STUDIES ON THE EVALUATION OF SELECTED TREE SPECIES FOR THEIR TOLERANCE TO SODICITY AND MECHANICAL IMPEDANCE IN A HIGHLY SODIG SOIL WITH PARTICULAR REFERENCE TO ROOT GROTH BEHAVIOUR

A
DISSERTATION
SUBMITTED TO THE KURUKSHETRA UNIVERSITY
FOR THE DEGREE OF
DOCTOR OF PHYLOSOPHY
(SOIL SCIENCE)
IN THE FACULTY OF DAIRYING
ANIMAL HUSBANDARY AND AGRICULTURE

BY
HARNAM SINGH GILL

DIVITION OF SOIL AND AGRONOMY
CENTRAL SOIL SALINITY RESEARCH INSTITUTE
(I. C. A. R.)
KARNAL – 132 001, INDIA

1985

Regn. No. 81-UD-Ph.D-20

STUDIES ON THE EVALUATION OF SELECTED TREE SPECIES FOR THEIR TOLERANCE TO SODICITY AND MECHANICAL IMPEDANCE IN A HIGHLY SODIC SOIL WITH PARTICULAR REFERENCE TO ROOT GROWTH BEHAVIOUR

A
DISSERTATION
SUBMITTED TO THE KURUKSHETRA UNIVERSITY
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
(SOIL SCIENCE)
IN THE FACULTY OF DAIRYING,
ANIMAL HUSBANDRY AND AGRICULTURE

By
HARNAM SINGH GILL

DIVISION OF SOILS AND AGRONOMY
CENTRAL SOIL SALINITY RESEARCH INSTITUTE
(I. C. A. R.)
KARNAL - 132001, INDIA
1985

Regn. No. 81 - UD - Ph D-20

Dated: December 30 ,1985.

Dr.I.P. ABROL
Director,
Central Soil Salinity Research Institute,
Karnal - 132001.

CERTIFICATE

This is to certify that the dissertation entitled "STUDIES ON THE EVALUATION OF SELECTED TREE SPECIES FOR THEIR TOLERANCE TO SODICITY AND MECHANICAL IMPEDANCE IN A HIGHLY SODIC SOIL WITH PARTICULAR REFERENCE TO ROOT GROWTH BEHAVIOUR" submitted for the degree of Doctor of Philosophy in the subject of Soil Science of the Kurukshetra University, Kurukshetra is a bonafide research carried out by Mr. Harnam Singh Gill, Regn. No. 81UD.Ph.D. 20, under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

I.P. Abrol

(I. P. ABROL)

ACKNOWLEDGEMENTS

Accomplishment of this dissertation based on field studies necessiated me to avail valuable guidance and help from my reverred teachers, friends and colleagues to whom I wishes to express my gratitude. I feel it a pleasure to convey the depth of my feelings of gratitude to my Major Advisor, Dr.I.P.Abrol, Director, Central Soil Salinity Research Institute, Karnal for his keen interest, able guidance, unflinching help, constructive criticism and fructuous inspiration throughout the course of investigation and compilation of this disseration.

I take this opportunity to express my heartiest thanks to Dr.J.S.P.Yadav, Chairman, ASRB, New Delhi and former Director of C.S.S.R.I., Dr.R. Chhabra and Dr.G.P. Bhargava, Senior Soil Scientists of Soils and Agronomy Division of C.S.S.R.I., the esteemed members of Advisory Committee for their valuable suggestions in planning and execution of field trials and preperation of thesis. I am grateful to Dr.J.S.Samra, Dr. R.K. Gupta, Dr.P.S. Minhas and Dr.D.L.N.Rao for informal discussion and their earnest desire to raise my mental horisc through valuable suggestions.

A deep sense of gratitude is also due to my friends particularly Dr.H.S. Baddesha, Dr.C.P. Singh, Dr.Surinder Singh, Mr.B.S.Yadav, Mr.A.K. Bansal and V.G. Mohan Nair whose affection and cheerful compare let me work hard enthusiastically. Sincere thanks are also due to Mr.Bharat Bhushan for his help in analytical work, Mr.Chain Singh for preparing tracings and Mr.Shiv Kumar for his unstinted help and cooperation in the laboratory.

My sincerest thanks are also due to Mr.B.N. Sharma and S.K.B. Singh for their kind cooperation and help in preparing photographs at different stages of field experimentation.

My vocabulary falls short of adequate words to acknowledge the unending help and inspiration received from my respected parents, brothers and a sister. My sincerest gratitude is due to my beloved wife for giving finishing touch to this dissertation.

Harnam Singh Gill
(HARNAM SINGH GILL

Dated: December 30, 1985.

CONTENTS

--.--

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

Tree species are an integral and indispensable constituent of our natural surroundings. They make the environment agile and benevolent. Landscapes devoid of trees or treeless lands are generally called wastelands considered an undesirable inheritance. Though a tree means different to different people but avoiding much controversy it may be defined (Kunkel, 1978) as a long living woody or fibrous plant, with a single or multiple trunk, in its mature stage and in a suitable environment larger than a bush. Sometimes trees are referred as high and upright terrestrial plants. Their growth over an extensive area of land is called a forest.

Trees have always been regarded as representing the apex of development in the plant kingdom (Huber, 1937). This is why the forests are ranked remarkably efficient ecosystems for achieving very high levels of biomass production besides a number of other resource uses for welfare of the mankind. Approximately 90 per cent of the biomass accumulated on the earth is found in forests predominantly in the form of tree trunks, branches, leaves, roots and fallen matter, together with the animals and microorganisms feeding upon it (Lieth and Whittacker, 1975; Lieth, 1977). The annual net biomass production is estimated to be about 50 billion t which exceeds that of all fields, meadows, pastures, steppes, tundras and other forms of vegetation producing biomass through photosynthesis, the chief process of chemical synthesis on the earth.

Inter alia, thus the forests are of paramount importance and uniqueness for their significant contributions measuring prosperity and economy of a nation. They help significant economic development (Westoby, 1962; Brown, 1967; Pant, 1980). The other marked benefits of trees and forests are their influence on the environment (Kittredge, 1948; FAO, 1962; Singh, 1976; Tejwani, 1979). This influence helps in stabilizing the soil (Lundgren, 1978; Rice, 1978) which is a vital natural resource, preventing soil erosion (Anderson et al., 1976; Brunig, 1977; Kunkle, 1978), controlling water run-off in catchment areas (Kunkle, 1974; Ghosh, 1978; Tejwani, 1977; Ghosh and Rao, 1979), providing shelter from wind and heat (Payne, 1968; Delwaulle, 1977; Sangar et al., 1977; FAO, 1978a) and against sand and dust storms (Musa, 1977). Despite these glaring facts and revealation in history that highly developed civilizations went down at the same time as their forests were lost (Geiger, 1965), the forest resource is disappearing fast over the world in general (IUCN, 1977; Ovington, 1965) and developing and or tropical countries in particular (Ovington, 1972; Spears, 1979; World Bank, 1978). India in this respect could not be an exception to this serious drift.

In ancient times, extensive and dense forests occupied very large tract of India. But their exploitation over the last very many decades for continual generation of basic necessities of life for alarmingly increasing population of the country has left it poor with only about 22 per cent of its total area under forests (Anonymous, 1982). For example, the whole of erstwhile north Punjab was a forest in days of Alexander the Great but at present most of this large area is becoming dry and treeless (Puri, 1960).

Continuation of this unfortunate trend unchecked would impoverish agricultural based economy by endangering the health of the agro-ecological system.

Insurance of ecological security to sustain agricultural production in long term also rests on the proportion of the total area under forests. Universally recognized minimal 33 per cent of the geographical area under forest cover very much coincides with India's National Forest Policy enunciated long back on May 12, 1952. Its implementation, however, has remained to achieve. But multiplicity of developmental activities in the mean time in other spheres built up on consistent pressure to produce more and more food to feed rapidly burgeoning population infatuated the forest cover to shrink further. Between 1951-52 and 1975-76 about 4.15 million ha of forest have been deforested to utilise land for agricultural use, rivery valley projects, establishment of industries, construction of roads, conzurbation and other miscellaneous purposes (Swaminathan, 1980). In developing countries about half of the forest land are reportedly (World Bank, 1978) cleared for agricultural use between 1900-1965. Though forecasts vary, it is estimated that in developing countries forests are disappearing at a rate of 15-20 million ha annually (World Bank, 1978). At present levels of demand the remaining tropical forest will disappear in 60 to 80 years (Spears, 1979). Indiscriminate deforestation for agricultural use of land in countries like ours to meet food requirement is the most serious cause behind this undesirable trend.

A large fraction (about 80 per cent) of Indians are rural inhabitants. Firewood is the chief source of warmth and energy to cook food (Argal, 1978). Depending upon climate (mainly warmth and wood scarcity), consumption of firewood varies between 0.5 to 2.0 cubic metre per person annually (Arnold, 1978). The present supply of firewood and timber in our country is exceedingly less than its demand and this gap is predicted to widen further (Swaminathan, 1980). Therefore, illicit felling of trees and production forests besides burning of a few million t of nutrient elements in the form of dung patties and other agricultural wastes of potential manurial value nearly equal to the present consumption of fertilizers occur as a consequence of this dismatch. The National Commission on Agriculture (1976) while reviewing the situation emphasised extension of forest cover through afforestation (establishment of trees on bare or grass land having no forest for at least 50 years; FAO, 1967a) of about 40 million ha land presently lying barren due to one or the other constraint. Sector policies of the World Bank (1978) and the Asian Development Bank (Richardson, 1978) endorse the important development potential of plantation (a forest crop or stand raised artifically, either by sowing or planting; Ford-Robertson, 1971). Therefore, many countries have initiated afforestation programmes aimed more directly at local needs of the given areas (FAO, 1978b).

The Government of India has also recently unequivocally emphasised to devise plans for afforestation of wastelands in the country. A promising category among such lands occupying a sizeable chunk in India (Abrol and Bhumbla, 1971) and the world (Szabolcs, 1977) is commonly referred as salt affected soils. The salt affected soils are wide spread in many states of the country but this problem is being witnessed principally in the Indo-Gangetic plains, arid and semi-arid area of Gujarat, Rajasthan, black cotton soils and the coastal tracts. Nearly 40 per cent of the salt affected soils are confined to the Indo-Gangetic plains of U.P., Haryana and Punjab (Bhumbla, 1977). Principal constraint that impairs their productivity is the soil sodicity hazard. Sodic soils in this region have been formed under the influence of sodium carbonate salt whose hydrolysis imparts high pH and ESP (exchangeable sodium percentage) throughout the soil profile. High ESP and pH cause these soils to possess poor physico-chemical (Abrol, 1977; Acharya and Abrol, 1978; Sandhu et al., 1980; Gupta et al., 1981) and biological conditions (Rao and Ghai, 1985). Sodic soils generally have a hard kankar pan (calcic horizon) of width varying between 40 to 60 cm around one metre depth of the profile. This acts as a barrier not only against downward growth of plant roots but also in the transmission of moisture within the soil profile.

Utilization of sodic soils for afforestation appears to be a promising land use because of the increasing pressure on good soils for food production, fast exhaustion of firewood resources and for healthy maintenance of the agro-ecological system. Unlike the reclamation of only the surface (0-15 cm) layer of sodic soils for viable crop production through gypsum application (Abrol et al., 1973; Abrol and Bhumbla, 1979), management of these soils for afforestation requires amelioration of the soil with limited quantity of gypsum to a deeper depth of the soil profile. Only a few efforts have been made to afforest these soils in the past (Yadav, 1980) and these were mostly complete failures for want to scientific information evolved through research work on the field level. Thus, lack of systematic experimental evidances pose a severe restriction on successful planning and planting operations. Tolerance of various tree species commonly grown on good soils to soil sodicity and mechanical impedance confronted by their roots because of compact and indurated nature of sodic soils at different depths is completely lacking. Therefore, field experiments were undertaken to evaluate selected tree species for their tolerance to soil sodicity and mechanical impedance in a highly sodic soil with particular reference to their root growth behaviour. Following were the objectives of experimentation:

1. Evaluation of selected tree species for their tolerance to high soil sodicity
2. Study of the changes in root systems of selected tree species due to varying degrees of sodicity and
3. Isolation of the effect of sodicity and mechanical impedance on the growth of selected tree species.

REVIEW OF LITERATURE

Enormously increasing population and its expanding demands for livelihood have caused over exploitation and mismanagement of the earth's most abundant natural resource : its forests. For example, about 7.5 million ha forest are being deforested annually (Lanly and Clement, 1979) to put the land under other uses in the humid tropics of the Third World alone. Thus, the most urgent task that faces mankind today demands mitigating the problems of hunger and malnutrition by ways that do not overburden the non-renewable resources of energy and that do not impoverish the environment. One of the important avenues considered relevant in this respect throughout the world is afforestation of barren and degraded forest lands.

These days, therefore, growing awareness is being witnessed regarding planting of trees and management of forests not simply for commercial logging but also for the diverse benefits and requirements of the local community (Joshi, 1982). Several workers (Bene, 1974; King, 1975; Wood, 1975; Johnston, 1976; Eckholm, 1979; Swaminathan, 1980) have urged continued investment on plantation after considering the viability of this concept of planned use of trees for the benefit of villagers and integration of trees into agricultural systems so as to sustain greater productivity of firewood, fodder and food. In order to cope forest resources of India in long term, National Commission on Agriculture (1976) has emphasised the extension of forest cover through afforestation of estimated 40 million ha land presently lying waste. Among various wastelands, salt affected soils occupy a sizeable acreage that possess a vast scope for afforestation. But the scientific information in this respect is greatly limited. The literature pertinent to this investigation was, therefore, reviewed and is presented under five heads:

1. Salt Affected Soils - Their Genesis, Classification and Extent

Salt affected soils are familiar to man for a long time and were studied earlier mostly in academic interest. Population pressure, however, caused it to become an important economic use for their valuable inherent potential agriculturally. These soils are generally characterized as those that have been adversely modified for the growth of most plants by the action or presence of soluble salts (saline) or exchangeable sodium (sodic) or both (Lutz et al., 1965). As a general term for popular use, salt affected soils include both the saline and the sodic soils (Bower et al., 1958). Many workers in India (Leather, 1893; 1897; Talati, 1941, 1947; Agarwal and Yadav, 1954; Hoon, 1955; Kanwar, 1961; Uppal, 1962; Kanwar and Bhumbla, 1969; Abrol and Bhumbla, 1971; Bhargava et al., 1972; Bhumbla, 1977; Bhargava and Abrol, 1978; Abrol et al., 1980) and abroad (Sigmond, 1924; Richards, 1954; Kovda, 1965, 1971; Szabolcs, 1965 and 1980) investigated their nature and properties for their classification and measures of amelioration. In different parts of India, salt affected soils are known by different local terms. They are called Kallar or Thur in Punjab, Usar or Reh in U.P., Luni in Rajasthan, Khar or Kshar in Gujarat and Maharashtra, Choudu and Uippu in A.P. and Chopan in Karnataka.

1.A. Genesis of the Salt Affected Soils: Most of the salt affected soils occur in the arid and semi-arid regions. In general soils in these regions reflect largely the properties of parent material (Buol, 1965) and their formation under natural conditions is a part of the continual geochemical processes going on since ancient geological time. Salt affected soils are formed wherever soluble salts accumulate, sometimes only temporarily, in excessive amounts. The ultimate source of soluble salts in soil originate from the weathering of primary minerals being the rocks; structural constituents (FAO, 1967b, 1973; UNESCO/FAO, 1973). The possible cause of the excess salts are one or more of the several sources namely (a) original salt deposits in the soil, (b) salts contained in the irrigation water applied or lost in conveyance through irrigation distribution system, (c) salts in water inflows (seepage) from upslope, and (d) salts from upward movement (capillary rise) of water from groundwater close to the soil surface (Abrol and Fireman, 1977).

It has been well recognized that soluble salts move with water from land to ocean and extent of their transfer depends largely upon their relative solubilities and extent of rain washing in the soil profile. Soluble salts in course of their transfer from land along-with water confront soils and sub-soils, soil solutions, ground waters, drainage outlets, streams and rivers before reaching the oceans ultimately. This is continuous and reversible process. The position of this cycle is determined again largely by relative solubilities of the salts present (UNESCO/FAO, 1973; FAO, 1973) and the amount of water (rainfall) available (Sen, 1958) to dissolve them.

Definite types of relief and geomorphology play a significant role in salt accumulation in the soil. Thus, a combination of geological (Leather, 1893; 1897; Holland and Christie, 1909; Kovda, 1961), climatological (Shah et al., 1958; Bhargava et al., 1980) and hydrological (Noble, 1950; Kelley, 1951; Kulkarni, 1961; Pandey et al., 1972) factors are reported to determine nature and formation of a salt affected soil. Activities of man were also found to play a significant role in this context (FAO, 1973). A considerable area under normal or only to a very low degree saline or sodic soils face degradation by salinization and or sodification due to human intervention especially irrigation. Such soils are referred potential salt affected soils.

1.B. Classification of the Salt Affected Soils: The major indices used to categorize salt affected soils are (a) salinity of the soil saturation extract as measured by electrical conductivity (ECe) at 25°C, (b) exchangeable sodium percentage and (c) pH of the soil saturation extract or paste or soil water suspensions in a given ratio. Broadly these soils can be divided into five classes (Szabolcs, 1980) namely (a) saline soils, (b) sodic soils, (c) gypsiferous soils, (d) acid sulphate soils and (e) strongly degraded sodic soils. However, first two represent the bulk of salt affected soils (Sigmond, 1924; Talati, 1941; Bower et al., 1958; Kanwar and Sehgal, 1962; Kovda, 1965, 1971; Bhumbla, 1977). A third category of saline-sodic soils is reported (Richards, 1954) to possess attributes both of the saline and sodic group but recently a few workers (Sehgal et al., 1975; Bhargava et al., 1976; Bhargava, 1977; Bhumbla, 1977; Abrol and Bhumbla, 1978; Bhumbla and Abrol, 1979; Abrol et al., 1980 and Szabolcs, 1980) have emphasised that based upon analytical data and mode of amelioration, such soils should be categorized either saline or sodic. The salient characteristics and criteria which distinguish them are depicted in Table 1. However, the salt content or the exchangeableable sodium above which plant growth is impaired depends upon several other factors; texture, distribution of electrolyte or exchangeable sodium in the soil profile, composition of the electrolyte and plant species (Richards, 1954). Physical condition of all soils was also reported (McNeal and Coleman, 1966; Kovda, 1971; Bhumbla, 1977) to be affected differently as the degree of soil sodicity and or salinity increases.

Physico-chemical characteristics of salt affected soils reflect amount and type of the salt present. This is used to classify such soils and is determined by analysis of the soil water under field moisture conditions, though it is not convenient. Therefore most often a soil sample is tested in the laboratory. The standard procedures require saturation of a soil sample with distilled water and then extract with vacuum filtration the moisture from the soil for analyses (Richards, 1954) for EC, pH, quantity and quality of soluble cations (Ca, Mg, Na and K) and anions (Cl, SO_4, HCO_3 and CO_3). Thus, composition of the saturation extract and the relative proportion of exchangeable cations determined by the soil analyses is used to categorize soils into saline, sodic and normal.

1.C. Extent of the Salt Affected Soils: Salt affected soils in India (Abrol and Bhumbla, 1971) and the world (Szabolcs, 1977) are estimated to occupy 7 and 952 million ha of otherwise reasonably fertile land respectively. These soils are prevalent throughout the cross-section of the country (Fig.1) but confine largely in

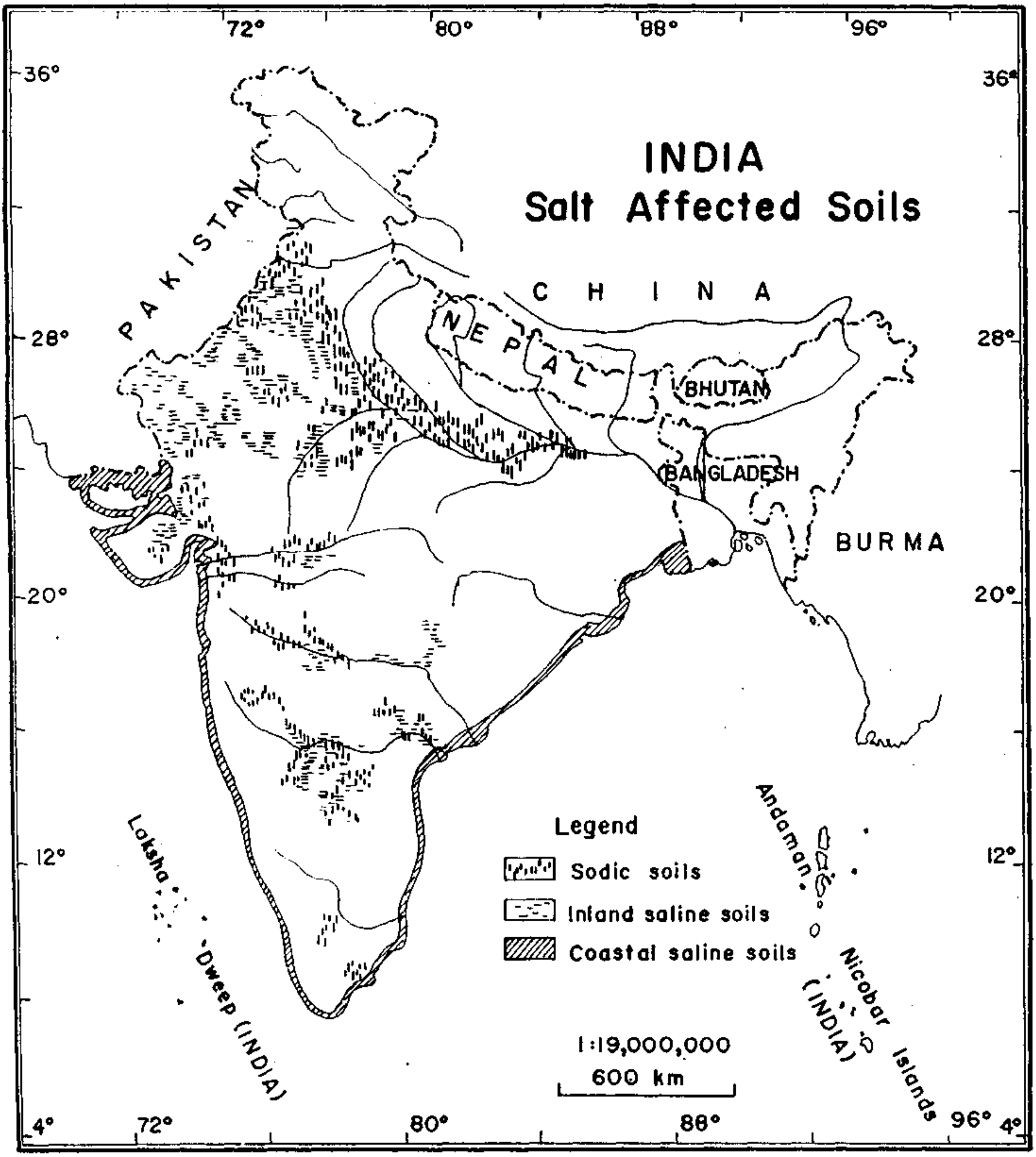


Fig.1. Distribution of salt affected soils.

Table 1. Criteria used to distinguish saline and sodic soils

Characteristics	Saline soils	Sodic soils
Soil saltiness (ECe in dSm^{-1})	4.0 or more	Less than 4.0
Exchangeable sodium percentage	Less than 15	15 or more
Soil reaction (pHe)	Less than 8.3	8.3 or more
Chemistry of soil solution	Dominated by sulphate and chloride anions	Dominated mainly by carbonate and or bicarbonate anions
Effect of electrolytes on soil particle	Flocculation	Dispersion
Main adverse (toxic) effects	High osmotic pressure of soil solution	Alkalinity of soil solution
Geographical distribution	Associated mainly with arid and semi-arid areas	Associated mainly with semi-arid and semi-humid areas
First aim of reclamation	Removal of excess electr-lyte through leaching	Lowering or neutralizing the high pH through chemical amelioration

Source: Szabolcs (1980).

the sub-humid and arid and semi-arid regions and in the coastal areas subject to inundation. Increasing pressure on land resources has affected their reclamation to some extent for agricultural crops particularly in Punjab and Haryana during the past few years. But the exact estimates of area under salt affected soils has not been studied in great detail more recently.

Based on the nature of the soil problem and their geographical distribution, salt affected soils in the country were broadly grouped (Table 2) by Bhumbla (1977). The Figures given in Table 2 are only approximate, as pointed out by Kanwar (1977)

Table 2. Broad groups of the salt affected soils and their extent in India

Broad group	States in which the soils occur	Approximate area (000 ha)
1. Coastal salt affected soils		
(a) Coastal salt affected soils of arid regions	Gujarat	714 (10.14)
(b) Deltaic coastal salt affected soils of the humid regions	W.Bengal, Orissa, A.P. & Tamil Nadu	1394 (19.79)
(c) Acid salt affected soils		16 (0.23)
2. Salt affected soils of the medium and deep black soil regions.	Karnataka, M.P. A.P. and Maharashtra	1420 (20.15)
3. Salt affected soils of the arid and semi-arid regions	Punjab, Haryana and U.P.	1000 (14.20)
4. Sodic soils of the Indo-gangetic plains	U.P., Haryana, Punjab, Bihar, M.P. and Rajasthan	2500 (35.49)
		7044

Figures in parentheses are percentages of the total.

the magnitude of the problem is much more severe because an additional 20 million ha in the canal irrigated areas already run the risk of being degraded through the influence of salts. As this investigation was carried out on a representative sodic soil of the Indo-Gangetic plain, following few paragraphs are devoted to their distribution and salient physico-chemical properties.

Sodic soils in the Indo-Gangetic plains are generally confined to areas with a mean annual rainfall between 550-1000 mm (Bhargava et al., 1980). Sodic soils also occur in isolated patches in Rajasthan, M.P. and Karnataka. Soils in the coastal areas in Navasari district of Gujarat have been reported (Talati, 1947) to have sodicity problem. Salt affected soils rarely occur in areas with rainfall more than 1000 mm whereas in areas with rainfall less than 550 mm dominant soluble salts are chlorides and sulphates which impart the soils saline character rather than sodic (Bhargava et al., 1976; Abrol and Bhumbla, 1977; Bhumbla and Abrol, 1978). Sodic soils occur interspersed with normal soils and may extend, sometimes, to a few thousand ha at a stretch. Sodic soils usually occupy somewhat lower elevation in the otherwise flat terrain (Bhargava et al., 1980).

During the rainy season (July to Sept.), water accumulates in the low lying areas. Weathering of alumino-silicate minerals provides a steady state of alkali bicarbonates which accumulate in the undrained basins. During the ensuing dry season evaporation causes soil solution concentrated resulting in an increase of SAR (sodium adsorption ratio) of the soil solution. In turn, soil ESP and pH increases. The displaced calcium precipitates affecting formation of sodic soils. Continuance of this mechanism over many centuries appears to cause origin of sodic soils and sodium carbonate. Rise in ground water level in regions where such waters have a high sodium fraction relative to divalent and/or high residual alkalinity (RSC) also favour accumulation of sodium in the root zone. In some areas use of ground waters with high sodic hazard for irrigation has resulted in the extension of sodic soils.

Leather (1893) is credited (Agarwal et al., 1979) as the first scientific worker who took up systematic studies on the nature, formation and improvement of sodic soils occurring in U.P. However the findings remained obscure until the implications of the principles of cation exchange phenomena in soils were fully understood. Renewed and vigorous research efforts to understand problems of sodic soils were made between the period 1955 to 1966 by Agarwal, Yadav and associates working in U.P. (Agarwal et al., 1979) and Kanwar, Bhumbla and associates working in Punjab (Kanwar and Bhumbla, 1960-62). The impact of these researches led to the establishment of an institute (CSSRI) in 1969 to undertake mission oriented research which could ultimately benefit the farming community.

Research efforts over the recent past have resulted considerable information on the physico-chemical characteristics of sodic soils of the Indo-Gangetic plains. These soils have several common features(Kanwar and Sehgal, 1962; Govindarajan and Murthy, 1969; Kanwar and Bhumbla, 1969; Bhumbla et al., 1972; Bhargava et al., 1972; Bhargava and Abrol,1978). The salient characteristics are summed up below:

(a) Excess soluble salts are present chiefly in the surface (0-30 cm) layer. Sodium carbonate and bicarbonate form an appreciable fraction of the total soluble salts. Soils have high pH, upto 10.5 of soil-water suspension in 1:2 ratio.

(b) Excess sodium carbonate in the soil causes precipitation of calcium in the soil solution resulting accumulation of sodium on the exchange complex, high pH and high ESP. The ESP values of 80-90 or more are common in the surface layers. Generally, sodicity decreases with depth.

(c) The soils are highly dispersed and consequently have poor physical properties resulting in very low hydraulic conductivity and restricted air movement. The upper most horizon has platy structure.

(d) Sodic soils are usually calcareous and always contain calcium carbonate throughout the profile with often a zone of calcium carbonate accumulation in amounts large enough to qualify as a calcic horizon. This zone varies around 90-140 cm below the surface.

(e) Ground waters in sodic soil areas generally have low to medium electrolyte concentration and are fit for profitable irrigation. However, the ground water may have significant proportion of bicarbonate ion.

(f) The water table may be near the surface in the monsoon season but recedes to about 4 m subsequently.

(g) The soils also show ferro-manganese concretions about the calcic horizon.

(h) There is usually a layer of clay accumulation with very high bulk density. Many soils may have natric horizon usually without a columnar structure.

(i) The common vegetation in the highly sodic areas includes *sporobolus marginatus* Hochst ex.A.Rich and in low lying areas of low salt incrustation *Diplachne fusca* (L.) P.Beauv.

2. Tolerance of Tree Species to Salt Affected Soils and their Afforestation

Multifarious benefits of trees and forests on the ecology (Ghosh et al., 1982; Watson, 1983; Pal, 1984) and economy of a nation (Westoby, 1962; Brown, 1967; Singh, 1975; Richardson, 1978; World Bank, 1978; Grainger, 1980) are a force behind many countries in the world which have undertaken large afforestation programmes (Lanly and Clement, 1979). These programmes require a suitable land for growing trees. Though it is difficult to grow trees on some sites yet there are only a few environments where tree growth is impossible. Apart from these environments, correct choice of tree species and a careful treatment of the site may aid establishment of trees on many very uncompromising sites. Many species are remarkably tolerant of poor growing conditions but raising trees on naturally inhospitable sites usually require special treatment. This needs a thorough understanding of the factors that make the site hostile for plant growth.

A large fraction of salt affected soils in Haryana, Punjab and U.P. form a part of the village common lands or the *Panchayat* (a judicial village body) lands. Although these lands are meant to be used as grazing grounds for village cattle, most often these are devoid of any vegetation of economic value. Thus, these lands do not contribute to the village economy in any way but add to the socio-economic and environmental problems by encouraging run-off and soil erosion. Afforestation of such areas or forestry for rural communities (Arnold, 1978; FAO, 1978b) may generate resources to mitigate local needs.

The _Usar_ Land Reclamation Committee, U.P. (Anonymous, 1938), Bhargava, 1948 and Yadav (1956) first suggested possible exploitation of the salt affected soils for afforestation because trees are considered relatively more tolerant to inhospitable sites. The National Commission on Agriculture (1976) has recently advocated again the need of carrying systematic research on the multiple utility based forestry in diverse agro-climatic regions of India. Therefore, growing of tree crops in the salt affected soils have assumed still special significance.

2.A. _Trials and Techniques on Tree Planting:_ In view of the constraints impairing plant growth in salt affected soils, establishment of a plantation requires a suitable planting technique which fulfils requisites such as (a) availability of soil environment favourable for optimum root growth (b) manipulation of micro-relief conducive for leaching of soluble salts (c) maximum retention of available moisture by soil mass (d) maintenance of soil fertility through application of fertilizers and organic manures and (e) perforation of any type of hard pan present in the subsoil.

Only a few efforts have been made in the past to afforest salt affected soils in India and elsewhere. The earliest evidence dates back to 1863. In 1884, _Acacia_ _nilotica_ (L.) Willd ex Del. (_Babul_), _Dalbergia_ _sissoo_ Roxb. (_Shisham_) and _Azadirachta_ _indica_ Juss.

(Neem) were planted in an area of 1155 ha called Fisher Forest near Etawah. Establishment of Babul plantation during initial stages was good but showed mortality after 10 to 12 years of growth. Duthie (1896) recommended planting of Butea monosperma (Lamk.) Taub. (Dhak) in salt affected soils. Tamarix articulata Vahl. (Tamarisk) and T.gallica L. were also found to adopt well on saline soils. In M.P., Babul, Neem and Mesquite were found (Bhargava, 1956) suitable for afforestation on saline sodic soils.

In an investigation started in 1951 near Lucknow, the comparative performance of Babul, Neem, Siris white (Albizia procera Benth) and Prosopis juliflora (Sw.) DC. (Mesquite) was better (Pande, 1956) when planted in pits 120 cm deep and refilled with good soil. Experiments conducted by the silviculturist of U.P. at different places also showed that planting of trees in circular pits, 40 cm wide and 120 cm deep, refilled with good soil yielded varying success depending on the degree of soil salinity, sodicity, nature and extent of kankar pan.

Ploughing deep to 35 cm alongwith mulching of a 20 cm chernozem soil layer was found (Antipov-Karataev et al., 1957) best for growth of many trees. Bol shakov and Erpert (1956) also emphasised the need of deep ploughing before planting. Technique of sowing or planting of Mesquite on ridges rather than pits gave good performance (Shah, 1957). This may be attributed to the decreased salt content of the ridges through leaching. Joshi (1957) observed heavy casualities in sowing of tree species in saline areas of Kutch desert. Surface and subsoil salinity in conjunction with salty winds blowing from the sea in the coastal areas of Gujarat was observed a major adversity for plant growth. In such areas, planting of

Mesquite saplings gave better results than its direct sowing (Kulkarni, 1959).

Khan and Yadav (1962) suggested that successful afforestation of salt affected soils had rather limited prospects unless the soil conditions were ameliorated to a desired level by adopting suitable methods. State forest departments of Punjab, Haryana and U.P. have made several attempts during the last three decades to raise plantations on such soils but without much success. Pande (1967) reported that soil replacement technique aids a lot for afforestation of salt affected soil. This involved digging of circular pits, 90 cm each in depth and width, and their refilling with good soil from another area before planting tree saplings.

Planting of trees on ridges adjoining trenches has been observed fairly suitable for saline and waterlogged soils as ridge provides relatively salt free conditions and favourable soil mass for root growth. Yadav and Singh (1970) observed about 50 per cent decrease in soluble salts in the soil of ridges as compared to the original level and ascribed this reduction to leaching effected during the rainy season. In Kuwait, salt tolerant species are raised in pits and trenches adjoining ridges with and without irrigation. In saline soils, small mounds of soil are made between the planted rows so that salt water moves toward them by capillary action and leaves behind salts on evaporation on these heaps instead of around the plants (Raja Singh, 1965). Planting of 150 cm cuttings of Tamarix aphylla (L.) Karst. (Tamarisk) gave good results in comparison to its plants in containers.

In Sudan, seedlings of Eucalyptus microtheca F.Muell grown in polythene tubes containing a mixture of river silt and sand were planted to raise irrigated plantations on salt affected vertisols rich in sodium salts and low permeability (Jackson, 1977). Area to be planted is plowed to produce a series of ridges 60-100 cm high and 240-270 cm apart for application of irrigation through channels inbetween the ridges.

Mixing of 10 kg gypsum and 24 kg FYM with original sodic (pH 10.0) soil per pit, 90 cm each in depth and diameter, was reported (Yadav et al., 1975) at par with the good soil for survival and early growth of selected tree species. Alkali Regional Experiment state at Puspokladany in Hungary (Yadav, 1980) has adopted a technique that requires making ridges 100 cm high and 10 m apart by scrapping normal soil of A horizon. This increases the amount of good soil in form of a ridge and tree planting is done both by transplanting two year old seedlings and direct seeding on the top as well as sides of ridges. This helps in rain water conservation. As the A horizon is acidic, lime is added at the rate of 25 t ha^{-1} in the ridge area. Good plantations of Oaks and Populus have been raised on the chernozem soil with a natric B horizon.

In an experiment conducted in 1964 by the silviculturist of Rajasthan on a saline sodic soil at Chaksu near Jaipur, planting technique included staggered interrupted trenches 3.3 m apart within the lines and 16 m apart between the rows. Pits with 60 cm each in diameter and depth were dug at a distance of 16 m between rows of trenches. Half the trench was refilled with the original soil whereas the pits were refilled differently with good and original soil and its mixture with half kg gypsum per pit (Yadav, 1980). Various species tried included *Acacia senegal* (L) Willd., *Tamarindus* indica L., *Prosopis juliflora* (Sw) DC., *Prosopis spicigera* L., *Tamarix articulata* Vahl. and *Parkinsonia aculeata L.* State Forest department of Haryana conducted an experiment on a highly sodic soil in Saraswati area in 1975 and planted *Eucalyptus* hybrid, *Babul* and Siris black (*Albizia lebbec* (L.) Benth. in pits treated with 5 kg gypsum and 20 kg FYM. Survival of Eucalyptus and *Babul* was more than 60 per cent but it was only 16 per cent in *Siris*. In another trial on the same site, replacement of the original soil with good soil and mixing of gypsum with original soil demonstrated greater survival. Mesquite performed better than *Babul* but *Neem* was a failure.

Better survival of saplings planted in the deep pits (60 cm x 60 cm x 90 cm) than in the shallower ones (30 cm x 30 cm x 50 cm) was reported by Ghosh (1977). In another experiment on soil with pH 9.0 - 9.5 and scattered *kankar* pan in the subsoil, trenches (45 cm width and 60 cm depth) adjoining ridges and pits with 120 cm each in depth, length and breadth were dug. Lower half of the pit soil was replaced by good soil (non-sodic) in half of the pits and in the remaining pits whole of the soil was replaced. Vermicullite, gypsum and FYM were mixed separately in different pits. Irrigation was applied in half of the pits. Results showed better growth in irrigated pits but plants in pits having complete replacement with good soil or addition of gypsum showed best survival.

In saline soils of Rann of Kutch area of Gujarat, trenches of 69 cm x 45 cm x 30 cm were dug at a spacement of 3 m x 3 m. Mesquite raised in polythene bags was planted in these trenches. In A.P., trenching and bunding for sowing seeds on <u>bunds</u> (ridges) is considered an easiest method of raising Mesquite plantations. In Sunderban area of West Bengal, ridges 183 cm high are made to prevent saline water entry during tides. The area is kept fallow for 1-2 years to leach out accumulated salts and then coconut plants are planted on small mounds (Ghosh, 1977).

2.B. <u>Tolerance of Tree Species to Salt Affected Soils</u>: Tolerance of tree species to soil salinity and or sodicity can be defined as the ability of plants to survive and produce economic growth under adverse conditions caused by excess of soluble salts or exchangeable sodium percentage respectively. Tolerance of agricultural crops to salt affected soils is typically expressed in terms of yield reduction as a result of an increase in soil salinity or sodicity or as the relative crop yield on a salt affected versus nonsaline-nonsodic soils (Maas and Hoffman, 1977). The salt tolerance of ornamental plants, however, is better expressed on the basis of survival and appearance because yield is not generally important for such species. Trees may also be evaluated as the ornamental plants during initial stages of growth. But the ultimate and determining criteria for their suitability to the salt affected soils would, obviously, rest on their economic growth. Apparaisal regarding tolerance of tree species to a given salt affected soil is generally investigated according to the following guidelines (a) ability of the tree species to survive on salt affected soils, (b) growth of the tree species on salt affected soils, and (c) the relative production of biomass (timber, fuelwood, forage, fruits etc.) by trees on salt affected soils as compared with its production on a normal soil (nonsaline and or nonsodic).

The adverse effects of salt affected soils on tree species can be divided into the following three categories and should be noticed while studying a given salt affected soil:

(a) Osmotic or total salt affect. This phenomenon is due to the osmotic movement of water from the cell towards the more concentrated soil solution causing shrinkage of the protoplasmic lining (plasmolysis). The cell then collapses and ultimately the plant also. But that critical concentration varies with the nature of soluble salts, their proportional amounts, their total concentration and their distribution in the solum. The structure of the soil and its drainage and aeration are also important.

(b) Specific-ion effects or toxicity of specific ions to various plant physiological processes. In sodic soils dominated by active sodium carbonate and bicarbonate three detrimental effects normally observed are, (i) caustic influence of the high sodicity exerted by sodium carbonate, (ii) toxicity of the bicarbonate anions, and (iii) the adverse effects of active sodium ions on plant metabolism and nutrition.

The capacity of higher plants to grow satisfactorily on salt affected soils depends on a number of interrelated factors. The physiological constitution of the plant, its stage of growth and rooting habits certainly are among them. A review of salt tolerance studies made so far indicate focus on the evaluation of agricultural crops and ornamental plants for saline soils. A first semi-quantitative salt tolerance groupings were made by the U.S. Salinity Laboratory Staff (Richards, 1954) and other researchers have added plant species to these lists as more salt tolerance data have become available (Wilcox, 1960; Bernal et al., 1974; Carter, 1975; Maas and

Hoffman, 1977). Plants have not been grouped as extensively with respect to their tolerance to exchangeable sodium as compared to soil salinity, however, some workers (Pearson, 1960; Bernstein et al., 1972; Bernstein, 1975; Abrol, 1982) have made attempts in this direction. Crop yields generally show no significant reduction until the salinity or sodicity exceeds a specific value for each crop. This value is called the threshold salinity/sodicity level or the threshold salinity (ECe)/sodicity (ESP) forthat crop.

Studies on the tolerance of tree species to salt affected soils are a very few. It has been observed, however, that certain forest tree species show greater tolerance to the saline and sodic soil conditions as compared to the agricultural crops. Like crop plants tree species differ greatly in their tolerance to saline and sodic conditions. But only a few efforts were made to investigate trees for their suitability to salt affected soils. This may be attributed to our priority for agricultural production and immense difficulties faced by research workers while investigating trees. Major factors are their longer life spans, slow growth and nutrition and greatly different relationship with the soil system as compared to agricultural crops.

An investigation of the soil profiles under natural growth of a few forest species were undertaken by Hoon and Mehta (1936) who reported great variation among the tree species in their tolerance to salinity and sodicity status. They noticed a fair degree of sodification but low salt content in the soils under Prosopis spicigera L. whereas soils under Tamarix articulata Vahl. had very high salt content and somewhat low pH values. Soils growing Capparis aphylla Roth. showed high pH and high salt content in the lower depths.

A greater variation among the tree species for their tolerance to salt affected soils under different natural flora was reported (Yadav and Pathak, 1957; Khan and Yadav, 1962) associated with place to place in different states of India. Trees like *Acacia* species, *Butea monosperma* (Lamk.) Taub., *Tamarix articulata* Vahl., *Prosopis juliflora* (Sw.) DC., *Prosopis spicigera* L., *Azadirachta indica* Juss. and *Albizia* species were suggested for planting in salt affected soils.

Griffith (1945, 1946) conducted a few field experiments in the erstwhile Punjab to evaluate suitability of different tree species on sodic soils and reported *Acacia nilotica* (L.) Willd.ex.Del., *Prosopis juliflora* (Sw.) DC. and *Prosopis spicigera* L. to be more promising species. Chopra (1945) found *Tamarix articulata* Vahl. good on salt affected (*kallar*) soil though it developed into an open crop. He also prepared a comprehensive list (Chopra, 1939) of trees suitable for afforestation and land reclamation. List included *Acacia dealbata* Link., *Acacia modesta* Wall., *Acer caesium* Wall., *Acer pictum* Thumnb., *Butea frondosa* Roxb., *Capparis aphylla* Roth., *Cedrela serrulata* Mig., *Cupressus torulosa* D.Don., *Dodonaea viscosa* Jacq., *Eucalyptus robusta* Sm., *Maclura aurantiaca* Nutt., *Melia azedarach* L., *Parkinsonia aculeata* L., *Prosopis glandulosa* P. *juliflora* (Sw.) DC., P. *spicigera* L., *Rubina pseud-acacia* L., *Salix babylonica* L., *Tamarix articulata* L., *T.dioica* L., *Thevetia nerilfolia* Juss. Bakshi (1946) has also found *Acacia arabica* auct. mult. to be a valuable species for planting in *kallar* and still clay soils.

Acacia nilotica (L.) Willd. ex. Del., *Butea monosperma* (Lamk.) Taub., *Dalbergia sissoo* Roxb., *Prosopis juliflora* (SW.) DC., *Acacia tortilis* (Forsk.) Hayne, *Salvadora persica* L. and *Tamarix articulata* Vahl. were suggested (Yadav, 1958; Rege and Tamhane, 1964) as tolerant trees for planting in saline and sodic soils that cannot be reclaimed economically for agricultural crops. Yadav and Mathur (1962) reported that seedlings of *Shorea robusta* Gaertn. grew well only in the pH range of 5.6 to 7.8 but failed to survive above this range.

In the Negev Region of Israel, *Eucalyptus cameldulensis* Dehn. and *Pinus halepensis* Mill were found to be most tolerant to soil salinity (Bidner-BarHava and Ramati, 1967). The chlorine content in the leaves of tolerant Eucalyptus species was found to be similar to same species when grown in non-saline soil in humid region. In Kuwait and Sudan, *E.cameldulensis* Dehn. has also provided to be most promising species in arid and saline sites (Raja Singh, 1965). Other species of Eucalyptus found tolerant in such conditions are *E.microtheca* F.Muell., *E.terticornis* Sm. in Sudan and *E.gomphocephalla* A.DC. and *E.obtusa* L.Herit in Kuwait.

Kaushik et al. (1969) reported that *Eucalyptus hybrid* failed to grow on saline sodic soils with pH more than 10.0 and soluble salt content above 0.7 per cent and a compact indurated subsoil mostly due to *kankar*. This species was found to grow satisfactorily on soils having pH below 9.0 and a soluble salt content of upto 0.3 per cent. But better growth occurred when soil pH and soluble salts were less than 8,5 and 0,2 per cent respectively. Yadav and Singh (1970) investigated the range of tolerance of important species for salt affected soils in Vrijbumi Afforestation Division of U.P. All the species showed mortality in soils having pH above 10.0 and soluble salt content above 3.42 in the surface and 1.14 per cent in the subsoil and an indurated subsoil with a cemented bed of *kankar* nodules. *Prosopis juliflora* (SW.) DC. would grow on soils having pH upto 9.5 and soluble salt content upto 0.54 per cent though it could also tolerate a soil having pH upto 10.0 and soluble salt content upto one per cent. *Acacia nilotica* (L.) Wild. ex. Del. could grow satisfactorily on the soils having pH below 9.0 and soluble salt content below 0.3 per cent. *Azedirachta indica* Juss., *Butea monosperma* (Lamk.) Taub., *Dalbergia sissoo* Roxb., *Pongamia glabra* Vent. and *Terminalia arjuna* Wight et. Arn. were found to grow on soils free of salts in the top 60 cm but pH upto 9.8 and soluble salts upto 0.45 per cent in the subsoil.

Mohindra (1973) observed that afforestation of salt affected soils in Punjab was a serious problem unless such soils are ameliorated to the desired level. All the species planted during 1963 (Silviculturist Research Division, Bhadson, Patiala) failed to grow due to excessive salinity and sodicity. In another field trial *Prosopis juliflora* (SW.) DC., *Tamarix articulata* Vahl. and *Eucalyptus tereticornis* Sm. did well whereas all the plants of *Dalbergia sissoo* Roxb., *Albizia procera* Benth., *Acacia nilotica* (L.) Willd. ex. Del. and *Salix tetrasperma* Willd. died.

Eucalyptus cameldulensis Dehn. has been found (Karschon, 1966) to possess high tolerance (in the *Rift Valley* in Israel) of soils rich in calcium carbonate and high levels of soluble salts mainly chlorides and sulphates with pH 7.6 to 8.1. In Kuwait and in Sudan *E.cameldulensis* Dehn. has also proved to be the most promising species in the arid and saline sites (Raja Singh, 1965). *E. microtheca* F.Muell., *E.tereticornis* Sm. and *E.gomphocephala*. A.DC., *E.obtusa* L.Herit. were found tolerant under such conditions in Sudan and Kuwait respectively. *Tamarix mannifera* Ehrenb. has been reported (Karschan, 1966) to do well in solonchak soils of Israel. *Eucalyptus cameldulensis* Dehn., *Acacia eburnia* Willd., *Casuarina torulosa* Dryland,, *Cupressus sempervirons* L. and various species of *Tamarix* have been found to give good results under saline water irrigation in French Sahara

(Karschon, 1956). The cuttings of *T.aphylla* (L.) Karst. have been found (Raja Singh, 1965) successful in soils of Kuwait having alkali salt concentration at surface with poor N and nutrient status and hard pan formed by magnesium and calcium carbonate. Migunova (1976) reported ability of *T.ramosissima* Ledeb. and *T.tetrandra* L. to root successfully in soil horizons containing salts upto 6 per cent including more than 3 per cent sulphates and one per cent chlorides.

Zelenin (1976) in a trial started in 1962 on solonets soils found *Ailanthus altissima* Desf. to be a promising species in dry and saline conditions. Brawn et al. (1978) in a green house experiment observed *Alnus glutinosa* Medic., *Hippophae rhamnoides* L. *Populus* 'Oxford' L., *Salix purpurea* L. and *S.rubens* L. to be highly tolerant to salts. In Pakistan, *Zizyphus jujuba* Lamk., *Albizia lebbec* (L.) Benth., and *Acacia nilotica* (L.) Willd. ex. Del. were found most salt tolerant species (Bangash, 1977). Lohani (1979) reported that *Leucaena leucocephala* (Lamk.) de Wit. a fast growing leguminuous tree of tropics showed good growth on moderate to heavy salt affected soils having pH 9-10. Yadav (1980) showed that *Prosopis juliflora* (SW.) DC., *Eucalyptus* hybrid and *Acacia nilotica* (L.) Willd. ex. Del. can be grown on calcareous sodic soils by treating the soil of the planting pit with gypsum and FYM alongwith applications of a small dose of nitrogen and phosphorus fertilizers. Chaturvedi (1984) reported that *Eucalyptus* hybrid grows well in the first year as long as the roots are confined to the top layer of sand soil but stagnates as it reaches the clay layers offering severe mechanical impedance. Other species namely *Prosopis juliflora* (SW.) DC., *Acacia nilotica* (L.) Willd. ex. Del., *Terminalia arjuna* Wight. et. Arn., *Albiza lebbec* (L.) Benth. grows well.

