect of waterlogging and salt stress than *E. globulus* and *P. halepensis*. Based on Surivability, height, and collor dimeter, Muthana and Jain (1984) categorised *P. juliflora* and *L. leucocephala* as the most tolerant whereas, *Cassia siamea* as the most sensitive to soil salinity. Chaturvedi (1984) reported that *Eucalyptus* hybrid grew well in first year as long as roots were confined to top layer of sandy soil but stagnated when roots reached clay layers offering severe mechanical impedence. Results of a pot culture experiment conducted by Kretinin and Dobovskaya (1984) in Russia revealed the following order of tolerance of trees to chloride salinity; Black locust > Siberian elm > green ash > English oak. Gogate *et al.* (1984) emphasised afforestation of salt-affected soils with *Casuraina obesa* as it was tolerant to soil salinity as high as 10 dSm^{-1}. Species like *A. nilotica, C. cristeta* and *C. cunninghamina*, on the contrary, were found to tolerate upto only 5 dSm^{-1} ECe.

In a field study, Tomar and Gupta (1985) found critical water table of 80cm for different tree species. They have recommended growing of *A. auriculaeformis, T. arjuna* and *Leucaena leucocephala* in area where soil salinity is not associated with high ground water table conditions. Tree species like *C.equisetifolia, T. articulata* and *P. juliflora* performed better where high soil salinity and shallow water table conditons exist seperately or simulataneously. Seedling of *P. juliflora* and *A. nilotica* were raised satisfacotorly with irrigation water of EC as high as 7 and 5 dSm^{-1}, respectively but, *Eucalyptus* hybrid seedlings could only be grown with good quality water (< 0.6 dSm^{-1}) (Tomar and Yadav, 1985). Considering leaf area and crown volume, Biddiscombe *et al.* (1985) ranked *E. globulus, E. maculata, E. Cladocalyx* at most tolerant *Eucalyptus* species at 800m rainfall. Abrol (1986), through a study on performance of trees in saline and shallow water table fields, reported that *C. equisetifolia, T. articulata* and *P. juliflora* withstood these conditons whereas, *Pongamia pinnata, T. arjuna* and *A. nilotica* grew well when either high salinity or high water table was a major problem, but with both the stresses, their performance was not as good. *Azadirachta indica* was moderately tolerant, to high salinity and shallow water table.

Based on tree survivability, height, leaf, stem and total fresh weight, root length and root: shoot ratio it was concluded that *A. nilotica* and *E. camaldulensis* could be grown with less than 50 per cent growth reduction in soil with 5 dSm^{-1} salinity (Gupta *et al.*, 1986). *Casuarina equisetifolia* was moderate in salt tolerance. *Ceiba pentandra* and *A. auriculaeformis* were highly sensitive tree species and did not survive beyond 2.5 dSm^{-1}. Singh *et al.*(1986) were able to grow babul (*A. nilotica*) on saline soils of Vrijbhumi (coarse loamy Natric cambonthids) having maximum values of pH 8.8, ECe 15 dSm^{-1} with a pre-dominance of neutral salts of Cl^{-} and SO_4^{-2} of Na without much reduction in growth. In heavy textured coastal saline soils (ECe 8 dSm^{-1}) with shallow water table (0.63 m), Bandopadhyay (1986) noticed more or less normal establishment, height and girth of *C. equisetifolia*.

Totey *et al.* (1986) reported that *Emblica officinalis* was relatively more tolerant and recorded better survival at higher salinity (more than 6 dS/m) compared to *Dendrocalamus strictus* and *A. auriculaeformis*. *Acacia nilotica* was a promising tree species, for saline soils with shallow water table (Grewal and Abrol, 1986 and 1987).

Bandopadhyay *et al.* (1987) studied the effect of soil salinity on germination and growth of *Casuarina*

equisetifolia in sand culture and field and reported that seeds did not germinate when soil salinity was above 8 dSm^{-1} and a significant reduction in tree height when EC was above 8. Chaturvedi *et al.* (1987) obtained bio-mass yield of 52.7 tonnes per hectare from *Prosopis juliflora* within a growth period of four years in an alkali soil (pH 9.0) with irrigation and no chemical ammendements or fertilizer. However, other species like *Leucaena leucocephala, A. indica, A. procera, A. lebbek* and *A. auriculaeformis* had failed between third and fourth year.

Roy *et al.* (1987) conducted studies on establishment and growth of five fodder cum fuel trees viz., *Acacia tortilis, Albizzia amara, Dichorostachys cineria, A. lebbeck* and *D. sissoo* in ravinous saline-sodic wastelands of Madhya Pradesh. Amongst the species, *A. tortilis* was found most suitable followed by *D. cineria* and *A. amara* for such difficult wastelands. However, *D. sissoo* completely failed to establish.

In a green house experiment on tolerance of important local species to soil salinity equivalent to 1, 8,18,27 and 33 dSm^{-1} were compared in South Andaman (Singh *et al.*, 1987a). The study indicated that *A. auriculaeformis, T.*

procera and *C. equisetifolia* survived under all salinity levels but *T. arjuna* failed to grow when salinities exceeded 18 dSm^{-1}. Other species like *Pterocarpus delberginoides,* cashew and bamboo were sensitive to excess salt. In another green house experiment under sand culture conditions, Singh *et al.* (1987b) studied the effect of different soil salinity levels on growth and bio-mass production of certain forest species, viz., *Syzygium cuminii, Acacia nilotica, Prosopis juliflora, Albizzia lebbeck* and *Halophragma adenophyllum* and reported that *P. juliflora* and *A. nilotica* were relatively more tolerant than *S. cuminii, A. lebbeck* and *H. adenophyllum.* In a similar investigation, Shankarnarayan and Kolarkar (1987) found *P. juliflora, P. chilensis, Tamarix articulata, A. tortilis* and *E. camaldulensis* as the promising ones for afforestation of salt-affected soils of Indian arid zone. While, Srivastava *et al.* (1988) recommonded *Eucalyptus* hybrid, *E. globulus, E. camaldulensis, E. tereticornis, A. nilotica, P. juliflora, P. chilensis, P. spicigera, A. indica, A. Senegal, T. articulata, C. equisetifolia Leucaena leucocephala, Pongamia glabra and B. monosperma* as suitable for extensive planting on salt-affected soils based on their survival percentage, rate of growth, success of plantation and economic utility.

Casuarina obesa was more tolerant to saline waterlogged conditions with no seedling deaths and lower reductions in growth compared to *Eucalyptus* spp. (Van der Moezel *et al.*, 1988). Exclusion of Na and Cl together with production of specialised roots by *C. obesa* were suggested as possible factors relating to their higher tolerance. In a field experiment conducted by Rhodes and Felker (1988), *P. juliflora, P. alba, P. articulata* and *P. chilensis* were found tolerant to sea water irrigation (3.3% NaCl) while, other species such as *P. glandulosa* and *P. tamarugo* and *L. leucocephala* failed to grow at 1.2 per cent salt in irrigation water. In a pot culture experiment conducted with 20 kg coastal saline soils with 2.0, 10.0, 15.0 and 20.0 dSm^{-1} ECe, Bandopadhyaya (1988) recorded no reduction in height of *Eucalyptus* and *Casuarina* upto ECe of 10.0 and 15.0 dS/m, respectively. A study with 4 *Casuarina species* namely, *C. glauca, C. obesa, C. equisetifolia* and *C. cunninghaminii* was started in 1986 indicated that *C. glauca* was the best amongst all the species of *Casuarina* tested (Tomar and Gupta, 1988). From a field experiment of Tomar and Gupta (1987) it was reported that tree species such as *A. nilotica, A. tortilis, Casuarina* sp. and *E. camaldulensis* hold promise for large scale plantation in saline soils with shallow and saline

ground water. Singh *et al.* (1990) noted the satisfactory growth of *Casuarina equisetifolia* at ECe 32.5 dSm^{-1} whereas, *A. nilotica, Eucalyptus* hybrid and *Pongamia pinnata* grew only upto 16.3 dSm^{-1} and *D. Sissoo* and *Araucaria cunninghaminii at* upto 8.1 dSm^{-1}. Tomar and Gupta (1989-90) reported that *Casuarina glauca* performed better when average surface salinity (root zone) was within 25 dSm^{-1} and ground water salinity was not more than 12 dSm^{-1}. At lower salinity of the soil and ground water, *C. equisetifolia* also performed well. On the basis of survivability, observed 5 months after planting, the species such as *Acacia pennatula* (91%), *A. fernesiana* (83%), *Caesalpinia eriostachys* (77%), *Crescentia alata* (81%), *Senna atomaria* (83%), *Leucaena lecocephala* (96%), *Parkinsonia aculeata* (93%), *Pithocellobium dulce* (87%), and *Prosopis juliflora* (99%) had significantly better survivability than all other species evaluated.

In a field experiment of Gupta *et al.* (1991) it was observed that tree growth reduced by 23 per cent in *E. camaldulensis*, 41 per cent in *C. equisetifolia* and 50 per cent in *Tamarindus indica* at soil salinity of 12 dSm^{-1} whereas, in pot culture experiment *A. nilotica* and *E. camaldulensis* grew with less than 50 per cent growth reduction upto the salinity

of 5 dSm^{-1}. *Casuarina equisetifolia* tolerated 2.5 dS/m salinity and *Ceiba pentandra* and *Acacia auriculaeformis* were sensitive to salinity. A maximum increase in height was observed in case of *Acacia farnesiana* followed by *P. juliflora, Parkinsonia aculeata, Pithocellobium dulce, A. pennatula, Leucaena shannoni* and *L. leucocephala* by Tomar and Gupta (1991-92) in salt affected soils of Karnal. Hebbara *et al.* (1992) reported 100 per cent survival of *C. equisetifolia, Eucalyptus* hybrid, *Glyricidia maculeata* and *Inga dulse* in salt affected vertisols of Tungabhadra command area. Data on tree height revealed a highest growth rate in case of *C. equisetifolia* (653.2 cm) followed by *S. grandiflora* (449.2 cm), *A. auriculaeformis* (306.5 cm) and *D. Sissoo* (285.6 cm) after 2 years of planting. Similar observations were also made on collar girth of the tree species. An experiment conducted at Sampla (Haryana) on a sandy loam (Coarse loamy mixed hyperthermic camborthids) salt affected soils, it was observed that germination of *C. equisetifolia* and *C. glauca* was delayed and reduced with increasing salinity stress (Batra and Ashok Kumar, 1993), However, *C., equisetifloia,* was able to germinate and withstand salinity upto 10 dSm^{-1} and *C. glauca* upto 5.0 dSm^{-1}.

2.4 Influence of soil salinity and waterlogging on ionic composition of tree tissue

Both soil salinity and waterlogging are known to affect the ionic composition of tree tissue. Monk and Peterson (1956) reported that Ca and Na content of leaf and stem increased in many trees and shrubs with increase in salt concentration of irrigation water. The Na content of tissue increased by 2 to 8 times while, in case of Ca increase was by less than twice in trees irrigated with saline water compared to check. The Ca content of three tolerant species (Honey locust, Russian olive and tamarix) remained relatively constant at all levels of salt additions to soil. On the basis of investigation carried out on 20 tree species, it was concluded that Ca seems to be a better index of salt tolerance than the ability to withstand higher concentration of Na. No relation was found between salt concentration of the plots and Mg, K or P content of the tissue. The mineral content of some trees such as green ash was slightly influenced by salt concentration of the soil on which they were grown.

In a pot culture experiment, Bernstein *et al.* (1972) observed that accumulation of both Na and Cl increased in leaves of many ornamental shrubs with increasing salinity of soil. Most shrubs accumulated more than one per cent of Cl in

leaf tissue without injury and chloride accumulation was more than sodium maintaining linear function with soil salinity. The leaf injury associated with higher Cl accumulation was particularly strong in guava, rose, holly, ivy, hibiscus and viburnum.

Leaf analysis of 23 native species of Mojave and Great basin deserts, revealed that tree species tended to accumulate Na when grown on salt affected areas (Wallace *et al.*, 1973). Sodium content in leaves of *Lycium* sp. were inversely related to those of Ca. In contrast to other species, *Grayina spinosa* had accumulated more K instead of Na, even in saline soils. In general, members of chinopodaceae accumulated more Na in leaves. In an experiment conducted on alkali and normal soils of Bathra, variation in N and P concentration in leaves of *Zizyphus, phyllanthus, Mangifera* and *Psidium* were more apparent due to soil (Garg and Khanduja, 1976). *Zizyphus* suffered the least and phyllanthus the most in their capacity to assimilate the essential nutrients from alkali soils. *Mangifera* and *Psichium* remained intermediate. A substantial drop in N and P uptake was noted by *Phyllanthus* leaves grown in alkali soils. However, the drop in K and Mg uptake was less pronounced in *phyllanthus* leaves.

Shaybany and Kashirad (1978) recorded increased Na and Cl and decreased K content of leaves and stem of *A. Saligna* with higher salt concentration of irrigation waters. However, P, Mn and N in shoots and Fe and N levels of roots were not affected by salt concentration of irrigation water. In case of 10 year old trees *A. nilotica, Bauhinia diphylla, cassia siamea, Callistemon phoenicecus, Pongamia glabra* and *T. arjuna*, concentration of leaf Na varied widely among *P. glabra, T. arjuna* and C. phoenicecus despite the fact that differences in soil exchangeable Na in root zones of these species were small. On the other hand, differences in soil Na existed in case of *A. nilotica* and *B. diphylla* were not reflected in their leaves when grown in salt affected soils (Garg and Khanduja, 1979).

A green house trial with *Disphyma australe* by Neales and Sharkey (1981) revealed that Na and Cl ions constituted 96 per cent of total ionic content of leaves when tree was irrigated with 200 mol m^3 NaCl water whereas, K was predominant ion with 35 per cent of total solute content in leaves at lowest salinity level. An increasing external salinity induced decrease in the concentration of all other inorganic ions (K^+, Mg^{2+}, Ca^{2+} and NO^-_3) in leaves. The salt tolerant *T. alexandrium* regulated transport of Na^+ and Cl^-

ions to leaves while, the transport was linearly increased and accumulated in leaves of salt sensitive *T. Pratense* (Winter and Lauchli, 1982). The root Na : K ratio hardly exceeded 2 despite external soil-solution Na: K ratios of 25 and higher, indicating dual mechanism of ion uptake. In both the species of *Trifolium*, K^{+} and Ca^{+2} content of leaves declined with higher soil salinity.

A linear increase in chloride concentration was observed with salt concentration in case of leaves, stem and roots of different citrus species (Walker and Douglas, 1983). While, concurrent reduction in potassium content with salt treatment occured in shoot and roots. A similar observations on Cl^{-} and K^{+} was reported in 11 species of *Casuarina* (Clements *et al.*, 1983). In contrast, Jeschke and Steller (1983) recorded the preferential absorption of potassium over sodium at higher salt concentration of external solution in garden orache due to operation of system-I in ion uptake. The leaf chemical analysis of *P. juliflora* grown in salt affected soils of Thar desert area by Sharma (1984) indicated that leaves contained very high levels of sodium (3.94-4.51 per cent), apart from observing significant positive correlation between soil and leaf phosphorus and potassium (r=0.61 and 0.74, respectively).

Ten *Casuarina* and *Allocasuarina* species had higher tissue concentration of Na^+ and Cl^- at increasing level of soil salinity but K was selectively accumulated in tolerant species (Laurd and El-Lakany, 1984). Those species which survived highest salinities had lower content of Na^+ and Cl^- in shoots and root tissue and lower Na/K ratios than more sensitive species at higher external salinities. Based on the observation of a pot culture experiment, Kretinin and Dobovskaya (1984) concluded that the content of chloride, nitrogen, sodium, phosphorus and sometimes calcium and sulphur increased in leaves of Siberian elm, while silica decreased, as chloride salinity of soil increased. But in green ash leaves, only chloride, calcium, sodium and sulphur increased with increasing salinity of soil. Foliar analysis carried out by Rogers (1985) revealed that leaf chloride and sodium content of most of *Eucalyptus* species grown on saline sites were about 50 and 100 per cent higher than non-saline sites. However, foliar analysis was not found to be a reliable indicator of relative salt-tolerance of *Eucalyptus* species. On an average, sodium concentration ranged from 0.15 mg g^{-1} dry matter in *E. melliodera* to 12.1 mg g^{-1} in *E. astrigens* and mean chloride concentration from 3.3 mg g^{-1} in *E. rudis* to 18.1 mg g^{-1} in *E. astrigens*.

The highly saline tolerant *Casuarina* species like *C. equisetifolia* and *C. glauca* accumulated little Na^+ and Cl^- ions in their shoots and they decreased from old to young growing needles compared to moderately tolerant species like *C. cunnighamiana* where no concentration gradient of Na^+ and Cl^- ions betwen young and old shoots was observed (Aswathappa and Bachelard, 1986). Van der Moezel *et al.* (1988) reported that higher leaf chloride content than 10.6 mg g^{-1} in *Eucalyptus* and 17.8 mg g^{-1} in *Casuarina* caused leaf injury. Higher Ca:Na and K:Na ratios in leaf tissues of trees was essential for good growth under saline conditions.

Russian thistle (*Salsola iberica*) was grown with saline water irrigation of 1.3, 10.6, 19.5 26.8 and 33.9 dSm^{-1} in a greenhouse experiment (Flowers *et al.*, 1988). With increasing salinity of irrigation water, tissue composition of sodium, chloride, zinc and calcium tended to increase while, magnesium decreased and potassium either decreased or remained constant. Singh *et al.* (1990) reported that sodium concentration in leaf tissue of *C. equisetifolia, Eucalyptus* hybrid, *A. nilotica, D. sissoo, P. pinnata* and *Araucaria cunninghaminii* increased with increasing salinity of soil in a pot culture experiment, whereas calcium decreased and magnesium and potassium remained unaffected. The ratios of

Na/K, Na/Ca and Na/Mg ratio in tree tissue increased with increasing salinity.

2.5 Bio-amelioration of salt affected soils through tree cover

The growth of trees is reported to influence soil physical, chemical and biological properties and also soil fertility and productivity. Accumulation of salts on surface is arrested since most of soil moisture is lost through transpiration rather than evaporation from surface. Further, tree canopy shade retards soil moisture evaportion, thus reducing upward fringe of ground water. Hoon and Mehta (1936) in their studies on soil profiles under natural growth of certain forest species, noticed lower salinity and alkalinity under *Prosopis spicigera*. On the contrary, soils under *Tamarix articuleata* were found to contain varying amounmt of salts with low pH. However, soils under *Capparis aphylla* cover showed higher pH and salt content at lower depths.

Mukherjee *et al.* (1950) suggested planting of deep rooted trees such as arecanut or co-conut for several years to break the hard pan in coastal areas of West Bengal. Vadiunia (1957) observed soil loosening effect by tamarix growth and increase in moisture capacity of soil. Application of gypsum

at 8 to 12 tonnes per heactare further hastened the ameliorative process. Shah (1957) and Shah and Vora (1965) found that the growth of *P. juliflora* reduced salinity and alkalinity of soil after prolonged occupation. Smith (1961) suggested growing blue bush (*Kochia bravifolia*) for reclamation of severely affected salty lands of Western Australia. Various species of *Atriplex* have also been reported to help in removing salts to a considerable extent in Australia.

From a comparative chemical study of soils under cultivation and forest cover, Ghildyal *et al.* (1962) reported that the soil under forest cover maintained higher organic carbon and nitrogen content than under continuous cultivation. Forest soil maintained a higher P_2O_5 and K_2O while, lower in cultivated soils, due to crop removal every year. Sumbur (1963) observed increase in content of exchangeable Ca equal to twice the amount of calcium applied through gympsum in soda solonetzes of wooded steppe. The increase in exchangeable Ca was attributed to ameliorative effect of trees themselves.

Vadiunia (1964) reported that tree growth in solonetz increased water permeability substantially and reduced the salt as a result of leaching. Under forest

plantation, water permeability was recorded to be 17 mm as against 10 mm under agricultural crops and only 4 mm in Virgin lands.

Boyko and Boyko (1966) observed high salt intake by secculent *Calotropis* and therefore cultivation of these species offered desalinization possibilities for salt affected soils. Kretinin (1967) noted desalinization and desolonetsization under 30 year old shelter belts.

In a study of forest plantation on salt affected soils near Aligarh, Yadav and Singh (1970) observed a decrease in pH values and soluble salt content and increase in amount of organic matter and nitrogen in upper 15 cm under *P. juliflora*, though, the soluble salt content increased to some extent below 15 cm presumably due to leaching as a result of improved soil permeability. On moderately solonetz soils in USSR, Migunova (1972) found desolonetisation under tree cover. Mohindra (1973) observed decrease in electrical conductivity from 1.5 to 1.26 dSm^{-1} after 2 years of planting with trees like *P. juliflora, T. articuleata, D. Sissoo, A. procera, A. nilotica, E. tereticornis* and *salyx tetrasperma*, but in lower layers the soil salinity increased Yadav (1980) recommonded growing of *Cressa cretica* Linn., a small shrub occuring in

parts of Raichur district, to reclaim the saline soils as it absorbs large quantities of salts from soil. Crystals of salts were seen on its leaves in winter. Analysis on dry weight basis of *Cressa cretica* showed that the plant contained higher amounts of salts (EC 20 dS m^{-1}) with pH 6-8, Na and Cl 8 and 9.43 per cent, respectively. Under forest cover higher rain water infilteration (Ghosh and Rao, 1979) reduced the soil water runoff (Mathur *et al.*, 1976 and Ghosh, 1978) and consequent beneficial effects on soil water storage and leaching (Anderson *et al.*, 1976; Bruning, 1977 and Kenkel, 1978) have been reported.

Ameliorative role of grass in terms of organic matter buildup, soil aggregation, water conservation and improved water transmission in soils is well recognised (Kumar *et al.*, 1980, Kumar and Abrol, 1979 and 1984). Joshi *et al.* (1980) found that growing of grasses like *Diplanche fusca, Bracharia mutica* and *chloris gayana* lowered soil pH from 9.8 to 8.05, 9.0 and 9.25 and ECe from 7.0 to 1.2, 2.1 and 1.4 dS m^{-1} respectively in one year.

Ojeniyi and Agbede (1980) observed no change in exhangeable Ca, Mg and K, pH, soil N and P under different tree and crop combinations grown for three years. However,

soil N and P increased marginally under tree plantations. In a systematic study on ameliorative role of mesquite (*P. juliflora*) plantation, Virginia and Jarrel (1983) found total N (both nitrate and ammonical), organic carbon, $NaHCO_3$ extractable P and saturation extract K were significantly higher in soil beneath mesquite. Sodium and chloride were signficantly higher in soils between mesquite trees. The differences in pH, osmotic potential , saturation percentage and suphur content were nonsignficant between mesquite and bare soils. The SAR of 0-30cm soil was signficantly reduced at the centre of the canopy (7.9) than between treees (17.3) and lower than ground water (17.98). Further, foliar analysis indicated that mesquite was excluding sodium apart from fixing nitrogen and mobilizing other nutrients in surface beneath their canopies which may be an important feature in maintaining long term productivity of the arid ecosystems.

Grewal (1984) reported a considerable decrease in soil pH and EC when Karnal grass was grown in association with forest trees in salt affected soils. Similarly, appreciable increase in organic carbon and avaialable N contents of salt affected soils under mesquite plantations was reported by Gill (1985). Mehta (1988) observed a reduction in soil pH and electrical conductivity of saline alkali soils due to

Eucalyptus tree growth for 3 years. Notable decline in pH and ECe of surface (0-15 cm) soil from original 10.5 and 21.5 dS m^{-1} to 9.0 and 4.23 dS m^{-1} in *A. nilotica plantations* and to 9.6 and 7.54 dS m^{-1} in *E. tereticornis* plantations was observed after 6 years of planting. (Gill and Abrol, 1990). Soil organic cabon increased signficantly (100%) in both *Eucalyptus* and *Acacia*. Increase was, however, by more than three and a half times the intial values under latter species. Infiltertion rates also improved with progressive growth years. In general, amelioration was rapid in plantations producing good quality litter (narrower C/N ratio and/or relatively less lignified). The modifying effect on ambient temperature and thermal regimes of soil was greater by closed canopy trees like *A. nilotica* than with considerably open canopy tree, *E. tereticornis*.

Studies undertaken to know amelioration of arid lands in Western Rajastan indicated that organic carbon increased from 0.03 to 0.4 per cent, total N from 0.007 to 0.04 per cent, available P from 7.5 to 17.0 kg/ha with growing of trees like *Zyzyphus nummularia*, *P. cineraria* and *Balanitis aegyptica* (Sharma *et al.*, 1990). A significant decrease in ECe, pH and ESP of soils under *P. juliflora*, grown for 4 years was reported by Maliwal *et al.* (1990) compared to fallow and

sorghum fields in absence of shallow water table. But presence of shallow water table did not bring in the decrease of ECe, pH and ESP of soils under *P. juliflora*.

Singh *et al.* (1993) reported that trees with higher annual bio-mass yield had better ameliorative effects. The species like *A. nilotica* (2.54 - 5.75t/ha^{-1}) brought about better and faster amelioration of salt affected soils than *E. tereticornis* (1.03-1.13 t/ha).

CHAPTER - III

MATERIAL AND METHODS

III MATERIAL AND METHODS

A field experiment was initiated to evaluate the performance of tree species under saline and shallow water table conditions at the Agricultural Research Station, Gangavati during 1991. Details on various parameters considered in the present investigation and the techniques employed are described in this chapter.

3.1 Experimental site

3.1.1 Location

The experiment was initiated during 1991 at ARS, Gangavati of University of Agricultural Sciences, Dharwad, Karnataka state. The station lies in the semi-arid tract of northern part of Karnataka state and located between 15°-15'-40" North (latitude) and 76°-31'-40" East (longitude) with an altitude of 419 m above MSL.

3.1.2 Climatic conditions

Data on the average rainfall for the period from 1979-91 (13 years) was compared to the one received during, 1990-91, 1991-92 and 1992-93. However, in case of temperature, relative humidity, evaporation etc., were not compared with those of 1979-91 due to non-availability of the

data and presentation are made for the period under investigation. These were required to relate to the fluctuation of water table, soil salinity, ground water salinity etc. Methods followed in collection of the data (App. 1) essentially remained the same as per the guidelines out lined by meteorologists.

3.2 Physico-chemical properties of soil

The physico-chemical characteristics of the experimental site were investigated before planting. The site was described interms of texture, soil salinity, soil reaction, composition of soil solution, lime status, organic carbon etc. The details of methods followed in the estimation of each of the above parameters are as follows.

3.2.1 Soil sample collection and preperation

To have some insight of the initial physico-chemical nature of the site, depth wise profile samples were drawn before planting from each treatment and replication of the investigation (details of the plan of lay-out is made available under Section 3.4). Soil samples thus drawn were allowed to dry in shade before grounding them to pass through 2mm sieve. Soil properties as mentioned above were determined by adopting standard protocols suggested, which are as follows.

3.2.1.1 Texture of the soil was known after determining the particle - size analysis adopting international pipette method (Piper, 1950) and refering to the US textural diagram.

3.2.1.2 Electrical conductivity was determined in 1:2.5 soil water suspension and were expressed on saturation moisture basis by applying appropriate correction factor. The method remained essentially the same as described by Jackson (1967).

3.2.1.3 Soil reaction of the soils was determined by the method (soil solution of 1:2.5 soil water suspension) as described by Jackson (1967), using glass electrode.

3.2.1.4 Soil Solution composition was determined to investigate nature of salinity. The analytes included the parameters such as Na, K, Ca & Mg for cationic series and $CO^{=}_{3}$, HCO^{-}_{3}, $SO^{=}_{4}$ and Cl^{-} for the anion series. The solution Na^{+} and K^{+} were determined by using flame emission photometer and Ca and Mg by versenate method. Carbonates and bi-carbonates were determined by simple acid base titrations while, chlorides by argenti-metry as described by Jackson (1967). Sulphate in the solution was, however, determined by turbidometric method (Verma *et al.*, 1977).

3.2.1.5 Total calcium carbonate was determined by acid neutralization method as per the procedure outlined by Piper (1950).

3.2.1.6 Organic carbon content of soil was determined by Walkley and Black's wet-oxidation method as suggested by Jackson (1967).

3.2.1.7 Exchangeable sodium percentage of the soil was computed on the basis of soil solution SAR using empherical equation suggested by the staff of USSL, (1968).

3.3 Water table and salinity relationship

The water table (hydro-morphic) and soil salinity relationships of the experimental site were investigated through installation of piezometers/observation wells covering 2 replications of each treatment. For this PVC pipes of 4 cm dia (ID) were used for fabrication and installation and had a total length of 1.15 m. The bottom end of each piezometer (leaving 5 cm from bottom) had perforations to a length of 10 cm and were covered by winding with coir twine around the tube. This was done to prevent entry of silt into the tube and blockage. The top end above the ground of all the piezometers were covered with cap to avoid the foreign objects falling into the tubes. Each piezometer was driven into soil

to a depth of 1 m leaving 0.15 m projection above ground level.

The water table from each treatment and replication were monitored at weekly interval throughout the year to investigate the seasonal fluctuations of water table as well as effects of tree on it, if any. Similarly, on the basis of depth and salinity of the ground water table, a relationship between soil salinity and depth of water table, soil salinity and salinity of ground water table etc, were worked out (App. 2, 3 and 4).

3.4 Experimental details

Evaluation of tree species for soil salinity and water table were carried out involving 6 tree species to cover the objectives as mentioned under section I.

A pithole of suitable dimensions, were made to plant tree sampling with a spacing of 4x2 m and the saplings were planted during October, 1991. The design that was followed was essentially randomized complete block design (RCBD) with four replications. The details of experimental design are presented in Fig. 1 and trees included in this investigation were,

R–I

T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6

R–II

T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6

R–III

T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6

R–IV

T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6
T_1	T_2	T_3	T_4	T_5	T_6

T_1 *H. binata*
T_2 *S. grandiflora*
T_3 *A. nilotica*
T_4 *D. sissoo*
T_5 *C. equisetifolia*
T_6 *A. indica*

Fig. 1. PLAN OF LAYOUT–I

1. *Haradwickia binata*
2. *Sesbania grandiflora*
3. *Acacia nilotica*
4. *Dalbergia sissoo*
5. *Casuarina equisetifolia*
6. *Azadirechta indica*

Each tree species received the following fertilizers dose

a) 50 g mixture of 16N:32 P_2O_5: 16K_2O at planting.

b) 50 g mixture of 16N:32 P_2O_5: 16K_2O after 6 months.

c) 75 g mixture of 16N:32 P_2O_5: 16K_2O after 12 months.

To investigate the effects of soil salinity, water table etc., on various tree growth parameters and also the tree had on soil parameters (bio-amelioration) were also evaluated. Each treatment had 30 trees at a spacing of 4 x 2 m in a plot of 20 x 12m.

3.4.1 Soil sampling

Apart from initial soil sampling, profile samplings were also drawn from each treatment during January/February of each year after planting. The samples collected were processed and used for further analysis as discussed under paragraph 3.2.

Effects of salinity and water table on trees were evaluated in terms of per cent establishment and growth parameters such as height, number of branches, DSH (Stem diameter at stump height), DBH (Stem diameter at breast height), pruned bio-mass and crown width etc. The methods followed in each of these parameters are mentioned in brief in the following paragraphs.

3.4.2 Per cent establishment

Number of individual trees survived out of 30 planted trees were counted and experessed as survival per cent 6 and 12 months after planting (MAP).

3.4.3 Number of branches

Number of branches borne by each tree were counted and are presented as number of branches per tree.

3.4.5 DSH

Stem diameter at stump height (DSH) was measured by vernier caliperse at 5 cm above ground and expressed in cm.

3.4.6 DBH

Stem diameter at breast height (DBH) was measured by vernier caliperse at 130 cm above ground surface and expressed in cm.

3.4.7 Pruned biomass

The fresh biomass (twigs and leaves) felled after pruning to 1/3rd height was weighed and expressed in g. at 12 MAP and Kg at 24 MAP.

3.4.8 Crown width

The diameter of crown was measured in two opposite directions by holding poles and was averaged to express crown width in cm.

3.5 Effect of trees on soil properties

Soil samples were collected every year from each plot to study the extent of amelioration. The soil was analysed for salinity, organic carbon, free calcium carbonate and SAR. Exchangeable sodium per cent was calculated from SAR (Details of chemical analysis are presented under section 3.2).

3.6 Concept of SEWN (Sum of excessive water number)

In most realistic situations, especially in command areas, both soil salinity and waterlogging occur together and is difficult to seperate. Generally, any plant/tree growing under these situations experiences the confounded effects of both of these parameters. It was because of this possible confounded effect, the relation between various growth parameters and soil salinity and water table in terms of SEWN

were worked out. On the basis of preliminary indications, the combined effects of salinity and water table was more realistic than their individual effects, therefore, it was found essential to introduce the concept hereafter called SEWN. This concept which combined both salinity and waterlogging was computed taking water table and soil salinity data collected over a period of time.

A water table depth of 80 cm was considered (Tomar and Gupta, 1985) as reference water table (RWT) and water table that remained within 80 cm was considered as excessive water table. The period of such a excessive water table (EW) days were summed up (cummulative excessive water table days) and was refered as sum of excessive water table days (SEW). Since, the trees not only experienced excessive water table i.e., SEW but also varying levels of soil salinity during this period. Thus, a sum of excesssive water table number (SEWN) was computed by taking the product of SEW and average soil salinity of the treatment. The relation thus developed was

SEWN = (RWT-WT) x SEW x ECe

All the tree growth parameters as already listed under paragraph 3.4 were related to SEWN.

The SEWN concept was also extended to study its effect on ionic composition in leaves of various tree species.

3.7 Leaf composition

Leaf analysis was carried out for the content of Na, K, Ca, Mg, S and Cl etc., to relate the effects of water table, salinity and SEWN.

Leaf (well developed matured and disease free) sample was drawn from each tree species from middle of the crown. The samples thus drawn were dried in oven at 80±1°C for 8 hours before powdering them in a Willey mill and stored in polythene bottle for future analysis.

Two seperate methods were followed to determine leaf composition which are detailed below.

3.7.1 Powdered plant meterial was digested in di-acid HNO_3: $HClO_4$ mixture in 10:4 ratio before dissolving the residue in 6N HCl. The digested plant material was used for determination of Na, K, Ca, Mg and S by following standard protocals as described under section 3.2.1.4

A seperate method was followed to determine chloride in leaf and it remained essentially same as the one described by Yoshida *et al.* (1972).

3.8 Statistical analysis

The data obtained on depth and salinity of ground water table of the experimental site was related to soil salinity for the year 1992 and 1993 (Appendix 3 and 4). The statistical treatment was given to understand the relationships between soil salinity, water table and various growth parameters. Soil salinity was grouped into <5, 5-10, 10-15 and >15 dSm^{-1} and water table was categorised into shallow (<70 cm in October and <80 cm in April), medium (71 - 80 cm in October and 81-90 cm in April) and deep (>80 cm in October and >90 cm in April). The plots whose salinity or water table fall in the classified groups are averaged. Based on per cent reduction in growth parameter at highest salinity and shallow water table, tree species were ranked from one to six. The species with highest per cent reduction scored lowest rank.Similarly, SEWN was related to various tree growth parameters. The data obtained on the effect of SEWN on tree growth parameters was analysed by following nested design with fixed effects model as suggested by Dowdy and Wearden (1983). To employ this design, all the treatments and replications of tree species as indicated in fig. 1.were grouped into various SEWN categories (<1, 1-100, 100-500 and >500) on the basis of water table, soil salinity existed in the experimental area

R–I

T_1 <1	T_2 <1	T_3 <1	T_4 <1	T_5 <1	T_6 <1
T_1 1–100	T_2 1–100	T_3 1–100	T_4 1–100	T_5 1–100	T_6 1–100
T_1 100–500	T_2 100–500	T_3 100–500	T_4 100–500	T_5 100–500	T_6 100–500
T_1 >500	T_2 >500	T_3 >500	T_4 >500	T_5 >500	T_6 >500

R–II

T_1 <1	T_2 <1	T_3 <1	T_4 <1	T_5 <1	T_6 <1
T_1 1–100	T_2 1–100	T_3 1–100	T_4 1–100	T_5 1–100	T_6 1–100
T_1 100–500	T_2 100–500	T_3 100–500	T_4 100–500	T_5 100–500	T_6 100–500
T_1 >500	T_2 >500	T_3 >500	T_4 >500	T_5 >500	T_6 >500

T_1 *H. binata*
T_2 *S. grandiflora*
T_3 *A. nilotica*
T_4 D. sissoo
T_5 C. equisetifolia
T_6 *A. indica*

Fig. 2. PLAN OF LAYOUT–II

(fig. 2). The SEWN values assigned for each treatment and replication were related to growth parameters and for above design analysis. Similarly, attempts were also made to relate effects of SEWN, soil solution ion concentration on leaf composition of various tree species and the regression lines were developed between soil solution and leaf composition whenever found essential.

The effect of trees on various soil parameters, to understand their role in bio-amelioration, were also subjected to statistical treatment such as Nested design analysis with fixed effects model as was done and explained in earlier paragraphs.

CHAPTER - IV

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

Results of present investigation are presented in brief under following paragraphs. The parameters considered for presentation of results are as under.

* Initial soil properties of the experimental area
* Effect of soil salinity/water table on various tree growth parameters
* Effect of SEWN on various tree growth parameters
* Effect of SEWN on ionic ratios of leaf tissue composition
* Effect of soil solution compositon on tissue composition and
* Effect of tree species on soil chemical environment (bio-amelioration)

4.1 Initial soil properties of experimental area

Soils of the experimental site were examined for soil texture, salinity (ECe), pH, soil solution composition, lime status, organic carbon, SAR and ESP (P) are presented in table 1. Results represent 72 profile samples drawn from the experimental areas covering each treatment and replication.

4.1.1 Soil texture of experimental site revealed that it was clay upto 60 cm depth, However, the texture remained clayloam

Table 1. Some of the chemical properties of the experimental site

Properties	0–15	15–30	30–60	60–90	90+
	Depth (cm)				
1. Texture	c	c	c	cl	g
2. ECe (dSm^{-1})					
Range	1.3–42.9	1.3–32.8	1.8–27.3	2.1–22.9	2.6–21.0
Mean	14.0	12.3	12.5	11.7	10.7
3. pH range	7.52–8.26	7.59–8.35	7.72–8.20	7.38–8.21	7.34–8.29
4. Soln.Compn. (1:2.5) Cations (me/l)					
a. Na+					
Range	2.6–172.1	2.6–158.3	3.5–133.9	5.2–104.6	4.4–100.0
Mean	116.8	93.6	100.8	86.8	84.2
b. K+					
Range	0.06–0.54	0.03–0.32	0.05–0.29	0.03–0.26	0.04–0.19
Mean	0.43	0.29	0.28	0.24	0.25
c. Ca++					
Range	1.5–32.5	1.5–27.1	1.5–26.0	1.5–25.0	0.5–26.0
Mean	30.4	24.7	25.6	22.3	21.83
d. Mg++					
Range	0.5–17.5	0.5–19.0	0.5–19.8	0.5–19.0	0.5–15.5
Mean	12.8	10.1	11.2	9.6	8.7
Anions (me/l)					
a. CO3–					
Range	–	–	–	–	–
Mean					
b. HCO3–					
Range	1.2–7.2	1.0–7.7	1.4–5.8	1.4–6.8	0.4–7.5
Mean	8.9	6.6	6.5	3.8	6.5
c. SO4=					
Range	1.5–181.2	1.5–176.9	3.0–168.3	7.7–202.2	5.3–214.0
Mean	122.0	109.0	112.8	105.5	98.1
d. Cl–					
Range	1.0–97.0	1.0–53.0	1.0–32.0	1.0–25.8	1.0–19.0
Mean	27.0	14.6	10.6	8.7	10.4
5. CaCO3 (%)					
Range	8.9–15.9	9.03–15.9	9.7–16.8	10.0–17.2	10.4–18.6
Mean	12.4	12.6	13.0	13.9	14.6
6. O.C. (%)					
Range	0.39–1.05	0.12–0.97	0.12–0.81	0.19–0.81	0.10–0.47
Mean	0.76	0.55	0.43	0.3	0.31
7. SAR (mmol/l)1/2					
Range	2.6–34.4	2.6–33.0	3.5–28.2	5.2–22.2	6.2–22.0
Mean	15.2	15.0	15.5	15.2	15.8
8. ESPp					
Range	2.5–33.1	2.5–32.7	3.8–28.7	6.0–23.9	7.3–23.8
Mean	17.1	17.5	17.3	17.2	16.9

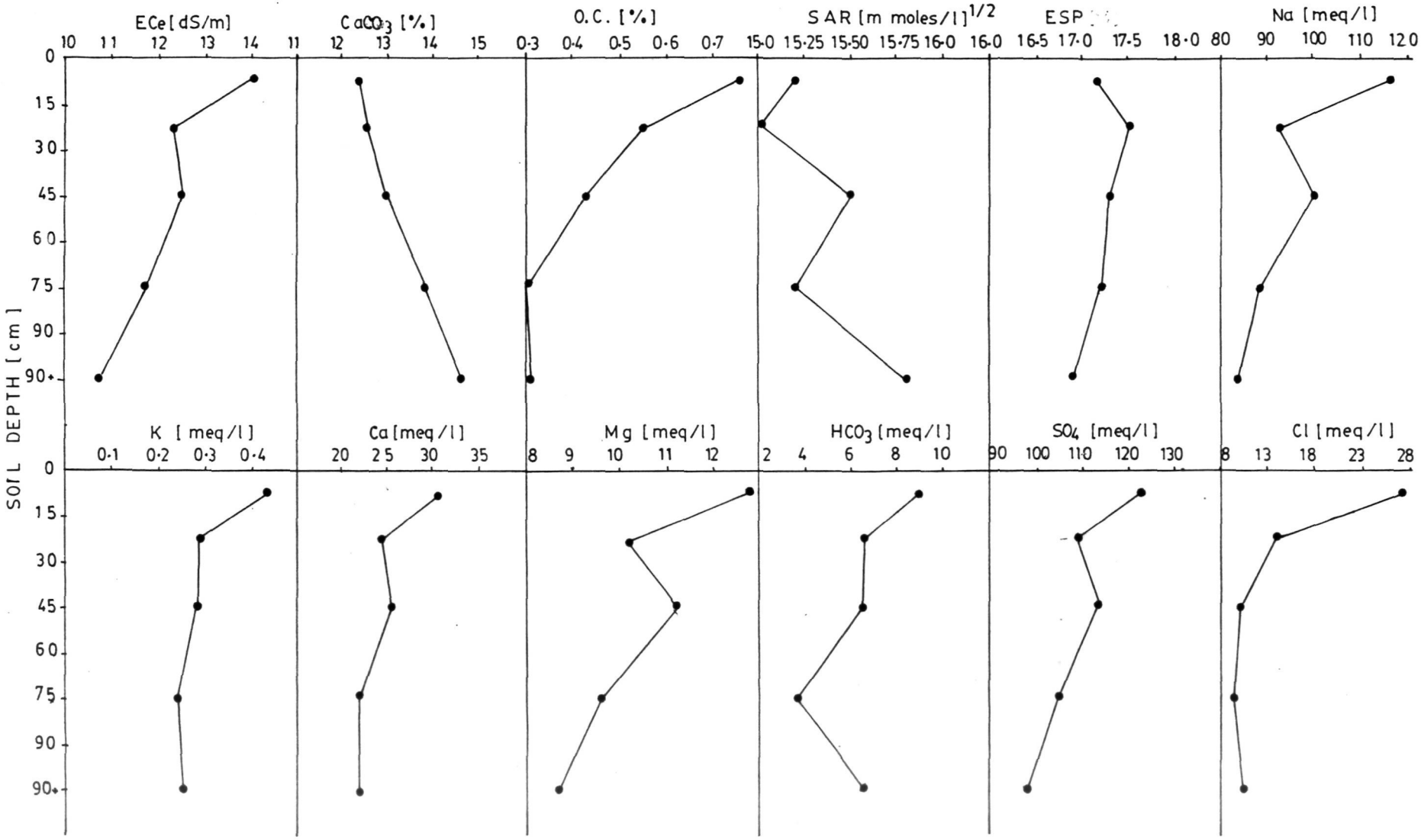


FIG.3 : SOME OF THE CHEMICAL PROPERTIES OF EXPERIMENTAL SITE

when examined at 60-90 cm and below which it remained calcarious gravelly.

4.1.2 Soil salinity of experimental area showed wide variations both within the profile as well as between sampling site. It ranged from 1.3 to 42.9 dS m^{-1} in surface and decreased as depth increased (fig 3). The values remained in the range of 2.6-21.0 dS m^{-1} when samples were drawn from 90+cm. The mean salinity of the profiles indicated a highest (14.0 dS m^{-1}) in surface (0-15 cm) and lowest (10.7 dS m^{-1}) when depth was 90+ cm indicating the decreasing tendency of the salinity within the profile.

4.1.3 Soil reaction: Measured in terms of pH values, remained by and large neutral to raction. The values ranged from 7.52-8.26 in Surface (0-15 cm). A similar trend in pH values was observed with no appreciable variation within the profile.

4.1.4 Soil solution composition

Examined for soil solution sodium, potassium, calcium and magnesium representing cations and carbonate, bi-carbonate, sulphate and chloride representing anions, are presented in the paragraphs below.

4.1.4.1 Cations

4.1.4.1.1 Sodium was found to vary not only within profile but also between sites. A highest mean sodium (116.8 me/l) was found in surface (0-15 cm) samples. Within samples drawn from surface (0-15 cm), sodium concentration varied considerably as indicated by range of values obtained (2.6-172.1 meq/l). Similar variations were also observed within the profile. The values of both range (4.4-100.0 me/l) and mean (84.2 me/l) remained lower in samples representing 90+cm. On the basis of mean values, it clearly indicated that Na decreased with depth and a highest of 116.8 and lowest of 84.2 me/l were observed in surface (0-15 cm) and at depth of 90+cm, respectively (fig 3). However, levels of Na of soil solution between these two extreme depths remained intermediary.

4.1.4.1.2 Potassium On the contrary to sodium levels potassium in soil solution remained for lower but, the tendencies of its distribution both within profile and between sites, remained similar to the one observed in case of Na. The solution composition of potassium was higher (0.43 me/l) in surface and decreased with depth with lowest (0.24 me/l) values when samples represented 60-90cm depth. The values of K in soil solution for surface samples ranged from 0.06-0.54

me/l indicating the a spatial variability of K from site to site.

4.1.4.1.3 Calcium levels remained only next to sodium in its order of magnitude. On the basis of results, it revealed that the spatial variability was also quite evident in respect of Ca. It ranged from 1.5-32.5 me/l in surface and decreased with depth. Calcium values ranged from 0.5-26.0 me/l in case of samples drawn from 90+ depth. This indicated not only the decreasing trendency with depth but also large variation between sites. On the basis of mean values worked out from samples drawn at various depths, it indicated a highest in case of surface (30.4 me/l) with lowest (21.83 me/l) in case of samples drawn from 90+ cm. This gave ample evidence of decreasing trend in calcium with depth (fig 3).

4.1.4.1.4 Magnesium remained next in order of sodium and calcium but were appreciably higher than potassium. Results on Mg representing both depth and site indicated that the values representing surface samples remained higher than from other depths (table 1 and fig 3). It ranged from 0.5-17.5 me/l for the samples drawn from surface while, it was 0.5-15.5 me/l for samples drawn from depth representing 90+ cm. Mean values worked out for various depths suggested that magnesium

was highest (12.8 me/l) in surface (0-15 cm) and lowest (8.7 me/l) for deepest (90+ cm) layer examined suggesting decreasing tendency of Mg with depth.

On the basis of cationic composition of soil solution, it was found that sodium was the predominant ion in soil solution followed by calcium, magnesium and potassium and soil solution remained of Na: Ca: Mg: K type.

4.1.4.2 Anions

The anionic composition of solution was examined in terms of carbonate, bi-carbonate, Sulphates and chlorides (table 1 and Fig 3). The results pertaining to anions are presented in the following paragraphs.

4.1.4.2.1 Carbonate Soil solution remained free of carbonates. This was in confirmity with soil reaction values.

4.1.4.2.2 Bi-carbonate level generally remained low and gave some indication of variability between sites but variations were drastic within profile as indicated by the values. The values for surface ranged from 1.2 to 7.2 me/l with a highest mean of 8.9 me/l. As depth increased, there was a perceptible decrease in both range and mean values (fig 3) with lowest (3.8 me/l) observed in case of samples drawn from 60-90 cm depth. Like cations, bi-carbonates also decreased with depth.

4.1.4.2.3 Sulphate was the most predominant anion in solution. On the basis of values obtained, there was a spatial variability in respect of sulphate both within profile and between sites (table 1). The values ranged from 1.5 to 181.2 me/l with highest mean of 122.0 me/l for samples drawn from 0-15 cm. On the contrary, a lowest (98.1 me/l) was recorded at a 90 + cm depth. For other depths, the value remained intermediatory between the extremes.

4.1.4.2.4 Chloride also recorded similar trend as that of bi-carbonate and sulphate (table 1 and Fig 3). It ranged from 1.0-97.0 me/l with a mean value of 27.0 me/l for the samples drawn from the surface (0-15 cm). In contrast, lower values recorded ranged from 1 to 19.0 me/l with a lowest mean (10.4 me/l) for the samples representing 90+ cm. The range and mean values in respect of chloride other depths remained intermediary demonstrating chloride had decreasing tendency with depth (fig 3) as was observed in case of other anions.