3. Ameliorative Effect of Tree Plantations on Salt Affected Soils

Planting and establishment of trees on salt affected soils, degraded lands, sites used for the disposal of industrial wastes and sand dunes can be the first important step in soil rehabilitation and land reclamation. The influence of trees and forest on the environment is well understood (Kittredge, 1948; Singh, 1960; FAO, 1962; Tejwani, 1979; Ghosh et al., 1982; Pal, 1984) as it is conducive for reclamation of sites, provision of shelter and shade, watershed management, soil stabilisation and prevention of erosion and arrest of desertification. Tree growth is reported to cause amelioration of salt affected soils by improving their physical, chemical and biological properties. However, studies which examined change in soil characteristics as a result of tree growth are too few to permit generalize its ameliorative impact.

The soil improvement is based on the penetration of strong roots, improvement of humus and nutrients content through return of organic substances from decomposed plant parts and on the enrichment of nitrogen status of the soil through symbiotically fixed nitrogen in case of N fixing trees. Tree species with deep and farreaching roots loosen the soil to promote access of oxygen and water and thus facilitate development of microfauna and flora in the soil. Species that are shading and covering the soil with their canopies change the microclimate drastically enabling the soil fauna to survive and humus to develop rapidly. A suitable climate also plays a major role in the rate of decay of plant parts and determines amount and quality of humus that develops. Thus, suitability of a tree species for purposes of land reclamation require possession of following three characteristics, i.e. (a) General pioneering qualities, i.e. species should be spontaneous raw mineral soil invaders and reach their climax there. They disappear only after having provided the necessary conditions for the development of more complex plant communities. (b) The ability to surive the soi and (c) The ability to stabilize and bind the soil. Chopra (1939) in his monumental publication mentioned suitability of some species out of a comprehensive list for afforestation and reclamation of land in Punjab, although, information regarding their impact on soil improvement was not available then.

Tree growth in solonetzic soil was observed (Vadiunina, 1964) to increase water permeability substantially and lowering salt content of soil as a result of efficient leaching. Water permeability was 17 mm under forest plantations against 10 mm and 4 mm under agricultural crops and virgin land, respectively. Similar observations were made by him earlier (Vadiunina, 1957) also with various shrubs especially Tamarix which exerted a loosening effect in the soil and increased its moisture capacity.

Growth of Prosopis juliflora (SW.) DC. was found (Shah, 1957; Shah and Vora, 1965) to lower salinity and exchangeable sodium percentage of the soil after prolonged occupation. A beneficial effect was also observed under the growth of Tamarix articulata Vahl. Smith (1961) advocated growing of Kochia brevifolia L. for reclamation of severely affected salty lands of Western Australia. Ghildyal et al. (1962) reported that soil under forest cover maintained a higher organic carbon and nitrogen content than under continuous cultivation. Forest soils maintain high status of phosphate and potash whereas continuous cultivation of crops show removal every year with alumina from surface to deeper horizons occured in cultivated soil. Increase in exchangeable calcium applied through gypsum in soda solonetzes of the wooded steppe was observed by Sumbur (1963) in a field experiment. Boyko and Boyko (1966) reported that succulent leaves of Calotrophis show a high salt intake and its cultivation offers desalinization possibilities for saline soils.

Kretinin (1967) noted desalinization and desolonetsization under 30 years old shelter belts. On moderately solonetz-like soils in USSR, Migunova (1972) found desolonetsization under the tree growth. Yadav and Singh (1970) reported a decrease in the pH values and soluble salt content and an increase in the amount of organic matter and nitrogen in the surface soil (0-15 cm) under Prosopis juliflora (SW.) DC. though the soluble salts increased to some extent below 15 cm depth peresumably due to their downward translocation through leaching as a result of improved permeability of sodic soil.

If left undisturbed the ground beneath trees becomes covered with a layer of debris called forest litter comprising dead leaves, twigs, branches, flowers, fruits and seeds etc. This litter layer further protects the soil surface. Loss of an effective litter layer frequently leads to soil erosion. Bell (1973) found that soil loss during one year under teak stands was two and a half to nine times more than under natural forest. Ghosh (1978) also reported an increase in raindrop erosion from 10 to 90 times depending upon rainfall intensity under Shorea robusta Gaertn. forest where the litter had been lost through burning.

Beneath a forest there is generally an almost uninterrupted mat of roots which binds and stabilizes soil particles. The total quantities of roots are very large. Even in a simple ecosystem such as a plantation of Cupressus lusitanica Mill., Lundgren (1978) found

6.1 t ha^{-1} fine roots (less than 5 mm dia.) in the top 50 cm soil layer which almost half were in the top 10 cm. The total below ground biomass of all roots, stumps and root crowns was 71 t ha^{-1}. While trees are alive this root mat is continually renewed and if a root dies a new one soon replaces it. This living network of roots provides mechanical support on steep slopes and is the main contribution to slope strength and prevention of land slides (Rice, 1978).

Under forest cover rain water infiltrates at a higher rate (Ghosh and Rao, 1979) which reduces runoff markedly (Mathur et al., 1976; Ghosh, 1978) and consequent benefit reported (Anderson et al., 1976; Brunig, 1977; Kunkle, 1978) was significant reduction in erosion and sediment loading of streams and rivers. In India, study of 17 major reservoirs showed that sediment deposition rates averaged 917 m^3 km^{-2} annually which is three times greater than was planned because vast areas of forests in the catchment areas had been deforested (Tejwani, 1977). Other effects of trees and forests reported beneficial are shelter from winds (Payne, 1968; Delwaulle, 1977; Sangar et al., 1977; FAO, 1978a), dust and sand storms (Musa, 1977), moderation of evapotranspiration stress (Delwaulle, 1977), arrest of desertification (Darling, 1969; Mikola, 1978; Sharma, 1978; Kassas, 1979) and amelioration of industrial wastes (Hartley, 1977).

In addition to growth of trees on salt affected soils, their effects on the changes in succession of understory vegetation and their growth are completely lacking. Different tree species would have different effects on the undergrowth of natural grasses. Such effects of different tree species need to be evaluated since planting of trees in combination with crops (agroforestry, farm-forestry, shelterbelts) are practised commonly in agriculturally advanced states of India.

Some plants can avoid drought by releasing chemicals which inhibit seed germination and growth of adjacent plants (allelopathy). Such allelopathic chemicals may be released from plants by leaching, volatilization, excretion, exudation and decay either directly or through microbial activity. Among the naturally occurring compounds having inhibitory effects on growth of neighbouring plants are organic acids, lactones, fatty acids, quinones, terpenoides, steroids, phenols, benzoic acids, cinnamic acid, coumarins, flavonoids, tannins, amino acids, polypeptides, alkaloides, cyanohydrins, sulphides, mustard oil glycosides, purines and nulceosides (Rice, 1974).

Best known allelopathic chemical is juglone in *Juglans*. It is washed into the soil from leaves and fruits and inhibits growth of adjacent plants. Went and Westergaard (1949) observed, in California deserts, that *Larrea* seedlings died in the vicinity of adult *Lerrea* plants because of the toxic action of chemical excreted by roots of adult plants. Inhibition of seed germination by existing shrubs was shown in the case of *Salvia mellifera* L. which almost completely prevented establishment of *Adenostema* seedlings under it (Went, 1952). Naturally occurring plant growth inhibitors are widely distributed in tropical and subtropical vegetation. Inhibitors of fruits of *Ilex Vomitoria* A. Gray inhibited germination of seeds of *Prosopis juliflora* (SW.) DC. (Boyey and Diaz-Colon, 1969). In India, *Prosopis juliflora* (SW.) DC. forms dense thickets of small shrubs to large trees. Very few plants come up within the community of these trees and shrubs and the ground is covered with a thick layer of leaf litter. Inhibitors in the leaves inhibit seed germination and growth of shoots and roots of seedlings (Lahiri and Gaur, 1969).

4. Effect of Mechanical Impedance and Soil Salinity on Root Growth Behaviour of Plants

Roots are the only plant organs that keep close intimacy with the growth medium, soil, for almost all the terrestrial plants. But until recently this intimacy was considered to anchor plant in the soil and absorb water and nutrients while shoots entrap solar radiation through photosynthesis elaborating the metabolites on which all growth depends. But it is now evident that interrelationships between roots and shoots are considerably more complex. Mechanisms governing growth of the entire plant depend on growth substances produced both by roots and shoots and the effect of unfavourable soil conditions are sometimes primarily due to interference with these mechanisms rather than to reduced absorption of water and nutrients.

Most commonly recognised factors that make the soil inconducive for optimum plant growth (Arkin and Taylor, 1981) and problematic include salinity, moisture stress, mechanical impedance, nutrient stress, temperature stress, oxygen stress, aluminium toxicity and pathogen effects. Most of the researchers on root systems of plant confine to agricultural crops. Information regarding growth behaviour of tree roots under conditions of good soils in general and salt affected soils in particular is lacking. Since this study dealt with growth of trees in salt affected (sodic) soils where major problems that check plant growth are salinity stress of alkali producing sodium salts, mechanical impedance due to calcic horizon in the soil profile and unfavourable soil structure, relevant literature is reviewed under two heads, i.e. effect of (i) mechanical impedance and (ii) soil salinity on growth behaviour of plants with particular emphasis on roots.

4.A. Mechanical Impedance and Plant Root Growth: The term mechanical impedance refers to the growth response of some plant part as it is mechanically contributed by a volume of soil. Compaction of the soil reduces the volume occupied by pores causing greater mechanical impedance or resistance to root extension, gas and water transmission characteristics of the soil. The parameters that measure soil compactness are (a) Bulk density, mass of oven dried solids contained in a unit volume of soil, (b) The ratio of the volume of voids to volume of solids void ratio, (c) Porosity, the ratio of volume of voids to total volume of soil, (d) Soil texture, relative proportion of variously sized particles in a soil mass (Donahue et al., 1977), and (e) Soil structure, the fortuitous arrangement of aggregates and primary particles as influenced by total past history (Gill and Vander Berg, 1967).

Root growth in soil take place when new cells are formed and the turgor pressure inside these cells is sufficient to overcome constraint of the cell walls and any external constraint caused by the surrounding soil matrix. The difference between turgor pressure and cell wall constraint is defined as root growth pressure (Gill and Bolt, 1955). Growth pressure must be greater than the impedance acting on the crosssection of the plant root if it is to grow.

Dynamic nature of soil water content universally affects soil mechanical properties. Devices used to evaluate the effects of soil water content and bulk density on soil mechanical properties include soil penetrometers (Davidson, 1965), shear vanes (Freitag, 1971) unconfined compressive strength machines (Sallberg, 1965), modulus of rupture (Reeve, 1965) and tensile strength machines (Gill and Vanden Berg, 1967). Soil penetrometers have been used to a greater extent than the other devices for determining the effects of soil bulk density and water content on root penetration. As soil bulk density increases or as the soil water content decreases, penetrometer values increase, however, exact change is soil dependent. Penetrometers of various sizes and shapes have been used in mechanical impedance studies. The three main groups include: (a) Those which measure the pressure required to push the tip to a specific distance into the soil volume usually called a static tip penetrometer, (b) Those which measure the pressure (or force) required to move the tip through the soil at a more or less constant rate, called a moving tip penetrometer, and (c) Those which record the number of blows required to drive the penetrometer tip through a specific depth of soil, called an impact penetrometer.

It has been considered easier to show the relationship between presence of mechanically impeding layers and root growth or shoot emergence than it is to show that such a relationship exists between mechanical impedance and crop yield. Several reasons for this are: (a) Plants require water, essential nutrients and anchorage from the soil. If impeding layers do not increase plant stresses because of a lack of these items at any time of growth cycle, impedance will not affect yield, (b) Definitive experiments showing that mechanical impedance reduces root growth were conducted in the laboratory under conditions of closely controlled uniformity but these conditions seldom exist in fields where most yield trials are conducted and (c) All commonly used strength sensing devices integrate their measurements over soil volumes substantially larger than the size of the plant root.

Small flexible plant roots can penetrate soil layers through soil cracks, worm holes, root channels and other voids that do not significantly affect results obtained with strength sensing devices (Davis et al., 1968; Nash and Balingar, 1974).

Despite these limitations, many experiments (Carter et al., 1965; Barton et al., 1966; Taylor and Bruce, 1968; Lowery et al., 1970; Rogers and Thurlow, 1973; Grimes et al., 1975) have shown that crop yields decrease as the strength of soil layers or volumes increase. Since mechanical impedance is a function of both soil bulk density and water content, addition of water or occurrence of rain (Taylor et al., 1964) decreases soil strength and increases root penetration. The literature also possess references to the pan shattering abilities of various plants such as alfalfa, sweet clover and guar. Elkins et al. (1977) reported that bahiagrass root penetrate soil layers that mechanically impede cotton roots.

The value of penetration resistance at which root eloggation (critical strength) ceases have been reported to range between 8-50 bars (Barley and Greacen, 1967 and Greacen et al., 1968). Soil strength, but not bulk density, was reported to be a critical impedance factor controlling root penetration (Taylor and Gardner, 1963; Taylor and Burnett, 1964). Menzel et al. (1968) found increased crop yields by deep ploughing and very little effect of sodium carbonate application at the rate of 22.4 t ha^{-1}. However, Eck and Davis (1971) reported decrease in root yields (Sudan grass, Soyabeans and Sugarbeets) with deep ploughing but roots tended to be evenly distributed throughout the 90 cm profile when 22.4 t ha^{-1} sodium carbonate was applied to 90 cm plough depth. Sodium carbonate treatment implies use of a chemical that discourages rooting. It was found (Menzel et al., 1967) effective to do so while investigating and segregating the effects of soil moisture, tillage, deep ploughing and profile modification etc. on rooting habits of crops.

Sands et al. (1979) reported that organic matter and management were important in maintaining favourable soil structure were important in maintaining favourable soil structure of sandy soils in Australian Radiata pine forests. Gerard et al. (1982) reported that bulk density, voids and clay content influence soil strength at all depths. They found significant influence of soil strength, volumetric water content, voids and clay content on root growth. The critical strength defined as the probe pressure at which root elongation stopped was a function of clay content and ranged from 60-70 bars in coarse textured to 25 bars in clay soils. The climatic factors like temperature and rainfall are also very important in this context. Low temperature in the planting season imposes a major restriction on early root regeneration which in turn inflicts water stress in the transplants (Nambiar et al., 1979). This needs to be considered during the planning of planting and fertilization.

Viewing foregoing discussion in light of objective of present study it emphasises great important of the mechanical impedance to tree growth. Because of perennial growth of tree species and their deep and extensive root system, studying growth behaviour toward root impeding layers in sodic soils is imperative. This understanding may help manipulating a planting technique and selection of tree species for successful establishment of plantations in sodic soils which are generally dense and compact with a hard clay layer or a cemented bed of kankar in the lower depth and present severe impedance to root growth and development.

4.B. Soil Salinity and Root Growth: Most of the reported studies on plant response to soil salinity show that predominant influence of soil salinity on plants is growth suppression. Typically, growth decreases linearly as salinity or sodicity increases. Comprehensive enumeration regarding salt tolerance of agricultural and horticultural crops has been done by several workers (Pearson, 1960; Wilcox, 1960; Bernstein, 1975; Carter, 1975; Reisenauer, 1976; Maas and Hoffman, 1977; and Abrol, 1982). Inspite of better understanding of effects of soil salinity on plant growth, much still is unknown. Alleviation of salinity stress through agronomic management and reclamation of root zone for agricultural production in salt affected soils has drawn much attention (Hoffman, 1981). But information about root growth behaviour of plants under such situations is limited.

It is well known that soil effects the plant primarily through its effect on the root system. Amounts of nutrients available to roots, oxygen supply, soil moisture content, soil temperature, level of toxins and pathogens in the soil, system of pores into which the roots can grow, shear strength and compressibility of soil are the principal factors determining the rate at which the root system of a plant will grow. But in salt affected soils, beside these factors, reductions in growth occur from; (a) osmotic stress caused by the total soluble salt concentration, (b) toxicities of nutrient imbalances created when specific solutes become excessive, and (c) a reduction of water penetration through the root zone caused by excess sodium inducing a deterioration of soil structure.

Abrol and Acharya (1975) observed that during the initial years of sodic soil reclamation, root distribution is restricted to surface soil because of high sodicity in the subsoil. The tolerance of root systems of different species to sodicity at lower depth, therefore, determines the soil volume confronted by roots for nutrition and water requirements. Acharya et al. (1979) reported that with increasing exchangeable sodium the root zone becomes limited and this coupled with reduced upward flux of water to the growing roots results in rapid depletion of the surface soil. Taylor and Klepper (1973) found that corn roots deep in the profile were probably more efficient per cm of root for water uptake than shallow roots because they were younger and in the wetter zone. Root distribution of different crops on different soils were investigated by several workers (Bloodworth et al., 1958; Long, 1959; Foth, 1962; Mech et al., 1967; Burnett and Hauser, 1968; Eck and Taylor, 1969). Carlson (1966) and recently Bohm (1979) reviewed numerous methods for characterization of root systems and their advantages and disadvantages. But such studies in salt affected soils are met general overlook.

The development of roots from an anatomical viewpoint has been reported for many tree species (Bannan, 1940; Stout, 1956; Kramer and Kozowski, 1960; Wilcox, 1962; Bray, 1963; Wilson, 1964; Kozlowski, 1971) and it was found that root structure is similar among widely separate genera of trees (Laitakari, 1929; Sasu, 1943; Wilcox, 1954; Wilson, 1964; Lyr and Hoffman, 1967; Zimmermann and Brown, 1971). Generally salinity checks root growth as well as shoot growth of plants. Suberisation occurs closer to the root tip in the salt affected soils because root growth is retarded. Sometimes bu[illegible] regions develop just behind the tip. But effect of soil salinity and sodicity on the root growth behaviour of different tree species, has not been evaluated thus far. Information on these aspects is, however, vital for planning forestry programmes. Further-more, most of the available information about trees of temperate climate studied either under controlled (green house) or natural forest conditions holds no good for relatively fast growing tropical and subtropical trees grown under diverse situations of soil and climate.

5. Water Relations and Tree Growth

The distribution of vegetation on the earths surface is controlled more by the availability of water than by any other single factor (Kramer, 1969). The adverse effects of plant water stress resulting from lack of precipitation can be checked by irrigation. For efficient water use in crop production, water must be stored in soil and plants must be capable of extracting it easily for growth and reproductive purposes. The posy system form a reservoir for the water that enables plants to survive and grow, even though the water additions are intermittent (Gardner, 1968).

Factors which affect soil water storage include soil texture, organic matter content, depth to impervious layers, density and structure. The upper limit of water availability to plants (field capacity) generally base on water contents after saturated soil has freely drained by subjecting wetted soil to pressures in the range from 0.05 to 0.3 bar (5-30 kPa) in pressure chamber. The lower limit (permanent wilting point) is estimated by determining the water content at which indicator plants growing in the soil wilt and then fail to recover turgor when subjected overnight to a humid atmosphere, or by determining the equilibrium water content of wetted soil subjected to pressures of 15 bars (1500 kPa) in an appropriate equipment (Peters, 1965; Kramer, 1969). But this range may vary with plant species and soil types.

Sodic soils are dense and have compact subsoil underlain by a calcareous (kankar) soil zone. The dense, high sodium-soil and indurated calcic layer restrict water infiltration and root development (Abrol and Acharya, 1975; Acharya et al., 1979). Thus, root zone modifications for alleviating plant water stress are made to change the physical and chemical environment of soils so that more water is made available for plant growth. This implies that in sodic soils any modification which expands root zone would be helpful. Deep rooted woody vegetation extracts more water from a greater soil depth than the grassy vegetation (Bethlahmy, 1962; Rogerson, 1976; Gray, 1977; McColl, 1977) so that moisture extraction and storage in the profile is differential with different plants. Deep ploughing has been reported to increase crop yields in salt affected soils by improving water storage (Rasmussen et al., 1964; Sandoval et al., 1972; Carins and Bowser, 1977) and by lessening of soil strength (Taylor and Burnett, 1964; Taylor and Bruce, 1968).

A favourable internal water balance is also an important factor determining the growth of forest trees. Water maintains turgor of photosynthetically active guard cells. Importance of high turgor to photosynthesis cannot be overemphasized. Furthermore the loss of growth frequently attributed to competition or root injury is often traceable to decreased absorption of water leading to desiccation of the tree crown. Thus, ability of root system to absorb water has an important bearing on the water relations of tree species.

Trees primarily obtain water from the soil but they may also obtain from the atmosphere (Slatyer, 1957; Waisel, 1960; Fritschen and Doraiswamy, 1973; Azevedo and Morgen, 1974) and from adjacent trees if their roots are grafted together (Kozlowski and Cooley, 1961; Eis, 1972). Transpiration demands can be fulfilled atleast in part by water stored in various tissues. This is particularly evident in orchard trees having fruits with large amounts of water (Chaney and Kozolowski, 1971; Waring and Running, 1976; Pereira and Kozlowski, 1978).

Water deficits in trees have been characterized in terms of moisture content on fresh or dry weight basis, relative water content also called relative turgidity, saturation deficits and water potential. Water deficits in trees affect many physiological processes resulting loss of growth. Severe water stresses may injure trees and often kill them. Zahner (1968) reviewed the information showing adverse effects of water deficits on tree growth. However information on relationship of tree growth and water balance of soil and plants is limited and needs to be studied intensively.

MATERIALS AND METHODS

The present study aimed at the evaluation of selected tree species for their tolerance to sodicity and mechanical impedance in a highly sodic soil with particular reference to their root growth behaviour was accomplished by carrying out field experiments beside detailed analytical appraisal of the soil of experimental site (Plate 1) for its salient physical and chemical characteristics. Field experiments were conducted at an experimental farm of the Central Soil Salinity Research Institute near village Gudha of Karnal district of Haryana (Fig.2). High soil sodicity hazard of the site is representative of the sizeable chunk of sodic soils occurring in the Indo-Gangetic plains of Haryana, Punjab, Uttar Pradesh, Bihar, Madhya Pradesh and Rajasthan.

3.1 Physico-chemical Characteristics of the Experimental Site

Before experimentation, pits were dug to expose vertical section of the soil throughout its horizons extending down to a depth of two metres (soil profile) at three places within the experimental field. This was done to have an insight into the problems of high soil sodicity and mechanical impedance of an indurated hard pan in the soil which may explain behaviour of the soil towards its use and management for growing tree plantations. Some of the important physico-chemical properties of different horizons of soil are presented in Table 3. The morphological description of the representative soil profile within the experimental field was recorded and is presented below:

Plate 1

Natural landscape of a highly sodic soil

A young (42 months old) plantation of Acacia on a highly sodic soil.

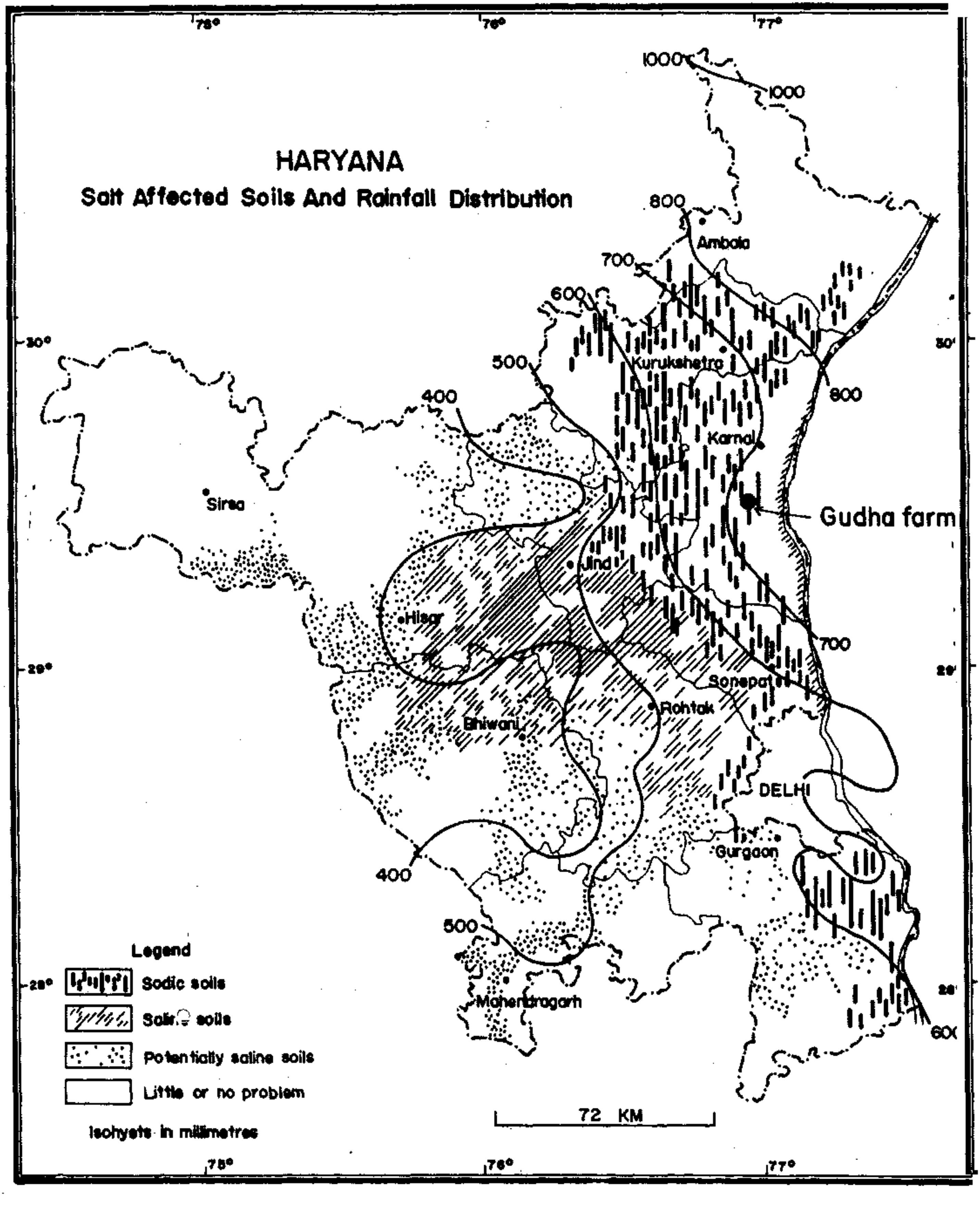


Fig. 2. Distribution of salt affected soils.

Table 3. Some important physico-chemical properties of a highly sodic soil profile in the experimental field.

Soil horizon	pH*	EC* (dSm^{-1})	Detritus	$CaCO_3$	Sand	Silt	Clay	Textural class	ESP
			($g\ 100\ g^{-1}$ soil)						
0- 15 cm	10.5 (10.3-10.6)	3.98 (3.6-5.2)	0.58 (0.4-0.9)	0.68 (0.5-1.1)	54 (52-58)	27 (22-32)	18 (16-20)	sil	96 (94-98)
16- 27 cm	10.2 (10.1-10.4)	1.76 (1.4-1.8)	2.46 (1.1-3.2)	0.72 (0.6-1.1)	51 (48-52)	27 (25-31)	23 (21-24)	sil	97 (96-99)
28- 46 cm	10.1 (10.0-10.2)	1.04 (0.9-1.4)	3.88 (3.6-4.0)	0.79 (0.6-0.9)	49 (46-50)	26 (24-28)	24 (21-25)	sil	98 (97-98)
46- 87 cm	10.0 (9.9-10.)	1.12 (0.9-1.2)	5.82 (3.6-9.2)	0.92 (0.6-1.8)	54 (50-58)	20 (18-23)	25 (22-28)	cl	96 (94-98)
87-139 cm	10.0 (9.1-10.1)	0.96 (0.8-1.2)	34.26 (21.6-46.4)	6.32 (2.6-9.4)	51 (46-54)	23 (21-27)	19 (16-23)	l	92 (90-94)
140-200 cm	9.9 (9.3-10.1)	0.62 (0.4-1.1)	7.46 (5.4-11.2)	9.37 (8.6-18.7)	65 (62-67)	18 (16-20)	11 (8-14)	ls	72 (58-78)

Figures in parentheses indicate observed variation among six determinations.

*Measured after shaking soil water suspension in a ratio of 1:2 for half an hour.

Textural classes are designated following triangular textural diagram based on international fractions.

Soil horizon	Morphological description
0 - 15 cm	Yellowish brown (10 YR 5/4) when moist and very pale brown (10 YR 7/3) when dry; silty loam; moderate to strong; fine to medium; platy and subangular blocky; sticky and plastic; slightly firm when moist, hard on drying; common fine and medium oblique pores; few fine roots; clear smooth boundary.
16 - 27 cm	Dark yellowish brown (10 YR 4/4) when moist and very pale brown (10 YR 7/3) when dry; silty loam; strong, coarse, subangular blocky; very sticky, very plastic; firm when moist; extremely hard on drying; few fine pores; very few fine roots; strong effervesence; clear smooth boundary.
28 - 46 cm	Dark yellowish brown (10 YR 4/4) when moist and pale brown (10 YR 6/3) when dry; few, fine prominent, yellowish red (5 YR 4/6) mottles; silty loam; strong, coarse, angular blocky; very sticky, very plastic; firm when moist, extremely hard when dry; thin patchy cutans; common fine pores; very few fine roots; strong effervescence; clear smooth boundary.
47 - 87 cm	Dark yellowish brown (10 YR 4/4) when moist and pale brown (10 YR 6/3) when dry; few fine, faint yellowish brown (10 YR 5/6) mottles; clay loam; strong, coarse, angular blocky; very very sticky, very plastic; slightly firm when moist; thick patchy clay skins on ped surfaces; common fine pores; strong effervescence; few fine iron-manganese concretions (less than 5 mm); wavy, smooth boundary.

88 - 139 cm	Brownish yellow (10 YR 6/6) when moist and light yellowish brown (10 YR 6/4) when dry; loam; strong, medium, subangular blocky; sticky, plastic and friable when moist; few fine, oblique pores; violent effervescence; few fine iron-manganese concretions (less than 5 mm); abundant, fine to very coarse calcium carbonate concretions (upto 60 per cent); wavy, smooth boundary.
140 - 200 cm	Yellowish brown (10 YR 5/4) when moist; few medium distinct yellowish brown (10 YR 5/6) mottles; loamy sand; weak and fine subangular blocky; non-sticky, non-plastic; friable when moist; thin patchy cutans; few fine pores; violent effervescence; coarse calcium carbonate concretions; very strong effervescence; very few iron-manganese concretions (less than 5 mm).

The pH and ESP were very high throughout the soil profile. The soil of experimental site had a layer of calcium carbonate concretions at a depth of 80-90 cm to 130-140 cm. But there was significant local variation in respect of the width and position of concretion (kankar) layer in the profile, size of concretions and $CaCO_3$ content of the soil (excluding detritus of more than 2 mm diameter). Detailed analysis of soil for some of the important physical and chemical characteristics of soil layers each of 15 cm width from the surface down to 240 cm was carried out to identify and quantify their effect on growth of tree species and for better understanding of the growth constraints in a highly sodic soil.

The relevant data obtained from this analytical exercise are presented and discussed in Chapter - IV. The specific details of each of the experiments including the materials and methods are presented in the next chapter separately alongwith the experimental results for the sake of brevity. The methodology common to all the experiments is presented below.

3.2 Cultural Practices Adopted for Experimentation

(a) Bunding of the Experimental Field: First operation involved in carrying out field trials was construction of adequately strong and high bunds on periphery of the experimental plot. This was done to restrict entry of run-off water from outside into the experimental area and conservation of good quality rain water within the field so that its use can be made by the growing tree plants and natural vegetation effecting reclamation. Channels were provided for the drainage of excess water accumulated on heavy occurrence of rainfall, if any, sometimes during the rainy season or otherwise. Within an experimental field as many plots were made to accommodate the given number of replications of each treatments. In each replication four saplings were planted. Number and size of the plots depended on the spacing and treatments in an experiment. The network of ridges favoured conservation of rain water by preventing its accumulation in depressions within the field and in turn checking of run-off losses.

(b) Digging of Postholes and Pits for Planting Trees: Postholes and pits (where required) were dug out using soil augers and an assortment of implements like spades and shovels respectively. Two types of soil augers were used. The first type included augers operated manually and the mechanically operated auger run through tractor power constituted the second. Manually operated soil augers were fabricated locally but the mechanical one was purchased from the Union Forging, Ludhiana (Plate 2). The dimensions (depth and diameter) of the postholes were controlled mainly through the size of auger blades and their working to dug out postholes down to the desired depth. The rapid preparation of postholes was found convenient following addition of water in postholes being dug out through manually operated soil augers. This resulted in the soil turning into a paste unsuitable for reuse in preparing a filling mixture. Therefore, the soil used in the filling mixture was prepared arresh (explained on the next page separately). But making of postholes with mechanically auger did not involve addition of water and the dug out soil could be used for filling of postholes after mixing proper doses of amendments with it. However, to minimise variation in the nature of soil to effect sapling growth during early stages of planting, soil from the same location was used to prepare a filling mixture for all the postholes and or pits within an experiment.

(c) Filling of the Postholes and Pits: The dug out postholes and pits were refilled with an appropriate filling mixture. A filling mixture means the amended soil mass prepared by through mixing of amendments like gypsum, FYM, sand, rice husk and fertilisers with the original sodic soil collected from a suitable site within the experimental field. Their dose varied depending upon the objective of an individual experiment. The amount of mixture required to refill a posthole or a pit was determined by filling a dummy in each case. After knowing the quantity of mixture required to fill a given posthole and pit, postholes and pits were packed compact by pressing the mixture added

Plate 2

A tractor power driven mechanical posthole digger

in increments through simultaneous blowings of an appropriately sized wooden log. This was done to effect compact refilling so that there should be little settling down of filling mixture within the postholes and pits upon watering to the planted saplings of tree species.

(d) Preparation of a Filling Mixture: Based upon the results of detailed analysis of soil representing different locations within the experimental field, it was observed that spots supporting natural vegetation comprising grasses like Diplachne fusca (L.) P. Beauv. (Karnal grass), Cynodon dactylon (L). Pers (Bermuda grass) and Dichanthium annulation (Forsak.) stapf. have relatively lesser alkalinity and salinity hazard. Such spots were selected for preparation of the posthole/pit filling mixtures. But surface soil showing natural growth of Desmostachya bipinnata (L.) stapf. and Sporobolus marginatus Hochst. ex. A. Rich was found severely affected with either high soil salinity or alkalinity or both. Therefore, depending upon the natural vegetation, trenches 500 cm long, 200 cm wide and 30 cm deep ($500 \times 200 \times 30\ cm^3$) were dug with spades to collect about 5 t of the soil per trench at as many locations to suffice the calculated requirement for the given number of postholes and or pits in an experiment.

Dug out soil was crushed to break clods and stubbles into a fine tilth amendable for thorough mixing of amendments. Before mixing the amendments, finely prepared soil was left in the sun for drying so that it did not favour clod formation and remained in a friable state. Stubbles and extraneous material was picked or removed during the digging and mixing operations. Digging of wet soil is conducive to clod formation and difficult to work with whereas too dry soil required laborious digging and simultaneous troublesome clod crushing. After preparing a friable soil mass the desired amount of amendment was mixed to the soil thoroughly with spades for use as a filling mixture. Composition of the filling mixture varied depending upon the treatment and thereby different types of filling mixture were prepared separately using the soil for all types of mixtures from the same location.

(e) Planting of Tree Saplings in Pits and Postholes: In the differently prepared pits and postholes, saplings of a given tree species were planted. Required number of robust saplings for each experiment were segregated from a large population in respect of their uniform growth to eliminate development of significant differences among them subsequent to planting due to differences in their growth before planting. Saplings for all the experiments were selected from nurseries raised by the State Forest Department of Haryana at locations nearby the experimental site. Saplings were raised mostly in individual containers (polythene bags) and were taken to the planting site. Saplings were planted with an intact fall of soil around the roots (after removing the polythene bag) in the centre of each posthole or pit in such a way that whole of the ball was burried 10 cm below the surface level. Ameliorated soil around the ball was replaced and pressed with the toes to effect compaction. An earthen ring 60 cm in diameter around each saplings was built with the same filling mixture to enable watering/irrigation. An earthen ring means a deep saucer made of soil mass with plant in the centre for maximum use of applied water by the plant. This also kept excess water away.

(f) Watering of Planted Saplings: Immediately after planting the saplings in pits or postholes and construction of earthen rings around them, plants were watered. Saplings were watered for about six months subsequent to planting on the need felt basis to ensure their establishment. Frequency of watering to planted saplings depended on the weather conditions, growth stage and depth of the posthole or pit. Further, it also varied with the planting season. Saplings planted during spring season (March-April) required more frequent watering than those planted during the monsoon (July - September) season.

(g) Weed Control: Weeds tended to grow around the sapling subsequent to planting because of congenial availability of ameliorated soil mass and regulated moisture supply from otherwise barren sodic soil. Weeds were controlled by manual hoeings until 24 months past plantings. Hoeings may also be required to break strong crustation, occured after watering or irrigation, to induce proper aeration. Natural growth of weeds mostly grasses on areas between the earthen rings with tree plants in the centre was not disturbed. This vegetation was usually harvested during winter season (December-January) and the biomass yield ha^{-1} was recorded on oven dry basis. After 24 months of planting weed control measures were not practised and their growth was accounted for with the vegetation harvested every winter season.

3.3 Growth Measurements: Growth of saplings subsequent to planting was monitored by recording following indices at monthly intervals during the first year and quarterly afterwards.

(a) Height: This was measured to the nearest cm by a calibrated two metre rod. But in case of taller plants, a tape fixed on a straight wooden pole or on iron rod of appropriate length was used to measure height.

(b) Girth Girth growth was monitored by measuring diameter of the stem periodically at 5, 30 and 137 cm height above ground level.

(i) Diameter at Stump Height (DSH): It is the diameter in mm of the stem of plant at stump height (5 cm above the ground level). This was measured over the bark using a calliper.

(ii) Diameter at Breast Height (DBH): It is the diameter in mm of the stem of plant at breast height (137 cm) above the ground level) and was measured with a calliper over the bark. This observation was made only when the tree plants were observed grown up to about two metres height.

(iii) In one experiment girth was also measured at 30 cm height of the stem.

3.4 Biomass Production

(a) Tree Biomass: Total biomass production was estimated by harvesting standing tree plants at different stages of growth. Total biomass comprised weight of each of the different plant components namely foliage, woody material including the bole and billets and the roots. Fresh as well as oven dry weight of these components was measured separately to compute total biomass of a given plant and is expressed in kg or g plant^{-1}. Corresponding value in kg or t ha^{-1} is also given where considered necessary accounting for the spacing allowed as density (area plant^{-1}) of a plantation effect marked influence on the biomass productivity.

(b) Shoot: Root Relations: The shoot : root ratio (a measure of the distribution of dry weight between shoot and root systems of the plants) evaluates relationship between above ground and below ground growth of plants and was calculated from the actual weight of the two components.

(c) Biomass Production of Grasses: In a few experiments natural growth of vegetation mostly grasses (*Diplachne fusca* (L) P. Beauv., *Cynodon dactylon* (L.) Pers., *Sporobolus marginatus* Hochst. ex. A. Rich. and *Dicanthium annulatum* (Forssk.) Stapf). was let undisturbed on the ground except in the vicinity of standing tree plants until 24 months past planting. Subsequently natural growth was allowed all over the surface (no weed control). Air and oven dry biomass yield (kg ha^{-1}) of plots was estimated by harvesting grown up vegetation only once a year during December.

3.5 Root Studies

Root systems of different tree species at various growth stages were studied intensively. The procedure followed to expose the complete root system involved removal of the surrounding soil through careful excavation of the soil surrounding the individual root. After selecting a tree plant, its growth indices were determined and recorded. Aerial parts of large plants were harvested before starting excavation but in young plants this was not done. Different steps involved are briefly discussed below:

(a) Digging of the Trench: After selecting a specimen, a trench was dug at a distance of 200-500 cm depending on the species, growth stage and vigour. Depth of trench varied considerably depending upon the depth of root penetration of a given plant and ranged between 100-300 cm.

(b) Excavation of the Root System: To expose the root system of a plant after digging the suitable trench, combination of finely rounded tapered point of screw driver and water under pressure (often referred to as wet excavation procedure) was utilised to remove soil particles from the root system starting with the surface soil and gradually working downward and into the face of the exposed profile. Water pressure helped dislodging and flushing away the soil particles rapidly without causing breakage and loss of fine roots. Two types of nozzle used included one which produces a fine spray or mist and another which supplies a pulsating stingle narrow stream of water at relatively higher pressure. Under water accumulated on one side of the sloped bottom of trench and was bailed out manually.

(c) Layer-wise sampling of Root System: After exposure of the root system of a tree on its eastern side, entire system was sampled in layers of 15 cm each down to the point of maximum penetration separately in different rectangular sieves (120 cm X 180 cm) alongwith the soil. This was achieved by harvesting all the roots alongwith the soil first from the surface layer and then downward likewise with the help of spades, sharp shovels and a small saw.

(d) First Washing of Sampled Roots: Roots alongwith the soil sampled in sieves were immersed for half an hour in such a way in water bath that allowed no loss of roots by floating. Repeated swirlings given to sieves afterwards helped flushing down the soil. Apart from this, roots were washed with hand and moderately hard hair brush to remove the sticking soil particles.

(e) Cleaning of the Washed Roots: Adequately washed roots were then cleaned of extraneous organic materials (rice husk, FYM particles, roots of weeds etc.) and inorganic (detritus, soil etc.) materials manually with the help of forcepts and washing of roots in smaller lots by hand in the field itself. Washed roots were packed in appropriately sized moistened cotton cloth bags for transport to laboratory.

(f) Storage of Roots: Roots packed in cloth bags were stored in a dry cool room for further processing immediately. The storage of roots for not more than a week was practised by preserving them in dilute solution of 4 percent formaline or 10 per cent ethanol. But preservation of roots for more than a week was done by storing in a freezer.

(g) Second Washing of Roots: Transfer of root samples from the field to laboratory followed by their washing in 5 per cent hydrochloric acid (1.18 g cm^{-3}) solution. Soil particles were rubbed and washed away with a tooth-brush. Two washings with distilled water were given subsequently before processing of root samples for measuring selected parameters whereas second washing to stored roots was given only when taken up for recording root parameters.

(h) Segregation of Root Samples: After second washing of roots in laboratory, each sample was segregated into two sub-samples containing (i) fine (less than or equal to 5 mm diameter) and (ii) large (more than 5 mm diameter) roots using callipers and secateurs. These samples were later used to measure different root parameters.

3.6 Measurement of Root Parameters

The root parameters selected to express root growth behaviour and the method of their measurement are briefed as follows:

(a) Root Weight: Fresh as well as dry weight of roots collected from each layer were measured for each plant as below:

(i) Fresh weight: The fresh weight of roots was determined after four hours air drying of washed root samples in the laboratory just before segregating the total lot into fine and large roots. Air drying time varied during winter and summer to ensure complete loss of free moisture adhering to the root samples.

(ii) Dry weight: This was determined after oven drying of each root sample at 75°C for 60 hours or until content weighing of root samples.

(b) Maximum Root Diameter: The maximum root diameter was measured with a calliper directly on freshly washed roots samples in the field.

3.7 Estimation of Root Cation Exchange Capacity (RCEC)

On exposure of root system of a plant in the field, root samples with diameter (mm) less than 2, 2-5, 5-10, 10-20, 20-40 and more than 40 were collected each from the root zone representing 0-25, 26-50, 51-75 and 76-100 per cent of the maximum root penetration depth. These samples were washed carefully with deionised water in the laboratory to wash away adhering soil. The roots were dried for 48 hours at 80°C and ground to pass one mm sieve in a Willey mill. Subsamples of 0.2 g for leguminuous and 0.4 g for nonleguminuous trees were withdrawn for cation exchange capacity measurements. The RCEC was determined in triplicate by suspending the ground-up roots in 0.01 N HCl for 5 minutes and then washing with distilled water and titrating with 0.01 N KOH until the pH of the roots changed from acid to neutral. The RCEC values were computed as me 100 g^{-1} of dry root tissue (Crooke, 1964).

3.8 Analysis of Plant Materials for Chemical Composition

Different plant material like leaves (Juvenile, fully developed, Old, Chlorotic and shed), shoots (stem or boll, billets and juvenile branches) and roots (very fine, fine, small, medium, large and very large with root diameter (mm) less than 2, 2-5, 5-10, 10-20, 20-40 and more than 40 respectively) were analysed for their chemical composition. Specificity adopted in their collection is briefed in methodology of the given experiment. After collection, given plant materials were ~~w~~ washed well with acidulated (0.1% HCl), distilled and double distilled water prior to oven drying at 70°C for 60 hours. These were later ground in a Willey mill to pass through a one mm stainless sieve and stored in polythene bags. These samples were analysed for total Na, K, Ca, Mg, Fe, Mn, Zn, Cu, P and S following their digestion in diacid (HNO_3: $HClO_4$ :: 3:1) mixture as outlined by Piper (1950). The samples were also analysed for total N following the method described by Wolf (1982). Uptake of the said nutrient elements by a tree plant was also computed taking into account for their concentration in foliage, woody material (boll and billets), roots and oven dry biomass of each plant component.

3.9 Measurement of Relative Turgidity

In order to investigate effect of different practices related to planting of selected tree species on plant water relations, relative turgidity (RT) of leaves was estimated following the procedure outlined by Barrs (1968) and the formula given below:

$$RT = \frac{(\text{fresh weight} - \text{dry weight})}{(\text{fully turgid weight} - \text{dry weight})} \times 100$$

3.10 Analysis of Soil for Chemical and Physical Properties

Composite soil samples were collected from at least four locations in each experiment in 16 layers of 15 cm each from the surface to 240 cm depth before starting an experiment. Soil samples were air dried under the shade and subsequently each sample was divided into two subsamples manually. One of the two ground in a wooden pestle and mortar was passed through a 2 mm sieve. The concretions left over were ground separately to pass through a 60 mesh (0.25 mm) sieve. The whole of the second subsamples was ground to pass through a 60 mesh sieve. Analysis of these differently processed samples for the important physical and chemical characteristics was carried out in the laboratory following standard procedures outlined by Black (1965) and Jackson (1967). Soil bulk density and distribution of concretions in the profile were measured in the field following core sampling.

3.11 Measurement of Mechanical Impedance of Soil

Mechanical impedance of soil profile down to the depth of root penetration in layers of 15 cm each was measured using a static-tip penetrometer (that which measures the energy (J or KJ) required to push the tip a specific distance into the soil volume). This penetrometer (Fig.3) was fabricated from the local market as per the requisite specifications. This may also be called an impact penetrometer which records the number of blows required to drive the penetrometer tip through a specific depth (15 cm) of the soil. It consisted of the following parts:

(a) Cone: This was made of solid piece of iron with a cross-section area (m^2) of 7.0686×10^{-4}. Its total length was 10 cm and the angle of tapering towards the tip 45 degrees.

(b) Graduated Extension Rod: This rod was hollow from inside and solid at both ends. On its lower end, a cone is fixed with screws inside the extension rod. The upper end bears a solid iron plateform which receives a blow from a falling weight. The extension rod is graduated in 2.5 cm (1.0 inch) markings to observe the specific depth of penetration.

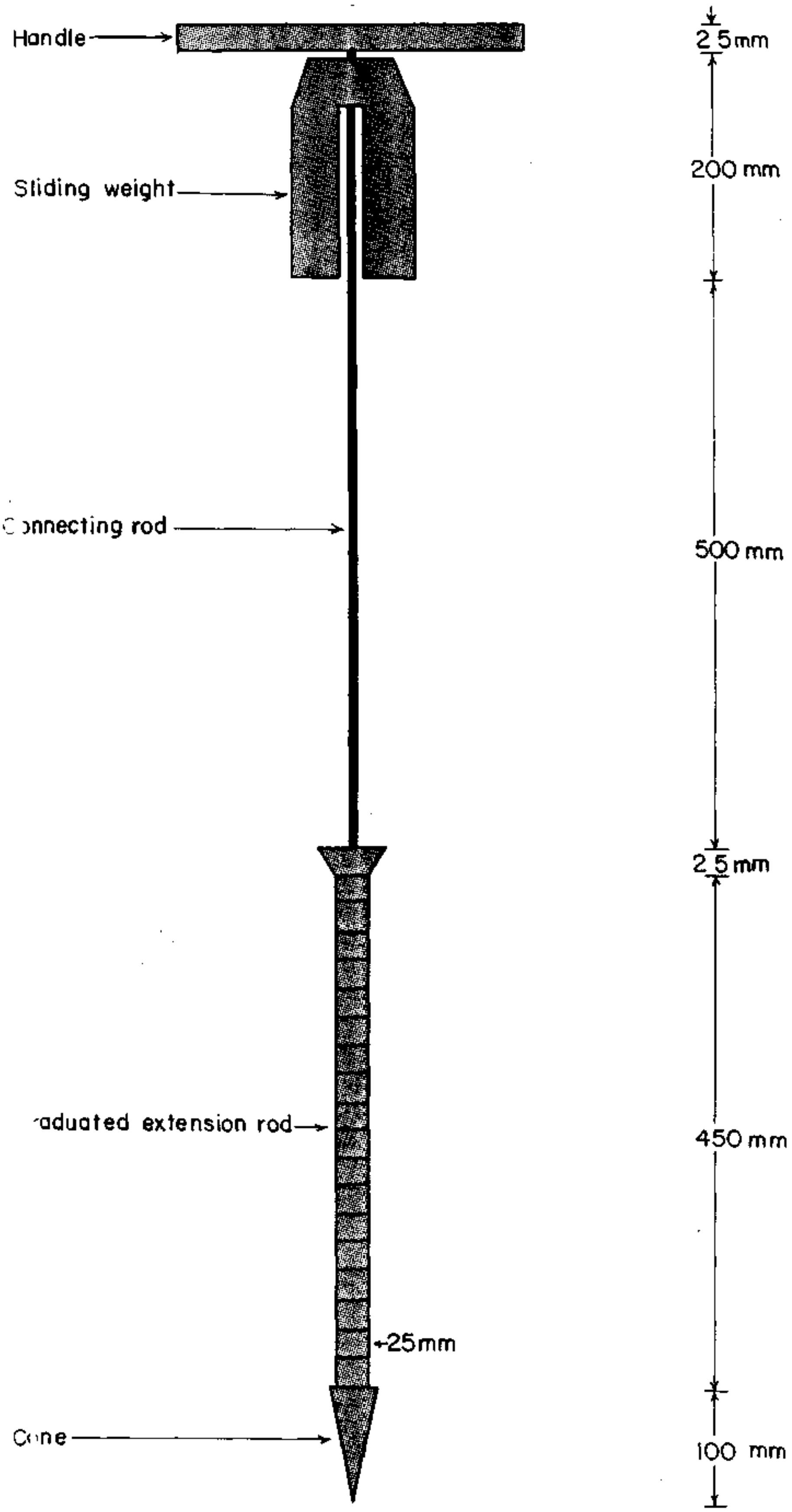


Fig.3. AN IMPACT PENETROMETER

(c) Sliding Rod: It joins the iron plateform on upper end of the graduated extension rod and handle at the top. Its total effective sliding length is 50 cm. It passes through a circular weight that slides between the handle and the plateform. It is solid from inside. Its cross-sectional area is 1.33 cm^2.