Results on anionic composation indicated that sulphate predominated anionic scene followed by chloride and bi-corbonate and soil solution remained of SO_4^{2-}: Cl^-: HCO_3^-: type.

4.1.5 Calcium carbonate: status of the expeirmental soil also revealed spatial variability. The surface samples had lower $CaCO_3$ than deeper layers (table 1 and Fig 3). The surface samples had $CaCO_3$ in the range of 8.9-15.9 per cent and increased slightly with depth. This tendency remained in contrast to both cationic as well as anionic, comoposition of soil solution. A lowest mean value of 12.4 per cent $CaCO_3$ was observed for samples representing surface (0-15 cm) as against 14.6 per cent in case of samples representing 90+ cm indicating the increasing tendency with depth.

4.1.6 Organic carbon: decreased with depth with highest mean of 0.76 per cent for samples drawn form 0-15cm and lowest of 0.3 per cent beyond the depth of 60 cm. The mean values remained intermediary for depths of both shallow and deeper layers (table 1 and fig 3). The values on range suggested some degree of variability in distribution of organic carbon both depth wise as well as sites. The values ranged from 0.39 to 1.05 per cent in case of samples drawn from 0-15 cm whereas, they were from 0.1 to 0.47 per cent when samples represented 90+ cm. These variations in sampels confirmed the variability with space.

4.1.7 SAR: A mean soil solution SAR remained fairly uniform (arround 15 m $mol/l^{1/2}$) despite spatial variability as

indicated by the range of values recorded for both different sites as well as depths (table 1 and fig 3). The values ranged from 2.6 to 34.4 (m mol/l)$^{1/2}$. A similar variation was observed for lower horizons and sites.

4.1.8 ESP (p): The predicted ESP followed the trend observed in case of solution SAR and remained fairly uniform throughout the profile. Values of ESP (p) ranged from 2.5 to 33.1 per cent in case of the surface (0-15 cm) samples. A similar variability was also observed in case of other depths and sites.

4.2 Effect of soil salinity and water table on various growth parameters

Results showing the effects of soil salinity and water table on per cent establishment, plant height, number of branches, DSH, DBH, pruned bio-mass and crown width are presented in following paragraphs.

4.2.1 Soil salinity

Data on the effect of soil salinity on various tree growth parameters are presented as under.

4.2.1.1 Eastablishment: Results pertaining to the effect of soil salinity on establishment of various trees observed 6 and

Table 2. Effect of soil salinity on establishment of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 6 MAP					
1. *H. binata*	95.6	91.7	82.2	76.3	87.2
2. *S. grandiflora*	70.0	73.3	66.7	62.7	68.2
3. *A. nilotica*	100.0	99.4	95.0	96.7	97.8
4. *D. sissoo*	94.0	93.3	80.0	73.3	85.2
5. *C. equisetifolia*	93.3	87.8	82.0	75.0	84.5
6. *A. indica*	90.0	82.5	53.3	48.9	68.7
b) 12 MAP					
1. *H. binata*	94.3	90.7	79.7	73.0	84.4
2. *S. grandiflora*	70.0	67.0	64.3	53.0	63.6
3. *A. nilotica*	100.0	98.7	94.0	94.0	96.7
4. *D. sissoo*	93.3	90.3	76.7	67.7	82.0
5. *C. equisetifolia*	93.3	85.3	78.7	70.7	82.0
6. *A. indica*	87.7	78.7	49.0	42.0	64.4

12 MAP are presented in table 2 and fig 4. From the results, it is quite evident that higher establishment was observed when soil salinity remained less than 5 dS m^{-1}. This was observed in all the tree species under investigation. Amongst tree species, a highest establishment (100%) was observed in case of *A. nilotica* at both 6 and 12 MAP and was closely followed by all except *S. grandiflora* which recorded 70 per cent establishment even 12 MAP . In rest of the species, per cent establishment remained on or arround 90 per cent. As soil salinity increased, per cent establishment decreased and no tree remained exception to this phenomenon. Species such as *A. nilotica, H. binata* and *C. equisetifolia* recorded higher degree of establishment compared to other speceis. The overall performance of tree species as observed over various salinity ranges revealed that *A. nilotica* was found most promising followed by *H. binata, C.equisetifolia* and *D. sissoo.* Nearly 40 per cent reduction was observed in case of *S. grandiflora* and *A. indica* while, 10-20 per cent decrease in case of other species. Performance of the tree species in terms of establishment was found to follow (12 MAP) the order of; *A. nilotica* (96.7%) > *H. binata* (84.4%) > *C. equisetifolia* (82.0%) = *D. sissoo* (82.0%) > *A. indica* (64.4%) > *S. grandiflora* (63.6%).

4.2.1.1 Height: Results showing the effect of soil salinity on tree height measured at 6, 12 18 and 24 MAP, are presented in table 3 and fig 5. It is quite clear from the results that increase in height was recorded by all the tree species when soil salinity remained less than 5 dS m^{-1}. However, there was a lot of variation in plant height of various tree species investigated. Amongst tree species, a highest of 221.4 cm was recorded (6 MAP) in case of *S. grandiflora* followed by *A. nilotica* (131.5 cm), *D. sissoo* (115.2 cm), *C. equisetifolia* (80.8 cm) and *A. indica* (55.8 cm) while, a lowest was found in case of *H. binata* where it could record only 42.5 cm. When soil salinity increased beyond 15 dS m^{-1}, there was marked reduction in plant height and this was observed in all the tree species. However, it is interesting to note that per cent reduction over increasing salinity differed with tree species. A lowest reduction (15%) was observed in case of *A. nilotica* and *C. equisatifolia* while, a highest (66.6%) in *D. sissoo*. Sepcies such as *H. binata* and *A. indica*, although, recorded lower plant height compared to *D. sissoo*, yielded lower per cent reduction.

Performance of tree spcies 6 MAP followed the order (in terms of % reduction) of:

Table 3. Effect of soil salinity on height (cm) of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 6 MAP					
1. *H. binata*	42.5	35.1	33.5	31.3	35.6
2. *S. grandiflora*	221.4	195.2	202.1	179.6	199.6
3. *A. nilotica*	131.5	130.4	119.0	112.4	123.3
4. *D. sissoo*	115.2	83.7	45.8	38.9	70.9
5. *C. equisetifolia*	80.8	72.4	82.7	69.0	76.2
6. *A. indica*	55.8	51.8	52.2	40.6	50.1
b) 12 MAP					
1. *H. binata*	130.6	115.2	102.7	98.4	111.7
2. *S. grandiflora*	457.4	447.1	436.1	408.5	437.3
3. *A. nilotica*	285.5	273.7	267.1	248.7	268.8
4. *D. sissoo*	328.1	260.1	227.6	197.8	253.4
5. *C. equisetifolia*	200.3	176.7	168.9	158.7	176.2
6. *A. indica*	118.5	95.1	86.8	72.0	93.1
c) 18 MAP					
1. *H. binata*	216.1	198.5	179.0	126.2	180.0
2. *S. grandiflora*	528.9	514.9	448.1	412.9	476.2
3. *A. nilotica*	345.8	363.9	336.8	342.0	347.1
4. *D. sissoo*	487.4	494.8	368.7	236.8	396.9
5. *C. equisetifolia*	270.1	274.7	250.5	208.8	251.0
6. *A. indica*	153.3	141.5	119.3	67.1	120.4
d) 24 MAP					
1. *H. binata*	278.6	278.8	240.7	179.5	244.4
2. *S. grandiflora*	618.3	547.5	557.9	439.4	541.8
3. *A. nilotica*	472.8	488.6	428.3	421.6	452.8
4. *D. sissoo*	568.4	474.8	454.5	246.4	436.0
5. *C. equisetifolia*	397.9	372.2	394.9	296.1	365.3
6. *A. indica*	180.0	158.2	136.6	87.3	140.5

D. sissoo (66%) > *A. indica* (27%) > *H. binata* (26%) > *S. grandiflora (19%)* > *C. equisetifolia* (15%) = *A. nilotica* (15%).

This trend was slightly altered when observed 12 MAP. *Dalbergia sissoo* continued to record poor performance as per cent reduction in height remaind higher (40%). This was closely followed by *A. indica* (39%) and took the place *H. binata* (25%). The species such as *H. binata* was found better than *A. indica* and *D. sissoo*. The performance of tree spcies as indicated by per cent reduction in their height 12 MAP, revealed the folowing order of performance: *D. sissoo* (40%) > *A. indica* (39%) > *H. binata* (25%) > *C. equisetifolia* (21%) > *A. indica* (13%) > *S. grandiflora* (11%).

Performance of tree species became more stabilised when observed 18 and 24 MAP as the per cent reduction in plant height due to increasing salinity remained fairly stabilized. However, a higher reduction in plant height due to increasing salinity was observed in *A. indica* (56%) and *D. sissoo* (57%) 18 and 24 MAP, respectively. These species were consistantly followed by *H. binata*. However, *C. equisetifolia* improved (in plant height) over *S. grandiflora* when observed 24 MAP. But, it shoud be noted that *A. nilotica* consistantly performed

better over other species and soil salinity values as per cent reduction in plant height due to increasing salinity was far lower than other species. On the basis of per cent reduction, the order of performance at increasing soil salinity 24 MAP was in the order of *D. sissoo* (57%) > *A. indica* (52%) > *H. binata* (35%) > *S. grandiflora* (29%) *C. equisetifolia* (26%) > *A. nilotica* (11%).

4.2.1.3 Number of branches Data on number of branches in respect of trees under investigation showing the effect of soil salinity are presented in table 4 and fig 6. From the results, it was observed that soil salinity had marked influence on branching habits of tree species. All the species were affected as branching potential of species was reduced due to increasing salinity of soil. However, the effect was found minimal when salinity was less. A higher number of branches were observed when salinity remained less than 5 dS m^{-1}. A highest number of 18.92 branches were observed in case of *A. nilotica* when salinity was less than 5 dS m^{-1}. The number of branches incresed to some extent at higher salinity, but decreased (17.36) when salinity remained higher than 15 dS m^{-1}. Amongst the tree species, a lowest number of branches were observed in case of *A. indica* (1.76) closely followed by *H. binata* (6.02). species such as *S.*

Table 4. Effect of soil salinity on number of branches of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 6 MAP					
1. *H. binata*	7.76	6.05	5.21	5.04	6.02
2. *S. grandiflora*	17.01	17.40	18.20	14.74	16.84
3. *A. nilotica*	18.92	20.23	20.67	17.36	19.30
4. *D. sissoo*	18.18	11.17	7.60	5.32	10.57
5. *C. equisetifolia*	17.21	14.07	14.81	13.48	14.89
6. *A. indica*	2.50	1.98	1.46	1.09	1.76
b) 12 MAP					
1. *H. binata*	15.84	14.00	12.38	9.45	12.92
2. *S. grandiflora*	25.05	24.26	23.46	20.19	23.24
3. *A. nilotica*	32.61	32.08	33.06	27.76	31.38
4. *D. sissoo*	29.56	26.46	22.69	17.22	23.98
5. *C. equisetifolia*	26.35	22.86	24.69	20.88	23.70
6. *A. indica*	9.18	7.07	6.28	5.08	6.90
c) 18 MAP					
1. *H. binata*	24.95	20.67	18.03	14.81	19.62
2. *S. grandiflora*	30.11	27.50	24.74	21.00	25.84
3. *A. nilotica*	62.67	61.38	51.95	50.44	56.61
4. *D. sissoo*	50.13	46.45	39.19	25.10	40.22
5. *C. equisetifolia*	50.85	45.27	44.14	35.21	43.87
6. *A. indica*	13.19	10.85	8.61	6.50	9.79
d) 24 MAP					
1. *H. binata*	29.04	25.86	24.93	16.14	23.99
2. *S. grandiflora*	32.12	29.07	27.53	23.79	28.13
3. *A. nilotica*	61.33	61.18	56.95	55.57	58.76
4. *D. sissoo*	57.67	55.00	49.43	32.01	48.55
5. *C. equisetifolia*	53.20	46.46	46.94	36.53	45.78
6. *A. indica*	28.50	21.62	14.04	7.83	18.00

grandiflora, *D. sissoo*, and *C. equisetifolia*, although remained closer to *A. nilotica*, the extent of reduction due to increasing salinity varied markedly. A highest redution of 71 per cent was observed in case of *D. sissoo* followed by *A. indica* (56%), *H. binata* (35%) etc, when salinity remained more than 15 dS m^{-1}. This clearly demonstrated genetic variability of species as for as salt tolerance was concerned. On the basis of over all performance of trees, in terms of per cent reduction in number of branches observed 6 MAp remained in the order of : *D. sissoo* (71%) > *A. indica* (56%) > *H. binata* (35%) > *C. equisetifolia* (22%) > *S. grandiflora* (13%) > *A. nilotica* (8%)

Effect of soil salinity on number of branches ramained similar 12 MAP as of 6 MAP. However, the observations made 18 and 24 MAP revealed that *D. sisso* which recorded higher (over 50%) reduction improved its performance only over *A. indica* taking the place of *D. sissoo* in registering a highest reduction. However, the order of performance in terms of per cent reduction in number of branches due to salinity remained unaltered and was found in the order of *A. indica* (73%) > *D. sissoo* (44%) = *H. binata* (44%) > *C. equisetifolia* (31%) > *S. grandiflora* (26%) *A. nilotica* (9%).

4.2.1.4 Diameter at stump height (DSH) was measured 5 cm above ground level and remained as a function of salinity and time. Data pertaining to these effects are presented in table 5 and fig 7. Influence of soil salinity was quite marked on DSH and decreased as salinity increased. No trees remained exception to this yardstick as all the species suffered under the influence of salinity. However, there existed a differential response amongst tree species. A highest DSH (4.45 cm) was observed in case of *S. grandiflora* when soil salinity remained well witnin 5 dSm^{-1}. This was followed by *A. nilotica* (2.23cm) and *D. sissoo* (1.55cm) and remained lower in other species when soil salinity was lower than 5 dSm^{-1}. As soil salinity increased, DSH decreased with higher (66%) per cent decrease observed in case of *D. sissoo* followed by *S grandiflora* (36%), *A. indica* (34%) and *H. binata* (29%). However, it remained marginal in case of *C. equisetifolia* (6%) and *A. nilotica* (19%) when soil salinity was higher than 15 dSm^{-1}. On the basis of per cent reduction observed 6 MAP, the order of performance of tree species was *D. sissoo* (66%) > *S. grandiflora* (36%) > *A. indica* (34%) > *H. binata* (29%) > *A. nilotica* (19%) > *C. equisetifolia* (6%).

As trees grew older (12 MAP), there was some evidence of adoptibility of tree species. Species which were

Table 5. Effect of soil salinity on DSH (cm) of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 6 MAP					
1. *H. binata*	0.62	0.55	0.48	0.44	0.52
2. *S. grandiflora*	4.45	4.38	3.59	2.92	3.86
3. *A. nilotica*	2.23	2.09	1.90	1.81	2.01
4. *D. sissoo*	1.55	1.21	0.95	0.53	1.06
5. *C. equisetifolia*	0.86	0.87	1.02	0.81	0.89
6. *A. indica*	0.67	0.68	0.65	0.44	0.66
b) 12 MAP					
1. *H. binata*	1.78	1.54	1.38	1.34	1.51
2. *S. grandiflora*	9.50	8.69	7.58	7.15	8.23
3. *A. nilotica*	6.06	5.34	5.21	4.67	5.31
4. *D. sissoo*	4.35	3.63	2.89	2.10	3.24
5. *C. equisetifolia*	2.94	2.70	2.60	2.44	2.67
6. *A. indica*	2.42	1.88	1.68	1.30	1.82
c) 18 MAP					
1. *H. binata*	3.97	3.55	2.96	2.41	3.22
2. *S. grandiflora*	10.64	9.27	9.51	8.57	9.50
3. *A. nilotica*	9.53	8.15	8.59	6.73	8.25
4. *D. sissoo*	7.18	6.06	6.10	3.23	5.64
5. *C. equisetifolia*	5.35	4.81	4.00	3.83	4.50
6. *A. indica*	2.89	2.26	1.68	1.38	2.05
d) 24 MAP					
1. *H. binata*	4.97	4.36	3.58	3.19	4.03
2. *S. grandiflora*	11.33	11.28	9.93	8.51	10.26
3. *A. nilotica*	11.58	11.67	10.29	9.71	10.81
4. *D. sissoo*	9.95	8.46	7.96	6.60	8.24
5. *C. equisetifolia*	6.04	5.88	4.91	4.12	5.24
6. *A. indica*	3.78	2.77	2.27	1.98	2.70

registering higher per cent reduction became more adoptible and recorded lower reduction. This was quite evident as the order of performance, changed when compared with the one observed 6 MAP. The changed order of performance 12 MAP was *D. sissoo* (52%) > *A. indica* (46%) > *H. binata* (25%) = *S. grandiflora* (25%) > *A. nilotica* (23%) > *C. equisetifolia* (17%).

Soil salinity continued to influence the performance ot tree species. It is interesting to note that *S. grandiflora* which was influenced more by salinity in early phases of its growth (6 and 12 MAP), became more adoptible as per cent reduction due to increasing salinity got reduced drastically. The per cent reduction in DSH was 36 and 25 per cent when observed 6 and 12 MAP, respectively in *S. grandiflora*. This reduction got reduced to 19 and 25 per cent 18 and 24 MAP, respectively.

Effect of salinity on DSH generally remained similar to the one already observed. As salinity increased, DSH of all the species decreased. But, the species differed in respect of the magnitude of reduction. A highest DSH of 11.58 cm was observed in case of *A. nilotica* when soil salinity remained less than 5 dSm^{-1} as against a lowest of 3.78 cm in

A. indica, 24 MAP. As mentioned earlier, all the species suffered due to increasing soil salinity. A highest reduction of 48 per cent was noticed in case of *A. indica* as against a lower reduction of 16 per cent in case of *A. nilotica* when soil salinity was greater than 15 dSm^{-1}. The order of performance as observed on the basis of per cent reduction if DSH, 24 MAP remained as *A. indica* (48%) > *H. binata* (36%) > *D. sissoo* (34%) > *C. equisetifolia* (32%) > *S. grandiflora* (25%) > *A. nilotica* (16%).

4.2.1.5 Diameter at breast height was measured 130cm above the ground level. Data pertaining to this parameter are available in Table 6 and Fig. 8. Of the 6 tree species, the data is presented only for those which had attained 130 cm height at the time of making observations. When observations were made 12 MAP, only 4 species such as *S. grandiflora*, *A. nilotica*, *D. sissoo* and *C. equisetifolia* had grown above 130cm and are presented. Amongst them *S. grandiflora* registered a highest (6.86cm) DBH while, lowest (1.14cm) was in *C. equisetifolia* when soil salinity remained less than 5 dSm^{-1}. As salinity increased, DBH values decreased with some species registering higher degree of reduction than other. *Delbargia sissoo* was one which registered a higher (68%) reduction in DBH compared to 18 per cent observed in case of *A. nilotica* at

Table 6. Effect of soil salinity on DBH (cm) of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 12 MAP					
1. *H. binata*	–	–	–	–	–
2. *S. grandiflora*	6.86	6.38	5.81	5.70	6.19
3. *A. nilotica*	2.16	2.15	1.93	1.86	2.03
4. *D. sissoo*	2.98	1.62	1.26	0.95	1.70
5. *C. equisetifolia*	1.14	0.99	0.90	0.80	0.96
6. *A. indica*	–	–	–	–	–
b) 18 MAP					
1. *H. binata*	–	–	–	–	–
2. *S. grandiflora*	8.58	7.91	7.73	6.51	7.68
3. *A. nilotica*	4.42	4.48	4.00	3.30	4.05
4. *D. sissoo*	5.21	5.20	4.10	3.04	4.39
5. *C. equisetifolia*	2.33	2.49	2.00	1.55	2.09
6. *A. indica*	–	–	–	–	–
c) 24 MAP					
1. *H. binata*	–	–	–	–	–
2. *S. grandiflora*	8.66	7.85	7.50	6.08	7.52
3. *A. nilotica*	5.63	5.51	5.38	4.66	5.30
4. *D. sissoo*	6.21	6.11	5.18	3.62	5.28
5. *C. equisetifolia*	3.26	3.32	2.72	2.07	2.84
6. *A. indica*	–	–	–	–	–

soil salinity greater than 15 dSm^{-1}. The decreasing trend in DBH with salinity was also observed 18 and 24 MAP. All species in general recorded a higher values of DBH with time. Performance of tree species as observed 24 MAP was in the order of:

D. sissoo (42%) > *C. equisetifolia* (37%) > *S. grandiflora* (30%) > *A. nilotica* (17%).

4.2.1.6 **Pruned biomass** : The trees were pruned to 1/3rd of their stand and pruned biomass was recorded on fresh weight basis. Results pertaining to this parameter are presented in Table 7 and Fig. 9. The pruned biomass observed 12 MAP was highest (1992.4g) in case of *A. nilotica* as against lowest (87.8g) in case of *H. binata* when salinity remained less than 5 dSm^{-1} with *S. grandiflora* (1148.0g), *D. sissoo* (958.5 g) following *A. nilotica* in that order. The biomass yeld in case of *A. indica* remained poor (149.3g) but was appreciably higher than *H. binata*. As the salinity increased, biomass yield decreasd in all the tree species tried. However, the extent of decrease varied with species. A highest reduction of 52 per cent was observed in case of *D. sissoo* followed by *H. binata* and *A. indica* (around 40%). The reduction was less in case of *C. equisetifolia* and *A. nilotica* registering a moderate value of 20 per cent. The overall rating of

Table 7. Effect of soil salinity on pruned bio-mass per tree of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 12 MAP (bio-mass in g)					
1. *H. binata*	87.80	76.40	68.40	50.50	70.80
2. *S. grandiflora*	1148.00	1140.60	926.70	802.40	1004.40
3. *A. nilotica*	1992.40	1896.20	1821.00	1513.40	1805.80
4. *D. sissoo*	958.50	906.40	727.10	462.90	763.70
5. *C. equisetifolia*	456.90	474.20	388.60	365.70	421.40
6. *A. indica*	149.30	131.00	108.60	86.60	118.90
b) 24 MAP (bio-mass in kg)					
1. *H. binata*	1.66	1.55	1.20	0.98	1.35
2. *S. grandiflora*	3.80	3.52	3.10	2.33	3.19
3. *A. nilotica*	10.00	9.80	9.24	8.75	9.45
4. *D. sissoo*	9.86	8.83	7.35	4.58	7.66
5. *C. equisetifolia*	6.68	6.32	6.05	4.49	5.89
6. *A. indica*	0.77	0.71	0.41	0.38	0.57

performance of trees on the basis of per cent reduction 12 MAP, was in the order of :

D. sissoo (52%) > *A. indica* (42%) = *H. binata* (42%) > *S. grandiflora* (30%) > *A. nilotica* (24%) > *C. equisetifolia* (20%).

Performance of tree species observed 24 MAP revealed considerable improvement in biomass yield. This was observed in all the tree species with a highest biomass of 10.0 kg in *A. nilotica* followed by *D. sissoo* (9.86 kg). In contrast, a lowest of 0.77 kg was observed in *A. indica* when soil salinity remained less than 5 dSm^{-1} . Like in case of observations made 12 MAP, salinity had marked effect on biomass yield. As salinity increased, all species suffered. However, *A. nilotica* (13% decrease) was found to suffer to a lesser magnitude than other species. Effect of salinity was found drastic in respect of *D. sissoo* (54%) and *A. indica* (51%) as per cent reduction values remained larger than 50 per cent at soil salinity higher than 15 dSm^{-1}. In general, the pruned biomass increased with time and overall rating of tree species on the basis of reduction in biomass yield observed 24 MAP followed the following order;

D. sissoo (54%) > *A. indica* (51%) > *H. binata* (41%) > *S. grandiflora* (39%) > *C.equisetifolia* (33%) > *A. nilotica* (13%).

4.2.1.7 Crown width : The data on crown width are presented in Table 8 and Fig. 10. The observations were made 6, 12, 18 and 24 MAP. Results pertaining to this parameter indicate the effect of time and salinity on crown width. When soil salinity remained less than 5 dSm^{-1}, a highest crown width of 65.6 cm was recorded in case of *A. nilotica* follwed by *S. grandiflora* (48.6 cm), *D. sissoo* (47.0 cm) and *C. equisetifolia* (35.7 cm) compared to lowest crown width recorded in *A. indica* (27.5 cm). As soil salinity increased, a reduction in crown width was very clear in all the tree species. *Acacia nilotica* with highest (65.6cm) crown width also recorded a lowest per cent reduction (11%) even when soil salinity remained higher than 15 dSm^{-1}. The per cent reduction in crown width under similar salinity conditions *C. equisetifolia* (11%) was found to record a reduction comparable to *A. nilotica*. However, a highest per cent reduction (37%) was observed in case of *D. sissoo* and *H. binata*. The species such as *S. grandiflora* and *A. indica* had 26 and 28 per cent reduction, respectively when observations were made 6 MAP.

Effect of salinity on trees continued even when observations were made 12 and 18 MAP. Species like *C. equisetifolia* which was found comparable to *A. nilotica* recorded higher per cent of recduction in crown width when

Table 8. Effect of soil salinity on crown width (cm) of tree species

Tree species	Soil salinity (dSm^{-1})				Mean
	<5	5–10	10–15	>15	
a) 6 MAP					
1. *H. binata*	34.1	31.5	30.1	21.6	29.3
2. *S. grandiflora*	48.6	47.5	40.4	36.1	43.2
3. *A. nilotica*	65.6	66.7	58.3	58.7	62.3
4. *D. sissoo*	47.0	40.3	34.1	29.5	37.7
5. *C. equisetifolia*	35.7	35.5	32.0	31.6	33.7
6. *A. indica*	27.5	26.0	23.2	19.9	24.2
b) 12 MAP					
1. *H. binata*	55.0	50.9	44.6	38.0	47.1
2. *S. grandiflora*	169.2	173.2	155.7	152.6	162.7
3. *A. nilotica*	288.0	269.5	258.9	238.1	263.6
4. *D. sissoo*	225.8	220.5	188.8	91.7	181.7
5. *C. equisetifolia*	128.5	125.0	121.1	57.2	108.0
6. *A. indica*	77.1	69.2	58.0	41.8	61.5
c) 18 MAP					
1. *H. binata*	91.5	88.0	69.6	55.3	76.1
2. *S. grandiflora*	236.4	240.9	214.0	200.8	223.0
3. *A. nilotica*	351.0	335.1	301.8	288.8	319.2
4. *D. sissoo*	318.7	310.5	216.3	148.2	248.4
5. *C. equisetifolia*	215.6	200.2	163.2	126.0	176.3
6. *A. indica*	96.6	83.6	65.7	44.8	72.7
d) 24 MAP					
1. *H. binata*	125.7	116.3	103.6	68.1	103.4
2. *S. grandiflora*	257.1	240.6	223.6	209.6	232.7
3. *A. nilotica*	376.6	344.8	339.6	305.4	341.6
4. *D. sissoo*	341.2	296.4	246.3	130.9	253.7
5. *C. equisetifolia*	258.2	290.0	239.7	171.2	239.8
6. *A. indica*	118.0	116.6	89.4	51.4	93.9

observed 12 and 18 MAP, while, *D. sissoo* improved its performance marginally when observed 18 MAP.

The crown width measured 24 MAP indicated that *A. nilotica* was again the most promising species, as it registered a highest values of 376.6 cm as against lowest (118.0) in case of *A. indica* when soil salinity remained lesser than 5 dSm^{-1}. As salinity increased beyond 15 dSm^{-1} a marked reduction in crown width of all the species was observed with a lowest reduction in case of *S. grandiflora* (18%) and *A. nilotica* (19%). However, the species such as *D. sissoo* (62%), *A. indica* (56%) and *H. binata* (46%) recorded higher degree of reduction. On the basis of these results, the performance of tree species followed the order : *D. sissoo* (62%) > *A. indica* (56%) > *H. binata* (46%) > *C equisetifolia* (34%) > *A. nilotica* (19%) > *S. grandiflora* (18%).

The overall performance of tree species on the basis of per cent reduction observed in various growth parameters indicated better performance of *A. nilotica* (5.4) followed by *S. grandiflora* (4.8) and *C.* equisetifolia (4.5) (Table 9) *H. binata* (2.9), *A. indica* (1.9) and *D. sissoo* (1.5) recorded higher degree of growth reduction and were found to suffer more than other species.

Table 9. Ranking of tree species in terms of per cent reduction (ECe > 15 dSm^{-1}) in various growth parameters

Tree species	Height				No. of branches				DSH				Bio-mass		Crown width				Overall ranking
	Months after planting				Months after planting				Months after planting				Months after planting		Months after planting				
	6	12	18	24	6	12	18	24	6	12	18	24	12	24	6	12	18	24	
1. *H. binata*	2	3	3	3	3	3	3	2.5	4	3	3	2	2.5	3	1.5	4	4	3	2.9
2. *S. grandiflora*	4	6	5	4	5	5	5	5	2	4	6	5	4	4	4	6	6	6	4.8
3. *A. nilotica*	5.5	5	6	6	6	6	6	6	5	5	4	6	5	6	5.5	5	5	5	5.4
4. *D. sissoo*	1	1	2	2	1	1	2	2.5	1	1	1	3	1	1	1.5	1	1.5	1.5	1.5
5. *C. equisetifolia*	5.5	4	4	5	4	4	4	4	6	6	5	4	6	5	5.5	2	3	4	4.5
6. *A. indica*	3	2	1	1	2	2	1	1	3	2	2	1	2.5	2	3	3	1.5	1.5	1.9

4.2.2 Water Table

Results on the effects of water table on values of growth parameters are presented in succeeding paragraphs.

4.2.2.1 Establishment of tree species as a function of water table was studied and the data pertaining to these are presented in table 10 and Fig. 11. From the results, it is quite clear that there was a inverse relationship between depth of water table and establishment of trees. Performance of trees was affected under shallow (less than 70 cm in October and 80 cm in April) water table conditions. Species such as *A. nilotica* recorded a highest (98.1%) per cent establishment when water table remainned shallow. In contrast to these species, *A. indica* was able to establish only to the extent of 49.1 per cent. As the water table went deeper (more than 80 cm in October and 90 cm in April), the performance of tree species improved. A highest (99.8%) per cent establishment was observed in case of *A. nilotica* when it was deeper than 80 cm in October and 90 cm in April (6MAP). It is interesting to note that species like *D. sissoo, C, equisetifolia, S. grandiflora* and *A. indica* whose establishment was not promising under shallow water table were found to establish well when water table remained deeper. For instance, *A. indica* which had only 49 per cent establishment

Table 10. Effect of water table on establishment (per cent) of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 6 MAP				
1. *H. binata*	80.3	85.4	96.1	87.3
2. *S. grandiflora*	60.9	63.4	74.3	66.2
3. *A. nilotica*	98.1	98.3	99.8	98.7
4. *D. sissoo*	73.2	86.2	92.8	84.1
5. *C. equisetifolia*	74.6	81.2	95.9	83.9
6. *A. indica*	49.1	63.9	90.3	67.8
b) 12 MAP				
1. *H. binata*	70.7	83.5	95.0	83.1
2. *S. grandiflora*	58.5	60.3	71.5	63.4
3. *A. nilotica*	95.1	98.5	99.6	97.7
4. *D. sissoo*	64.1	79.9	91.2	78.4
5. *C. equisetifolia*	73.5	80.2	90.3	81.3
6. *A. indica*	42.5	57.1	88.2	62.6

in shallow water table situations registered higher per cent of establishment (90.3%) under deep water table situations. Performance of tree species remained almost similar when observed 12 MAP except that some species registered a marginal decline in establishment. The efect of water table as observed 12 MAP, appeared to follow the order of;
A. nilotica (95.1%) > *C. equisetifolia* (73.5%) >*H. binata* (70.7%) > *D. sissoo* (64.1%) > *S. grandiflora* (58.5%) > *A. indica* (42.5%).

4.2.2.2 Height : Effect of water table on height was compared under three hydrological situations such as shallow, medium and deep water table conditions. Results pertaining to these are made available in table 11 and fig. 12. Effect of water table on height were observed 6, 12, 18 and 24 MAP. All tree species had lower plant height at shallow and higher when water table remained deeper when observed 6 MAP. A highest plant height of 200.7 cm was recorded in *S. grandiflora* followed by *A. nilotica* (108.0 cm) under shallow water table conditions. The effect of deeper water table on tree height was marked and remained positive. The tree height was highest in case of *S. grandiflora* (217.9cm) followed by *A. nilotica* (118.2cm) and *D. sissoo* (116.8cm). *Hardwickia binata* (41.2cm) and *A. indica* (57.5 cm) recorded poor growth as

Table 11. Effect of water table on height (cm) of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 6 MAP				
1. *H. binata*	36.1	38.8	41.2	38.7
2. *S. grandiflora*	200.7	202.4	217.9	207.0
3. *A. nilotica*	108.0	116.1	118.2	114.1
4. *D. sissoo*	46.8	96.9	116.8	86.8
5. *C. equisetifolia*	70.0	77.6	81.0	76.2
6. *A. indica*	36.7	45.3	57.5	46.5
b) 12 MAP				
1. *H. binata*	101.7	110.4	122.2	111.4
2. *S. grandiflora*	390.8	411.2	490.9	431.0
3. *A. nilotica*	256.5	266.9	282.5	268.6
4. *D. sissoo*	226.2	277.1	319.6	274.2
5. *C. equisetifolia*	164.0	191.1	203.4	186.2
6. *A. indica*	77.8	88.2	104.6	90.2
c) 18 MAP				
1. *H. binata*	125.3	183.4	214.2	174.3
2. *S. grandiflora*	423.1	466.5	498.2	462.6
3. *A. nilotica*	339.4	348.9	354.1	347.3
4. *D. sissoo*	259.0	396.9	457.3	401.1
5. *C. equisetifolia*	186.5	255.4	273.2	238.4
6. *A. indica*	74.8	123.8	141.1	113.2
d) 24 MAP				
1. *H. binata*	161.9	256.6	288.9	235.8
2. *S. grandiflora*	418.5	550.4	573.0	514.0
3. *A. nilotica*	426.0	431.3	492.1	449.8
4. *D. sissoo*	269.8	438.3	572.0	426.7
5. *C. equisetifolia*	325.1	353.5	410.4	363.0
6. *A. indica*	97.8	133.1	180.9	137.3

height was low compared to other species under deep water table situations despite registering improvement over shallow water table conditions and the effects remained similar when observed 12 MAP. Effect of water table was found minimal in species such as *A. nilotica* (13%), *C. equisetifolia* (21%) and *S. grandiflora* (27%) in that order as the per cent reduction in height under shallow water table remained lower. This was observed 24 MAP. Other species such as *D. sissoo* (53%), *A. indica* (46%) and *H. binata* (44%), however, recorded a higher per cent of reduction in plant height when water table remained shallow.

4.2.2.3 Number of branches of tree species were evaluated against water table and the data are presented in table 12 and Fig. 13. Number of branches borne by trees were influenced by both water table and time. The number of branches recorded by tree species were less in shallow water table conditions and increased as it went deeper. *Acacia nilotica* recorded highest (19.0) number of branches as against only 2.36 in case of *A. indica* when water table was deeper. Species such as *D. sissoo* (17.85), *C. equisetifolia* (17.58) and *S. grandiflora* (17.15) closely followed *A. nilotica* in terms of number of branches. *Hardwickia binata*, however, remained marginally higher (7.51) than *A. indica* when observed 6 MAP.

Table 12. Effect of water table on number of branches per tree of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 6 MAP				
1. *H. binata*	6.06	6.93	7.51	6.83
2. *S. grandiflora*	14.58	15.32	17.15	15.68
3. *A. nilotica*	17.52	18.46	19.00	18.33
4. *D. sissoo*	8.27	13.16	17.85	13.09
5. *C. equisetifolia*	14.83	15.82	17.58	16.08
6. *A. indica*	1.15	1.92	2.36	1.81
b) 12 MAP				
1. *H. binata*	12.10	13.88	16.66	14.21
2. *S. grandiflora*	19.76	21.60	23.15	21.50
3. *A. nilotica*	30.59	32.00	33.64	32.08
4. *D. sissoo*	14.25	21.52	30.68	22.15
5. *C. equisetifolia*	18.96	22.22	24.75	21.98
6. *A. indica*	5.62	8.21	10.95	8.26
c) 18 MAP				
1. *H. binata*	12.15	21.11	23.81	19.03
2. *S. grandiflora*	22.74	26.83	31.24	26.92
3. *A. nilotica*	47.51	51.76	57.83	52.38
4. *D. sissoo*	27.12	44.75	49.79	40.59
5. *C. equisetifolia*	38.37	46.97	51.81	45.77
6. *A. indica*	5.75	9.37	13.14	9.48
d) 24 MAP				
1. *H. binata*	18.98	24.48	28.68	24.05
2. *S. grandiflora*	21.63	26.09	33.37	27.03
3. *A. nilotica*	53.92	61.33	60.55	58.60
4. *D. sissoo*	33.96	49.43	51.32	44.87
5. *C. equisetifolia*	36.98	44.04	48.46	43.16
6. *A. indica*	9.57	13.93	22.54	15.35

As the trees grew older, all the species registered number of branches increased as water table became deeper. A highest (60.55) number of branches were observed in case of *A. nilotica* against a lowest (22.54) in case of *A. indica*, 24 MAP. Species such as *A indica* whose number of branches were around 2.36, 6 MAP increased appreciably to 22.54 when observed 24 MAP. *Dalbergia sissoo* (51.32) and *C. equisetifolia* (48.46) closely followed *A. nilotica* while, *H. binata* (28.68) did with *A. indica*. On the basis of observations made in terms of number of branches 24 MAP, the tree species followed the order as ;

A. nilotica (60.55) > *D. sissoo* (51.32) > *C. equisetifolia* (48.46) > *S. grandiflora* (33.37) > *H. binata* (28.68) > *A. indica* (22.54).

4.2.2.4 Diameter at stump height of tree species were measured 5 cm above ground level. Effects of water table and time on this parameter are presented in Table 13 and Fig. 14. The observations made 6 MAP revealed that water table had similar effect on DSH as was observed on all other parameters already presented. Diameter at stump height values remained higher when water table was deeper and decreased as water table became shallow. A highest DSH was observed in case of *S. grandiflora* (4.60cm) followed by *A. nilotica* (2.23) and *D.*

Table 13. Effect of water table on DSH (cm) of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 6 MAP				
1. *H. binata*	0.44	0.50	0.54	0.49
2. *S. grandiflora*	3.17	4.21	4.60	3.99
3. *A. nilotica*	2.14	2.12	2.23	2.16
4. *D. sissoo*	0.72	1.21	1.67	1.21
5. *C. equisetifolia*	0.73	0.79	0.88	0.80
6. *A. indica*	0.48	0.55	0.67	0.57
b) 12 MAP				
1. *H. binata*	1.40	1.64	1.85	1.63
2. *S. grandiflora*	8.33	9.71	10.39	9.45
3. *A. nilotica*	5.26	5.94	6.01	5.73
4. *D. sissoo*	3.07	3.42	4.39	3.54
5. *C. equisetifolia*	2.28	2.64	3.18	2.70
6. *A. indica*	1.46	1.82	2.55	1.94
c) 18 MAP				
1. *H. binata*	2.49	2.98	3.68	3.05
2. *S. grandiflora*	8.58	10.46	10.85	9.95
3. *A. nilotica*	7.45	8.59	9.30	8.45
4. *D. sissoo*	4.13	6.29	7.34	5.92
5. *C. equisetifolia*	3.62	4.28	5.14	4.31
6. *A. indica*	1.43	1.70	2.30	1.81
d) 24 MAP				
1. *H. binata*	2.82	3.98	4.62	3.81
2. *S. grandiflora*	8.82	10.22	11.08	10.04
3. *A. nilotica*	9.99	10.71	11.51	10.74
4. *D. sissoo*	6.00	7.36	8.73	7.43
5. *C. equisetifolia*	4.39	5.10	6.36	5.28
6. *A. indica*	1.82	2.20	3.19	2.40

sissoo (1.67cm). On the contrary, a lowest of 0.67 cm was observed in case of ;

A. indica which was followed by *H. binata* (0.54cm) and *C. equisetifolia* (0.88).

As the tree grew older, DSH of trees increased and this increase varied with species depending upon water table. As has already been mentioned, there was a reduction in DSH when water table came closer to the sufrace. Species which showed least reaction to shallow water table were *A. nilotica* (13%) followed by *S. grandiflora* (20%), *C. equisetifolia* (31%) and *D. sissoo* (31%). However, *A. indica* recorded higher (43%) per cent reduction in DSH when observed 24 MAP.

4.2.2.5 Diameter at breast height was measured 130 cm above ground level and the trees which had attained this height at the time of making observations are presented in table 14 and fig. 15. Like DSH, the effect of time and water table was quite descernible. The values were higher when trees were not exposed to waterlogged conditions (shallow water table with less than 70 cm in October and 80 cm in April) and when water table became shallower, DBH got reduced and the extent of reduction varied with species. A highest reduction of 41 per cent was observed in *D. sissoo*, as against a lowest reduction

Table 14. Effect of water table on DBH (cm) of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 12 MAP				
1. *H. binata*	–	–	–	–
2. *S. grandiflora*	5.42	6.26	7.01	6.16
3. *A. nilotica*	1.94	2.12	2.25	2.10
4. *D. sissoo*	1.14	1.44	1.94	1.51
5. *C. equisetifolia*	0.89	0.99	1.22	1.03
6. *A. indica*	–	–	–	–
b) 18 MAP				
1. *H. binata*	–	–	–	–
2. *S. grandiflora*	6.14	7.50	8.32	7.32
3. *A. nilotica*	3.40	4.33	4.52	4.08
4. *D. sissoo*	3.14	4.75	5.27	4.39
5. *C. equisetifolia*	1.35	1.78	2.38	1.84
6. *A. indica*	–	–	–	–
c) 24 MAP				
1. *H. binata*	–	–	–	–
2. *S. grandiflora*	6.50	7.39	8.18	7.36
3. *A. nilotica*	4.27	5.63	6.04	5.31
4. *D. sissoo*	3.84	5.45	6.19	5.16
5. *C. equisetifolia*	1.78	2.91	3.12	2.60
6. *A. indica*	–	–	–	–

of 14 and 25 per cent in *A. nilotica* followed by 23 and 26 per cent in *S. grandiflora*, 12 and 18 MAP, respectively. In general, DBH values improved with time and the performance of tree species in terms of per cent reduction as observed 24 MAP remained in the order of ;

S. grandiflora (21%) < *A. nilotica* (29%) < *D. sissoo* (38%) < *C. equisetifolia* (43%).

4.2.2.6 Pruned biomass was recorded 12 and 24 MAP. The results pertaining to this parameter are presented in Table 15 and Fig. 16. Like other parameters, the pruned biomass was also found to follow the relationship that was observed in other parameters. *Acacia nilotica* recorded a higher pruned biaomass (1943.7g) when it was grown under deeper water table situations. Species such as *S. grandiflora* (1181.2g) and *D. sissoo* (916.6g) remained next best to *H. binata* which recorded a lowest pruned biomass of 78.9g under deep water table situations, 6 MAP. As water table came closer to the surface, all the species were affected and recorded lower pruned biomass. The species which recorded marginal reduction under shallow water table situations were *A. nilotica* (12%) followed by *C. equisetifolia* (18%). On the contrary, *D. sissoo* (48%) and *A. indica* (44%) recorded more than 40 per cent reduction in pruned biomass due to rising water table.

Table 15. Effect of water table on pruned bio-mass production of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 12 MAP (bio-mass in g)				
1. *H. binata*	52.20	60.80	78.90	64.00
2. *S. grandiflora*	820.70	953.90	1181.20	985.30
3. *A. nilotica*	1706.60	1878.10	1943.70	1842.80
4. *D. sissoo*	472.40	751.40	916.60	713.50
5. *C. equisetifolia*	379.00	406.60	460.70	415.40
6. *A. indica*	81.80	112.90	144.90	113.10
b) 24 MAP (bio-mass in kg)				
1. *H. binata*	0.93	1.21	1.52	1.22
2. *S. grandiflora*	2.41	3.11	3.73	3.08
3. *A. nilotica*	8.79	9.25	9.66	9.23
4. *D. sissoo*	5.35	8.13	9.42	7.63
5. *C. equisetifolia*	4.68	6.25	6.61	5.85
6. *A. indica*	0.34	0.52	0.79	0.55

As the trees grew older and when observations were made 24 MAP, the pruned biomass in general, was found appreciably higher than observed at 12 MAP. No trees remained exception to these observations. Again *A. nilotica* recorded a highest biomass of 9.66 kg. On the contrary, *A. indica* as was in earlier case, found to yield a lowest (0.79 kg) pruned biomass. *Hardwickia binata* (1.52 kg) closely followed *A. indica*. These observations were made when water table remained deeper. When water table become shallower, biomass yield got reduced in all the tree species investigated. *Acacia nilotica* was again found promising as per cent reduction in biomass yield due to increasing water table conditions was of the order of 9 per cent. In contrast, *A. indica* (57%), *D. sissoo* (43%), *H. binata* (39%) and *S. grandiflora* (35%) recorded a higher degree of reductin in pruned biomass yield. As described earlier, all the tree species considerably improved in terms of biomass yield with time. Performance of trees under varying water table situations as found 24 MAP remained in the order of ;

A. nilotica (9%) > *C. equisetifolia* (29%) > *S. grandiflora* (35%) > *H. binata* (39%) > *D. sissoo* (43%) > *A. indica* (57%). This was observed in terms of per cent reduction in pruned biomass under the influence of water table.

4.2.2.7 Crown width was also related to fluctuating water table conditions. The data showing effects of water table depth and time are presented in Table 16 and Fig. 17. The values in general, were higher when water table remained deeper. This tendency was observed at all periods of observations. A highest crown width of 69.7 cm was recorded in *A. nilotica* as against a lowest of 27.9 cm in *A.indica* when observed 6 MAP. Under the influence of rising water table, crown width of all the tree species reduced and the extent of reduction varied with species. Species such as *H. binata* (12%) and *C. equisetifolia* (15%) recorded a reduction which remained lower than 15 per cent while, *D. sissoo* (33%) and *A. indica* (35%) recorded reduction more than 30 per cent. However, *A. nilotica* and *S. grandiflora* recorded 21 per cent reduction in crown width when observed 6 MAP.

With passage of time, the trees became more adoptable to water table conditions and their crown width increased but, reduced under the influence of water table which varied with species. When trees grew older some degree of inconsistancy in their performance was observed. For instance, *A. nilotica* which recorded 21 per cent reduction 6 MAP improved marginally to record 16 per cent when observed 12 MAP, before stabilizing. This tendency was also observed in

Table 16. Effect of water table on crown width (cm) of tree species

Tree species	Water Table			Mean
	Shallow	Medium	Deep	
a) 6 MAP				
1. *H. binata*	25.4	28.6	28.9	27.6
2. *S. grandiflora*	39.6	43.1	50.2	44.3
3. *A. nilotica*	55.1	58.1	69.7	61.0
4. *D. sissoo*	27.8	39.4	41.3	36.2
5. *C. equisetifolia*	30.7	30.1	36.3	32.4
6. *A. indica*	18.1	23.4	27.9	23.1
b) 12 MAP				
1. *H. binata*	38.3	46.6	52.5	45.9
2. *S. grandiflora*	148.5	159.1	171.2	159.6
3. *A. nilotica*	233.0	247.1	276.7	252.3
4. *D. sissoo*	107.5	193.9	221.0	174.1
5. *C. equisetifolia*	82.6	110.3	138.4	103.8
6. *A. indica*	43.9	58.5	69.1	57.2
c) 18 MAP				
1. *H. binata*	53.7	58.1	81.5	64.4
2. *S. grandiflora*	191.7	232.1	230.1	218.0
3. *A. nilotica*	273.7	300.2	339.4	304.4
4. *D. sissoo*	180.2	215.4	310.7	235.4
5. *C. equisetifolia*	131.9	171.8	195.5	166.4
6. *A. indica*	47.2	68.3	93.6	69.7
d) 24 MAP				
1. *H. binata*	63.8	97.4	118.5	93.2
2. *S. grandiflora*	196.5	221.7	253.8	224.0
3. *A. nilotica*	328.7	331.8	369.2	343.2
4. *D. sissoo*	152.8	247.5	311.3	237.2
5. *C. equisetifolia*	198.8	236.4	296.0	243.7
6. *A. indica*	47.5	83.7	117.5	82.9

case of *D. sissoo*. However, with passage of time. the crown size increased and water table effects continued at marginally reduced rate when observations were made 24 MAP. *Acacia nilotica* continued to out perform other species. The crown width was highest (369.2 cm) in *A. nilotica* compared to a lowest (117.5cm) observed in case of *A. indica*. Species such as *D. sissoo* (311.3cm), *C. equisetifolia* (296.0cm) and *S. grandiflora* (253.8cm) followed *A. nilotica* in that order when water table remained deeper. The trend on the effect of water table remained same when water table become shallower accompanied by corresponding decrease in the crown width. *Acacia nilotica* remained far superior to other species as per cent reduction in crown width remained around 10 per cent, while, other species had more than 30 per cent except in case of *S. grandiflora* where the reductin was around 20 per cent. On the basis of per cent reduction in crown width, the tree species found to follow the order of ;

A. indica (60%) > *D. sissoo* (51%) > *H. binata* (46%) > *C. equisetifolia* (33%) > *S. grandiflora* (23%) > *A. nilotica* (11%)

The overall picture of the effect of water table on various tree growth parameters investigated suggested that *A. nilotica* (Table 17) was found far superior over its compatriates as overall per cent of reduction of various tree

Table 17. Ranking of tree species in terms of per cent reduction (shallow water table) in various growth parameters

Tree species	Height				No. of branches				DSH				Bio-mass		Crown width				Overall ranking
	Months after planting				Months after planting				Months after planting				Months after planting		Months after planting				
	6	12	18	24	6	12	18	24	6	12	18	24	12	24	6	12	18	24	
1. *H. binata*	3	5	3	3	3	3	2	2.5	4	4	3	2	3	3	6	4	3	3	3.3
2. *S. grandiflora*	6	3	5	4	5	5	4	4	3	5	3	5	4	4	3.5	6	5	5	4.4
3. *A. nilotica*	5	6	6	6	6	6	6	6	6	6	6	6	6	6	3.5	5	6	6	5.8
4. *D. sissoo*	1	1	2	1	1	1	3	2.5	1	2	1	3.5	1	2	2	1	2	2	1.7
5. *C. equisetifolia*	4	4	4	5	4	4	5	5	5	3	4	3.5	5	5	5	2.5	4	4	4.2
6. *A. indica*	2	2	1	2	2	2	1	1	2	1	2	1	2	1	1	2.5	1	1	1.6

growth parameters remained lower (as indicated by higher values of rating) The species such as *S. grandiflora* (4.4), *C. equisetifolia* (4.2) closely followed *A. nilotica* while, *A. indica* (1.6) and *D. sissoo* (1.7) remained far from satisfactory as their rating remained lower (table 17). It is interesting to note that species such as *H. binata* remained of mid category when all parameters were considered.

4.3 Concept of SEWN :

The relation between soil salinity, water table and various tree growth parameters such as plant height, DSH and crown width were worked out interms of correlation coefficients. Similarly, the relation between SEWN and various tree growth parameters were also computed. Results pertaining to these parameters are presented in Table 18 and Fig. 18 a, b and c. From the results, it is quite clear that the values of correlation coefficient between soil salinity and tree growth parameters and between water table and growth parameters, although, remained significant in most of the tree species, their level of significance was not of the same level as was observed between SEWN and tree growth parameters. This suggested that the relationship between SEWN and tree parameters was of higher order than observed between soil salinity, water table and tree growth parameters with few

Table 18. Relationship between tree growth and various stress parameters (24 MAP)

Tree species	Tree parameters	Stress parameters		
		SEWN	Soil salinity	Water table
1. *H. binata*	Plant height	-0.96^{**}	-0.83^{**}	-0.60^{*}
	DSH	-0.91^{**}	-0.78^{*}	-0.75^{*}
	Crown width	-0.96^{**}	-0.80^{*}	-0.72^{*}
2. *S. grandiflora*	Plant height	-0.95^{**}	-0.72^{*}	-0.65^{NS}
	DSH	-0.87^{**}	-0.65^{NS}	-0.58^{NS}
	Crown width	-0.96^{**}	-0.73^{*}	-0.85^{**}
3. *A. nilotica*	Plant height	-0.80^{*}	-0.51^{NS}	-0.83^{**}
	DSH	-0.96^{**}	-0.70^{*}	-0.97^{**}
	Crown width	-0.87^{**}	-0.63^{NS}	-0.95^{**}
4. *D. sissoo*	Plant height	-0.95^{**}	-0.71^{*}	-0.37^{NS}
	DSH	-0.95^{**}	-0.77^{*}	-0.93^{**}
	Crown width	-0.90^{**}	-0.73^{*}	-0.92^{**}
5. *C.equiseti-folia*	Plant height	-0.82^{**}	-0.85^{**}	-0.92^{**}
	DSH	-0.95^{**}	-0.69^{**}	-0.88^{**}
	Crown width	-0.89^{**}	-0.77^{*}	-0.77^{*}
6. *A. indica*	Plant height	-0.92^{**}	-0.71^{*}	-0.92^{**}
	DSH	-0.88^{**}	-0.74^{*}	-0.98^{**}
	Crown width	-0.92^{**}	-0.72^{*}	-0.95^{**}

exceptions such as in case of *A. nilotica* where effect of water table on height, DSH and crown width remained on par with effect of SEWN. Similarly, the effect of water table (-0.98^{**}) on DSH remained on par with effect of SEWN (-0.88^{**}) in case of *A. indica*. Therefore, this suggested that tree growth parameters were better explained in terms of SEWN other than rather studied in isolation such as soil salinity and water table.

Relation between SEWN and plant height was -0.96^{**} as against -0.83^{**} and -0.60^{*} observed between plant height and soil salinity and water table, respectively in *H. binata*. Similar results were also observed in case of DSH and crown width. In view of this strong relation existed between SEWN and tree parameters, the SEWN concept was introduced and the effect of SEWN on various tree growth parameters are presented in succeeding paragraphs.

4.4 Effect of SEWN on various tree growth parameters

Establishment, plant height, number of branches, DSH, DBH, pruned biomass and crown width were investigated and are presented in brief under succeeding paragraphs.

4.4.1 Establishment : Results showing the effect of SEWN and time on establishment of various tree species under

Table 19. Combined effect of soil salinity and waterlogging (SEWN) on establishment (%) of tree species

Tree species	SEWN				
	<1	1–100	100–500	>500	Mean
		a> 6 MAP			
1. *H. binata*	97.4	95.2	87.7	79.0	89.8
2. *S. grandiflora*	72.9	74.9	69.0	62.7	70.1
3. *A. nilotica*	100.0	99.4	97.6	97.0	98.5
4. *D. sissoo*	94.0	90.6	84.8	72.9	85.5
5. *C. equisetifolia*	93.9	89.9	82.7	75.0	85.4
6. *A. indica*	89.3	82.7	56.2	49.0	69.3
		b> 12MAP			
1. *H. binata*	96.9	93.6	87.0	72.1	87.4
2. *S. grandiflora*	72.7	71.3	62.7	53.3	65.0
3. *A. nilotica*	100.0	98.6	96.5	94.1	97.3
4. *D. sissoo*	93.5	99.4	76.5	66.4	81.7
5. *C. equisetifolia*	92.5	88.0	81.3	70.6	83.1
6. *A. indica*	88.4	82.6	52.3	43.6	66.7

investigation are presented in Table 19 and Fig. 19. As SEWN increased from less than one to more than 500, establishment of trees decreased and this phenomenon was observed in all tree species when observed 6 MAP. Effect of SEWN was higher (72.9 establishment) in *S. grandiflora* at lower SEWN (less than one) as compared to other tree species. However, when SEWN increased, *A. indica* appeared more proned (49% establishment) as establishment of this species remained lower than 50 per cent. *Sesbania grandiflora* (62.7%) recorded lower establishment at higher SEWN (more than 500). Under similar SEWN conditions, a highest (100%) establishment was observed in case of *A. nilotica* and decreased with increasing SEWN, the per cent establishment remained higher (97.0%) compared to other species. However, the species such as *H. binata* (79.0%), *C. equisetifolia* (75.0%) and *D. sissoo* (72.9%) could establish around 70 per cent and remained next better to *A. nilotica* in that order. These observations were made 6 MAP. As tree grew older, the establishment count made (12 MAP) revealed that there was a marginal decline in establishment of all the tree species investigated. But, the effect of SEWN remained similar to the one observed 6 MAP.

On the basis of mean establishment values computed over SEWN, the performance of tree species was in the order of;

A. nilotica (97.3%) > *H. binata* (87.4%) > *C. equisetifolia* (83.1%) > *D. sissoo* (81.7%) > *A. indica* (66.7%) > *S. grandiflora* (65.0%).

4.4.2 Height : Effect of SEWN on tree height are presented in table 20 and fig. 20, a, b and c. As SEWN value increased, the tree height decreased and this trend was observed in all the species investigated. A highest height of 215.6 cm was recorded in *S. grandiflora* when SEWN was lower than 1. But, as SEWN increased, there was a reduction in plant height to the tune of 16 per cent. *Acacia nilotica* recorded 125.4cm when SEWN was still under 1. The corresponding decrease when SEWN remained more than 500 was only 9 per cent compared to 16 per cent observed in *S. grandiflora*. However, a highest reduction (68%) in plant height was in *D. sissoo* when SEWN was higher than 500. The per cent reduction in tree height remained intermediary for other species when SEWN was higher than 500 and observed 12 MAP. A higher reduction which was observed in *D. sissoo* (68%) 6 MAP improved considerably as it recorded only 40 per cent 12 MAP when SEWN was more than 500. On the contrary, *A. indica* registered 39 per cent reduction 6 MAP and further suffered as the per cent reduction in height increased to 53 per cent when observed 12 MAP at same SEWN value. The species such as *S. grandiflora* and *A. nilotica*

Table 20. Combined effect of soil salinity and waterlogging (SEWN) on height of tree species

Tree species	SEWN					SEWN				
	<1	1–100	100–500	>500	Mean	<1	1–100	100–500	>500	Mean
	a) 6 MAP					b) 12 MAP				
1. *H. binata*	44.8	39.7	39.9	34.1	39.6	136.1	128.3	115.6	78.6	114.6
2. *S. grandiflora*	215.6	222.3	200.4	180.0	204.6	443.2	485.5	424.3	398.4	437.8
3. *A. nilotica*	125.4	128.5	128.0	113.6	123.9	289.4	303.6	282.1	253.4	282.1
4. *D. sissoo*	131.2	105.4	80.6	42.4	89.9	330.2	299.8	236.1	197.2	265.8
5. C. equisetifoli	84.3	78.6	70.9	63.1	74.2	212.0	184.2	172.2	157.8	182.3
6. *A. indica*	52.7	51.7	39.5	32.1	44.0	122.2	104.1	94.6	57.6	94.6

	S.Em±	C.D.(0.05)	S.Em±	C.D.(0.05)
Between trees species	13.0	22.6	24.74	42.8
Between SEWN within tree species	6.1	10.5	7.98	13.65

	c) 18 MAP					d) 24 MAP				
1. *H. binata*	209.3	199.4	179.0	128.8	179.1	285.9	271.1	244.2	172.2	243.4
2. *S. grandiflora*	516.7	498.6	459.8	414.7	472.4	614.0	570.6	545.6	421.6	537.9
3. *A. nilotica*	350.8	359.5	345.1	335.2	437.7	487.6	488.8	424.0	432.6	458.2
4. *D. sissoo*	462.8	479.2	378.2	234.0	388.6	545.4	487.2	445.0	243.9	430.4
5. *C. equisetifolia*	279.6	271.4	251.4	204.0	251.6	412.2	377.6	371.4	299.2	365.1
6. *A. indica*	146.6	138.2	118.1	67.0	117.5	184.0	180.8	128.6	85.2	144.6

	S.Em±	C.D.(0.05)	S.Em±	C.D.(0.05)
Between trees species	39.2	67.9	51.8	89.8
Between SEWN within tree species	20.2	34.6	14.5	24.8

continued to register a lower per cent reduction in height due to increasing SEWN 12 and 24 MAP compared to other species.

Differences between tree species and also between SEWN remained statistically significant when data was analysed adopting nested design with fixed effects model 6 MAp. A similar observations were also drawn 12, 18 and 24 MAP. On the basis of performance of tree species observed 24 MAP revealed that the tree species followed the following order (based on per cent reduction in height);
A. nilotica (11%) < *C. equisetifolia* (27%) < *S. grandiflora* (31%) < *H. binata* (40%) < *A. indica* (54%) < *D. sissoo* (55%).

4.4.3 Number of branches : were recorded as a function of SEWN 6, 12, 18 and 24 MAP. Data pertaining to these are presented in table 21 and fig. 21 a, b, c and d. In case of *H. binata*, number of branches decreased with increased SEWN and decrease remained gradual as SEWN increased from less than 1 (8.4) to 100-500 (7.6). However, when SEWN increased beyond 100-500, the effect was drastic as the per cent reduction rose from 17 to 43 per cent when observed 24 MAP. Similar effect were also noticed 6, 12 and 18 MAP at lower range of SEWN.

In case of *S. grandiflora* effect remained marginal when SEWN values remained lower than 100, drastic when SEWN

Table 21. Combined effect of soil salinity and waterlogging (SEWN) on number of branches of tree species

Tree species	SEWN					SEWN				
	<1	1–100	100–500	>500	Mean	<1	1–100	100–500	>500	Mean
	a) 6 MAP					b) 12 MAP				
1. *H. binata*	8.4	7.6	7.0	5.7	7.2	15.6	16.0	13.2	10.2	13.7
2. *S. grandiflora*	17.8	18.4	16.5	14.4	16.8	30.6	28.9	20.8	19.2	28.9
3. *A. nilotica*	19.6	19.4	18.0	16.8	18.4	32.2	32.4	31.5	29.9	31.7
4. *D. sissoo*	18.4	17.5	8.6	6.4	12.7	31.3	34.5	22.1	16.7	26.1
5. *C. equisetifolia*	17.9	17.0	16.0	13.7	16.2	26.3	27.6	24.8	21.9	25.2
6. *A. indica*	3.4	3.1	2.4	1.4	2.6	9.8	8.5	6.8	5.6	7.7
				S.Em±	C.D.(0.05)				S.Em±	C.D.(0.05)
Between trees species				2.0	3.5				3.1	5.4
Between SEWN within tree species				1.0	1.7				1.0	1.7
	c) 18 MAP					d) 24 MAP				
1. *H. binata*	24.1	22.4	18.9	14.4	20.0	29.1	26.4	24.2	16.7	24.1
2. *S. grandiflora*	29.8	28.2	23.8	22.6	26.1	31.3	29.0	27.3	22.4	27.5
3. *A. nilotica*	60.2	62.2	56.4	51.3	57.5	62.0	62.9	58.2	54.0	59.3
4. *D. sissoo*	49.3	48.8	37.7	24.4	40.1	57.6	55.8	48.4	32.0	48.5
5. *C. equisetifolia*	50.8	47.8	45.2	36.6	45.1	52.9	47.1	45.2	37.4	45.7
6. *A. indica*	14.0	11.8	8.4	6.8	10.3	26.7	17.5	14.1	9.4	16.9
				S.Em±	C.D.(0.05)				S.Em±	C.D.(0.05)
Between trees species				4.5	7.7				4.9	8.5
Between SEWN within tree species				1.7	2.8				4.3	7.3

values were more than 100-500. The number of branches increased sharply (16.8 to 28.9) between 6 and 12 MAP and stabilized 12 MAP.

In case of *A. nilotica*, effect was quite descernible and remained gradual. However, it is interesting to note that branches increased linearly upto 18 MAP and stabilized there after. In contrast to *A. nilotica*, *D. sissoo* did not suffer significantly when SEWN remained lower than 100. However, when SEWN values were higher than 100, number of branches reduced drastically as per cent reduction remained higher than 50 as against 8-10 per cent observed in case of *A. nilotica*. At higher SEWN values (>100), although, number of branches increased with time, increase was not in the same order as was observed when SEWN remained lower than 100.

In general, increase in SEWN decreased number of branches in *C. equisetifolia* but remained marginal. A lowest per cent (5, 6 and 11% at 6, 18 and 24 MAP) of reduction was noticed when SEWN was lower than 100 as against a highest reduction (23, 17 and 28% at 6, 18 adn 24 MAP) in case where SEWN values remained greater than 500. Performance of trees with time remained gradual upto 7-8 months and increased afterwords. The increase in number of branches remained

gradual with time like the effect of SEWN itself had on number of branches. However, 7-8 months after planting (fig. 21 c) number of branches rose linearly at all SEWN values despite decreasing trend with increasing SEWN, before stabilizing 14-15 MAP.

Azadirahta indica maintained very low number of branches and decreased with increasing SEWN values. Effect of SEWN appeared more drastic (59% decrease) as it rose from less than 1 to more than 500 when observed 6 MAP. A highest number of branches (26.7) were recorded when SEWN was lower than 1 as against lowest (9.4) when SEWN was more than 500, when observed 24 MAP. This decrease was in the order of 65 per cent. With time, the tree species were able to maintain only a marginal increase in number of branches upto 16 MAP but, showed increasing trends aftarwards.

Performance of tree species as emerged 24 MAP revealed that all species suffered under increasing SEWN values but improved with time. There was marked variations in their performance against SEWN values. The species such as *A. indica* suffered 65 per cent reduction in number of branches against only 13 per cent reduction in case of *A. nilotica* when SEWN values were more than 500. The species such as *D. sissoo*

(44%) and *H. binata* (43%) registered a fairly higher level of reduction when SEWN remained more than 500.

The differences between tree species and SEWN remain statistically significant. The order of the performance of trees in terms of per cent decrease in number of branches against SEWN observed 24 MAP remained in the order of ; *A. indica* (65%) > *D. sissoo* (44%) > *H. binata* (43%) > *C. equisetifolia* (29%) > *S. grandiflora* (28%) > *A. nilotica* (13%).

4.4.4 Diameter at stump height : Effect of SEWN and time on DSH measured 5 cm above ground level are presented in table 22 and fig. 22 a, b and c. As the SEWN increased, DSH decreased at all the periods of observations. The effect of SEWN was more clear when trees grew older. A highest value was observed in case of SEWN values lower than 1 while, lowest when SEWN remained greater than 500. This was the case in all tree species. The detrimental effect of increasing SEWN on tree species continued even when observed 24 MAP. However, it is interesting to note that the effect was less when trees were younger and became more apparant when grew older (fig. 22,a). The growth measured in terms of DSH was found increased with time. Unlike other species which had more or

Table 22. Combined effect of soil salinity and waterlogging (SEWN)on DSH (cm) of tree species

Tree species	SEWN					SEWN				
	<1	1–100	100–500	>500	Mean	<1	1–100	100–500	>500	Mean
	a) 6 MAP					b) 12 MAP				
1. *H. binata*	0.32	0.41	0.38	0.20	0.33	1.74	1.56	1.36	1.32	1.49
2. *S. grandiflora*	2.39	2.25	2.26	1.47	2.09	9.52	9.42	8.18	7.13	8.56
3. *A. nilotica*	1.14	1.09	1.08	1.03	1.08	6.14	5.46	5.26	4.68	5.38
4. *D. sissoo*	0.78	0.71	0.49	0.30	0.57	4.34	4.05	3.26	2.18	3.46
5. *C. equisetifolia*	0.47	0.44	0.42	0.36	0.42	2.76	2.56	2.42	2.35	2.52
6. *A. indica*	0.38	0.31	0.36	0.24	0.32	2.41	1.96	1.73	1.36	1.87
				S.Em ±	C.D.(0.05)				S.Em ±	C.D.(0.05)
Between tree species				0.28	0.49				0.49	0.85
Between SEWN within a tree species				0.13	0.23				0.24	0.41
	c) 18 MAP					d) 24 MAP				
1. *H. binata*	4.05	3.59	2.90	2.52	3.26	4.80	4.44	3.70	3.02	3.99
2. *S. grandiflora*	10.76	10.49	10.22	8.40	9.97	10.84	11.11	10.35	8.61	10.23
3. *A. nilotica*	9.26	8.76	8.50	7.84	8.59	11.90	11.23	10.76	10.08	10.99
4. *D. sissoo*	7.47	6.79	6.03	3.38	5.92	9.54	8.60	7.61	6.44	8.05
5. *C. equisetifolia*	5.12	4.99	4.16	3.73	4.50	6.26	5.79	4.54	4.28	5.21
6. *A. indica*	2.64	2.19	1.80	1.39	2.01	3.54	2.92	2.36	1.53	2.59
				S.Em ±	C.D.(0.05)				S.Em ±	C.D.(0.05)
Between tree species				0.70	1.22				0.68	1.17
Between SEWN within a tree species				0.21	0.36				0.25	0.43

less linear relationships with time, *S. grandiflora*, however, registered a exponential form of growth. Effect of SEWN was found negligible (lower per cent reduction) when SEWN values remained lower than 100-500 but, increased at higher SEWN when observed 6, 12, 18 and 24 MAP. The decrease was in the order of 21 per cent, 24 MAP. The negative effect of SEWN on tree DSH remained satistically significant and the performance of trees in terms of DSH observed 24 MAP was in the order of : *A. nilotica* (10.08cm) > *S. grandiflora* (8.61cm) > *D. sissoo* (6.44cm)*C. equisetifolia* (4.28cm) > *H. binata* (3.02cm) > *A. indica* (1.53cm).

4.4.5 Diameter at breast height : The results depicting the effect of SEWN and time on stem diameter measured at breast height (130 cm above ground level) are presented in table 23 and fig. 23. Effect of SEWN on DBH followed the pattern that was observed in case of other tree growth parameters. Data collected 12 MAP indicated that *D. sissoo* appeared more affected than any other species as reduction was in the order of 72 per cent when SEWN remained higher than 500 as against a lowest of 17 per cent observed in case of *S. grandiflora*. *Acacia nilotica* closely followed *S. grandiflora* as per cent reduction remained in the order of 22 per cent. However, in case of *C. equisetifolia* (37%), the reduction was higher than

Table 23. Combined effect of soil salinity and waterlogging (SEWN) on DBH (cm) of tree species

Tree species	SEWN				
	<1	1–100	100–500	>500	Mean
a) 12 MAP					
1. *S. grandiflora*	6.92	6.60	6.30	5.71	6.38
2. *A. nilotica*	2.29	2.42	2.14	1.78	2.16
3. *D. sissoo*	3.04	2.48	1.78	0.86	2.04
4. *C. equisetifolia*	1.18	0.96	0.94	0.74	0.96
				S.Em ±	C.D.(0.05)
Between tree species				0.40	0.71
Between SEWN within a tree species				0.14	0.24
b) 18 MAP					
1. *S. grandiflora*	8.28	8.02	7.42	6.36	7.52
2. *A. nilotica*	4.44	4.32	4.10	3.29	4.04
3. *D. sissoo*	5.50	5.12	4.26	3.16	4.51
4. *C. equisetifolia*	2.42	2.34	1.88	1.59	2.06
				S.Em ±	C.D.(0.05)
Between tree species				0.53	0.94
Between SEWN within a tree species				0.16	0.28
c) 24 MAP					
1. *S. grandiflora*	8.54	8.05	7.48	6.44	7.59
2. *A. nilotica*	5.91	5.61	5.36	4.54	5.36
3. *D. sissoo*	6.29	5.94	5.22	3.42	5.22
4. *C. equisetifolia*	3.34	2.95	2.78	1.98	2.76
				S.Em ±	C.D.(0.05)
Between tree species				0.62	1.10
Between SEWN within a tree species				0.33	0.58

observed in both *S. grandiflora* and *A. nilotica* but remained far lower than *D. sissoo*. Similar effects continued when observed 18 and 24 MAP. Species such as *D. sissoo* which had higher (72% at 12 MAP) per cent reduction at the initial phases of growth, markedly reduced (43 and 46% at 18 and 24 MAP) when grew older. On the contrary, other species had a marginal increase in per cent reduction of DBH as observed 24 MAP. *Sesbania grandiflora* (25%) and *A. nilotica* (23%) registered a lower per cent reduction as against appreciably higher reduction observed in case of *D. sissoo* (46%) and *C. equisetifolia* (41%). As SEWN values decreased, there was a decrease in per cent reduction due to improvement in DBH. This was observed in all the above tree species investigated except, offcourse, in *H. binata* and *A. indica* where observations were not made due to non attainment of required height of 130 cm above the ground level. The difference between tree species and SEWN and tree species when subjected to statistical treatment, revealed significant difference.

4.4.6 Pruned biomass of tree species was monitored 12 and 24 MAP and the relevant data is presented in table 24 and fig. 24. On the basis of biomass obtained it revealed that *A. nilotica* was found promising as it had recorded a highest biomass of 1972.5 g when SEWN values remained lower than 1.

Table 24. Combined effect of soil salinity and waterlogging (SEWN) on pruned bio-mass of tree species

Tree species	SEWN				
	<1	1–100	100–500	>500	Mean
a) 12 MAP					
1. *H. binata*	80.4	78.4	64.2	53.8	69.2
2. *S. grandiflora*	1217.9	1152.2	936.7	863.4	1042.6
3. *A. nilotica*	1972.5	1919.4	1852.0	1615.4	1839.8
4. *D. sissoo*	955.5	899.2	734.6	487.9	769.3
5. *C. equisetifolia*	473.0	468.2	394.2	354.2	422.4
6. *A. indica*	152.1	120.2	109.7	88.4	117.6
				S.Em ±	C.D.(0.05)
Between tree species				92.1	159.7
Between SEWN within a tree species				36.7	62.8
b) 24 MAP					
1. *H. binata*	1.60	1.56	1.26	1.04	1.37
2. *S. grandiflora*	3.86	3.60	3.06	2.34	3.22
3. *A. nilotica*	10.10	9.46	9.28	8.86	9.43
4. *D. sissoo*	9.88	9.10	7.33	4.50	7.70
5. *C. equisetifolia*	6.79	6.42	5.98	4.86	6.01
6. *A. indica*	0.81	0.76	0.56	0.32	0.61
				S.Em ±	C.D.(0.05)
Between tree species				0.72	1.34
Between SEWN within a tree species				0.22	0.38

This species was folowed by *S. grandiflora* (1217.9 g) and *D. sissoo* (955.5 g) in that order. As SEWN increased, there was a reduction in biomass yield and this reduction was highest in all the species when SEWN values were more than 500. *Acacia nilotica* was still found promising when SEWN remained more than 500 as it recorded a highest pruned biomass of 1615.4 g. This is as against a lower in case of *H. binata* (53.8g). *Sesbania grandiflora* (863.4g) which followed *A. nilotica* had, however, recorded only 50 per cent and *D. sissoo* 25 per cent of biomass recorded by *A. nilotica*. Similar trend continued even 24 MAP. Performance of tree species as observed by per cent reduction when SEWN remained more than 500, was found to follow the order of ;

A. nilotica (12%) < *C. equisetifolia* (28%) < *H.* binata (35%) < *S. grandiflora* (39%) < *D. sissoo* (54%) < *A. indica* (60%).

4.4.7 Crown width measured 6, 12, 18 and 24 MAP are presented in table 25 and fig. 25 (a, b and c). Results available indicated decreased crown width at higher SEWN and the decrease remained gradual. In case of *H. binata*, when observed 6 MAP, a highest reduction of 27 per cent was recorded when SEWN remained more than 500. Effect of SEWN with time appeared detrimental as values of reduction rose from 27 to 44 per cent when observed 6 and 12 MAP. It is

Table 25. Combined effect of soil salinity and waterlogging (SEWN) on crown width (cm) of tree species

Tree species	SEWN					SEWN				
	<1	1–100	100–500	>500	Mean	<1	1–100	100–500	>500	Mean
	a) 6 MAP					b) 12 MAP				
1. *H. binata*	33.0	30.9	29.2	24.0	29.3	56.1	51.4	42.1	38.8	47.0
2. *S. grandiflora*	50.4	48.6	42.4	37.9	44.8	163.2	174.4	145.6	149.3	160.4
3. *A. nilotica*	67.8	68.0	61.2	56.0	63.3	281.0	271.3	256.0	233.0	260.4
4. *D. sissoo*	42.2	39.9	36.0	28.0	36.8	226.8	216.6	183.5	95.8	180.7
5. *C. equisetifolia*	36.6	35.8	31.8	32.2	34.1	132.6	125.2	119.0	56.9	108.4
6. *A. indica*	29.4	26.6	24.6	20.6	25.3	73.2	68.0	56.3	46.4	61.2
				S.Em ±	C.D.(0.05)				S.Em ±	C.D.(0.05)
Between tree species				3.4	5.8				21.4	37.2
Between SEWN within a tree species				1.7	2.9				8.9	15.2
	c) 18 MAP					d) 24 MAP				
1. *H. binata*	93.8	86.8	66.4	54.2	75.3	124.3	112.8	93.4	69.0	99.9
2. *S. grandiflora*	232.8	243.0	214.6	193.8	221.1	255.3	243.2	218.9	205.2	230.6
3. *A. nilotica*	344.8	336.4	309.1	286.0	319.1	372.8	343.2	337.4	320.6	343.5
4. *D. sissoo*	319.4	314.0	214.9	140.5	247.2	349.5	289.4	245.9	130.7	253.9
5. *C. equisetifolia*	218.8	194.7	159.9	122.2	173.9	263.6	300.7	234.4	171.4	242.5
6. *A. indica*	92.2	89.0	64.2	45.2	72.7	125.6	115.0	88.4	56.5	96.4
				S.Em ±	C.D.(0.05)				S.Em ±	C.D.(0.05)
Between tree species				30.5	52.9				34.2	59.3
Between SEWN within a tree species				17.0	29.0				12.6	21.5

interesting to note that despite increasing crown width with time, per cent reduction in this parameter did not decrease but increased.

Similarly, increasing SEWN values decreased the growth of *S. grandiflora*. A decrease of 25 per cent in crown width was observed when SEWN remained more than 500 at 6 MAP. However, this decreament was found to decrease with time. The growth of *S. grandiflora* improved at 12 MAP, however, further improvement in growth was not marked. Similarly, difference between growth attained 18 and 24 MAP was found lower suggesting stabilization in the growth habits of the tree.

In case of *A. nilotica*, per cent reduction in crown width with SEWN also remained marginal (17%) like in case of *S, grandiflora*. Effect of SEWN, although, continued with time, the magnitude of reduction remained similar to the one observed 12, 18 and 24 MAP. Like in case of *S. grandiflora*, growth of *A. nilotica* registered a marked improvement but, remained gradual when observed 12 MAP.

In case of *D. sissoo*, reduction in crown width was found quite appreciable compared to other species mentioned above and remained in the order of 34 per cent when SEWN was more than 500 at 6 MAP. Like other species mentioned above,

increase in SEWN values decreased crown width. *Dalbergia sissoo* recorded fairly higher values of reduction in crown width (table 25) with time due to higher SEWN (more than 500). A highest (63%) reduction in crown width was observed 24 MAP as against 56 and 58 per cent observed 18 and 12 MAP when SEWN values remained more than 500.

Performance of *C. equisetifolia* was better than *D. sissoo* but increasing SEWN enhanced reduction of crown width. The decrease in crown width was lower in early phases but higher in latter stages of observations. The reduction in crown width remained in the order of 12, 57, 44 and 35 per cent when observed 6, 12, 18 and 24 MAP, respectively. These reductions in crown width were observed when SEWN increased beyond 500.

Azadirachta indica also remained no exception to the effects of SEWN. The crown width of the tree species decreased as SEWN increased. The per cent decrease as a function of SEWN was, however, remained marginal when observed 6 (30%) and 12 (37%) MAP but became of higher order when observed 18 (51%) and 24 (55%) MAP (Fig. 25, c). A higher reduction of 55 per cent in crown width was observed 24 MAP when SEWN was more than 500.

Table 26. Ranking of tree species in terms of per cent reduction (SEWN > 500)in various growth parameters

Tree species	Height				No. of branches				DSH				Bio-mass		Crown width				Overall ranking
	Months after planting				Months after planting				Months after planting				Months after planting		Months after planting				
	6	12	18	24	6	12	18	24	6	12	18	24	12	24	6	12	18	24	
1. *H. binata*	4	2	3	3	3	4	3	3	3	4	3	2	3	4	3	4	4	3	3.2
2. *S. grandiflora*	5	6	5	4	5	3	5	5	2	3	5	6	4	3	4	6	6	5	4.6
3. *A. nilotica*	6	5	6	6	6	6	6	6	6	5	6	5	6	6	5	5	5	6	5.7
4. *D. sissoo*	1	3	2	1	1	1	2	2	1	1	1	3	1	2	1	1	1	1	1.5
5. *C. equisetifolia*	3	4	4	5	4	5	4	4	5	6	4	4	5	5	6	2	3	4	4.3
6. *A. indica*	2	1	1	2	2	2	1	1	4	2	2	1	2	1	2	3	2	2	1.8

Overall performance of trees when considered as function of time and SEWN revealed the following order (table 26). *Acacia nilotica* (5.7) was found most promising followed by *S. grandiflora* (4.6) and *C. equisetifolia* (4.3). However, *D. sissoo* (1.5) was found to suffer under higher SEWN values (Saline and waterlogged conditions) than any other species. This was closely followed by *A. indica* (1.8). However, it should be noted that the species carrying lower rating such as *H. binata* (3.2) and *A. indica* (1.8) were slow growers.

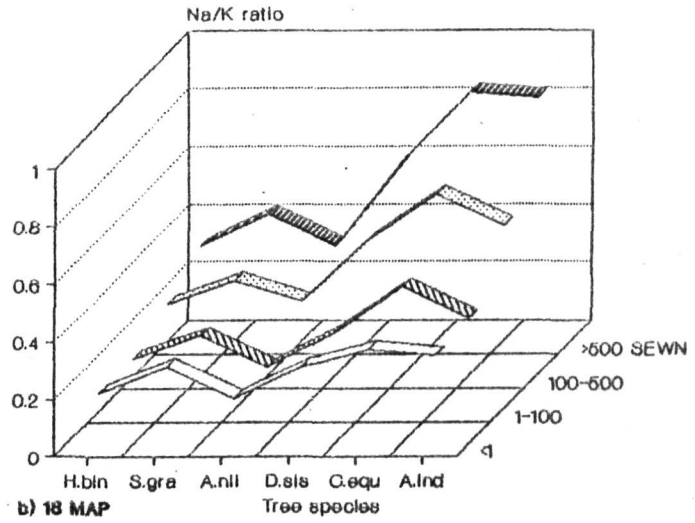
4.5 Effect of SEWN and time on ionic ratios in leaf tissues of tree species ies

4.5.1 Sodium / potassium uptake pattern were investigated in terms of their rations are presented in table 27 fig. 26. In general, as SEWN increased, uptake of Na increased resulting in increased values of Na/K. Variations between species was marked as far as uptake pattern was concerned. Species such as *H. binata* (0.24, 0.41 and 0.47 at 12, 18 and 24 MAP) and *A. nilotica* (0.23, 0.23 and 0.21 at 12, 18 and 24 MAP) registered higher uptake of K over Na resulting in lower values of Na/K but, increased with time. In contrast, *C. equisetifolia* (0.56, 0.54 and 0.48 at 12, 18 and 24 MAP) and *A. indica* (0.50, 0.47 and 0.60 at 12, 18 and 24 MAP) recorded higher values of Na/K and increased with increasing SEWN. A highest

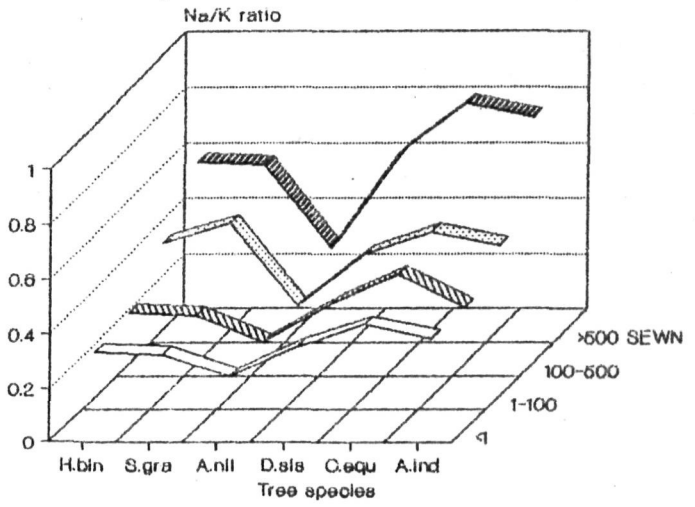
Table 27. Effect of SEWN on leaf Na/K ratio

Tree species	SEWN				Mean
	<1	1–100	100–500	> 500	
a) 12 MAP					
1. *H. binata*	0.18	0.18	0.25	0.33	0.24
2. *S. grandiflora*	0.27	0.29	0.33	0.44	0.33
3. *A. nilotica*	0.16	0.15	0.26	0.33	0.23
4. *D. sissoo*	0.27	0.27	0.47	0.63	0.41
5. *C. equisetifolia*	0.33	0.43	0.63	0.86	0.56
6. *A. indica*	0.31	0.32	0.52	0.84	0.50
b) 18 MAP					
1. *H. binata*	0.29	0.31	0.44	0.61	0.41
2. *S. grandiflora*	0.28	0.30	0.51	0.60	0.42
3. *A. nilotica*	0.20	0.20	0.21	0.30	0.23
4. *D. sissoo*	0.31	0.34	0.40	0.60	0.41
5. *C. equisetifolia*	0.39	0.45	0.48	0.82	0.54
6. *A. indica*	0.34	0.33	0.43	0.77	0.47
c) 24 MAP					
1. *H. binata*	0.30	0.35	0.54	0.69	0.47
2. *S. grandiflora*	0.26	0.23	0.37	0.50	0.34
3. *A. nilotica*	0.19	0.13	0.23	0.28	0.21
4. *D. sissoo*	0.34	0.36	0.49	0.88	0.52
5. *C. equisetifolia*	0.36	0.42	0.43	0.71	0.48
6. *A. indica*	0.37	0.48	0.59	0.97	0.60

a) 12 MAP



b) 18 MAP



c) 24 MAP

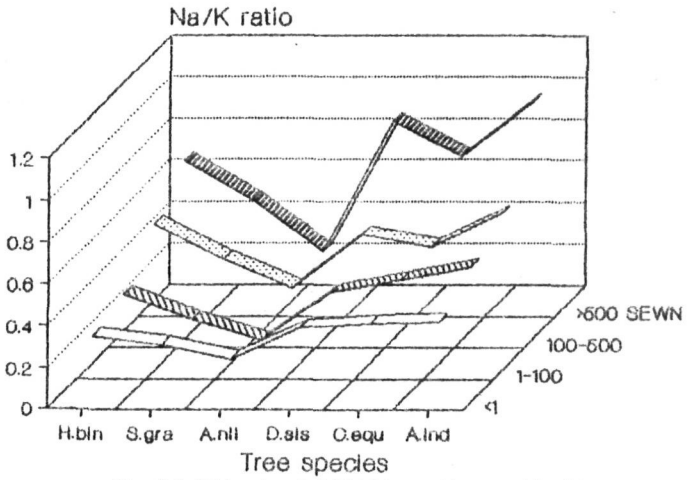


Fig.26 Effect of SEWN on tissue Na/K ratios

ratio of 0.86 was observed in case of *C. equisetifolia* as against a lower value of Na/K ratio observed in case of *H. binata* (0.33) and *A. nilotica* (0.33) when observed 12 MAP. The species such as *D. sissoo* (0.63) followed *C. equisetifolia* and *A. indica* while, *S. grandiflora* (0.44) remained closer to *A. nilotica* and *H. binata* when observed 12 MAP.

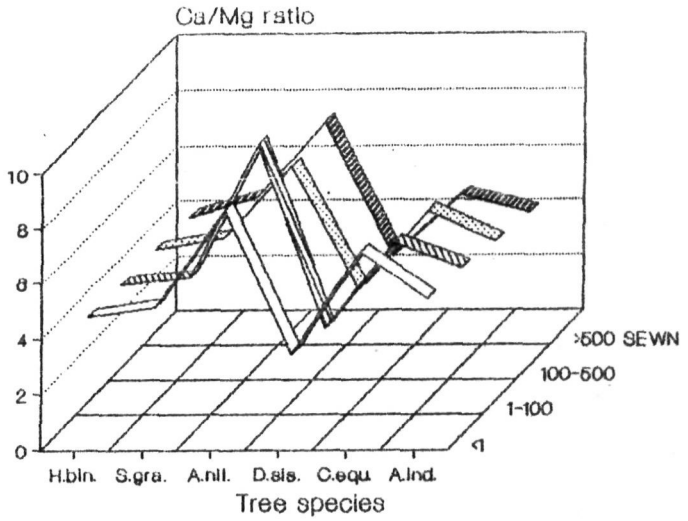
The values of Na/K ratios, 18 and 24 MAP, followed the same trend as was observed 12 MAP with few exceptions as far as the effect of SEWN was concerned. In case of *A. nilotica* adn *S. grandiflora*, it appeared that Na/K was maintained with SEWN and time (more than 18 MAP). Similar stabilization in value of Na/K ratios with time was observed in case of *C. equisetifolia*.

4.5.2 Calcium/Mangnesium ratio as function of SEWN and time is presented in table 28 and fig. 27. The values of Ca/Mg ratios, in general, remained greater than unity and suggested more of Ca was absorbed than Mg. However, as SEWN increased, the absorption of calcium was compensated by magnesium as indicated by decreasing values of Ca/Mg ratios. The values of Ca/Mg ratios remained highest in case of *A. nilotica* (8.09, 5.83 and 6.41 and 12, 18 and 24 MAP) and also the effect of SEWN did not remain any exception to the observations made

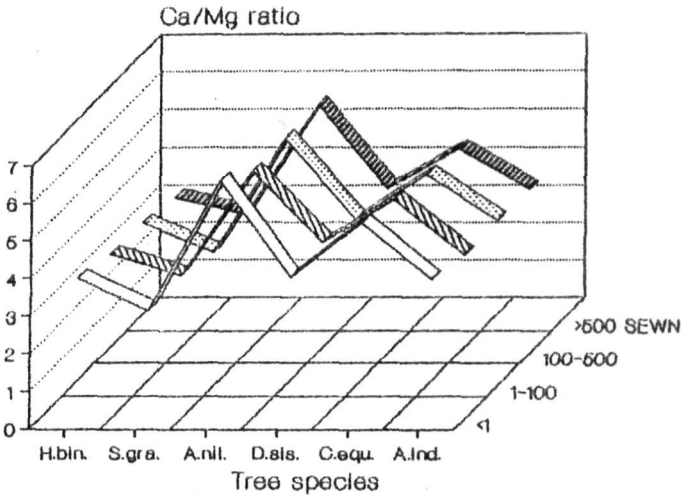
Table 28. Effect of SEWN on leaf Ca/Mg ratios

Tree species	SEWN				
	<1	1–100	100–500	> 500	Mean
a) 12 MAP					
1. *H. binata*	4.30	4.22	4.26	4.19	4.24
2. *S. grandiflora*	4.46	4.67	4.67	4.91	4.68
3. *A. nilotica*	8.20	9.30	7.28	7.59	8.09
4. *D. sissoo*	2.96	2.63	2.75	2.76	2.78
5. *C. equisetifolia*	6.63	5.75	5.63	4.96	5.74
6. *A. indica*	4.93	4.80	4.53	4.33	4.65
b) 18 MAP					
1. *H. binata*	3.69	3.46	3.42	3.22	3.45
2. *S. grandiflora*	2.83	2.88	2.63	2.78	2.78
3. *A. nilotica*	6.30	5.68	5.66	5.68	5.83
4. *D. sissoo*	3.71	3.76	3.52	3.45	3.61
5. *C. equisetifolia*	5.16	4.92	4.70	4.52	4.83
6. *A. indica*	3.65	3.43	3.49	3.44	3.50
c) 24 MAP					
1. *H. binata*	4.33	3.89	4.26	4.14	4.16
2. *S. grandiflora*	3.60	4.02	3.53	3.27	3.61
3. *A. nilotica*	6.79	6.34	6.52	5.97	6.41
4. *D. sissoo*	3.23	4.73	3.48	3.51	3.74
5. *C. equisetifolia*	6.26	5.65	5.49	5.31	5.68
6. *A. indica*	3.83	3.55	3.87	3.44	3.67

a) 12 MAP



b) 18 MAP



c) 24MAP

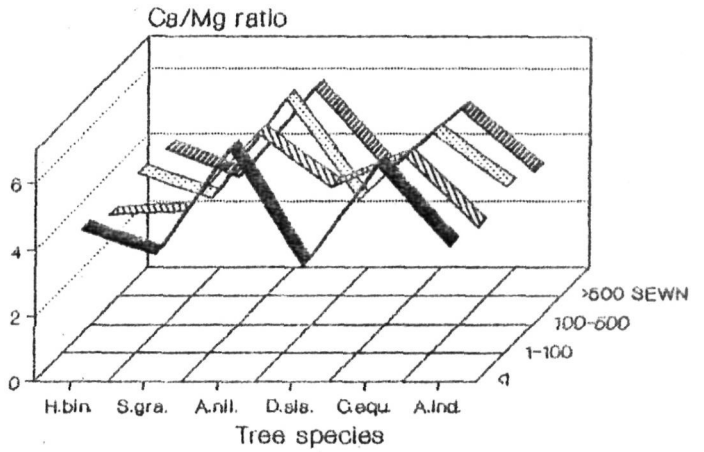


Fig.27:Effect of SEWN on tissue Ca/Mg ratios

earlier. A highest Ca/Mg ratio of 7.59 was noticed in case of *A, nilotica* when SEWN remained higher than 500 when observed 12 MAP. In contrast, the species such as *D. sissoo* maintained a lowest ratio of 2.76 under similar conditions as was observed in case of *A. nilotica*. *Casuarina equisetifolia* (4.96) and *S., grandiflora* (4.91) also maintained higher values of Ca/Mg ratios but, remained far lower than that of *A.* nilotica. *Hardwickia binata* (4.19) and *A. indica* (4.33) maintained ratios closer to those observed in case of *C, equisetifolia* and *S. grandiflora* when observations were made 12 MAP. However, as tree grew older Ca/Mg ratios dropped marginally but, the effect of SEWN still persisted and Ca/Mg ratios decreased as SEWN increased. However, it is interesting to note that *A. nilotica* which maintained a lowest Na/K ratio (0.3 at SEWN more than 500, 18 MAP), maintained highest (5.68) Ca/Mg ratio. Similar observations were also made in case of *C. equisetifolia*. In contrast to these, *A. indica* which was maintaining a higher value of Na/K (0.97 at SEWN more than 500, 18 MAP) maintained lower Ca/Mg ratio (3.44). The variations between the tree species especially amongst those which were maintaining lower (*D. sissoo, A. indica* and *S. grandiflora*) as well as higher values (*A. nilotica, C. equisetifolia* and *H. binata*) became more

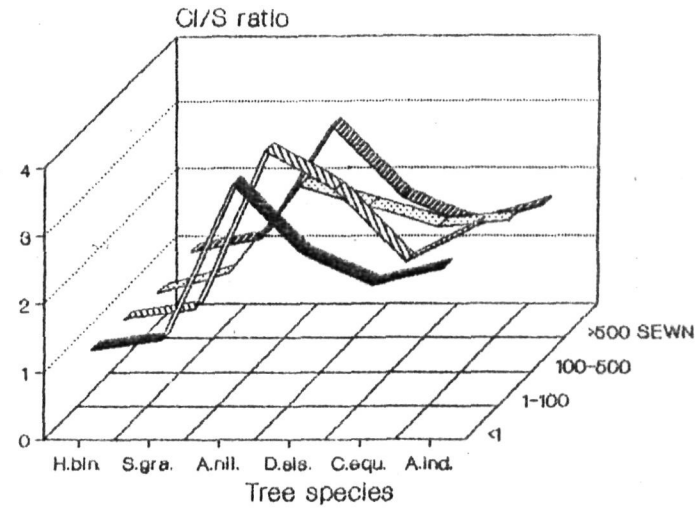
stabilized with time.