(d) Sliding Weight: It is a piece of solid iron weighing 5.179 kg, with length and cross sectional area of 20 cm and 46.6 cm^2 respectively. It is hollow at the centre throughout its length except its upper 2.5 cm. Hollow cross sectional area equals 9.62 cm^2. But at the upper end of 2.5 cm length, cross-sectional rod (1.33 cm^2) passing across the weight facilitating its free fall from 50 cm height on the plate form. However, there might be some loss of energy due to friction when falling weight touches the sliding rod. But that remains more or less constant and is not likely to effect the measurements in any way. The energy of a single blow can be calculated as below:

Mass of sliding weight = 5.179 kg
Fall distance = 0.5 m
Force (N) = m x g = 5.179 x 9.8 m sec^{-2}.
= 50.754 N

Energy blow^{-1} = Force (N) x distance (m)
= 50.754 x 0.5
= 25.377 N m (J or KJ)

Total energy for x number of blows = 25.377 X x KJ
Energy per unit cross section area of cone x^{-1} blows, thus, would be
= 35904 J or 35904 KJ

Procedure: In the vicinity and opposite side of the trench dug out to excavate the root system of a tree plant, an area (2 m^2) was marked with ridges around it. The given area was flooded with water for 10 days to saturate the surface soil (0-15 cm) layer. Standing water was drained and the area was left for drying. Number of blows required to push the tip 15 cm into the surface soil layer were recorded at 10 locations in a single plot after 2, 4, 6, 8, 12, 16, 20 days of draining standing water. Each time soil was sampled for its percent moisture content (g 100 g^{-1} soil). Soil was also sampled in a core of known volume (986 cm^3) to determine bulk density, texture, pH and EC of soil:water :: 1:2 suspension, $CaCO_3$, per cent concretions (g 100 g^{-1}). Following this procedure mechanical impedance of the profile was evaluated to pin point the factors affecting root growth behaviour of selected tree species.

3.12 Statistical Analysis

Results of field investigations were processed and analysed statistically following standard procedures outlined by Snedecor and Cochran (1967) and Panse and Sukhatme (1978).

3.13 Climate

As climate of a place is the most important among the external environment in determining and regulating biological growth and cellular reactions, important meteorological parameters of Karnal climate are presented in Table 4. Figure 4 shows periodic atmospheric and soil (5 cm depth) temperature for the reported growth periods in different field experiments. Table 5 indicates maximum storm rainfall that may occur in 1-4 days against various return periods and maximum dry spells during monsoon season. Figure 5 depicts potential evapotranspiration (PET) and rainfall distribution during 1979-1984 alongwith the various components of the soil water budget.

Table 4. Mean monthly meteorological parameters at CSSRI, Karnal

Month	Temp. °C		Rainfall	PE	RH	Daily
	Max.	Min.	(mm)	(mm)	(per cent)	sunshine hours
January	19.5	6.1	23	1.8	69	7.7
February	21.6	7.8	17	2.8	66	8.3
March	27.0	12.1	29	4.3	63	8.8
April	35.0	17.7	15	7.8	43	10.4
May	39.1	23.1	23	10.9	34	10.7
June	37.8	24.6	78	9.1	56	8.8
July	33.3	25.9	271	5.1	76	6.7
August	32.5	25.2	210	4.0	82	7.4
September	32.8	22.9	73	4.1	75	9.2
October	31.9	16.7	16	3.5	64	9.5
November	27.1	11.0	10	2.5	62	8.6
December	21.8	6.8	11	1.9	67	7.9
Mean/Total*	30.0	16.7	776*	4.8	63	8.7

Source: Annual Reports 1971-1984, CSSRI, Karnal.

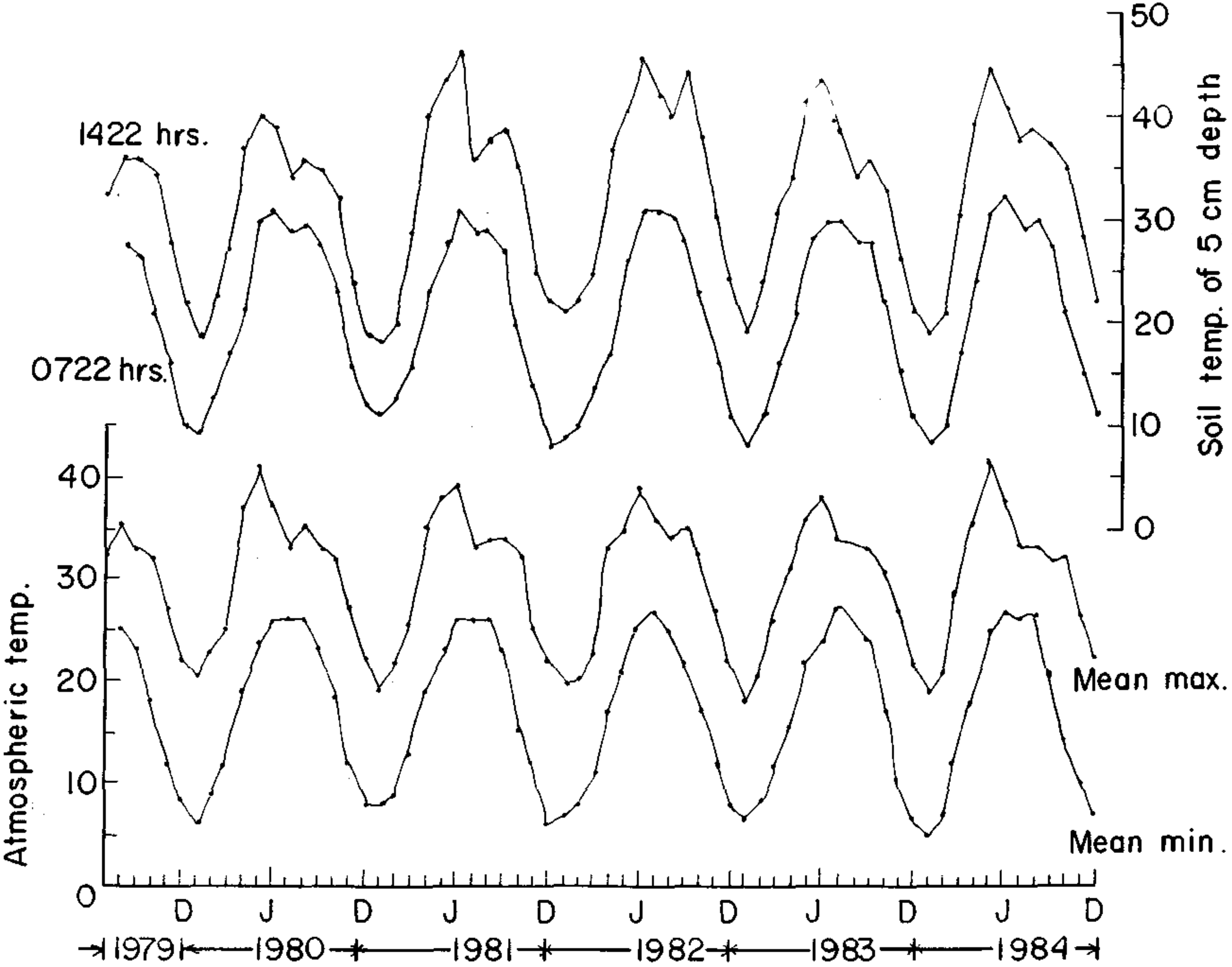


Fig.4. Periodic thermal regime of the atmosphere and the soil.

Table 5. Maximum storm rainfall (mm) and dry spells (days) for different return periods.

Item	Return period, years					
	1.01	2.33	5	10	25	100
Maximum one day rainfall	41	120	152	183	221	289
Maximum two days rainfall	51	155	201	238	285	355
Maximum three days rainfall	61	171	219	258	307	381
Maximum four days rainfall	67	179	228	268	318	394
Maximum dry spell during monsoon season	15	28	34	39	45	54

Source: Narayana et al. 1978.

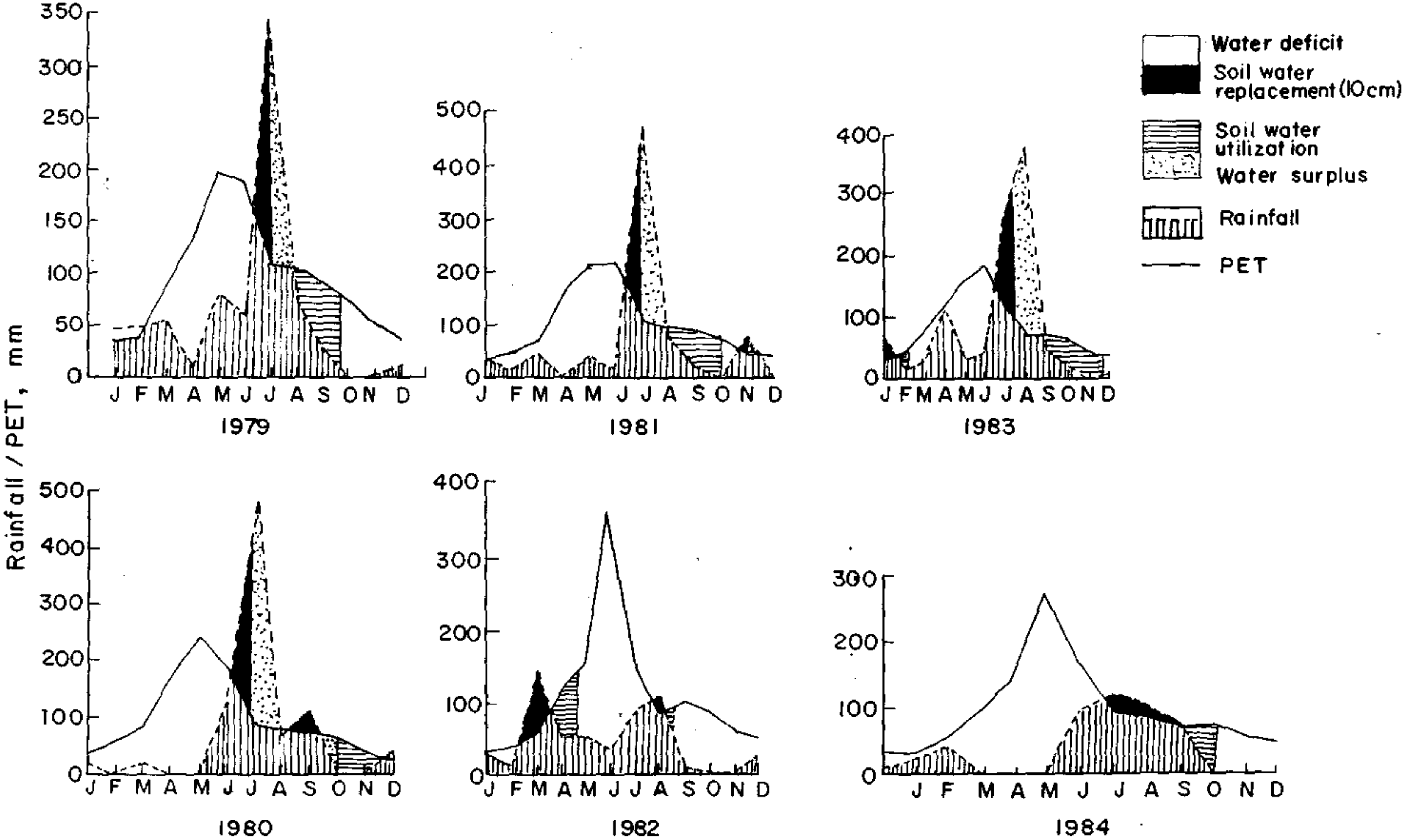


Fig. 5. Rainfall and potential evaporation at Karnal during 1979–1984.

RESULTS AND DISCUSSION

Results of the investigations are presented and discussed experiment wise. The specific methodology to achieve the objectives of each of the given experiment is also included, however, details common to all are given in the preceding chapter.

4.1 Analysis of Soil Profile for the Identification and Intensity of Constraints for the Growth of Trees in a Highly Sodic Soil

Introduction: An intensive approach to search out a package of practices for widely advocated afforestation of considerable areas under sodic soils presently lying barren in the Indo-Gangetic plains require generation of information about the (a) relationships among the root growth behaviour, tree growth, local climate, (b) root zone manipulation and (c) diagnosis of the rooting medium for identification of the problems and prescription of corrective measures that will reduce stress of growth limiting hazards. Sodic soils in India have been mostly studied (Abrol, 1982) for their suitability and reclamation for crop production. This involves amelioration of only the surface (0-15 cm) soil through addition of appropriate amendments. But management of these soils for afforestation, because of deep rooted system of trees, requires improvement of the rooting zone to deeper depths of the soil profile with adequate quantities of an amendment. To characterize a highly sodic soil in respect of important physico-chemical properties of its profile, a detailed study was carried out.

Methodology: The soil profile (0-240 cm) analysis of the highly sodic soil was conducted to not only pinpoint the salient constraints which may impair growth of tree species but also their lateral and vertical variation. The composite soil samples in layers of 15 cm each were collected using a Belgian-Dutch type soil auger from the spots representing the natural landscape of the experimental area. These samples were analysed for the important physical and chemical characteristics in the laboratory after processing them properly. However, analysis of soil layers for bulk density of soil and concretions separately as well as collectively was carried out following core (986 cm^3) technique in the field itself. Volume of concretions collected was measured by immersion in water before oven drying. Immersion was done after washing them in a saturated $CaCO_3$ solution (and removal of water using blotting paper and air drying for 15 (summer) to 30 (winter) minutes. The standard methods following for soil analysis are listed in the preceding chapter.

Results and Discussion The analytical results of highly sodic soil are presented under two heads; (a) physical and (b) Chemical characteristics.

A. Physical Characteristics

(a) Mechanical Composition: Data in Table 6 show marked variation observed in the relative proportions of the different sized primary particles among different soil layers of the profile. Average clay content (g 100 g^{-1} soil) in 0-15 cm layer was low (15.4) but it increased gradually with depth down to 60 cm. It varied between 20.3 - 32.3 in 61-120 cm depth and declined gradually to 11.2 in 151-165 cm layer. This fraction indicated only a slight variation (10.2 - 13.8) among various layers between 151 - 240 cm depth of the profile. Unlike the clay content, silt fraction varies between 14.2 - 18.6 g 100 g^{-1} soil in 121-240 cm depth. Amount (g 100 g^{-1} soil) of silt (29.2) in surface (0-15 cm layer) was slightly less

Table 6. Mechanical composition (g $100g^{-1}$ soil), textural class and dispersion ratio of given layers of a highly sodic experimental site (Mean of 8 composite samples).

Soil profile depth (cm)	Mechanical composition			Textural class	Dispersion ratio
	Sand	Silt	Clay		
0 - 15	54.3 (50.2 - 58.2)	29.2 (26.4 - 31.3)	15.4 (13.2 -16.8)	sil	94.2 (93.6-95.4)
16 - 30	46.8 (44.8 - 52.3)	33.9 (30.8 - 34.9)	18.2 (15.6 -19.9)	sil	92.8 (91.2-94.2)
31 - 45	44.4 (42.8 - 47.2)	34.2 (32.6 - 35.2)	19.6 (18.6 -21.3)	sil	90.6 (88.6-92.8)
46 - 60	45.6 (43.6 - 49.1)	24.8 (22.8 - 27.3)	25.7 (23.6 -27.2)	sil	91.6 (89.3-93.4)
61 - 75	46.4 (40.8 - 48.2)	23.3 (21.4 - 25.3)	24.6 (20.8 -32.3)	sil	93.8 (88.6-95.8)
76 - 90	44.8 (41.6 - 47.3)	24.4 (22.7 - 26.2)	24.3 (20.6 -28.6)	sil	88.6 (84.8-92.2)
91 - 105	47.8 (42.8 - 53.2)	20.5 (19.6 - 21.6)	23.4 (21.2 -26.3)	l	85.2 (80.6-89.9)
106 - 120	49.6 (46.4 - 54.8)	18.3 (17.4 - 19.2)	22.0 (20.3 -24.4)	l	82.8 (76.4-88.6)
121 - 135	52.9 (47.9 - 55.3)	16.3 (14.6 - 17.8)	18.2 (16.6 -19.8)	l	83.6 (76.2-88.5)
136 - 150	54.8 (50.6 - 56.8)	17.6 (15.4 - 18.6)	13.0 (11.6 -15.2)	l	79.4 (75.2-81.3)
151 - 165	63.3 (54.6 - 66.2)	16.8 (14.6 - 17.2)	11.2 (10.8 -13.6)	ls	77.6 (72.9-83.1)
166 - 180	64.4 (60.6 - 68.2)	17.3 (14.2 - 17.8)	11.0 (10.2 -13.8)	ls	75.3 (70.2-80.4)
181 - 195	65.8 (62.6 - 69.3)	17.4 (14.8 - 17.9)	10.8 (10.0 -12.9)	ls	76.2 (71.5-79.9)
196 - 210	64.2 (62.2 - 68.6)	18.8 (14.6 - 18.6)	10.4 (10.0 -13.1)	ls	76.4 (70.8-80.2)
211 - 225	65.6 (60.4 - 70.2)	17.6 (14.2 - 18.2)	10.4 (10.0 -13.0)	ls	75.2 (70.2-79.1)
226 - 240	65.4 (60.6 - 69.8)	18.2 (14.4 - 18.4)	10.6 (10.0 -13.6)	ls	71.7 (65.8-74.3)
Mean (0 - 240)	54.8 (41.6 - 70.2)	21.8 (14.2 - 35.2)	16.8 (10.0 -32.3)	l	83.4 (65.8-95.8)

Figures in parentheses denote correspondingly observed variation.

than in 16-30 cm (33.9) and 31-45 cm (34.2) layers. It declined gradually with profile depth of 120 cm and varied very little in deeper layers. However, its proportion was almost constant between 46-90 cm depth. Mean value of sand in the surface soil was 54.3 g 100 g^{-1} soil, relatively more than (44.4 - 49.6 g 100 g^{-1} soil) in layers between 16-120 cm depth. Sand fraction in 121-135 cm layers was about equal to the value for surface layer. Between 151-240 cm, proportion of sand fraction was considerably more but variation among average values (63.3 - 68.5 g 100 g^{-1}) for the given layers was only negligible. Based on the relative proportion of the three fractions (sand, silt and clay) and Triangular Texture Diagram on International Fractions (Day, 1965), all the soil layers between 0-90 cm, 91-150 cm and 151-240 cm are classified as silty loam, loam and loamy sand respectively with loam as an average value accounting for the whole profile. Data on mechanical composition brings out the high inherent physical fertility attributable to greater content of clay and site and in turn greater surface area and CEC of the soil whose productivity is constrained by high sodicity hazard. High sodicity throughout the profile causes high dispersion ratio (Table 6) and therefore structure (arrangement of primary and secondary soil particles into secondary units or peds) of the soil is very poor and inducive for desired transmission of moisture and air within active root zone of the profile.

(b) Moisture Retention Characteristics: Water retention at 0.03 MPa and 1.5 MPa pressure representing about field capacity and the permanent wilting point moisture respectively showed difference among various layers of silty loam (0-90 cm), loam (91-150 cm) and loamy sand (151-240 cm) portion of the profile in descending order. In each layer, moisture retained (generally called available) between the given two suctions ranged 5 to 6 per cent. Saturation moisture indicated similar variation within the profile and for each layer was approximately double the field capacity. Contrary to its being four times and permanent wilting point for normal soils, it was about three times in each layer. This deviation may be ascribed to the dependence of soil moisture content corresponding to a definite equilibrium pressure on the mineralogical composition and exchangeable cations. Presuming mineralogical composition constant, quality of the solid surface as influenced by exchangeable cations particularly sodium (Acharya and Abrol, 1978; Sandhu et al. 1980). Monovalent cations effect a higher water density for adsorbed water, more specific surface and a large number of molecular layers. Hence, relatively very high exchangeable Na^+ (sodicity) causes a distinctly higher value of soil moisture content than Ca^{++} at the same value of pF (Kutilek, 1973).

(c) Oxidizable Organic Matter Content: The organic matter content was maximum in the surface layer and absolute value was low (Table 7). Its amount declined with profile depth. Based on this, soil is designated very low in organic matter, a store house of nutrients particularly N, P and S essential to plant growth, source of food and energy for microbes and promoter of a desirable soil structure. Low organic matter content of such a highly sodic soil may be ascribed to its being barren and devoid of economic growth of vegetation and burning action of the high alkali. This also imparts the surface layer dark colour after which such soils are sometimes called black alkali.

(d) Concretions: Data (Table 7) on amount of concretions (kankar granules) in different layers of the profile show that large quantity of calcium as insoluble calcium carbonate present in the soil which

Table 7. Moisture retention at 0.07 MPa (field capacity) and 1.5 MPa (wilting point) pressure, saturation moisture concretions and oxidizable organic matter content (g 100g^{-1}soil) of given layers of a highly sodic experimental site.

Soil profile depth (cm)	Moisture retention 0.03 MPa	1.5 MPa	Saturation moisture	Organic matter	Concretions
0 - 15	18.2 (15.9-18.8)	12.3 (12.1-12.8)	35.6 (34.4-37.2)	0.457 (0.410-0.515)	0.44 (0.26-0.60
16 - 30	17.9 (17.4-18.8)	12.0 (11.9-12.3)	36.4 (35.6-37.2)	0.424 (0.384-0.484)	0.56 (0.38-0.72)
31- 45	17.6 (17.2-18.4)	11.9 (11.7-12.2)	35.2 (34.6-36.8)	0.329 (0.292-0.422)	0.72 (0.66-0.84)
46 - 60	17.8 (17.2-18.6)	12.0 (11.6-12.4)	35.1 (34.3-36.8)	0.319 (0.280-0.374)	1.30 (1.15-1.46)
61 - 75	18.0 (17.0-19.1)	12.1 (11.7-12.4)	35.6 (34.4-37.0)	0.308 (0.272-0.346)	4.80 (3.20-6.06)
76 - 90	17.4 (16.9-18.2)	11.8 (11.6-12.0)	35.3 (34.6-36.9)	0.297 (0.246-0.332)	8.28 (6.76-11.13)
91 -105	17.6 (16.9-18.6)	11.2 (10.9-11.4)	34.8 (33.6-37.2)	0.284 (0.222-0.336(	10.64 (7.06-20.86)
106 -120	16.9 (16.6-17.4)	10.8 (10.6-11.1)	35.1 (34.8-36.4)	0.228 (0.208-0.318)	24.23 (18.26-41.22)
121 -135	16.8 (16.2-17.4)	10.6 (10.4-10.9)	34.3 (33.2-35.6)	0.203 (0.184-0.246)	34.84 (24.64-48.62
136 -150	16.2 (16.0-16.5)	10.2 (9.9-10.6)	33.8 (32.8-34.2)	0.162 (0.152-0.180)	26.63 (20.84-34.68
151 -165	15.6 (15.2-16.4)	10.0 (9.8-10.4)	32.2 (30.4-33.8)	0.148 (0.136-0.172)	10.32 (6.16-12.36)
166 -180	15.8 (15.0-16.6)	9.6 (9.2-10.0)	30.7 (29.6-32.2)	0.140 (0.126-0.164)	7.86 (6.28-10.26)
181 -195	15.2 (14.8-16.1)	9.5 (9.2- 9.8)	30.2 (28.6-31.8)	0.128 (0.120-0.152)	3.24 (2.46-6.88)
196 -210	15.0 (14.6-15.8)	9.7 (9.4 -9.9)	29.8 (28.2-32.0)	0.152 (0.126-0.168)	2.86 (2.40-4.89)
211 -225	15.0 (14.8-15.3)	9.4 (9.2- 9.7)	29.6 (28.3-32.1)	0.128 (0.120-0.164)	1.96 (1.28-4.04)
225 -240	15.1 (14.4-15.6)	9.3 (9. 0- 9.6)	29.7 (28.2-32.3)	0.107 (0.090-0.120)	2.08 (1.32-3.12)
Mean (0 -240)	16.6 (14.4-19.1)	10.8 (9.0-12.8)	33.3 (28.2-37.2)	0.238 (0.090-0.515)	8.67 (0.26-38.62)
Determinations(No.)	5	5	15	10	12

Figures in parentheses denote correspondingly observed variation.

requires additional application of calcium as calcium sulphate to ameliorate it for viable plant growth. Concretions (g 100 g^{-1} soil) were less than unity in each of the three surface layers (0-45 cm). But their amount increased subsequently regularly to have 1.30, 4.80, 8.28 and 10.64 g 100 g^{-1} soil in 46-60, 61-75, 76-90 and 91-105 cm respectively. Then there was an abrupt increase and soil layers between 106-150 cm had 24.23 - 34.84 g concretions 100 g^{-1} soil. Beyond 150 cm, each succeeding layer exhibited a decrease in concretions content. This data indicated the presence of a potential barrier that may offer severe mechanical impedance to growth of roots down the profile. This may also affect moisture transmission within the profile adversely.

(e) Bulk Density (Db): Bulk density 1.70 - 1.85 g cm^{-3} throughout the given layers of profile (Table 8). Except the surface layer, Db values were relatively high for layers down to 120 cm than for the rest beyond this depth. Similar was the trend when the soil mass as a whole (soil + concretions) was accounted for computing Db for the corresponding layers. However, bulk density of concretions measured by their air dry weight and immersion in water to know the volume after wax coating revealed no marked variation for different layers. Data, thus, indicated relatively greater compactness of the soil and porosity varying between 0.31 - 0.36 cm^3 cm^{-3}. Compactness results from strong dispersive action of soil colloids due to high sodicity and low organic matter content of such a soil.

(f) Particle Density (Dp): The particle density of each of the layers ranged 2.54 - 2.76 g cm^{-3} for the soil, 2.82 - 2.98 g cm^{-3} for concretions and 2.62 - 2.94 g cm^{-3} for the soil mass comprising

Table 8. Bulk and particle densities (g cm^{-3}) of the soil and concretions of the given layers of a highly sodic experimental site.

Soil profile depth (cm)	Bulk density			Particle density		
	Soil	Concretions	Soil+ Concretions	Soil	Concretions	Soil + Concreti
0- 15	1.74 (1.70-1.76)	2.28 (2.22-2.36)	1.75 (1.72-1.78)	2.66 (2.62-2.68)	2.90 (2.88-2.92)	2.69 (2.64-2.7
16- 30	1.82 (1.75-1.84)	2.34 (2.28-2.38)	1.82 (1.76-1.84)	2.64 (2.60-2.70)	2.92 (2.90-2.94)	2.66 (2.62-2.7
31- 45	1.80 (1.72-1.90)	2.32 (2.30-2.36)	1.84 (1.78-1.88)	2.68 (2.62-2.72)	2.92 (2.88-2.94)	2.77 (2.68-2.7
46- 60	1.85 (1.78-1.90)	2.28 (2.24-2.40)	1.88 (1.82-1.92)	2.66 (2.64-2.76)	2.90 (2.86-2.92)	2.72 (2.68-2.7
61- 75	1.84 (1.76-1.88)	2.32 (2.28-2.38)	1.88 (1.86-1.92)	2.68 (2.62-2.76)	2.88 (2.84-2.92)	2.75 (2.70-2.8
76- 90	1.82 (1.76-1.86)	2.24 (2.20-2.30)	1.90 (1.84-1.96)	2.68 (2.64-2.74)	2.90 (2.86-2.94)	2.72 (2.68-2.7
91-105	1.85 (1.80-1.90)	2.26 (2.22-2.30)	1.90 (1.88-1.94)	2.70 (2.68-2.74)	2.94 (2.90-2.96)	2.78 (2.72-2.8
106-120	1.82 (1.74-1.88)	2.26 (2.24-2.32)	1.94 (1.90-2.02)	2.70 (2.64-2.72)	2.92 (2.88-2.94)	2.84 (2.76-2.8
121-135	1.78 (1.74-1.86)	2.34 (2.26-2.38)	1.96 (1.92-2.00)	2.72 (2.66-2.74)	2.94 (2.90-2.98)	2.87 (2.78-2.9
136-150	1.78 (1.76-1.80)	2.32 (2.28-2.36)	1.96 (1.94-2.00)	2.68 (2.64-2.74)	2.92 (2.88-2.94)	2.84 (2.78-2.9
151-165	1.76 (1.72-1.84)	2.32 (2.30-2.34)	1.92 (1.86-1.96)	2.64 (2.60-2.70)	2.90 (2.86-2.94)	2.81 (2.76-2.9
166-180	1.74 (1.70-1.80)	2.36 (2.30-2.40)	1.84 (1.80-1.90)	2.62 (2.56-2.66)	2.92 (2.86-2.94)	2.74 (2.70-2.8
181-195	1.76 (1.70-1.81)	2.24 (2.22-2.28)	1.82 (1.74-1.86)	2.64 (2.58-2.70)	2.88 (2.84-2.92)	2.78 (2.74-2.8
196-210	1.70 (1.68-1.73)	2.28 (2.24-2.32)	1.82 (1.74-1.86)	2.60 (2.56-2.70)	2.90 (2.86-2.94)	2.81 (2.70-2.8
211-225	1.72 (1.66-1.70)	2.34 (2.30-2.38)	1.80 (1.72-1.86)	2.62 (2.54-2.66)	2.86 (2.82--2.90)	2.78 (2.72-2.8
226-240	1.72 (1.64-1.76)	2.36 (2.32-2.38)	1.78 (1.74-1.88)	2.60 (2.58-2.62)	2.94 (2.88-2.96)	2.72 (2.70-2.7
Mean (0-240)	1.79 (1.70-1.85)	2.31 (2.20-2.40)	1.86 (1.72-2.02)	2.66 (2.54-2.76)	2.91 (2.82-2.98)	2.74 (2.62-2.9
Determintions	12	12	12	8	8	8

Db was measured following core method and Dp of disturbed soil by PAU soil-moisture gauge (Prihar and Sandhu, 1968) using 0.1 N Na_2CO_3 solution instea of deionized water.

concretions and the soil (Table 8). Measurements were made on the soil and concretions ground to pass through a 2 mm sieve following PAU soil moisture gauge (Prihar and Sandhu, 1968). In case of concretions $CaCO_3$ saturated solution (pH 7.0) was used instead of deionized water to eliminate error due to solubility of concretions in water, if any. Relatively greater values of Dp also confirm the indurated nature of the soil mass. This was also evident from laborious hardship required to dig out the profiles in the field.

B. Chemical Characteristics

(a) Soil pH: Data on reaction of soil profile as measured by pH of the soil and water suspension in 1:2 ratio (pH 1:2) and the saturation extract (pHe) showed (Table 9) that this was extremely alkali. The pH values determined by both methods showed strong relationship (Fig. 6a). Soil pH was the maximum of the surface (0 - 15 cm) layer and decreased with depth. The pHe for a given sample was less than pH 1.2 by 0.1 to 0.4 units. Such a difference was more with high pH values. This may primarily be ascribed to the dilution effect and decomposition of appreciable amount of carbonates upon extraction under pressure. The observed soil reaction would favour presence of most of the essential nutrient elements in unavailable forms beside having a deleterious effect on physical and biochemical processes. The high pH may be attributed to the presence of carbonate (Cruz-Romero and Coleman, 1975).

(b) Soiluble Salts: Soil salinity as measured by electrical conductivity (EC) of the soil and water suspension in 1:2 ratio (EC 1:2), and the saturation extract (ECe), indicated (Table 9) high content of soluble salts of the soil layers down to 90 cm depth.

Table 9. Soil pH and electrical conductivity of given layers of highly sodic experimental farm.

Soil profile depth (cm)	$pH_{1:2}$	pH_e	$EC_{1:2}$	ECe
0- 15	10.56 (10.42-10.70)	10.26 (10.14-10.38)	3.75 (2.64-4.84)	20.82 (17.84-26.42)
16- 30	10.44 (10.20-10.58)	10.15 (9.92-10.26)	2.16 (1.18-33.38)	12.38 (8.24-14.64)
31-45	10.36 (10.15-10.44)	10.08 (9.80-10.15)	1.94 (1.26-2.64)	10.36 (8.06-11.60)
46-60	10.22 (10.06-10.32	10.02 (9.74-10.08)	1.18 (1.02-1.68)	7.44 (6.56- 8.44)
61-75	10.20 (10.04-10.26	9.96 (9.86-10.02)	0.97 (0.84-1.36)	4.38 (3.68-5.72)
76-90	10.12 (9.98-10.22)	9.88 (9.70-9.92)	0.84 (0.76-1.24)	4.04 (3.04-4.16)
91-105	10.06 (9.90-10.16)	9.82 (9.75-9.85)	0.72 (0.68-0.92)	3.16 (2.22-3.82)
106-120	9.97 (9.86-10.12)	9.72 (9.62-9.82)	0.66 (0.54-0.96)	2.96 (1.36-3.06)
121-135	10.01 (9.88-10.10)	9.70 (9.58-9.78)	0.65 (0.46-0.84)	1.88 (1.24-2.68)
136-150	9.92 (9.74-10.02)	9.65 (9.48-9.75)	0.53 (0.42-0.68)	1.86 (1.22-2.46)
151-165	9.88 (9.72-9.96)	9.58 (9.42-9.66)	0.45 (0.38-0.66)	1.80 (1.46-2.04)
166-180	9.80 (9.68-9.92)	9.56 (9.30-9.62)	0.36 (0.32-0.54)	1.62 (1.54-2.02)
181-195	9.68 (9.48-9.82)	9.32 (9.18-9.46)	0.33 (0.30-0.39)	1.46 (0.84-1.66)
186-210	9.48 (9.34-9.68)	9.24 (9.02-9.38)	0.31 (0.22-0.44)	1.34 (0.80-1.82)
211-225	9.36 (9.22-9.46)	9.08 (8.92-9.12)	0.25 (0.20-0.38)	1.26 (0.86-1.64)
226-240	9.22 (9.04-9.38)	8.92 (8.68-9.10)	0.25 (0.22-0.36)	1.32 (0.76-1.70)
Mean (0-240)	9.96 (9.04-10.70)	9.68 (8.92-10.38)	0.97 (0.20-4.84)	4.88 (0.76-26.42)
Determinations(No.)	24	15	24	15

Figures in parentheses denote correspondingly observed variation.

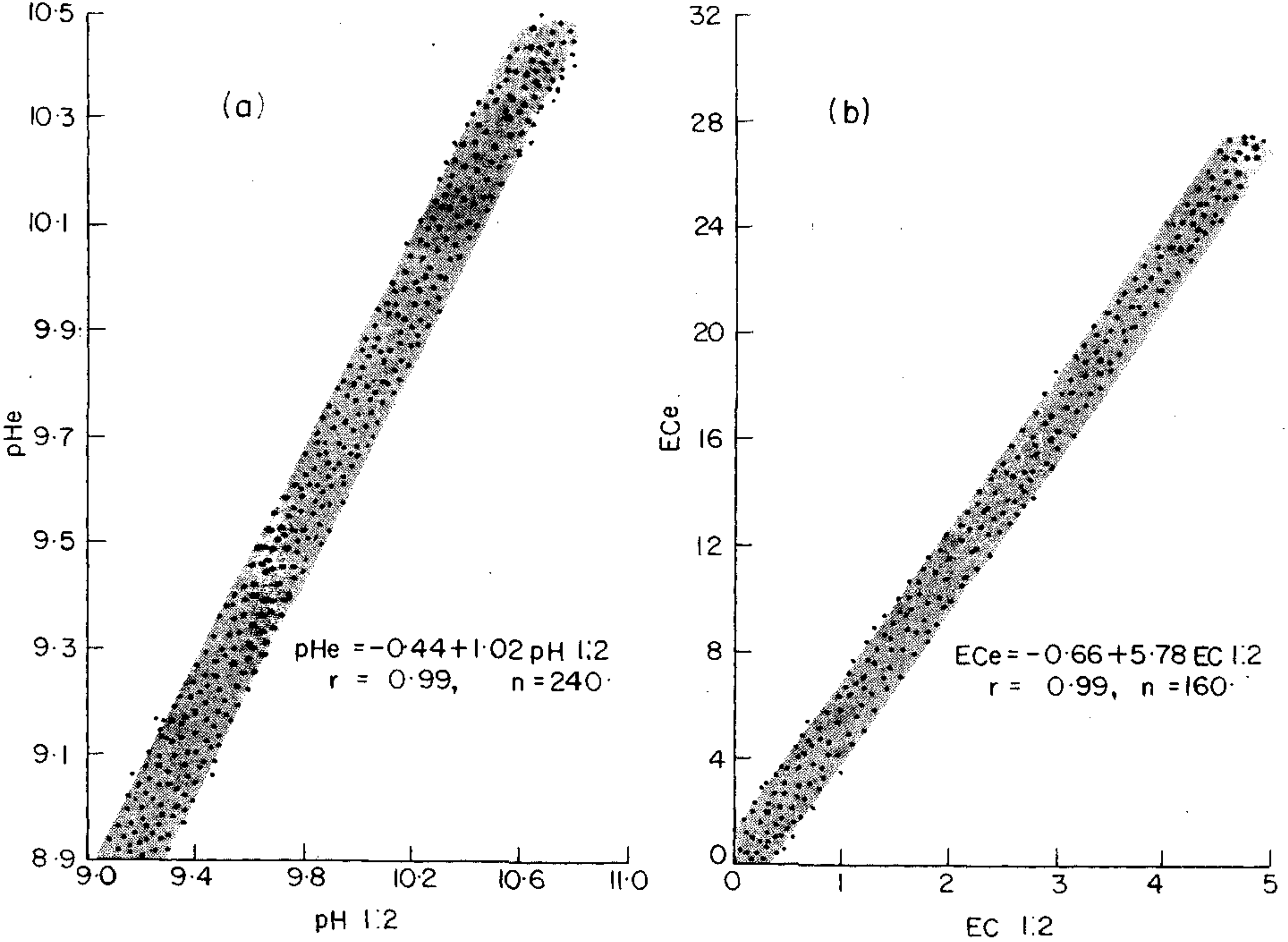


Fig. 6. Relationship of pH (a) and EC (b) of the soil saturation extract and soil : water suspension in a ratio of 1:2.

Maximum soluble salts occurred in the surface layer and decreased with depth. All the soil layers of profile below 90 cm depth were relatively non-saline. The EC determined following two methods showed high degree of correlation between them (Fig. 6b) and ECe of a given sample was computed 5-6 times the EC 1:2 depending upon other factors. High EC of the surface layers is caused by the presence of sodium carbonate. Therefore, this soil can be classified a sodic rather than saline based on the chemistry of the soil solution and the aim of reclamation (Bhumbla, 1977; Abrol et al., 1980; Szabolcs, 1980).

(c) Chemical Composition of the Saturation Extract: Quantitative analyses of the saturation extracts was done for both the predominant (a) cations and (b) anions:

(i) Cationic Composition of the Saturation Extract: Layer wise distribution of sodium, potassium, calcium and magnesium (Table 10) in the profile showed that sodium is the predominant cation. Its concentration was maximum in the surface (0-15 cm) soil and showed a regular decrease with each layer down to 150 cm. But it varied little among layers between 151 - 240 cm. Concentration of both calcium and magnesium was very low and less than unity in layers between 0-105 cm of the profile. Both were found increasing with depth but their relative amounts were very low despite the large quantities of calcium carbonate (Table 13) present in the profile. This may be attributed to the precipitation of these ions as carbonates because of high pH and presence of ample carbonates in the profile. Relative proportion of sodium to the total cations (soluble sodium percentage) was very high (98.8) in the surface soil. It indicated decrease with depth, however, in the layers between

Table 10. Cationic composition (me L^{-1}) of saturation extract of given soil layers of highly sodic experimental farm (each value a mean of 15 determinations).

Soil profile depth (cm)	Sodium	Potassium	Calcium	Magnesium	Total	Soluble sodium percentage
0-15	356.7 (215.6-486.9)	3.5 (2.6-5.8)	0.3 (0.6-0.6)	0.4 (0.3-0.5)	360.9 (219.6-398.8)	98.8 (97.4-99.0)
16-30	194.8 (98.4-248.2)	2.3 (1.8-4.6)	0.4 (0.3-0.7)	0.4 (0.4-0.6)	197.9 (108.2-256.1)	98.4 (97.6-98.7)
31-45	154.6 (88.8-196.4)	2.2 (1.6-5.1)	0.4 (0.2-0.9)	0.4 (0.3-0.7)	157.7 (93.0-203.1)	98.0 (96.8-98.6)
46-60	119.2 (65.8-146.8)	2.2 (1.8-3.2)	0.5 (0.3-1.2)	0.6 (0.4-0.7)	122.5 (66.5-151.9)	97.9 (93.8-98.0)
61-75	97.6 (62.8-134.4)	3.8 (1.6-8.6)	0.5 (0.4-1.0)	0.7 (0.5-0.9)	102.5 (64.3-144.8)	95.2 (92.4-96.6)
76-90	89.1 (59.6-132.2)	3.0 (1.8-7.2)	0.7 (0.5-1.3)	0.9 (0.6-1.1)	98.7 (60.7-144.6)	90.7 (84.8-96.4
91-105	77.7 (52.8-126.4)	3.1 (1.2-8.4)	0.9 (0.8-1.4)	0.9 (0.6-1.3)	86.6 (56.3-138.1)	89.7 (84.6.90.8
106-120	59.5 (42.8-96.2)	3.3 (1.8-5.7)	1.2 (0.8-1.6)	1.1 (0.8-1.3)	75.0 (42.4-105.8)	91.5 (83.6-93.9
121-135	52.3 (40.6-81.6)	3.1 (1.6-7.3)	1.0 (0.8-1.9)	1.1 (1.0-1.5)	57.5 (41.0-96.2)	90.9 (82.8-94.2
136-150	34.8 (20.8-65.8)	1.7 (1.4-3.6)	1.6 (1.1-1.8)	1.8 (1.2-2.4)	39.9 (24.4-74.5)	87.3 (82.3-92.9
151-165	22.6 (15.9-38.2)	2.1 (1.1-4.4)	1.9 (1.3-2.2)	1.8 (1.7-2.5)	28.4 (20.5-46.3)	79.5 (74.6-86.3
166-180	26.4 (16.8-40.6)	2.4 (1.3-5.0)	1.8 (1.4-2.6)	1.9 (1.6-2.6)	32.5 (20.7-52.5)	81.2 (75.9-84.6
181-195	21.7 (14.2-42.2)	1.7 (0.8-4.6)	1.8 (1.5-2.4)	1.9 (1.5-2.5)	27.1 (18.7-51.4)	80.0 (72.8-85.3
196-210	20.7 (15.6-41.8)	1.1 (0.9-2.8)	2.0 (1.7-3.2)	2.1 (1.5-2.9)	25.9 (19.0-52.7)	79.8 (73.8-84.0
211-225	21.9 (14.4-38.9)	1.3 (1.0-4.2)	2.1 (1.8-2.8)	2.3 (1.6-3.2)	27.5 (16.4-50.9)	79.5 (72.2-82.8
226-240	20.4 (15.2-37.3)	1.2 (0.6-3.4)	2.0 (1.8-2.8)	2.2 (1.7-3.4)	25.9 (16.0-48.9)	78.9 (70.6-84.2
Mean (0-240)	75.0 (14.2-386.9)	2.4 (0.6-8.6)	1.2 (0.1-3.2)	1.3 (0.3-3.4)	80.1 (16.0-398.8)	88.5 (70.6-99.0

Figures in parentheses denote correspondingly observed variation.

0-75 cm depth of profile the value did not vary much (92.4 - 99.0). Similarly in profile depth between 76 - 150 cm and 151-240 cm indicated little fluctuations. Results thus showed that sodium is the predominant cation which exerted its impact physically causing dispersion and chemically to form alkali upon hydrolysis of carbonates favouring precipitation of calcium, magnesium and other ions beneficial for plant growth and a stable soil structure.

(ii) Anionic Composition of the Saturation Extract: Data on (Table 11) distribution of major anions in different layers of the profile showed predominance of carbonate and bicarbonate ions. Amount of carbonate was markedly higher in the surface layer (188.4 me L^{-1}) and it decreased abruptly to 86.6 me L^{-1} in 15-30 cm and regularly but gradually with depth. But variation between 181-240 cm was not so evident. Bicarbonate ion also showed a decrease with depth. But its content in the surface layer was not markedly higher as that of carbonate. Deeper layers between 136-240 cm depth of profile indicated about similar bicarbonate content. Amounts of chloride and sulphate were relatively low, however, both showed a decline with the profile depth and being maximum in the surface (0-15 cm) layer. Anionic composition, thus, clearly showed a significant influence of the chemistry of carbonate and bicarbonate ions that impart high soil pH upon their hydrolysis beside their corrosive deterimental effects for the plant roots. Sum of cations exceeded that of anions for each of the layers of the soil profile. Cations : anions ratio varied between 1.02 - 1.46 (Table 11) showing average value for most of the layers between 1.10 - 1.30.

(d) Cationic Composition of the Exchange Complex: The CEC of different layers of soil profile varied between 7.00 - 12.68 me 100 g^{-1} soil. It was 10.66 me 100g^{-1} soil for surface layer but

Table 11. Anionic composition (meL^{-1}) of saturation extract of given soil layers of highly sodic experimental farm (each value is a mean of 15 determinations).

Soil profile depth (cm)	Carbonate	Bicarbonate	Chloride	Sulphate	Total	Cations: Anions ratios
0- 15	188.4 (122.6-342.8)	58.6 (40.6-78.6)	14.6 (6.8-27.2)	12.4 (4.2-30.8)	 (148.3-466.9)	1.32 (1.06-1.46)
16- 30	86.6 (64.7-200.2)	40.8 (32.2-56.4)	12.3 (5.2-21.6)	13.2 (5.8-28.3)	152.9 (112.6-294.2)	1.29 (1.10-1.42
31- 45	68.6 (52.2-162.8)	32.3 (26.6-42.3)	11.8 (5.8-18.8)	8.3 (4.0-19.9)	121.0 (84.3-220.2)	1.30 (1.06-1.46)
46 - 60	52.8 (40.4-116.6)	31.6 (21.8-44.4)	11.3 (5.2-19.1)	6.1 (3.8-14.6)	101.8 (68.9-202.6)	1.20 (1.12-1.34)
61 - 75	42.3 (31.8-96.4	30.4 (22.8-42.9)	10.8 (4.9-16.7)	5.1 (2.2-12.0)	88.6 (54.7-186.2)	1.16 (1.08-1.28
76 - 90	36.7 (28.8-74.9)	30.2 (20.8-46.2)	10.7 (4.8-14.6)	4.2 (1.8-10.6)	81.8 (52.8-158.9)	1.21 (1.14-1.36
91- 105	30.8 (14.7-48.4)	29.8 (20.8-41.4)	12.3 (5.2-16.2)	2.8 (0.9-4.8)	75.7 (40.8-120.6)	1.14 (1.02-1.32)
106- 120	24.6 (16.6-44.2)	26.8 (21.6-36.2)	11.3 (5.6-14.3)	2.2 (0.6-4.8)	64.9 (36.3-106.8)	1.16 (1.08-1.26)
121- 135	21.9 (15.6-41.8)	20.9 (16.3-22.8)	6.2 (4.1-12.2)	2.3 (0.8-5.6)	51.3 (34.6-98.2)	1.12 (1.02-1.16
136- 150	16.6 (10.2-42.6)	17.7 (14.6-28.2)	6.5 (3.2-11.8)	1.9 (10.8-5.0)	42.7 (28.6-74.4)	1.21 (1.10-1.32
151-165	14.3 (7.8-36.2)	17.2 (13.2-10.4)	4.8 (0.6-4.4)	1.5 (0.6-4.4)	37.8 (18.2-56.3)	1.19 (1.12-1.32)
166-180	13.2 (6.8-28.3)	18.8 (14.5-29.2)	4.3 (3.6-10.2)	1.6 (0.8-3.2)	36.9 (16.4-60.2)	1.21 (1.11-1.36)
181-195	8.6 (6.4-21.9)	17.6 (13.6-32.8)	4.3 (3.6-10.8)	1.2 (0.6-2.9)	31.7 (18.8-42.4)	1.25 (1.14-1.39)
196-210	8.4 (5.2-21.2	16.8 (14.2-24.2)	3.8 (1.8-10.2)	1.1 (0.4-2.2)	30.0 (21.6-36.8)	1.30 (1.16-1.42)
211-225	8.6 (5.8-14.6)	17.8 (14.6-28.3)	3.1 (1.8-10.3)	0.9 (0.4-2.4)	30.4 (24.6-41.2)	1.35 (1.28-1.46)
226-240	8.3 (5.6-21.2)	17.2 (14.4-26.8)	3.6 (1.2-10.6)	1.1 (0.6-2.3)	30.2 (24.8-44.4)	1.28 (1.22-1.38)
Mean	39.1 (5.2-342.8)	26.5 (13.2-78.6)	8.2 (1.2-27.2)	4.1 (0.4-30.8)	78.0 (16.4-466.9)	1.15 (1.02-1.46

Figures in parentheses denote correspondingly observed variation.

showed an increase of about one unit for layers between 16-135 cm depth. The lower layers exhibited little variations. Data (Table 12) on cationic composition showed that sodium was the predominant cation on the exchange complex and its content ranged 4.36 - 11.94 me $100g^{-1}$ soil for different layers of the soil profile. Its content in layers between 0-90 cm depth was more or less constant and relatively higher than the deeper layers. It decreased with depth beyond 90 cm although CEC of the deeper layers also decreased. Among rest of the three cations, Ca and Mg increased with depth. Their relative amount was low in each of the 16 layers. This may be attributed to the high pH and excessive Na presence causing their precipitation and removal from the exchange complex simultaneously. Amount of K on the exchange complex varied between 0.22 - 0.89 me $100g^{-1}$ soil but followed no particular trend like the other cations. Computed values for ESP and ESR and SARe for different layers of the soil profile (Table 13) decreased with depth. But the rate of decrease of ESP and ESR was gradual without marked difference among the soil layers between 0-90 cm depth. But SARe showed abrupt decrease with each layer down to 165 cm depth with little change beyond this depth. These results again show high sodicity hazard throughout the profile, however, its severity was maximum in the surface layers and decreased with depth. The ESP showed high degree of correlation with pH 1:2 (r = 0.95**), pHe (r = 0.96**), ESR (r = 0.92**) and SSP (r = 0.93**) and only a weak relationship with SARe (r = 0.63**). The SARe exhibited a weak relationship with pH 1:2 (r = 0.76**), pHe (r = 0.74**) and ESR (r = 0.81**). These values indicated that pH 1:2, pHe, and ESP are more interrelated and should be preferred to designate the sodicity hazard of the profile over SARe. Computation of ESR yield information on the ratio with which the exchange complex is occupied by sodium.