4.5.3 Chloride/Sulphur ratio observed in tree species as affected by SEWN and time are presented in table 29 and fig. 28 (a, b and c). From the results presented, it is quite clear that a higher Cl/S ratio were maintained by tree species such as *A. nilotica, D. sissoo, C. equisetifolia* and *A. indica* when trees were less than 12 months old and decreased as grew older. On the contrary, the values were more than 2 in case of *A. nilotica* (3.17), *D. sissoo* (2.43) and *A. indica* (2.16). Effect of SEWN remained more or less similar and the ratios decreased marginally with increasing SEWN. A highest Cl/S ratios of 2.96, 1.83 and 1.54 were observed in case of *A. nilotica* when observed 12, 18 and 24 MAP, respectively as against a lowest of 1.08, 1.03 and 1.29 at SEWN more than 500 in case of *H. binata*. At higher level of SEWN (more than 500), it gave ample evidence that chloride uptake was compensated by sulphur causing reduction in ratios. But in case of *A. nilotica*, it continued to absorb higher chloride than any other species in comparison to sulphur as the ratios remained fairly higher. With time, the uptake of both chloride and sulphur stabilized and chloride was taken in higher propotions only when they were younger. The chloride was, however, compensated by sulphur when they grew older. *Acacia nilotica*,

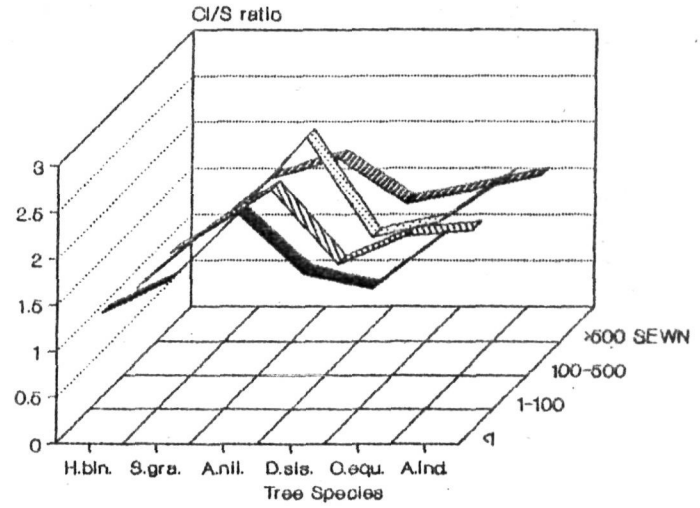
Table 29. Effect of SEWN on leaf Cl/S ratios

Tree species	SEWN				
	<1	1–100	100–500	> 500	Mean
a) 12 MAP					
1. *H. binata*	1.14	1.09	0.98	1.08	1.07
2. *S. grandiflora*	1.28	1.24	1.28	1.28	1.27
3. *A. nilotica*	3.58	3.58	2.54	2.96	3.17
4. *D. sissoo*	2.55	3.00	2.26	1.89	2.43
5. *C. equisetifolia*	2.10	1.93	1.97	1.46	1.87
6. *A. indica*	2.34	2.45	2.05	1.78	2.16
b) 18 MAP					
1. *H. binata*	1.28	1.17	1.16	1.03	1.16
2. *S. grandiflora*	1.63	1.79	1.62	1.62	1.67
3. *A. nilotica*	2.35	2.24	2.43	1.83	2.21
4. *D. sissoo*	1.70	1.44	1.36	1.35	1.46
5. *C. equisetifolia*	1.54	1.74	1.52	1.49	1.57
6. *A. indica*	2.09	1.81	2.00	1.65	1.89
c) 24 MAP					
1. *H. binata*	1.45	1.41	1.31	1.29	1.37
2. *S. grandiflora*	1.47	1.41	1.55	1.37	1.45
3. *A. nilotica*	1.71	1.81	1.80	1.54	1.72
4. *D. sissoo*	1.57	1.46	1.57	1.40	1.50
5. *C. equisetifolia*	1.56	1.59	1.47	1.44	1.52
6. *A. indica*	1.69	1.54	1.41	1.46	1.53

a) 12 MAP



b) 18 MAP



c) 24 MAP

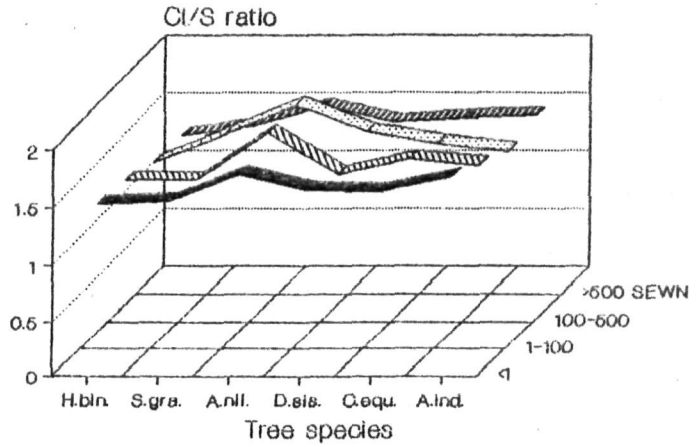


Fig.28: Effect of SEWN on tissue Cl/S ratios

although still maintained (1.71, 1.81, 1.80 and 1.54 at SEWN <1, 1-100 100-500 and > 500, respectively) comparatively higher and more stabilized ratios than observed in other sepcies, 24 MAP. The differnce between tree species especially 24 MAP in respect of Cl/S was not as large as observed in case of Na/K and Ca/Mg ratios.

4.6 Effect of soil solution on tissue composition

Soil solution composition and their correspondig tissues accumulation in respect of sodium, potassium, calcium, magnesium, sulphur and chloride was investigated. Pertaining results are presented species wise in fig. 29 a, b, c, d, e and f.

4.6.1 *Hardwickia binata* : Soil solution sodium, sulphate and chloride strongly influenced their accumulation in tissues as the relation between two remained stronger. However, soil solution calcium also influenced its uptake but, the level of significance ($r=0.70^{*}$) was not as strong as in case of sodium ($r=0.81^{**}$), Sulphur ($r=0.74^{**}$) and chloride ($r=0.72^{**}$). Potassium and magnesium in leaf tissues remained largely independent of their soil solution concentration as the relation between them remained non significant (Fig. 29a). From these results, it was clear that *H. binata* absorbed more

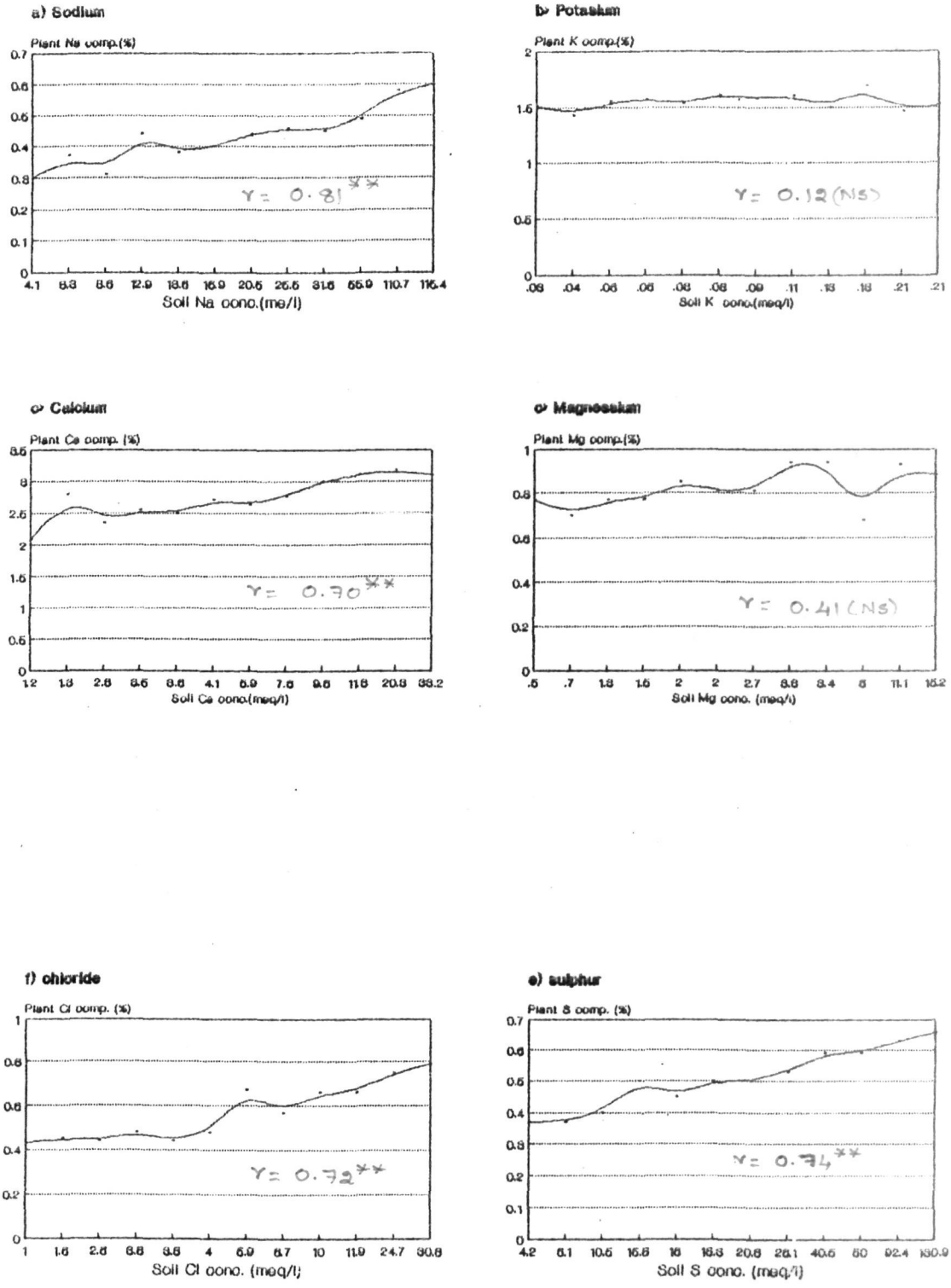


Fig.29a : Relation between soil solution and leaf tissue composition of *H.binata* (18 MAP)

of sodium, calcium, chloride and sulphur than potassium and magnesium. The increasing levels of sodium uptake was dependent on soil solution concentration and found to have a linear relation. Uptake of potassium remained largely independent resulting in higher Na/K ratios. However, Ca/Mg ratios decreased marginally with increase in soil solution concentration and SEWN (Table 28). Similar trends were also observed in Cl/S ratios as their accumulation in tissue was of equal magnitude.

4.6.2 *Sesbania grandiflora* : The tissue sodium was linearly related to soil solution concentration and was highly significant ($r=0.79^{**}$) as against non significant relation observed in respect of potassium (0.24 NS). This indicated that sodium increased linearly with increase in soil solution sodium but potassium remained independent of soil solution concentration. This led to the increased Na/K ratios in case of *S grandiflora*. Chloride ($r=0.815^{**}$) and sulphur ($r=0.75^{**}$) levels registered a highly significant relation with their corresponding solution composition. The increasing chloride and sulphate at similar magnitude, yielded relatively constant Cl/S ratios. Similarly, calcium level in tissue was dependent on soil solution composition at equal magnitude with magnesium. Despite on par level of significance between

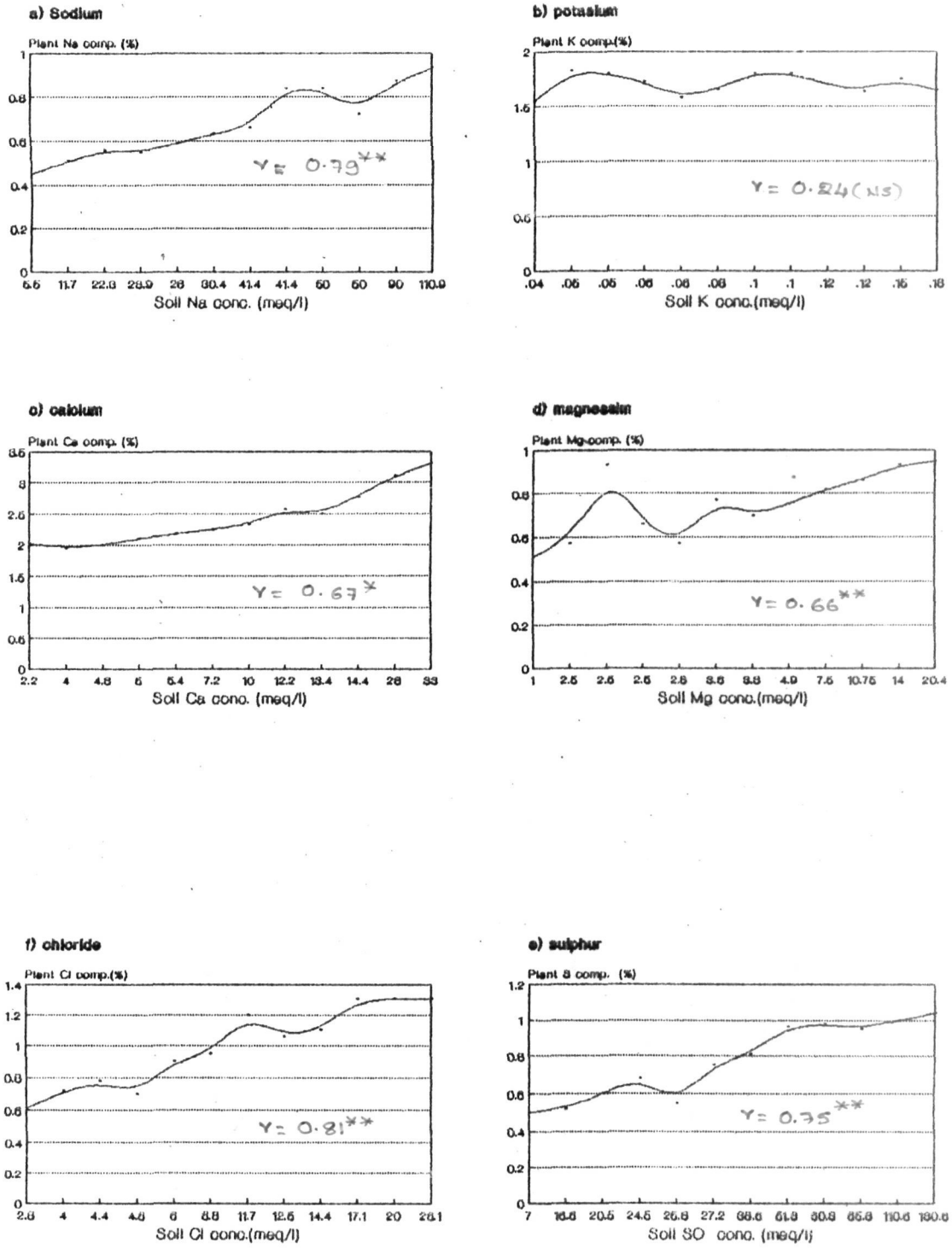


Fig.29b : Relation between soil solution and leaf tissue composition of *S.grandiflora* (18 MAP)

magnesium and calcium, lower Ca/Mg ratios were recorded in tissue (table 28).

4.6.3 *Acacia nilotica* : Unlike in other species, relationship between soil solution and tissue sodium, interestingly, registered lower level of significance ($r=0.65^{**}$). This suggested that uptake of sodium was not of the similar magnitude as observed in case of other species. In contrast to sodium, relationship between tissue and soil solution potassium was not significant (r=0.46 NS). The lower uptake of sodium accompanied by potassium uptake which remained independent of solution concentration resulted in marginal increase of Na/K ratios with soil solution compared to other species (table 27). Calcium in tissue depended more ($r=0.78^{**}$) on soil solution concentration as the level of significance was of higher order (1 per cent) but, magnesium depended ($r=0.63^{*}$) to lesser extent on soil solution concentration compared to calcium. Chloride in tissue related strongly ($r=0.79^{**}$) and depended on soil solution concentration than sulphur (0.74^{**}).

4.6.4 *Dalbergia sissoo* : From the results it appeared that the tissue composition in respect of potassium ($r=0.63^{*}$) and magnesium ($r=0.68^{*}$), which were remaining nearly independent

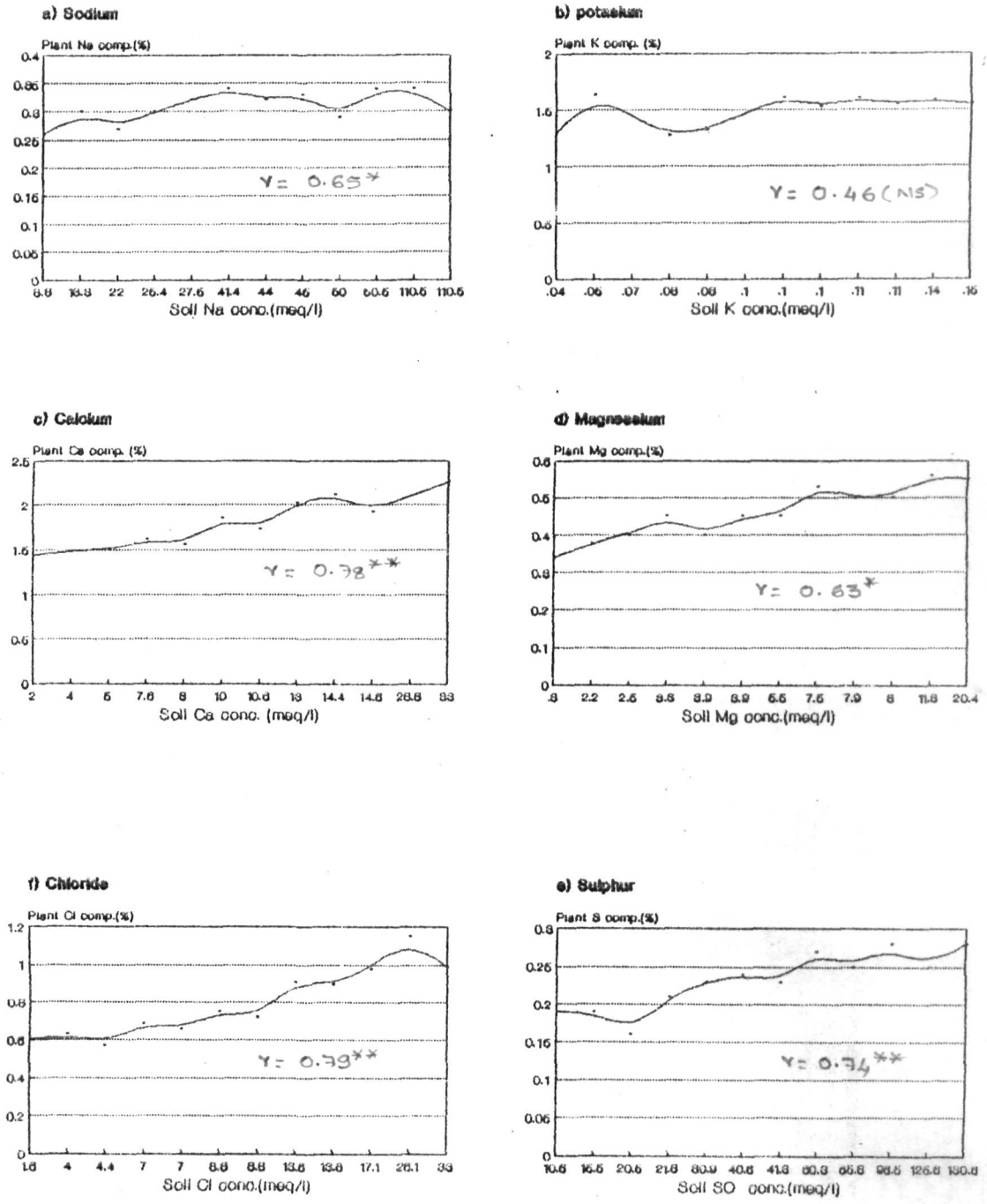


Fig.29c : Relation between soil solution and leaf tissue composition of *A.nilotica (18* MAP)

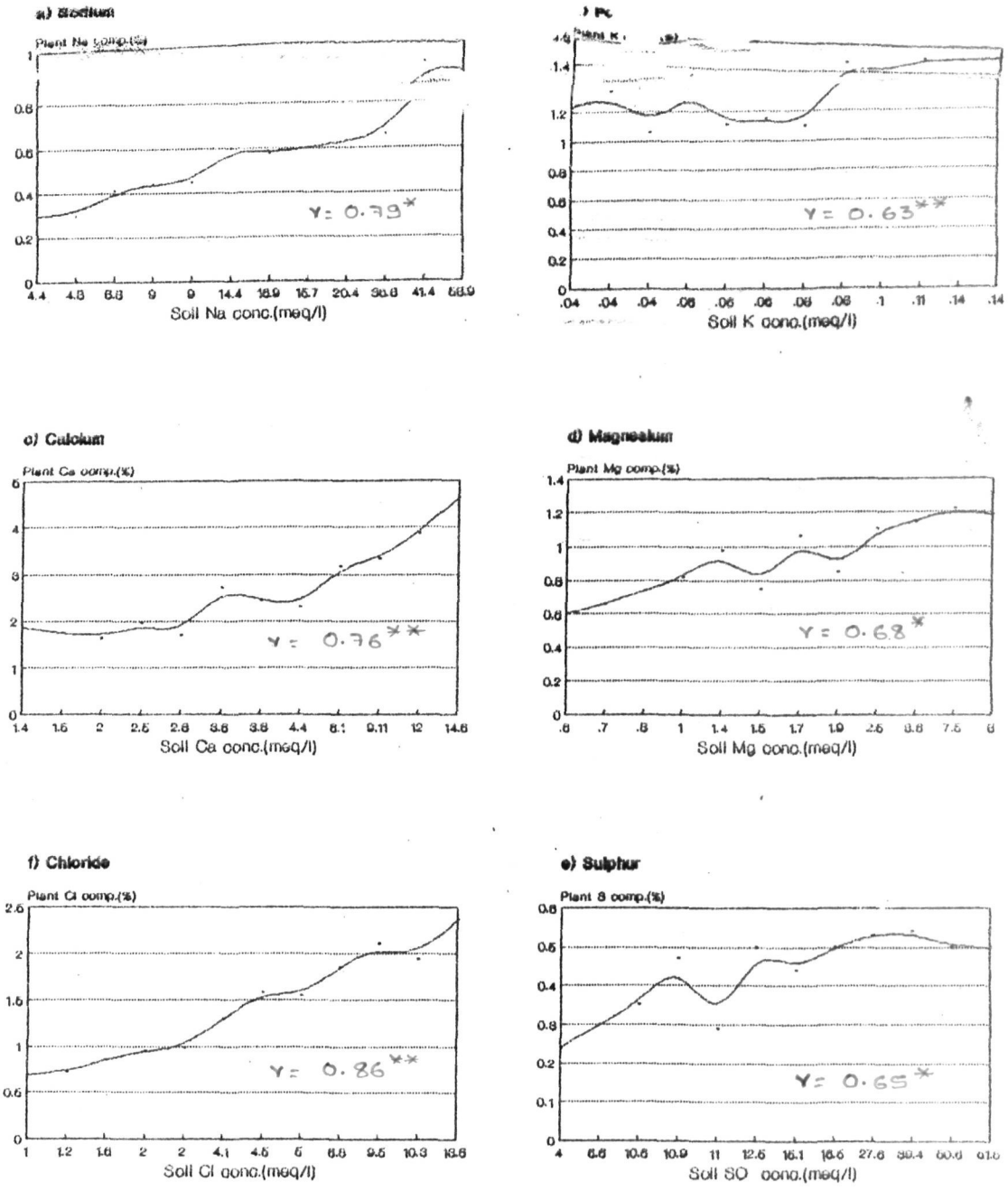


Fig.29d : Relation between soil solution and leaf tissue composition of *D.sissoo (18* MAP)

of solution compositions in *H. binata*. *S. grandiflora* and *A. nilotica*, were found to depend on it in *D. sissoo*. Potassium levels in tissue increased with increase in solution concentration but level of significance remained low (5 per cent). Similar kind of relation was obsrved in case of magnesium in species such as *A. nilotica* ($r=0.63^{**}$) and *S. grandiflora* ($r=0.66^{**}$). Like in other species, tisse sodium ($r=0.79^{**}$), calcium ($r=0.76^{**}$) and chloride ($r=0.86^{**}$) dependent largely on the corresponding levels of soil solution and their relation remained highly significant. As sodium levels in soil solution increased tissue sodium also increased. The increase was far higher than observed for potassium yielding higher Na/K ratios. Calcium level of tissue was of lower order which, resulted in neither decreased nor increased Ca/Mg ratio of tissue. Tissue chloride was not strongly depended on soil solution concentration compared to sulphur. Despite stronger relation between chloride content of tissue and soil solution than sulphur, Cl/S ratios were lower at higher soil solution concentration and SEWN more than 500 (table 29).

4.6.5 *Casurina equisetifolia* : As the soil solution concentration of sodium, calcium and chloride increased, corresponding tissue composition also increased. This

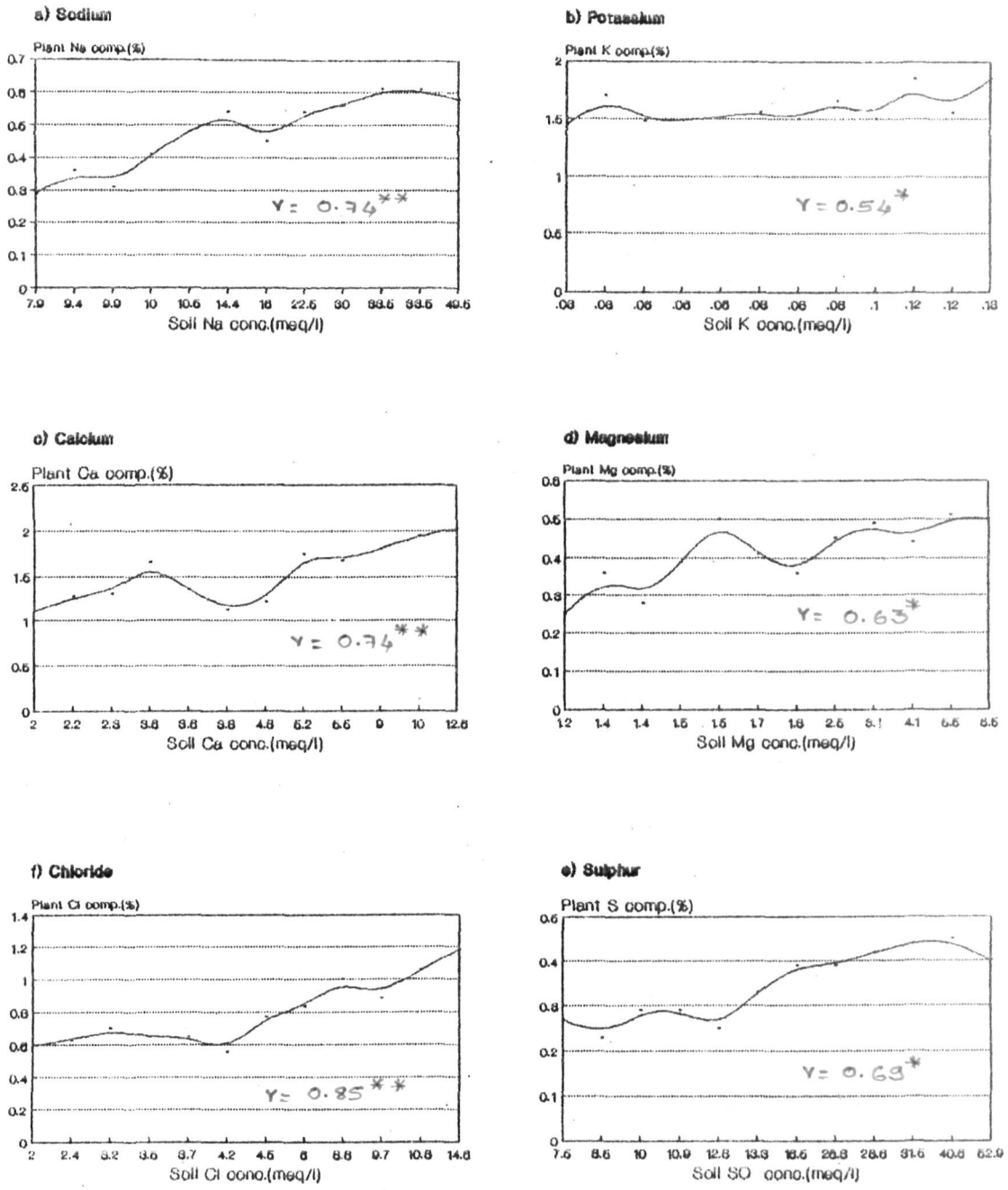


Fig.29e : Relation between soil solution and leaf tissue composition of *C.equisetifolia* (18 MAP)

increase remained highly significant (r values for Na, Ca and Cl. were 0.74^{**}, 0.74^{**} and 0.85^{**}, respectively). Similarly tissue potassium, ($r=0.54^{*}$) magnesium ($r=0.63^{*}$) and sulphur ($r=0.69^{*}$) also increased with increasing solution composition but, increases were not in the same order as observed for sodium, calcium and chloride. The higher level of significance of sodium compared to potassium resulted in higher Na/K ratios in leaf tissue at increased soil solution concentration and SEWN (Table 27). In contrast, Ca/Mg ratio declined marginally, though, magenesium was less dependent on soil solution concentration for its accumulation in leaf tissue compared to calcium. Despite stronger relation of chloride than sulphur between soil solution and tissue composition, the Cl/S ratio was not affected by either soil solution composition or SEWN (Table 29).

4.6.6 *Azadirachta indica* : The association between soil solution sodium and tissue composition remained highly significant ($r=0.79^{**}$) but, it is interesting to note that the potassium levels in tissue of all other species either remained independent or less dependent become highly dependent in case of *A. indica* ($r=0.73^{**}$). Similar highly dependent relation between soil solution and tissue composition were observed in respect of calcium ($r=0.79^{**}$) sulphur ($r=0.74^{**}$)

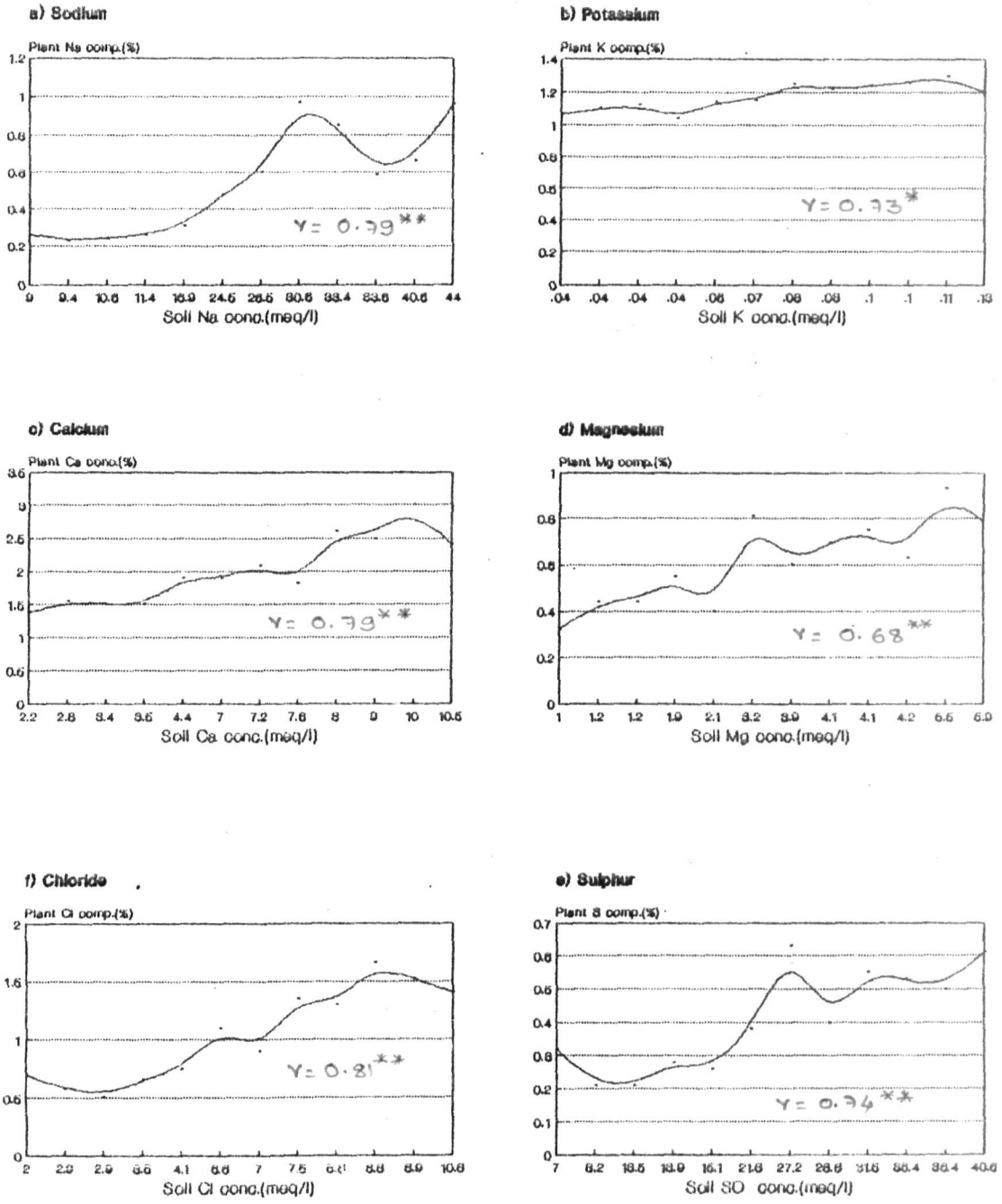


Fig.29f : Relation between soil solution and leaf tissue composition of *A.indica (18 MAP)*

and chloride ($r=0.81^{**}$). However, magnesium levels in tissue was less dependent ($r=0.68^{*}$) on soil solution concentration compared to other ions.

4.7 Effect of tree cover on bio-amelioration

Role of trees on bio-amelioration was examined interms of soil salinity, organic carbon build up, mobilization of calcium carbonate, SAR, ESP (p) etc., and are presented in table 30, 31, 32, 33 and 34 and fig. 30, 31, 32 and 33. Results are presented parameter wise in the following paragraphs.

4.7.1 Soil Salinity : Data on soil salinity monitored at various depths and time in each tree species (table 30 and fig. 30) indicated the definitive role of trees in reducing soil salinity. Performance of tree species, in general, was affected as SEWN values increased. However, the effect of trees when examined interms of soil salinity (0-15 cm) appeared that salinity values remained lower 24 MAP compared to before planting (BP). This was observed in all tree species when soil depth remained 0-15 cm. It is interesting to note that the decrease in soil salinity was in the order of 37 per cent wherever *A. nilotica* was planted. Similarly, the decrease was also of higher order under *S. grandiflora* (20

Table 30. Effect of trees on soil salinity (dSm^{-1})

Tree species	Soil depth									
	0–15 cm		15–30 cm		30–60 cm		60–90 cm		90 + cm	
	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP
1. *H. binata*	12.56	11.86	11.90	12.21	11.20	10.20	11.00	11.40	10.40	10.80
2. *S. grandiflora*	17.00	13.60	16.80	14.90	16.10	14.10	15.00	14.80	11.80	12.00
3. *A. nilotica*	15.80	9.90	14.70	11.80	14.20	10.80	11.30	8.70	10.20	8.60
4. *D. sissoo*	12.60	11.08	8.70	7.90	9.60	9.20	9.00	9.60	9.90	9.70
5. *C. equisetifolia*	12.61	11.16	10.30	9.30	12.00	11.40	13.00	12.00	11.40	12.40
6. *A. indica*	13.79	14.46	11.30	10.70	11.70	11.10	10.90	10.70	10.60	10.70

per cent). However, reduction in salinity remained only marginal in species like *C. equisetifolia* (11 per cent) with exception of *A. indica* where there was a marginal (5 per cent) increase in soil salinity.

As depth increased, effect of different trees remained of similar dimension in reducing soil salinity as observed in case of 0-15 cm. The salt removed from the surface was found to redistribute in the lower horizons (fig. 30). But, in *A. nilotica* it was of same magnitude throughout the profile.

4.7.2 Organic Carbon : Results depicting the effect of tree cover on soil organic carbon are presented in table 31 and fig. 31. In general, a marginal increase in organic carbon was observed in all the tree species. This effect was quite evident even at lower depths of the profiles. *Hardwickia binata* registered a marginal increase of 3 per cent 24 MAP in surface layer. Despite decrease in organic carbon with depth, there was slight buildup with time. *Sesbania grandiflora* also registered increase in organic carbon both in surface and within profile. The increase was higher than that of *H. binata*. It should be noted that the increase in case of *A. nilotica* was of higher order (21 per cent) and stood highest

Table 31. Effect of trees on soil organic carbon (%)

Tree species	0–15 cm		15–30 cm		30–60 cm		60–90 cm		90 + cm	
	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP
1. *H. binata*	0.77	0.79	0.55	0.56	0.44	0.46	0.41	0.43	0.35	0.37
2. *S. grandiflora*	0.69	0.75	0.56	0.58	0.43	0.45	0.36	0.42	0.27	0.28
3. *A. nilotica*	0.67	0.81	0.49	0.57	0.36	0.44	0.31	0.35	0.27	0.27
4. *D. sissoo*	0.81	0.95	0.62	0.68	0.39	0.45	0.38	0.42	0.29	0.33
5. *C. equisetifolia*	0.83	0.91	0.53	0.63	0.54	0.56	0.36	0.38	0.28	0.28
6. *A. indica*	0.77	0.77	0.54	0.52	0.47	0.43	0.43	0.35	0.35	0.25

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amongst the species and increase was noticeable even at lower depths. This species was closely followed by *D. sissoo* which registered nearly 15-16 per cent increase in organic carbon. *Casuarina equisetifolia* (10 per cent increase) also contributed to organic carbon pool of soil but, the order of magnitude was much lower than *A. nilotica* and *S. grandiflora*. Like in case of salinity where the effect *A. indica* remained of little consequence, the contribution of this species towards organic carbon of soil was meagre.

In general, all the species except *A. indica* registered marginal increase in their organic carbon level of surface layer (0-15cm) and was also fact when it was probed into lower horizons.

4.7.3 Sodium Adsorption Ratio : Soil solution composition in respect of SAR was examined and data related to this parameter are presented in table 32 and fig. 32.

Effect of trees on SAR revealed beneficial influence as soil solution SAR has decreased. This was observed both in surface as well as within the profile. But it was of higher order in 0-30 cm depth. *Hardwickia binata* with slow growth habits and lower canopy recorded marginal decrease of less than 10 per cent in SAR values 24 MAP. The reduction,

Table 32. Effect of trees on SAR (m. mol/l)$^{\frac{1}{2}}$

Tree species	0–15 cm		15–30 cm		30–60 cm		60–90 cm		90 + cm	
	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP
1. *H. binata*	14.74	13.63	14.09	12.85	13.47	13.58	13.30	13.34	12.12	11.48
2. *S. grandiflora*	13.84	10.97	12.51	10.11	14.11	13.90	12.30	12.24	13.61	14.09
3. *A. nilotica*	13.83	8.27	14.32	10.00	13.00	11.01	13.50	13.50	12.17	11.62
4. *D. sissoo*	13.74	12.14	14.83	12.86	13.72	13.62	12.41	13.69	12.41	12.45
5. *C. equisetifolia*	13.70	9.40	14.72	12.48	13.33	14.68	12.84	13.31	12.35	11.98
6. *A. indica*	14.88	13.73	13.22	13.86	14.69	14.61	12.63	14.37	13.16	13.35

however, remained of lower order when observed below 30 cm depth. Unlike *H. binata*, *S. grandiflora* was found more effective in reducing SAR and the effect was of higher order in surface than in sub-surface. *Acacia nilotica* was the most efficient in reducing sodium in soil solution as the decrease in SAR was in the order of 40 per cent in the surface layer. Influence of *A. nilotica* in reducing soil salinity was found to a depth of upto 60 cm beyond which there was no marked reduction in SAR values. The magnitude of reduction remained larger in case of *D. sissoo* (12%) and was slightly higher than those of *H. binata* (8%) and *A. indica* (8%). *Casuarina equisetifolia* was found next better species to *A. nilotica* in reducing sodium load in soil solution as the values of SAR remained around 30 per cent in surface and decreased as depth increased.

4.7.4 Exchangeable sodium percentage : The data pertaining to this parameter are presented in table 33 and fig. 33. The ESP values predicted on the basis of soil solution SAR remained similar to those observed in case of SAR. Trees had positive effects on ESP (P) values and decreased under tree cover. *Acacia nilotica* was found more efficient in reducing sodium (20%) hazard compared to other species. This was closely followed by the species such as *S. grandiflora* (13%), *D.*

Table 33. Effect of trees on soil ESP (p)

Tree species	0–15 cm		15–30 cm		30–60 cm		60–90 cm		90 + cm	
	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP
1. *H. binata*	14.92	14.57	15.21	14.18	16.11	16.18	14.02	14.09	14.77	15.16
2. *S. grandiflora*	15.50	13.53	15.93	14.06	15.72	14.58	14.21	14.67	13.50	13.32
3. *A. nilotica*	15.11	12.07	14.63	12.77	15.73	15.08	13.77	13.24	14.23	14.38
4. *D. sissoo*	15.66	14.05	15.43	14.09	14.57	14.56	13.81	13.68	15.06	15.52
5. *C. equisetifolia*	16.42	14.77	15.00	13.81	14.18	14.07	13.37	13.55	14.94	15.36
6. *A. indica*	15.57	15.34	16.08	16.64	16.03	14.49	14.79	14.52	14.50	14.71

Table 34. Effect of trees on soil calcium carbonate (%)

Tree species	0–15 cm		15–30 cm		30–60 cm		60–90 cm		90 + cm	
	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP	BP	24MAP
1. *H. binata*	12.5	12.0	12.7	12.6	13.1	13.0	14.3	14.6	14.9	15.3
2. *S. grandiflora*	12.6	11.6	12.8	12.4	13.2	12.8	14.2	13.9	15.4	15.4
3. *A. nilotica*	12.1	12.3	12.2	13.2	12.6	13.2	13.5	14.6	14.7	16.1
4. *D. sissoo*	12.7	13.3	13.1	14.0	13.5	14.6	13.7	15.1	14.6	16.3
5. *C. equisetifolia*	12.3	12.2	12.8	12.5	12.8	13.1	13.6	13.9	14.2	15.3
6. *A. indica*	12.2	12.3	12.9	12.7	12.8	13.2	13.2	13.5	13.9	14.3

sissoo (10%) and *C. equisetifolia* (10%). In contrast to these species where reduction was in the order of 10-12 per cent (surface 0-15cm), species like *H. binata* (2%) and *A. indica* (1%) were found to have little significance in reducing sodium hazard as they caused only marginal decline in ESP (p) values. In general, the effect of trees was more pronounced in surface (0-15cm) than at lower depths.

4.7.5 Calcium carbonate : The picture of the lime status showing the effect of trees was not clear when observed 24 MAP. Although some tree species caused decrease in lime status, others showed buildup. However, the picture on lime status appeared to remain inconclusive 24 MAP.

CHAPTER - V

DISCUSSION

V DISCUSSION

Results of the present investigation on the performance of tree species under saline and waterlogged conditions are discussed under following paragraphs.

5.1 Effect of soil salinity/waterlogging on tree growth parameters.

Influence of salt and waterlogging stress on growth parameters of trees such as establishment, height, number of branches, DSH, DBH, pruned biomass and crown width are discussed as under.

5.1.1 Soil Salinity:

Adverse effects of soil solution salt concentration on plants are many fold and are brought about by decreased osmotic potential of soil solution and increased specific ion effects causing either toxicity or deficiency. Plants suffer by impaired bio-chemical and physiological processes thus fails to put on normal growth. Such reduced growth of trees observed under saline conditions in the present investigation are detailed in the following paragraphs.

5.1.1.1 Establishment : of all the tree species decreased with increasing soil salinity at 6 as well as 12 MAP. However,

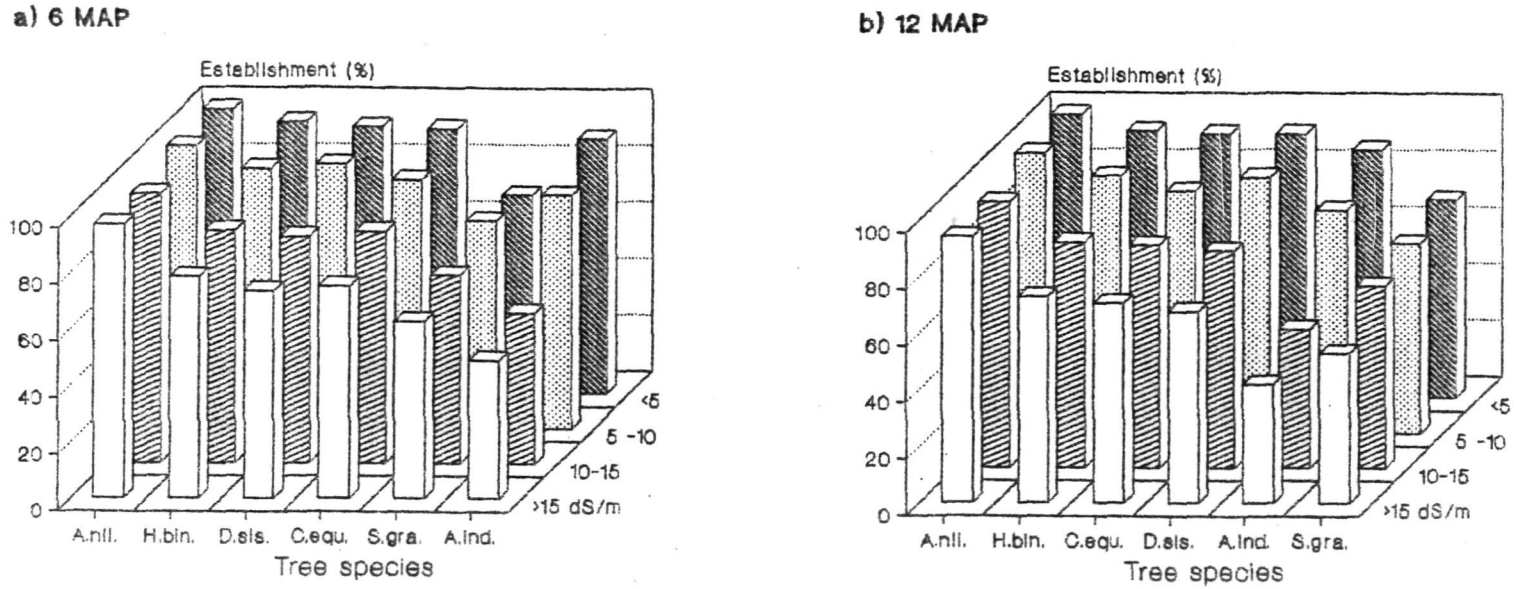


Fig. 4 Effect of soil salinity on establishment of tree species

tree species differed to a large extent in establishment when salinity was both lower (< 5 dSm^{-1}) and higher (> 15 dSm^{-1}) Amongst tree species, *A. nilotica* better established at all the salinity levels. Initial sapling mortality was as low as 3.3. and 6.0 per cent 6 and 12 MAP, respectively even when salinity remained higher (>15 dSm^{-1}). This indicated that this species adopted and established better under hostile conditions than others. This was followed by *H. binata* and *C. equisetifolia* with better estblishment at all salinity levels. Such higher potentiality of establishment and adoptibility, was also observed by Tomar and Yadav (1980) and Sandu and Abrol (1981) in case of *A. nilotica* and Singh *et al.* (1987b), Hebbara *et al.* (1992) and Batra and Ashok Kumar (1993) in *C. equisetifolia*. A large sapling mortality of *A. indica* and *S. grandiflora* at both lower and higher salinity indicated their inability to adopt to saline conditions when observed 6 and 12 MAP. *Dalbergia sissoo* registered better establishment at lower salinity but its mortality increased with increased salinity due to higher osmotic effects. Poor performance of *D. sissoo* under saline conditions of soil was further confirmed by Roy *et al.* (1987). Irrespective of species, a reduction in establishment was observed at higher soil salinity due to increased concentration of neutral salts

of chlorides and sulphates of sodium in soil solution (table 1) and their excessive accumulation in tissues (table 29) causing mortality. In contrast, Gupta *et al.* (1986) recorded only 50 per cent survival in *A. nilotica* and *C. equisetifolia* when soil salinity remained in the order of 15 and 2.5 dSm^{-1}, respectively.