Table 12. Composition of exchange complex of the soil in given layers of highly sodic experimental farm (each a mean of 12 determinations).

Soil profile depth (cm)	Exchangeable cations (me 100g^{-1} soil)				CEC (me 100g^{-1} soil)
	Sodium	Potassium	Calcium	Magnesium	
0– 15	9.92 (8.78–10.68)	0.42 (0.38–0.64)	0.12 (0.08–0.18)	0.10 (0.06–0.22)	10.66 (9.92–11.40)
16– 30	10.68 (9.26–11.94)	0.40 (0.32–0.64)	0.16 (0.06–0.26)	0.10 (0.06–0.18)	11.62 (10.14–12.54)
31– 45	10.78 (9.38–11.12)	0.38 (0.30–0.72)	0.22 (0.12–0.34)	0.10 (0.06–0.20)	11.68 (10.66–12.06)
46– 60	11.16 (9.06–11.64)	0.28 (0.22–0.42)	0.20 (0.16–0.26)	0.18 (0.12–0.26)	12.06 (11.36–12.68)
61– 75	10.87 (9.26–11.78)	0.30 (0.18–0.58)	0.32 (0.22–0.44)	0.16 (0.10–0.22)	11.92 (11.34–12.56)
76– 90	10.62 (9.68–11.16)	0.52 (0.34–0.76)	0.41 (0.28–0.82)	0.24 (0.18–0.32)	11.84 (10.92–12.48)
91–105	10.06 (9.04–10.66)	0.46 (0.30–0.68)	0.46 (0.32–0.76)	0.32 (0.26–0.52)	11.68 (10.56–12.42)
106–120	9.32 (9.16–10.65)	0.38 (0.32–0.89)	0.62 (0.36–0.88)	0.96 (0.64–1.76)	11.52 (10.06–12.16)
121–135	8.88 (8.08–9.46)	0.42 (0.30–0.76)	0.66 (0.44–0.92)	1.36 (0.80–1.58)	11.36 (9.84–11.88)
136–150	7.88 (6.16–9.32)	0.46 (0.32–0.72)	0.60 (0.38–0.90)	1.68 (1.26–1.82)	10.64 (9.72 –11.72)
151–165	7.28 (6.26–8.64)	0.40 (0.34–0.58)	0.80 (0.52–1.82)	1.82 (1.64–1.98)	10.35 (8.30–11.32)
166–180	6.95 (5.92–7.36)	0.42 (0.26–0.62)	1.32 (1.14–1.68)	1.12 (0.88–1.32)	9.70 (7.26–10.28)
181–195	7.12 (5.84–7.68)	0.56 (0.32–0.76)	1.22 (1.09–1.72)	1.16 (0.94–1.28)	9.95 (7.02–10.44)
196–210	5.52 (4.86–6.84)	0.52 (0.42–0.78)	1.38 (1.06–1.84)	1.42 (1.06–1.74)	8.98 (7.14–9.88)
211–225	4.84 (4.36–6.26)	0.62 (0.40–0.84)	1.32 (1.12–1.66)	1.86 (1.42–2.26)	8.75 (7.20–9.70)
226–240	5.34 (4.44–6.13)	0.56 (0.40–0.72)	1.36 (1.10–1.71)	1.64 (1.40–1.96)	9.05 (7.00–9.64)
Mean (0–240)	8.58 (4.36–11.94)	0.45 (0.22–0.89)	0.70 (0.06–1.84)	0.90 (0.06–2.26)	10.74 (7.00 – 12.68)

Figures in parentheses denote correspondingly observed variation.

Table 13. ESP, ESR, SARe and $CaCO_3$ content of given layers of the soil profile of highly sodic experimental site.

Soil profile depth (cm)	ESP	ESR	SAR_e (meqL^{-1})	$CaCO_3$ equivalent (g100^{-1} soil)		
				Soil	Soil+ Concretions	Concretions
0- 15	93.1 (92.2-96.4)	13.4 (11.6-15.8)	602.9 (486.4-672.4)	1.75 (1.64-2.04)	2.04 (0.44-3.76)	40.42 (39.16-41.44)
16- 30	91.9 (90.3-93.2)	11.4 (9.8-14.2)	308.0 (266.4-388.1)	1.26 (1.18-1.38)	1.42 (0.24-2.08)	40.74 (38.64-42.12)
30- 45	92.3 (90.0-94.8)	12.0 (9.9-13.9)	245.4 (196.2-311.3)	1.46 (1.22-1.68)	1.92 (0.64-3.52)	39.06 (37.78-41.86)
46-60	92.5 (91.6-94.8)	12.4 (10.1-14.0)	160.7 (132.8-248.4)	2.34 (1.84-3.26)	3.76 (0.40-6.80)	41.46 (38.32-44.02)
61- 75	91.2 (89.6-94.0)	10.4 (8.8-13.1)	126.0 (91.9-188.7)	5.52 (2.46-8.96)	11.15 (8.08-13.84)	38.64 (36.66-41.38)
76- 90	89.7 (87.8-92.3)	8.7 (7.2-10.0)	99.6 (82.7-142.4)	6.12 (5.04-10.18)	14.88 (9.92-22.08)	40.72 (38.26-43.12)
91-105	86.1 (84.2-89.2)	6.2 (5.8-7.0)	81.9 (70.6-108.2)	7.10 (6.84-10.26)	18.19 (16.32-19.44)	42.66 (39.16-45.34)
106-120	80.9 (76.8-86.6)	4.2 (3.2-6.4)	55.5 (46.6-78.4)	10.42 (7.18-11.64)	24.61 (18.72-28.06)	43.76 (41.02-47.68)
121-135	78.2 (74.8-82.8)	3.6 (2.2-5.1)	51.0 (44.3-70.7)	12.64 (8.68-15.62)	29.45 (24.36-32.36)	41.62 (38.65-45.05)
136-150	74.0 (70.6-78.9)	2.8 (2.0-4.2)	26.7 (22.5-32.8)	14.58 (10.12-16.36)	23.56 (20.12-24.92)	39.76 (37.12-43.03)
151-165	70.3 (68.6-75.3)	2.4 (1.8-3.6)	16.6 (13.8-21.2)	8.86 (5.26-13.52)	20.77 (15.60-24.56)	42.68 (38.64-44.36)
166-180	71.6 (66.4-74.4)	2.5 (1.6-3.8)	19.4 (13.6-28.6)	6.66 (4.18-10.06)	20.56 (14.80-26.82)	44.32 (40.56-48.78)
181-195	71.6 (65.2-75.1)	2.5 (1.4-3.8)	16.0 (12.9-20.7)	5.80 (3.10-9.96)	17.80 (12.08-19.68)	42.32 (39.26-46.06)
196-210	61.5 (58.8-64.2)	1.6 (0.9-2.6)	14.5 (13.2-17.3)	6.22 (3.84-8.78)	13.04 (10.56-14.72)	41.34 (40.36-44.16)
211-225	55.3 (52.6-61.3)	1.2 (0.6-2.0)	14.8 (12.6-16.9)	6.66 (4.18-9.74)	12.59 (11.32-13.36)	40.02 (38.10-43.08)
226-240	56.0 (52.6-64.2)	1.4 (0.6-2.1)	14.1 (12.0-17.3)	6.34 (4.44-8.04)	11.36 (7.36-8.04)	42.36 (38.82-45.12)
Mean	78.7 (52.6-96.4)	6.0 (0.6-15.8)	115.8 (12.0-672.4)	6.24 (1.18-16.36)	12.82 (0.24-32.36)	41.39 (36.66-48.78)
Determinations	12	12	15	12	12	12

Figures in parentheses denote correspondingly observed variation.

(e) Calcium Carbonate: Distribution of $CaCO_3$ content (g $100g^{-1}$ soil) in different layers of the soil profile (Table 13) was interesting in view of intended growing of deep rooted tree crops in such a soil. The average $CaCO_3$ content of the soil mass (less than 2 mm) free of concretions varied between 1.18 - 3.26 g $100g^{-1}$ soil for layers between 0-60 cm. However, the remaining soil layers had a mean content of more than 5 g $100g^{-1}$ soil. But middle portion (91-165 cm) of the profile showed an enrichment of $CaCO_3$ varying between 5.26 - 15.62 g $100g^{-1}$ soil. When concretions (greater than 2 mm) were included in the soil, $CaCO_3$ content for each of the layers increased appreciably depending upon the amount of concretions in different layers (see Table 7) but it followed the same distribution trend for the soil profile. The concretions in the different layers were found invariably having about the same $CaCO_3$ content. All this showed highly calcic nature of the profile except the upper 60 cm. Thus, this soil being calcic also could result in plants suffer from nutritional disorder as $CaCO_3$ is generally considered a cogent cause of chlorosis.

(f) Available Nutrients: Results (Table 14 and 15) on the fertility status in respect of availability of important nutrient elements are presented under two sub-heads below:

(i) Macro-nutrients: The average available (that fraction of total content of a nutrient element which is susceptible to absorption by plants) or 0.32 per cent $KMnO_4$ - extractable (Subbiah and Asija, 1956) N content of the soil profile was very low as a whole. Its average content was maximum (25.2 mg kg^{-1}) in the surface soil and decreased with depth. Poor available N is due to very low organic carbon content (Table 14) of the soil and there existed a close relationship

Table 14. Organic carbon and available N, P and K of the soil is given layers of the highly sodic experimental farm.

Soil profile depth (cm)	Oxidizable organic Carbon (g100g-1 soil)	Available nutrient (mg kg-1 soil) Nitrogen	Phosphorus	Potassium
0- 15	0.265 (0.240-0.299)	25.2 (18.6-32.8)	37.4 (19.2-56.3)	186.9 (181.8-227.3)
16- 30	0.246 (0.223-0.281)	23.6 (19.8-26.6)	23.0 (13.5-28.5)	189.4 (159.2-227.3)
31- 45	0.191 (0.169-0.245)	22.6 (18.7-24.3)	16.2 (12.2-21.0)	170.5 (148.7-205.6)
46- 60	0.185 (0.162-0.217)	20.8 (16.4-23.3)	9.6 (7.0-11.6)	159.1 (124.8-202.8)
61- 75	0.179 (0.158-0.201)	17.9 (14.8-22.6)	8.6 (7.0-10.5)	151.5 (102.1-193.1)
76- 90	0.172 (0.143-0.193)	15.4 (12.2-19.1)	6.2 (2.8-9.5)	147.7 (102.1-181.8)
91-105	0.165 (0.129-0.193)	12.8 (9.6-16.8)	5.2 (3.2-8.0)	132.6 (102.1-159.2)
106-120	0.132 (0.121-0.184)	11.7 (9.4-14.4)	2.8 (0.5-4.5)	121.0 (102.1-147.5)
121-135	0.118 (0.107-0.143)	11.0 (9.6-12.6)	1.7 (1.1-2.4)	121.2 (90.9-159.2)
136-150	0.095 (0.086-0.104)	10.5 (8.6-11.2)	1.7 (0.5-1.9)	113.5 (94.6-136.3)
151-165	0.086 (0.079-0.100)	11.2 (8.8-12.4)	1.4 (0.5-1.1)	106.0 (86.3-124.8)
166-180	0.081 (0.074-0.095)	10.5 (9.2-12.6)	1.5 (1.0-2.5)	98.3 (79.4-124.8)
181-195	0.074 (0.070-0.082)	10.9 (8.8-13.2)	1.5 (0.5-3.0)	87.0 (68.1-128.1)
196-210	0.088 (0.074-0.095)	9.2 (8.8-12.4)	1.4 (0.5-2.4)	94.6 (68.9-126.6)
211-225	0.074 (0.070-0.086)	8.8 (8.2-10.6)	1.5 (0.5-2.2)	94.6 (79.4-113.5)
226-240	0.062 (0.054-0.070)	9.0 (8.2-11.3)	1.5 (0.8-1.9)	98.4 (0.8-116.6)
Mean (0-240)	0.138 (0.054-0.299)	14.5 (8.2-32.8)	7.6 (0.5-56.3)	130.1 (68.1-227.3)
Determinations	10	6	10	10

Figures in parentheses denote correspondingly observed variation.

($r = 0.92^{**}$) between the two. Organic carbon is a measure of soil organic matter content, a store house of N supply. But available P and K contents in the soil were enough (Table 14). Available P in the surface soil was very high (37.4 mg kg^{-1}) but it decreased to 23.0, 16.2, 9.6, 8.6, 6.2 and 5.2 mg kg^{-1} soil of layers in the descending order. Soil below 105 cm depth showed further decline and all these layers were poor in available P. Chhabra et al. (1981) also reported high available P in highly sodic soils of this region. Although amount of available K also indicated a decrease with depth but based upon its content in each layer the soil profile between 0-120 cm may be designated high and the rest medium for K supplying capacity. About Ca, Mg and S, their contents as found in the saturation extract and on the exchange complex are also very low and need their applications for amelioration as well as to meet nutritional requirements of plants in such soils.

(ii) Micro-nutrients: The available or DTPA-extractable (Lindsay and Norvell, 1969), Fe, Mn, Zn and Cu data (Table 15) indicated their contents to be sufficiently high except that of Zn. Amount of Fe, Mn and Cu showed an accumulation in the surface layers and a decrease with depth. Despite the high pH and $CaCO_3$ reported by several workers in a review (Kanwar and Randhawa, 1978) to reduce their availability drastically their amount was high throughout the profile depth. Although depthwise distribution of available Zn followed a similar trend but its amount was low throughout the soil profile. The results thereby reveal the necessity of Zn application to achieve optimum growth of plants in such a highly sodic soil.

The physical and chemical characteristics of the soil profile, thus, clearly show the following possible constraints with their severity maximum in the surface layers. Based on these results, the

Table 15. Available amounts of Fe, Mn, Zn and Cu in the soil of given layers of the profile of highly sodic experimental farm (each a mean of 10 determinations).

Soil profile depth (cm)	DTPA-extractable micro-nutrients (mg kg^{-1} soil)			
	Iron	Manganese	Zinc	Copper
0- 15	77 (68-94)	96 (88-118)	0.52 (0.33-0.60)	2.30 (1.78-2.82)
15- 30	93 (78-116)	115 (102-134)	0.44 (0.28-0.52)	2.24 (1.88-2.66)
31- 45	83 (70-98)	109 (98-122)	0.39 (0.28-0.48)	1.73 (1.56-2.12)
46- 60	60 (62-72)	89 (78-100)	0.28 (0.20-0.39)	1.02 (0.88-1.24)
61-75	53 (42-63)	74 (65-88)	0.41 (0.26-0.52)	0.81 (0.66-0.96)
76- 90	43 (36-52)	65 (60-73)	0.39 (0.28-0.46)	0.62 (0.52-0.72)
91-105	47 (36-61)	60 (52-66)	0.35 (0.26-0.42)	0.53 (0.46-0.60)
106-120	43 (30-55)	59 (50-68)	0.16 (0.08-0.28)	0.43 (0.36-0.51)
121-135	47 (38-58)	47 (38-58)	0.21 (0.10-0.32)	0.45 (0.36-0.53)
136-150	47 (36-59)	59 (52-66)	0.15 (0.12-0.19)	0.50 (0.30-0.58)
151-165	40 (32-50)	54 (44-66)	0.15 (0.10-0.21)	0.38 (0.32-0.46)
166-180	33 (30-38)	51 (40-60)	0.21 (0.14-0.31)	0.40 (0.30-0.52)
181-195	37 (30-44)	52 (44-58)	0.13 (0.10-0.22)	0.31 (0.22-0.38)
196-210	30 (26-36)	46 (42-56)	0.12 (0.08-0.16)	0.30 (0.20-0.42)
211-225	30 (24-38)	42 (36-52)	0.10 (0.06-0.16)	0.28 (0.20-0.36)
226-240	37 (28-46)	41 (36-54)	0.13 (0.08-0.15)	0.31 (0.26-0.42)
Mean	50 (24-116)	67 (36-134)	0.26 (0.06-0.60)	0.79 (0.20-2.82)

soil of the experimental site can be classified highly sodic and a representative of such soils occupying about 2.5 million ha (Abrol and Bhumbla, 1971) area in the Indo-Gangetic plains. These soils have been studied by several workers (Agarwal and Yadav, 1954; Govinda Rajan and Murthy, 1969; Kanwar and Bhumbla, 1969; Abrol and Bhumbla, 1971; Bhargava et al., 1972; Bhargava and Abrol, 1978; Abrol and Bhumbla, 1978; Abrol and Bhumbla, 1979; Abrol et al., 1980; Bhargava et al., 1980; Gupta et al., 1981; Abrol, 1982) in the past. Consideration of their findings and analytical data on the experimental highly sodic field under the present investigations, a few of the constraints may be pin-pointed as below:

(a) Presence of excessive soluble salts chiefly sodium carbonate in the surface layers (0-30 cm) of the soil.

(b) High pH of the soil, upto 10.5 in a 1:2 soil-water suspension.

(c) Excessive amount of ions namely sodium, carbonate and bicarbonate in the saturation extract.

(d) High ESP of the soil throughout the soil profile.

(e) Highly dispersive and indurated nature of the soil.

(f) Strong calcareousness of the profile except the upper 60-75 cm.

(g) Presence of a calcic horizon (<u>kankar</u>) around the metre depth of the soil profile which offers severe mechanical impedance to downward growth of roots.

(h) Poor organic matter, available N, S, Ca, Mg and Zn status of the soil make it vulnerable from the fertility point of view.

(i) Low water availability of the soil between field capacity (0.03 MPa) and permanent wilting point (1.5 MPa) tensions.

(j) High pH and ESP are reported (Abrol, 1977; Acharya and Abrol, 1978; Sandhu et al., 1980; Sandhu et al., 1982; Acharya et al., 1984) to affect adversely moisture transmission and retention characteristics of the soils.

4.2 Evaluation of Selected Site Preparation Techniques on the Performance of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del. in a Highly Sodic soil

Introduction: The physico-chemical constraints which make a highly sodic soil inhospitable for economic growth of the most tree species when planted following techniques suited for normal soils require an appropriate modification to achieve reasonably high per cent survival and rapid early growth. The given modification must ensure besides a package of other management practices, (a) availability of the soil environment favourable for optimum root growth, (b) manipulation of the root zone conducive for leaching of excess soluble salts, (c) maximum retention of available moisture within the root zone soil mass, (d) perforation of any type of hard pan on mechanical impediment present in the sub-soil, and (e) maintenance of the soil fertility through application of fertilizers and organic manures. Research efforts of several workers (Khan and Yadav, 1962; Pande, 1967; Pathak, 1967; Yadav et al., 1975) in the past showed that successful afforestation of highly sodic soils had rather limited prospects unless the soil conditions were ameliorated to a desired level by adopting suitable techniques.

The recently suggested technique (Pande, 1967; Yadav et al., 1975) for planting of trees in the sodic soils require making pits, 90 cm each in depth and diameter, refilled with a mixture of the sodic soil, 25 kg FYM and 50 per cent of GR per pit before planting a tree sapling. There are a few intrinsic bottlenecks in this technique e.g. (a) considerably higher requirement for the amendments, (b) laborious and time consuming pit digging operation, (c) greater earth work in preparing the filling mixture and refilling of the pits with it, (d) no perforation of the calcic horizon of about 40-60 cm width between 90-140 cm depth of the soil profile, and (e) limited scope of making pits mechanically. These limitations caused adoption of this method to a very limited extent. In view of the above limitations and need for bringing refinement in planting techniques, this experiment was carried out to evaluate the response of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del. to selected site preparation techniques in a highly sodic soil. The principal hyopthesis based on the reality is that in tree plants, by virtue of their having deep rooted systems, management of the root zone by modifying the soil environment with limited quantity of amendments in the profile to a deeper depth has a vital role in their establishment unlike for the agricultural crops.

Methodology: The selected site preparation techniques comprised planting of *Eucalyptus tereticornis* Sm. (a very popularly planted species in India) and *Acacia nilotica* (L.) Willd. ex. Del. (a species that grow naturally in salt affected landscapes) in different four type of postholes and a pit prepared using various sized soil augers and an assortment of spades and shovels respectively. These postholes and pits were refilled with the sodic soil mixed with gypsum and FYM. Details relating to the dimensions (diameter x depth) of the postholes, the pit and the amounts of amendments used for their refilling are given in Table 16.

About six months old saplings of the two species raised in polythene bags were planted on July 17, 1979. Experiment was laid out in a randomized block design and replicated four times. Each replicate represented a plot (6 m x 6 m) growing four plants with a spacing of 3 m between the rows and the plants. Nitrogen (urea) was

Table 16. Details of treatments at a glance

Sr. No.	Dimensions (dia x depth in cm)	Volume (cm^3)	Gypsum (kg)	FYM (kg)
Postholes				
T_1	10 x 120	9425	3 (0.32)	4 (0.42)
T_2	10 x 180	14137	3 (0.21)	6 (0.42)
T_3	15 x 120	21206	3 (0.14)	8 (0.38)
T_4	15 x 180	31809	3 (0.09)	12 (0.38)
Pit				
T_5	90 x 90	572555	12 (0.02)	24 (0.04)

Figures in parentheses denote gypsum and FYM in g cm^{-3} of pit or posthole.

applied at the rate of 20 and 10 g N plant^{-1} on Aug. 4 and Nov. 26 of 1979 respectively. Plants were watered on the need felt basis until a year past planting. Growth observations were recorded monthly during the first year and quarterly subsequently. Acacia trees were lopped of undesired branches after 16 and 42 months after planting. The biomass lopped as foliage and woody material was estimated on fresh and oven dry basis. Chemical analysis of the biomass was done and removal of essential nutrient elements was computed. Firewood value of different sized billets of Eucalyptus and Acacia at different moisture contents caused by differential air drying was estimated 42 months past planting using a Bomb Calorimeter.

Growth Underneath the Canopy: The biomass productivity resulted from the natural growth of vegetation, primarily grasses, underneath the canopies of the two tree species was quantified by harvesting whole of the grown up vegetation in plots allocated to different site preparation treatments once a year in Dec. of 1982 to 1984. Biomass yield was estimated on oven dry basis. Randomly drawn samples were analysed for chemical composition and computation of the removal of important nutrient elements.

Reclaiming Effect and Micro-climate Modification: During Jan. 1982 - Dec. 1984, variation in soil moisture content in eight layers of 15 cm each between 0-120 cm profile was monitored by sampling monthly and measuring the moisture content on dry weight basis gravimetrically. Similarly, the mean soil temperature at 5 and 20 cm depths, the mean canopy temperature (at 137 cm height from the soil surface) of Acacia and Eucalyptus plantations at similar locations and on the neighbouring dummy bare land at the same height was monitored on 15th and 30th day of each month at 0722 and 1422 hours during Jan. 1, 1982 - Dec. 30, 1984. The reclaiming effect of trees and natural growth of vegetation underneath the canopies of Acacia and Eucalyptus was evaluated by analyzing the soil samples of the profile (0-5 cm, 6-15 cm, 16-30 cm, 31-45 cm and 46-60 cm) for pH, EC and organic carbon in Sept. of 1982 and 1984 besides at the planting time in 1979. Water infiltration was also measured in the field for plots under different spacing.

Litter Production: Irrespect of the site preparation techniques, the average foliage shed in Acacia and Eucalyptus plantations during July-Aug., Sept. - Oct., Nov. - Dec., Jan. - Feb., March - April and May-June between July 1982 and April, 1985 were estimated through collection of foliage shed in containers, 120 cm long and 60 cm wide, in numbers sufficient to represent all possible locations of the canopies of the two trees. Amounts were expressed on oven dry basis. Randomly drawn samples from the collected litter were analysed chemically to ascertain the amounts of important nutrient elements being recycled or added to the soil.

Results and Discussion: Experimental findings are presented and discussed below under different headings:

A. Per Cent Survival: Survival of both Acacia and Eucalyptus for all the site preparation treatments continued to be cent per cent until 72 months past planting. About 12 per cent of Eucalyptus planted in postholes (T_3) with 15 cm dia. and 120 cm depth were observed dead between 36-42 months of growth period. These observations show that planting of the given two trees in postholes of considerably limited width but greater depth and refilled with original sodic soil (OS) mixed with limited quantities of gypsum and farm yard manure (FYM) survive as good as in pits requiring high doses of amendments. Digging of pits with 18-60 times greater volume than the postholes further make it a laborious proposition. The posthole technique has a genuine scope for its mechanical adoption as well. And nowadays power operated (tractor) posthole diggers with diverse specifications are being fabricated and marketed in the country.

B. Growth Parameters

(a) Height Growth: Data on the effect of selected site preparation techniques on the periodic height of Eucalyptus (Table 17) and Acacia (Table 18) indicate that differences were not significant statistically at all the noted growth stages during the initial 72 months of growth. Height growth of the two species was rapid until the initial 24-36 months of planting but was much slower afterwards. Eucalyptus trees presented a chlorotic look with limited growth of yellowish brown foliage whereas Acacia developed a dense (Plate 3) lush green canopy. Cumulative mean monthly height growth of Eucalyptus

Table 17. Effect of site preparation techniques on the mean period height (cm) growth of *Eucalyptus* *tereticornis* Sm. in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
0	70	65	61	74	55	65	NS
1	74	71	68	81	59	71	NS
2	91	90	82	102	78	89	NS
3	106	106	94	115	90	102	NS
4	116	121	100	126	99	112	NS
5	120	123	103	129	101	115	NS
6	121	125	106	133	106	118	NS
7	124	129	110	137	111	122	NS
8	132	138	121	152	123	133	NS
9	161	177	159	222	168	177	NS
10	228	256	232	286	239	248	NS
11	259	304	260	348	316	297	NS
12	292	352	296	392	342	335	NS
15	350	424	349	466	385	395	NS
18	362	439	362	478	398	408	NS
21	408	476	422	526	494	465	NS
24	446	530	470	592	562	520	NS
27	538	612	556	616	633	591	NS
30	596	638	602	652	668	631	NS
33	610	648	622	666	677	645	NS
36	624	658	636	679	698	659	NS
39	646	676	662	688	732	681	NS
42	654	689	676	702	756	695	NS
45	662	700	681	716	774	706	NS
48	670	713	687	730	793	719	NS
51	676	715	696	745	809	728	NS
54	681	719	706	759	822	737	NS
57	696	734	724	776	840	754	NS
60	743	783	768	813	883	798	NS
63	756	798	772	826	898	810	NS
66	762	812	776	834	906	818	NS
69	771	820	782	840	913	825	NS
72	779	829	789	846	920	833	NS

Table 18. Effect of site preparation techniques on the mean periodic height (cm) growth of *Acacia nilotica* (L.) Willd. ex. Del. in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
0	53	52	54	58	46	53	NS
1	56	54	58	62	49	56	NS
2	65	67	71	72	76	70	NS
3	74	78	82	82	90	81	NS
4	78	94	89	88	99	90	NS
5	81	104	98	98	108	98	NS
6	82	104	100	99	109	99	NS
7	82	104	100	100	110	99	NS
8	86	108	104	106	115	104	NS
9	132	142	156	163	174	153	NS
10	194	210	214	222	242	216	NS
11	242	251	256	264	278	258	NS
12	276	282	274	290	310	286	NS
15	309	318	307	334	348	323	NS
18	313	324	313	337	356	329	NS
21	334	352	356	364	372	356	NS
24	374	396	390	409	412	396	NS
27	441	464	478	484	494	472	NS
30	458	482	494	497	513	489	NS
33	462	488	499	506	518	495	NS
36	478	502	543	555	562	528	NS
39	496	519	582	571	596	553	NS
42	500	526	594	582	620	564	NS
45	511	536	602	596	632	575	NS
48	523	552	617	614	650	589	NS
51	556	588	629	621	660	611	NS
54	570	610	638	626	667	622	NS
57	572	614	640	630	668	625	NS
60	580	617	642	638	674	630	NS
63	584	626	644	641	680	635	NS
66	586	630	644	643	682	637	NS
69	590	635	645	644	684	640	NS
72	596	639	647	645	685	643	NS

Plate 3

A poorly developed open canopy of Eucalyptus with a chlorotic look,

A well developed lush green canopy of Acacia.

and Acacia (Fig. 7) showed highest increments in the initial one year of planting but significant decrease was evident in later years. A careful analysis of data showed relatively higher increments for Eucalyptus in posthole technique (T_4) than the pit method (T_5). But reverse was true for Acacia. Among the given posthole types, diameter of postholes did not influence the height growth, however, depth of 180 cm favoured Eucalyptus to edge out that of 120 cm. But response of Acacia to variations in diameter or depth of postholes was indifferent.

(b) Girth Growth: Data on periodic DSH and DBH of Eucalyptus (Tables 19 and 20) and Acacia (Tables 21 and 22) again show that effect of the site preparation techniques of planting did not result in significant differences in the girth of the two species at all the observed growth stages. In Eucalyptus, depth of the posthole rather than its diameter was important though such a trend was not obvious in case of Acacia. Unlike height,growth, increment in girth growth (DSH) of Eucalyptus was observed (Fig.8) maximum during the second year, however, it also showed a gradual decrease with subsequent years. But this pattern did not occur in Acacia. Increments in DSH of Acacia plants in all the treatments were more in the first year of planting than in the second and third year of growth. After third year, growth of Acacia occurred at a rate to effect increments greater in the fourth year. But subsequent cumulative mean monthly DSH increments in the fifth and sixth year of the growth period were low. The girth growth increments of Eucalyptus were greater than that of Acacia in the initial three years but were less in the subsequent years. This shows that Eucalyptus and Acacia followed different patterns in girth growth.

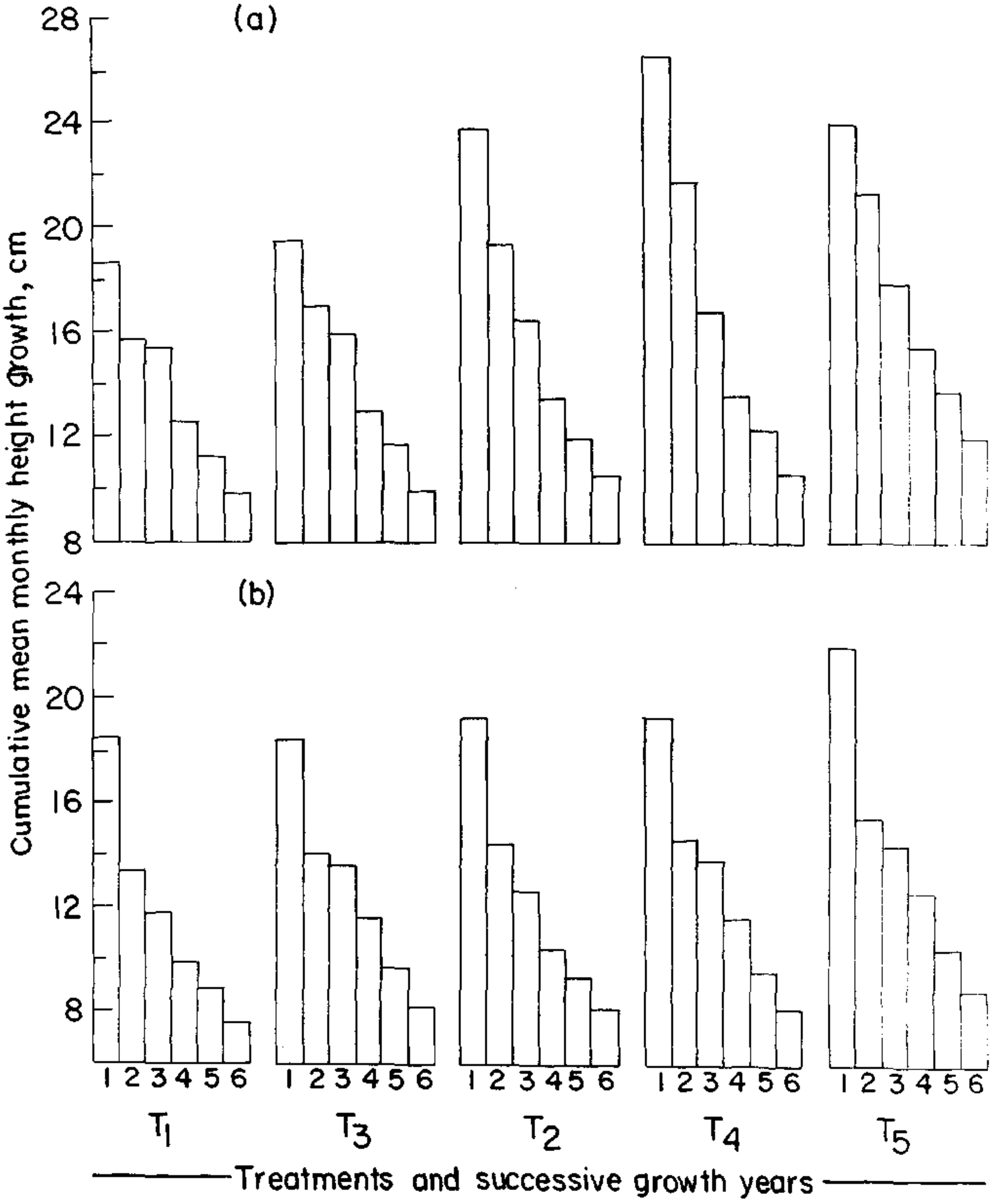


Fig.7. Site preparation techniques vis–a–vis cumulative mean monthly height growth of Eucalyptus (a) and Acacia (b) during successive growth years

Table 19. Effect of site preparation techniques on the mean period on DSH* (mm) of *Eucalyptus tereticornis* Sm. in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
0	5.3	5.2	5.2	5.4	5.3	5.3	NS
1	6.6	7.3	6.8	7.8	6.4	7.0	NS
2	7.8	8.0	7.8	8.3	7.7	7.9	NS
3	9.5	9.7	9.6	10.3	9.9	9.8	NS
4	15.2	16.8	14.9	17.1	15.8	16.0	NS
5	16,2	17.1	16.6	18.0	16.2	16.8	NS
6	17.4	18.6	18.2	19.6	16.8	18.1	NS
7	18.3	19.6	19.0	20.4	18.8	19.2	NS
8	23.7	25.6	24.1	26.2	24.7	24.9	NS
9	29.6	30.3	30.2	31.8	29.9	30.4	NS
10	31.3	33.6	32.2	34.8	34.6	33.3	NS
11	34.6	36.4	35.8	37.4	36.8	35.8	NS
12	37.8	40.4	39.2	42.7	40.3	40.1	NS
15	52.2	55.6	53.4	57.4	56.2	55.0	NS
18	62.6	65.7	64.2	68.2	65.1	65.2	NS
21	81.3	86.3	82.0	87.7	85.8	84.6	NS
24	101.3	104.8	102.6	106.6	105.3	104.1	NS
27	111.6	113.3	112.0	116.2	115.2	113.8	NS
30	114.4	115.6	113.8	120.4	121.3	117.1	NS
33	116.7	123.8	118.4	125.3	124.2	121.7	NS
36	120.2	127.8	123.6	132.4	131.9	127.2	NS
39	121.6	132.2	125.8	136.2	134.2	130.0	NS
42	122.8	134.4	126.2	138.3	136.6	131.7	NS
45	123.0	136.2	130.3	142.8	140.3	134.5	NS
48	123.8	143.2	133.4	146.6	142.0	137.8	NS
51	126.2	143.8	133.6	147.1	143.2	138.8	NS
54	128.1	144.2	134.0	148.0	144.6	139.8	NS
57	130.2	146.8	134.0	151.3	144.8	141.4	NS
60	134.0	150.2	134.2	153.4	145.0	143.4	NS
63	133.8	148.3	136.6	154.8	157.3	146.2	NS
66	134.2	149.8	138.2	155.5	160.3	147.6	NS
69	134.0	150.2	140.4	157.1	162.2	148.8	NS
72	134.0	151.0	143.0	158.0	165.0	150.0	NS

*DSH stands for girth diameter at stump height (5 cm).

Table 20. Effect of site preparation techniques on the periodic DBH* (mm) of *Eucalyptus tereticornis* Sm. in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
9	12.6	13.2	12.8	13.6	11.9	12.8	NS
10	15.7	16.7	15.8	17.1	15.2	16.1	NS
11	19.3	20.8	19.9	21.2	20.3	20.3	NS
12	23.8	27.8	24.4	27.8	26.6	26.0	NS
15	33.2	36.9	33.8	37.6	35.9	35.5	NS
18	36.4	39.2	37.6	41.8	38.8	38.8	NS
21	41.6	45.5	44.2	47.3	44.6	44.6	NS
24	52.3	55.6	54.2	58.7	54.8	55.1	NS
27	64.8	72.3	69.7	74.6	71.3	70.3	NS
30	66.3	76.2	71.8	79.8	78.2	74.5	NS
33	71.2	80.6	74.3	82.9	82.4	78.3	NS
36	76.7	84.3	79.3	86.8	85.4	82.5	NS
39	78.2	87.3	81.8	88.4	87.2	84.6	NS
42	78.6	88.0	82.2	88.9	87.8	85.1	NS
45	80.8	89.1	83.6	90.5	89.1	86.6	NS
48	82.4	90.9	85.6	91.8	90.9	88.3	NS
51	84.3	93.2	87.3	94.6	94.6	90.8	NS
54	85.5	94.3	88.1	96.2	95.7	92.0	NS
57	86.4	96.7	90.6	100.8	99.3	94.8	NS
60	89.3	99.0	92.3	104.1	102.3	97.4	NS
63	89.1	101.2	94.7	106.3	106.8	99.6	NS
66	89.2	101.8	95.2	107.1	108.9	100.4	NS
69	89.0	102.9	96.8	108.4	112.7	102.0	NS
72	89.0	104.6	97.6	109.1	115.3	103.1	NS

*DBH stands for girth diameter at breast height (137 cm).

Table 21. Effect of site preparation techniques on the mean periodic DSH* of *Acacia nilotica* (L.) Willd. ex. Del. in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
0	11.6	10.9	11.4	11.6	9.8	11.1	NS
1	11.8	11.1	12.2	12.3	10.1	11.5	NS
2	12.3	12.4	13.3	13.4	12.1	12.7	NS
3	14.7	13.8	14.8	15.2	13.8	14.5	NS
4	17.2	15.8	16.2	17.1	15.6	16.6	NS
5	17.3	17.0	16.4	17.3	15.8	16.8	NS
6	17.3	17.2	16.5	17.6	16.2	17.0	NS
7	17.5	17.9	17.0	17.8	16.6	17.4	NS
8	19.3	20.2	20.0	21.3	21.1	20.4	NS
9	22.2	23.4	21.8	24.6	24.2	23.2	NS
10	28.4	29.2	27.6	30.5	30.0	29.1	NS
11	32.7	33.8	34.3	35.1	35.5	34.3	NS
12	37.4	39.0	37.4	38.8	39.4	38.4	NS
15	41.4	48.7	45.9	53.4	55.9	49.1	NS
18	42.6	50.2	46.4	54.0	56.2	49.9	NS
21	46.4	51.6	49.5	54.8	56.6	51.8	NS
24	48.8	53.8	52.8	55.6	57.3	53.7	NS
27	58.4	62.4	63.9	64.8	64.6	62.8	NS
30	59.2	63.8	65.2	66.2	66.8	64.2	NS
33	63.8	70.9	72.3	77.3	78.4	72.5	NS
36	69.8	77.4	78.2	85.6	89.8	80.2	NS
39	80.4	88.6	93.9	100.1	109.6	94.5	NS
42	83.6	92.9	95.6	103.4	114.6	98.0	NS
45	96.4	102.8	106.9	110.8	121.3	107.6	NS
48	111.3	116.4	117.3	121.6	131.8	119.7	NS
51	116.2	124.1	126.6	127.3	136.8	126.2	NS
54	116.8	125.6	127.2	128.2	137.4	127.0	NS
57	121.4	131.8	133.2	135.6	144.6	133.3	NS
60	126.6	135.8	135.8	142.0	155.4	139.1	NS
63	129.8	138.2	139.9	145.0	160.2	142.6	NS
66	130.1	138.4	140.0	145.6	161.4	143.1	NS
69	133.6	141.6	142.2	152.4	165.8	147.1	NS
72	135.4	144.6	145.0	159.0	169.0	150.6	NS

*DSH stands for girth diameter at stump height (5 cm).

Table 22. Effect of site preparation techniques on the periodic DBH* (mm) of *Acacia nilotica* (L.) Willd.ex. Del in a highly sodic soil.

Growth stage (months past planting)	Site preparation techniques					Mean	LSD (0.05)
	T_1	T_2	T_3	T_4	T_5		
9	9.8	9.6	9.5	10.1	10.2	9.8	NS
10	12.3	12.4	11.8	12.8	12.6	12.4	NS
11	14.6	14.4	13.9	15.3	15.2	14.7	NS
12	18.7	18.9	17.9	19.7	20.1	19.1	NS
15	21.7	22.2	19.8	24.5	25.6	22.8	NS
18	22.2	23.1	20.5	25.6	26.4	23.6	NS
21	24.7	25.8	23.6	27.2	29.3	26.1	NS
24	26.3	28.4	27.6	29.8	31.4	28.7	NS
27	38.4	49.3	37.9	40.4	44.3	42.1	NS
30	40.5	50.9	39.1	42.2	46.1	43.8	NS
33	46.8	55.8	47.9	56.3	58.2	53.0	NS
36	56.8	60.7	61.8	63.6	64.9	61.6	NS
39	65.5	71.9	73.3	74.7	78.2	72.7	NS
42	66.8	72.8	74.2	75.6	80.0	73.9	NS
45	72.3	81.2	80.8	86.7	91.8	82.6	NS
48	80.8	91.3	88.4	98.6	103.8	92.6	NS
51	83.3	96.8	95.8	105.7	114.6	99.2	NS
54	85.6	97.6	96.4	107.3	117.8	100.9	NS
57	91.7	103.8	102.6	113.9	121.6	106.7	NS
60	99.3	107.8	108.3	121.8	128.8	113.2	NS
63	100.1	108.6	109.2	122.0	128.8	113.7	NS
66	100.4	109.1	110.0	122.6	129.0	114.2	NS
69	101.3	110.6	110.5	123.5	130.4	115.3	NS
72	102.0	111.6	111.4	124.7	132.6	116.5	NS

*DBH stands for girth diameter at breast height (137 cm).

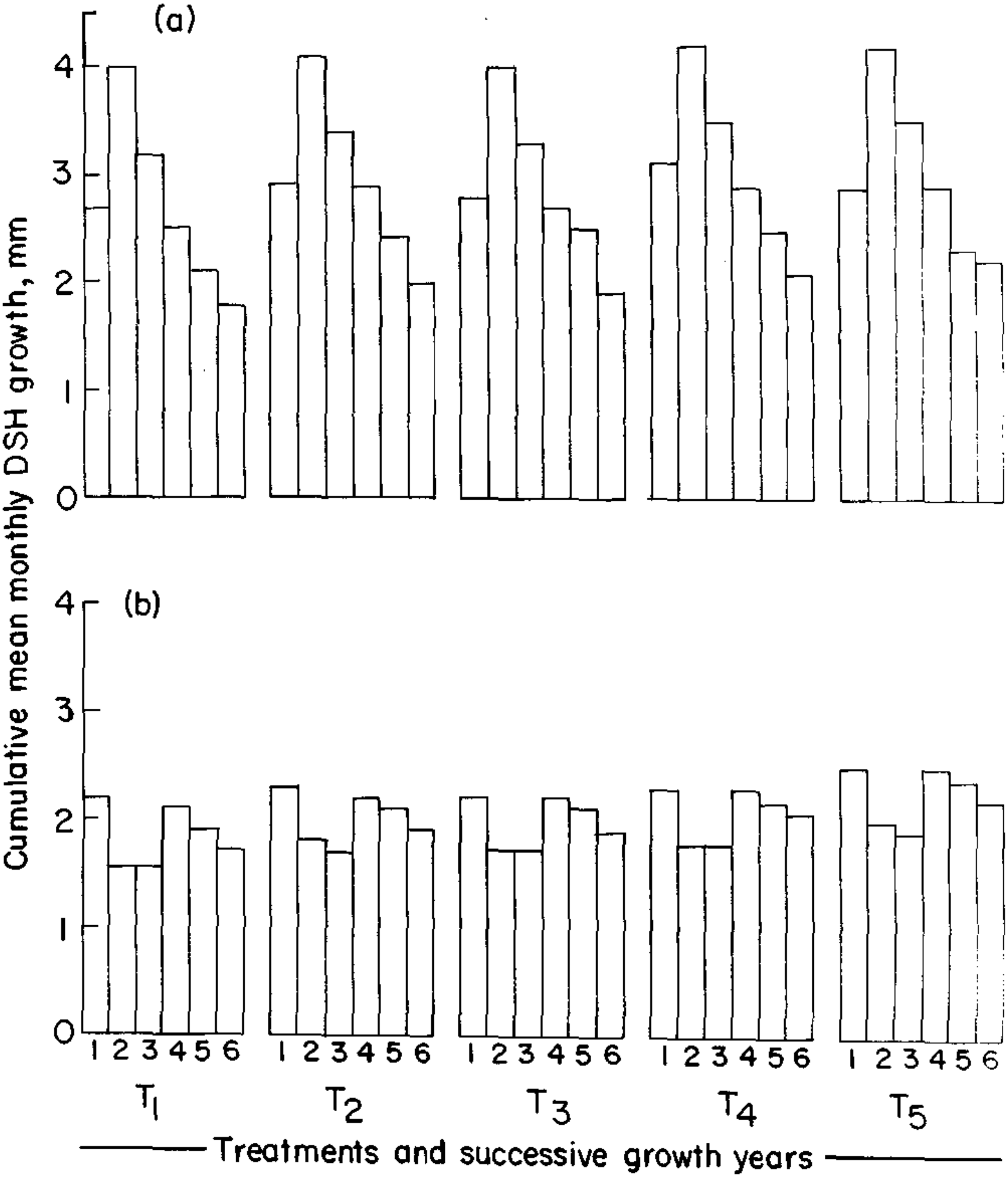


Fig. 8. Site preparation techniques vis-a-vis cumulative mean monthly girth (DSH) growth of Eucalyptus (a) and Acacia (b) during successive growth years.

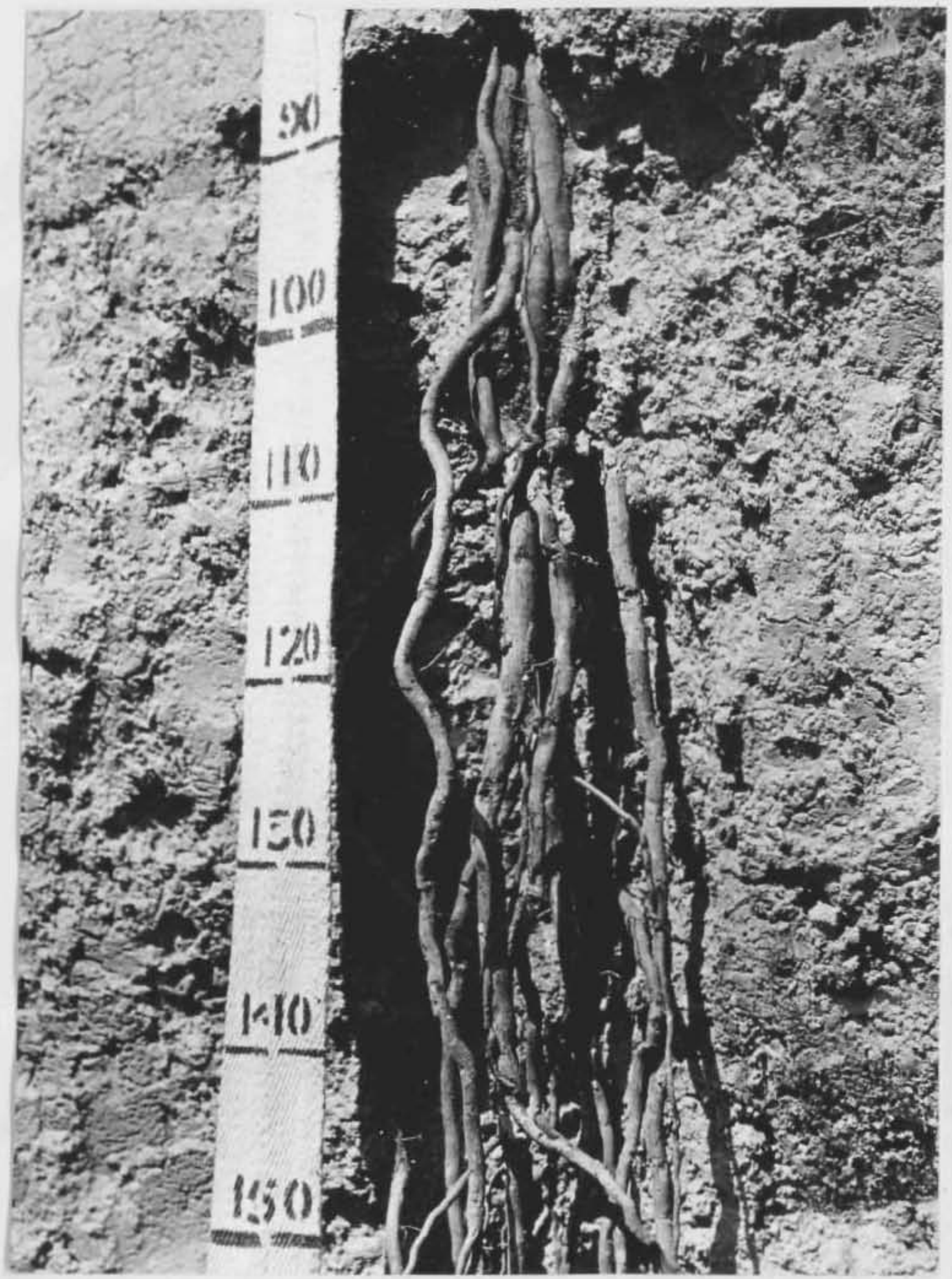
Comparable height and girth (DSH and DBH) growth of Eucalyptus and Acacia planted in posthole (15 cm dia. and 180 cm depth, T_4) and pit (90 cm x 90 cm) techniques bring out the development of a new technique for planting of the tree species in highly sodic soils. In view of average potential height and girth (DBH) reported (NAS, 1980, 1983) to be attained by *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del. under diverse situations of soil types and agro-climates, the former was found to have reached nearly stagnation after three years of planting despite very encouraging growth during the first three years. Growth of Acacia was observed to occur satisfactorily. Periodic height and girth growth data also indicate that Eucalyptus was somewhat sensitive to the posthole depth than the diameter. This implies that Acacia is relatively more tolerant to the mechanical impedance faced by roots to penetrate the calcic horizon in case of shallow postholes. This is also evident from about same magnitude of growth of Eucalyptus in postholes refilled with amended mixtures containing varying dose (0.09 - 0.32 g cc^{-1} of posthole volume) of gypsum.