5.1.1.2 Height: Soil salinity had similar effect on height as observed in case of establishment. Observations made at 6, 12, 18 and 24 MAP revealed a wide variations in their reaction to soil salinity. *Acacia nilotica* recorded a meagre 15, 31, 1 and 11 per cent decrease in height when soil salinity remained beyond 15 dSm^{-1} when observed 6, 12, 18 and 24 MAP, respectively exibiting its better growth under saline conditions. Despite increasing sodium and magnesium concentration in soil solution, *A. nilotica* was able to maintain lower Na/K and higher Ca/Mg ratios in leaf tissues (table 27 and 28). A lower Na/K and higher Ca/Mg ratios maintained in leaf tissues indicated its ability to exclude Na and Mg and selectively absorb more of K and Ca by the species resulting in satisfactory growth in saline soils (> 15 dSm^{-1}). Similar adoptability of *A. nilotica* to saline conditions was also reported by Singh *et al.* (1986). Performance of *C. equisetifolia* and *S. grandiflora* remained

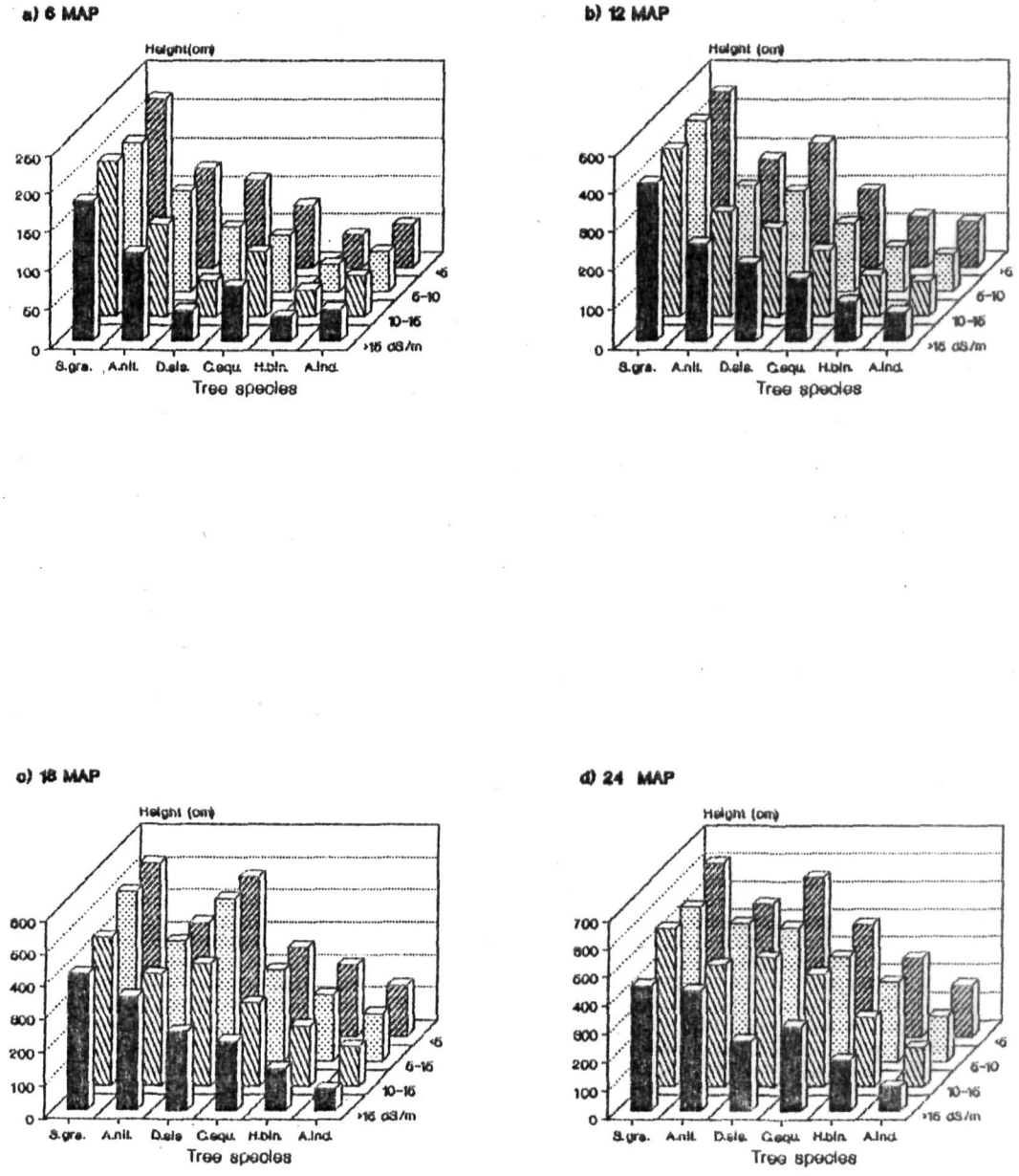


Fig. 5:Effect of soil salinity on height of tree species

comparable to *A. nilotica* and the better performance of *S. grandiflora* , like *A. nilotica* was attributed to its lower accumulation of sodium relative to potassium as revealed by lower tissue Na/K ratios (table 27). Both *S. grandiflora* and *A. nilotica* many have developed mechanism either to exclude sodium from absorption or accumulate in roots by way of controlled xylum translocation to aerial parts like leaves as indicated by lower values of Na/K ratios compared to other species. On the contrary, *C. equisetifolia* , although, recorded lower reduction in height, had higher Na/K ratios in tissues suggesting Na/K ratios did not control the tolerance in this species. Such little influence of high Na/K ratios in *C. equisetifolia* were also reported by Clements *et al.* (1983), Gill and Abrol (1983), El-Lakany and Laura (1982), Bandopadhyay (1988) and Hebbara *et al.* (1992). However, reduction in height with increasing soil salinity accompanied by higher Na/K ratios was appreciable in *D. sissoo* and *A. indica* indicating their poor growth under salt affected soils. Bhargava (1951) and Pande (1956) recorded similar poor performance of *D. sissoo* and *A. indica* under saline conditions.

5.1.1.3 Number of branches: Adverse effects of soil salinity on number of branches was observed in all the tree species.

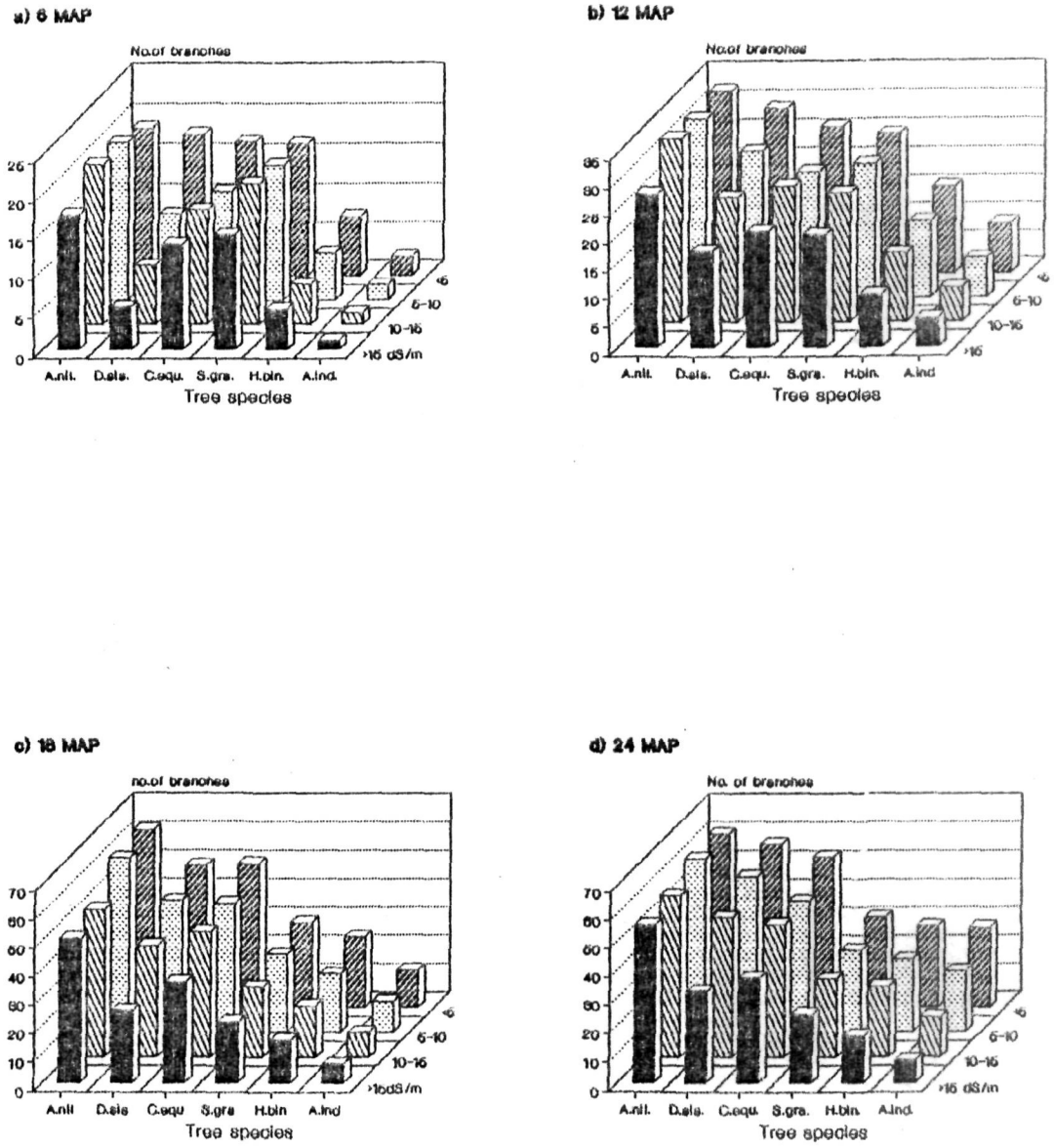


Fig.6 Effect of soil salinity on number of branches of tree species

The decrease in branches was in the order of 73 per cent in *A. indica* when observed 24 MAP and when soil salinity remained higher than 15 dSm^{-1}. Such a higher reduction in their growth parameter was also observed in *D. sissoo* and *H. binata* revealing their inability to adopt to saline conditions. The branching potential of *A. nilotica* , *S. grandiflora* and *C. equisetifolia* was little affected by increasing soil salinity. Amongst these, *A. nilotica* was found better and more tolerant compared to *C. equisetifolia* and *S. grandiflora* under saline conditions. The decreased branching might have been due to excessive accumulation of sodium in tissues. The susceptible species like *D. sissoo* and *A. indica* had higher Na/K ratios at higher soil salinity (> 15 dSm^{-1}). The growth was, therefore, affected either by excessive accumulation of sodium or deficiency of potassium. In contrast, the species which maintained higher branches had lower sodium concentration in leaves relative to potassium. Similar observations of Na accumulation in leaf tissue of susceptible species was made by Winter and Lauchli (1982).

5.1.1.4 **DSH;** Like other parameter discussed above, DSH of all the tree species, in general, decreased with increase in soil salinity. A reduction in stem diameter at stump height varied to a large extent amongst the species. At all the time

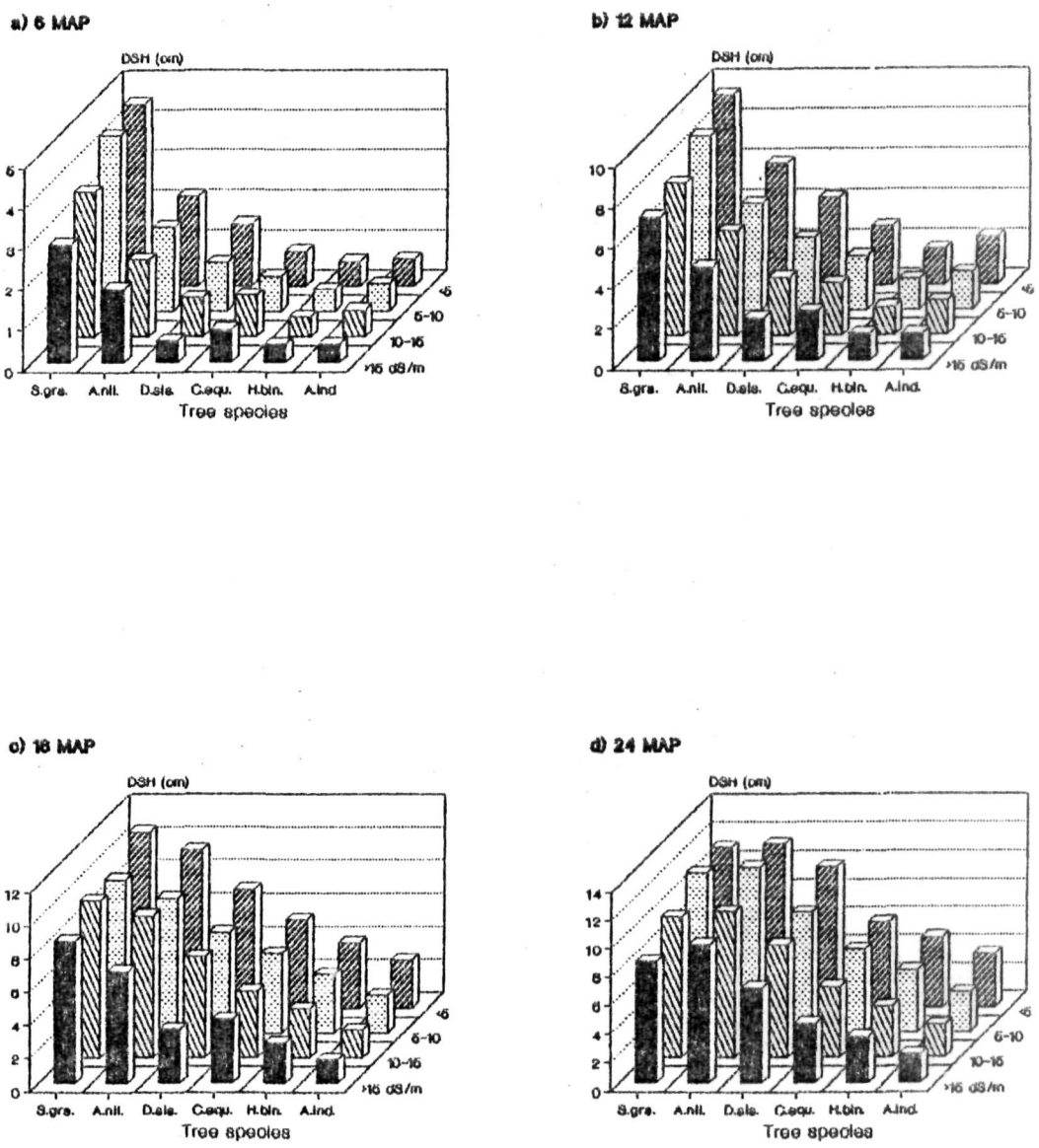


Fig.7 Effect of soil salinity on DSH of tree species

of observations (6, 12, 18 and 24 MAP) , *A. nilotica* and *C. equisetifolia* recorded a lowest reduction in DSH revealing their tolerance to soil salinity followed by *S. grandiflora*. A lower decrease in DSH in case of these species might be attributed to lower Na/K ratios of leaf tissue except, in case of *C. equisetifolia* where ratios remained higher. Hebbara *et al.* (1992) recorded higher DSH values in case of *C. equisetifolia, S. grandiflora* and *D. sissoo* under saline and waterlogged soils contrary to lower values recorded for *D. sissoo* in the present experiment. Tomar and Yadav (1983) and Muthana and Jain (1984) categorised *Eucalyptus* hybrid and *P. juliflora* respectively as tolerant species because of lower decrease in stem diameter. Similar methods have also been used sparingly while describing salt tolerance of the species in this investigation. Bandopadhyaya (1986) reported lower reduction in DSH due to increasing soil salinity in case of *C. equisetifolia* which also confirmed the results of the present investigation. On the contrary to *A. nilotica* , *C. equisetifolia* and *S. grandiflora,* species such as *D. sissoo* , *A, indica* and *H. binata* recorded higher reduction in DSH due to increasing salinity. When soil salinity remained higher than 15 dSm^{-1}, *A. indica* and *D. sissoo* recorded lower values of stem diameter (DSH) and reduction remained in the order of

over 50 per cent due to increased soil salinity. The poor performance of these species as already presented was due to higher Na/K ratios and osmotic effects resulting in poor adoptability under saline conditions. Both *D. sissoo* and *A. indica* had increased accumulation of sodium in comparision to potassium. This imbalance in Na/K ratio in leaf tissue might have affected the performance of these species. Jain *et al.* (1983b) and Muthana and Jain (1984) found *Dichrostachys glomerata* and *cassia siamia,* respectively as the most sensitive species because of similar decreased DSH at higher soil salinity as obseved in present investigation.

5.1.1.5 DBH; The factors that controlled height and DSH were also found to control DBH of various tree species Effect of salinity on this parameter fell in line with that of DSH. As soil salinity increased, DSH measured 24 MAP revealed that species such as *S. grandiflora , A. nilotica, D. sissoo* and *C. equisetifolia* were tall enough to register measurable height. Amongst these species, *A. nilotica* and *S. grandiflora* recorded lower per cent reduction in DBH due to increasing soil salinity. Amongst the species tried, *A. nilotica* was found better adopted to such conditions than other species as reduction in DSH when observed 24 MAP remained lower (17 per cent). In contrast, species such as *A. indica* and *H. binata*

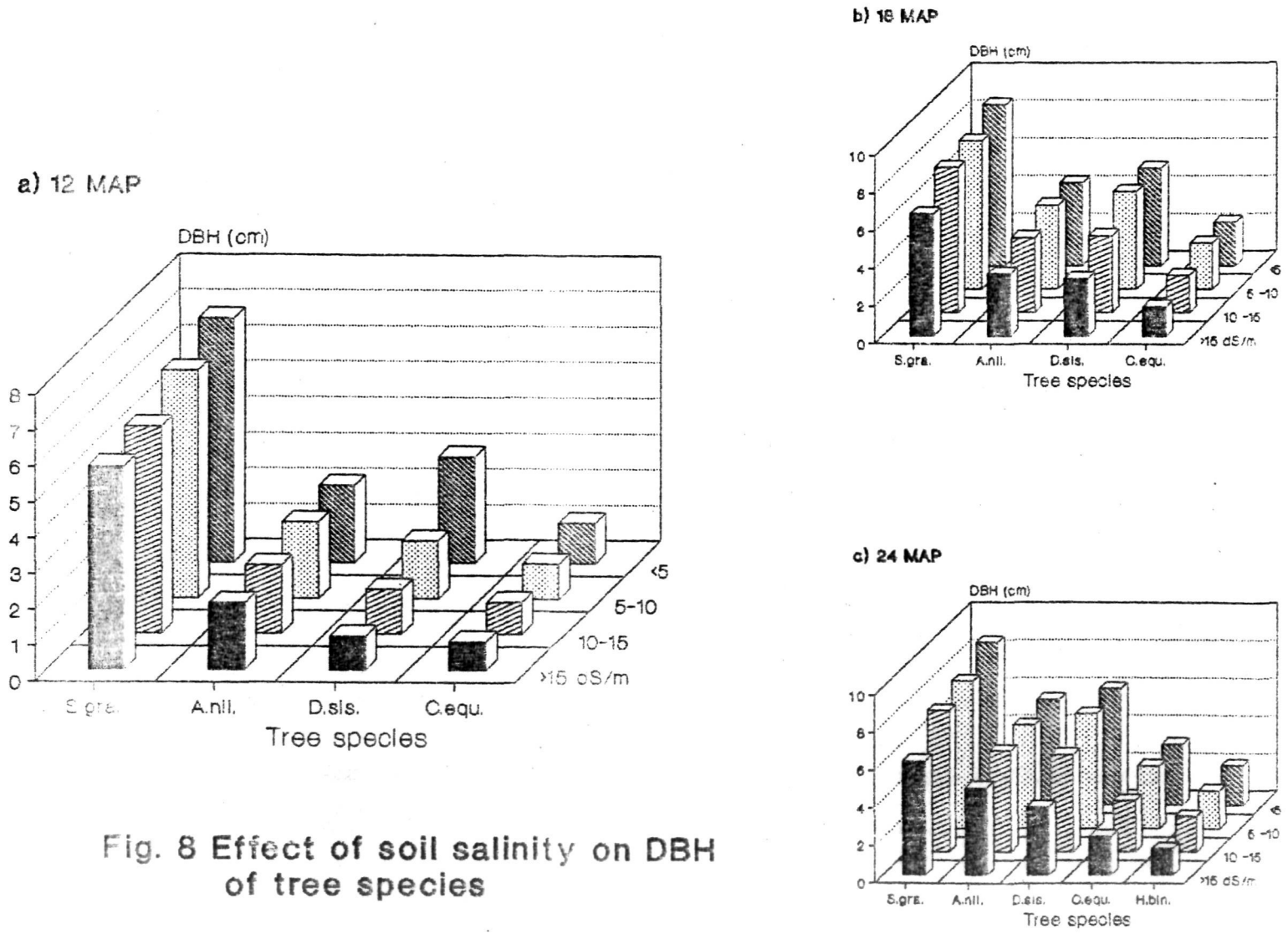


Fig. 8 **Effect of soil salinity on DBH of tree species**

did not attain measurable height due to their genetic slow growth habits. However, adverse effect of salinity was also found in case of these species due to imbalanced ionic composition of leaf tissue leading to higher Na/K and lower Ca/Mg and Cl/S ratios. This might have resulted in the poor performance under saline conditions. In addition, adverse effects of salinity such as low osmotic potential, toxicity of some ions (Na, Cl or/and S) might have affected the potentiality of trees. The neutral salts of chlorides and sulphates of sodium dominated the soil solution of the experimental site (table 1) and due to which susceptibe ones such as *D. sissoo* accumulated more of these in leaf tissues. In contrast, hardy species like *A. nilotica* maintained lower Na/K ratios despite increasing solution concentration thereby avoiding toxic effects of sodium. A stronger and negative relationship between soil salinity and DBH of *D. sissoo* further confirmed its susceptibility of this species (APP. 5a). With respect to absorption of Na, *D. sissoo* recorded higher relationship with soil solution concentration (fig. 29d) resulting in excessive accumulation. Similar growth and adoptibility of *A. nilotica* over *D. sissoo* to salinity was observed by Khan (1962) and Pande (1956). Singh *et al.* (1991) also reported that *A. nilotica* and *C. equisetifolia* were

more tolerant to salinity (lower per cent decrase in stem girth) compared to susceptible (higher decrease in girth) *D. sissoo.*

5.1.1.6 **Pruned bio-mass:** Collected as fresh weight of leaves and twigs after pruning to a 1/3rd height, prouned bio-mass remained no exception to the salinity effects. Bio-mass yield of the species depended on salinity and it decreased as salinity increased. The biomass of *D. sissoo* and *A. indica* followed this trend. Their bio-mass reduced by nearly 50 per cent at higher soil salinity (> 15 dSm^{-1}) when observed 12 and 24 MAP. A similar reduction in bio-mass yield with increased salinity was observed in case of *H. binata* which recorded over 40 per cent reduction. As other growth parameters like height, No. of branches, DBH and DSH which directly controlled bio-mass,had been already affected, the parameter alsq remained affected. Hence, reduction in these parameters due to increasing soil salinity contributed to the decreased bio-mass production of trees. The susceptible species like *A. indica* and *D. sissoo* which recorded higher reduction in their growth parameters resulted in higher decrease of pruned bio-mass. On the contrary, species such as *A. nilotica* and *C. equisetifolia* which were marginally affected, registered only marginal decrease in their pruned

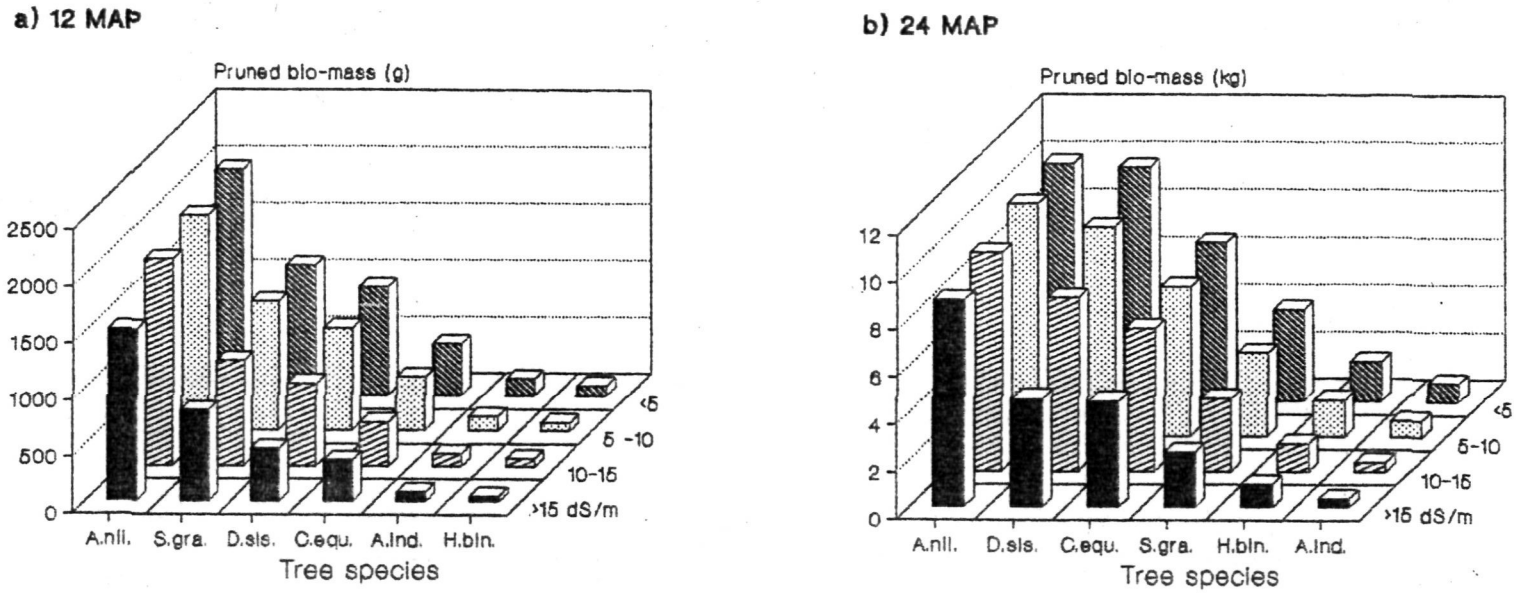


Fig.9 Effect of soil salinity on pruned bio-mass of tree species

bio-mass . As discussed in the previous parameters, increased Na/K ratio and decreased Ca/Mg and Cl/S ratios under elevated salinity stress, caused general decrease in pruned bio-mass of all the tree species. However, rate of reduction varied amongst different species based on their adoptability probably by way of ion exclusion mechanism. A significant higher relation existed between soil solution and uptake of Na further, confirmed the toxic accumulation of Na in leaf tissues (fig. 29d) of *D. sissoo* and *A. indica* compared to *A. nilotica* and *S. grandiflora*. Susceptibility of *A. indica* and *D. sissoo* was also evident through stronger relationship between soil salinity and pruned bio-mass production by these species (App. 5 a). Observations made in the present experiment are in confirmity with those of Tomar and Yadav (1985), Gupta *et al.* (1986), Walker and Douglas (1983) and Chaturvedi *et al.*(1987) who also observed a marginal decrease in bio-mass production of *A. nilotica* and *c equisetifolia* and higher in case *A. indica* due to increasig soil salinity.

5.1.1.3 Crown width:

Observations made 6, 12, 18 and 24 MAP indicated detrimental effects of higher salt concentration on crown width. A lowest decrase in crown width was recorded in case of *S. grandiflora* and reduction in general, decreased with

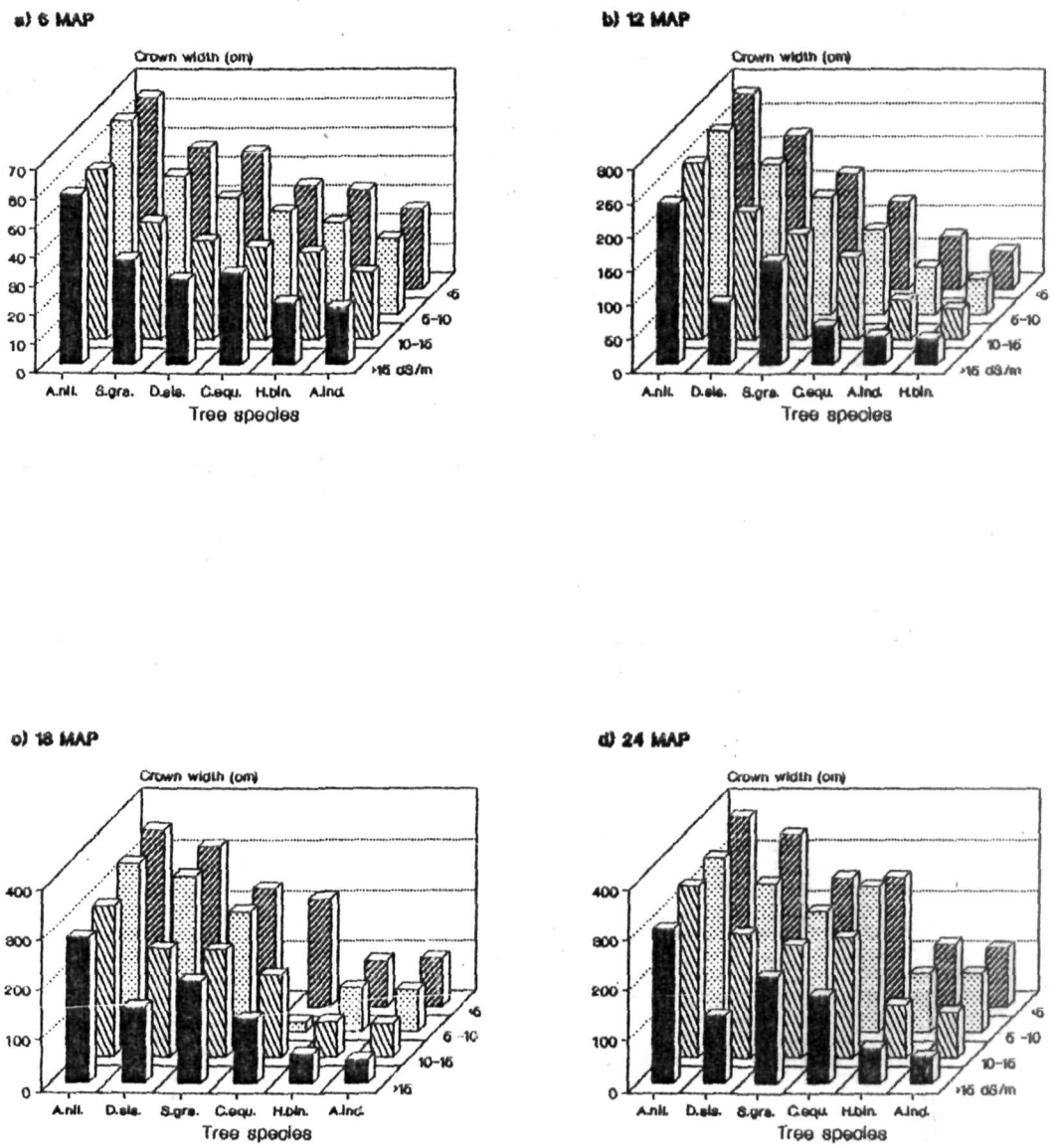


Fig. 10 Effect of soil salinity on crown width of tree species

time. This trend was also observed in case of *A. nilotica* but reduction remained ony marginal. In contrast, *A. indica* and *D. sissoo* recorded a higher per cent reduction in their crown width (over 30 per cent) due to increasing soil salinity. A higher reduction in crown width indicated their susceptibility to soil salinity. Biddiscombe *et al.* (1985) grouped *Eucalyptus globulus, E. maculeata* and *E. cladocalyx* as the most tolerant species to soil salinity based on higher crown volume possessed under saline conditions. *Casuarina equisetifolia* which registered higher (55 per cent) reduction 12 MAP maintained fairly lower decrease at 18 and 24 MAP confirming its better performance. This was as a result of better height, number of branches, DSH and DBH values. As crown width of trees was directly related to other growth parameters such as number of branches, any increase in such parameters also enlarges the volume of crown. The decrease in number of branches observed in *D. sissoo* and *A. indica* under saline conditions also resulted in reduced crown width. Performance of *C. equsetifolia* and *H. binata* in terms of crown width under saline conditions was neither as bad as *D. sissoo* nor as good as *S. grandiflora*. Increased accumulation of sodium at the expense of potassium in leaf tissue must have affected the optimum growth of trees . Similar reduction in

growth to the extent of 47 per cent was also observed by Winter and Lauchli (1982) in *Trifolium alexandrium* under saline conditions.

Considering per cent decrease in all the growth parameters at highest soil salinity (>15 dSm^{-1}) , *D. sissoo* was found least tolerant followed by *A. indica*. The species, like *H.binata* appeared moderately tolerant as its growth parameters decreased to a lesser extent compared to *A. indica* and *D. sissoo*. Reduction in growth parametes due to increasing soil salinity was the least in *A. nilotica* indicating better adoptability and tolerance to salinity. Both *S. grandiflora* and *C. equisetifolia*, although, appeared to tolerate soil salinity but not as good as *A. nilotica*.

5.1.2 Water table:

The shallow water table conditions are known to affect growth of plants due to impaired aeration in soils and thereby affecting normal functioning of roots like nutrient and water uptake. In addition, waterlogging also brings about many chemical, physical and biological transformations in soils which generally affect normal growth of trees.

Results showing deleterious effects of water table on growth parameters of various tree species are discussed under following paragraphs.

5.1.2.1 Establishment of all the tree species was markedly influenced by the water table and were affected due to rising water table. Amongst the species, *A. nilotica* was found to suffer to a lesser extent as sapling mortality under shallow water table situations remained lower. It recorded as high as 98.1 and 95.1 per cent establishment 6 and 18 MAP, respectively. The species such as *C. equisetifolia* and *H. binata* closely followed *A. nilotica* as the per cent establishment of these also remained of higher order.

Promising performances of *A. nilotica* and *C. equisetifolia* were found under shallow water table conditions (Tomar and Gupta, 1987). In contrast, the species such as *S. grandiflora* registered a highest sapling mortality both at deep and shallow water table conditions indicating the establishment of the species rather appeared crucial at initial phases of its establishment. *Dalbergia sissoo* which had better establishment under deep water table situations became suspect as establishment decreased drastically with rising water table. Establishment of *A. indica* was also found to be poor under shallow water table situations. A higher mortality in shallow water table conditions was probably due to impeded root growth. Whenever shallow water

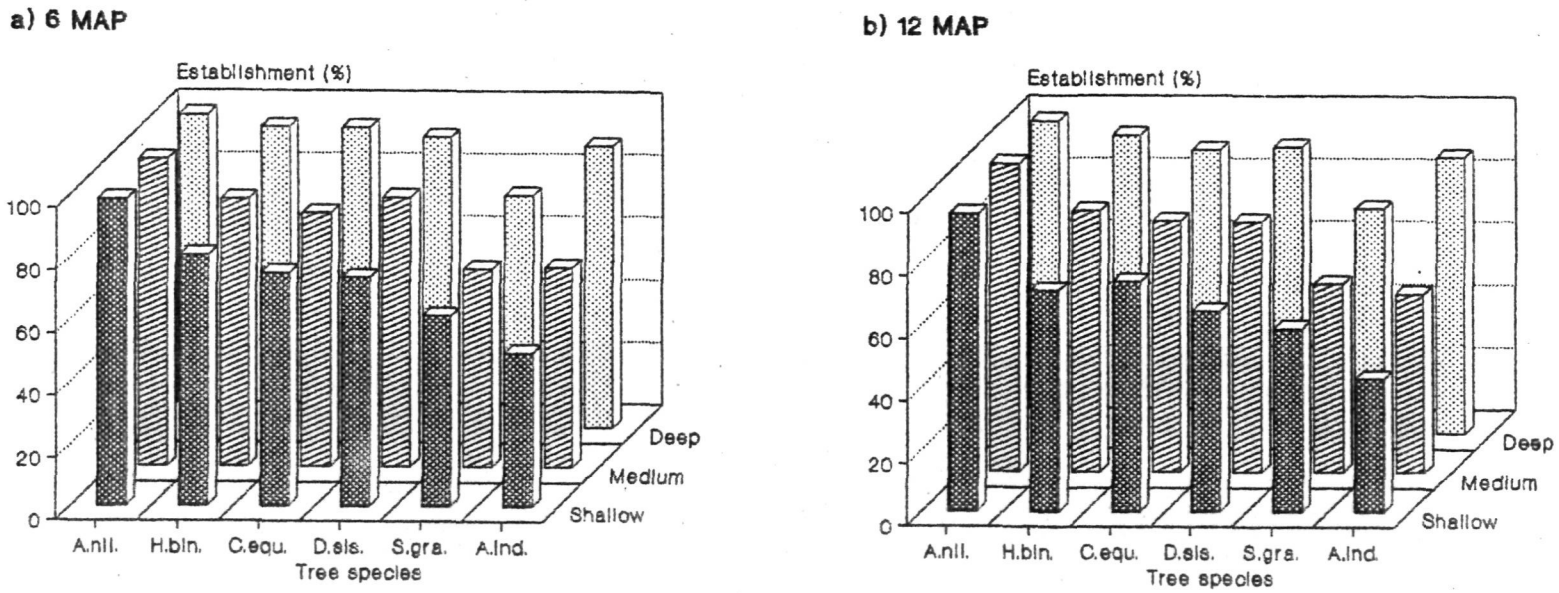


Fig. 11 Effect of water table on establishment of tree species

table was accompanied by saline ground water (app 2 and 4), the confounded effects of aeration and osmotic stress had deleterious effects on saplings. Some exotic Australian tree species have been reportedly able to establish better via exclusion of Na^+ and Cl^- together with production of specialized roots (Van der Moezel *et al.*, 1988) and such mechanisms must have operated in *A. nilotica, C. equisetifolia and H. binata* as their establishment was found better than other species.

5.1.2.2. Height All tree species recorded better tree height when water table was deep but, decreased progresively as it became shallower. Both *D. sissoo* and *A. indica* were found sensitive as reduction in tree height was higher under shallow water table situations. Similar reaction to shallow water table conditions was noticed in case of *A. indica* which recorded well over 30 per cent reduction in tree height due to increasing water table. *Hardwickia binata* remained semi-tolerant to shallow water table condition as the reduction in height was lower than that of *D. sissoo*. The adverse effects of shallow and saline ground water table was due to restricted aeration and imbalanced nutrition causing decreased height in case of sensitive tree species. Influence

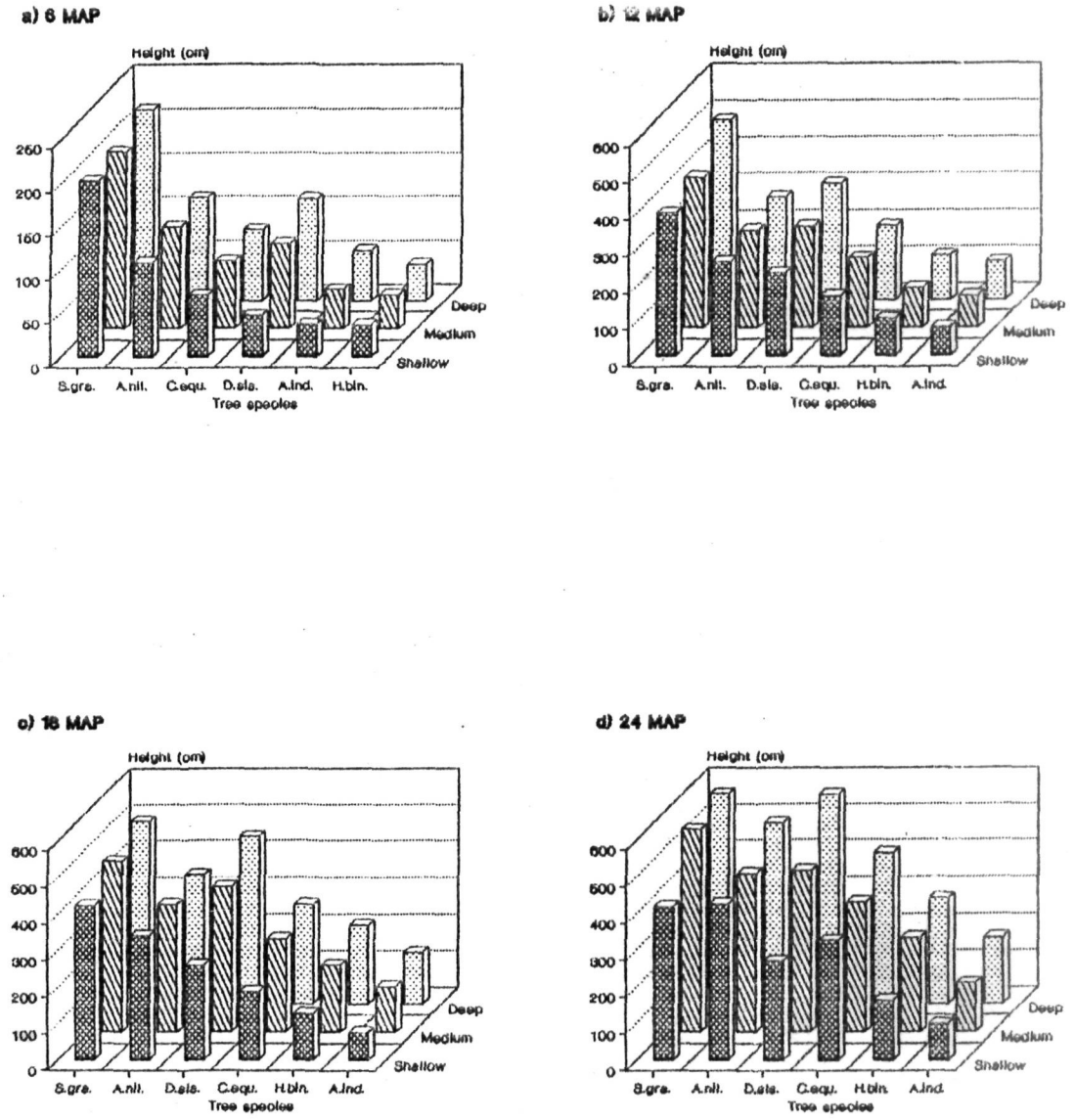


Fig. 12 Effect of water table on height of tree species

of water table on species such as *A. indica* and *C. equisetifolia* was minimal and were found to withstand shallow water table conditions. The reduction in height in case of *S. grandiflora* was comparable to *C. equisetifolia* indicating its potentiality to tolerate and grow under shallow water table conditions. These tolerant species (because of lower reduction in height) might have adopted to overcome the inevitable hostile conditions of waterlogging by maintaining low sodium and high calcium in leaf tissues. On the contrary, susceptible species had excessive absorption of sodium and magnesium from saline ground water which was predominated by neutral salts of sodium and magnesium. Relatively higher accumulation of sodium and magnesium compared to potassium and calcium impaired normal bio-chemical, physiological and metabolical functions of sensitive leaf tissues. Abrol (1986) and Tomar and Gupta (1985) have opined similar effects on the performance of *C. equisetifolia, A. nilotica* and *P. juliflora* under shallow water table/waterlogged conditions.

5.1.8.3 Number of branches:

The potentiality of trees to bear branches was reduced under shallow water table conditions. But magnitude of decrease in production of branches differed amongst tree

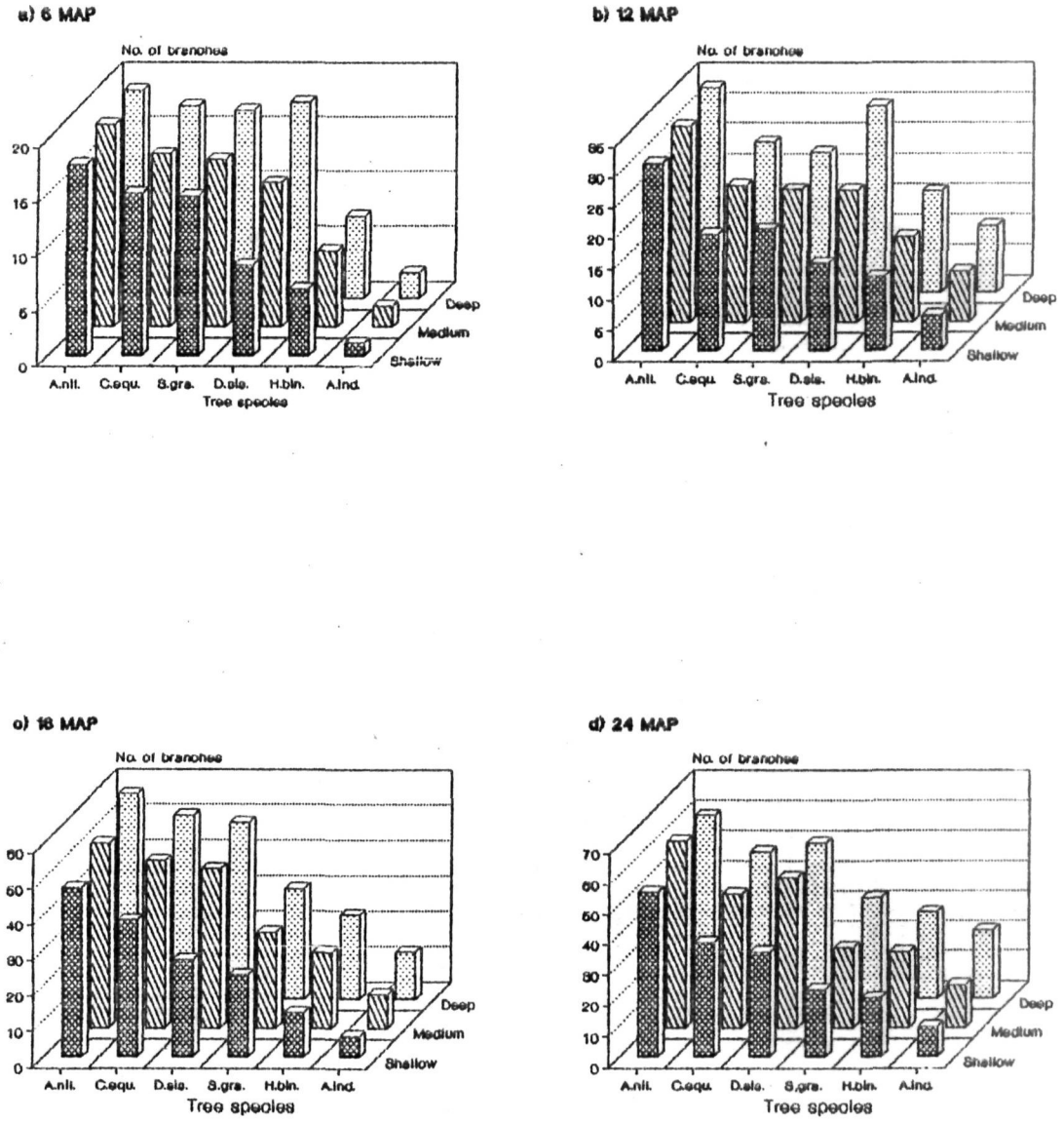


Fig. 13 Effect of water table on number of branches of tree species

species. Species such as *A. indica* had suffered to a greater extent as water table rose and reduction was over 50 per cent. This clearly demonstrated its vulnarability to waterlogging. Species which remained comparable to *A. indica* was *D. sissoo* which recorded a similar (over 35 per cent) reduction in branching ability. The restricted growth and branching ability under shallow water table conditions was because of higher salinity of both soil and ground water (app. 4). A higher soil salinity accompanied by higher salinity of ground water affected these susceptible species to greater extent by way of imbalanced nutrition as reflected by the differences in ionic composition of leaf tissues. *Acacia nilotica* and *C. equisetifolia* were categorised as tolerant to waterlogging as they recorded a marginal reduction in number of branches. Tomar and Gupta (1988) have also reported similar promising growth of both *A. nilotica* and *C. equisetifolia* under saline soils with shallow and saline ground water. The weak association (fig. 29 a-f) observed between soil solution sodium and magnesium with leaf composition in tolerant species like *A. nilotica* and *C. equisetifolia* suggested the possible operation of ion exclusion mechanisms in these species while in susceptible ones like *A. indica* and *D. sissoo*, the association which remained stronger indicating absence of such

regulatory mechanisms. So the excessive accumulation of sodium and magnesium without regulation might have affected performance of trees.

5.1.2.4. DSH; As observed in case of height and number of branches, stem diameter at collar height also decreased with rising saline ground water. Though there was reduction in all the tree species, the extent of reduction varied between species. Stem diameter of *A. nilotica* reduced only marginally (arround 10 per cent) indicating adoptability to shallow water table situations. A height reduction of 31 per cent was, however, noticeable in case of *S. grandiflora* and *C. equisetifolia* when observed 6 and 12 MAP, respectively. All the three species viz, *A. nilotica, C. equisetifolia* and *S. grandiflora* were thus, grouped as tolerant for shallow water table/waterlogged situations. Better growth of *A. nilotica* was due to selective absorption of higher potassium and calcium from saline soils and ground water and thereby maintained lower level of Na/K and Ca/Mg ratio. In addition, correlation between soil and tissue sodium concentration were also lower in *A. nilotica* suggesting exclusion of sodium from absorption. But in case of *C. equisetifolia* it remained exception to this phenomenon as it had higher ratios of Na/K

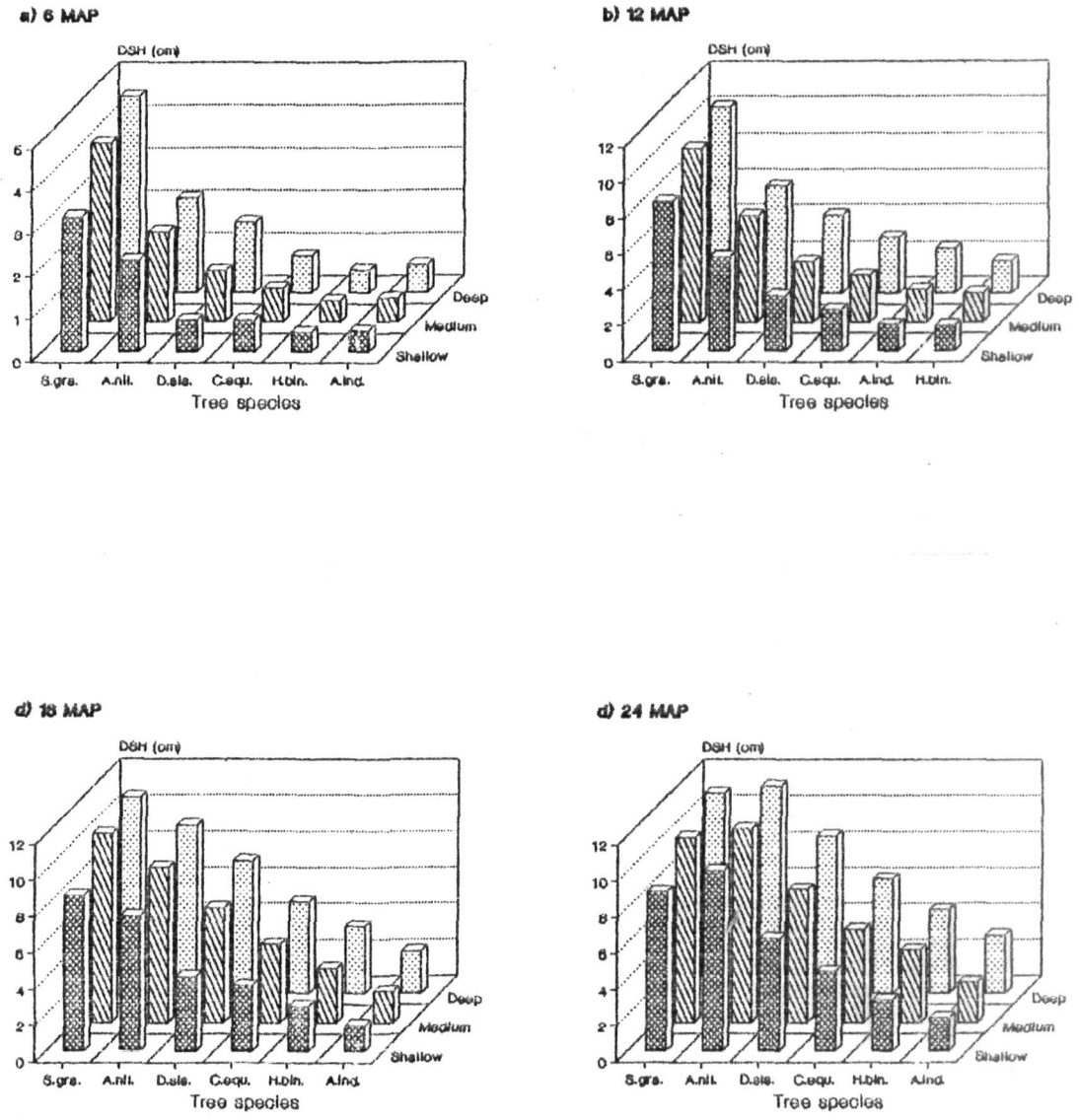


Fig. 14 Effect of water table on DSH of tree species

in tissues. The better performance of this species despite maintaining higher Na/K was possibly due to better physiological mechanisms and adoption to tolerate accumulation of sodium. Similar, normal growth with marginal reduction in collar girth of *C. equisetifolia* and *A. nilotica* were observed by Bandopadhyay (1986) and Grewal and Abrol (1986) and (1987).