The results, thus, showed that use of limited amount of amendments in a limited volume but greater profile depth has a vital role in achieving high per cent survival and rapid early growth of selected tree species planted in highly sodic soils. The posthole method of tree planting was observed congenial for plants to grow roots in the deeper layers where moisture availability is high. Eucalyptus was found developing a good root system (Plate 4) rapidly after planting in postholes refilled with sodic soil amended with gypsum and FYM. The high per cent survival and early growth of Acacia and Eucalyptus

Plate 4

An exposed root system of a six month old Eucalyptus planted through posthole technique in a highly sodic soil.

A close up of root proliferation of Eucalyptus in deeper horizons of highly sodic soil profile.


90
100
110
120
130
140
150

planted in postholes demonstrated the promise of this new technique. Yadav et al. (1975) reported similar results obtained following pit method. But growth of Eucalyptus after three years of planting occurred at a much slower rate than anticipated on the basis of rapid growth rate during initial stages.

C. <u>Biomass Yield on Lopping of Acacia</u>: Crown growth of Acacia was very encouraging unlike that of Eucalyptus throughout the growth period. Thus, to maintain a proper balance between the crown and the boll for producing quality timber, undesirable shoots on trunk of trees were lopped 16 and 42 months after planting. Woody matter and foliage yields were estimated. Data (Table 23) show that woody matter and foliage yield resulted from lopping was the highest in T_5. But differences were statistically significant only in yields caused by lopping after 16 months of planting. Results also indicate some relationship with the growth by showing a decrease or increase in biomass lopped with growth parameters recorded for the given treatments. Woody matter including billets or branches and foliage yielded may be used as firewood and forage respectively. Total yield of foliage (oven dry) and woody matter varied between 1921-2828 kg ha^{-1} and 5306 - 7616 kg ha^{-1} respectively from both the loppings.

Results on chemical composition of foliage (Table 24) and woody matter (Table 25) indicate that effect of the different site preparation techniques was not significant on the concentration of Na, K, Ca, Mg, N, P, S, Fe, Mn, Zn and Cu in both of the components. However, their relative concentration in foliage lopped after 16 months were higher than the same lopped after 42 months of planting. This may be attributed to the dilution effect of continual growth. But in case

Table 23. Biomass (kg ha^{-1}) lopped as branches growing on the tree bolls after (16(a) and 42(b) months of planting *Acacia nilotica* (L.) Willd.ex.Del.

Treatment	Woody matter			Foliage			Woody matter + Foliage
	a	b	a+b	a	b	a+b	
T_1	1662 (2216)*	3644 (4796)	5306 (7012)	565 (2942)	1356 (7051)	1921 (9993)	7227
T_2	1835 (2548)	4427 (5983)	6262 (8531)	642 (3274)	1681 (8741)	2323 (12015)	7943
T_3	1874 (2677)	3360 (4667)	5234 (7344)	676 (3515)	1396 (7259)	2072 (10774)	6630
T_4	2264 (3059)	4333 (6018)	6597 (9077)	874 (4545)	1698 (8493)	2572 (13038)	9169
T_5	3015 (4074)	4601 (6573)	7616 (10647)	1012 (5262)	1816 (8898)	2828 (14160)	10444
Mean	2130 (2915)	4073 (5607)	6203 (8522)	754 (3908)	1589 (8088)	2343 (11996)	8283
LSD (0.05)	756 (1009)	NS (NS)	NS (NS)	106 (8188)	NS (NS)	NS (NS)	NS

*Figures in parentheses decnote corresponding value on air dried basis for woody material and fresh weight basis for the foliage.

Table 24. Chemical composition (mmol.kg^{-1}) of the foliage of Acacia lopped after 16 (a) and 42 (b) months of planting.

Treatment	Sodium		Potassium		Calcium		Magnesium	
	a	b	a	b	a	b	a	b
T_1	43.5	34.8	338	302	385	340	266	200
T_2	34.8	26.1	333	287	380	350	270	175
T_3	35.7	30.4	353	282	382	345	279	183
T_4	47.8	30.4	359	294	405	355	275	191
T_5	39.1	34.8	346	307	395	345	266	195
Mean	40.2	31.3	346	294	389	347	271	189

	Phosphorus		Sulphur		Nitrogen		Iron	
	a	b	a	b	a	b	a	b
T_1	124	86.5	132	74.8	1250	918	23.9	16.4
T_2	116	94.2	133	82.2	1262	892	22.8	17.2
T_3	120	92.3	131	80.4	1282	900	24.2	15.8
T_4	124	99.9	132	84.6	1260	910	25.2	16.6
T_5	132	94.8	130	70.8	1242	884	21.7	14.8
Mean	123	93.6	132	77.8	1259	901	23.6	16.2

	Manganese*		Zinc*		Copper*		Na:Mg	
	a	b	a	b	a	b	a	b
T_1	29.3	19.8	9.4	5.5	2.7	2.0	0.16	0.17
T_2	28.6	18.6	8.8	4.8	2.6	1.9	0.13	0.15
T_3	28.7	20.2	9.1	5.2	2.4	1.8	0.13	0.17
T_4	26.9	21.1	8.9	5.3	2.5	1.9	0.17	0.16
T_5	27.3	18.6	9.0	5.1	2.5	2.0	0.15	0.18
Mean	28.2	19.6	9.0	5.2	2.5	1.9	0.15	0.17

	Na:K		Na:Ca		Na:K+Ca		Ca:Mg	
	a	b	a	b	a	b	a	b
T_1	0.13	0.12	0.11	0.10	0.06	0.05	1.44	1.70
T_2	0.10	0.09	0.09	0.07	0.05	0.04	1.40	2.00
T_3	0.10	0.11	0.09	0.09	0.05	0.05	1.37	1.88
T_4	0.13	0.10	0.12	0.09	0.06	0.05	1.47	1.85
T_5	0.11	0.11	0.10	0.10	0.05	0.05	1.48	1.76
Mean	0.11	0.11	0.10	0.09	0.05	0.05	1.43	1.83

*Concentration of Mn, Zn and Cu is in mmol kg^{-1}X 10.

Table 25. Chemical composition (mmol.kg^{-1}) of the woody matter of Acacia lopped after 16 (a) and 42 (b) months of planting.

Treatment	Sodium		Potassium		Calcium		Magnesium	
	a	b	a	b	a	b	a	b
T_1	31.3	22.8	174.4	166.8	125.3	118.9	52.8	41.4
T_2	29.8	23.2	182.6	176.4	128.2	121.6	46.6	36.2
T_3	27.6	21.6	178.2	166.5	136.3	130.5	50.3	41.0
T_4	30.8	24.5	188.5	172.6	122.8	124.2	54.3	42.4
T_5	32.4	24.8	194.2	176.8	120.6	125.8	48.2	46.3
Mean	30.4	23.4	183.6	171.8	126.6	124.2	50.4	41.5

	Phosphorus		Sulphur		Nitrogen		Iron*	
	a	b	a	b	a	b	a	b
T_1	71.2	48.4	84.3	46.8	45.3	38.8	2.5	2.2
T_2	68.3	56.7	80.0	52.4	44.0	40.8	2.4	2.3
T_3	64.6	58.2	76.6	54.0	52.6	36.4	2.5	2.2
T_4	65.3	60.6	72.8	46.7	46.4	42.8	2.3	2.4
T_5	70.2	50.8	78.2	48.2	45.0	40.8	2.4	2.3
Mean	67.9	54.9	78.4	49.6	46.7	39.9	2.4	2.3

	Manganese*		Zinc*		Copper*		Na:Mg	
	a	b	a	b	a	b	a	b
T_1	2.6	2.5	2.2	2.1	1.0	1.0	0.59	0.55
T_2	2.6	2.6	2.3	2.2	1.1	0.9	0.64	0.64
T_3	2.7	2.7	2.4	2.2	1.0	1.0	0.55	0.53
T_4	2.6	2.7	2.2	2.4	0.9	1.1	0.57	0.58
T_5	2.6	2.6	2.3	2.3	1.0	1.1	0.67	0.54
Mean	2.6	2.6	2.2	2.2	1.0	1.0	0.60	0.56

	Na:K		Na:Ca		Na:K+Ca		Ca:Mg	
	a	b	a	b	a	b	a	b
T_1	0.18	0.14	0.25	0.19	0.10	0.08	2.37	2.87
T_2	0.16	0.13	0.23	0.19	0.10	0.08	2.75	3.36
T_3	0.15	0.13	0.20	0.17	0.09	0.07	2.71	3.18
T_4	0.16	0.14	0.25	0.20	0.10	0.08	2.26	2.93
T_5	0.17	0.14	0.27	0.20	0.10	0.08	2.50	2.72
Mean	0.17	0.14	0.24	0.19	0.10	0.08	2.51	2.99

* Concentration of Fe, Mn, Zn and Cu is in mmol kg^{-1} x 10.

of woody matter, there was only a marginal decrease or no change in the concentration of these nutrient elements with lopping at the two stages. In general, all the nutrient elements except Na, had a higher concentration in the foliage than in the woody matter. This is reflected in calculated ratios of Na to K, Ca, Mg and K + Ca for the foliage and woody matter. Relatively narrower ratios in foliage than in the woody matter indicate that accumulation of the element Na in leaves did not occur in levels toxic for the normal functioning of the metabolic processes.

The mean total removal of Na (241 mol ha^{-1}) through the lopped biomass was considerably less than that of K (1827 mol ha^{-1}), Ca (1618 mol ha^{-1}) and Mg (781 mol ha^{-1}). Results (Table 26) indicate greater removal through biomass lopped after 42 than 16 months of planting. This is because of greater biomass harvested with the former lopping. The amounts of Na, K, Ca and Mg removed through biomass were more in treatments which yielded higher biomass. Similar trend was observed in the mean total removal of P (592 mol ha^{-1}), S (592 mol ha^{-1}), N (2641 mol ha^{-1}), Fe (44.7 mol ha^{-1}) Mn (6.85 mol ha^{-1}), Zn (2.90 mol ha^{-1}), and Cu (1.12 mol ha^{-1}). Data (Table 27) on N was interesting in pointing out its greater removal than the rest of the elements despite poor available N status of the sodic soil. This may be ascribed to the ability of Acacia to symbiotically fix atmospheric dinitirogen. Among the micronutrients, removal of Fe and Mn through foliage was considerably more than through the woody matter (Table 28) whereas Zn and Cu were removed equally by both the components of biomass. Data on nutrients removal thus showed that despite considerably greater concentration of the given nutrient element (except N) in the foliage of Acacia, their removal occurred more through woody component because it constituted

Table 26. Removal of Na, K, Ca and Mg (mol. ha^{-1}) through biomass lopped after 16 (a) and 42 (b) months of planting Acacia.

Treatment	Foliage			Woody matter			Total
	a	b	a+b	a	b	a+b	
				Sodium			
T_1	24.5	47.1	71.7	52.0	83.0	135	206
T_2	22.3	43.8	66.2	54.6	102.7	157	223
T_3	24.1	42.4	66.5	51.7	72.5	124	190
T_4	41.7	51.6	93.4	69.7	106.1	175	269
T_5	39.5	63.2	102.7	97.6	114.1	211	314
Mean	30.4	49.6	80.1	65.1	95.7	160	241
				Potassium			
T_1	191	410	601	289	607	897	1499
T_2	213	482	696	335	780	1115	1812
T_3	239	393	633	333	559	893	1526
T_4	313	500	814	426	748	1174	1989
T_5	350	558	909	585	813	1398	2308
Mean	261	469	730	394	701	1096	1827
				Calcium			
T_1	217	461	678	208	433	641	1320
T_2	243	588	822	235	538	773	1595
T_3	258	481	740	255	438	693	1434
T_4	353	602	956	278	538	816	1772
T_5	399	626	1026	363	578	942	1968
Mean	294	552	844	268	505	773	1618
				Megnesium			
T_1	150	271	421	87.8	150	238	660
T_2	173	294	468	85.6	160	245	713
T_3	188	255	444	94.3	137	232	676
T_4	240	325	565	122.9	183	306	872
T_5	269	355	625	145.3	213	358	983
Mean	204	300	505	107.1	169	276	781

Table 27. Removal of P, S and N (mol. ha^{-1}) through biomass lopped after 16(a) and 42(b) months of planting Acacia.

Treatment	Foliage			Woody matter			Total
	a	b	a+b	a	b	a+b	
				Phosphorus			
T_1	70	117	187	118	176	294	471
T_2	74	158	233	125	251	376	627
T_3	81	128	210	121	195	316	512
T_4	108	169	278	147	262	410	673
T_5	134	172	306	211	233	445	679
Mean	93	149	243	144	223	368	592
				Sulphur			
T_1	74	101	176	140	170	310	486
T_2	85	138	224	146	231	378	602
T_3	89	112	201	143	181	324	526
T_4	115	143	259	164	202	367	626
T_5	132	128	260	235	221	457	718
Mean	99	124	224	166	201	367	592
				Nitrogen			
T_1	706	1245	1951	75	141	216	2168
T_2	810	1500	2310	80	180	261	2571
T_3	866	1257	2123	98	122	220	2344
T_4	1101	1545	2646	105	185	290	2937
T_5	1256	1606	2863	135	187	323	3187
Mean	948	1431	2379	99	163	262	2641

Table 28. Removal of Fe, Mn, Zn and Cu (mmol.ha^{-1}) through biomass lopped after 16(a) and 42(b) months of planting Acacia.

Treatment	Foliage			Woody matter			Total
	a	b	a+b	a	b	a+b	
			Iron				
T_1	13503	22238	35741	415	801	1217	36959
T_2	14637	28913	43550	422	1018	1440	44991
T_3	16359	22056	38416	468	739	1207	39623
T_4	22024	28186	50211	520	1039	1560	51772
T_5	21960	26876	48837	723	1058	1781	50619
Mean	17697	25654	43351	510	931	1441	44793
			Manganese				
T_1	1655	2684	4340	432	911	1343	5683
T_2	1836	3126	4962	477	1151	1628	6590
T_3	1940	2819	4760	505	907	1413	6173
T_4	2351	3582	5934	588	1169	1758	7692
T_5	2762	3377	6140	783	1196	1980	8120
Mean	2109	3118	5227	557	1067	1624	6852
			Zinc				
T_1	531	745	1276	365	765	1130	2407
T_2	564	806	1371	422	973	1395	2767
T_3	615	725	1341	449	739	1188	2530
T_4	777	899	1677	498	1039	1538	3215
T_5	910	925	1836	693	1058	1751	3588
Mean	679	820	1500	485	915	1401	2901
			Copper				
T_1	152	271	423	166	364	530	954
T_2	166	319	486	201	398	600	1086
T_3	162	251	413	187	336	523	936
T_4	218	322	541	203	476	680	1221
T_5	253	363	616	301	506	807	1423
Mean	190	305	496	212	416	628	1124

higher amounts. This implies that foliage of Acacia may serve as a good forage and woody matter a good firewood as low ash content (inorganics) is regarded to improve the heat value of wood (NAS, 1980).

D. Firewood Value of Acacia and Eucalyptus Billets: The firewood value in terms of KCal kg^{-1} of oven dry woody material of Acacia and Eucalyptus was found to be different from one another and varied with the thickness of billets or branches of both the species (Fig.9). The firewood value of Eucalyptus was less than Acacia by 200-300 KCal kg^{-1} for dry wood harvested from differently thick branches. Heat value of oven dry wood of Acacia and Eucalyptus increased with increasing thickness of the firewood billets. Heat value of firewood of differently thick branches of Acacia and Eucalyptus was estimated to show drastic decrease with increasing moisture (Fig.10) content of the wood. Decrease in heat value of wood with moisture content was observed to be of greater magnitude for relatively thick branches of both the species.

Woody material lopped should be segregated into different categories depending upon the thickness of billets and dried properly or seasoned before use. It was observed that fine branches of Acacia and Eucalyptus contained considerably higher moisture than the thick ones at the time of lopping. But their seasoning caused rapid drying. Thick branches although contained low moisture at lopping time but took more time for loss of moisture. This shows that thick branches should be split and stored for adequate span of time (Arnold, 1978) before burning. In addition, fine branches when dry should be consumed before the thick ones for different use of firewood. Data

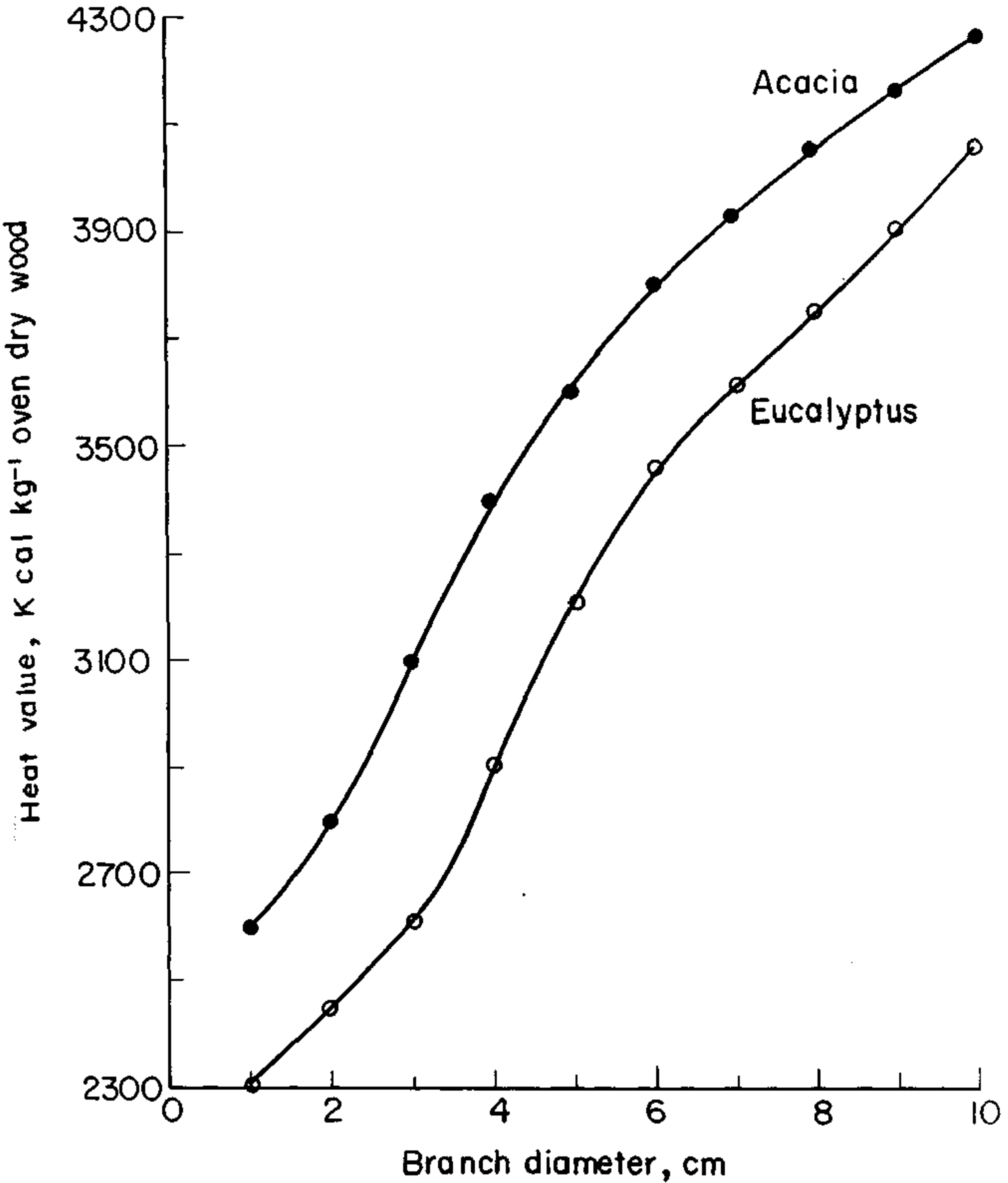


Fig. 9.

Firewood value of differently thick branches of Acacia and Eucalyptus on oven dry basis.

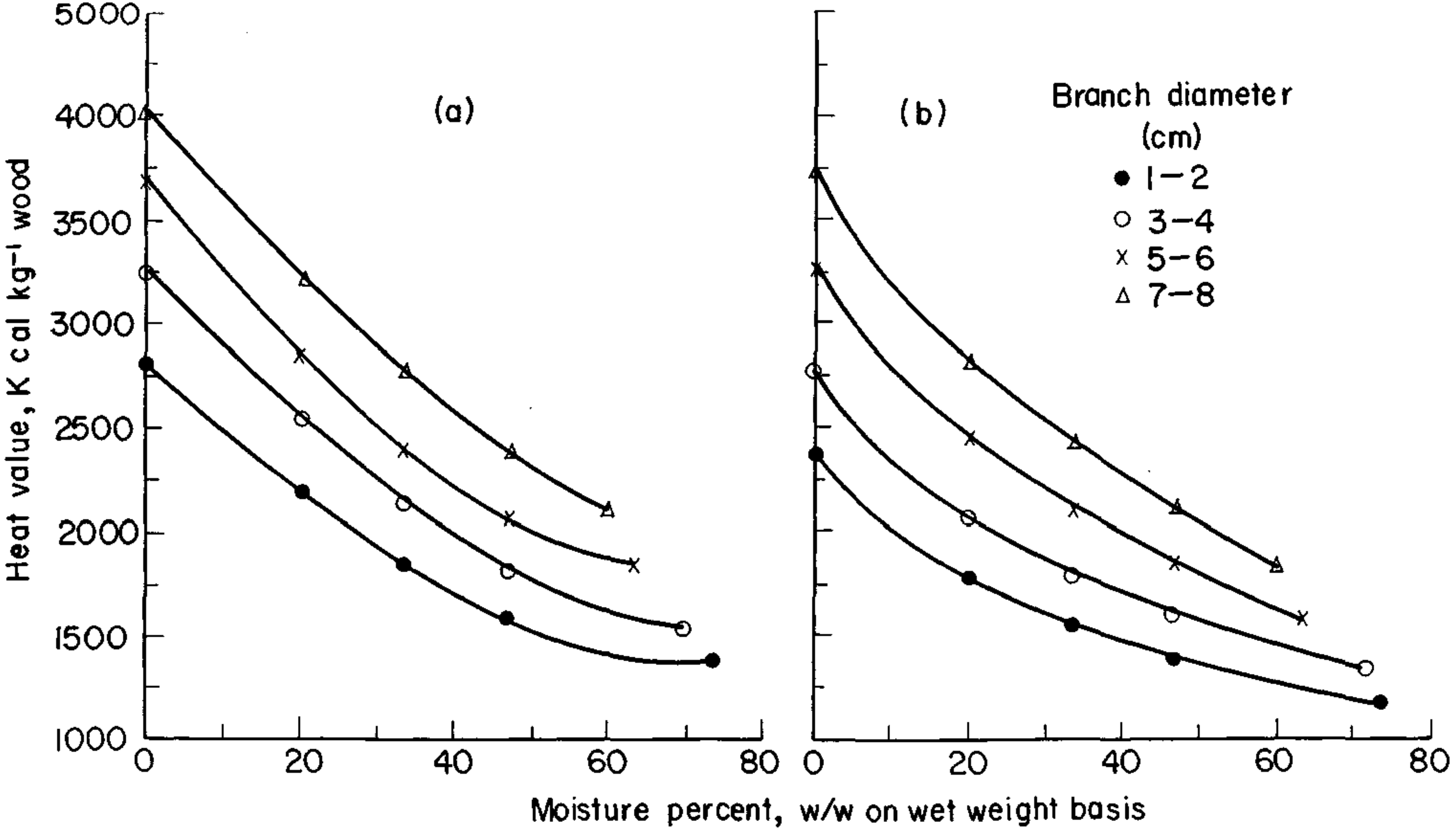


Fig.10. Effect of wood moisture content on heat value of differently thick (diameter range) Acacia (a) and Eucalyptus (b) branches.

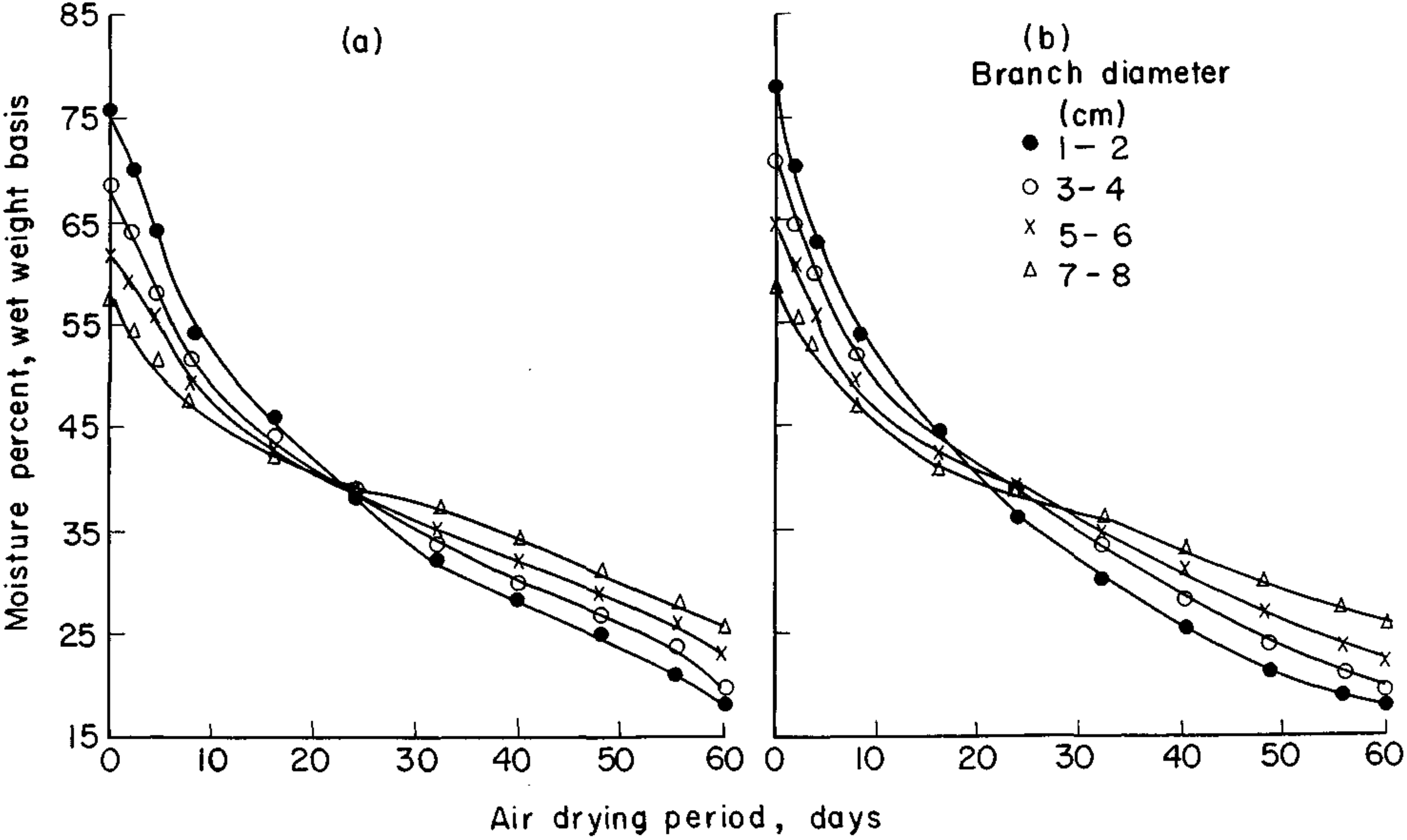


Fig.II.Rate of moisture loss on air drying of differently thick branches of Acacia (a) and Eucalyptus (b) during Jan. 17 to March 18, 1983.

on firewood value of Acacia and Eucalyptus demonstrate that former species should be given priority in afforestation programmes meant for the generation of firewood resources.

E. Growth of Natural Vegetation Underneath the Canopies: Biomass yield of natural growth of vegetation, primarily grasses, underneath the canopies of Eucalyptus and Acacia during 1982-84 showed significant variation. Effect of site preparation techniques on the biomass yield was not significant, however, canopies of two trees influenced the yield significantly. In a drought year (1982), the biomass (Table 29) yield was more in plots underneath the Acacia canopy. But during relatively wet years (1983 and 1984) it was more in plots under the Eucalyptus plantation. This variation was found related to the greater availability of soil moisture in Acacia plantation during drought conditions. Dense canopy of Acacia may also play a role in checking evapotranspiration whereas open canopy of Eucalyptus favoured the opposite. During wet years, growth of grasses make use of easily available solar radiation and adequate supply of soil moisture to yield more biomass in Eucalyptus than in the Acacia plantation where excess of moisture and limited supply of solar radiation effect poor growth of natural vegetation. The vegetation comprised of grasses like Diplachne fusca (L.) P. Beauv., Cynodon dactylon (L.) Pers., Dicanthium annulatum (Forsk.) stapf. and Sporobolus marginatus Hochst ex. A. Rich was observed (Bhumbla et al., 1972) to tolerate high soil sodicity and or salinity. More than 90 per cent of the biomass resulted from the growth of Diplachne fusca (L.) P. Beauv. which was reported (Kumar and Abrol, 1983) to tolerate highly sodic conditions.

Table 29. Average biomass (oven dry) yield (kg ha^{-1}) of naturally grown up vegetation under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex.Del.

Year	Canopy	Site preparation techniques					Mean	LSD (0.05)
		T_1	T_2	T_3	T_4	T_5		
1982	Eucalyptus	3694	3082	3856	2639	3148	3284	NS
1982	Acacia	5395	5849	5734	5565	5472	5603	NS
Mean		4545	4466	4795	4102	4310	4444	NS
1983	Eucalyptus	7077	5462	8146	5285	4876	6169	NS
1983	Acacia	3858	3962	3816	3176	3012	3065	NS
Mean		5468	4712	5981	4231	3944	4867	NS
1984	Eucalyptus	4385	3388	3804	3696	3592	3773	NS
1984	Acacia	3056	2678	3026	2892	1939	2718	NS
Mean		3721	3033	3415	3294	2766	3246	NS
LSD (0.05)				1982	1983	1983		
		Canopy or species		748	932	834		
		Interaction		984	1168	1006		
		Years		-	-	-	1236	

Data on the concentration of Na, K, Ca, Mg (Table 30), N, P, S (Table 31), Fe, Mn, Zn and Cu (Table 32) of the biomass indicate that effect of different site preparation treatments was not significant in all of the three years (1982-1984). But the concentration of all the nutrient elements, except N, decreased with successive years. Same was true for N in biomass harvested from plots under Eucalyptus plantation but contrary was observed in the case of Acacia. This can be attributed to the added biomass which in turn released N that might be assimilated by the underneath vegetation. Concentration of Na in each of the years was more than of K and followed by Mg and Ca. This implies that vegetation able to tolerate high sodium and poor Ca availability in the sodic soil can grow and reflect the same in its chemical composition. Among N, P and S, relative concentration of N was markedly high. Nitrogen concentration of the biomass harvested from Acacia plantation showed an increase with years though it decreased in the case of Eucalyptus. Concentr tion of P was marginally more than S in the biomass during each of the three years but absolute concentration of both the nutrients may be considered adequate. Among the micronutrients (Table 32), the highest accumulation of Fe was observed. Iron followed Mn, Zn and Cu in order of decreasing concentration.

Data (Table 33) on average removal of Na, K, Ca and Mg exhibited the role of biomass rather than concentration of these nutrient elements. Their removal was more through the biomass harvested from Acacia than Eucalyptus plantation in 1982. But opposite was tfue during 1983 and 1984. This follows the trend of biomass production during the three years. The removal of Na was more than that of K

Table 30. Average concentration (mmol. kg^{-1}) of Na, K, Ca and Mg in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex.Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Sodium				
T_1	435	347	275	352	410	385	306	367
T_2	479	398	326	401	452	360	288	367
T_3	414	323	296	344	427	396	298	374
T_4	522	362	331	405	463	379	272	371
T_5	462	337	316	372	428	390	316	378
Mean	463	353	309	375	436	322	296	372
				Potassium				
T_1	206	182	164	184	230	185	170	195
T_2	232	211	146	197	245	198	163	202
T_3	225	173	157	185	233	179	170	194
T_4	249	203	167	206	216	186	176	193
T_5	236	198	153	196	232	190	168	197
Mean	230	193	157	194	231	188	170	196
				Calcium				
T_1	64.4	62.9	70.6	66.0	56.7	60.7	62.8	60.1
T_2	56.8	60.8	72.6	63.4	62.6	68.6	64.9	65.4
T_3	68.2	65.2	64.8	66.1	60.4	59.3	60.1	59.9
T_4	56.2	66.4	61.8	61.5	58.2	66.8	58.4	61.1
T_5	60.3	68.3	67.3	65.3	64.8	68.3	56.7	63.3
Mean	61.2	64.7	67.4	64.5	60.5	64.7	60.6	62.0
				Magnesium				
T_1	187	154	121	154	194	160	131	162
T_2	176	148	118	147	188	154	126	156
T_3	196	143	127	155	190	157	136	161
T_4	189	156	126	155	183	163	127	157
T_5	190	146	131	156	198	150	131	160
Mean	187	150	125	155	191	157	130	159

Table 31. Average concentration (mmol kg^{-1}) of P, S and N in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex. Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Phosphorus				
T_1	90.8	76.7	62.6	76.7	86.8	82.8	71.4	80.3
T_2	86.4	77.8	70.8	78.3	82.5	80.7	72.2	78.5
T_3	92.6	74.3	66.4	77.8	84.6	84.2	74.3	81.0
T_4	96.4	82.5	68.3	82.4	87.9	82.0	71.8	80.6
T_5	90.8	84.4	70.2	81.8	90.2	84.7	74.8	83.2
Mean	91.4	79.1	67.7	79.4	86.4	82.9	72.9	80.7
				Sulphur				
T_1	82.5	68.9	62.6	71.3	84.6	72.8	68.3	75.2
T_2	78.8	74.3	66.4	73.2	76.8	70.3	64.4	70.5
T_3	84.6	66.5	65.9	72.3	75.4	68.2	65.5	69.7
T_4	85.2	73.2	66.6	75.0	80.9	69.9	66.7	72.5
T_5	80.5	73.8	64.8	73.0	84.2	70.8	62.8	72.6
Mean	82.3	71.3	65.3	73.0	80.4	70.4	65.5	72.1
				Nitrogen				
T_1	270	230	190	230	314	360	415	363
T_2	282	242	200	242	299	373	423	365
T_3	269	227	196	230	313	365	418	365
T_4	286	239	206	244	305	378	420	368
T_5	276	244	205	242	317	385	437	379
Mean	276	236	200	237	310	372	423	368

Table 32. Average concentration (mmol kg^{-1}) of Fe, Mn, Zn and Cu in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex. Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Iron				
T_1	10.72	6.66	5.14	7.51	11.64	8.48	6.32	8.81
T_2	11.16	9.32	6.68	9.05	9.68	9.32	8.16	9.05
T_3	9.92	5.78	6.32	7.34	10.55	8.64	7.68	8.96
T_4	11.84	8.96	5.76	8.85	10.04	8.00	7.24	8.43
T_5	10.92	9.14	5.92	8.66	11.68	8.34	8.82	9.61
Mean	10.91	7.97	5.96	8.28	10.72	8.56	7.64	8.97
				Manganese				
T_1	2.18	2.64	2.16	2.33	1.88	2.72	2.30	2.30
T_2	2.34	2.46	2.24	2.35	1.82	2.64	2.42	2.29
T_3	2.04	2.48	2.16	2.23	1.94	2.78	2.40	2.37
T_4	2.38	2.36	2.36	2.37	1.88	2.74	2.32	2.31
T_5	2.24	2.44	2.39	2.36	1.96	2.70	2.36	2.34
Mean	2.24	2.48	2.26	2.33	1.90	2.72	2.36	2.32
				Zinc				
T_1	0.36	0.28	0.21	0.28	0.34	0.30	0.18	0.27
T_2	0.32	0.26	0.19	0.26	0.32	0.26	0.22	0.27
T_3	0.38	0.28	0.20	0.29	0.32	0.28	0.22	0.27
T_4	0.32	0.26	0.19	0.26	0.34	0.30	0.20	0.28
T_5	0.38	0.32	0.20	0.27	0.32	0.30	0.18	0.27
Mean	0.35	0.28	0.20	0.27	0.33	0.29	0.20	0.27
				Copper				
T_1	0.16	0.10	0.09	0.12	0.18	0.12	0.09	0.13
T_2	0.18	0.12	0.08	0.13	0.17	0.13	0.07	0.12
T_3	0.14	0.09	0.09	0.11	0.18	0.12	0.08	0.13
T_4	0.18	0.12	0.09	0.13	0.17	0.13	0.10	0.13
T_5	0.20	0.12	0.09	0.14	0.19	0.12	0.10	0.14
Mean	0.17	0.11	0.09	0.13	0.18	0.13	0.09	0.13

Table 33. Average removal (mol ha^{-1}) of Na, K, Ca and Mg through harvest of biomass from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
Sodium								
T_1	1609	2460	1208	5277	2216	1488	936	4640
T_2	1476	2175	1106	4757	2647	1427	773	4848
T_3	1598	2628	1127	5354	2447	1511	903	4862
T_4	1378	1914	1222	4515	2573	1203	788	4565
T_5	1456	1642	1137	4236	2400	1175	613	4189
Mean	1503	2164	1160	4828	2456	1361	802	4621
Potassium								
T_1	762	1290	722	2775	1242	712	521	2475
T_2	717	1151	496	2364	1430	785	436	2652
T_3	866	1406	596	2868	1334	681	515	2531
T_4	656	1071	616	2344	1204	591	509	2305
T_5	744	966	549	2259	1299	573	326	2199
Mean	749	1177	596	2522	1302	668	461	2432
Calcium								
T_1	237	445	309	992	305	234	191	732
T_2	175	332	246	753	366	271	173	811
T_3	263	531	246	1040	346	226	181	754
T_4	148	350	228	727	323	201	113	638
T_5	189	333	241	764	354	205	109	670
Mean	202	398	254	855	339	227	154	721
Magnesium								
T_1	693	1094	534	2321	1049	618	402	2071
T_2	544	809	401	1756	1100	613	338	2052
T_3	757	1161	482	2400	1091	598	410	2099
T_4	482	826	465	1773	1017	517	366	1900
T_5	598	713	471	1784	1085	453	253	1792
Mean	615	921	471	2007	1068	560	354	1983

followed by Mg and Ca. However, the total removal of these four elements through biomass harvested during 1982–1984 was only marginally more in case of Eucalyptus than in Acacia plantation. Similar results were observed concerning the removal of P and S (Table 34), Fe, Mn, Zn and Cu (Table 35). But total removal of N was more through biomass produced under Acacia plantation despite lower yields during 1983 and 1984. This can be attributed to greater supply of N from the soil and its accumulation (Table 34).

F. Ameliorative Effect and Micro-Climate Modifications

(a) Soil Moisture: Data on periodic per cent soil moisture (w/w) content of different layers of the soil profile (0–120 cm) indicated that besides soil sodicity availability of soil moisture is an important factor causing differences in growth of vegetation including both of the tree species and natural grasses. Moisture content of the soil under Eucalyptus plantation (Table 36) was observed low in each of the layers at all the sampling stages than under the Acacia. The fluctuations in moisture content were more pronounced in 0–15, 15–30, and 30–45 cm layers than in rest of the deeper horizons. Variation was also more marked in Eucalyptus than in Acacia plantation. In general, moisture content of different profile layers under Acacia (Table 37) was found higher by 2–3 per cent than the respective figures for Eucalyptus. Such differences were marked throughout the sampled depth of profile but were more consistent in the upper layers. In a relatively dry year (1982), the moisture content of the profiles under both Acacia and Eucalyptus was observed as low as the permanent wilting point during May–July. The maintenance of relatively high moisture content of the soil profile under Acacia plantation may be due to (i) the shade effect of dense canopy on checking losses through

Table 34. Average removal (mol ha^{-1}) of P, S and N through harvest of biomass from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Phosphorus				
T_1	335	542	274	1152	468	319	218	1005
T_2	266	424	239	931	482	319	193	995
T_3	357	605	252	1214	485	321	224	1031
T_4	254	672	252	1178	489	260	207	957
T_5	285	411	252	949	505	255	145	905
Mean	299	531	254	1085	486	295	197	979
				Sulphur				
T_1	304	487	274	1066	456	280	208	946
T_2	242	405	225	873	449	411	172	1032
T_3	326	541	250	1118	432	260	198	890
T_4	224	386	246	857	450	222	192	865
T_5	253	359	232	846	460	213	121	795
Mean	270	436	245	952	449	277	178	906
				Nitrogen				
T_1	998	1631	834	3464	1697	1392	1269	4358
T_2	870	1324	679	2873	1748	1477	1132	4358
T_3	1028	1845	746	3621	1793	1391	1265	4450
T_4	755	1262	762	2780	1699	1201	1215	4116
T_5	870	1190	735	2796	1733	1158	847	3739
Mean	904	1450	751	3107	1734	1324	1145	4204

Table 35. Average removal (mol ha^{-1}) of Fe, Mn, Zn and Cu through harvest of biomass from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex. Del.

Treatment	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
Iron								
T_1	39.60	47.13	22.54	109.27	62.80	32.72	19.31	114.83
T_2	34.40	50.91	22.63	107.94	56.62	36.93	21.85	115.40
T_3	38.25	47.08	24.04	109.37	60.49	32.97	23.24	116.70
T_4	31.25	47.35	21.29	99.89	55.87	25.41	20.94	102.22
T_5	34.38	44.57	21.26	100.21	63.91	25.12	17.10	106.13
Mean	35.58	47.41	22.35	105.34	59.94	30.63	20.49	111.06
Manganese								
T_1	8.05	18.68	9.47	36.20	10.14	10.49	7.03	27.66
T_2	7.21	13.44	7.59	28.24	10.65	10.46	6.48	27.59
T_3	7.87	20.20	8.22	36.29	11.12	10.61	7.26	28.99
T_4	6.28	12.47	8.72	27.47	10.46	8.70	6.71	25.87
T_5	7.05	11.90	8.58	27.53	10.73	8.13	4.58	23.44
Mean	7.29	15.34	8.52	31.15	10.62	9.68	6.41	26.71
Zinc								
T_1	1.33	1.98	0.92	4.23	1.83	1.16	0.55	3.54
T_2	0.99	1.42	0.64	3.05	1.87	1.03	0.59	3.49
T_3	1.23	2.28	0.76	4.27	1.83	1.07	0.67	3.57
T_4	0.84	1.37	0.70	2.91	1.89	0.95	0.58	3.42
T_5	1.20	1.56	0.72	3.48	1.75	0.90	0.35	3.00
Mean	1.12	1.72	0.75	3.59	1.83	1.02	0.55	3.40
Copper								
T_1	0.59	0.71	0.39	1.69	0.97	0.46	0.21	1.64
T_2	0.55	0.66	0.27	1.48	0.99	0.52	0.19	1.70
T_3	0.54	0.73	0.34	1.61	1.03	0.46	0.24	1.73
T_4	0.48	0.63	0.33	1.44	0.95	0.41	0.29	1.65
T_5	0.63	0.59	0.32	1.54	1.04	0.36	0.19	1.59
Mean	0.56	0.66	0.33	1.55	1.00	0.44	0.22	1.66

Table 36. Periodic changes in per cent (w/w) moisture content of given layers of the soil under Eucalyptus plantation.

Observational date (15th of each month)		Soil profile layer, cm							
		0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120
1982	Jan.	7.68	8.88	9.68	10.65	11.32	14.65	15.84	17.21
	Feb.	6.44	8.98	10.16	10.52	10.94	14.46	15.10	16.88
	March	5.62	7.94	8.82	9.16	9.18	12.36	13.92	15.26
	April	4.16	6.16	7.64	8.78	9.26	10.94	12.84	14.11
	May	3.26	4.92	6.66	8.65	8.88	10.24	11.65	13.98
	June	2.85	3.65	5.45	6.12	7.32	8.65	10.14	12.46
	July	3.59	4.65	5.86	6.16	7.15	8.84	10.86	11.88
	Aug.	11.53	13.63	16.24	18.52	18.64	17.64	18.80	18.65
	Sept.	8.56	9.68	11.16	11.56	11.68	12.72	14.32	15.68
	Oct.	4.14	8.16	11.12	11.76	11.61	12.24	12.63	13.97
	Nov.	5.11	7.87	8.78	10.26	11.50	12.45	13.82	14.16
	Dec.	5.56	8.70	9.16	11.76	12.25	12.65	13.98	14.11
1983	Jan.	8.64	8.95	9.27	8.60	9.52	13.71	17.75	19.52
	Feb.	12.46	8.65	9.66	11.68	15.96	18.49	20.45	22.01
	March	7.76	8.55	10.56	11.23	12.06	15.50	19.45	20.80
	April	4.09	4.99	12.78	12.09	12.85	13.22	15.93	17.99
	May	6.58	11.79	16.14	17.15	18.48	19.96	21.70	21.89
	June	5.50	5.70	14.38	14.96	16.90	16.74	19.42	20.32
	July	6.68	9.66	11.28	14.02	15.68	17.81	17.62	17.46
	Aug.	7.43	8.62	10.48	12.62	13.28	14.76	16.82	18.80
	Sept.	18.87	18.80	18.96	16.78	15.07	17.27	19.90	22.85
	Oct.	14.21	15.00	14.11	13.35	12.96	15.73	17.35	20.10
	Nov.	9.82	10.23	10.35	10.07	10.51	13.15	17.79	20.34
	Dec.	9.23	10.71	13.29	13.05	12.05	17.03	22.01	22.45
1984	Jan.	8.88	9.62	10.02	10.16	11.68	14.56	15.80	16.19
	Feb.	7.14	11.44	11.48	11.44	12.51	15.26	16.80	17.80
	March	6.21	9.88	10.37	13.25	13.55	16.21	16.82	16.92
	April	6.18	8.76	10.14	11.68	12.24	14.45	15.10	15.86
	May	4.06	8.37	9.82	10.16	12.45	12.74	13.19	14.76
	June	4.84	5.66	8.16	8.64	9.48	10.02	11.99	14.32
	July	9.12	9.98	10.46	11.02	10.96	11.58	11.90	15.04

Table 37. Periodic changes in per cent (w/w) moisture content of given layers of the soil under Acacia plantation.

Observational date (15th of each month)		Soil profile layers, cm							
		0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120
1982	Jan.	8.85	10.45	11.35	12.64	13.84	16.68	17.82	19.26
	Feb.	8.52	10.26	12.72	12.92	12.78	16.54	17.84	18.64
	March	7.78	10.82	11.64	12.62	12.80	15.17	16.94	17.16
	April	7.12	9.84	10.84	11.96	11.98	13.65	15.78	16.92
	May	7.26	9.76	9.66	10.48	10.77	11.14	12.72	14.86
	June	4.45	7.18	7.65	8.88	8.99	9.24	9.68	10.82
	July	4.14	7.32	8.86	9.16	9.68	10.32	11.65	13.36
	Aug.	13.68	14.68	16.48	18.32	19.64	20.12	20.96	21.75
	Sept.	11.54	13.52	13.68	14.52	14.44	15.12	16.72	17.26
	Oct.	8.16	11.16	13.54	13.64	13.78	14.96	15.60	16.20
	Nov.	8.12	10.94	11.65	12.72	12.82	13.52	15.04	15.88
	Dec.	8.84	11.55	11.02	12.84	13.95	14.16	15.68	16.88
1983	Jan.	10.62	13.68	11.32	11.64	12.16	13.36	14.65	15.68
	Feb.	14.35	13.56	10.96	12.76	13.64	14.84	16.94	18.96
	March	9.68	11.36	10.84	12.65	12.88	14.76	18.78	19.21
	April	8.04	10.04	11.16	12.76	13.12	14.56	17.96	18.88
	May	9.13	11.16	15.92	18.36	19.45	20.65	21.65	22.20
	June	8.92	10.84	14.84	16.16	18.32	18.16	20.94	21.16
	July	9.74	11.68	13.15	15.54	17.88	17.96	19.56	19.88
	Aug.	10.65	12.16	11.96	14.82	15.72	15.64	18.14	19.54
	Sept.	18.12	18.66	19.65	20.78	21.64	22.02	23.65	22.98
	Oct.	18.32	19.10	18.44	17.62	17.64	18.36	19.96	20.55
	Nov.	12.84	14.16	14.86	15.16	15.21	16.96	18.16	19.36
	Dec.	12.48	14.92	13.84	14.65	13.65	15.16	21.65	22.14
1984	Jan.	11.16	13.68	13.74	14.10	12.92	14.26	18.78	19.26
	Feb.	10.94	12.65	13.15	13.76	13.84	15.32	17.82	18.66
	March	9.88	11.32	11.96	12.68	13.76	14.96	17.79	18.34
	April	9.76	11.64	12.10	12.56	13.60	14.88	17.62	18.18
	May	8.16	10.96	11.32	12.14	13.82	14.82	16.94	17.36
	June	8.35	10.54	10.88	11.65	12.50	13.52	14.84	15.68
	July	14.36	16.32	16.94	17.65	18.10	18.65	18.46	16.48

evaporation and transpiration, (ii) mulch effect of the litter, and (iii) low demand of Acacia trees for moisture than of Eucalyptus.