5.1.2.5 DBH; None of the species were tall enough to record DBH 6 MAP. *Azadirachta indica* and *H. binata* were slow growers and did not grow taller than 130 cm even 24 MAP. Other species which did attain this height 12 MAP which made possible to record the observations and therfore results pertaining to these are discussed.

Stem diameter at breast height was higher under deep water table conditions and became lower as water table rose. As observed in case of other parameters, effect of water table on DBH in case of *A. nilotica* and *S. grandiflora* remained minimal but was higher in case of *C. equisetifolia* under Shallow water table conditions. The factors that affected the DSH also remained true for DBH because of their close relationship. AS usual, poor performance of *D. sissoo* was observed with higher reduction in DBH values. *Dalbergia*

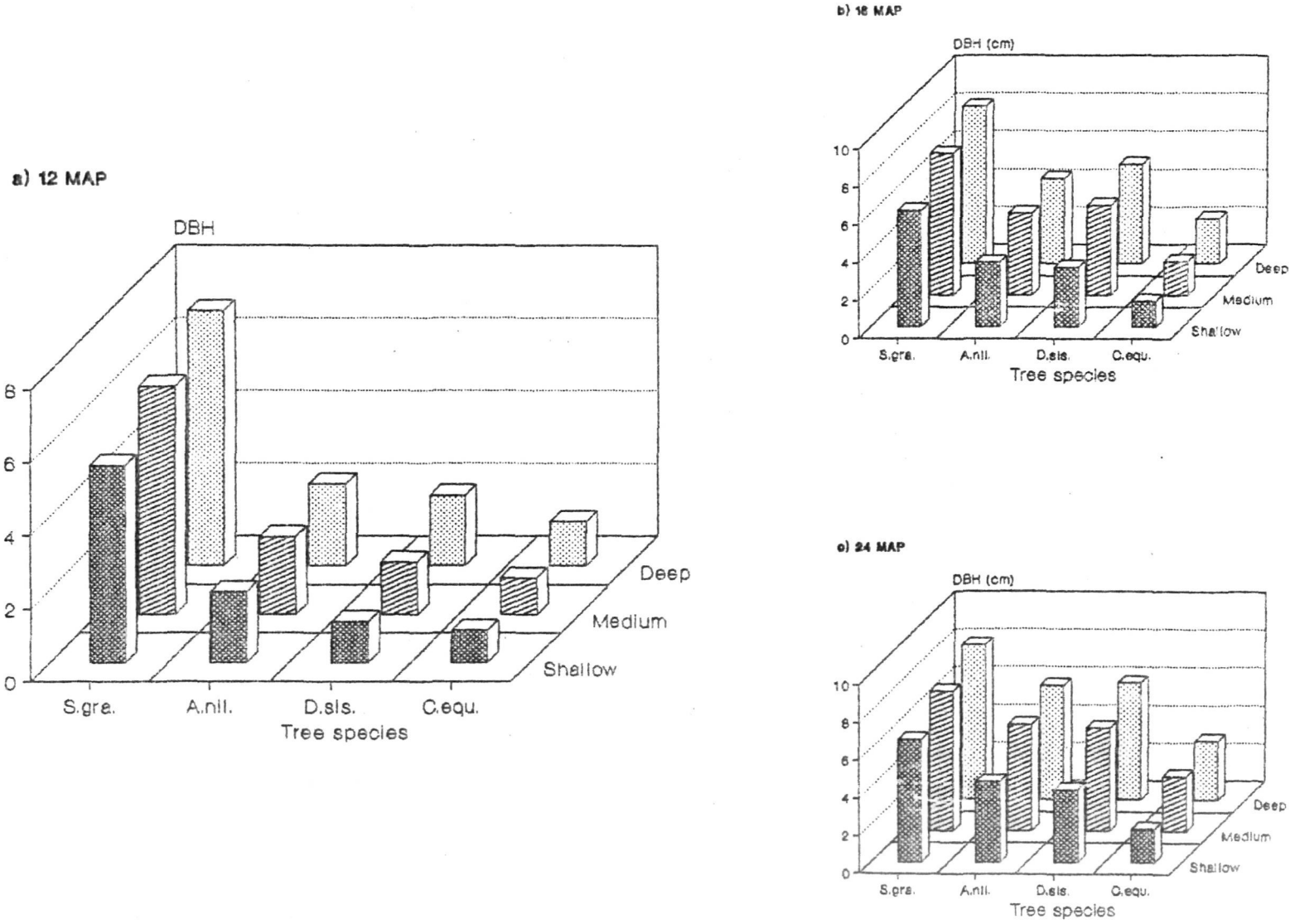


Fig.15 Effect of water table on DBH of tree species

sissoo appeared not a suitable species for shallow and saline ground water situations . Its inability to avoid uptake of sodium and imbalanced nutrition as well as accumulation of ions in its tissues might have affected metabolical and physiological functions resulting in poor performance. Higher values of DBH in case of *A. nilotica* and *S. grandiflora* indicated their higher tolerance to waterlogging or shallow watertable. *Acacia nilotica*, although, was exposed to saline ground water, ionic ratios of leaf tissue were maintained without affecting normal physiological functions under waterlogging. Similar results depicting the effects of shallow water table was also reported by Bandopadhyay (1988) in case of *Eucalyptus* hybrid.

5.1.2.6 Pruned bio-mass: Influence of shallow water table on pruned bio-mass was similar to those observed in case of height, number of branches and DSH because pruned bio-mass is a function of other growth parameters. Reduction in any of the growth parameters would cause a proportionate decrease in pruned bio-mass of trees. The decrease in pruned bio-mass production at shallow water table conditions differed to large extent between different tree species and reduction due to waterlogging was as low as 12 and 9 per cent in *A. nilotica*

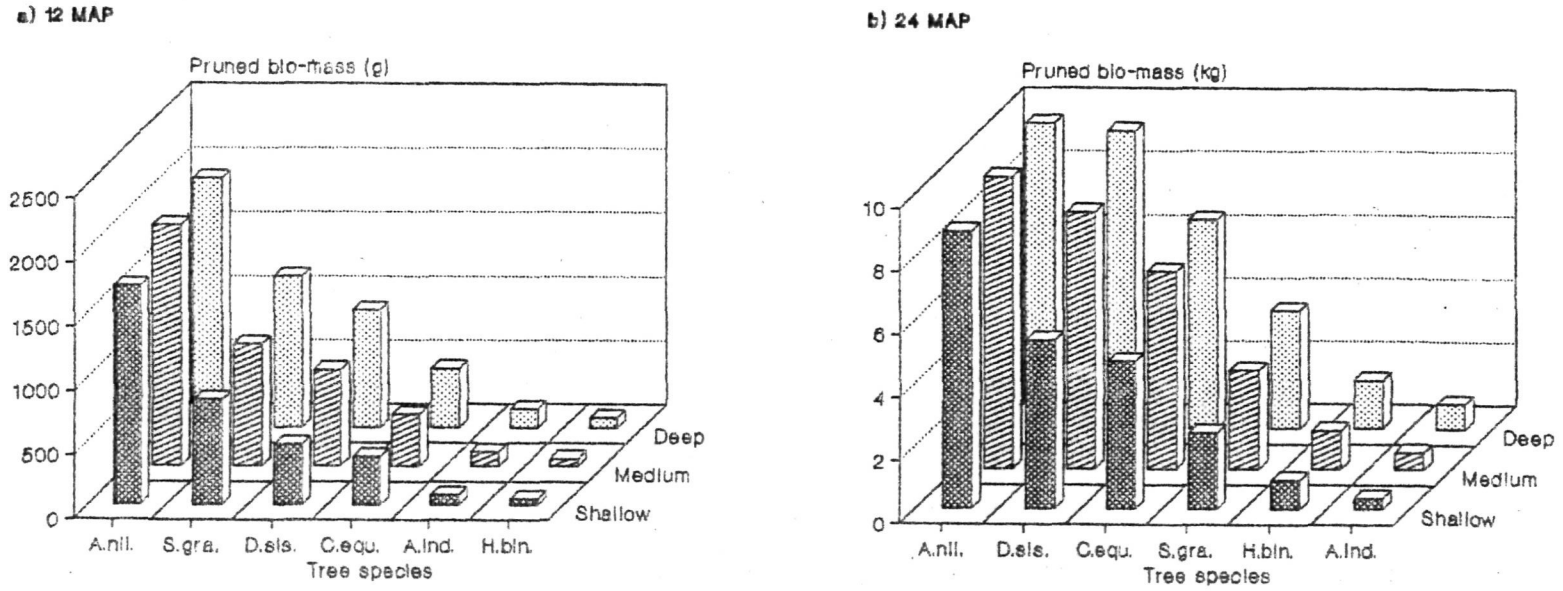


Fig. 16 Effect of water table on pruned bio-mass of tree species

and 18 and 29per cent in *C. equisetifolia* when observed 6 and 12 MAP indicating their tolerance to waterlogging conditions than other species. The continued better performance of *A. nilotica* and *C. equisetifolia* was due to only marginal decrease in height, number of branches and DSH and thereby recorded higher bio-mass yield, under shallow water table conditions. *Sesbania grandiflora* and *H. binata* closely followed *A. nilotica* and *C. equisetifolia* with respect to reduction in pruned bio-mass under shallow water table. Other species such as *D. sissoo* and *A. indica*, however, recorded higher order of decrease in height, number of branches, DSH and DBH resulting insignificant reduction in pruned bio-mass yield when water table remained shallow. This large decrease in pruned bio-mass justified their poor performance and susceptibility to high water table conditions due to disruption of normal physiological and bio-chemical process of plants under salt and aeration stress. Tang and Kozlowaski (1984) found that *Ulmus americana, Fraxinus, Pennsylvania, Melaleua quinaqenervia* and *E. camaldulensis* withstood higher aeration and salinity stress than *C. glauca* and *P. halepensis*. These observations were based on reduction in bio-mass yield recorded under stress conditions.

5.1.2.7 Crown width: Effect of waterlogging differed to a greater extent in reducing crown width of tree species. Nonetheless, no species was spared and all recorded decreased growth. It was again *A. nilotica* and *S. grandiflora* which recorded lowest reduction in crown width when water table was closer to surface. *Sesbania grandiflora* recorded 21, 13, 17 and 23 per cent decrease in crown width when observed 6, 12, 18 and 24 MAP, respectively and the corresponding reduction in *A. nilotica* were 21, 16, 19 and 11 per cent. The species which were found better suited than others was due to modification in their physiological and bio-chemical processes to suit new edaphalogical properties. Species which recorded higher reduction in height and number of branches also had larger reduction in crown size because it depended on both height and numberof branches. *Azadirachta indica* and *D. sissoo* recorded a reduction of more than 50 per cent confirming their susceptibility to shallow water table conditions. *Hardwickia binata* was also found sensitive to waterlogging stress as the decrease was of fairly higher order when water table was closer to surface. Tomar and Gupta (1985) observed similar performance of *C. equisetifolia T. articuleata* and *P. juliflora* compared to *A. auriculaeformis, T. arjuna* and *Leucaena leucocephala* under shallow ground

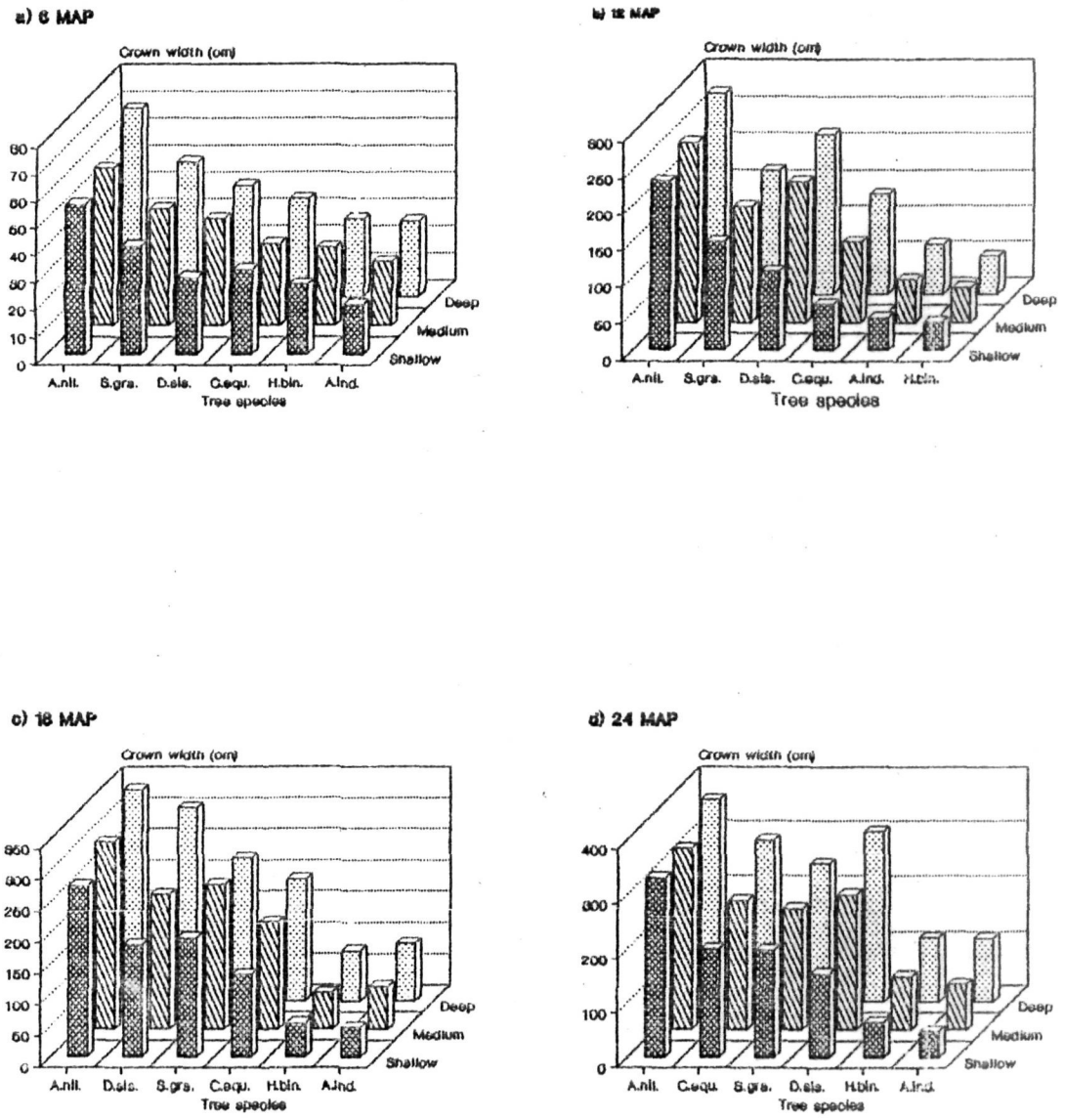


Fig. 17 Effect of water table on crown width of tree species

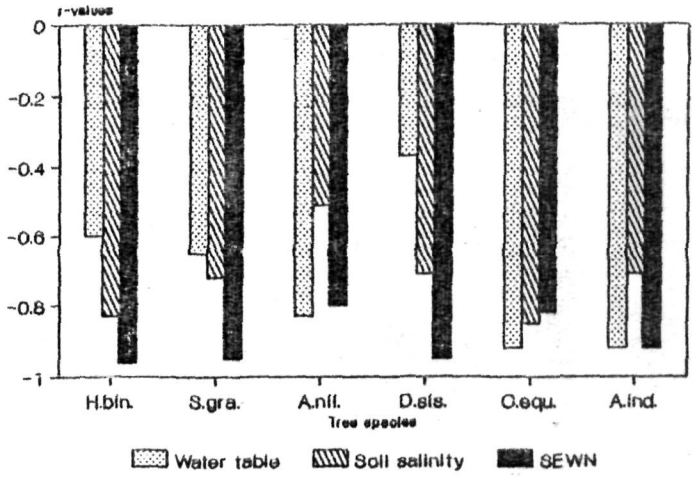
water table conditions. The waterlogging and aeration stress further slowed the growth of *A. indica* and *H. binata* making them unsuitable for waterlogged situations.

Overall growth behaviour of trees under shallow and saline ground water revealed that *A. nilotica* was the best species followed by *S. grandiflora* and *C. euisetifolia.* Except lower establishment, *S. grandiflora* was found inferior to none except *A. nilotica.* The species such as *H. binata* appeared better species compared to *A. indica* and *D. sissoo.* Waterlogging or aeration stress had inflicted a largest growth reduction in *D. sissoo* and *A. indica* than in any other species indicating their poor performance

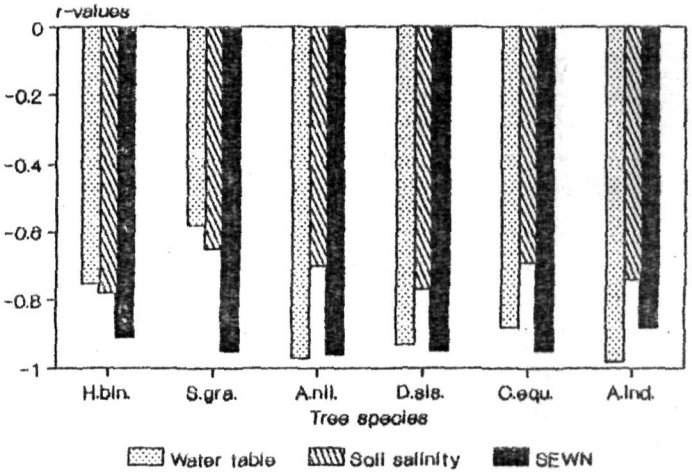
5.2. Effect of SEWN on tree growth parameters.

The confounded effects of soil salinity and water table refered to as SEWN was related to the performance of tree species. The relation between salinity, water table and SEWN gave a significant inverse relation between SEWN and growth parameters than soil salinity or water table when examined individually (table 18). In reality trees experienced both salinity and restricted aeration due to shallow water table together rather than alone. The confounded effects of these, thus, gave better indication than

a) Plant height



b) DSH



c) Crown width

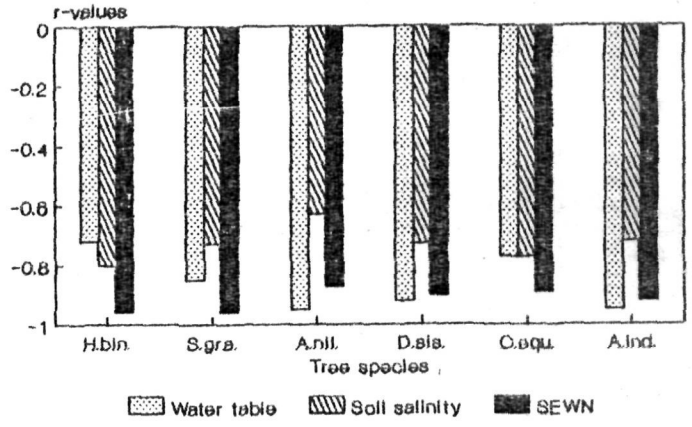


Fig.18:Relationship between tree growth and various stress parameters(24 MAP)

when they were related individually. Since this concept is newly introduced, the literature showing the efect of SEWN on tree growth parameters are not available. However, the literature on effect of salinity and water table are quoted in support of SEWN in this chapter.

5.2.1 Establishment: Like salinity and shallow water table, SEWN had also detrimental effect on establishment. With increasing SEWN, sapling mortality of all the tree species increased (Table 19) but there was variations between the species. Influence of SEWN remained marginal in *A. nilotica* closely followed by *H. binate* and *C. equisetifolia* due to their specialized root system to overcome the effects of SEWN. A similar marginal decrease in establishment of *C. obesa* was observed by Van der Moezel *et al.* (1988) under stress due to Waterlogging and Salinity. In contrast, *S. grandiflora* and *A. indica* recorded poor establishment both at lower as well as higher SEWN values due to their genetic character. However, *S. grandiflora* once established did register better growth parameters and remained comparable to *A. nilotica* and *C. equisetifolia*. *Sesbania grandiflora* recorded only 62.7 and 53.3 per cent against 49.0 and 43.6 per cent observed in case of *A. indica* when SEWN rmained more than 500 at 6 and 12 MAP

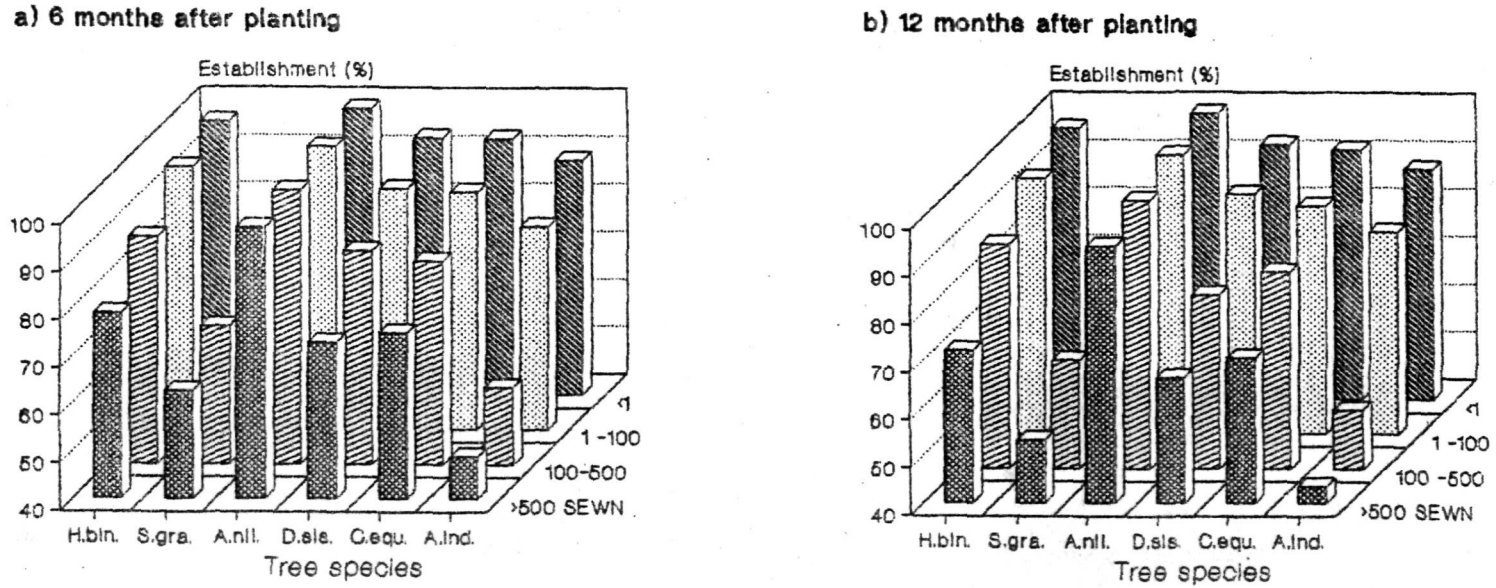


Fig. 19 Effect of SEWN on establishment of tree species

exibiting their susceptibility to SEWN. The species *D. sissoo* had higher establishment and decreased significantly due to increasing SEWN. The unsatisfactory performance of *S. grandiflora , A, indica* and *D. sissoo* at higher SEWN suggested extra measures needed at the establishment phases of species. In the absence of tolerance mechanisms such as ion exclusion and specialized root production, susceptible species suffered due to aeration and salt stress registering lower establishment. The adverse effects of SEWN on susceptible species such as *A. indica* and *D.sissoo* was further indicated by a significant inverse coefficient of correlation between SEWN and establishment (App. 5b). Roy *et al.* (1987) observed similar poor establishment in *D. sissoo* under saline conditions. Hebbara *et al.* (1992) on contrary, reported better establishment of *D. sissoo* under saline and shallow watertable conditions.

5.2.2 **Height:** Effect of SEWN on height was found similar to that of salinity and water table. Tree species differed to a great extent in their reaction to increasing SEWN (Table 20). Amongst species, *A. nilotica* appeared more tolerant to these confounded stresses (SEWN) because of lower reduction in height and the reduction was in the order of around 10 per

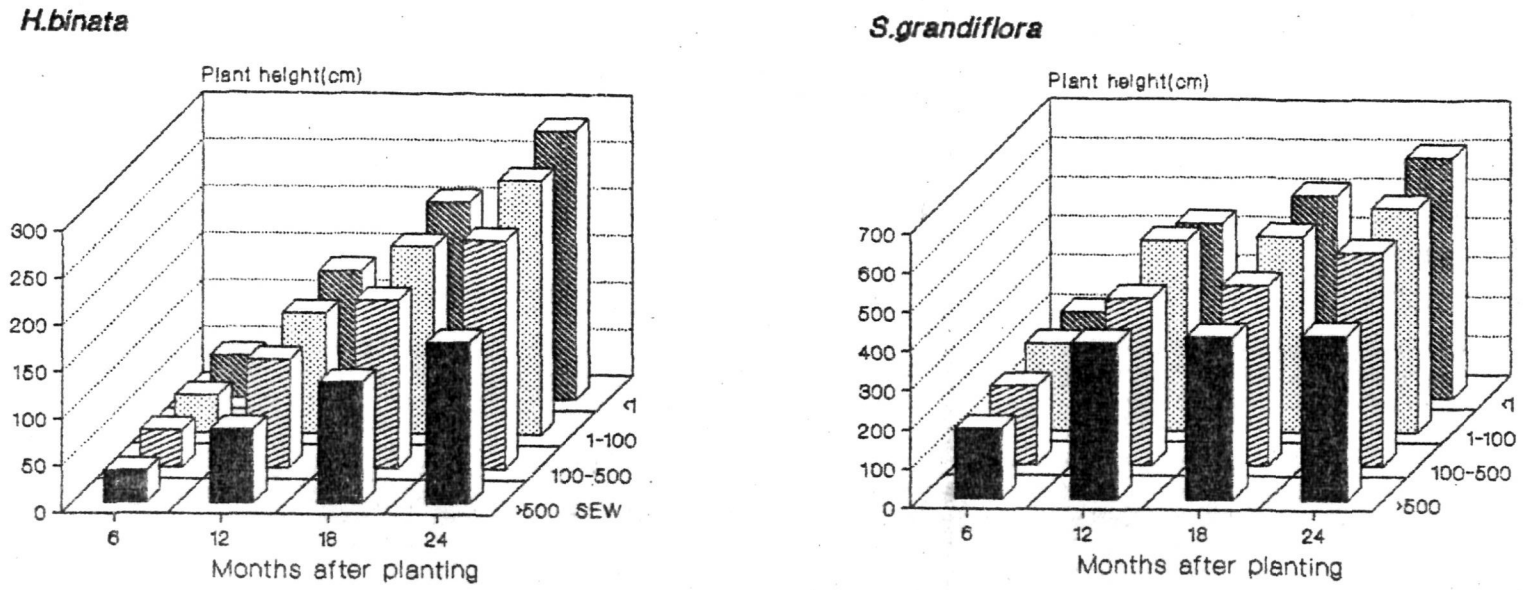


Fig.20 a) Effect of SEWN and time on height of tree species

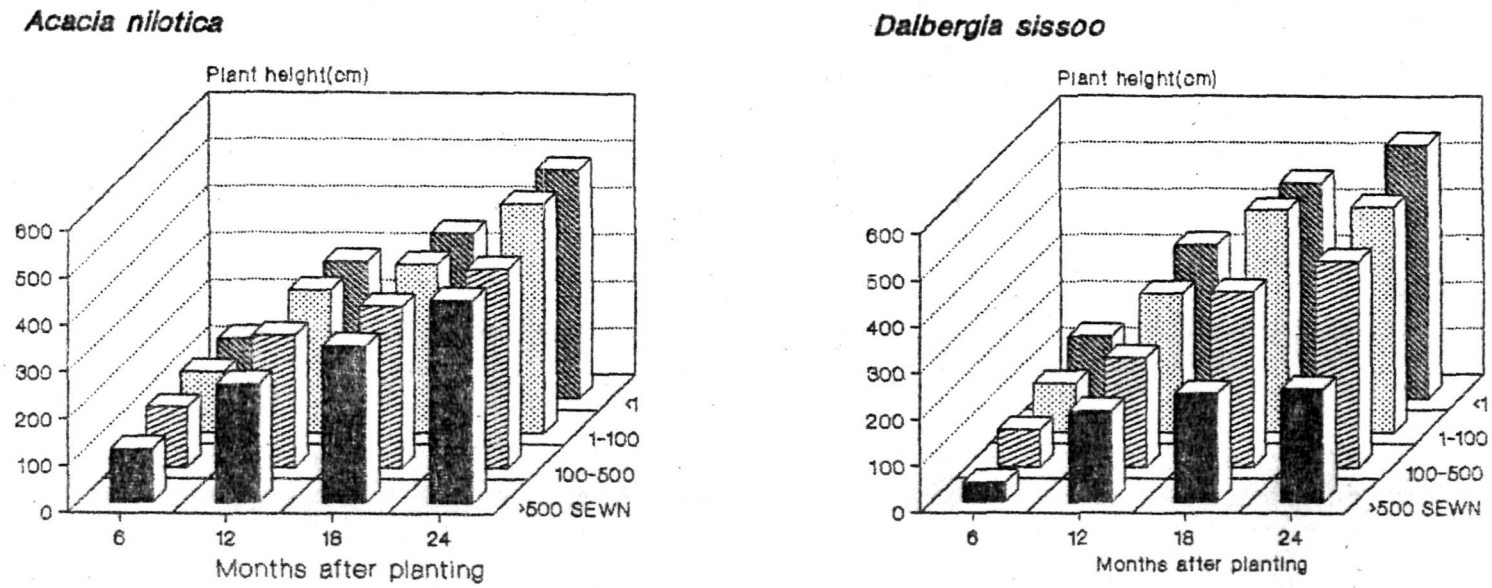


Fig.20 b) Effect of SEWN and time on height of tree species

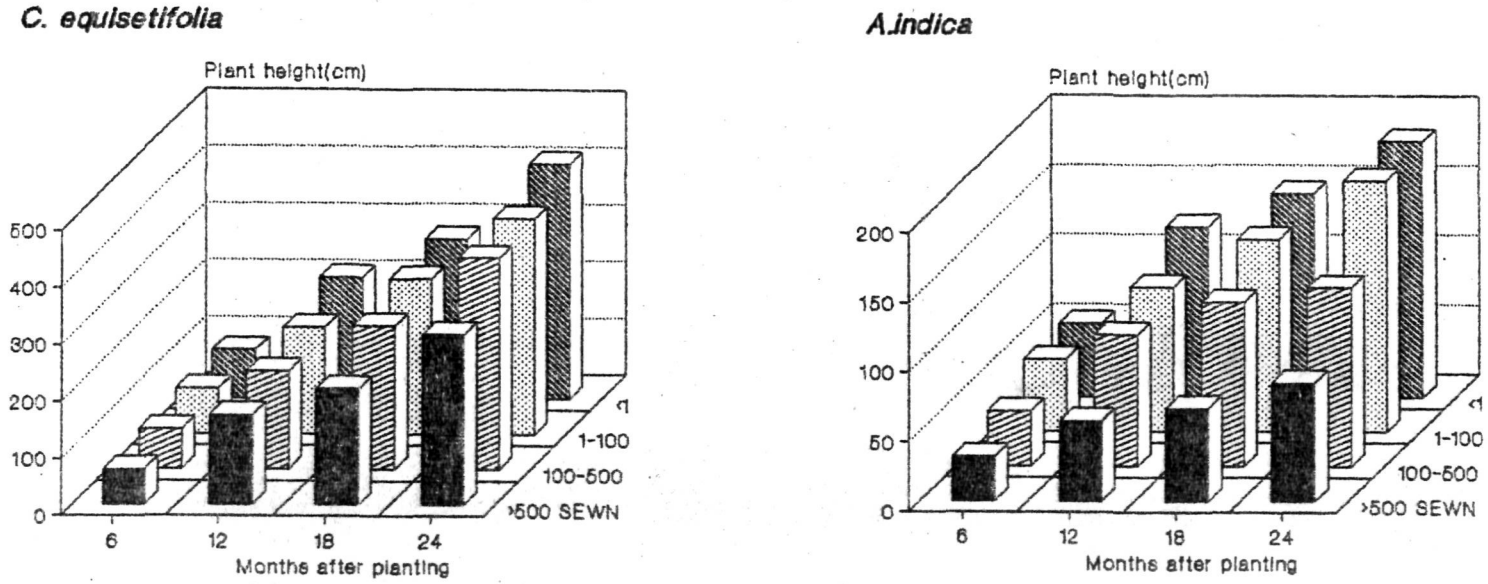


Fig.20 c) Effect of SEWN and time on height of tree species

cent despite when SEWN remained more than 500. This was mainly due to the regulatory mechanisms operated in this species to maintain Na/K ratios in tissues so that it did not affect balanced nutrition. Jeschke and Stellar (1983)also observed preferential absorpiton of K over Na in Garden orache. Despite maintaining highr Na/K ratio in leaf tissue, *C. equisetifolia* did not suffer much due to adoption to a higher levels of leaf Na by way of re-translocative mechanisms within the plants to maintain a desirable ionic balance. Similar observations leading to adoption of *Casuarina* spp. to higher sodium has been reported by Clements, *et al.* (1983). Karchan (1966) also recorded higher degree of tolerance of *C. equisetifolia* with lower decrease in height. On the contrary, Bhargava (1951) found *P. juliflora* and *A. indica* as better species than *C. equisetifolia* for salt-affected soils of Madhya Pradesh. In case of *D. sissoo,* reductin in height was 68, 40, 49 and 55 per cent while, *A. indica* recorded 39, 53, 54 and 54 per cent decrease when observed 6, 12, 18 and 24 MAP exibiting their poor growth when SEWN values were higher. Both species had higher Na/K ratios in leaf tissues and presence of higher sodium in leaf tissue might have affected ionic balance in the species unlike *C. equisetifolia* resulting in poor growth. In support of this, we observed a highly

significant inverse relationship between height and SEWN in case of *A. indica* (-0.92**) and *D. sissoo* (0.95**) as compared to *A. nilotica* (-0.80**) and *C. equisetifolia* (-0.82**) confirming their susceptibility to increasing SEWN values (Ap. 5(b). Results showing poor growth of *A. indica* and *D. sissoo* under the combined stress have been reported by Pande (1956) and Abrol (1986). In contrary to these reports, Khan (1962), however, reported that *A. indica* and *D. sissoo* were tolerant to salinity. But, our observations confirms the results of farmer workers.

5.2.3 Numbr of branches: Irrespective of the species, all recorded reduction in number of branches, (tabe 21). However, reaction of the species to varyng SEWN values varied. Amongst the secies, *S grandiflora, A, nilotica* and C. *equisetifolia* registered only marginal decrease while, *A. indica* and *D. sissoo* recorded higher reduction in branches with increasing SEWN values. These obsevation led to the impression that *A. nilotica, C. equisetifolia* and *S. grandiflora* continued to register only a marginal reduction in number of branches like in case of height. This was mainly due to better root proliferation and selective ion absorption mechanisms adopted by the species. Such adoptions of tree species to edaphalogical changes especially in case of *C.*

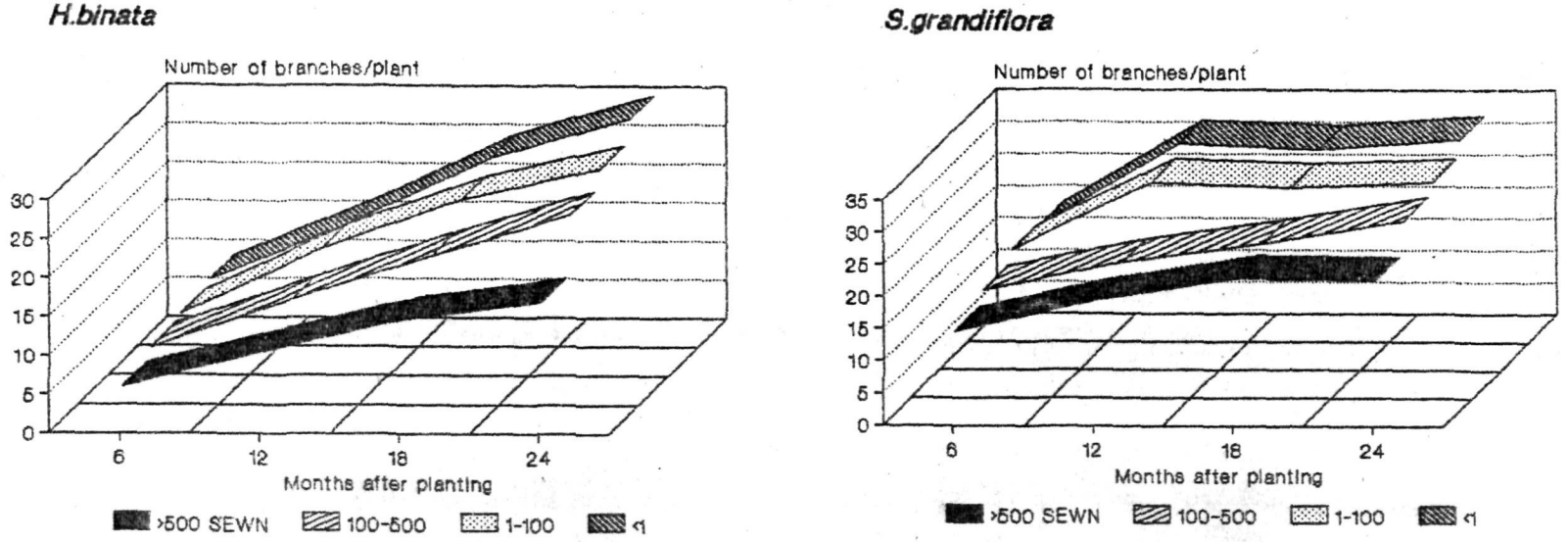


Fig.21 a) Effect of SEWN and time on number of branches of tree species

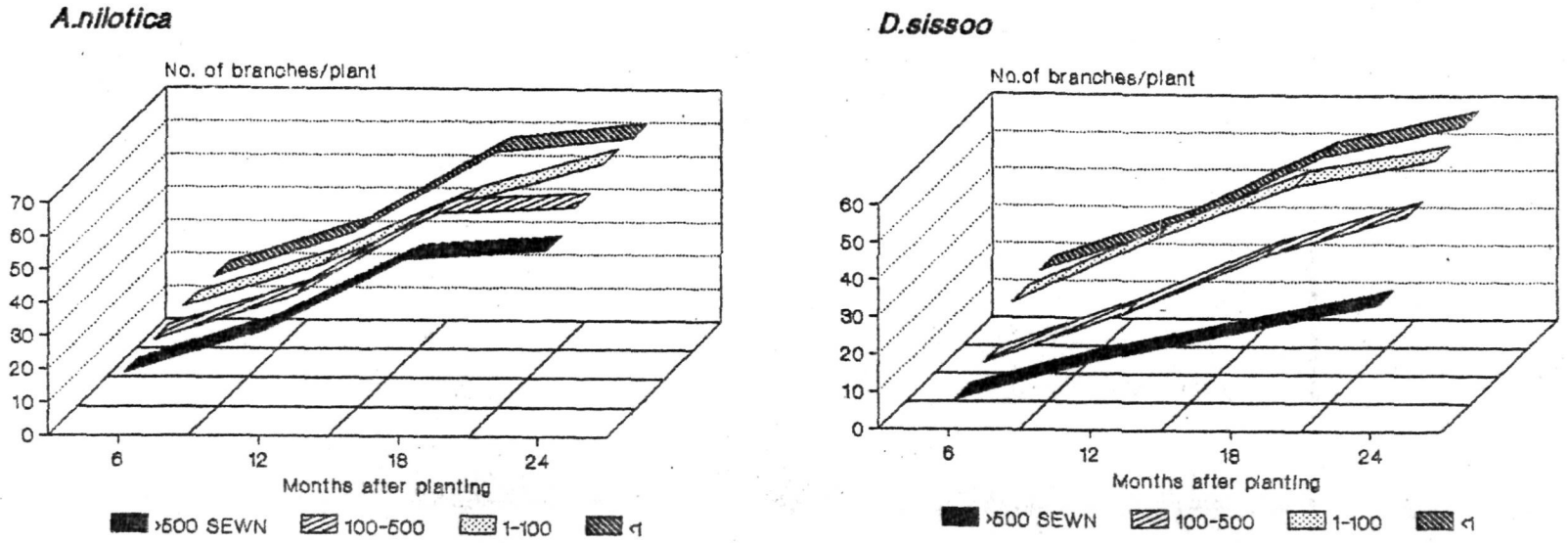


Fig.21 b) Effect of SEWN and time on number of branches of tree species

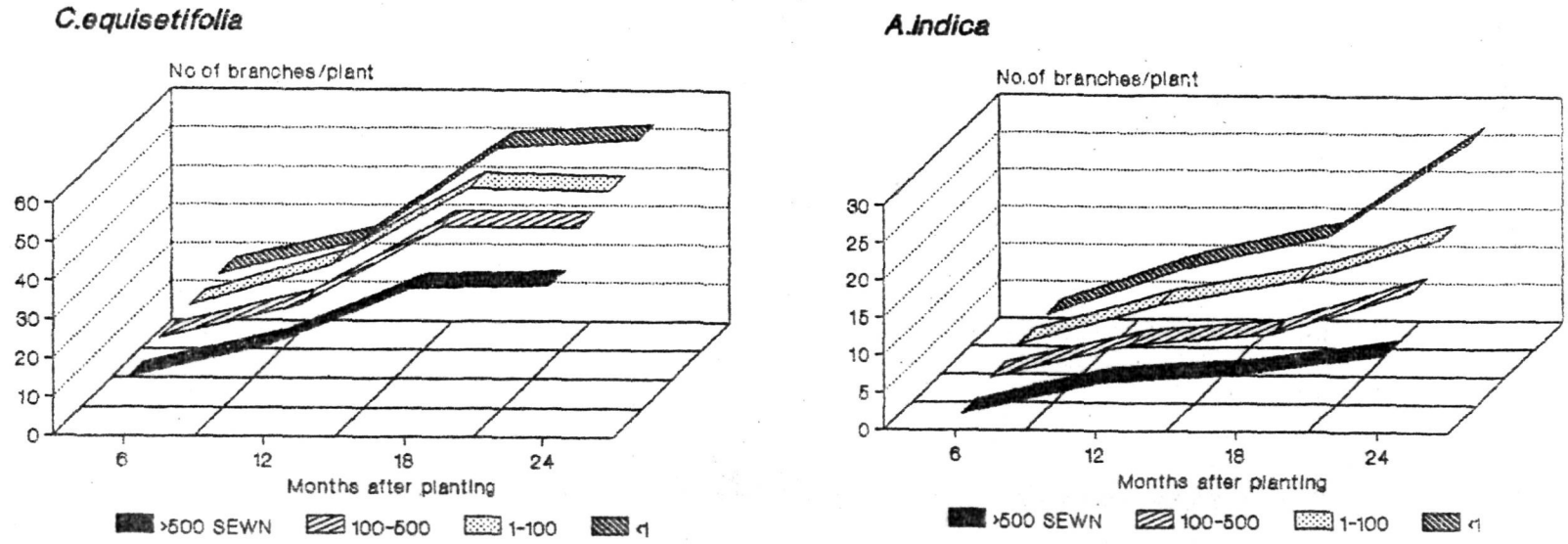


Fig.21 c) Effect of SEWN and time on number of branches of tree species

equisetifolia has been reported by Clements *et al.* (1983) and Tomar and Gupta (1987). A lower significant relation between soil solution and tissue sodium in *A. nilotica* (0.65*) further suggested existance of such regulatory mechanism. In addition (fig. 29c) a inverse relation between number of branches and SEWN values in tolerant species such as *A. nilotica* (-0.87*) and susceptible ones like *D. sissoo* (-0.96*) confirmed such mechanisms. On the other hand, the poor performance of *A. indica* and *D. sissoo* at higher SEWN values was due to the absence of such rgulatory mechanisms in ion uptake as revealed by a significant correlation between soil solution and tissue sodium leading to ionic imbalance in leaf tissues. This observation was further supported by their higher Na/K and lower Ca/Mg ratios (Table 27 and 28) in leaf tissues. Similar observations on performance of *A. indica* under waterlogged and salt sress conditions was made by Tomar and Yadav (1980).

5.2.4. DSH: Reaction of species to SEWN values differed to a larger extent based on their inherent genetic diffences. Species such as *A. nilotica, S. grondiflora* and *C. equisetifolia* exibited better performance in terms DSH against combined stress of SEWN. Amongst *A. nilotica, S. grandiflora* and *C. equisetifolia, A. nilotica* out performed

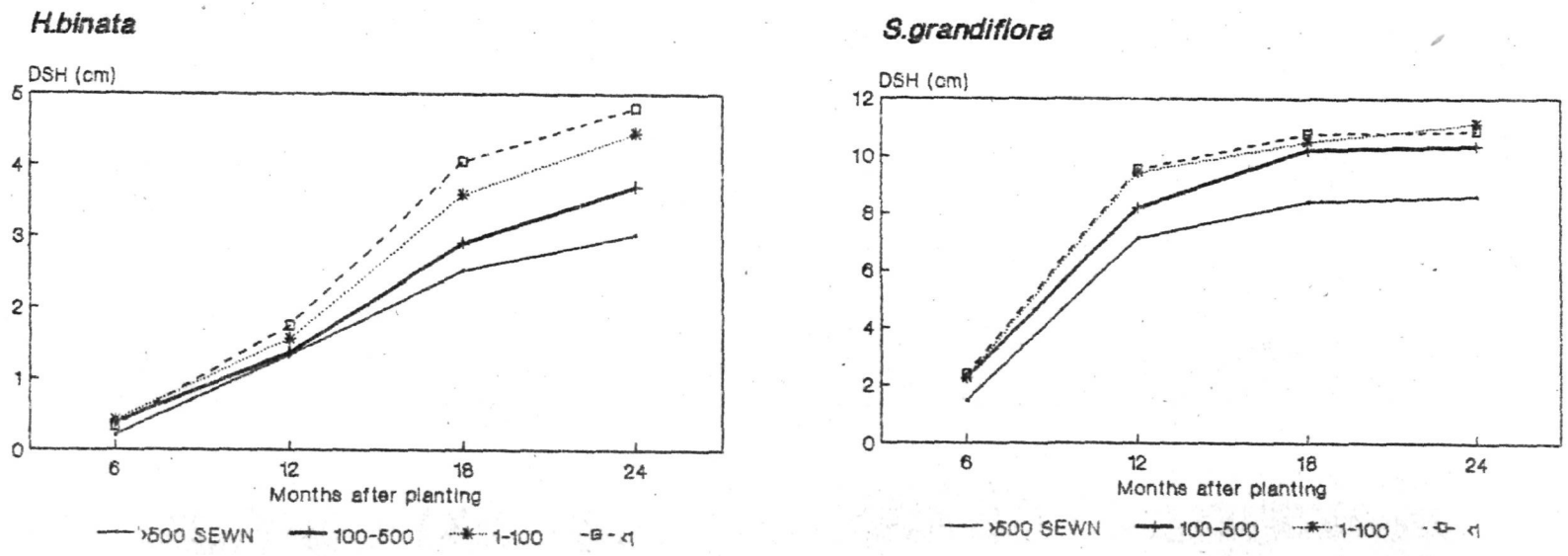


Fig.22 a)Effect of SEWN and time on DSH of tree species

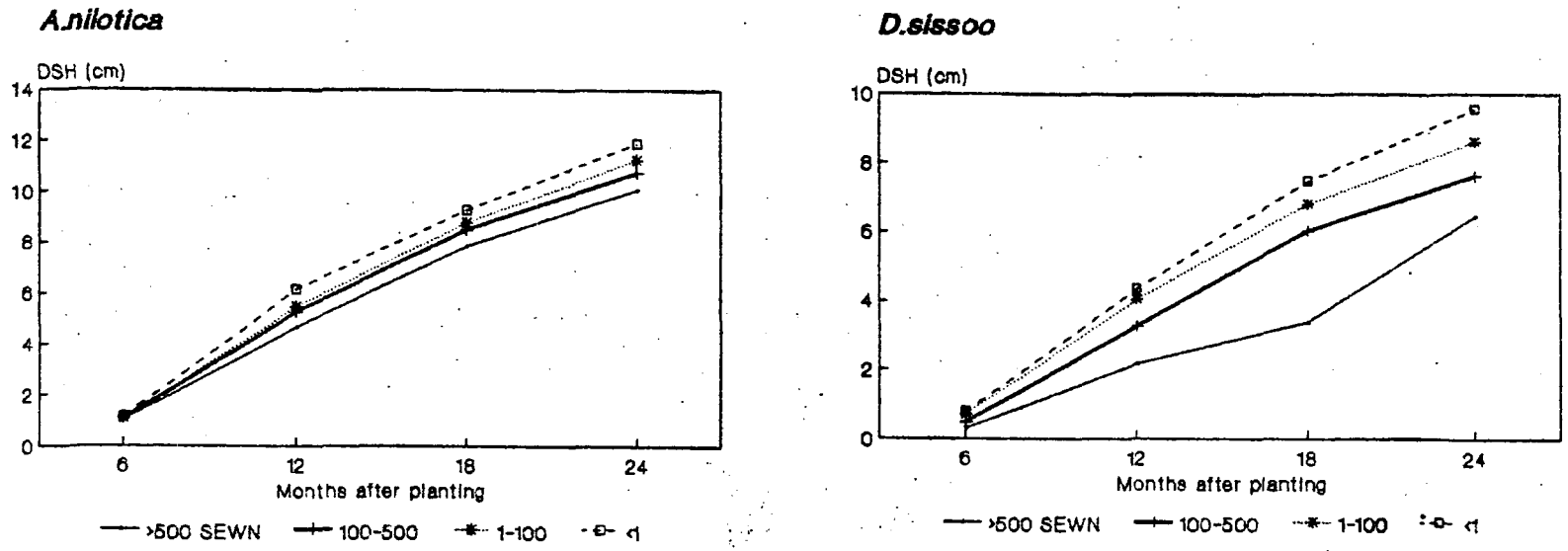


Fig.22 b) Effect of SEWN and time on DSH of tree species

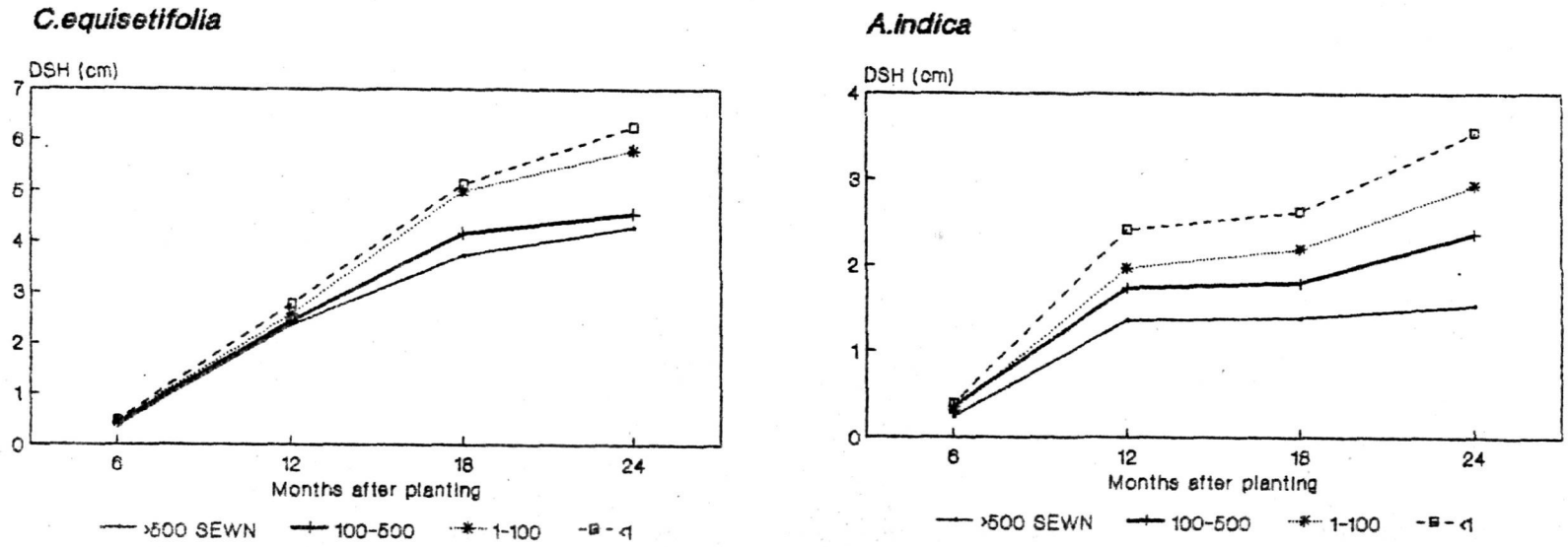


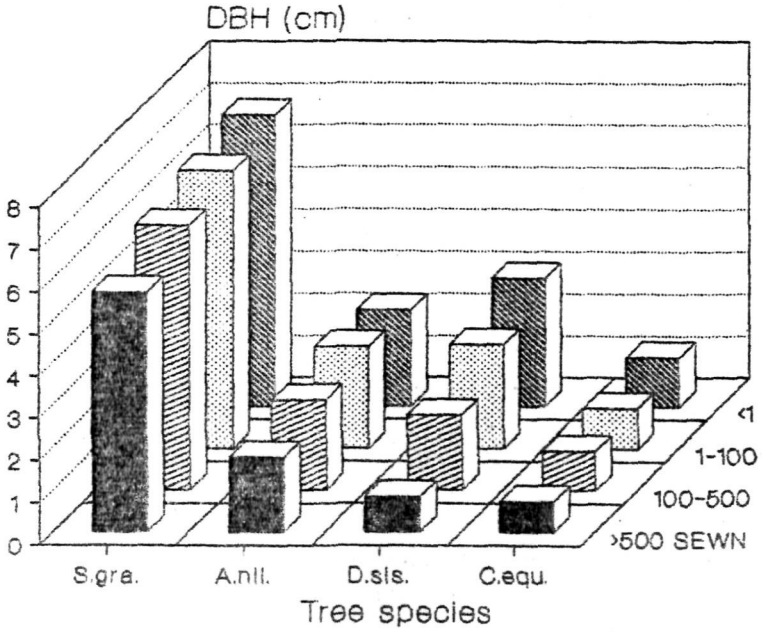
Fig.22 c) Effect of SEWN and time on DSH of tree species

other two as the reduction in DSH values remained arround 15-20 per cent when observed at different period of its growth and SEWN remained highr than 500. A lower reduction in DSH observed in case of *A. nilotica* and *C. equisetifolia* confirmed by the existance of a weak inverse relationship between SEWN and DSH. Bandopadhyay (1986) and Gerewal and Abrol (1986) and (1987) reported similar higher DSH values in case of *C. equisetifolia* and *A. nilotica*. Further, *A. nilotica* had lower sodium in their tissues as compared to potassium and type of this uptake patterns resulted in lower Na/K ratios whih was rather helpful for the species to avoid possible sodium accumulation and its related ionic imbalances. However, such a mechanism was not prevelent in case of *C. equisetifolia*. Despite having higher Na/K ratio, it registered higher DSH values but its better performance was due to its genetic and/or re-translocation mechanisms to over come excessive sodium absorbed by the species. Relation between soil solution sodium concentration and its uptake was significant to the extent of 5 per cent in case of *S. grondiflora* and *C. equisetifolia* (fig. 29 b and c). Selective accumulation of potassium in tolerant species was also noticed by Laurd and El-Lakany (1984).

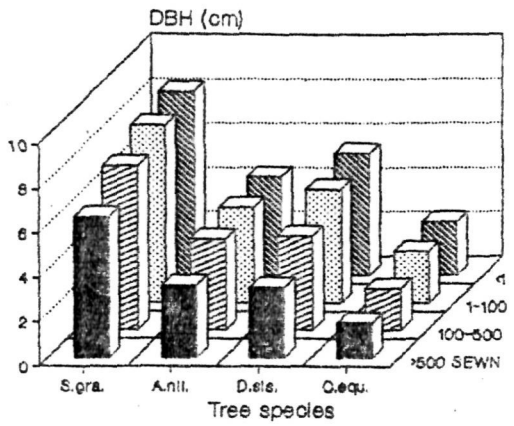
The species such as *D. sissoo* and *A. indica* which came under the influence of SEWN, DSH values decreased by more than 35 per cent resulting in poor performance. The reduced growth accompained by higher sodium and magnesium uptake relative to potassium and calcium led to higher Na/K and lower Ca/Mg ratios resulting in inonic imbalance and poor performance. *Hardwickia binata* also suffered to a larger extent due to SEWN. Poor performance of *D. sissoo* and *A. indica* was further confirmed by a strong and negative relation between SEWN and DSH (App. 5 b). Jain *et al.* (1983) observed retarded growth and collar diameter of *Dichrostachys glomerata* and *Tomarix articuleata* under saline and waterlogged soils and the results of this investigation are in confirmity with those of above workers.

5.2.5 DBH: As observed in case of DSH, SEWN appeared to have deleterious effects on stem diameter at breast height. It was *D. sissoo* which suffered the most since it recorded higher decrease in DBH. Though *C. equisetifolia* recorded marginal decrease in DSH values, its performance with respect to DBH was not satisfactory. Nonetheless, it apeared to be better than *D. sissoo*. Both these species had higher accumulation of sodium in their leaf tissues due to higher absorption of

a) 12 months after planting



b) 18 months after planting



c) 24 months after planting

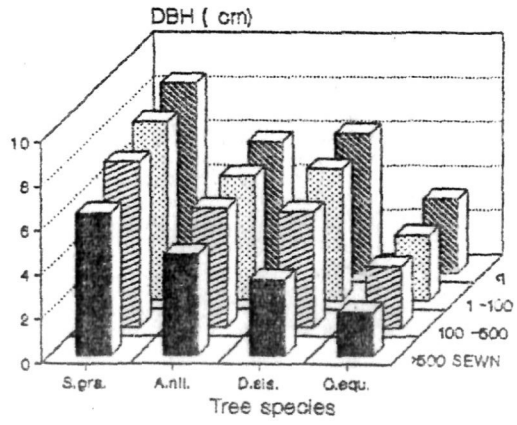


Fig.23:Effect of SEWN on DBH of tree species

sodium by the species. This was further confirmed by a significant and linear relationship between soil solution and leaf tissue sodium (fig 29 d and e). The increased sodium stress might be the cause for upsetting the ionic balance leading to failure of the species to put on optimum growth. Similarly Van der Moezal *et al.* (1988) reported requirement of higher K: Na ratio in leaves of *C. equisetifolia* for optimum growth. A significantly higher order of inverse relation between SEWN and DBH in case of *C. equisetifolia* (-0.94*) and *D. sissoo* (-0.89**) than *A. nilotica* (-0.58 NS) revealed their susceptibility to higher sodium and SEWN (App. 5 b). In contrast to these observations, El-Lakany and Laurd (1982) reported better growth of *C. equisetifolia* which was not affected by salinity and aeration stress but remained in agreement with those of Bhargava (1951). The better performance of *A. nilotica* and *S. grandiflora* was due to lower Na/K ratio in leaf tissue (Table 27). The lower level of significant relation (fig 29b) between soil solution and tissue chloride in *A. nilotica* (0.79**) compared to susceptible species revealed regulated absorption and its subsequent accumulation of chloride in tissues affecting growth only marginally. Tomar and Yadav (1985) Grewal and Abrol (1986) have made similar observations on *A. nilotica.*

5.2.6 **Pruned bio-mass:** As pruned bio-mass is depended on other growth parameters such as height, number of branches, and stem diameter at stump as well as breast height, any reduction in these parameters under influence of increasing SEWN values caused decreased bio-mass production. Based on pruned bio-mass yield, there was a striking difference between species when exposed to higher SEWN values. Species such as *A. nilotica* and *C. equisetifolia* registered no marked reduction in pruned bio-mass production while, *D. sissoo* and *A. indica* came under the deleterious effects. Reduction in case of *A. nilotica* was in the order of 18 and 12 per cent when observed 6 and 12 MAP, respectively. A lower osmotic potential and higher toxicity of predominant ions (Na or Cl) affected the performance of the species. The effect remained marginal as it regulated absorption of sodium, magnesium and chloride. The favourable performance of *A. nilotica* interms of bio-mass roduction has been reported by Tomar and Yadav (1985) and Gupta *et al.* (1986). In species like *D. sissoo* absence of regulative mechanism as observed in *A. nilotica* lead to the increased absorption and accumulation of sodium and chloride in tissue. A similar, reduction in pruned bio-mass production due to excessive accumulation of sodium and chloride in leaf tissue in case of *A. Saligna* has been

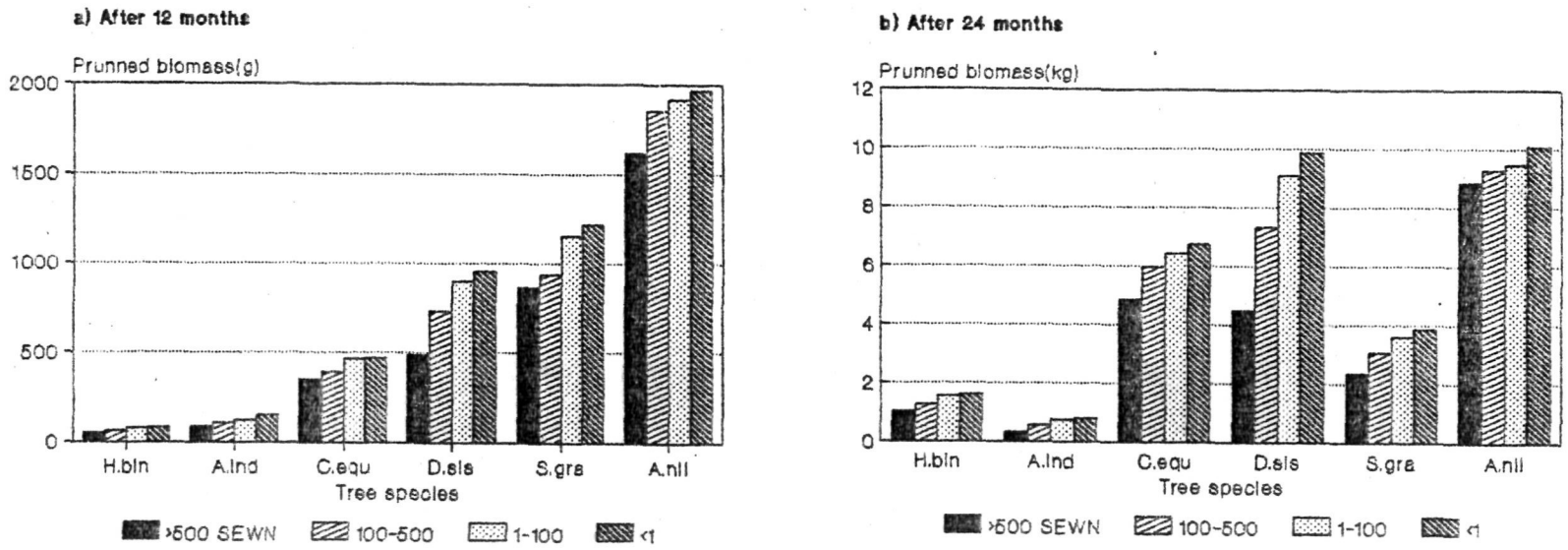


Fig.24 Effect of SEWN and time on prunned biomass of tree species

reported by Shaybany and Khashirad (1978). The performance of tree species like *H. binata* under the influence of stress like SEWN was not satisfactory because of higher per cent reduction in bio-mass. The slower growth habit of the species might have been further delayed by the stress. Despite maintaining relatively lower Na/K and Cl/S ratios, *H. binata* suffered possibly due to aeration stress more than salinity of the soil when SEWN values were higher.

5.2.7 Crown width: Because of variations in genetic character, the species differed in their response to SEWN. As SEWN increased, there was decrease in crown width of all the tree species due to sodium accumulation and decreased aeration created by shallow water table. Species which recorded marginal decrease in growth parameters also had little reduction in crown width. *Acacia nilotica* and *S. grandiflora* were the ones which fell into this category and were found tolerant. This lower reduction in crown width was attributd to the reasons already explained such as exclusion of sodium and chloride from absorption (table 27 and 29). Similar, observations on the performance of *A. nilotica* in terms of crown width has been reported by Totey *et al.* (1986), Gupta *et al.* (1991) and Yadav (1977). Performance of *C. equisetifolia*

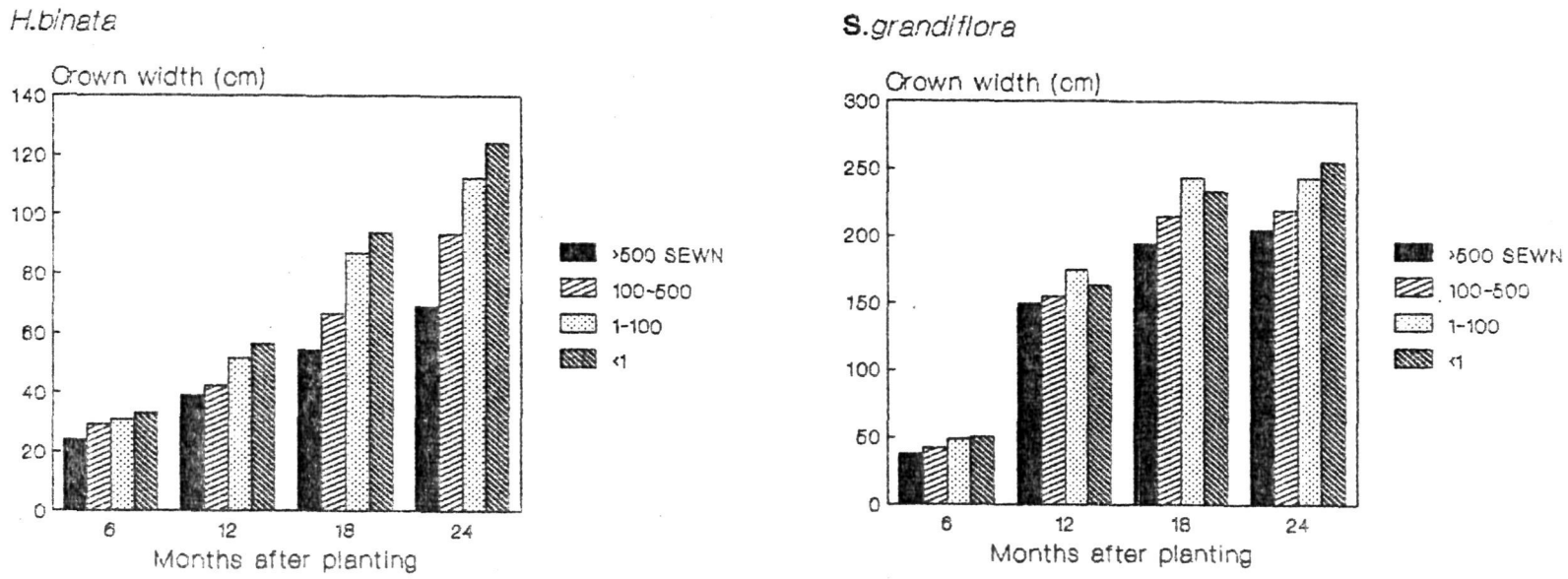


Fig.25a:Effect of SEWN and time on crown width of tree species

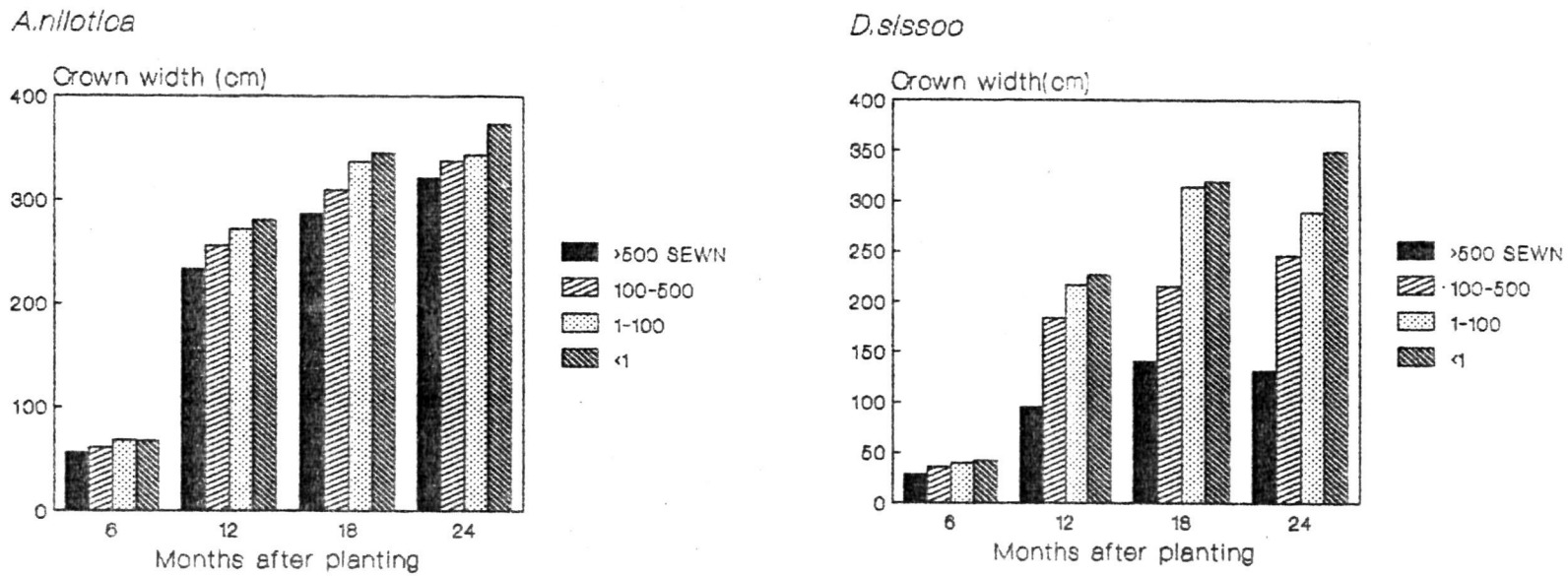


Fig.25 b) Effect of SEWN and time on crown width of tree species

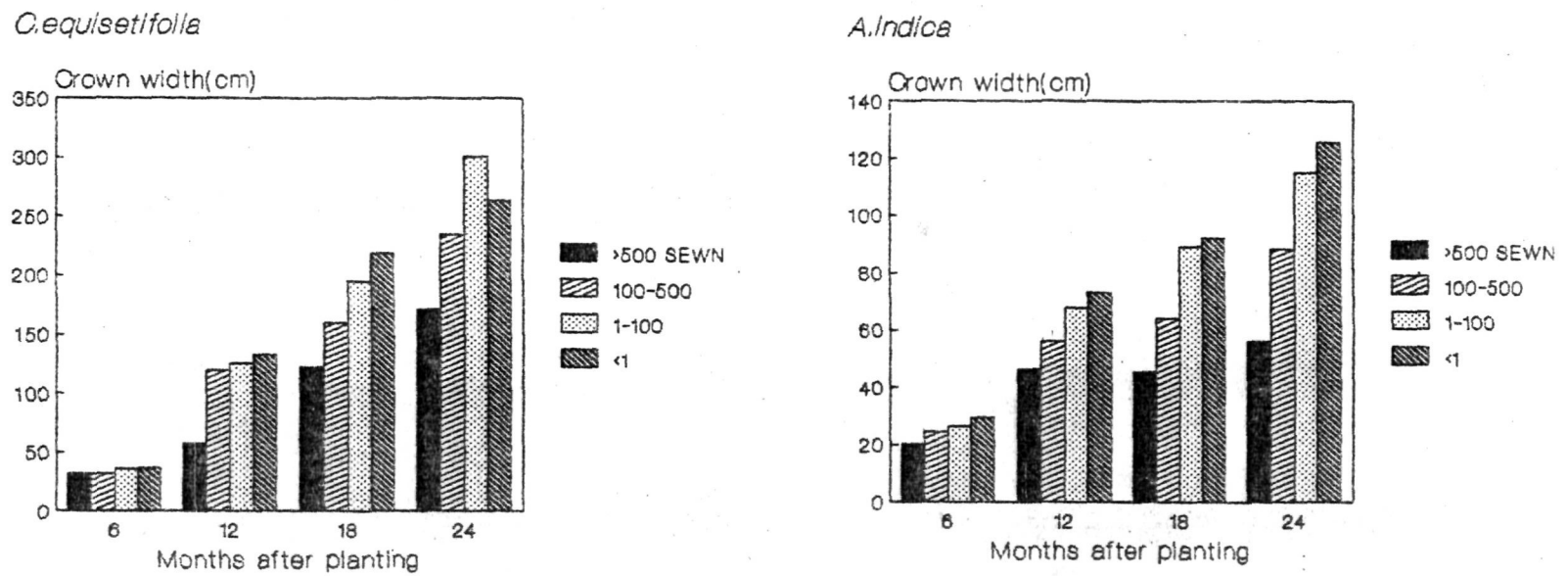


Fig.25 c) Effect of SEWN and time on crown width of tree species

and *H. binata* was termed moderate as the decrease in crown width remained in the order of 25-35 per cent. However, in case of *A. indica and D. sissoo,* crown width reduced to a larger extent indicating their poor growth at highest SEWN values. Susceptibility in terms of higher reduction was because of uncontrolled uptake and accumulation of sodium, mgnesium and chloride in their tissues (table 27 , 28 and 29). In addition, *A. indica* and *D. sissoo* might have suffered from aeration stress created by rising water table when SEWN increased. Despite large differences in Sodium absorption, tolerance of tree species was unaffected (Garg and Khanduja, 1979). Contrary to this, species of the present investigation largely depended on uptake of sodium and aeration except *C. equisetifolia*. Laurd and El-Lakany (1984) offered similar measures as made in the present investigation.

The overall performance of trees under saline soils accompained by shallow and saline water table (higher SEWN) indicatd that *A. nilotica* followed by *S. grandiflora* and *C. equisetifolia* were found better species for soils with higher SEWN values due to mechanisms developed by them to tolerate both salt and aeration stresses. In contrast, *D. sissoo* and *A. indica* appeared to be unsuitable in early phases of growth to withstand high SEWN values. However, *H.*

binata was moderately tolerant and found better than *D. sissoo* and *A. indica* which remained susceptible to higher SEWN (combined stress of salinity and waterlogging) values.

5.3 Effect of tree cover on soil chemical environment. (Bio-amelioration):

Tree growth on salt affected and waterlogged soils is known to influence soil physical, chemcial and biological environment. Results on such beneficial effects of tree cover on soil properties such as salinity, organic carbon, calcium carbonate, SAR and ESP(p) are presented in the following paragraphs.

5.3.1 Salinity: Tree species showed marked variations in reducing soil salinity. Except *A. indica*, all other species favoured salt leaching from soil. Salt removal from surface was more evident and was found either to re-distribute within profile or leached out. The decrease in salinity was as high as 37 per cent in *A.nilotica* and 20 per cent in case of *S. grandiflora*. Both of these species with vigorous growth, higher root bio-mass production and better canopy covering, contributed to organic matter through litterfall. Larger canopy controlled salinity by way of reduced direct evaporation from soil surface thereby decreased salt

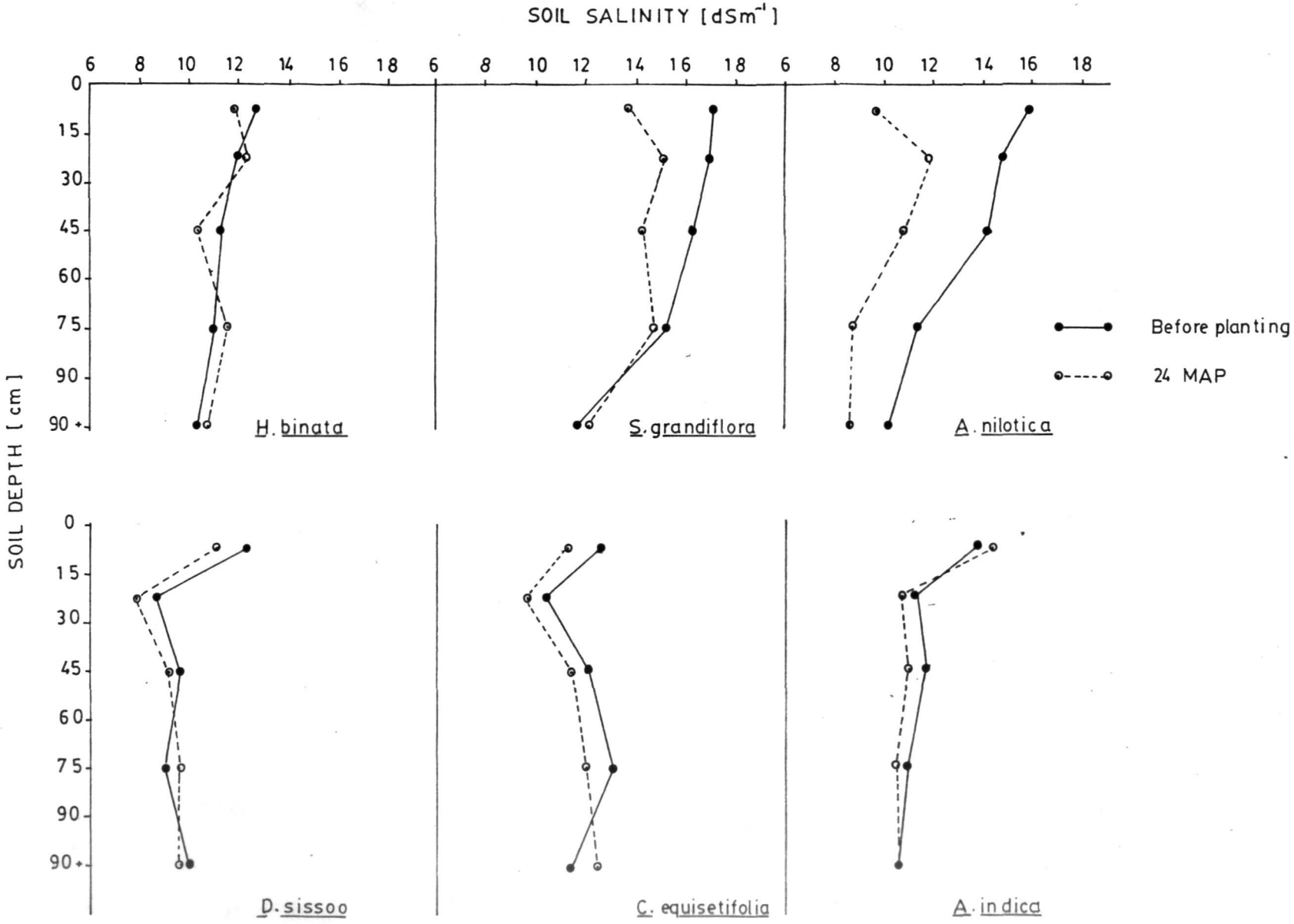


FIG.30 : INFLUENCE OF TREES ON BIO-AMELIORATION OF SALINE SOILS—SALINITY

deposition through reversing upward salt flux. The other species such as *C. equisetifolia, D. sissoo* and *H. binata* also reduced soil salinity but reduction remained marginal. All these species had tendencies to absorb and accumulate sodium, magnesium, chloride and sulhate in their tissues than observed under normal conditions. This led to higher removal of salt contributing towards reduction of soil salinity to some extent despite not being halophytes. Boyko and Boyko (1966)observed higher salt intake by *Calotropis* when grown on salt affected soils offering desalinization possibilities by tree species. Singh *et al.* (1993) and Mohindra (1973) observed decrease in soil salinity two years after keeping soils under the cover of *P. juliflora ,T. articuleata, D. sissoo, A, procera* and *A. nilotica.* These observations confirmed the results obtained in the present investigation. The species, although, reduced the soil salinity in surface, the reduction at lower depths was not in the same order as was observed in surface becaue of lower root activity and proximity of saline ground water to surface.

5.3.2 Organic carbon increased under tree cover due to litterfall but the magnitude of buildup, as observed after 2 years, differed to large extent due to variations in their bio-mass production and litterfall. The species such as *A.*

nilotica and *D. sissoo* with larger bio-mass production recorded higher organic carbon in surface as well as at lower depths. The increase in organic carbon at lower depths was attributed to their root bio-mass additon and exudation. Ghildyal *et al.*(1962), Yadav and Singh (1970), Virginia and Jarrel (1983), Gill (1985) and Gill and Abrol (1990) recorded such increased carbon in soils which were under tree cover. The results of present investigation remained in confirmity with findings of those above workers. The species, *C. equisetifolia* and *S. grandiflora* had only marginal increase in organic carbon content of soils compared to *A. nilotica* and *D. sissoo* because of lower litterfall. Some species which have slow growing habits have lower bio-mass production and little litterfall and contributed very little to organic carbon and such observations were made in *H. binata* and *A. indica*. The decreased organic carbon at lower depths under *A. indica* indicated lower root activity during its early phases of growth.

5.3.3 Sodium Adsorption Ratio Beneficial effects of tree growth on SAR was quite evident as it decreased under tree cover. The decrease insoil solution SAR was due to increased root activity in soils brought under the cover of trees. There was, however, large variation among the tree species in

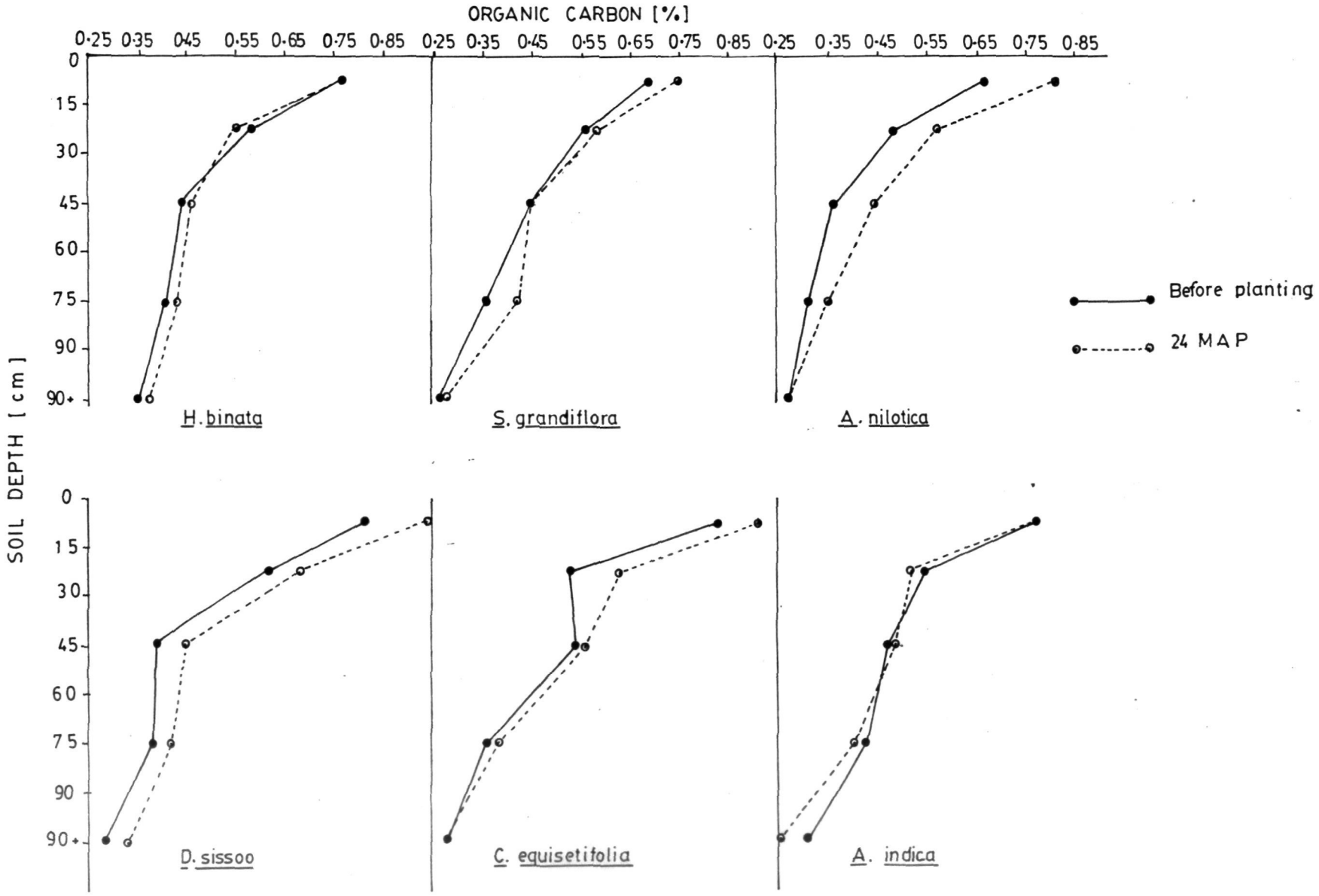


FIG. 31 : INFLUENCE OF TREES ON BIO-AMELIORATION OF SALINE SOILS—ORGANIC CARBON

their effect on soil solution composition. Species such as *A. nilotica, S. grandiflora* and *C. equisetifolia* found to reduce soil solution SAR to a greater extent than others. This was achieved primarily by way of increased leaching or by ion uptake by trees. The decomposition of organic matter would have further produced organic acids and resulted in mobilization of calcium in solution from $CaCO_3$ and there by reduced SAR. The increased uptake of sodium by trees such as *D. sissoo* and *C. equisetifolia* might have possibly helped marginally in reducing the solution SAR. Existance of such phenomenon in blue bush and *P. juliflora* has been reported by Smith (1961) and Shah (1957).

5.3.4 **Exchangeable sodium percentage** Predicted ESP based on soil solution SAR decreased in soils under tree cover because ESP depended on SAR. Removal of soluble sodium from solution through leaching and increased calcium due to higher root activity through mobilization from $CaCO_3$ might have resulted in an equilibrium condition where sodium on exchange favoured solution rather than solid phase. Based on bio-mass production, litter fall and rate of growth, trees differed in reducing ESP(P) of the soil. A maximum decrease was in trees such as *A. nilotica, S. grandiflora, C. equisetifolia* and *D. sissoo* because of their vigorous growth and greater bio-mass

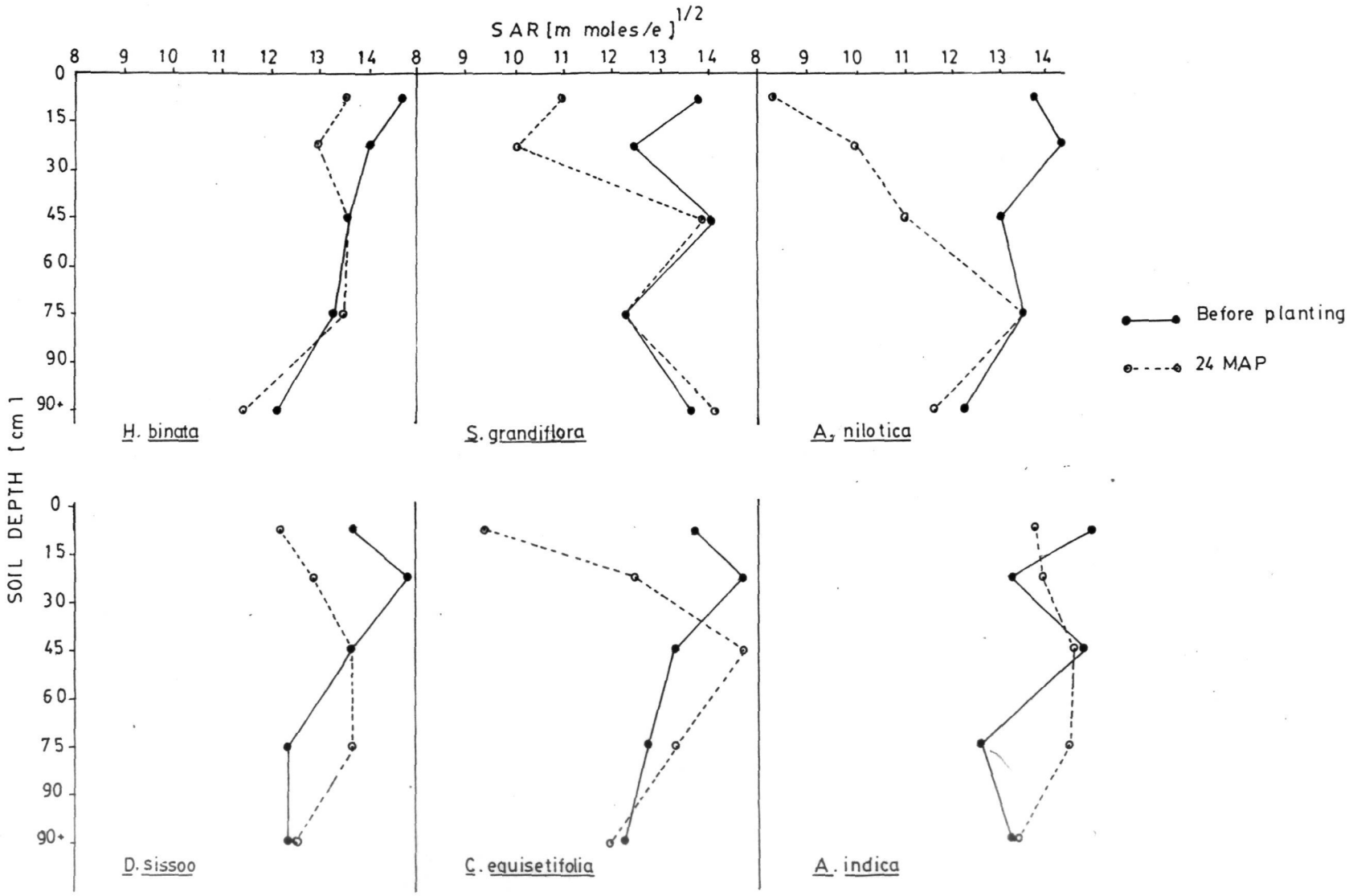


FIG. 32 : INFLUENCE OF TREES ON BIO-AMELIORATION OF SALINE SOILS - SAR

addition to soil. In contrast, slow growers like *H. binata* and *A. indica* did bring about small reduction in ESP (P) and effect of such specis had little consequence on ESP (P). Sumbur (1963) and Maliwal *et al.* (1990) also noted such reductions in ESP of soils under tree cover due to their ameliorative effects.

5.3.5 Calcium carbonate : Reduction in calcium carbonate content of soil was not consistant. Except under *S. grandiflora*, marginal effect of trees was observed. Although the tree species had favourable effect on organic carbon levels but, such increase was not marked enough to mobilize calcium carbonate of soil. However, it may be noted that the effect of trees may be either way. They might have increased under higher microbial activity leading to the enrichment of soil solution with microbially produced Co_2 or they might have dissolved native calcium carbonate through organic acids due to decomposition of organic residues added through litter fall. However, in one of the reports where Karnal grass was planted with trees like *E. umbellata, E. tereticornis, A. nilotica* and *P. aculata* found to hasten the process of soil amelioration in calcarious soils by dissoluing native $CaCO_3$ through release of carbonic acid produced by respiring roots

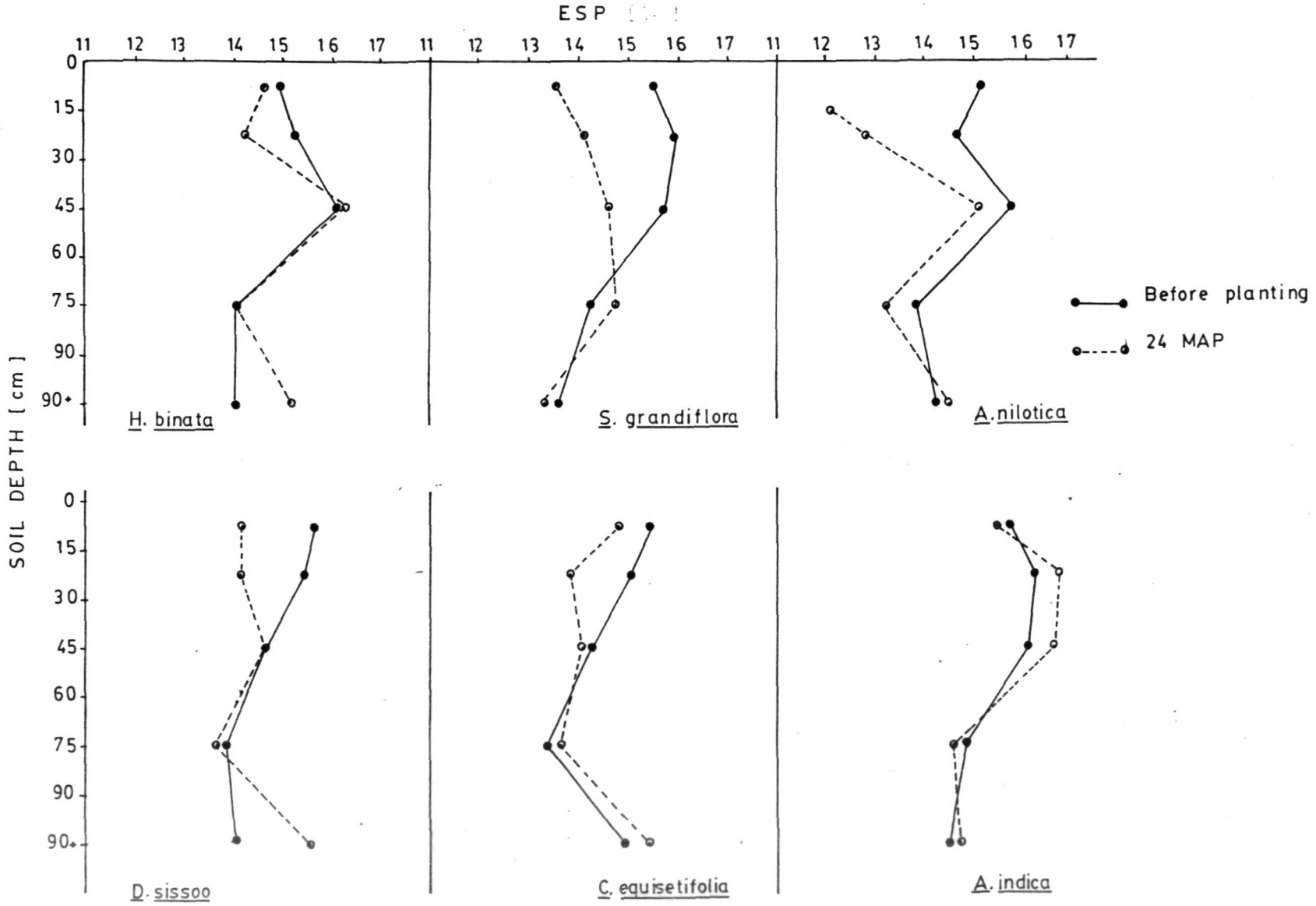


FIG. 33 : INFLUENCE OF TREES ON BIO-AMELIORATION OF SALINE SOILS-ESP

(Grewal and Abrol, 1987). But, this phenomenon seems to have little impact on $CaCO_3$ as observed in the present investigation therefore, the effect of trees on calcium carbonate remained inconclusive two years after planting.

CHAPTER - VI

SUMMARY

VI SUMMARY

Summary of results on the performance of different tree species under saline and waterlogged soils are presented in succeeding paragraphs.

Initial analysis of experimental soil revealed wide variations in soil salinity, which varied from 1.3 to 42.9 dSm^{-1} in surface 0-15 cm layer. Soil solution was dominated by neutral salts of cholorides and sulphates of sodium as indicated by neutral soil reaction. Observations made on water table fluctuations revealed existance of shallow and saline ground water table. So trees grown on these soils experienced varying degrees of salinity and water table.

Performance of trees under saline conditions of soil indicated wide differences amongst species in tolerance based on their physiological and metabolical mechanisms adopted. Salinity affected tree growth by way of decreased osmotic potential and toxic effects of predominating ions of soil solution. Based on reduction in different tree growth parameters like height, number of branches, diameter of stem at stump as well as breast height, pruned biomass and canopy width, it was found that *A. nolotica* was the most ideal

species followed by *S. grandiflora* and *C. equisetifolia* for saline conditions. Better growth of *A. nilotica* and *S. grandiflora* under salt stress was attributed to their regulated uptake of sodium, magnesium, chloride and sulphate. Though *S. grandiflora* performed better with little decrease in height, number of branches, DSH, DBH, pruned biomass etc, it failed to have a good establishment under salinity. Increasing salinity had deleterious effects on growth of *A. indica* and *D. sissoo*. These species recorded higher reduction in all the growth parameters. Uncontrolled accumulation of sodium and chloride was the cause for their poor growth under salt stress. Tolerance of *H. binata* was moderate as it recorded lower reduction compared to *A. indica* and *D. sissoo* in growth parameters due to salinity.