(b) Canopy Temperature: In comparison to the neighbouring open areas, the air or canopy temperature beneath the tree crowns or canopies of Acacia and Eucalyptus (Fig. 12) were modified by their sheltering effect in cutting insolation and by their blanketing effect in restricting the outflow of heat thereby keeping the ground warmer during winter months and coller during the summer months. This in turn helps the biological activity underneath the plantations. Such effect of Acacia plantation was more pronounced than of Eucalyptus. Air temperature under Acacia canopy during summer was found lower by 3-5 °C and higher during winter by 2-4 °C than the neighbouring open area. Effect of Eucalyptus canopy was there but its modifying impact was less than that of Acacia. These results corroborate the findings of other workers (FAO, 1962; Ghosh et al., 1982). This effect helps in checking the loss of soil moisture through evaporation and transpiration demands of the underneath vegetation.

(c) Soil Temperature: Effect of Eucalyptus and Acacia canopies on temperature of soil at 5 and 15 cm depths was also of modifying type (Fig. 13). The soil temperature at 15 cm depth was found lower throughout than at 5 cm depth. Fluctuations were particularly marked for the lower depth temperature recorded in the open. Effect of Acacia and Eucalyptus during summer months was that of blanketing and during winter months was of sheltering type. Rao et al. (1982) also reported similar observations. Moderation of soil temperature extremes by the Acacia and Eucalyptus plantations is attributed to the effects of their canopies, leaf litter and the growth of underneath

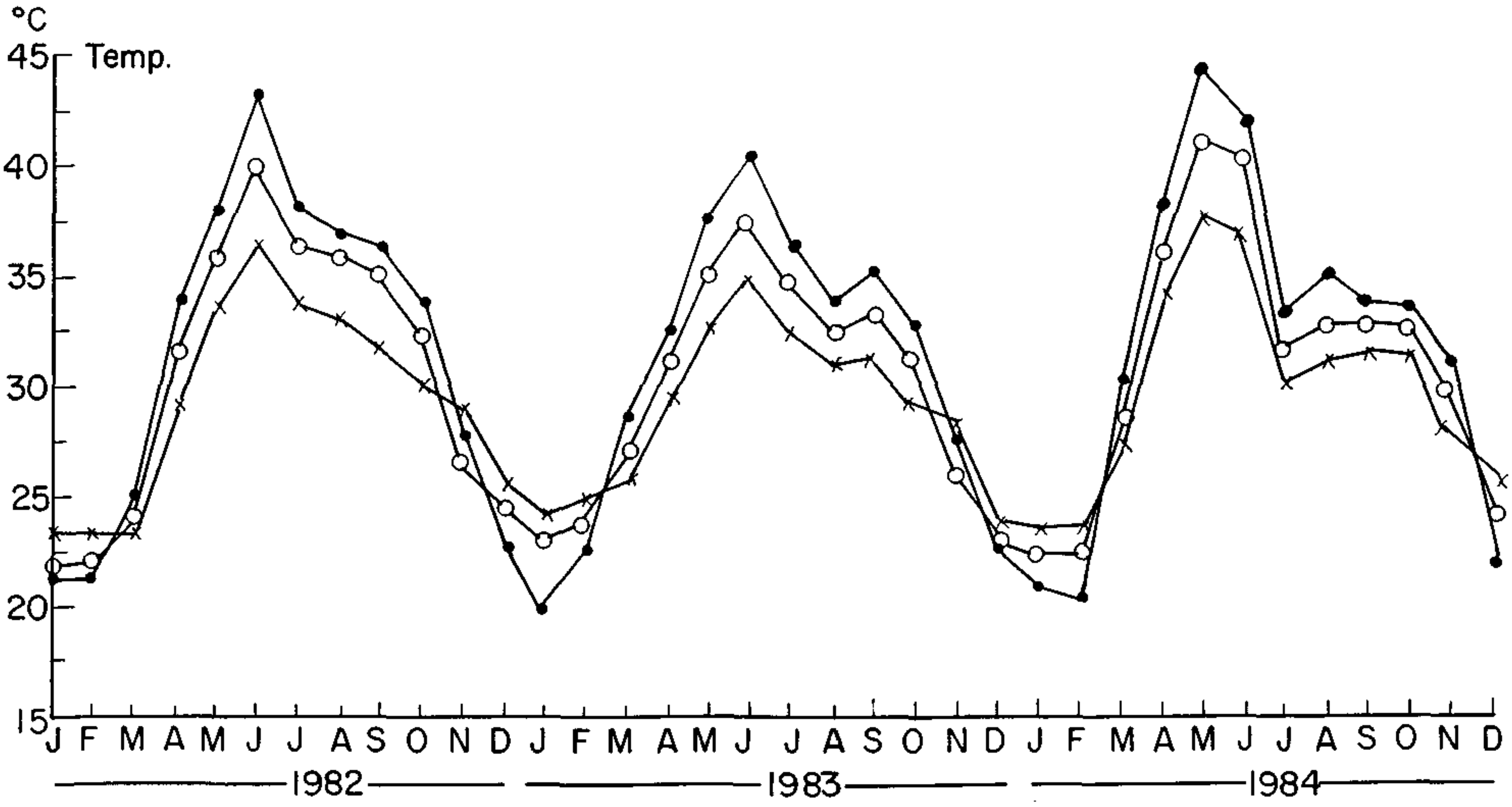


Fig. 12. Changes in atomospheric temperature recorded at 137 cm height in the open (•) and canopies of Eucalyptus (○) and Acacia (x).

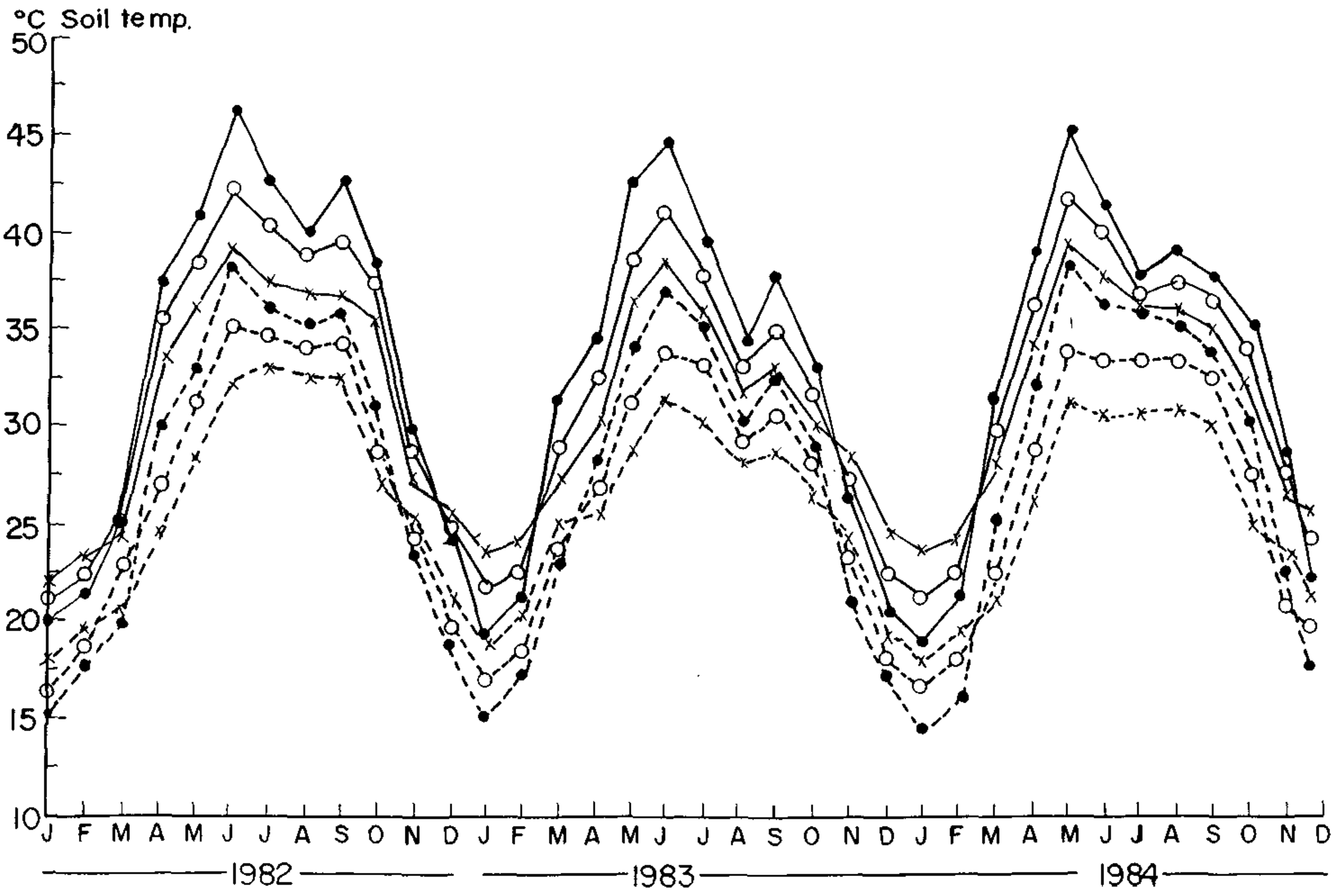


Fig. 13. Changes in soil temp. at 5 cm(——) and 15cm (----) depths in the open (•) and canopies of the Eucalyptus (○) and Acacia (X)

vegetation. Among these factors, a good development of dense canopy may be the principal factor because effect of Acacia to moderate the soil temperature was more than of Eucalyptus whose canopy was open and poorly developed (Plate 3) in comparison to the former species.

(d) Ameliorative Effect of Plantations on Soil Properties: Effect of Acacia and Eucalyptus plantations, irrespect of the site preparation treatments, on periodic changes in selected soil properties (pH, EC and organic carbon) of 0-60 cm profile was observed to be considerable. Both of the pH and EC (Fig. 14) of the soil were markedly lowered. Reduction was more in the surface layer and it decreased with depth to almost negligible at 60 cm depth. The soil organic carbon content was increased to double the initial value under Eucalyptus and about three times under Acacia plantations. Effect of Acacia on increase in soil organic carbon content was more than Eucalyptus, however, their influence on changes in soil pH and EC was similar. Greater increase in organic carbon of the soil under Acacia plantation is attributed to additions of more litter to the soil. These results are in agreement with the findings of other workers (Shah and Vora, 1965; Kretinin, 1967; Yadav and Singh, 1970; Migunova, 1972) who reported desalinization and desolonetsization of the soil under tree plantations. Amelioration of the soil occurs through the effects of growing trees and of the underneath natural vegetation through the penetration of roots, improvement of humus and nutrients status through return of organic substances from the decomposed plant parts and the enrichment of N status of the soil through symbiotically fixed N in case of leguminuous trees.

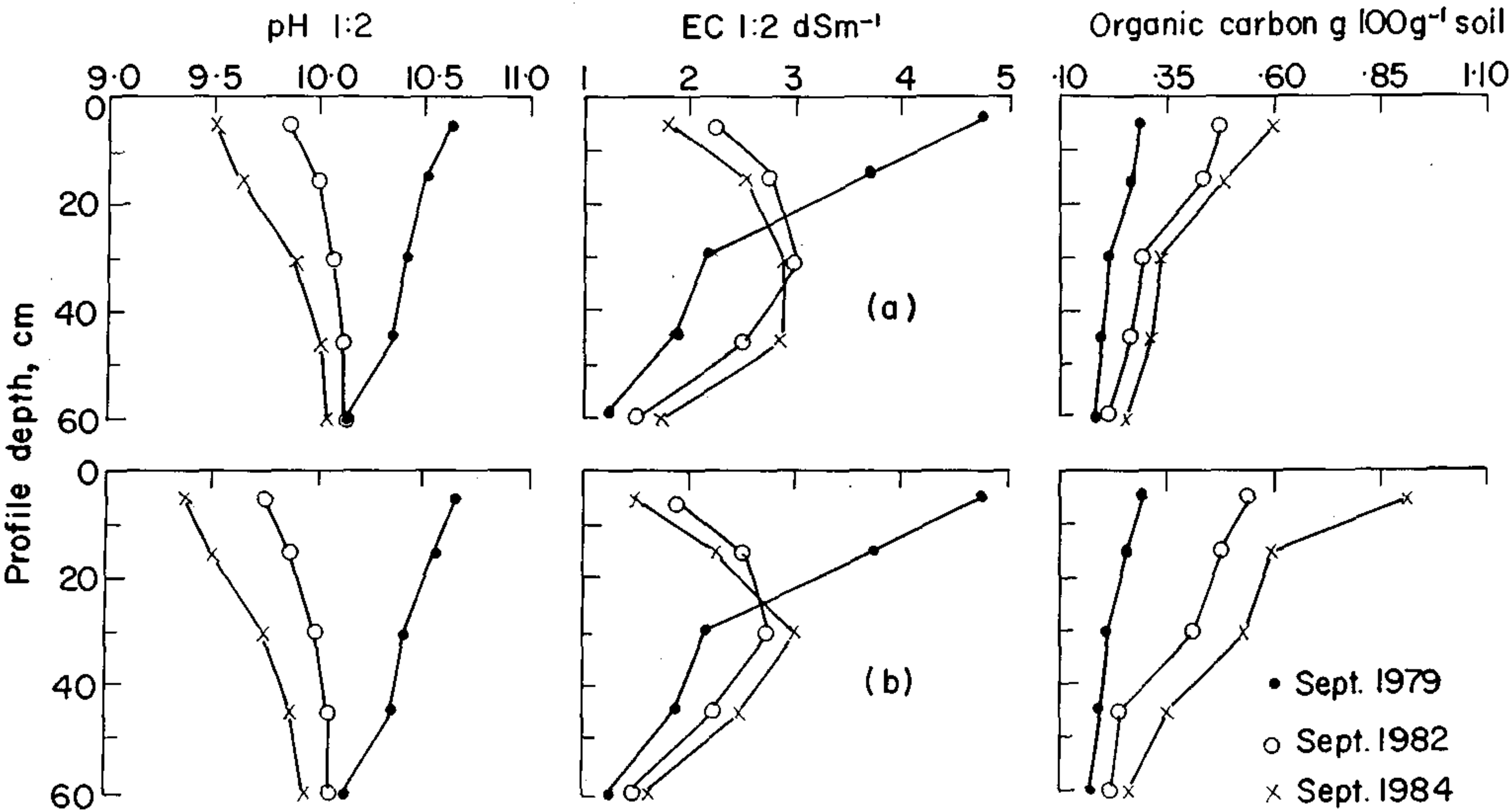


Fig. 14. Changes in pH, soluble salts and organic carbon content of a highly sodic soil under *Eucalyptus* (a) and *Acacia* (b) plantations.

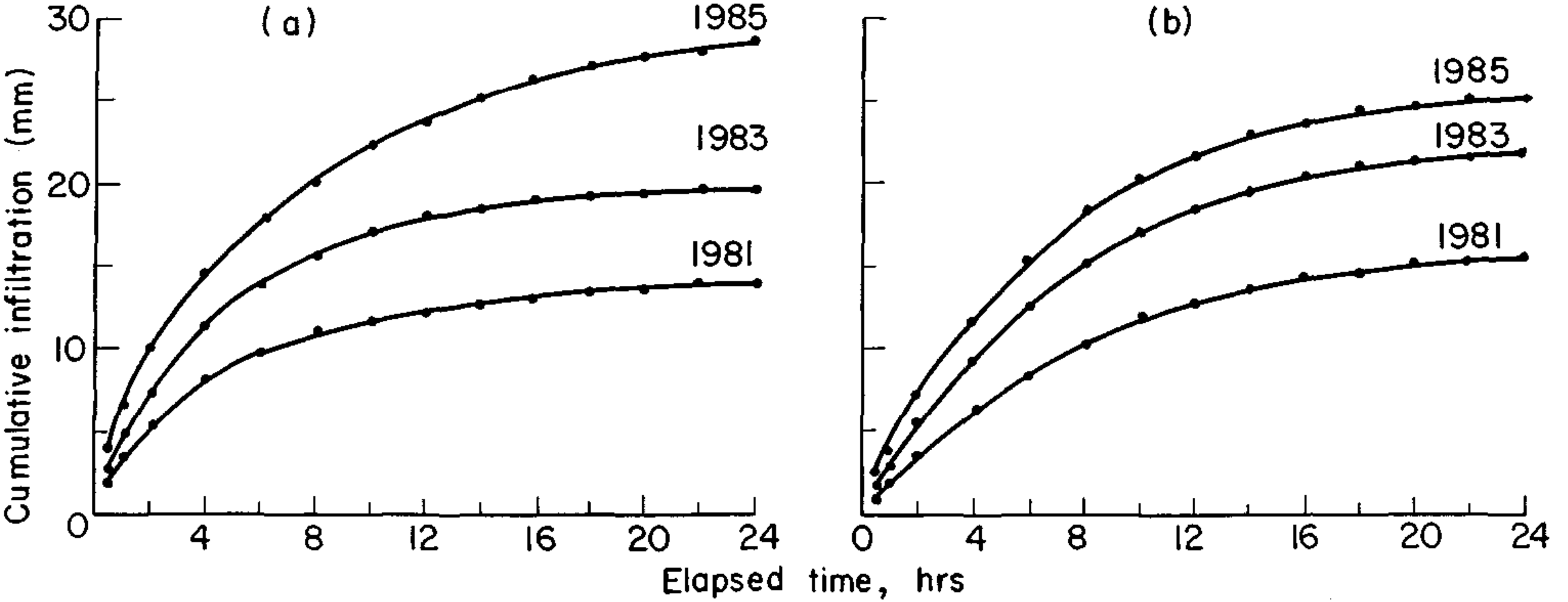


Fig. 15. Effect of Eucalyptus (a) and Acacia (b) plantations on cumulative infiltration of a highly sodic soil.

Infiltration characteristics of the soil under Acacia and Eucalyptus plantations were found improved with time (Fig. 15). Infiltration rate observed in 1983 was same for both the plantations. Increase in water infiltration can be attributed to a reduction in the soil pH, growth of trees and natural vegetation whose roots open up the otherwise highly dispersed soil, decomposition and addition of organic matter which stabilises the soil structure (Sands et al. 1979). Ghosh et al. (1982) reported that forest cover results in markedly greater infiltration in comparison to the cultivated fields and natural grass land. Influence of root ramification on infiltration was also observed.

Litter Production: Forest or plantation ecosystems contribute a lot of organic matter to the soil in the shape of leaf fall, twigs, branches and fruits, the nature and amount of which depend besides other factors on the species and the growth state of their canopies. Results (Table 38) showed that Acacia produced more litter than Eucalyptus plantation. Litter production of Acacia was increased with growth years whereas such an increase was not observed with Eucalyptus. Bimonthly distribution of litter produced in a year indicates that winter season (Nov. - Feb.) accounts for more than 40 and 50 per cent of the total for Acacia and Eucalyptus respectively. More litter production by Acacia than by Eucalyptus results from bumper aerial growth of the former (Plate 3). Such observations were also reported by Ghosh et al. (1982), however, amount of litter production is expected to vary greatly with the species and stocking rate.

G. Nutrients Recycled through Litter: Concentration of Na, K, Ca and Mg in litter produced by Acacia and Eucalyptus during different growth periods of all the three years (Table 39) did not vary

Table 38. Amount (kg ha^{-1}) of foliage shed during given time periods of the year by the canopies of Eucalyptus and Acacia in a highly sodic soil.

Time period	Eucalyptus canopy				Acacia canopy			
	1982	1983	1984	Mean	1982	1983	1984	Mean
July - August	148 (14.4)	152 (14.1)	132 (12.0)	144 (13.5)	252 (9.9)	465 (12.1)	552 (11.4)	423 (11.3)
September-October	165 (16.1)	178 (16.5)	184 (16.7)	176 (16.5)	218 (8.6)	326 (8.5)	386 (8.0)	310 (8.3)
November-December	252 (24.5)	234 (21.8)	262 (23.8)	249 (23.3)	924 (36.4)	1168 (30.3)	1494 (30.8)	1195 (31.9)
January-February	196 (19.1)	212 (19.8)	218 (19.8)	209 (19.6)	635 (25.0)	1096 (28.5)	1225 (25.2)	985 (26.3)
March-April	152 (14.8)	166 (15.5)	180 (16.3)	166 (15.5)	292 (11.5)	378 (9.8)	516 (10.6)	370 (9.9)
May-June	114 (11.1)	132 (12.3)	126 (11.4)	124 (11.6)	216 (8.6)	416 (10.8)	678 (14.0)	462 (12.3)
Total	1027	1072	1102	1067	2537	3849	4851	3746
LSD (0.05)	122 (11.9)	111 (10.3)	136 (12.3)	124 (11.6)	346 (13.6)	208 (5.4)	414 (8.5)	285 (7.6)

Figures in parentheses stands for corresponding per cent of the total amount.

significantly. Mean concentration of K, Ca and Mg showed a decline with successive years. There was not such change in Na concentration in the litter of Acacia whereas it was found to increase, though slightly, in Eucalyptus. Sodium concentration in the litter of Acacia was 3-4 times less than that of Eucalyptus. Reverse was true for K. There was not much difference in Mg concentration of Ca was more in the litter of Eucalyptus than of Acacia. Amount of Na, K, Ca and Mg recycled through litter (Table 40) of the two species varied significantly with the growth period of a year and with successive years (1982-1984). Their amount was more for the winter months (Nov. - Feb.) for both the species but the quantity of these nutrients increased considerably with successive years only in Acacia. In case of Eucalyptus, amount of K and Ca showed a gradual decrease but no change for Mg and an increase for Na with succeeding growth years.

Concentration of N, P, S (Table 41), Fe, Mn, Zn and Cu (Table 42) did not vary significantly among given growth periods of the three years. The mean concentfation of P, S and N was considerably higher in litter of Acacia than of Eucalyptus. However, their concentration showed a steady decrease with the successive years. Concentration of N in the litter of Acacia was about double the value for Eucalyptus. The absolute concentration of N in Eucalyptus and Acacia litter was more than S by 3-4 times. Phosphorus concentration was about half that of the S in Eucalyptus litter but only little less in Acacia litter. Among the micronutrients (Table 42), concentration of Fe was more than the rest in litter of Acacia whereas Mn had highest concentration in Eucalyptus litter. Concentration of Cu was lowest and was about half the values for Zn in litter of both the species. Concentration of Mn, Zn and Cu showed steady decrease in litter produced with the succeeding years. Same was found with Fe concentration in litter of Acacia but there occurred no such change for Eucalyptus litter.

Table 39. Concentration of Na, K, Ca and Mg (mmol kg^{-1}) in foliage shed during given growth periods by Eucalyptus and Acacia.

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Sodium				
July - Aug.	106	117	132	119	36.6	36.3	36.0	36.3
Sept.- Oct.	116	124	128	123	37.4	37.1	36.1	36.9
Nov. - Dec.	112	128	134	125	37.2	37.0	36.4	36.9
Jan. - Feb.	114	120	136	123	38.8	36.2	36.0	37.0
March- April	114	126	120	120	37.2	36.4	35.9	36.5
May - June	121	114	128	121	38.1	37.0	36.1	37.1
Mean	114	122	130	122	37.6	36.7	36.1	36.8
				Potassium				
July - Aug.	120	90	84.8	98	268	226	186	227
Sept.- Oct.	126	96	96.2	106	256	208	180	214
Nov. - Dec.	118	102	85.5	102	264	212	195	224
Jan. - Feb.	120	106	82.8	103	258	222	189	223
March- April	128	98	95.2	107	268	200	200	223
May - June	126	103	90.5	106	256	212	202	223
Mean	123	99	89.2	104	262	213	192	222
				Calcium				
July - Aug.	180	175	171	175	142	138	131	137
Sept.- Oct.	191	169	170	177	146	142	136	142
Nov. - Dec.	195	176	158	176	141	133	126	133
Jan. - Feb.	183	185	162	177	145	136	132	138
March- April	181	184	156	174	139	138	124	133
May - June	194	181	152	176	146	140	122	136
Mean	187	178	162	176	143	138	129	137
				Magnesium				
July - Aug.	168	160	151	160	170	152	131	151
Sept.- Oct.	172	164	160	165	168	160	135	154
Nov. - Dec.	166	166	155	163	164	156	136	152
Jan. - Feb.	162	166	164	164	160	152	130	148
March- April	174	160	151	162	166	158	133	152
May - June	168	154	148	157	165	164	130	150
Mean	168	162	155	162	166	155	133	151

Table 40. Amount (moles ha^{-1}) of Na, K, Ca and Mg added to the soil through shedding of Eucalyptus and Acacia foliage during given growth periods.

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Sodium				
July - Aug.	15.7	17.9	17.5	51.1	9.22	16.8	19.8	45.9
Sept. - Oct.	19.1	22.1	23.7	65.0	8.15	12.0	13.9	34.1
Nov. - Dec.	28.4	30.1	35.2	93.8	34.37	43.2	54.3	131.9
Jan. - Feb.	22.4	25.4	29.7	77.7	24.64	39.6	44.1	108.4
March - April	17.4	21.0	21.6	60.1	10.86	13.7	18.5	43.1
May - June	13.9	15.1	16.1	45.2	8.23	15.3	24.4	48.1
Total	117.1	131.8	144.0	393.1	95.47	141.0	175.2	411.7
				Potassium				
July - Aug.	17.8	13.8	11.9	42.8	67.6	105.	102	276
Sept. - Oct.	20.8	17.1	17.7	55.7	55.9	67	69	193
Nov. - Dec.	29.8	24.0	22.4	76.3	244.4	248	292	784
Jan. - Feb.	23.7	22.6	18.0	64.4	164.1	244	232	640
March - April	19.5	16.3	17.1	53.0	78.4	75	103	257
May - June	14.3	13.6	11.4	39.4	55.3	88	137	281
Total	126.1	107.7	97.8	331.7	665.9	829	937	2433
				Calcium				
July - Aug.	26.7	26.6	22.6	76.0	35.9	64.3	72.5	175
Sept. - Oct.	31.6	30.1	31.3	92.0	31.9	46.5	52.8	131
Nov. - Dec.	49.2	41.3	41.4	132.0	130.4	155.8	189.4	475
Jan. - Feb.	35.9	39.2	35.4	110.7	92.2	150.0	162.0	404
March - April	27.6	30.5	28.1	86.3	40.6	52.2	64.1	157
May - June	22.1	23.9	19.1	65.2	31.6	38.4	83.2	173
Total	193.3	191.9	178.3	562.5	362.8	527.4	624.3	1114
				Magnesium				
July - Aug.	24.8	24.4	19.9	69.3	42.9	70.8	72.4	186
Sept. - Oct.	28.4	29.3	29.5	87.3	36.6	52.3	52.2	141
Nov. - Dec.	42.0	39.0	40.8	121.8	152.0	182.6	203.4	538
Jan. - Feb.	31.8	35.1	35.8	102.8	102.1	167.1	160.2	429
March - April	26.4	26.6	27.2	80.4	48.7	59.8	68.7	177
May - June	19.1	20.3	18.7	58.2	35.7	64.4	88.7	188
Total	172.8	174.9	172.1	520.0	418.3	597.2	645.0	1661

Table 41. Concentration of P, S and N (m mol kg^{-1}) in foliage shed during given growth periods of Eucalyptus and Acacia.

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Phosphorus				
July - Aug.	25.6	21.8	15.7	21.0	70.7	61.9	51.6	61.4
Sept. - Oct.	28.2	23.6	16.6	22.8	68.2	62.3	55.7	62.1
Nov. - Dec.	26.4	22.8	17.4	22.2	64.8	65.4	58.2	62.8
Jan. - Feb.	29.3	24.4	18.6	24.1	66.5	60.4	54.0	60.3
March - April	26.5	20.0	15.5	20.7	68.2	63.8	52.8	61.6
May - June	25.4	20.8	16.0	20.7	66.7	61.0	54.4	60.7
Mean	26.9	22.2	16.6	21.9	67.5	62.5	54.4	61.5
				Sulphur				
July - Aug.	53.3	52.9	45.6	50.6	85.6	72.5	62.8	73.6
Sept. - Oct.	50.6	53.2	47.2	50.3	91.4	74.6	64.7	76.9
Nov. - Dec.	52.8	54.2	44.3	50.4	88.8	78.2	66.3	77.8
Jan. - Feb.	54.3	52.0	46.4	50.9	86.4	73.8	60.0	73.4
March - April	56.2	50.4	45.8	50.8	90.5	76.6	61.2	76.1
May - June	51.5	50.0	50.6	50.7	84.6	71.3	62.4	72.8
Mean	53.1	52.1	46.7	50.6	87.9	74.5	62.9	75.1
				Nitrogen				
July - Aug.	156	162	148	155	347	345	330	341
Sept. - Oct.	168	156	166	163	341	350	335	342
Nov. - Dec.	176	146	152	158	364	355	326	349
Jan. - Feb.	184	157	164	169	371	364	340	358
March - April	182	166	178	175	365	356	322	348
May - June	170	156	165	164	368	358	326	351
Mean	173	157	162	164	359	355	330	348

Table 42. Concentration of Fe, Mn, Zn and Cu (mmol kg^{-1}) in foliage shed during given growth periods of Eucalyptus and Acacia

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Iron				
July - Aug.	6.15	5.28	5.36	5.60	4.15	4.26	3.56	3.99
Sept. - Oct.	5.75	5.94	6.12	5.94	4.44	4.36	3.64	4.15
Nov. - Dec.	5.68	5.82	5.74	5.75	4.68	4.04	3.78	4.17
Jan. - Feb.	6.26	5.72	5.82	5.93	4.12	4.30	3.52	3.98
March - April	5.54	6.16	6.36	6.02	4.26	4.75	3.44	4.15
May - June	6.00	5.55	5.94	5.83	4.84	4.18	3.78	4.27
Mean	5.90	5.75	5.89	5.85	4.42	4.32	3.62	4.12
				Manganese				
July - Aug.	30.8	28.6	29.6	29.7	1.16	0.84	0.62	0.87
Sept. - Oct.	28.9	30.6	26.7	28.7	0.98	0.76	0.68	0.81
Nov. - Dec.	32.6	28.4	26.3	29.1	1.10	0.72	0.70	0.84
Jan. - Feb.	33.1	29.1	27.3	29.9	1.12	0.88	0.60	0.87
March - April	30.0	27.3	28.1	28.4	1.26	0.82	0.66	0.91
May - June	32.1	31.1	26.4	29.9	1.08	0.82	0.72	0.84
				Zinc				
July - Aug.	0.26	0.24	0.23	0.25	0.31	0.28	0.25	0.28
Sept. - Oct.	0.26	0.26	0.25	0.26	0.29	0.27	0.27	0.27
Nov. - Dec.	0.23	0.25	0.23	0.24	0.30	0.30	0.27	0.29
Jan. - Feb.	0.26	0.24	0.22	0.24	0.30	0.27	0.26	0.28
March - April	0.26	0.23	0.21	0.23	0.28	0.26	0.25	0.26
May - June	0.27	0.24	0.23	0.24	0.29	0.28	0.25	0.27
Mean	0.26	0.24	0.23	0.24	0.30	0.28	0.26	0.28
				Copper				
July - Aug.	0.15	0.12	0.11	0.13	0.15	0.12	0.10	0.12
Sept. - Oct.	0.14	0.12	0.10	0.12	0.15	0.14	0.12	0.14
Nov. - Dec.	0.14	0.11	0.12	0.12	0.14	0.13	0.10	0.12
Jan. - Feb.	0.15	0.10	0.12	0.12	0.14	0.12	0.12	0.12
March - April	0.12	0.13	0.10	0.12	0.16	0.14	0.11	0.14
May - June	0.14	0.12	0.12	0.13	0.15	0.12	0.10	0.12
Mean	0.14	0.12	0.11	0.12	0.15	0.13	0.11	0.13

Table 43. Amount (moles ha^{-1}) of P, S and N added to the soil through shedding of Eucalyptus and Acacia foliage during given growth periods.

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Phosphorus				
July - Aug.	3.79	3.31	2007	9.17	17.82	28.78	28.48	75.08
Sept. - Oct.	4.65	4.20	3.05	11.90	14.87	20.31	21.50	56.68
Nov. - Dec.	6.65	5.34	4.56	16.55	59.88	76.38	86.95	223.21
Jan. - Feb.	5.74	5.17	4.05	14.96	42.23	66.20	66.15	174.58
March - April	4.03	3.32	2.79	10.14	19.91	24.12	27.24	71.27
May - June	2.90	2.75	2.02	7.67	14.41	25.38	36.88	76.67
Total -	27.76	24.09	18.54	70.39	169.12	241.17	267.20	677.49
				Sulphur				
July - Aug.	7.89	8.04	6.02	21.95	21.57	33.71	34.67	89.95
Sept. - Oct.	8.35	9.47	8.68	26.50	19.93	24.32	24.97	69.22
Nov. - Dec.	13.31	12.68	11.61	37.60	82.05	91.34	99.05	272.44
Jan. - Feb.	10.64	11.02	10.12	31.78	54.86	80.88	73.50	209.24
March - April	8.54	8.37	8.24	25.15	26.43	28.95	31.58	86.96
May - June	5.87	6.60	6.38	18.85	18.27	29.66	42.31	90.24
Total	54.60	56.18	51.05	161.83	223.11	288.86	306.08	818.05
				Nitrogen				
July - Aug.	23.14	24.65	19.56	67.3	87.	160	182	430
Sept. - Oct.	27.77	27.89	30.69	86.3	74	114	129	318
Nov. - Dec.	44.40	34.26	39.98	118.6	337	415	487	1240
Jan. - Feb.	36.18	33.45	35.90	105.5	235	399	417	817
March - April	27.74	27.62	32.09	87.4	106	134	166	408
May - June	19.43	20.59	20.89	60.9	79	149	221	450
Total	178.66	168.46	179.11	526.2	921	1374	1604	3664

Table 44. Amount of Fe, Mn (moles ha^{-1}), Zn and Cu (mmoles ha^{-1}) added to the soil through shedding of Eucalyptus and Acacia foliage during given growth periods.

Growth period	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Iron				
July - Aug.	0.91	0.80	0.71	2.42	1.05	1.98	1.97	5.00
Sept. - Oct.	0.95	1.06	1.13	3.14	0.97	1.42	1.41	3.80
Nov. - Dec.	1.43	1.36	1.50	4.29	4.32	4.72	5.65	14.69
Jan. - Feb.	1.23	1.21	1.27	3.71	2.62	4.71	4.31	11.64
March - April	0.84	1.02	1.14	3.00	1.24	1.80	1.78	4.82
May - June	0.68	0.73	0.75	2.16	1.05	1.74	2.56	5.35
Total	6.04	6.18	6.50	18.72	11.25	16.37	17.68	45.30
				Manganese				
July - Aug.	4.57	4.35	3.91	12.83	0.29	0.39	0.34	1.02
Sept. - Oct.	4.78	5.45	4.93	15.16	0.21	0.25	0.26	0.72
Nov. - Dec.	8.23	6.66	6.90	21.79	1.02	0.84	1.05	2.91
Jan. - Feb.	6.50	6.18	5.96	18.64	0.71	0.96	0.74	2.41
March - April	4.56	4.54	5.06	14.16	0.37	0.31	0.34	1.02
May - June	3.67	4.12	3.33	11.12	0.23	0.34	0.49	1.06
Total	32.31	31.30	30.09	93.70	2.83	3.09	3.22	9.14
				Zinc				
July - Aug.	41.4	36.8	30.3	108.	78.1	130.	138	346
Sept. - Oct.	42.9	46.2	46.0	135	63.2	88	104	255
Nov. - Dec.	57.9	58.5	60.2	176	277.2	350	403	1030
Jan. - Feb.	50.9	50.8	47.9	149	190.5	295	318	804
March - April	39.5	38.1	37.8	115	81.7	98	129	309
May - June	30.7	31.6	28.9	91	62.6	116	169	348
Total	263.5	262.0	251.3	776	753.4	1079	1262	3095
				Copper				
July - Aug.	22.2	18.2	14.5	54.9	37.8	55.8	55.2	148.
Sept. - Oct.	23.1	21.3	18.4	62.8	32.7	45.6	46.3	124
Nov. - Dec.	35.2	25.7	31.4	92.4	129.3	151.8	149.4	430
Jan. - Feb.	29.4	21.2	26.1	76.7	88.9	131.5	147.0	367
March - April	18.2	21.5	18.0	57.8	46.7	52.9	56.7	156
May - June	15.9	15.8	15.1	46.9	32.4	49.9	67.8	150
Total	144.1	123.9	123.6	391.7	367.8	487.6	522.4	1378

Amount of P, S, N (Table 43), Fe, Zn and Cu (Table 44) recycled through litter production was significantly more in Acacia than in Eucalyptus during all of the three years. But opposite was observed in the case of Mn. Distribution of their total amount among the given growth periods of a year showed close association with the quantity of litter produced in each of the periods. Amounts of the micronutrients recycled was significantly lower than that of the macronutrients. But an unusual accumulation of Mn in the litter of Eucalyptus during 1982-84 was an exception and intriguing. Data on litter production, chemical composition of litter and amounts of nutrients recycled through litter showed that Acacia perform well than Eucalyptus. High N concentration beside P and S of Acacia litter make it easier to undergo rapid decomposition to produce organic compounds favourable for amelioration of physical, chemical and biological properties of the sodic soils. Being a N fixing tree and its observed encouraging growth further make it valuable to harvest atmospheric N for enrichment of the soil with the same.

4.3 Evaluation of the Growth Response of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del. to Composition of Selected Posthole Filling Mixtures in a Highly Sodic Soil.

Introduction: The cogent cause which constraints normal plant growth in sodic soils is the presence of excessive quantities of element sodium. Excess of sodium in the root environment is not only toxic for plant metabolism (direct action) but also results in extremely adverse soil conditions unfavourable for normal functioning of roots (indirect effect). The ability of tree species to grow satisfactorily on the sodic soils depends on a number of interrelated factors (physiological composition, growth stage and the rooting habits). Establishment of trees on such soils, thus, require amelioration of limited root zone to a satisfactory level. This may be achieved by use of either normal soil or amendments. The earliest documented reports (Pande, 1956 and 1967) suggested refilling of 120 cm deep pits with the normal soil for better survival and performance of a few tree species planted in sodic soils. But it lacked practical feasibility. Research efforts of Yadav et al. (1975) showed that mixing gypsum at the rate of 50 per cent of GR and 24 kg FYM with the sodic soil used for refilling of pits 90 cm each in depth and diameter yielded good results and comparable to the use of normal soil.

Pit method of planting trees in sodic soils involves high doses of gypsum and FYM and their mixing in soil of considerably large volume. These practices make this technique bottlenecked for general adoption on a wide scale. Therefore, a posthole technique which overcomes these difficulties was devised. This requires improvement of a limited volume of the soil than the pit method. The optimum dose and combination of amendments namely gypsum and FYM for better survival and rapid early growth of different tree species was hypothesized to be evaluated in this investigation. Tree species selected for the objective were Eucalyptus and Acacia. The former species, a fast growing and most widely planted in the country, was observed (Yadav et al., 1975) growing normally after its planting through pit method on a sodic (pH 10.0) soil. The latter is a relatively slow growing and mostly regarded capable of establishment on the sodic soils without using amendments and modification of the planting site.

Methodology: To investigate the growth response of given species of Eucalyptus and Acacia to the composition of posthole filling mixtures, this experiment was conducted on a highly sodic soil (Table 3).

For this purpose, postholes of constant dimensions (15 cm dia. and 120 cm depth) were dug out by a soil auger manually. These postholes were refilled with five filling mixtures whose composition is given in Table 45. The robust and uniform saplings of both the species were planted on July 17, 1979. Experiment was laid out in randomized block design and replicated four times. Each replicate comprised four saplings planted in rows at a distance of 3 m between the plants in 36 m^2 (6 m X 6 m) plot meant for the postholes refilled with the given five mixtures. Plants were watered on need felt basis for about a year after planting. Nitrogen (urea) at the rate of 25 and 10 g $plant^{-1}$ was applied on Aug. 4 and Nov. 26 of 1979 with the irrigation water respectively. Details of methodology for rest of practices and procedures are similar to those given in the preceding experiment. However, observations on the role of plantations to quantify soil reclamation and modification of microclimate and litter production were not made in this experiment.

Table 45. Details of composition of selected posthole filling mixtures

Filling mixture	Composition posthole-1 of 15 cm dia X 120 cm depth
M_1	Original sodic soil, OS
M_2	OS + 3 kg gypsum
M_3	OS + 6 kg gypsum
M_4	OS + 3 kg gypsum + 8 kg FYM
M_5	OS + 3 kg gypsum + 8 kg FYM

<u>Results and Discussion</u>: Experimental results on various aspects are presented and discussed below under the given headings:

A. <u>Per Cent Survival</u>: Results on periodic per cent survival of Eucalyptus and Acacia planted through posthole technique in a highly sodic soil (Table 46) showed that the two species responded differently to different posthole filling mixtures. Relative mortality of Eucalyptus was markedly greater than of Acacia for respective mixtures at all the noted growth stages. Mortality was observed to occur more between 6-24 months of planting. Mean survival of Eucalyptus and Acacia irrespect of the given mixtures was found stabilized at 55-60 and 78-81 per cent during 24-72 months of the growth period respectively.

Response of Eucalyptus to use of gypsum and FYM was more than of Acacia. However, application of gypsum was a must for both the species to achieve reasonably desired survival. Eucalyptus planted in postholes refilled with the original sodic soil (M_1) met complete mortality just after about a year of planting. Corresponding survival of Acacia lowered to a poor 6 per cent during 30-72 months of planting through gradual mortality. Use of combined application of gypsum and FYM with OS (M_4) and sand (M_5) resulted in significantly greater survival of Eucalyptus than with an equal dose (3 kg) of gypsum alone (M_2). Application of 6 kg gypsum alone (M_3) resulted in less mortality than only 3 kg and this treatment was inferior to the combined use of 3 kg gypsum and 8 kg FYM with OS or sand. Addition of gypsum either 3 or 6 kg alone or in combination with FYM to OS and sand caused no significant differences in per cent survival of Acacia. Use of gypsum and FYM yielded a survival of 94-100 per cent, significantly more than by planting Acacia in postholes refilled with original sodic soil. These observations, thus, show that combined

Table 46. Effect of composition of posthole filling mixtures on the periodic per cent survival of Eucalyptus and Acacia.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
			Eucalyptus				
0	100	100	100	100	100	100	NS
3	100	100	100	100	100	100	NS
6	88	100	88	100	100	95	NS
9	38	68	76	100	100	76	22
12	12	50	76	100	100	68	30
15	M	50	68	100	100	64	37
18	M	50	68	94	100	62	35
21	M	44	68	94	100	61	35
24	M	44	68	88	100	60	38
30	M	44	68	88	94	59	36
36	M	38	68	82	94	56	37
42	M	38	68	82	88	55	40
48	M	38	68	82	88	55	40
60	M	38	68	82	88	55	40
72	M	38	68	82	88	55	40
			Acacia				
0	100	100	100	100	100	100	NS
3	100	100	100	100	100	100	NS
6	100	100	100	100	100	100	NS
9	68	94	100	100	100	92	24
12	38	94	100	100	100	86	33
15	38	94	100	100	100	86	33
18	32	94	100	100	100	85	36
21	18	94	100	100	100	82	30
24	12	94	100	100	100	81	28
30	6	94	100	100	100	80	22
36	6	94	100	94	100	78	20
42	6	94	100	94	100	78	20
48	6	94	100	94	100	78	20
60	6	94	100	94	100	78	20
72	6	94	100	94	100	78	20

M stands for complete mortality.

use of 3 kg gypsum and 8 kg FYM per posthole was superior than gypsum alone either 3 or 6 kg for Eucalyptus. However, Acacia responded similarly to these combinations exhibiting its greater tolerance to the soil sodicity hazard. Results also contradict the general myth that Acacia can grow on highly sodic soil without using amendments. Yadav et al. (1980) also reported combined use of gypsum and FYM beneficial for Eucalyptus and Acacia planted using pit (90 cm X 90 cm) method. This may be attributed to the complementary interaction of FYM with gypsum for its ameliorative action on physico-chemical properties of the soil, supply of essential nutrients and increasing their availability (Gill, 1979) in the soil.

B. <u>Height Growth</u>: Data in Table 47 show that effect of selected post-hole mixtures on the height growth of Eucalyptus differed significantly at all the observed growth stages. Saplings planted using only OS increased a little in height and then decreased before complete mortality after 12 months of planting. Mixing of gypsum and FYM with OS (M_4) and sand (M_5) gave maximum and significantly higher response than use of 3 kg but it was inferior to the combined application of gypsum and FYM with OS or sand. This is also evident from (Fig. 16) depiction of cumulative mean monthly height increase of Eucalyptus during successive growth years. Results further show that addition of only gypsum, either 3 or 6 kg not only registered lower increments in height growth during respective years than its use in conjunction with FYM and or sand but also effected a change in the growth pattern. The latter treatments (T_4 and T_5) caused Eucalyptus to grow fast during first year and showed decreasing rate with subsequent years. But mean monthly height increments for mixtures containing only gypsum were

Table 47. Effect of composition of posthole filling mixtures on the periodic height (cm) of <u>Eucalyptus</u> <u>tereticornis</u> Sm. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1*	M_2	M_3	M_4	M_5		
0	59	60	60	65	58	60	NS
1	60	63	62	74	68	65	NS
2	65	72	73	85	82	75	8
3	74	81	86	106	100	89	10
44	73	84	88	113	108	93	12
5	71	86	91	115	110	97	15
6	69	88	95	120	116	98	16
7	62	89	98	123	120	98	16
8	62	94	114	148	149	113	21
9	63	102	136	180	186	133	35
10	65	112	159	212	234	156	50
11	60	124	170	240	276	174	52
12	60	132	182	273	308	191	56
15	-	142	199	292	341	244	95
18	-	148	222	308	358	259	98
21	-	178	266	352	396	298	102
24	-	216	318	396	444	344	122
27	-	244	340	434	492	378	126
30	-	262	372	458	516	402	132
33	-	280	396	486	538	425	138
36	-	324	438	512	594	467	146
39	-	346	472	578	659	514	155
42	-	368	484	592	678	531	160
45	-	396	502	648	726	568	165
48	-	431	534	685	794	617	169
51	-	436	552	698	798	621	170
54	-	438	562	716	800	629	175
57	-	445	583	736	812	644	180
60	-	450	597	761	819	657	187
63	-	452	604	774	822	663	196
66	-	454	610	782	824	668	212
69	-	456	616	800	826	675	241
72	-	459	625	820	828	683	256

*M_1 was excluded when data analysed statistically.

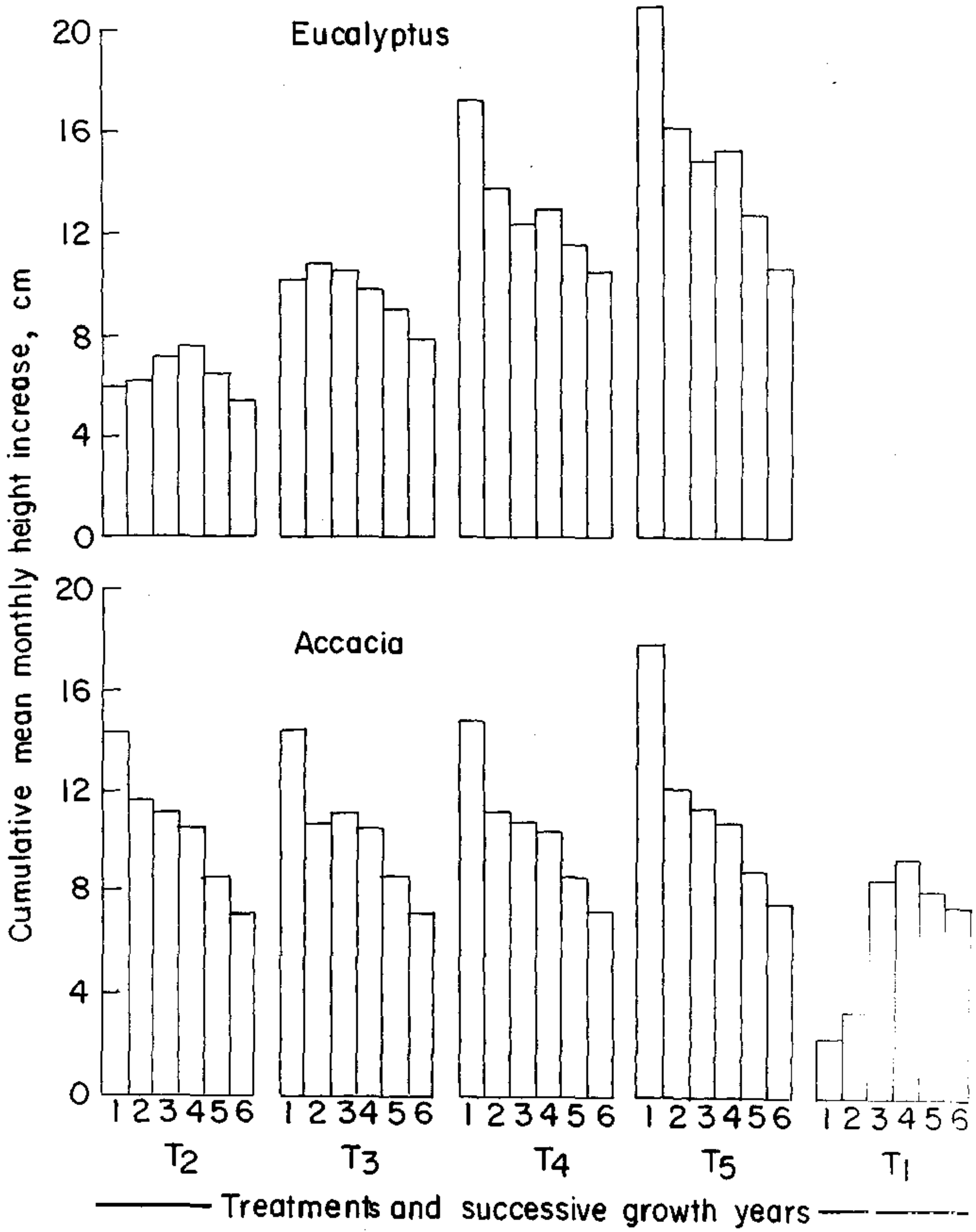


Fig.16. Effect of posthole filling mixtures on cumulative mean monthly height increments during successive growth years.

more during second or third year of growth although the differences were not as marked.

Effect of given posthole filling mixtures on the periodic height growth of Acacia (Table 48) was interesting to show that application of gypsum alone at the rate of 3 and 6 kg as well as its combined use with FYM and OS or sand yielded similar height response at all the growth stages. Addition of sand in combination with FYM and gypsum had an edge over rest of the mixtures and may possibly be due to its beneficial influence on physical properties of the soil within and in the vicinity of the posthole. Unlike Eucalyptus which met complete mortality after a year of planting, six per cent Acacia plants survived in postholes refilled with OS and their growth was significantly slower than in the other treatments during the initial two years. But in subsequent years their growth occurred at a rate comparable to plants in postholes refilled with differently amended soil. This confirms the general report that plants develop greater tolerance to a given stress environment with growth. This is why in programmes worked out for afforestation of salt affected soils early growth and high per cent survival of planted saplings holds the sway over their success. The mean monthly height increments of Acacia growth (Fig. 16) during first year of planting were nearly same for mixtures containing gypsum either 3 (M_2) or 6 kg (M_3) or both the gypsum and FYM with OS (M_4) or sand (M_5). In subsequent years, magnitude of increment declined gradually until fourth year and markedly in fifth and sixth year. This is in agreement to the general growth pattern of tree plants (Kozlowski, 1971). But opposite was the trend with height growth of Acacia in postholes refilled with only OS. Mean monthly increment in height was lowest during first and second year in ascending order and

Table 48. Effect of composition of posthole filling mixtures on the periodic height (cm) of *Acacia nilotica* (L.) Willd.ex. Del. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
0	42	41	44	45	43	43	NS
1	44	45	46	55	53	49	NS
2	45	52	58	64	62	56	6
3	46	64	73	74	75	66	10
4	48	69	79	81	89	73	12
5	50	78	84	86	100	80	12
6	50	78	85	88	103	81	12
7	50	79	85	86	102	80	12
8	52	90	92	91	109	87	14
9	55	134	132	130	148	120	32
10	62	168	166	164	182	148	58
11	67	187	192	196	228	174	66
12	71	214	218	222	256	196	78
15	74	227	247	257	295	220	82
18	78	242	259	262	302	229	94
21	92	278	274	278	314	247	98
24	125	319	304	316	336	280	104
27	256	358	352	358	378	340	NS
30	264	366	368	376	388	352	NS
33	314	398	404	414	426	391	NS
36	352	444	440	438	452	425	NS
39	396	476	471	474	490	461	NS
42	412	484	480	488	498	472	NS
45	472	516	518	530	544	516	NS
48	504	548	549	545	561	541	NS
51	512	552	555	549	568	547	NS
54	514	553	558	552	574	550	NS
57	520	555	560	559	578	554	NS
60	528	558	560	565	582	559	NS
63	539	560	562	565	584	562	NS
66	542	558	562	563	585	562	NS
69	571	558	565	564	587	569	NS
72	590	562	567	567	589	575	NS

their magnitude increased considerably in third to the maximum in fourth followed by decrease in the fifth and sixth years of growth. This observation to some extent supports the popular theory of the survival of the fittest. Absolute height of Acacia was less than Eucalyptus but its trees developed a dense and lush green canopy. Aerial growth of Eucalyptus into an open canopy and usual chlorotic foliage (Plate 3) clearly demonstrate that its plants are facing a stress whose nature may be nutritional disorder or toxicity of sodium or other related fact. The height growth data, thus, also prove the relatively greater tolerance of Acacia than of Eucalyptus to highly sodic soils and this corroborate the reports of many other workers (Griffith, 1945, 46; Rege and Tamhane, 1964; Yadav, 1975).

C. Girth Growth: Results on girth growth as measured by periodic DSH (Table 49) and DBH (Table 50) of Eucalyptus showed significantly different effect of the given posthole mixtures. Saplings planted in postholes refilled with only OS did not grow in girth until four months of planting after which DSH decreased gradually prior to complete mortality. This decrease may be attributed to the mobilization of stored energy in the stem to leaves and roots for achieving naturalization and establishment on a highly sodic environement. The DSH of Eucalyptus at all the growth stages was significantly more in postholes refilled with mixtures containing both gypsum and FYM in combination with OS (M_4) and sand (M_5) than gypsum alone at the rate of 3 kg per posthole. Girth diameter was more with application of gypsum at a rate of 6 than 3 kg posthole^{-1}. But these were considerably lower than those for mixtures having both gypsum and FYM. Similar response was observed in respect of monitored at selected stages (Table 48) of the growth period. This was also evident from

Table 49. Effect of composition of posthole filling mixtures on the periodic DSH* (mm) of *Eucalyptus tereticornis* Sm. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
0	5.2	5.5	5.5	5.8	5.4	5.5	NS
1	5.3	6.0	6.4	6.6	6.2	6.1	NS
2	5.2	6.4	7.0	7.5	7.3	6.7	NS
3	5.2	8.3	8.5	8.8	8.8	8.0	3.3
4	5.2	9.8	10.3	12.4	13.1	10.2	2.6
5	5.0	10.0	10.8	13.1	14.2	10.6	3.0
6	4.8	10.0	11.6	13.6	14.8	11.0	3.5
7	4.8	11.6	14.7	15.2	15.1	12.3	3.6
8	4.7	14.3	17.2	20.8	19.7	19.2	4.8
9	4.7	17.6	20.5	23.6	24.8	18.2	5.1
10	4.6	19.2	24.8	25.8	26.7	20.2	6.2
11	4.6	21.8	26.7	28.2	29.9	22.2	6.2
12	4.6	22.2	30.3	31.9	32.8	24.4	8.8
15	-	28.6	42.4	59.2	60.4	47.7	15.6
18	-	32.4	46.5	63.8	64.5	51.8	16.7
21	-	38.8	57.2	76.2	80.8	63.3	20.8
24	-	43.2	68.9	98.6	103.5	78.6	24.8
27	-	47.1	70.8	109.2	111.3	84.6	26.3
30	-	50.0	71.4	110.8	113.6	86.5	28.8
33	-	53.3	74.3	114.7	117.4	89.9	30.1
36	-	56,7	76.8	120.9	123.3	94.4	30.8
39	-	58.2	84.4	131.3	136.6	102.6	32.4
42	-	59.4	86.2	134.5	137.5	104.4	34.8
45	-	63.5	90.5	139.9	140.4	108.6	36.0
48	-	66.6	95.5	144.7	142.3	112.3	36.1
51	-	68.4	96.3	145.3	148.8	114.7	36.5
54	-	69.8	97.5	145.6	150.1	115.8	39.0
57	-	74.3	104.8	149.2	151.8	120.0	40.4
60	-	80.0	116.6	153.2	153.1	124.1	35.5
63	-	81.2	112.0	155.6	156.6	126.4	40.6
66	-	80.8	112.1	157.4	157.3	126.9	41.4
69	-	81.4	112.8	159.8	158.3	128.1	44.2
72	-	81.8	113.6	161.4	159.6	129.1	49.4

*DSH stands for girth diameter at stump height (5 cm).

Table 50. Effect of composition of posthole filling mixtures on the periodic DBH* (mm) of *Eucalyptus tereticornis* Sm. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
10	-	10.2	10.4	11.3	11.6	10.9	NS
11	-	12.3	12.6	13.2	13.8	13.0	NS
12	-	15.8	16.2	17.5	18.2	16.9	NS
15	-	18.8	23.4	31.4	40.8	28.6	11.1
18	-	18.8	24.1	34.6	44.2	30.5	11.5
21	-	19.0	30.7	43.8	53.6	36.8	14.8
24	-	19.2	34.6	53.8	61.3	42.5	20.4
27	-	24.5	40.7	61.7	72.7	49.9	26.6
30	-	25.8	41.4	63.2	74.5	51.2	27.8
33	-	29.3	44.8	74.3	83.8	58.0	29.2
36	-	34.8	50.6	88.6	90.7	66.2	30.2
39	-	36.2	51.9	89.0	94.4	67.9	31.7
42	-	37.4	53.3	91.2	96.8	69.7	32.4
45	-	38.2	56.7	92.7	97.3	71.2	33.3
48	-	38.0	57.2	91.8	97.8	71.2	34.3
51	-	39.1	60.9	92.9	98.8	72.9	35.1
54	-	39.8	63.8	93.6	100.2	74.5	35.7
57	-	42.2	65.7	94.2	103.3	76.4	33.8
60	-	45.2	70.7	99.5	105.6	80.8	32.4
63	-	45.4	71.2	100.4	108.9	81.5	33.2
66	-	44.8	71.9	100.2	109.4	81.6	34.1
69	-	45.6	72.6	104.6	112.7	83.9	33.0
72	-	45.6	73.8	106.4	116.5	85.6	34.3

*DBH stands for girth diameter at breast height (137 cm).

the cumulative mean monthly DSH increase during successive growth years (Fig. 17). Mean monthly increments to the cumulative DSH increase was low in the first year of planting and was maximum during the second year. Subsequently, there occurred a gradual decrease with each of the years. Increments withinp postholes refilled with mixing of gypsum and FYM in OS or sand were significantly increased than gypsum alone at both the rates. This again demonstrates that the interaction resulting from combined use of gypsum and FYM was complementary for Eucalyptus. The results, in turn, mean that growth of this species may be altered through modifications of the soil environment to effect rapid early growth for building greater tolerance to highly sodic conditions of the soil.

But the effect of different posthole filling mixtures on the periodic girth of Acacia at 5 (DSH) and 137 cm (DBH) height of stem above the ground level did not differ significantly (Tables 51 and 52 respectively) at all the observational stages except during 12-24 months of planting. Application of gysum alone at both the rates (M_2 and M_3) were on par but superior than refilling of the postholes with OS only though not significantly. This trend was also clear from the cumulative mean monthly DSH increase (Fig. 17) for different treatments and growth years. Unlike Eucalyptus, the increments to DSH were more for the first than the second after which the magnitude showed marginal increase for third and fourth and a decrease in fifth and sixth year. Increment in DSH of Acacia planted in postholes refilled with OS were small compared to the other mixtures. This indicates that despite very high mortality (94 per cent) of Acacia in case of this treatments, girth growth occured but at a rate slower than for height during the fifth and sixth years when it was on par with the other treatments.

Table 51. Effect of composition of posthole filling mixtures on the periodic DSH* (mm) of *Acacia nilotica* (L.) Willd. ex.Del. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
0	10.4	10.6	11.2	10.8	11.7	10.9	NS
1	10.6	11.2	10.9	11.0	12.0	11.1	NS
2	10.4	12.3	11.8	11.9	12.6	11.8	NS
3	11.6	14.2	13.9	12.5	13.2	13.1	NS
4	12.2	15.1	14.8	13.9	13.5	13.9	NS
5	13.3	15.2	15.0	14.8	13.8	14.4	NS
6	13.3	15.3	15.2	14.9	13.8	14.5	NS
7	13.4	15.3	15.3	15.0	14.0	14.6	NS
8	15.2	18.2	17.9	18.0	19.6	17.8	NS
9	17.3	21.6	20.8	21.1	23.5	20.9	NS
10	19.6	25.3	24.6	25.2	27.3	24.4	NS
11	21.2	31.2	31.3	33.3	32.9	30.0	9.8
12	23.2	34.5	36.2	38.9	39.3	34.4	10.6
15	28.5	38.9	41.4	43.8	44.8	39.5	10.8
18	30.2	40.2	42.3	46.2	45.2	40.8	11.2
21	34.8	45.1	47.7	50.4	50.6	45.7	11.6
24	38.6	50.2	52.6	54.4	55.3	50.2	12.1
27	47.5	60.2	59.7	60.8	61.6	58.0	NS
30	52.3	62.3	63.8	62.9	62.0	60.7	NS
33	58.7	68.8	70.2	71.8	72.7	68.4	NS
36	61.8	74.3	76.2	78.8	80.2	74.3	NS
39	64.6	85.2	84.3	86.2	89.4	81.9	NS
42	65.3	87.4	88.2	89.3	92.2	84.5	NS
45	69.3	94.8	95.5	105.2	108.3	94.6	NS
48	72.2	101.6	102.7	112.7	113.3	101.5	NS
51	76.0	102.4	10336	114.4	116.6	102.6	NS
54	81.8	105.4	105.6	120.2	120.5	107.4	NS
57	88.7	107.7	113.2	123.3	123.8	111.3	NS
60	96.4	108.6	121.5	126.6	128.4	116.5	NS
63	98.2	112.5	124.6	128.8	130.2	118.9	NS
66	98.4	113.8	125.8	129.2	130.8	119.6	NS
69	98.8	118.6	130.0	132.4	133.6	122.7	NS
72	100.2	124.8	132.3	135.2	138.2	126.3	NS

*DSH stands for girth diameter at stump height (5 cm).

Table 52. Effect of composition of posthole filling mixtures on the periodic DBH* of *Acacia nilotica* (L.) Willd. ex. Del. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures					Mean	LSD (0.05)
	M_1	M_2	M_3	M_4	M_5		
10	-	10.2	10.4	11.2	10.8	10.7	NS
11	-	12.3	12.8	13.6	14.2	13.2	NS
12	-	13.4	16.7	17.9	18.1	16.5	NS
15	-	17.6	24.0	28.3	29.4	24.8	6.0
18	-	17.7	24.3	29.0	29.9	25.2	6.4
21	-	20.6	25.8	29.7	30.8	26.7	6.5
24	-	22.5	27.3	30.1	32.4	28.1	6.6
27	26.3	36.7	38.4	40.6	41.3	36.7	10.4
30	27.7	38.2	39.8	40.9	41.8	37.7	NS
33	31.4	49.3	53.2	55.4	60.6	50.0	NS
36	34.3	64.2	65.8	69.5	78.4	62.4	NS
39	36.2	74.4	76.2	80.2	84.3	70.3	NS
42	37.8	76.2	78.1	81.8	86.2	72.0	NS
45	41.6	80.0	84.3	92.4	98.2	79.3	NS
48	45.8	83.6	91.4	105.2	106.7	88.1	NS
51	48.3	86.2	95.2	107.6	108.2	89.1	NS
54	49.6	86.6	96.4	108.8	107.4	89.8	NS
57	52.8	89.5	100.3	109.2	108.8	92.1	NS
60	61.2	92.6	103.6	111.7	109.3	95.5	NS
63	74.6	96.7	106.4	116.8	115.7	102.0	NS
66	77.3	98.7	106.8	117.2	116.4	103.3	NS
69	88.8	106.7	109.2	120.3	124.3	110.0	NS
72	102.4	111.3	111.6	124.3	132.8	111.3	NS

*DBH stands for girth diameter at breast height (137 cm).

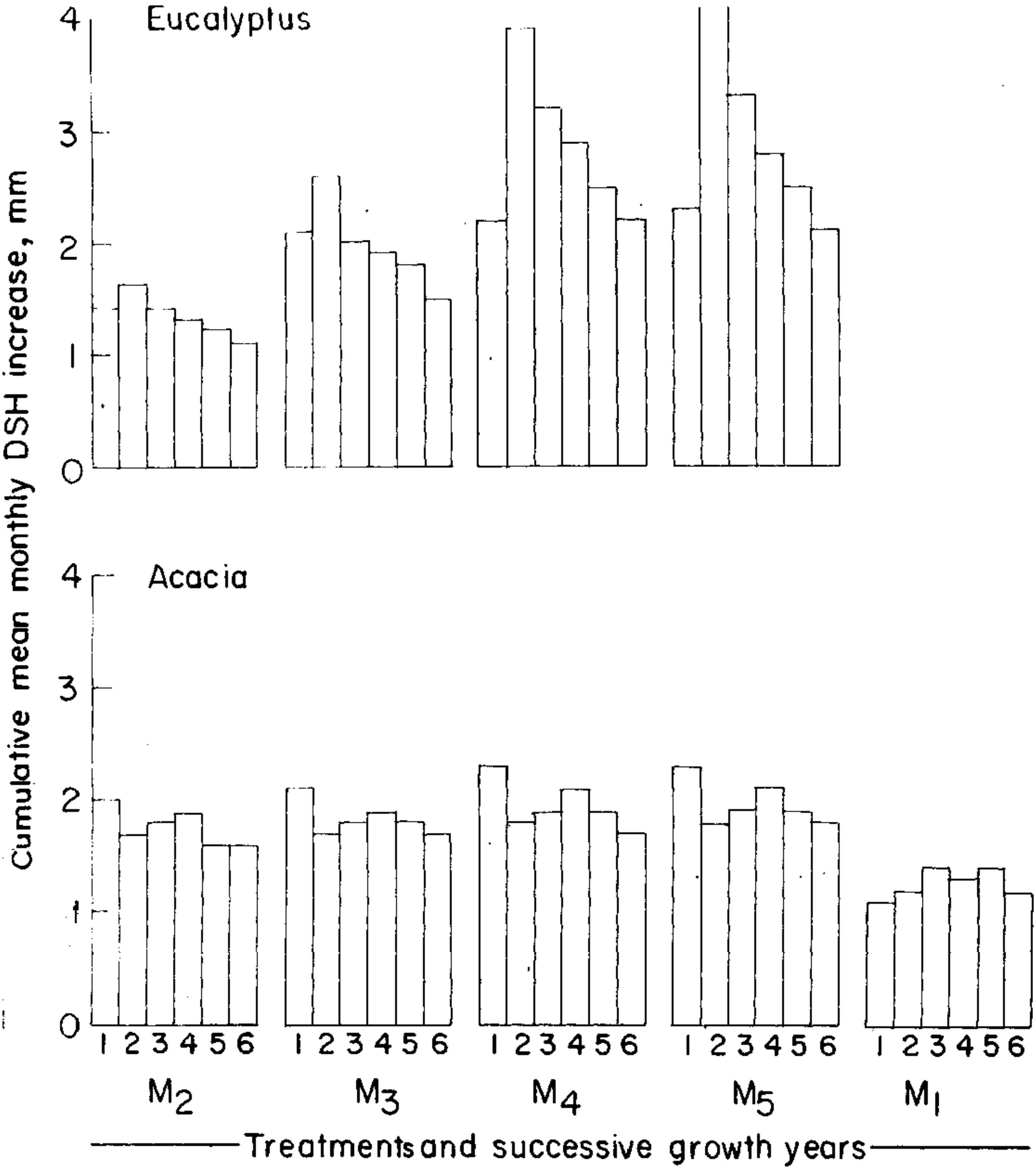


Fig.17. Effect of posthole filling mixtures on cumulative mean monthly DSH increments during successive growth years.

The results on periodic girth growth of Eucalyptus and Acacia in postholes refilled with different filling mixtures also demonstrated relatively greater tolerance of the latter than the former to highly sodic soil conditions. Growth of Eucalyptus showed only marginal edge over Acacia for posthole filling mixtures containing gypsum and FYM but opposite was true for the treatment involving application of gypsum alone. Considering potentially achievable DSH and DBH in respect of Eucalyptus and Acacia and their average life span, growth of Acacia excelled Eucalyptus in highly sodic soil. This experiment also proves that posthole technique of planting tree species in sodic soils performs equally well in terms of their growth (Yadav et al., 1975) and is considerably economical than the pit method. Application of gypsum for achieving desired survival and boost growth of both the species was observed very much imperative. This brings out that an appropriate modification of the site meant for planting tree species in sodic soils is a must next to the very important aspect of selecting a suitable species. The findings show that amelioration of limited soil environment with use of limited amounts of amendments (gypsum and FYM) is more important than no amendments or amendments in a considerably large planting pit (Yadav et al.,1975).

D. <u>Biomass Yield of Acacia on Lopping</u>: Eucalyptus being a straight growing tree with self (natural) pruning control, did not need lopping that could produce measurable amounts of biomass. But growth of secondary branches on the trunk of Acacia trees was enormous to practise low pruning for silvicultural and technical considerations twice after 16 and 42 months of planting. This yielded considerable biomass as foliage and woody matter in branches possessing potential value for their use as protein rich forage and as firewood respectively.

Table 53. **Biomass** (kg ha^{-1}) lopped as **branches growing** on **the three bolls after** 16 (a) **and** 42 (b) months of planting *Acacia nilotica* (L.) Willd. ex. Del.

Filling mixture	Woody matter			Foliage			Woody matter + Foliage
	a	b	a+b	a	b	a+b	
M_1	-	788 (864)	788 (864)	-	478 (2386)	478 (2386)	1266
M_2	1084 (1306)*	4964 (6715)	6048 (8021)	472 (2468)	1834 (8868)	2306 (10418)	8354
M_3	1282 (1336)	5120 (7044)	6408 (8380)	528 (2769)	1968 (9076)	2496 (11762)	8904
M_4	1838 (2656)	7086 (9862)	8916 (12518)	654 (3018)	2456 (11684)	3110 (13684)	12026
M_5	2455 (3318)	7154 (9988)	9609 (13306)	876 (4408)	2396 (11444)	3272 (12976)	12881
Mean	1665 (2154)	5022 (6895)	6354 (8618)	633 (3166)	1826 (8692)	2332 (10245)	8686
LSD (0.05)	1051 (1212)	1964 (2796)	2318 (3865)	114 (242)	460 (2384)	582 (1868)	2672

*Figures in parentheses denote corresponding value on air dried basis for woody material and fresh weight basis for the foliage.

Effect of selected posthole filling mixtures containing gypsum alone or in combination with FYM was although similar on periodic height and girth growth of Acacia plants, but it caused significant differences among them for their influence on the secondary growth of branches and in turn the development of canopy. These differences were reflected on the biomass yielded on lopping. Data (Table 53) shows that foliage as well as woody matter yields were significantly higher for postholes refilled with a mixture of 3 kg gypsum and 8 kg FYM with CS (M_4) and sand (M_5) than the gypsum alone irrespective of its rate for both of the loppings. Biomass yield produced on first lopping was lower than in the second by about 3-4 times. The mean foliage yield obtained on both of the loppings constituted about 36-38 per cent of the mean woody matter on oven dry basis. Results, thus, indicates that the use of FYM in combination with gypsum resulted in higher biomass yields. This may be due to its beneficial effect through supply of essential nutrient elements and their increased availability through ameliorationof physico-chemical and biological properties of the soil. Lopping is normally a costly operation, though if the foliage or branches have a promose for yielding considerably valuable biomass as is the case in Acacia, it may pay for itself. The study suggests that afforestation programmes aimed at generation of firewood resources for rural cummunities may start yielding biomass at short intervals after planting tree species.

(a) Chemical Composition of Biomass: Chemical composition of foliage (Table 54) harvested from trees showed that concentration of the important nutrient elements did not vary significantly among different mixtures containing either gypsum alone or in combination with FYM. The Na, K, Mg, P, Fe, Mn, Zn and Cu concentration in the foliage yielded on second lopping of plants growing in postholes refilled with

Table 54. Chemical composition (mmol kg^{-1}) of the foliage of Acacia lopped after 16(a) and 42(b) months of planting.

Filling mixture	Sodium		Potassium		Calcium		Magnesium	
	a	b	a	b	a	b	a	b
M_1	-	62.8	-	378	-	198	-	275
M_2	42.5	35.5	346	317	367	276	248	198
M_3	36.6	34.7	326	311	388	268	236	188
M_4	32.8	30.2	371	332	362	266	256	169
M_5	31.1	31.4	374	326	376	270	242	174
Mean	35.8	38.9	354	333	373	256	246	201

	Phosphorus		Sulphur		Nitrogen		Iron	
	a	b	a	b	a	b	a	b
M_1	-	148	-	56.6	-	796	-	23.8
M_2	136	116	136	91.8	1282	916	22.5	18.2
M_3	125	109	156	103.4	1274	902	20.8	16.4
M_4	140	98	132	94.3	1256	878	24.6	14.6
M_5	138	95	136	90.9	1260	882	24.6	15.2
Mean	135	113	140	87.4	1268	875	23.1	17.6

	Manganese*		Zinc*		Copper*		Na:Mg	
	a	b	a	b	a	b	a	b
M_1	-	24.5	-	13.8	-	2.2	-	0.23
M_2	22.8	16.2	11.6	8.6	2.6	1.8	0.17	0.18
M_3	20.9	14.8	10.8	8.2	2.5	1.8	0.15	0.18
M_4	24.2	15.2	11.3	8.2	2.5	1.9	0.13	0.18
M_5	23.5	14.8	11.5	8.4	2.4	1.8	0.13	0.18
Mean	22.9	17.1	11.3	9.4	2.5	1.9	0.14	0.19

	Na:K		Na:Ca		Na:K+Ca		Ca:Mg	
	a	b	a	b	a	b	a	b
M_1	-	0.17	-	0.32	-	0.11	-	0.72
M_2	0.12	0.11	0.12	0.14	0.06	0.06	1.48	1.39
M_3	0.11	0.11	0.09	0.13	0.05	0.06	1.64	1.43
M_4	0.09	0.09	0.09	0.10	0.04	0.05	1.41	1.57
M_5	0.08	0.10	0.08	0.11	0.04	0.05	1.54	1.55
Mean	0.10	0,12	0.09	0.16	0.05	0.07	1.52	1.33

*Concentration of Mn, Zn and Cu is in mmol kg^{-1} X 10.

only OS was notably higher than with rest of the treatments but reverse was the trend for Ca, S and N. This may be attributed to dilution effect resulting from more growth and greater availability of nutrient elements from the use of FYM and gypsum. Concentration of all the elements except of Na, was considerably less in foliage collected from second than the first lopping although not remarkably in respect of K, Mg and P. Relative mean concentration of Na in foliage resulted on first (35.8 mmol kg^{-1}) and second (38.9 mmol kg^{-1}) lopping was lower than of K (354 and 333 mmol kg^{-1}), Ca (373 m and 256 mmol kg^{-1}) and Mg (246 m and 201 mmol kg^{-1}). The ratios of Na to K, Ca, K+Ca and Mg were very narrow and this highlights the ability of Acacia to maintain lower concentration of Na rendering it less toxic. This may be attributed to the selective absorption mechanism of the roots of Acacia plants growing in a highly sodic soil. Concentration of N was manyfolds more than P and S. This indicates that plants have established healthy symbiosis with Rhizobium sp. and are fixing atmospheric dinitrogen. Otherwise, such high concentration of N in a soil with very poor N supply seem difficult to explain. Among the micronutrients, concentration of Fe and Mn was more than of Zn followed by Cu. But their absolute values seemed normal in view of the achieved growth and figures reported elsewhere (Kanwar and Randhawa, 1978).

Effect of different mixtures having gypsum alone or its combination with FYM was not noticeable (Table 55) on the chemical composition of woody matter in respect of important nutrient elements. Unlike the foliage, concentration of nutrient elements in the woody matter yielded on first and second lopping showed only a marginal or no decrease. Absolute concentrations of these elements followed the

Table 55. Chemical composition (mmol kg^{-1}) of the woody matter of Acacia lopped after 16(a) and 42 (b) months of planting.

Filling mixture	Sodium		Potassium		Calcium		Magnesium	
	a	b	a	b	a	b	a	b
M_1	-	36.8	-	194	-	96	-	45.4
M_2	34.8	23.2	171	171	120	114	48.7	42.3
M_3	33.6	25.1	168	168	131	118	52.2	41.3
M_4	32.5	24.6	186	167	128	121	54.4	40.8
M_5	32.0	25.5	180	171	134	115	55.1	39.6
Mean	33.2	27.0	176	174	128	113	52.6	41.9

	Phosphorus		Sulphur		Nitrogen		Iron*	
	a	b	a	b	a	b	a	b
M_1	-	82.8	-	52.2	-	68.3	-	2.6
M_2	74.3	62.5	74.3	56.8	46.7	41.2	2.5	2.5
M_3	71.2	58.9	82.5	61.3	54.2	40.4	2.6	2.4
M_4	68.6	55.3	71.2	57.3	39.9	36.7	2.4	2.3
M_5	67.5	56.4	73.5	58.2	42.8	38.3	2.4	2.3
Mean	70.4	63.2	75.4	57.2	45.9	45.0	2.5	2.4

	Manganese*		Zinc*		Copper*		Na:Mg	
	a	b	a	b	a	b	a	b
M_1	-	2.6	-	2.2	-	1.1	-	0.81
M_2	2.6	2.5	2.2	2.0	1.0	0.9	0.71	0.55
M_3	2.7	2.6	2.4	2.1	1.0	0.9	0.64	0.61
M_4	2.7	2.6	2.3	2.1	0.9	1.0	0.73	0.60
M_5	2.7	2.6	2.3	2.1	1.1	1.2	0.71	0.64
Mean	2.7	2.6	2.3	2.1	1.0	1.0	0.70	0.64

	Na:K		Na:Ca		Na:K+Ca		Ca:Mg	
	a	b	a	b	a	b	a	b
M_1	-	0.19	-	0.38	-	0.13	-	2.13
M_2	0.20	0.14	0.29	0.20	0.12	0.08	2.48	2.71
M_3	0.20	0.15	0.26	0.21	0.11	0.09	2.51	2.86
M_4	0.17	0.15	0.25	0.20	0.10	0.09	2.36	2.97
M_5	0.18	0.15	0.24	0.22	0.10	0.09	2.44	2.93
Mean	0.19	0.16	0.26	0.24	0.11	0.10	2.45	2.72

*Concentration of Fe, Mn, Zn and Cu is in mmol kg^{-1} X 10.

trend observed in the case of the foliage except for Mg. Concentration of Mg in woody matter was much lower than of the foliage. It was only marginally more than of Na but considerably less than that of K and Ca in the woody matter. Ratios of Na to K, Ca and K+Ca for woody matter were only marginally wide than those for the foliage. But Na:Mg ratio for woody matter was 3-4 times wider than the same for foliage of Acacia due to relatively greater decrease in Mg concentration of the woody matter relative to that of Na. These observations again demonstrate tha ability of Acacia to avoid Na absorption and accumulation in plant parts. Concentration of micronutrients, K, Ca, Mg, P, S and N in the foliage were significantly higher than in the woody matter. But it was not so for Na whose concentration showed only a little change between the two components of biomass.

(b) Removal of Nutrients through Biomass: The removal of Na, K, Ca and Mg through the biomass lopped at two growth stages of Acacia plants in postholes refilled with mixtures containing both gypsum and FYM was significantly more than those having gypsum alone either 3 or 6 kg per posthole (Table 56). Amounts removed with lopping at 42 months stage were 2-3 times greater than that of 16 months after planting. Mean total removal of Na through biomass yielded from both the loppings (265 mol ha^{-1}) was much less than that of Mg (790 mol ha^{-1}) Ca (1483 mol ha^{-1}) and K (2251 mol ha^{-1}). Amount of Na removed through foliage was nearly the same for both of the biomass components. But amount of Mg removed through woody matter exceeded markedly that for the foliage. These differences may be ascribed to the changes in concentrations of these elements in the two components of the biomass and the biomass yield on lopping. These observations, thus, show

Table 56. Removal of Na, K, Ca and Mg (mol ha^{-1}) through biomass lopped after 16(a) and 42(b) months of planting Acacia.

Filling mixtures	Foliage			Woody matter			Total
	a	b	a+b	a	b	a+b	
				Sodium			
M_1	-	30.0	30.0	-	29	29	59
M_2	20.0	65.1	85.1	37.7	115	152	238
M_3	19.3	68.2	87.6	43.0	128	171	259
M_4	21.4	74.1	95.6	59.7	174	234	329
M_5	27.4	75.2	102.4	78.5	182	260	363
Mean	22.0	62.5	84.5	54.7	125	180	265
LSD(0.05)	2.8	5.7	8.1	14.7	40	44	50
				Potassium			
M_1	-	180	180	-	153	153	334
M_2	163	582	745	186	848	1034	1780
M_3	172	612	784	215	861	1077	1862
M_4	243	816	1059	342	1184	1527	2586
M_5	328	783	1111	443	1224	1667	2779
Mean	504	595	1099	297	854	1151	2251
LSD(0.05)	68	170	212	106	148	226	338
				Calcium			
M_1	-	95	95	-	76	76	171
M_2	173	507	680	130	569	700	1381
M_3	204	528	733	168	605	773	1507
M_4	273	654	927	236	859	1095	2023
M_5	327	646	974	330	829	1159	2134
Mean	235	486	722	216	587	761	1483
LSD(0.05)	40	92	148	60	146	173	226
				Magnesium			
M_1	-	131	131	-	35	35	167
M_2	117	363	481	52.7	209	262	743
M_3	124	370	495	66.9	211	278	774
M_4	167	416	584	99.9	289	389	973
M_5	212	418	630	135.2	283	418	1049
Mean	155	340	495	88.7	205	294	790
LSD(0.05)	30	38	46	24.6	41	68	92

that relative amounts of Na inplant system of Acacia are much lower than K, Ca and Mg known for their effect on suppressing toxic accumulation of Na. Therefore, it would appear that Acacia has a promise for greater recycling of Ca and Mg which are mostly deficient in sodic soils.

The removal of N, P and S through biomass lopped from Acacia trees in postholes refilled with OS was significantly less than those having mixtures (Table 57) including 3 (M_2) or 6 kg (M_3) gypsum alone. Use of gypsum at both the rates showed similar response but considerably less removal than the combined addition of gypsum and FYM with OS (M_4) or sand (M_5). Similar effect of different posthole mixtures was noticed on the removal of Fe, Mn, Zn and Cu through (Table 58) lopped biomass of Acacia. Mean removal of P (280 mol ha^{-1}) and S (258 mol ha^{-1}) through foliage yielded by both the loppings was almost equal. Removal of latter (416 mol ha^{-1}) was also on part of the former (410 mol ha^{-1}) through woody matter. This is due to similarity in concentration of P and S in both the components of biomass. Mean total removal of N (2697 mol ha^{-1}) was about four times more than that of P and S. But it was the foliage which accounted for more than 89 per cent of its mean total removal. Very high removals of N through foliage of Acacia, thus, indicate that the mechanism of symbiotic N fixation functioned normally under such extremely sodic soil conditions and will enrich them with N which is a major limitation for the normal growth of the plants. Among the micronutrients (Table 58), mean total removal of Fe (46270 mmol ha^{-1}) and Mn (6064 mmol ha^{-1}) was more than that of Zn (3721 mmol ha^{-1}) and Cu (1174 mmol ha^{-1}). But it was the foliage component which removed notably higher Fe, Mn, and Zn than the woody matter. However, removal of Cu through the woody

Table 57. Removal of P, S and N (mol ha^{-1}) through biomass lopped after 16(a) and 42(b) months of planting Acacia.

Filling	Foliage			Woody matter			Total
mixtures	a	b	a+b	a	b	a+b	
				Phosphorus			
M_1	-	71.0	71	-	65	65	136
M_2	64.6	213.4	278	80	309	389	667
M_3	66.4	214.7	281	91	301	392	673
M_4	91.9	241.6	333	126	391	517	851
M_5	121.3	229.3	350	165	403	569	919
Mean	86.0	194.0	280	115	294	410	690
LSD(0.05)	23.6	45.7	51	32	40	48	111
				Sulphur			
M_1	-	27.5	27	-	41	41	68
M_2	64.3	168	232	80	281	362	595
M_3	82.6	203	286	105	313	419	705
M_4	86.8	231	318	130	406	536	855
M_5	119.4	217	337	180	416	596	934
Mean	88.3	169	258	124	291	416	674
LSD(0.05)	21.6	41	52	38	58	80	123
				Nitrogen			
M_1	-	380	380	-	53	53	434
M_2	605	1680	2286	50.6	204	255	2541
M_3	672	1776	2449	69.4	206	276	2725
M_4	821	2157	2979	73.3	260	333	3313
M_5	1104	2113	3218	105.0	274	379	3597
Mean	801	1621	2423	74.6	199	274	2697
LSD(0.05)	136	210	276	30.1	48	72	352

Table 58. Removal of Fe, Mn, Zn and Cu (mmol ha^{-1}) through biomass lopped after 16(a) and 42(b) months of planting Acacia.

Filling mixtures	Foliage a	Foliage b	Foliage a+b	Woody matter a	Woody matter b	Woody matter a+b	Total
			Iron				
M_1	-	11376	11376	-	204	204	11581
M_2	10620	33378	43998	271	1241	1512	45510
M_3	10982	32275	43257	333	1228	1562	44819
M_4	16088	35857	51946	441	1629	2070	54016
M_5	21549	36419	57968	589	1645	2234	60203
Mean	14810	29861	44671	408	1189	1598	46270
LSD(0.05)	3816	5136	6444	88	240	314	7004
			Manganese				
M_1	-	1171	1171	-	204	204	1375
M_2	1076	2971	4047	281	1241	1522	5570
M_3	1103	2912	4016	345	1331	1677	5693
M_4	1582	3733	5315	496	1842	2338	7654
M_5	2058	3546	5604	666	1860	2526	8131
Mean	1455	2866	4322	446	1295	1742	6064
LSD(0.05)	414	468	612	112	268	362	684
			Zinc				
M_1	-	659	659	-	173	173	833
M_2	547	1577	2124	238	992	1231	3356
M_3	570	1613	2184	307	1075	1382	3566
M_4	739	2013	2752	422	1488	1910	4663
M_5	1007	2012	3020	564	1502	2066	5087
Mean	716	1575	2291	383	1046	1429	3721
LSD(0.05)	186	238	368	106	196	304	382
			Copper				
M_1	-	105	105	-	86	86	191
M_2	122	330	452	108	446	555	1008
M_3	132	354	486	128	460	589	1075
M_4	163	466	630	165	708	874	1504
M_5	210	431	641	270	858	1128	1770
Mean	157	337	494	168	512	680	1174
LSD(0.05)	30	60	82	36	112	165	218

matter was more than the foliage. It clearly brings out that use of foliage of Acacia as a forage or litter may serve an enriched biomass with high nutrient recycling efficiency in ecosystems and the soils under agroforestry systems respectively.

E. Biomass Production Underneath the Tree Canopies: Data (Table 59) on biomass production of natural growth of vegetation tolerant to the high soil sodicity underneath the canopies of Eucalyptus and Acacia showed that effect of different posthole filling mixtures was not reflected on biomass yield during all the three years of observations. But there were significant differences on yields under the two canopies in each of the three years. Biomass yields underneath Acacia trees in all the plots were more than double the same under the cover of Eucalyptus plantation in 1982. But during 1983 and 1984, biomass yields were significantly more in Eucalyptus than in Acacia plantation. Average biomass production in 1982 and 1983 irrespect of tree species was nearly similar but significantly more than in 1984. The observed significant differences in biomass yields of the underneath vegetation between Eucalyptus and Acacia plantations showed relationship with the agrometeorological conditions that prevailed during the observational years. In the relatively dry season (1982) when monsoon rains were inadequate, biomass yields underneath Acacia canopy were more, possibly due to greater availability of soil moisture as shade of its canopy and litter fall on the soil surface served as a mulch which checked the losses of moisture from soil through evapotranspiration. But during wet years (1983 and 1984), yields were more for Eucalyptus plantation whose open canopy allowed greater insolation. Thus, when soil moisture supply is not a limitation, the availability of solar radiation may affect the biomass productivity through its effect on

Table 59. Average biomass (oven dry) yield (kg ha^{-1}) of naturally grown up vegetation under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex. Del.

Year	Cancpy	Posthole filling mixtures					Mean	LSD (0.05)
		M_1	M_2	M_3	M_4	M_5		
1982	Eucalyptus	3098	3092	2498	3144	3106	2988	NS
1982	Acacia	6802	6330	6145	8063	5975	6463	NS
	Mean	4950	4711	6322	5104	4541	5126	NS
1983	Eucalyptus	6974	6556	5318	7312	6440	6521	NS
1983	Acacia	4946	4862	3734	4822	4262	4525	NS
	Mean	5960	5709	4526	6067	5353	5523	NS
1984	Eucalyptus	4615	3520	4440	3810	4110	4099	NS
	Acacia	3033	2305	2135	2515	2450	2488	NS
	Mean	3824	2913	3288	3163	3280	3294	NS

LSD (0.05)	Mean	1982	1983	1984	
	Cancpies	736	865	1012	
	Interaction	1084	1164	1138	
	Years	-	-	-	1096

photosynthetic processes of the vegetation underneath the Eucalyptus and Acacia canopies. Observations thereby prompt to conclude that under relatively arid or dry conditions Acacia may favour higher productivity of vegetation under its canopy.

Results on the concentration of Na, K, Ca and Mg in biomass harvested from underneath covers of Acacia and Eucalyptus plantations (Table 60) and their removals (Table 61) in the given years did not differ significantly among different posthole filling mixtures. Mean concentration of Na during 1982-84 varies between 336 - 453 and 303 - 419 mmol kg^{-1} for the biomass yielded under Eucalyptus and Acacia canopies respectively. Concentration of Na in all of the years was significantly higher than of K followed by Mg and Ca in the descending order. The absolute concentration of Ca and Mg showed little variation for biomass yield of the two canopies. The concentration of Mg showed a decrease with years. This was not so for Ca. Similarly, the Na and K contents decreased with years of biomass harvest. But absolute values of Na were relatively higher for biomass yields of 1982 and 1984 underneath Eucalyptus than under Acacia. Potassium and Mg concentration of biomass harvested in 1984 from under Acacia was more than under Eucalyptus plantation. These differences may be due to the dilution effect because of the extent of growth and varying availability and absorption of these elements in the soil. Removal of Na exceeded greatly that of K, Mg and Ca in all the years. The removal of the given elements (Table 61) in 1982 was considerably less through the underneath biomass production from Eucalyptus than from Acacia plantation. But during 1983 and 1984 the trend was reversed. These changes were more due to variation in the biomass yield during different years rather than the differences in concentration of nutrient elements in

Table 60. Average concentration (mmol kg^{-1}) of Na, K, Ca and Mg in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd.ex. Del.

Filling mixtures	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Sodium				
M_1	452	368	332	384	412	384	292	363
M_2	444	379	346	390	422	368	316	369
M_3	482	396	326	401	426	412	298	379
M_4	440	355	340	378	433	356	301	363
M_5	446	372	336	385	401	362	310	358
Mean	453	374	336	388	419	377	303	366
				Potassium				
M_1	224	188	171	194	246	233	180	220
M_2	232	196	162	197	238	226	168	211
M_3	246	218	175	213	242	244	182	223
M_4	230	179	166	192	231	236	176	214
M_5	218	206	171	199	252	230	170	217
Mean	230	197	169	199	242	234	175	217
				Calcium				
M_1	67.7	61.8	68.9	66.1	68.3	65.8	60.9	65.0
M_2	71.5	65.7	70.1	69.1	62.8	64.7	71.6	66.4
M_3	66.9	62.3	64.5	64.6	70.6	68.0	70.1	69.6
M_4	74.3	68.2	66.7	69.7	66.4	68.8	70.9	68.7
M_5	64.4	62.0	64.4	63.6	72.1	68.2	72.6	71.0
Mean	69.0	64.0	66.9	66.6	68.0	67.1	69.2	68.1
				Magnesium				
M_1	184	148	128	153	184	162	121	156
M_2	196	146	124	155	192	160	128	160
M_3	182	138	118	146	188	175	132	165
M_4	188	142	126	152	180	164	124	156
M_5	192	145	124	154	196	168	126	163
Mean	189	144	124	152	188	166	126	160

Table 61. Average removal (mol ha^{-1}) of Na, K, Ca and Mg through biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Posthole filling mixtures	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Sodium				
M_1	1402	2571	1533	5506	2807	1901	886	5596
M_2	1375	2485	1220	5081	2673	1793	730	5197
M_3	1204	2107	1449	4761	2620	1541	636	4797
M_4	1384	2599	1298	5281	3059	1719	758	5537
M_5	1386	2396	1384	5167	2400	1544	760	4704
Mean	1350	2432	1377	5159	2712	1700	754	5166
				Potassium				
M_1	696	1313	790	2799	1676	1154	547	3378
M_2	719	1286	573	2579	1508	1102	389	3000
M_3	614	1159	777	2552	1487	838	389	2715
M_4	725	1315	618	2659	1637	1140	443	3221
M_5	679	1331	703	2715	1507	982	418	2908
Mean	687	1281	692	2661	1563	1043	437	3044
				Calcium				
M_1	209	431	318	958	464	325	184	947
M_2	221	430	246	898	397	314	165	877
M_3	167	331	286	784	433	253	149	837
M_4	233	498	247	979	469	331	178	979
M_5	200	399	264	864	430	290	177	899
Mean	206	418	272	897	439	303	171	913
				Magnesium				
M_1	571	1037	592	2200	1257	804	368	2430
M_2	608	958	438	2005	1219	779	297	2296
M_3	456	738	527	1722	1157	654	282	2094
M_4	592	1041	470	2103	1274	792	313	2380
M_5	597	939	511	2048	1175	719	309	2204
Mean	565	942	508	2016	1216	750	314	2281

the biomass harvested from both the plantations. These observations clearly show that the concentration of Na and its removal through biomass yield of the underneath vegetation exceeded that of K, Ca and Mg. But this was not so for the biomass of Acacia lopped and reported earlier.

The concentration of P, S and N showed no change among the biomass yield obtained from plots under Acacia and Eucalyptus trees planted in postholes refilled with different mixtures during 1982-1984 (Table 62). The relative concentration of P was only marginally more than of S in the underneath biomass and both the elements showed a decline in their mean concentration with growth years. The mean concentration of N was more than of P and S by about three times. The biomass yields of Acacia showed an increase in accumulation of N with growth years. But opposite was the trend in case of Eucalyptus. This demonstrate greater N availability in the soil underneath Acacia than under Eucalyptus canopy and may be ascribed to the addition of N through the leaf litter rich in the said nutrient. Mean removals of P, S and N (Table 63) were higher in 1982 through the biomass produced from underneath Acacia than from underneath Eucalyptus plantation. But their removals except that of N were more in case of Eucalyptus in 1983 and 1984. The average N removal through biomass harvested from plots under Acacia was more than from Eucalyptus plantation in 1983 and 1984 despite the high yields of biomass reaped in case of the latter species. This is because of significantly higher accumulation of N in the biomass produced under the canopy of Acacia.

Among the micronutrients, average concentration of Fe in each of the years was higher than that of Mn, Zn and Cu in descending order (Table 64). Their average concentration showed considerable decrease

Table 62. Average concentration (mmol kg^{-1}) of P, S and N in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Filling mixtures	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Phosphorus				
M_1	96.5	81.5	70.9	83.0	94.9	84.9	76.2	85.3
M_2	91.4	78.3	66.4	78.7	96.7	80.7	72.9	83.4
M_3	98.3	72.9	64.7	78.6	92.8	82.6	78.2	84.5
M_4	92.5	80.4	66.2	79.7	94.7	82.0	76.2	84.3
M_5	94.8	86.2	68.5	83.2	94.7	83.3	74.3	84.1
Mean	94.7	79.9	67.3	80.6	94.8	82.7	75.6	84.3
				Sulphur				
M_1	83.6	73.7	66.7	74.6	82.7	73.6	67.8	74.7
M_2	81.9	74.2	64.8	73.6	85.2	71.7	72.3	76.4
M_3	85.7	70.8	62.5	73.0	83.1	70.4	66.7	73.4
M_4	80.5	69.2	63.7	71.2	81.9	75.3	68.2	75.1
M_5	84.6	71.3	60.8	72.2	83.8	70.9	66.4	73.7
Mean	83.3	71.8	63.7	72.9	83.3	72.4	68.3	74.7
				Nitrogen				
M_1	274	230	204	236	316	384	416	372
M_2	280	238	195	238	308	388	427	374
M_3	272	222	202	232	326	374	423	375
M_4	276	242	194	237	312	379	431	374
M_5	282	236	206	242	302	385	436	374
Mean	277	234	200	237	313	382	427	374

Table 63. Average removal (mol ha^{-1}) of P, S and N through biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Posthole filling mixtures	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Phosphorus				
M_1	299	568	327	1194	645	419	231	1296
M_2	282	513	233	1029	612	392	168	1172
M_3	245	387	287	920	570	308	167	1045
M_4	290	587	252	1130	668	395	191	1255
M_5	294	555	281	1131	565	355	182	1102
Mean	282	522	276	1081	612	374	188	1174
				Sulphur				
M_1	259	514	307	1081	562	364	205	1132
M_2	253	486	228	967	539	348	166	1054
M_3	214	376	277	868	510	262	142	915
M_4	254	506	242	1002	578	363	171	1113
M_5	262	459	249	971	500	302	162	965
Mean	248	468	261	978	538	328	169	1036
				Nitrogen				
M_1	851	1605	944	3401	2154	1902	1263	5320
M_2	866	1566	687	3120	1950	1887	984	4823
M_3	680	1182	900	2763	2007	1398	904	4311
M_4	868	1771	741	3382	2204	1616	1086	4906
M_5	877	1524	849	3251	1809	1643	1068	4521
Mean	828	1530	824	3183	2025	1689	1061	4776

with growth years. But variation in the absolute concentration of each was not as marked as that of other elements due to the differences in biomass yields of the three years for Acacia and Eucalyptus plantations. Effect of posthole filling mixtures on the concentration of micronutrients (Table 64) and their removals (Table 65) through the biomass yields of 1982-84 was not noticeable. Like other elements, removals of micronutrients were more in case of Acacia than Eucalyptus plantation in 1982 only owing to high biomass production in this year.