Shallow water also had deleterious effects on tree growth. Presence of shallow water table close to surface created aeration problems. More over, the salinity of ground water further aggravated the problem. So under such conditions trees suffered from both aeration as well as salinity stress. Amongst tree species, *A. nilotica* appeared most tolerant species under shallow and saline ground water conditions followed by *C. equisetifolia* which also recorded lower reduction in growth. This species had the ability to

produce special roots to overcome aeration problems. Another species which remained comparable to *A. nilotica* and *C equisetifolia*, except its initial establishment was *S. grandiflora*. Under shallow and saline ground water table, performance of *D. sissoo* and *A. indica* became suspect as their growth decreased to a large extent than any other. However, *H. binata* appeared better than *D. sissoo* and *A. indica*.

Growth of tree species was strongly related to combined stress of shallow water table and salinity (SEWN) than to isolated stress of shallow water table or salinity. This was observed in all the tree species irrespective of their tolerance to the stresses. Hence, SEWN (combined stress due to waterlogging and salinity) as a better tool was employed to evaluate the performance of tree species under the combined stresses of shallow and saline ground water table and soil salinity.

The combined stress due to restricted aeration, low osmotic potential and the possible toxic effects of dominating ions under saline and waterlogged soils, affected the growth of all the tree species. Based on regulated uptake of ions and physiological adoptibility to salinity and waterlogging, tree species differed in their tolerance to SEWN. *Acacia*

nilotica, as observed with salinity as well as water table, was found the most tolerant species against the combined stresses. The species such as *S. grandiflora* maintained lower sodium and choloride levels in leaf tissues like *A. nilotica*. Therefore, their tolerance was rather related to lower sodium and chloride content in tissues. Though *C. equisetifolia* had higher sodium in leaf tissues, it did not affect the performance possibly due to its physiological adoptions. Performance of *H. binata* was relatively better but not as good as observed in case of *A. nilotica* or *C. equisetifolia* because of its inherent slow growth. Uncontrolled accumulation of sodium and chloride in leaf tissues and poor growth in case of *D. sissoo* and *A. indica* confirmed their susceptibility to confounded effects of aeration and salinity stress in soils.

Growing trees on salt-affected soils had beneficial effects as tree species reduced soil salinity, SAR and ESP (p) and improved organic carbon content of soils. Decrease in soil salinity, SAR and ESP (p) was brought about by the penetrating sturdy roots of trees which facilitated in leaching of salts. Trees had also arrested evaporation from soil surface and drew their water requirements from lower depths by which they minimised accumulation of salts and also possibly controlled water table. By way of litterfall,

organic carbon content of soils beneath trees increased and organic acids released during the mineralization process and respiring roots hastened the process of bio-amelioration. Tree species such as *A. nilotica* and *S. grandiflora* brought about better amelioration as decrease in soil salinity, ESP (p) and SAR was of higher order than in others because of their vigorous growth and higher bio-mass production/addition. The slow growing species such as *H. binata* and *A. indica*, however, had only marginal effects on soil salinity and other parameters. The effect of trees on lime status of soil remained inconclusive during the period of investigation.

Conclusion

On the basis of overall performance of the tree species under saline condition, it was concluded that *A.nilotica* was the most ideal species followed by *S.grandiflora* and *C.equisetifolia* due to regulated uptake of salts from soil solution and better biomass yields. The performance of *H.binata* remained intermediary. The combined stresses of salinity and water logging was studied interms of SEWN concept and was found more ideal than when performance were evaluated on individualistic approach.

Trees had bio-ameliorative effects and the decrease in soil salinity, SAR and ESP and increase in organic carbon were observed

CHAPTER - VII

REFERENCES

VII REFERENCES

ABROL, I.P., 1982, Technology of chemical, physical and biological amelioration of deteriorated soils. Paper presented at meeting of panel of experts on *Amelioration and Development of Deteriorated soils in Egypt*. May 2-6, 1982, Cairo.

ABROL, I.P., 1986, Fuel and forage production from salt affected waste lands in India. *Reclamation Revegetation Res.*, 5: 65-74.

ABROL, I.P. AND BHUMBLA, D.R., 1978, Some comments on terminology relating to salt affected soils. *Proc. meetings of sub commission on salt affected soils in dry land and saline seep control* at 11th *Intrn. Soil Sci., Cong.*. Edomonton. pp. 6-19.

ABROL, I.P., DARAGAN, K.S. AND BHUMBLA, D.R., 1973, Reclaiming alkali soils. Bull. No. 2 CSSRI, Karnal. pp. 58.

ABROL, I.P. AND SANDU, S.S., 1981, Eucalyptus and *Acacia* can be grown in alkali soils. *Indian Fmg.* 31: 7-9.

*ANDERSON, H.W., HOOVER, M.D. AND REINHART, K.G., 1976, Forests and Waters: Effect of forest management on floods, Sedimentation and water supply. *Pacific Southwest and Range Expl. Sta.* PSW-18/1976. U.S. Forestry Service.

ARGEL, P., 1978, Role of wood energy in rural economy of India. *Proc. 8th World Forestry Congr.* FRC/3-8. Jakarta.

ARNOLD, J.E.M., 1978, Wood energy and rural communities. *Proc. 8th World Forestry Congr.* FRC/3-8, Jakarta.

ASWATHAPPA, N. AND BACHELARD, E.P., 1986, Ion regulation in the organs of *Casuarina* sp. during salt tolerance. *Aust. J. Plant Physiol.*, 13: 533-45.

BANDOPADHYAYA, A.K., 1986, *Casuarina equisetifolia* grows well in heavy textured coastal saline soils. *Indian Fmg.*, 36: 19-20.

BANDOPADHYAYA, A.K., 1988, A note on effect of salinity on growth of *Eucalyptus* and *Casuarina* seedlings. *Indian Forest.*, 114: 343-44.

BANDOPADHYAYA, A.K., DUTT S.R. AND BAL, A.R., 1987, Salt tolerance of *Casuarina equisetifolia*. *Proc. Int. Symp.*

Afforestation of salt affected soils. CSSRI, Karnal, Haryana, Vol. 2: 17-32.

BATRA, LALITA AND ASHOK KUMAR, 1993, Influence of salinity on germination, growth and nitrogen uptake by two casuarina species. *J. Indian Soc. Soil. Sci.*, 41: 527-530.

BERNSTEIN, L., FRANCOIS, L.E. AND CLARK, R.A., 1972, Salt tolerance of ornamental shrubs and ground covers *J. Am. Soc. Hort. Sci.*, 97: 550-556.

BHARGAVA, O.P., 1951, An experiment to afforest alkali areas in Madhya Pradesh. *Proc. VII Silva. Conf.*, 11: 103-106.

BICLORAI, I, SHALHEVET, J. AND LEVY, Y., 1978, Grape fruit response to variable salinity in irrigation waters and soil. *Irrg. Sci.*, 1: 61-70.

BIDDISCOMBE, E.F., ROGERS, A.L., GREENWOOD, E.A.N. AND BOER, E.S.De., 1985, Growth of tree species near salt seeps as estimated by leaf area, crown volume, and height. *Aust. Forest. Res.*, 15: 141-154.

*BINDER-BARGHAVA, N. AND RAMATI, B., 1967, The tolerance of some species of *Eucalyptus, Pinus* and other forest

trees to soil salinity and low moisture in Negave. *Isreal. J. Agric. Res.*, 17: 65-76.

BLAKE, T.J. AND REID, D.M., 1981, Ethylene-water relations and tolerance to waterlogging of three *Eucalyptus* spp. *Aust. J. Plant physiol.*, 8: 497-05.

BOYKO, H. AND BOYKO, E., 1966, *Salinity and aridity.* Dr. W. Junk Publishers. The Hague. pp. 214-82.

*BROWN, C.H., 1967, Afforestation programmes in relation to national economy. *Proc. World Symp.* on *man made forests and their industrial importance* FAO, Rome. pp. 117-139.

*BROWN, J.G., 1978, Investigations on the relative resistance of woody plants to de-icing salt (sodium chloride). *Allegemeine Frost and Jagdzeitung*, 149: 21-35.

*BRUNING, F.F., 1977, The tropical rainforest-a wasted asset or an essential bio-spheric resource. *Ambio*, 6: 187-91.

CHATURVEDI, A.N., 1984, Fir wood crops in areas of brakish waters. *Indian For.*, 110: 364-66.

CHATURVEDI, A.N., JAIN, R.K. AND GARG, V.K., 1987, Afforestation of Usar soils-A case study. *Proc. Int. Symp. Afforestation of salt affected* soils Vol. 3: 163-78.

CLEMENTS, J., CAMPBELL, L.C. AND NURISJAH, S., 1983, Germination, growth and mineral ion concentration of *Casuarina* species under saline conditions. *Aust. J. Bot.*, 31: 1-9.

DAYAL, R., SINGH, G. AND NAMBIER, K.K., 1968, Development of saline and alkali soils in the Chambal command and suggestions for their reclamation. *J. Soil water conserv.* (India), 16: 18-26.

*DABOVSKAYA, L.V., 1984, Reclamation of solonetz in chernozem zone. *Pochvovedenie*, 27: 13-25.

DOWDY, S. AND WEARDEN, S., 1983, *Stastistics* for *research.* John Wiley and sons, New York.

EL-LAKANY, M.H. AND LAURD, E.J., 1982, Comparative salt tolerance of selected casuarina species. *Aust. Forest. Res.*, 13: 11-20.

FELKAR, P., CLERK, F.R., LAAG, A.E. AND PRATT, P.F., 1981, Salinity tolerance of the legumes: mesquite (*Prosopis*

glandulosa) var *torryana*, *P. velutina*, *P. articulata* and algarrobo (*P. chilensis*), Kiawe (*P. Pollida*) and tamarago (*P. tamarugo*) grown in sand culture on N free media. *Plant soil*, 61: 311-17.

FLOWERS, J.L., HAGEMAN, J.H., SUZUKIDA, M. AND ASSADIAN, H., 1988, Evaluation of the salt tolerance of Russian-thistle, a potential forage crop. *Agron. J.*, 80: 250-258.

FOOD AND AGRICULTURAL ORGANISATION, 1962, *Forest influences*. Rome. pp. 87-95.

FRANCOIS, L.E. AND CLARK, R.A. 1978, Salt tolerance of ornamental shrubs trees and ice plants. *J. Amer. Hort. Sci.*, 103:280-283.

GARG, V.K. AND KHANDUJA, S.K.,1976, Nutritional status of some fruit trees grown on normal and alkali soils. *Scientia Horticulturae*, 5: 243-47.

GARG, V.K. AND KHANDUJA, S.K., 1979, Mineral composition of leaves of some forest trees grown in alkali soils *Indian Forest.*, 105: 741-45.

GHILDYAL, B.P., SHRIKHANDE, J.G. AND KHANGROT, A.S., 1962, Comparative study of Gangetic alluvium under

continuous cultivation and afforestation II. Chemical characteristics. *J. Indian. Soc. Soil Sci.*, 10: 27-33.

GHOSH, R.C., 1978, Evaluation and analysing environmental impacts of forests in India. *Proc. 8th World Forestry Congr.*, FOL/25-24, Jakarta.

GHOSH, R.C. AND RAO, B.K.S., 1979, Forests and floods. *Indian Forest.*, 105: 249-59.

GILL, H.S., 1985, Studies on evaluation of selected tree species for their tolerance to sodicity and mechanised impedence in a highly sodic soil with particular reference to root growth behaviour. *Ph. D. Thesis*, Kurukshetra University, India.

GILL, H.S. AND ABROL, I.P., 1983, *Casuarina* a promising tree for sodic soils. *Intensive Agric.*, 2: 5-6.

GILL, H.S., AND ABROL, I.P., 1990, Tree based land use systems and utilization of salt affected soils. *Int. Congr. soil. sci.*, Kyoto, Japan.

GOGATE, M.G., MITTAL, R.C. AND PYARELAL, A.M., 1984, Screening through germination trials-Australian species for saline areas. *Indian Forest.*, 110: 982-88.

GOSWAMI, P.C., 1982, Agroforestry practices and prospectus as combined land use system *Indian Forest.*, 108: 385-96.

GREWAL, S.S., 1984, Studies on rain water conservation for establishment of an agroforestry system on sodic soils. *Ph.D. Thesis*, Kurukshetra University Kurukshetra, India.

GREWAL, S.S. AND ABROL, I.P., 1986, Agroforestry on alkali soils. Effect of some management practices on initial growth, biomass accumulation and chemical composition of selected tree species. *Agroforestry systems*, 4: 251-32.

GREWAL, S.S. AND ABROL, I.P., 1987, Effect of rain water conservation in an alkali soil on trees and grass growth. *Proc. Int. symp. Afforestation of salt affected* soils, CSSRI, Karnal., Vol. 3: 87-104.

GRIFFITH, A.L., 1945, Afforestation of dry areas. Proc. VI silva conf., FRI and Colleges, Dehra Dun pp. 126-132.

GUPTA, G.N., PRASAD, K.G. AND MOHAN, S., 1991, Effect of salinity, alkalinity and mulch on tree growth in dry region. *Ann. Arid. Zone*, 30: 29-36.

GUPTA, G.N., PRASAD, K.G., MOHAN, S. AND MANIVACHAKAM, P., 1986, Salt tolerance in some tree species at seedling stage. *Indian Forest*. 112: 101-113.

GUPTA, I.C., 1979, Use of saline water in agriculture in arid and semi-arid zones of India. Oxford and IBH Publishing House, New Delhi. 210 pp.

GUPTA, T. AND MENON, D., 1982, Economics of tree versus annual crops on marginal agricultural lands. Oxford and IBH Publishing Co. New Delhi. CMA. Monograph No. 81.

GUPTA, R.K. AND KHOSLA, B.K., 1982, Seasonal variations in salt and water content of profiles of shallow and saline ground water table. *Indian J. Agric. Sci.*, 52: 506-10.

HEBBARA, M., VISWANATH, D.P. AND DEVARNAWADAGI, S.B., 1992, Performance of tree species on marginally saline vertisols of Tungabadra Project area. *J. Indian Soc. soil Sci.*, 40: 616-617.

*HOON, R.C. AND MEHTA, M.L., 1936, A study of soil profiles of Punjab plains with reference to their natural flora. *Punjab Irrg. Res. Instt.*, Pub. 3.

HUNT, F.M., 1951, Effect of flooded soil on growth of pine seedlings. *Plant physiol.*, 26: 363-68.

JACKSON, M.L., 1967, *Soil chemical analysis*. Printice Hall of India (Pvt.) Ltd., New Delhi.

JAIN, B.L., GOYAL, R.S. AND MUTHANA, K.D., 1983a, Performance of some tree species in relation to irrigation with saline waters. *Ann. Arid Zone*, 22: 233-238.

JAIN, B.L. AND MUTHANA, K.D., 1982, Performance of different tree species under saline irrigation at nursery stage. *My Forest*, 10: 175-180.

JAIN, B.L. AND MUTHANA, K.D., 1983, Note on the germination studies of tree spp. with saline waters for arid and semiarid regions. *Curr. Agric.*, 7: 93-95.

JAIN, B.L., MUTHANA, K.D. AND GOYAL, R.S., 1983b, Performance of tree species in salt affected soils in arid regions. *J. Indian Soc. Soil sci.*, 31: 731-735.

JESCHKE, D.O. AND STELLER, W., 1983, Ionic relation of Garden Orache, *Atriplex hortensis* L: Growth and ion distribution at moderate salinity and the function of bladder hairs. *J. Expt. Bot.*, 34: 795-810.

JOSHI, Y.C., ALI QUADER, BAL S.R., AND DWIVEDI, R.S. 1980, Selective adsorption and exclusion of toxic ions. *Anual Report*. CSSRI, Karnal 1980 pp. 78.

*KARCHAN, R., 1966, Environment and tree growth in rift valley oasis of Ein Hatseva. suppl. 2, La. Yaaron.

KAUL, R.N. AND GURUMURTHI, K., 1981, Forest of fuel planting for energy. *Science Today.*, Oct. pp. 43-45.

KAUL, R.N. AND MENON, H.S., 1977, Tree planting and energy crisis. *Indian Fmg.*, 26: 79-81.

KAUSHIK, R.C., QURESHI, I.M., YADAV, J.S.P. AND JAIPRAKASH, 1969, Suitability of soils for *Eucalyptus* hybrid in Haryana and Punjab. *Indian Forest.*, 95: 377-88.

KENKEL, S.H., 1974, Water-its quality often depends on forest *Unasylva,* 105: 10-16.

KENKEL, S.H., 1978, Forestry support for agriculture through watershed management, wind breaks and other conservation measures. *Proc. 8th World Forestry Cong.* FFF/5-0, Jakarta.

KHAN, W., 1962, Characteristics and afforestation problems of saline alkali soils. *Indian Forest.*, 88: 259-69.

KHOSHOO, T.N., 1986, Environmental priorities in India and subsistant development. *Proc. 73rd Indian Sci. Congr.* New Delhi pp.1-224.

*KITTREDGE, J., 1948 *Forest influences.* McGraw Hill, New York.

KOOL, Y.M., 1993, Estimation of seepage from canal to evaluate its role in the process of waterlogging in heavy soil. *J. Indian Soc. Soil Sci.*, 41: 413-417.

KRAMER, P.J., 1951, Causes of injury resulting from flooding of soil. *Plant physiol.*, 26: 722-36.

*KRETININ, V.M., 1967, Effect of Shelterbelts on soils of the palechestnat subzone. *Pochvoedenic*, 12: 124-132.

KRETININ, V.M. AND DUBOVSKAVA, L.V., 1984, Reaction of trees to soil salinity and alkalinity. *Soviet Soil Sci.* 16: 52-58.

KUMAR, A. AND ABROL, I.P., 1979, Effect of ex-Na on yield and chemical composition of five forage grass species. *Forage Res.*, 5: 101-108.

KUMAR, A. AND ABROL, I.P. 1984, Studies on the reclaiming effect of Karnal and para grass grown in highly sodic soils. *India J. Agric. Sci.*, 54: 189-93.

KUMAR, A. ABROL, O.P. AND DARAGAN, K.S., 1980, Karnal and Rhodes grass for alkali soils. *Indian Fmg.*, 30: 21-4.

LAURD, E.J. AND EL-LAKANY, M.H., 1984, Effects on *Casuarina* and *Allocasuarina* species of increasing sodium chloride concentration in solution culture. *Aust. J. Plant Physiol.*,11: 471-84.

LAYANCHY, P.F. AND MUSY, A., 1990, Salinization process in soils with shallow phreatic leavel. *Int. Congr. Soil. Sci.*, Kyoto, Japan.

LOHANI, D.N., 1979, Preliminary trials with high yielding varieties of *Leucaena leucocephala*. *Indian Forest.*, 105: 199-202.

*LUNDGREN, B., 1978, Soil conditions and nutrient recycling under natural and plantation forests of Tanzanian highlands. *Rep. Forest Ecol.*and *Forest soils* No. 31: Dept. Forest soils, Swed. Univ. Agric. Sci., Uppasala, pp. 426.

MALIWAL, G.L., NADIYADARA, S.H., PUNJANI, S.H. AND PATEL, C.L., 1990, Changes in soil properties as influenced by *Prosopis juliflora* and crop covers in salt affected soils. *Ann. Arid. Zone,* 30: 57-60.

MATHUR, H.N., BABU, R., JOSHIE, P. AND SINGH, B., 1976, Effect of clear felling reforestation on runoff and break rates in small watershed. *Indian Forest.*, 102: 219-26.

MEH-TA, K.K., 1988, Eucalyptus for alkali soils *Advances in Forestry research in India*. Vol. III. Ed. Ram Prakash, International Book Distributors, Dehra Dun 248 001.

MEHTA, K.M., GUPTA, V.K. AND NATHANI, G.P., 1968, Survey of depth and quality of underground waters in Chambal areas as affected by Canal irrigation. *J. Indian Soc. Soil Sci.*, 16: 285-88.

*MIGUNOVA, E.S., 1972, Desalinizing action of tree plantation of solonchalkous and Solonetz like soils. *Pochvovedenic*, 2: 123-35.

*MIGUNOVA, E.S., 1976, The root systems of woody species on saline soils in South Ukraine. *Lesovedenic*, 6: 27-36.

MISHRA, P.R. AND SINGH, G., 1968, *Proc. Symp. Water. Mgmt.* Udaipur.

MOHINDRA, V., 1973, Reclamation of saline alkali soils. *Indian Forest.*, 99: 143-48.

MONK, R. AND PETERSON, H.B., 1956, Tolerance of some trees and shrubs to saline conditions. *J. Amer. Soc. Hort. Sci.*, 81: 556-561.

*MUSA, O.S., 1977, The green belt of Khartoum *Beitr. Forstwirtsch*, 11: 95-97.

MUTHANA, K.D. AND JAIN, B.L., 1984, Use of saline water for raising tree seedlings. *Indian Fmg.*, 34: 37-38.

MUKHARJEE, S.K., DATTA, N.P. AND MUKHARJEE, N.N., 1950, Research into problems relating to coastal soils. *Indian J. Agric. Sci.*, 20: 1-4.

NATIONAL COMMISSION ON AGRICULTURE, 1976, *Report Part IX.* Ministry of Agriculture, Govt. of Inda. New Delhi. pp. 8-12.

NEALES, T.F. AND SHARKEY, P.J., 1981, Effect of salinity on growth and on mineral and organic constituents of halophyte *Disphyma australe* (Soland) Black. *Aust. J. Plant. Physiol.*, 8: 165-79.

OJENIYI, S.O. AND AGBEDE, O.O., 1980a, Effect of single crop agri-silviculture on soil analysis. *Expl. Agric.*, 16:371-75.

OJENIYI, S.O., AND AGBEDE, O.O., 1980b, Soil organic matter and yield of forest tree crops. *Plant Soil.*, 57: 61-67.

OJENIYI, S.O., AGBEDE, O.O. AND FABUERO, J.A., 1980, Increasing food production in Nigeria I. Effect of agrisilviculture on soil chemical properties. *Soil Sci.*, 130: 76-82.

PANDE, D.C., 1956, A short note on introduction of tree spp. in mild usar lands of UP. *Proc. 9th silv. Conf.*, 1: 337-42.

*PANT, M.M., 1980, The impact of social forestry in national economy of India. *The Int. Tree. Crops J.*, 1: 69-92.

PARKAR, J., 1950, The effects of flooding on trasnpiration and survival of some Southeastern forest tree species. *Plant Physiol.*, 25: 453-60.

PATIL, B.P., MAGAR, S.S., KADAM, R.H. AND PATIL, B.R., 1982, Effect of canal water seepage on water table fluctuations and salinity development in mula command. *Curr. Agric.*, 6: 135-141.

*PAYNE, C.B., 1968, Wind and fruit trees. *Hortus Rhodesia*, 5: 24-27.

PEREIRA, J.S. AND KOZLOWASKI, T.T., 1977, Variations amongst woody angiosperms in relation to flooding *Physiol. plant.*, 41: 184-92.

PIPER, C.S., 1950, *Soil and Plant analysis*. Univ. of Adelaide, Australia.

RAGHAV RAO, K.V., 1977, *Conf. Water, desalinization* Bhavanagar.

RHODES, D. AND FELKER, P., 1988, Mass screening of *Prosopis* (mesquite) seedlings for growth at sea water salinity conditions. *Forest Ecol. Mgmt.*, 24: 169-76.

RICE, R.M., 1978, The effect of forest management on erosion and sedimentation due to landslides. *Proc. 8th World Forest. Congr.*, FFF/5-10, Jakarta.

ROGERS, A.L., 1985, Foliar salt in *Ecualyptus* sp. *Aust. Forest Res.*, 15: 9-16.

ROY, D.R., PANJAB SINGH, AND PATHAK, P.S., 1987, Plantation of fodder cum fuel trees on salt affected ravinous waste lands under Silvipastoral system. *Proc. Int. Symp. Afforestation of salt affected soils,* CSSRI, Vol. 2 107-120.

SANDU, S.S. AND ABROL, I.P., 1981, Growth response of *Eucalyptus tereticornis* and *Acacia nilotica* to selected cultural treatments in highly sodic soils. *Indian J. Agric. Sci.*, 31: 437-43.

SHAH, R.K. AND VORA, J.C., 1965, *Prosopis juliflora* for improving saline soils. *J. Guj. Univ.*, 8: 210-14.

SHAH, S.A., 1957, Propagation of mesquite. *Indian Forest.*, 83: 472.

SHANKARNARAYAN, K.A. AND KOLARKAR, A.S., 1987, Some promising tree species suitable for afforestation of salt affected soils for Indian arid zone. *Proc. Int. Symp. afforestation of salt affected soils,* CSSRI, Karnal Vol. 2, 77-92.

SHARMA, B.D., 1984, Scrub forest studies-foliar and soil nutrient status *P. juliflora De. Indian Forest.*, 110: 367-74.

SHARMA, B.D., BAWA, A.K. AND GUPTA, I.C., 1990, Physico-chemical changes in soils as influenced by natural tree and grass cover in arid range lands. *Ann. arid zone*, 29: 15-18.

SHAYBANY, B. AND KASHIRAD, A., 1978, Effect of NaCl on growth and mineral composition of *Acacia saligna* in Sand culture. *J. Amer. Soc. Hort. Sci.*, 103: 823-26.

SINGH, G., SINGH, N.T. AND TOMAR, O.S., 1993, Agroforestry in salt affected soils. CSSRI Karnal-132 001 Haryana.

SINGH, K., YADAV, J.S.P. AND SINGH, B., 1986, Performance of *Acacia nilotica* on salt affected soils. *Indian J. Forest.*, 9: 296-303.

SINGH, K., YADAV, J.S.P. AND SINGH, V., 1990, Tolerance of trees to soil sodicity. *J. Indian Soc. Soil Sci.*, 40: 173-79.

SINGH, K., YADAV, J.S.P. AND SINGH, V., 1991, Tolerance of trees to soil salinity. *J. Indian Soc. Soil Sci.*, 39: 549-556.

SINGH, N.T., MONGIA, A.D. AND GANESHMURTHY, A.N., 1987a, Coastal Successions in relation to soil salinity in South Andeman. *Proc. Int. Symp. Afforestation of salt affected soils,* CSSRI, Karnal.

SINGH, P., 1976, Role of forestry in mitigating the energy crisis in India. *Indian Forest.*, 101: 589-96.

*SINGH, R.G.J., 1965, Dry zone afforestation in selected countries. *Fellowship Report*, FAO, Rome.

SINGH, U.N., BHAT, D.N. AND YADAV, R.D., 1987b, Growth and biomass production of certain forest tree species as influenced by varying pH levels. *Proc. Int. Symp. Agroforestry of Salt affected soils*, CSSRI, Karnal, Vol 2: 51-62.

SMITH, S.T., 1961, Reclamation of salt affected soils with blue bush. *J. Agric. W. Aust.*, 14th Ser., 57-59.

SPERGEON, D., 1979, Agroforestry - New Scope for subsistance farmers. *Nature*, 280: 533-34.

SRIVASTAVA, M.B., TEWARI, K.N. AND MINAKSHI SRIVASTAVA, 1988, Afforestation of salt affected soils in India. *Indian J. Forest.*, 11: 1-2.

*STORRIS, A., 1981, Conservation of forests in Zambia. *Intt. Agril. Develop.* pp. 36.

*SUMBUR, G.N., 1963, Mobility of Ex-Na and determination of ratio of application of gypsum during reclamation of Solonetz. *Pochvovedenic*, 11: 35-46.

*SWAMINATHAN, M.S., 1980, Indian forestry at cross roads. *Intt. Tree crops J.*, 1: 61-67.

TANG, Z.C. AND KOZLOWASKI, T.T., 1984, Ethyle production and morphological adoption of woody plants to flooding. *Can. J. Bot.*, 62: 1659-64.

TEJWANI, K.G., 1977, Trees reduce floods. *Indian Fmg.*, 26: 57-59.

TEJWANI, K.G., 1979, Soil fertility status maitainance and conservation of agroforestry systems on waste land in India. In *soils research in agroforestry*, pp. 141-174.

TOMAR, O.S. AND GUPTA, R.K., 1985, Performance of some forest tree species in saline soils under shallow and saline ground water table condition. *Plant soil*, 87: 329-35.

TOMAR, O.S. AND GUPTA, R.K., 1987, Performance of forest tree species in saline soils. *Annual Reports*, CSSRI, Karnal, Haryana, pp. 101-102.

TOMAR, O.S. AND GUPTA, R.K., 1988, Performance of casuarina species in Saline soils. *Annual Report*. CSSRI, Karnal, Haryana, pp. 128-131.

TOMAR, O.S. AND GUPTA, R.K., 1989-90, Performance of tree species in saline soils. *Annual Reports*, CSSRI, Karnal, Haryana pp. 160-161.

TOMAR, O.S. AND GUPTA, R.K., 1991-92, Performance of tree species in saline soils. *Annual Reports* CSSRI, Karnal, Haryana, pp. 98-99.

TOMAR, O.S. AND YADAV, J.S.P., 1980, Effect of saline irrigation water of varying EC, SAR and RSC levels on germination and seedling growth of some forest species. *Indian J. Forest.*, 3: 306-14.

TOMAR, O.S. AND YADAV, J.S.P., 1982, Effect of irrigation with saline and sodic waters on growth of *Albizia lebbeck* and soil properties. *Indian J. Forest.*, 5: 290-97.

TOMAR, O.S. AND YADAV, J.S.P., 1983, Effect of saline water in relation to phosphorus and nitrogen fertilization on performance of *Eucalyptus* hybrid at early growth stage. *Indian. J. Range, Mgmt.*, 4: 19-25.

TOMAR, O.S. AND YADAV, J.S.P., 1985, Effect of saline water irrigation and fertilizer application on growth of tree seedlings. *Ann. Arid. Zone*, 24: 94-100.

TOTEY, N.G., KULKARNI, R., BOWMIK, A.K., KATRI, P.K., DAHIA, V.K. AND ARUN PRASAD, 1986, Afforestation of salt affected waste lands-I. Screening of forest species of MP. for salt tolerance. *Indian Forest.*, 113: 805-815.

UNITED STATES SALINITY LABORATORY STAFF, 1968, Diagnosis and improvement of saline and alkali soils. U.S.D.A. Hand Book 60, U.S. Govt. Print Office, Washington D.C.

*UPPAL, V.B., 1967, Soil and ground water survey of Punjab Vol 1. Amritsar district and Vol. II. Kapoortala district *Land Reclamation, Irrigation* and *Power Research Institute*, Amritsar, Punjab.

*USAR LAND RECLAMATION COMMITTEE, 1938, *Report*, Govt. of India, New Delhi.

*VADIUNIA, A.F., 1957, Experiment on biological amelioration of solonetz by means of shrubs-I. Improvement of physical properties of solonetz under shrubs. *Pochvoved Geo. Gerogr.*, 4: 75-87.

VADIUNIA, A.F., 1964, Ameliorative effect of forest shelterbelt on soils of semidesert. *Proc. 8th Intn. Congr. Soil Sci.*, 8: 955-960. Bucharest.

VAN-DER, MOEZEL, P.G., WATSON, L.E., PEARCE-PINTO, G.V.N. AND BELL, D.T., 1988, Response of six *Eucalyptus* species and *Casuarina obesa* to the combined effect of salinity and waterlogging. *Aust. J. Plant Physiol.*, 15: 465-74.

*VERMA, B.G., SWAMINATHAN, K. AND SUD, K.C., 1977, An improved turbidometric procedure for the determination of sulphate in plants and soils. *Talanta*, 24: 49-51.

VIRGINIA, R.R. AND JARREL, M.W., 1983, Soil properties in a mesquite dominated Sonoran ecosystem. *Soil. Sci. Soc. Am. J.*, 47: 138-44.

WALKER, R.R. AND DOUGLAS, T.J., 1983, Effect of salinity level on uptake and distribution of chloride, sodium and potassium ions in citrus plants. *Aust. J. Agric. Res.*, 34: 145-53.

WALLACE, A., ROMNEY, E.M. AND HALE, V.Q., 1973, Sodium relations in desert plants: Cation contents of some plant species from the Mogava and Great Basin Deserts. *Soil Sci.*, 115: 284-87.

*WEGNER, G., 1976, Wood as a fuel and chemical feed stock. *Plant Res. Develop.*, 18: 27-36.

WEN-RUI YOU, 1990, Salt water dynamics of soil and prediction of salinity in coastal plain of Northern China. *Proc. Int.* 14th *Congr. Soil Sci.*, VI 119-124.

WESTOBOY, J.C., 1962, The role of forest industries in attack on economic under development. *Unasylva*, 16: 168-201.

WINTER, J. AND LAUCHLI, A., 1982, Salt tolerance of *Trifolium alexandrium* L. I Comparision of the salt response of *T. alexandrium* and *T. pratense*. *Aust. J. Plant physiol.*, 9: 221-26.

YADAV, J.S.P., 1956, *Usar* soils their characterization and exploitation in forestry. *Proc. 9th Silv. Conf.* Part.1: 347-52.

YADAV, J.S.P., 1973, In *Casuarina* ecology, management and ultilization (Ed. Midgley, S.J. *et al*). CSIRO, Canberra pp. 138-157.

YADAV, J.S.P., 1975, Improvement of saline alkali soils through biological methods. *Indian Forest.*, 101: 385-95.

YADAV, J.S.P., 1977, Tree growth in salt affected lands. *Indan. Fmg.*, 26: 43-45.

YADAV, J.S.P., 1980, Potentialities of salt affected soils for growing trees and forest plant. *Indian J. Range Mgmt.*, 1: 33-44.

YADAV, J.S.P. AND SINGH, K., 1970, Tolerance of certain forest species to varying degree of salinity and alkali. *Indian Forest.*, 96: 587-99.

YADAV, J.S.P. AND TOMAR, O.S., 1981, Effect of saline and sodic water irrigation on soil characters and growth of *Eucalyptus* hybrids. *Agrkemia Es. Talajtan Tom.*,30: 241-248.

YOSHIDA, S., FORNO, D.A., COOK, J.H. AND GOMEZ, K.A., 1972, Laboratory manual for physiological studies of rice. IARI, Los Banos, Laguna, Manila, Phillippines.

ZANG, Z.S., SHEN, S.M. AND QIAO, Q., 1983, Situation and regulation on agro-ecosytem of black soil region in China. *Soil Sci.*, 135: 54-58.

*ZELENIN, A.V., 1976, Afforestation of saline soils in the Salskaya steppes. *Lesnov Khozyaistva*, 9: 79-81.

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* Originals not seen.

APPENDICES

Appendix 1. Weather data of Agricultural Research Station, Gangavati

Months	Average Rainfall (mm)				Temperature (c)				
					Maximum			Minimum	
	1979–91	90–91	91–92	92–93	90–91	91–92	92–93	91–92	92–93
April	10.9	42.2	20.4	0.3	37.8	38.8	38.1	NA	24.0
May	34.9	20.8	66.8	9.1	39.0	40.2	38.1	NA	25.3
June	74.2	161.4	67.7	_	33.5	35.1	35.0	NA	25.3
July	80.2	34.6	21.2	68.3	29.9	33.1	36.5	23.8	24.0
August	71.8	44.8	87.8	248.4	30.9	31.5	31.5	22.9	22.9
September	138.0	50.4	73.4	75.4	33.6	32.4	30.6	21.9	22.0
October	91.4	27.9	34.3	163.2	34.1	31.9	31.7	22.3	21.9
November	33.9	–	275.7	12.1	29.8	29.2	30.1	19.9	18.8
December	8.1	–	–	140.0	30.1	28.1	–	14.6	–
January	0.4	–	–	–	29.0	30.3	–	15.0	–
February	–	–	–	–	33.3	31.6	–	16.4	–
March	–	–	1.0	–	37.1	35.1	–	21.2	–
Total	543.8	382.1	647.1	716.2					

Appendix 1 continued

Months	Relative humidity (%)						Evaporation (mm)	
	Morning			Evening				
	90–91	91–92	92–93	90–91	91–92	92–93	91–92	92–93
April	74.1	64.7	77.3	36.4	24.3	38.7	NA	7.4
May	73.9	72.0	78.4	36.4	29.7	36.9	NA	8.8
June	80.8	75.2	78.0	47.5	44.8	48.0	NA	5.9
July	82.5	77.9	84.2	60.9	51.5	54.6	NA	–
August	84.6	54.5	85.9	59.4	60.3	56.3	NA	–
September	87.9	80.1	82.5	51.8	56.3	56.6	4.5	4.9
October	83.8	83.7	87.6	56.3	54.1	62.2	4.7	–
November	81.6	84.1	81.9	52.1	60.9	49.4	3.7	3.2
December	80.0	84.3	–	42.1	43.8	–	3.6	–
January	80.4	82.0	–	38.0	38.7	–	4.8	–
February	69.8	71.0	–	31.7	43.9	–	4.9	–
March	67.8	75.5	–	22.3	38.6	–	5.5	–

NA not available

Appendix 2. Water table fluctuation of the experimental site

Months and year	P1	P2	P3	Mean
1. Feb' 92	79.4	76.9	75.0	77.1
2. Mar'92	84.9	78.9	75.9	79.9
3. April'92	85.6	84.3	78.5	81.8
4. May'92	90.6	84.9	84.9	85.8
5. June'92	92.5	88.5	86.0	89.0
6. July'92	93.9	87.3	85.5	88.9
7. Aug'92	87.7	79.9	76.0	81.2
8. Sept'92	86.6	76.9	73.2	78.9
9. OCt'92	84.5	70.6	64.8	72.3
10. Nov'92	79.1	62.6	61.4	67.7
11. Dec'92	78.5	67.7	63.2	69.8
12. Jan'93	82.6	72.7	69.7	75.2
13. Feb'93	83.6	70.6	71.4	75.2
14. Mar'93	87.9	77.9	75.4	80.4
15. April'93	91.3	78.2	79.2	82.9
16. May' 93	93.1	79.9	80.8	84.6
17. June'93	97.5	84.2	82.5	88.1
18. July'93	99.1	87.3	87.0	91.1
19. Aug'93	94.0	82.4	81.9	86.1
20. Sept'93	90.8	76.9	73.8	80.5
21. Oct'93	83.8	70.5	65.0	73.1

P1 – Average water table depth 87 m away from canal
P2 – Average water table depth 123 m away from canal
P3 – Average water table depth 167 m away from canal

Appendix 3. Surface soil salinity as influenced by the fluctuating water table

	April 1992		April 1993	
Sl. No.	Water table (cm)	Soil Salinity (dS/m)	Water table (cm)	Soil Salinity (dS/m)
1	77.0	22.6	70.1	24.6
2	78.6	31.1	70.4	33.6
3	78.8	21.9	72.4	23.5
4	79.3	28.8	72.8	19.0
5	80.4	19.4	73.0	17.2
6	80.5	19.8	73.4	17.7
7	82.1	15.9	75.0	15.7
8	82.5	18.8	75.4	13.4
9	83.3	15.5	76.0	13.6
10	83.5	18.3	76.4	11.4
11	83.6	15.6	76.4	12.0
12	83.6	15.5	77.3	11.0
13	83.9	14.5	77.3	10.3
14	84.1	15.3	77.4	9.5
15	84.2	16.1	77.6	10.0
16	86.3	11.4	77.6	9.8
17	86.4	13.3	77.6	9.6
18	86.5	10.6	70.3	7.5
19	86.8	11.3	70.5	8.0
20	86.9	11.1	79.8	8.8
21	87.3	13.6	79.9	7.6
22	87.4	11.3	80.1	8.8
23	87.7	8.8	80.6	7.9
24	87.7	9.1	82.0	6.5
25	87.8	9.3	82.6	6.6
26	89.0	9.6	84.3	2.7
27	89.2	5.7	85.7	5.1
28	89.2	6.1	86.1	5.7
29	89.8	8.3	86.5	4.2
30	89.8	6.6	86.6	5.4
31	90.4	5.8	87.5	5.3
32	90.7	6.1	87.6	3.2
33	91.0	7.5	88.0	2.9
34	91.5	3.5	88.7	3.7
35	91.7	2.3	90.1	3.1
36	94.8	4.7	—	—
37	97.8	3.4	—	—
r	—	−0.94	—	−0.89
Slope	—	−1.32	—	−1.14

Appendix 4. Relationship between ground water and surface soil salinity

	April 1992		April 1993	
Sl. No.	Ground water Salinity (dSm^{-1})	Soil Salinity (dSm^{-1})	Ground water Salinity (dSm^{-1})	Soil Salinity (dSm^{-1})
1	14.6	22.6	16.3	24.6
2	16.9	31.3	14.6	33.6
3	15.0	21.9	17.7	23.5
4	15.7	20.8	14.7	19.0
5	16.0	19.4	10.2	17.2
6	17.9	19.8	16.0	17.7
7	17.3	15.9	10.8	15.7
8	14.4	18.8	13.3	14.3
9	15.3	15.5	10.2	13.4
10	14.0	18.3	10.1	13.6
11	13.8	15.6	11.8	11.4
12	14.0	15.5	10.3	12.0
13	11.4	14.5	11.1	11.0
14	12.7	15.3	12.8	10.3
15	14.9	16.1	11.5	9.5
16	10.9	11.4	12.2	10.0
17	10.2	13.3	11.4	9.8
18	10.9	10.6	10.6	9.6
19	10.1	11.3	10.2	7.5
20	8.7	11.1	12.2	8.0
21	9.3	13.6	9.4	8.8
22	9.9	11.3	10.0	7.6
23	7.8	8.8	6.4	8.8
24	8.3	9.1	5.4	7.9
25	7.3	9.3	6.0	6.5
26	8.0	9.6	9.9	6.6
27	8.1	5.7	9.9	2.7
28	6.8	6.1	9.6	5.1
29	6.6	8.3	7.5	5.2
30	6.8	6.6	8.3	4.2
31	6.6	5.8	—	—
32	5.2	6.1	—	—
33	6.9	7.5	—	—
34	5.9	3.5	—	—
35	4.3	2.3	—	—
r	—	0.90	—	0.73
Slope	—	1.44	—	1.46

Appendix 5(a). Correlation coefficient (r), coefficinet of determination (r2) and regression line between soil salinity and tree growth parameters (24 MAP)

Parameters	r	r2	Y=a+bx
a) *H. binata*			
Establishment	-0.80^{*}	0.64	Y=95.6–1.01x
Height	-0.83^{*}	0.69	Y=303.6–4.97x
No. of branches	-0.68^{NS}	0.46	Y=27.81–0.43x
DSH	-0.78^{*}	0.61	Y=3.86–0.07X
DBH	–	–	–
Pruned bio–mass	-0.65^{NS}	0.42	Y=1.54–0.02x
Crown width	-0.80^{*}	0.64	Y=035.39–2.32x
b) *S. grandiflora*			
Establishment	-0.70^{*}	0.49	Y=72.2–0.67
Height	-0.72^{*}	0.52	Y=491.78–6.69x
No. of branches	-0.62^{NS}	0.38	Y=31.97–0.28x
DSH	-0.65^{NS}	0.42	Y=11.90–0.09x
DBH	-0.66^{NS}	0.44	Y=8.34–0.07x
Pruned bio–mass	-0.71^{*}	0.5	Y=3.98–0.06x
Crown width	-0.73^{*}	0.53	Y=223.9–1.88x
c) *A. nilotica*			
Establishment	-0.07^{NS}	0.005	Y=96.25–0.02x
Height	-0.51^{NS}	0.26	Y=461.53–2.19x
No. of branches	-0.61^{NS}	0.37	Y=63.21–0.35x
DSH	-0.70^{*}	0.49	Y=11.68–0.06x
DBH	-0.46^{NS}	0.21	Y=6.2–0.04x
Pruned bio–mass	-0.72^{*}	0.52	Y=9.71–0.04x
Crown width	-0.63^{NS}	0.4	Y=347.66–1.64x
d) *D. sissoo*			
Establishment	-0.84^{**}	0.71	Y=99.24–1.23x
Height	-0.71^{*}	0.51	Y=577.54–10.77x
No. of branches	-0.70^{*}	0.49	Y=64.09–0.94x
DSH	-0.77^{*}	0.59	Y=9.18–0.12x
DBH	-0.76^{*}	0.58	Y=4.64–0.11x
Pruned bio–mass	-0.78^{*}	0.61	Y=10.43–0.21x
Crown width	-0.73^{*}	0.53	Y=381.24–7.56x
e) *C. equisetifolia*			
Establishment	-0.68^{NS}	0.46	Y=94.34–0.80x
Height	-0.85^{**}	0.72	Y=446.80–4.40x
No. of branches	-0.76^{*}	0.58	Y=51.54–0.57x
DSH	-0.69^{NS}	0.48	Y=6.51–0.08x
DBH	-0.72^{*}	0.52	Y=3.32–0.05x
Pruned bio–mass	0.85^{**}	0.72	Y=6.95–0.08x
Crown width	-0.77^{*}	0.59	Y=358.68–5.92x
f) *A. indica*			
Establishment	-0.74^{*}	0.55	Y=99.98–1.80x
Height	-0.71^{*}	0.5	Y=236.92–3.63x
No. of branches	-0.73^{*}	–0.53	Y=22.48–0.45x
DSH	-0.74^{*}	0.55	Y=3.46–0.07x
DBH	–	–	–
Pruned bio–mass	-0.77^{*}	0.59	Y=0.95–0.02x
Crown width	-0.72^{*}	0.52	Y=135.66–2.7x

Appendix 5(b). Correlation coefficient (r), Coefficient of determination (r2) and regression line between SEWN and tree growth parameters

Parameters	r	r2	Y=a+bx
a) *H. binata*			
Establishment	-0.97^{**}	0.94	Y=93.58–0.037x
Height	-0.96^{**}	0.92	Y=283–.13–1.17x
No. of branches	-0.95^{**}	0.90	Y=27.51–0.02x
DSH	-0.91^{**}	0.83	Y=4.52–0.003x
DBH	–	–	–
Pruned bio-mass	-0.95^{**}	0.90	Y=1.59–0.001x
Crown width	-0.96^{**}	0.92	Y=130.14–0.084x
b) *S. grandiflora*			
Establishment	-0.89^{**}	0.79	Y=69.47–0.029x
Height	-0.95^{**}	0.90	Y=576.06–0.265x
No. of branches	-0.95^{**}	0.90	Y=29.91–0.013x
DSH	-0.87^{**}	0.76	Y=11.27–0.004x
DBH	-0.88^{**}	0.77	Y=8.20–0.003x
Pruned bio-mass	-0.90^{**}	0.81	Y=3.73–0.002x
Crown width	-0.96^{**}	0.92	Y=248.88–0.085x
c) *A. nilotica*			
Establishment	-0.61^{NS}	0.37	-
Height	-0.80^{*}	0.64	Y=484.48–0.102x
No. of branches	-0.87^{**}	0.76	Y=65.60–0.015x
DSH	-0.96^{**}	0.92	Y=11.20–0.003x
DBH	-0.58^{NS}	0.34	Y=5.68–0.002x
Pruned bio-mass	-0.92^{**}	0.85	Y=9.63–0.002x
Crown width	-0.87^{**}	0.76	Y=348.00–0.068x
d) *D. sissoo*			
Establishment	-0.93^{**}	0.86	Y=92.61–0.05x
Height	-0.95^{**}	0.90	Y=501.82–0.43x
No. of branches	-0.96^{**}	0.92	Y=57.54–0.04x
DSH	-0.95^{**}	0.90	Y=8.70–0.004x
DBH	-0.89^{**}	0.79	Y=6.08–0.004x
Pruned bio-mass	-0.85^{**}	0.72	Y=9.36–0.01x
Crown width	-0.90^{**}	0.81	Y=322.55–0.30x
e) *C. equisetifolia*			
Establishment	-0.91^{**}	0.95	Y=88.85–0.03x
Height	-0.82^{**}	0.67	Y=391.75–0.13x
No. of branches	-0.95^{**}	0.90	Y=47.46–0.02x
DSH	-0.95^{**}	0.90	Y=5.98–0.03x
DBH	-0.94^{**}	0.88	Y=3.176–0.002x
Pruned bio-mass	-0.90^{**}	0.81	Y=6.36–0.003x
Crown width	-0.89^{**}	0.79	Y=316.63–0.02x
d) *A. india*			
Establishment	-0.98^{**}	0.96	Y=87.84–0.07x
Height	-0.92^{**}	0.85	Y=211.17–0.14x
No. of branches	-0.86^{**}	0.74	Y=19.3–0.02x
DSH	-0.88^{**}	0.77	Y=2.94–0.003x
DBH	–	–	–
Pruned bio-mass	-0.90^{**}	0.81	Y=0.80–0.001x
Crown width	-0.92^{**}	0.85	Y=116.82–0.11x

ಕರ್ನಾಟಕ ವಿಶ್ವವಿದ್ಯಾಲಯ
ಜ್ಞಾನಭಾರತಿ ಆವರಣ
ಬೆಂಗಳೂರು-560 056

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