The data on biomass productivity resulted from underneath growth of grasses indicate that nature of the canopy (open or close) is more important in affecting the yield than the planting of tree species in postholes refilled with different mixtures. Effect of these mixtures was significant to cause marked changes in the growth of Eucalyptus and Acacia but influence of their differential growth was not reflected on the underneath growth of vegetation. The natural growth of vegetation was also significantly affected by the distribution and the amount of rainfall in a year. Similarly, chemical composition of biomass obtained on lopping of Acacia and the vegetation under its canopy showed marked differences. These observations show that growth of trees and natural vegetation together do not compete for nutrition but are complementary to each other. Grasses may feed upon the surface layers and will effect considerable improvement in physico-chemical properties. Considerable greater removal of Na comparable to K, Ca and Mg will definitely bring appreciable reduction in its concentration in the soil solution and nature of equilibrium consequently, there may occur a notable decrease in ESP of the soil with time. But tree species with deep root system feed upon the deeper layers and produce leaf litter to enrich the surface soil with

Table 64. Average concentration (mmol kg^{-1}) of Fe, Mn, Zn and Cu in biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Filling mixture	Eucalyptus				Acacia			
	1982	1983	1984	Mean	1982	1983	1984	Mean
				Iron				
M_1	10.9	7.5	6.8	8.4	11.6	9.5	8.1	9.7
M_2	11.3	7.4	5.9	8.2	10.7	8.9	7.6	9.1
M_3	10.8	8.5	6.2	8.5	9.9	9.1	8.8	9.3
M_4	11.5	7.9	5.7	8.4	10.9	8.1	7.9	9.0
M_5	11.0	8.1	6.3	8.5	11.6	9.2	8.4	9.7
Mean	11.1	7.9	6.2	8.4	11.0	9.0	8.1	9.4
				Manganese				
M_1	2.36	2.72	2.16	2.41	2.16	2.84	2.44	2.48
M_2	2.27	2.22	2.28	2.26	1.85	2.72	2.26	2.28
M_3	2.46	2.36	2.56	2.46	1.98	2.80	2.30	2.36
M_4	2.08	2.54	2.14	2.25	2.04	2.68	2.44	2.39
M_5	2.17	2.38	2.28	2.28	2.12	2.70	2.30	2.37
Mean	2.27	2.44	2.28	2.33	2.03	2.75	2.35	2.38
				Zinc				
M_1	0.40	0.32	0.24	0.32	0.34	0.26	0.22	0.27
M_2	0.36	0.28	0.20	0.28	0.30	0.28	0.20	0.26
M_3	0.38	0.30	0.24	0.31	0.32	0.30	0.22	0.28
M_4	0.34	0.32	0.22	0.29	0.34	0.30	0.12	0.27
M_5	0.34	0.30	0.22	0.29	0.30	0.30	0.20	0.27
Mean	0.36	0.30	0.22	0.29	0.32	0.29	0.20	0.27
				Copper				
M_1	0.18	0.12	0.09	0.13	0.18	0.12	0.09	0.13
M_2	0.18	0.10	0.08	0.12	0.18	0.13	0.11	0.14
M_3	0.14	0.12	0.09	0.12	0.17	0.13	0.10	0.13
M_4	0.16	0.10	0.09	0.12	0.19	0.14	0.10	0.14
M_5	0.16	0.12	0.09	0.12	0.18	0.14	0.09	0.14
Mean	0.16	0.11	0.09	0.12	0.18	0.13	0.10	0.14

Table 65. Average removal (mol ha^{-1}) of Fe, Mn, Zn and Cu through biomass harvested from under the canopies of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del.

Posthole filling mixtures	Eucalyptus				Acacia			
	1982	1983	1984	Total	1982	1983	1984	Total
				Iron				
M_1	33.8	52.5	31.6	118.0	79.4	47.1	24.6	151.2
M_2	35.1	49.0	20.9	105.0	68.1	43.6	17.6	129.3
M_3	27.0	45.5	27.7	100.3	61.2	34.2	18.7	114.2
M_4	36.3	58.0	21.8	116.2	77.4	39.4	19.9	136.8
M_5	34.4	52.5	26.2	113.1	69.6	39.3	20.7	129.7
Mean	33.3	51.5	25.6	110.5	71.1	40.7	20.3	133.2
				Manganese				
M_1	7.31	18.9	9.97	36.2	14.6	14.0	7.4	36.1
M_2	7.02	14.5	8.03	29.6	11.7	13.2	5.2	30.1
M_3	6.15	12.5	11.37	30.0	12.1	10.4	4.9	27.5
M_4	6.54	18.5	8.15	33.2	14.4	12.9	6.1	33.4
M_5	6.74	15.3	9.37	31.4	12.6	11.5	5.6	29.8
Mean	6.75	15.9	9.38	32.1	13.1	12.4	5.8	31.4
				Zinc				
M_1	1.24	2.23	1.11	4.58	2.31	1.29	0.67	4.27
M_2	1.11	1.84	0.70	3.65	1.90	1.36	0.46	3.72
M_3	0.95	1.60	1.07	3.62	1.97	1.12	0.47	3.56
M_4	1.07	2.34	0.84	4.25	2.40	1.45	0.45	4.30
M_5	1.06	1.93	0.90	3.89	1.79	1.28	0.49	3.56
Mean	1.09	1.99	0.92	4.00	2.07	1.30	0.51	3.88
				Copper				
M_1	0.56	0.84	0.42	1.82	1.22	0.59	0.27	2.08
M_2	0.56	0.66	0.28	1.50	1.14	0.63	0.25	2.02
M_3	0.35	0.64	0.40	1.39	1.04	0.49	0.21	1.74
M_4	0.50	0.73	0.34	1.57	1.34	0.68	0.25	2.27
M_5	0.50	0.77	0.37	1.64	1.08	0.60	0.22	1.90
Mean	0.49	0.73	0.36	1.58	1.17	0.60	0.24	2.01

nutrients. Litter also reduced moisture loss through evaporation. Its decomposition released organic compounds that improved soil structure and the nutrients status resulting im improved soil fertility which in turn facilitated more growth of grasses. Their combination, thus, resulted in a two storey system that enhanced both the biological activity and productivity of a highly deteriorated sodic soil. This would cause biological reclamation of the soil besides generation of additional biomass energy for multifarious purposes.

4.4 Evaluation of Casuarina equisetifolia L. for its Tolerance to a Highly Sodic soil.

Introduction: Because of the variety and specialized nature of the problems of highly sodic soils any sizeable afforestation project must be based on findings of the research trials carried out on the site to be restored. The first step is to identify which species will grow. However, choice will vary with the purposes of plantation, soil and agroclimatic conditions and growth habits of different species. But only two generalizations could be made; (a) only species which are naturally pioneers of impeverished sites merit inclusion in a trial, and (b) trees possessing N-fixing ability should be preferred. In view of these considerations and unsatisfactory observed performance of Eucalyptus tereticornis Sm., Casuarina equisetifolia L. was selected for investigation of its tolerance to a highly sodic soil conditions.

Casuarina equisetifolia L., a synomym of C. littoralis Salisb., is known for yielding best quality firewood in the world. It is a fast growing tree with an average height varying between 15-25 m, however, maximum attainable height and girth is reported (NAS, 1980) as great as 50 m and 100 cm respectively. Root nodules of this species possess N-fixing actinomyceter (Frankia) and capability of adaptation to diverse soil types and agro-climates. Australian beefwood tree, Bull-oak, Forest-oak, Swamp-oak, Horse tail tree, She-oak, Australian pine, Iron wood, Jor-tor and whistling pine (because of sound it generates in the blowing wind) are its other common names. In India, it is the most commonly growing and popular tree of the coastal areas. There are experimental evidences in its favour to tolerate considerably high salinity status of the soils. But there is no documented research report pertaining to its evaluation for sodic soils. Therefore, this experiment was carried out.

Methodology: To evaluate Casuarina for its tolerance to a highly sodic soil, a field experiment was conducted for investigating its growth response when planted in deep postholes refilled with (a) original sodic soil (OS) M_1; (b) OS mixed with 8 kg FYM posthole^{-1}, M_2; (c) OS mixed with 2 kg gyp~~f~~sum posthole^{-1}, M_3; and (d) OS mixed with 8 kg FYM and 2 kg gypfum posthole^{-1}, M_4. Postholes were dug out using a mechanical and manually operated soil augers. The upper portion (25 cm dia. X 0-80 cm depth) was dug out with a tractor operated auger and was deepened with a manually operated 15 cm dia. soil augers to 180 cm depth. Experiment was replicated twelve times within the purview of randomized block design. Saplings were planted on July 1, 1983 and watered for six months past planting on need felt basis (or when IW/PE reached = 1.0) to aid their establishment and naturalization.

Observations on per cent survival and growth parameters (maximum height, DSH and DBH) were recorded monthly during the first year and quarterly afterwards. Foliage (needles) samples were collected at different growth stages from all the plants and were analyzed for Na, K, Ca, Mg, P, S, N, Fe, Mn, Zn and Cu. Position of sampled foliage was kept uniform for all plants irrespect of the composition of posthole filling mixtures. Samples were taken from terminal or apical branch leaving newly developed or juvenile vegetation as well as the older on lower side so that each sample represents fully developed foliage. From the same position, needles (foliage) were sampled at specified growth stages for estimating the effect of watering and growth during summer and winter seasons on the relative turgidity of the foliage of Casuarina plants growing in postholes refilled with the said mixtures. Time of sampling at all the selected growth stages was same (1200 hours, noon).

Results and Discussion

A. Per Cent Survival: Periodic per cent survival of Casuarina saplings planted in postholes refilled with the said four mixtures exhibited high relative tolerance to a highly sodic soil (Appendix-I). There occurred no mortality in postholes having either gypsum alone or its combination with FYM. Per cent survival in postholes having only OS decreased to 92, 84, 75 and 67 at 15, 18, 21 and 24 months past planting respectively. But there was no further decline between 24-39 months of the growth period. Mixing of FYM with OS caused a significant reduction in mortality than using the only OS, however, it was inferior to the use of either gypsum alone or its combination with FYM. Per cent survival was complete until 15 months of planting Casuarina in postholes refilled with FYM mixed OS. But a decrease to 92 and then 84 per cent during 18–27 and 30–39 months of growth period was recorded. These observations in comparison to data on other species namely *Acacia nilotica* (L.) Willd. ex. Del., *Eucalyptus tereticornis* Sm., *Albizia lebbec* (L.) Benth, *Azadirachta indica* Juss. and *Syzycium fructicosum* Dc. clearly prove that *Casuarina equisetifolia* L. is a highly tolerant to extremely sodic conditions of the soil.

B. Height Growth: Data (Appendix II) on height growth recorded at 22 stages during 39 months growth period showed that the difference in composition of posthole filling mixtures effected significant differences in average height of the plants. Application of 2 kg gypsum in combination with 8 kg FYM posthole^{-1} yielded the highest height response followed by gypsum alone (Plate 5). Mixing of only FYM with the CS resulted in significant increase in the height than the control (M_1) but it was markedly inferior to the addition of gypsum either alone or in combination with FYM (Fig. 18). The observed height growth pattern also showed periodicity. Height growth was noted to be relatively fast during the summer (April – Oct.) than the winter season (Nov. – March). This may be attributed to the sensitivity of Casuarina to cold agroclimate. The per cent increase in height due to application of 8 kg FYM, or 2kg gypsum or 2 kg gypsum plus 8 kg FYM posthole^{-1} over the control (CS) was computed to be 54, 94 and 103 per cent at 12 months, 52, 91 and 97 per cent at 24 months and 110, 144 and 154 per cent at 36 months growth stages respectively. These findings, thus, showed that mixing of 2 kg of gypsum and 8 kg FYM or 2 kg gypsum alone with the CS to refill postholes for raising a bumper Casuarina plantation (Plate 6) in such an extremely sodic conditions suits the most. Cumulative mean monthly height increments to the

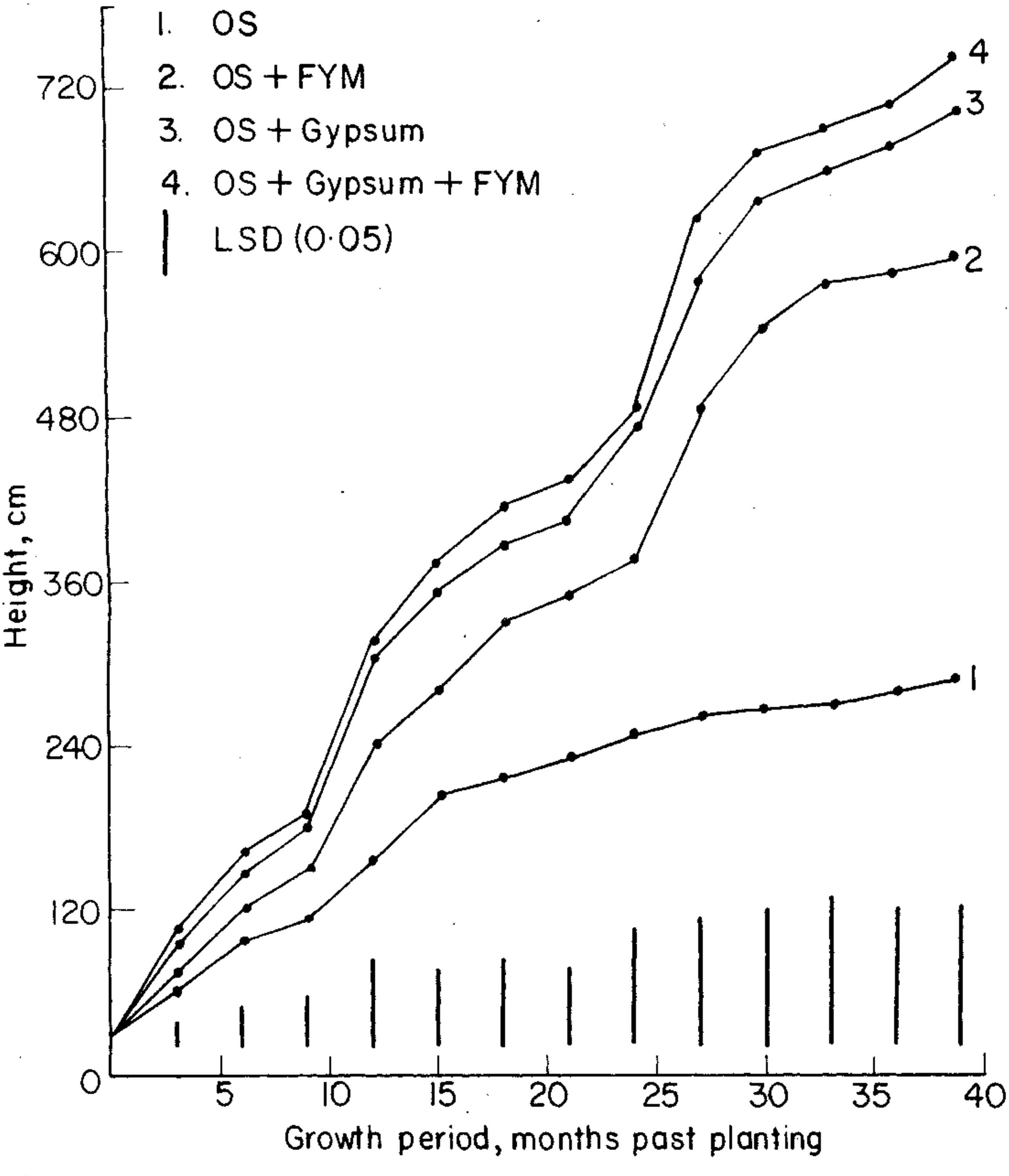


Fig. 18. Height growth response of <u>Casuarina equisetifolia</u> L. to selected posthole filling mixtures in a highly sodic soil.

Plate 5

Different posthole filling mixtures make a difference in growth of Casuarina equisetifolia L. (15 months old).

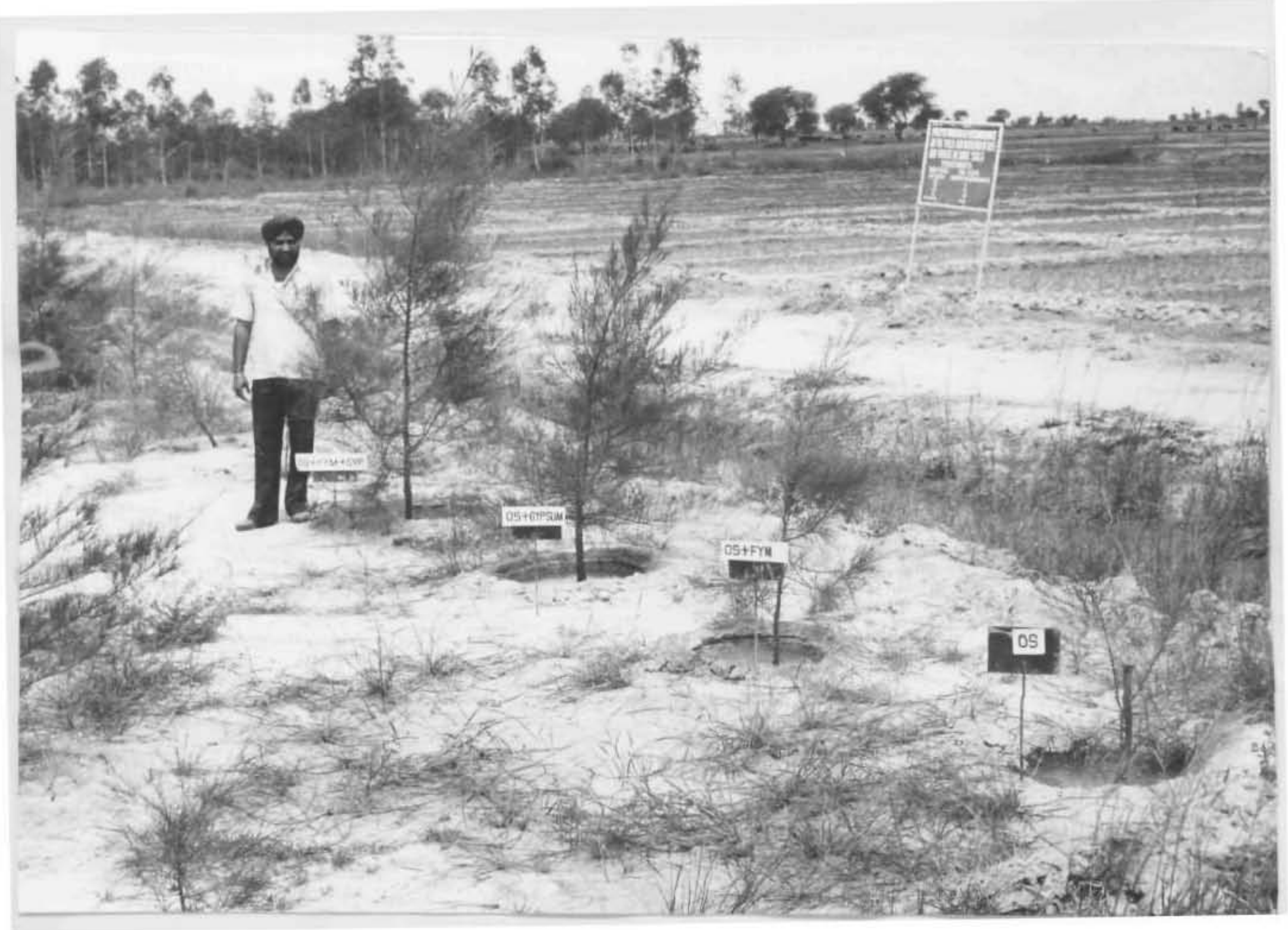

OS+FYM+GYP
OS+GYPSUM
OS+FYM
OS

Plate 6

A bumper growth of Casuarina plantation (3 years old) in a highly sodic soil proves its promise for sodic soils.

An inside view of Casuarina canopy producing greater amounts of the litter.

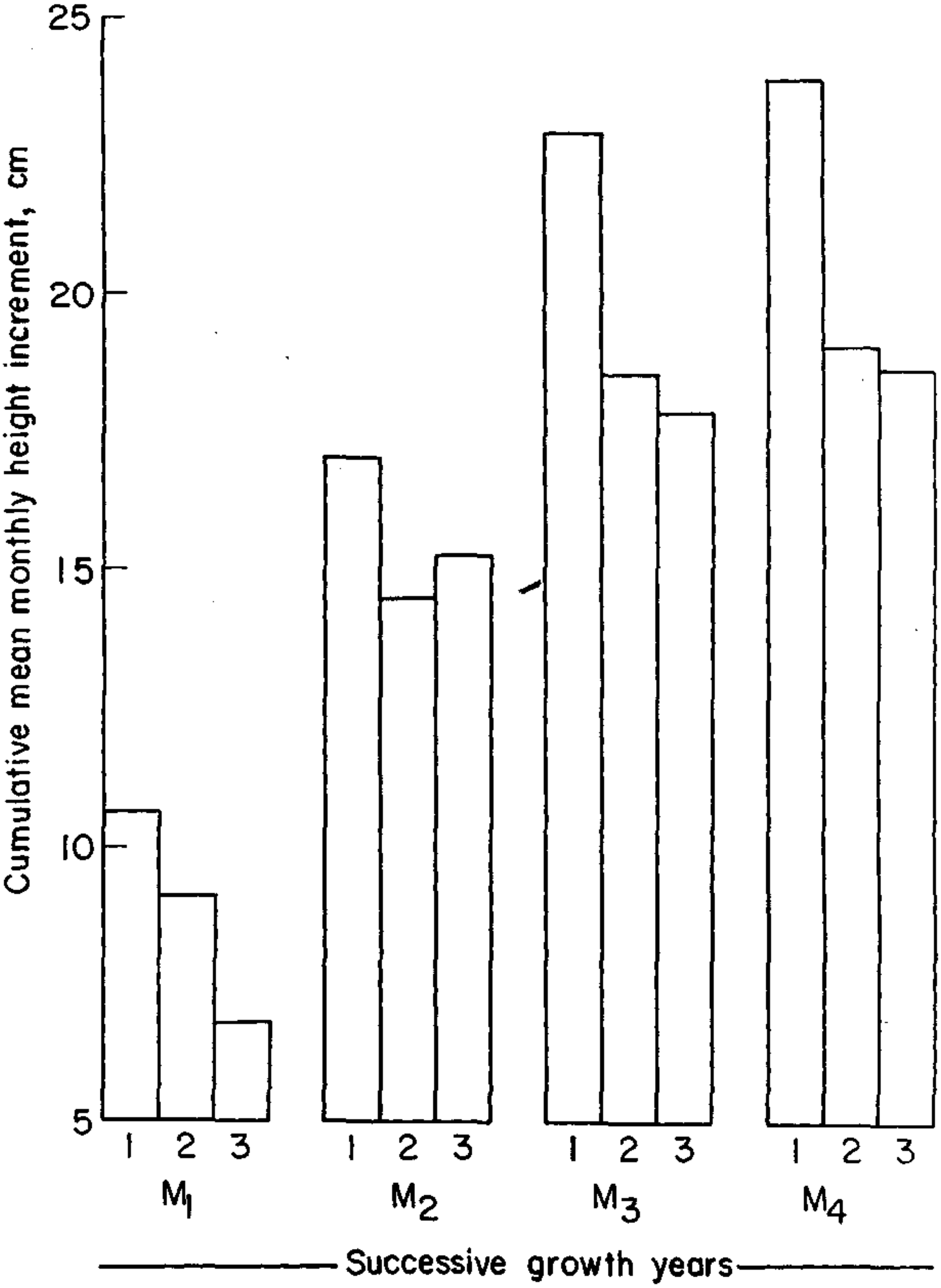


Fig. 19. Effect of selected posthole filling mixtures on mean monthly (cumulative) height increment of Casuarina during successive growth years.

average height of Casuarina during successive growth years (Fig.19) again indicated a similar trend. Magnitude of mean monthly increments in the first year was remarkably greater than in the second and the third year. In each year, mean increment was the highest for postholes refilled with gypsum plus FYM and gypsum alone with no significant difference between the two mixtures. Those having only FYM effected notably greater increments than the OS but differences among the three years were less marked than rest of the treatments. Thus, better growth response of Casuarina in postholes refilled with the OS mixed with amendments like FYM and gypsum than OS alone may be attributed to the amelioration of physico-chemical properties of the limited root zone of highly sodic soil to the desired extent. Gypsum is reported to modify the soil sodicity (Abrol, 1982) to the benefit of economical plant growth.

C. <u>Girth Growth</u>: The effect of given four posthole filling mixtures on the periodic girth growth indices, namely DSH (Table 66) and DBH (Table 67), showed that application of gypsum alone or its combination with FYM were on par. But both of the mixtures were significantly superior to the mixing of FYM alone and the OS in descending order at all the noted stages throughout the growth period of 39 months after planting. The per cent increase in DSH due to the application of 2 kg gypsum in conjunction with 8 kg FYM (M_4) or 2 kg gypfum (M_3) or 8 kg FYM per posthole^{-1} over the use of only OS was 88, 93 and 45 per cent at 12 months, 126,123 and 75 per cent at 24 months and 154, 144 and 89 per cent at 36 months growth stages respectively. The respective per cent increase in DBH was 511, 256 and 185 per cent at 12 months, 254, 215 and 156 per cent at 24 months and 195, 152 and 78 per cent at 36 months growth stages. These figures, thus, clearly show the greater

Table 66. Effect of selected posthole filling mixtures on the periodic DSH* (mm) of *Casuarina equisetifolia* L. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures				Mean	LSD (0.05)
	M_1	M_2	M_3	M_4		
0	2.5	2.5	2.5	2.6	2.5	NS
1	2.6	2.8	3.1	3.0	2.8	NS
2	4.3	6.8	8.5	8.2	7.0	1.4
3	7.2	10.5	15.8	15.6	12.3	2.2
4	10.2	12.7	18.3	17.9	14.8	2.4
5	12.5	16.0	20.2	19.2	17.0	3.7
6	13.2	17.2	21.3	21.0	18.2	3.6
7	15.0	18.9	23.2	22.4	20.1	3.5
8	16.0	21.3	25.2	25.0	21.9	4.1
9	17.1	23.4	28.4	27.4	24.1	5.2
10	19.2	26.8	34.9	34.7	28.9	5.3
11	20.4	28.2	37.8	37.4	33.5	5.0
12	21.6	31.4	41.7	40.6	33.8	4.6
15	28.1	42.4	65.6	54.0	45.0	8.5
18	29.2	45.6	60.2	59.8	48.7	10.1
21	31.3	54.6	71.9	72.3	57.5	10.6
24	34.4	60.2	76.8	77.8	62.3	11.2
27	34.8	63.8	80.8	84.4	66.0	25.0
30	36.3	68.4	83.2	86.2	68.5	14.2
33	37.2	69.2	87.4	89.6	70.9	16.3
36	37.7	71.1	92.1	95.7	74.1	17.7
39	38.3	74.4	96.8	104.6	78.5	19.3

*DSH stands for girth diameter at stump height (5 cm).

Table 67. Effect of selected posthole filling mixtures on the periodic DMH* of *Casuarina equisetifolia* L. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures				Mean	LSD (0.05)
	M_1	M_2	M_3	M_4		
9	1.8	4.2	6.2	6.0	4.6	1.1
10	2.0	5.1	7.8	7.7	5.7	1.4
11	2.4	6.8	8.4	8.5	6.5	2.0
12	2.7	7.7	9.6	13.8	8.5	3.5
15	5.5	13.3	18.2	25.1	15.5	6.0
18	6.0	21.2	31.3	30.8	22.3	6.2
21	9.2	29.4	40.3	40.6	29.9	5.9
24	14.9	38.2	47.0	52.8	38.2	6.2
27	16.3	38.8	51.3	55.7	40.5	7.1
30	17.3	39.0	52.4	56.9	41.4	8.8
33	19.8	39.3	55.8	61.8	44.2	12.3
36	22.7	40.3	57.2	66.9	48.5	16.1
39	23.1	42.4	62.8	72.8	50.3	16.7

girth growth response of Casuarina in postholes refilled with mixture comprising combination of gypsum and FYM with the OS. Use of gypsum alone was marginally inferior than its combination with FYM. But girth growth with addition of gypsum was significantly faster than the use of FYM alone. The girth growth rate was maximum in postholes refilled with the OS only. This trend was also reflected in the mean monthly (cumulative) DSH increments during the successive growth years after planting (Fig. 20). But unlike height growth, the magnitude of increments to DSH during the initial two years did show little variation for the postholes containing OS mixed with either FYM (M_2) or gypsum (M_3) or both (M_4). However, value of mean monthly increment for the third growth year showed a decline in these treatments without any appreciable change in the response trend. But mean monthly increments to the DSH growth in postholes refilled with only the OS indicated decrease with each of the successive growth years. This implies that application of amendments caused considerable boost in the growth of plants which in turn may increase their tolerance to the extremely sodic conditions of the soil.

The height and girth growth data in comparison to the reports of NAS (1980) show that growth and survival of Casuarina is satisfactory. Plants at 39 months growth stage were lush green and had developed a closed canopy at a spacing of 3 m between rows and 2 m between the plants (Plate 6). Its canopy was producing considerable litter which in turn will cause nutrient recycling, amelioration and microclimate modifications for the benefit of greater biomass productivity. Considering its relatively fast growth, superior fuelwood value, ability to fix atmospheric dinitrogen in symbiosis with an actinomycetes

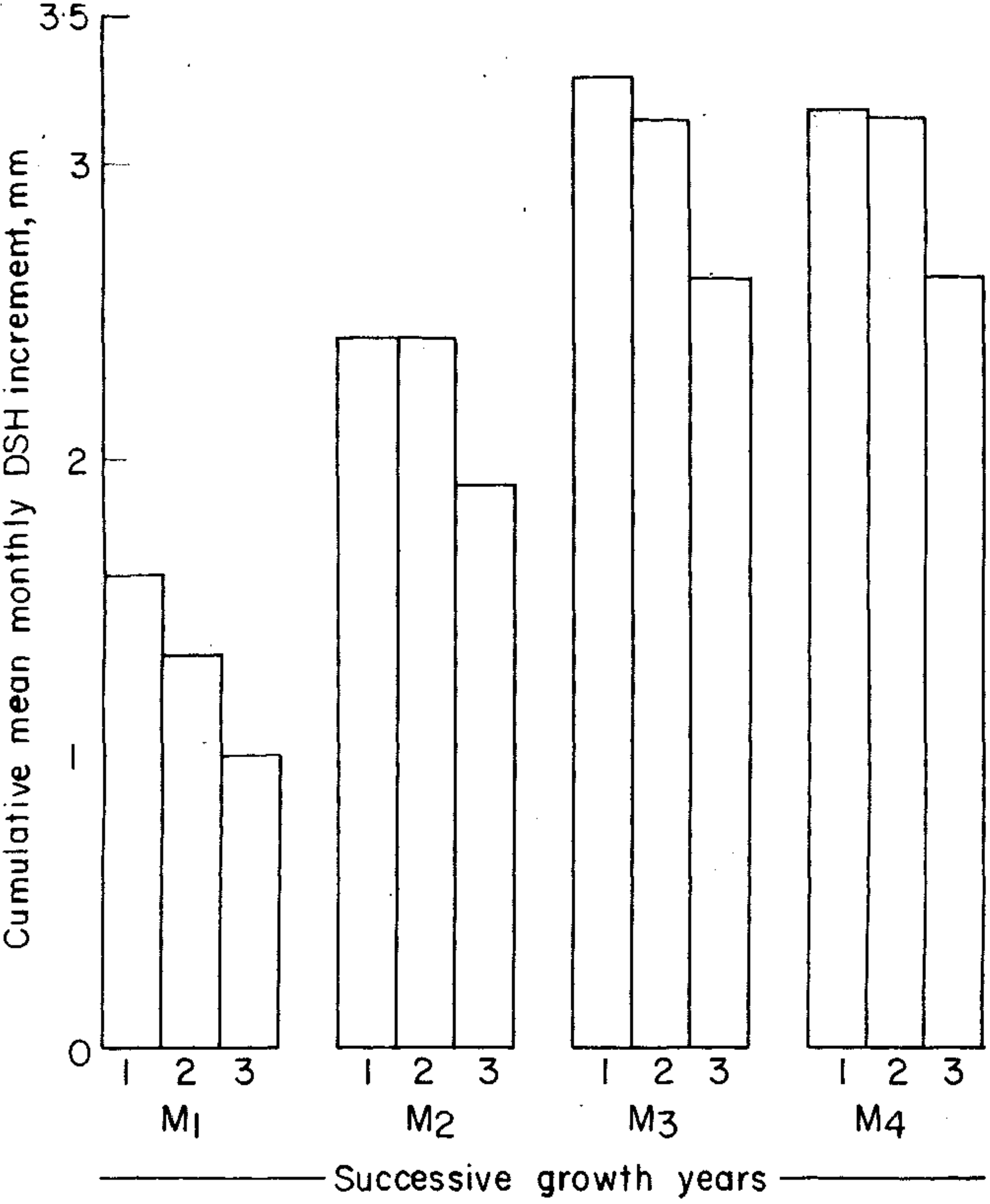


Fig.20. Effect of selected posthole filling mixtures on [redacted] mean monthly(cumulative) DSH increments of Casuarina during successive growth years.

(Frankia species) and its relatively high tolerance to an extreme of the soil sodicity hazard, it appears to be a promising tree species for the afforestation of sodic soils.

Periodic Chemical Composition: Trees differ markedly in their ability to tolerate varying degree of soil sodicity. The differences amongst some of them are reflected in differential absorption and accumulation of cations principally Na in their roots and shoots. But little information published or otherwise is available on this aspect of usefulness in determining the adaptation of tree species. In view of these considerations and promising initial growth of Casuarina in a highly sodic soil, periodic changes in chemical composition of the foliage and woody matter of plants growing in postholes refilled with differently composed mixtures were monitored and the results are discussed elementwise in the succeeding text.

(a) Sodium and Potassium: Average Na concentration in foliage and woody matter of plants (Table 68) growing in differently refilled postholes varied significantly at all the selected growth stages. Sodium accumulation was the highest in postholes refilled with OS followed by the mixture of OS and FYM. Its concentration was maximum in foliage and woody matter of plants grown in postholes having an application of either gypsum alone or gypsum plus FYM. Irrespect of other factors, Na concentration of foliage was observed to be 2-3 times greater than the respective figure for woody matter. Sodium concentration was the maximum in saplings but its accumulation occured with advancement of the growth period. Rate of accumulation was more in postholes containing only OS followed by OS mixed with FYM

Table 60. Effect of selected posthole filling mixtures on the period concentration (mmoles kg^{-1}) of Na and K in foliage and woody matter of Casuarina equisetifolia L.

Growth stage (months past planting)	Foliage						Woody matter					
	M_1	M_2	M_3	M_4	Mean	LSD (0.05)	M_1	M_2	M_3	M_4	Mean	LSD (0.0
						Sodium						
0	126	126	126	126	126	NS	147	147	147	147	147	NS
1	164	138	128	127	139	10	146	141	143	129	140	8
3	219	155	130	116	155	16	141	132	139	84	124	12
5	272	208	138	104	181	26	140	120	120	60	110	14
9	246	184	113	97	160	14	99	143	91	104	109	15
12	489	293	190	185	289	22	289	124	81	81	144	22
15	436	264	182	171	263	26	274	136	84	85	145	24
18	472	286	188	178	281	24	262	128	94	88	143	23
21	488	290	192	184	289	28	268	131	86	76	140	24
24	492	294	196	176	289	32	272	142	73	68	139	36
27	452	268	182	168	267	30	246	126	70	64	127	32
30	426	242	168	156	248	31	238	130	72	62	126	34
Mean	357	229	161	149	224	30	210	133	100	87	133	26
						Potassium						
0	76	76	76	76	76	NS	105	105	105	105	105	NS
1	85	91	90	104	93	11	111	116	100	113	110	11
3	97	110	110	135	113	15	125	123	97	141	121	15
5	102	141	128	161	133	18	130	133	102	156	130	16
9	153	200	171	176	175	17	94	156	189	189	157	20
12	92	130	120	143	121	21	53	102	89	105	110	22
15	116	142	152	160	143	22	48	100	116	132	99	24
18	104	134	146	159	136	23	56	116	134	148	113	25
21	118	146	154	171	147	20	61	124	131	142	114	26
24	126	145	150	160	145	18	54	121	127	134	109	22
27	111	136	156	167	143	21	50	114	136	141	110	19
30	108	128	142	159	134	20	54	120	123	130	107	27
Mean	107	132	133	148	130	18	79	119	121	136	114	30

than those containing OS treated with either gypsum alone or gypsum plus FYM. The highest Na accumulation was found to occur at 12 months growth stage in all the treatments. Subsequently, Na concentration of both the components of plants indicated less marked fluctuations. Sodium accumulation was more in the summer than in the winter season. This means when the growth rate is high, accumulation of Na may possibly be more due to tis greater absorption alongwith higher amounts of water taken up for meeting high transpiration demands during the summer season. A satisfactory growth of Casuarina plants in postholes refilled with different mixtures vis-a-vis considerably high accumulation of Na in foliage and woody matter demonstrate relatively high teclerance to high degree of soil sodicity and better chances for its adaptation to such an uncompromising site. This species, thus, differs from Acacia which allow less Na accumulation in shoots. Sodium accumulation has also been reported by other workers (Ayoub, 1975; Rouhani and Bassiri, 1976) who examined several tree species growing on saline and sodic soils. But important aspect is their satisfactory growth despite higher Na accumulation. This is what Casuarina stood promise for its fairly good performance in a highly sodic soil.

The average K concentration in the foliage of (Table 68) Casuarina was considerably more than its respective value for the woody matter. Difference was marked for plants growing in postholes containing only the OS. Potassium concentration was low at planting and it increased gradually to the maximum in both the components at 9 months growth stage. Subsequently, K accumulation showed fluctuations with the growth period. However, the highest K concentration was observed in foliage as well as woody matter of plants growing in postholes containing gypsum either alone or in combination with FYM. The former had an edge over the former to cause more accumulation of Na. This may be ascribed to the role of FYM for increasing the availability of K in the soil and K addition through it (Gill, 1979). The K concentration at all the growth stages was significantly less in the given components of plants growing in postholes refilled with the OS. Significantly higher accumulation of K in plants in postholes having gypsum application shows that K is being absorbed selectively from the root zone where Ca is present in excess although available K content of the given site is also high. Data, thus, indicate existence of antagonism between the absorption of K and Na. Plants growing in postholes refilled with the OS only showed accumulation of Na in foliage and woody matter 3-4 times and 4-5 times greater than that of K. But this was not the case in postholes where OS was treated with either of the amendments like gypsum and FYM or both. This may be the cogent cause which effected its reflection in term of the growth (Plate 5).

(b) <u>Calcium and Magnesium</u>: Data on periodic concentration of Ca and Mg in the foliage and woody matter (Table 69) showed their considerably greater accumulation in the former than in the latter component. Relative concentration of Ca was more than of Mg in the woody matter at all the growth. But the opposite was observed for foliage except in the initial growth stages.irrespect of differences in composition of posthole filling mixtures. Between 5-9 months of growth, Ca concentration was maximum and it showed a continuous but gradual decline subsequently. Accumulation of Ca was significantly more in plants growing in postholes refilled with gypsum treated OS than

Table 69. Effect of selected posthole filling mixtures on the periodic concentration (mmol kg^{-1}) of Ca and Mg in foliage and woody matter of <u>Casuarina equisetifolia</u> L.

Growth stage (months past planting)	Foliage						Woody matter					
	M_1	M_2	M_3	M_4	Mean	LSD (0.05)	M_1	M_2	M_3	M_4	Mean	LSD (0.05)
						Calcium						
0	342	342	342	342	342	NS	207	207	207	207	207	NS
1	346	364	348	364	353	NS	213	214	210	216	214	NS
3	350	395	350	387	370	30	222	222	212	230	222	NS
5	362	470	370	390	398	26	250	250	241	257	250	NS
9	380	450	370	410	403	27	160	192	193	202	187	18
12	230	262	325	275	273	31	115	147	136	145	136	21
15	246	285	364	336	308	32	121	152	158	164	149	20
18	218	266	344	324	288	30	118	148	148	152	142	23
21	196	247	328	306	269	38	104	136	162	166	142	21
24	182	222	312	292	252	34	98	124	154	156	133	19
27	194	218	292	276	245	20	112	146	156	151	141	18
30	176	226	288	272	241	20	92	126	152	158	132	12
Mean	268	312	336	330	312	22	151	172	178	184	172	16
						Magnesium						
0	229	229	229	229	229	NS	133	133	133	133	133	NS
1	216	218	221	224	220	NS	126	128	124	132	128	NS
3	204	204	206	205	205	NS	125	133	116	129	126	NS
5	162	158	162	158	160	NS	120	134	118	120	123	NS
9	379	370	408	358	379	20	91	95	95	100	96	NS
12	345	341	386	337	353	22	62	66	75	75	70	11
15	332	336	384	340	348	21	60	64	71	76	68	11
18	340	346	378	342	352	18	64	71	76	81	73	11
21	321	334	372	344	343	20	58	66	78	84	71	14
24	314	328	366	321	333	23	54	62	84	88	72	15
27	320	324	374	326	336	24	59	62	86	92	75	14
30	328	332	380	333	343	24	62	64	82	86	74	15
Mean	291	293	322	293	300	15	85	90	95	100	92	10

those having the OS only or FYM treated OS throughout the observed growth period except initially. Greater accumulation of Ca may be ascribed to its greater availability and suppressed availability of Na in the soil resulting from an application of gypsum. The concentration of Mg showed less marked differences, though statistically significant between 9-30 months of the growth period. Its accumulation was the highest in plants having application of the gypsum alone than its combination with FYM, FYM alone and only the OS. But relative concentration of Mg in foliage of plants growing with the use of only OS was considerably high and it was interesting to know of its greater absorption than of Ca from the root zone.having similar status of water soluble Ca and Mg. Ability of Casuarina to absorb considerably high amounts of Ca and Mg in a very high pH soil indicate that there may be some mechanism of acid metabolism which solublizes insoluble soil Ca and Mg through the action of acidic metabolites. Otherwise, their concentration should have shown a continuous decrease with the growth period due to the dilution effect. It is also evident from their relatively high accumulation in foliage of Casuarina plants in postholes having gypsum treated filling mixtures which effected bumper growth of species. But again the dilution effect of growth was not marked. Higher accumulation of Ca and Mg in foliage than in the woody matter may help interacting the deleterious effect of Na accumulation on normal metabolic and photosynthetic activities of the plants. Such a behaviour may contribute its but in the overall greater tolerance of Casuarina to highly sodic soil. This needs further investigation to understand the specific effects, if any.

(c) Phosphorus and Sulphur: Concentration of P in the foliage was only marginally more than that of the woody matter at all growth stages. Application of FYM alone to the OS used for refilling of postholes resulted in significantly greater accumulation of P in both of the components than rest of the posthole filling mixtures. Addition of gypsum alone followed by its combination with FYM showed minimum P concentration throughout the given stages of the growth period. This may be attributed to the dilution effect due to fast growth of plants in such postholes and antagonism of sulphate, added through gypsum, with the absorption of P from the soil. Irrespect of different posthole filling mixtures, P concentration of foliage and woody matter showed an increase with growth until 9 months stage. It declined afterwards abruptly and varied little between 12-18 months of growth period after which its concentration increased in the foliage. However, this was not so for the woody matter, whose P concentration after 9 months stage showed a steady decline with the growth. The dynamism of P accumulation pattern of the foliage may have resulted from its translocation from one component to another.

The relative concentration of S in the foliage was 2-3 times more than its value for the woody matter. Its accumulation was also considerably more in both of the components than that of P at all noted stages of the growth period. Sulphur concentration in foliage also showed an increase until 9 months past planting. Rate of accumulation was significantly higher for the plants growing in postholes containing gypsum alone or in conjunction with FYM followed by FYM alone. This is due to ample supply of sulphate through gypsum added to the root zone. But subsequently, S concentration was found reduced to about one-half at 15 months growth stage for plants

Table 70. Effect of selected posthole filling mixtures on the periodic concentration (mmol kg^{-1}) of P and S in foliage and woody matter of Casuarina equisetifolia L.

Growth stage (months past planting)	Foliage						Woody matter					
	M_1	M_2	M_3	M_4	Mean	LSD (0.05)	M_1	M_2	M_3	M_4	Mean	LSD (0.05)
					Phosphorus							
0	30.3	30.3	30.3	30.3	30.3	NS	21.3	21.3	21.3	21.3	21.3	NS
1	33.8	38.9	32.0	33.6	34.6	NS	24.4	22.3	26.3	24.5	24.4	NS
3	46.7	52.3	39.7	40.0	44.7	5.5	45.0	33.7	28.3	28.0	33.8	5.5
5	71.2	72.3	41.3	39.3	58.0	6.8	82.5	62.7	42.3	41.7	57.3	6.2
9	60.3	72.7	49.0	63.0	61.3	8.2	61.7	52.7	34.3	34.3	45.8	4.8
12	29.7	30.3	25.3	31.3	29.2	NS	31.3	28.3	19.3	22.3	25.3	5.0
15	32.8	36.9	22.3	24.5	29.1	8.0	32.6	30.4	18.6	19.4	25.3	6.2
18	34.6	41.4	24.8	26.5	31.8	7.6	28.7	26.5	17.5	18.2	22.7	6.2
21	28.8	42.8	36.5	38.8	36.7	8.7	26.4	24.8	19.2	19.5	22.5	5.2
24	36.5	48.3	42.2	41.4	42.1	8.0	31.8	26.2	20.5	18.2	24.2	5.2
27	41.6	46.4	44.3	42.8	43.8	NS	29.6	27.6	16.7	18.2	23.0	6.8
30	48.7	51.5	41.5	38.2	45.0	7,5	28.7	29.2	16.2	18.3	23.1	7.4
Mean	41.4	47.0	35.8	38.0	40.6	7.0	37.0	32.1	23.4	23.7	29.0	5.2
					Sulphur							
0	77.2	77.2	77.2	77.2	77.2	NS	48.1	48.1	48.1	48.1	48.1	NS
1	76.5	83.4	89.3	88.2	84.4	4.6	48.3	49.2	49.0	50.0	49.1	NS
3	79.7	91.9	107.2	101.6	95.1	10.4	48.8	49.3	49.1	43.1	48.1	8.0
55	89.7	105.1	139.1	111.3	111.3	12.8	47.8	53.0	50.0	39.7	47.7	7.6
9	106.6	97.2	109.7	117.8	107.8	14.4	35.0	47.5	60.3	50.0	48.2	8.3
12	90.3	73.8	71.9	68.4	76.1	6.8	28.1	45.0	76.9	48.4	49.6	10.2
15	82.4	71.3	60.5	56.3	67.6	6.2	22.2	41.6	74.8	52.6	47.8	9.8
18	85.5	74.2	61.7	58.5	70.0	7.1	24.5	32.8	62.3	50.8	42.6	11.6
21	76.7	64.5	52.6	55.7	62.4	8.2	26.6	34.7	61.8	54.7	44.5	10.7
24	62.8	71.8	54.3	56.2	61.3	8,0	30.3	32.3	60.4	56.2	44.8	11.6
27	66.4	76.2	56.8	58.3	64.4	8.6	24.2	27.2	53.1	52.5	39.5	12.4
30	71.5	78.3	57.9	59.2	66.7	7.7	21.3	24.6	50.6	48.4	36.2	11.2
Mean	80.4	80.4	78.2	75.7	78.7	NS	33.8	40.3	58.1	49.5	45.5	7.7

grown in gypsum treated postholes with little fluctuations between 15-30 months growth period. However, S concentration in the foliage of Casuarina plants, growing in postholes refilled with OS alone or OS plus FYM showed only a gradual decline after 9 months growth stage until 21 and 24 months stages. Between 12-30 months of growth period, accumulation of S was significantly more with both of the said mixtures. This may be attributed to relatively slower rate of plant growth obtained with three mixtures. But S concentration in woody matter was significantly low in postholes refilled with the OS alone or OS plus FYM than those containing gypsum or gypsum plus FYM mixed OS throughout the observed growth period.

(d) Nitrogen: Data (Table 71) on N concentration showed that its relative accumulation in foliage was significantly higher than in the woody matter like P and S. But its concentration was many times greater in both the components than that of P and S. Concentration of N in foliage and woody matter of saplings at planting was the highest. It was observed decreasing periodically with the advancement of growth. Results showed rapid decrease with posthole filling mixtures containing gypsum alone or its combination with FYM. It implies that this decrease is a consequence of rapid growth or the dilution effect. Therefore, Casuarina plants growing in postholes refilled with the OS alone or OS plus FYM indicated significantly higher accumulation of N at all the stages during the observed growth period. Relatively greater accumulation of N in the biomass produced by Casuarina in a highly sodic soil with low available N status demonstrates its ability to use atmospheric dinitrogen fixed through symbiosis with Frankia species (an actinomycetes). This species,

Table 71. Effect of selected posthole filling mixtures on the periodic concentration (mmoles kg^{-1}) of N in foliage and woody matter of *Casuarina equisetifolia* L.

Growth stage (months past planting)	Foliage M_1	M_2	M_3	M_4	Mean	LSD (0.05)
0	1714	1714	1714	1714	1714	NS
1	1672	1696	1652	1644	1666	NS
3	1446	1385	1164	1119	1279	50
5	1256	1064	872	826	1005	48
9	1166	1072	836	794	967	55
12	1087	926	744	715	868	65
15	1112	970	736	696	879	62
18	896	666	752	688	751	60
21	777	694	616	545	658	70
24	746	680	532	538	624	65
27	786	627	511	526	612	56
30	714	600	496	503	578	60
Mean	1114	1008	886	859	967	55
			Woody matter			
0	1136	1136	1136	1136	1136	NS
1	954	1064	1087	1045	1038	NS
3	862	846	694	711	778	20
5	744	712	676	666	700	23
9	622	548	494	506	543	30
12	536	504	412	430	471	32
15	590	506	428	444	492	35
18	488	432	386	412	429	38
21	376	394	313	340	356	40
24	412	366	302	321	350	42
27	384	325	266	272	312	44
30	426	276	274	284	315	48
Mean	628	593	539	547	577	51

therefore, has a promise to enrich such soils with N through fixation of dinitrogen and production of litter containing high amounts of N and other essential nutrient elements.

(e) Micronutrients: Among the micronutrients, relative concentration of Fe in foliage and woody matter of Casuarina was the highest followed by that of Mn (Table 72), Zn and Cu (Table 73). Their accumulation was more in the foliage component in general at all the stages. Concentration of these four nutrients was maximum in the Casuarina saplings at planting. The concentration showed a decrease with the growth. As growth was significantly more in postholes refilled with the OS treated with either gypsum alone or its combination with FYM, plants growing in such postholes had significantly low concentration of micronutrients due to the dilution effect. Because of slow rate of growth of plants in postholes refilled with the OS alone, the relative concentration of Zn and Mn in the foliage was high, however, Fe and Cu accumulation was more with postholes refilled with FYM treated OS. But differences in concentration of these four micronutrients in the woody matter were not marked due to the effect of different posthole filling mixtures. Absolute concentrations of Fe, Mn, Zn and Cu in the foliage of Casuarina showed that plant growth may not suffer due to the deficiency of any of these. These values may be regarded optimum in view of the generalized values reported by Kanwar and Randhawa (1978) for different types of plants.

(f) Water Relations of Casuarina: Casuarina plants growing in postholes refilled with the given four different mixtures to watering during the winter and the summer seasons (Fig.21) showed marked differences in their water relations. Relative turgidity (RT) of

Table 72. Effect of selected posthole filling mixtures on periodic concentration (mmoles kg^{-1}) of Fe and Mn in foliage and woody matter of *Casuarina equisetifolia* L.

Growth stage (months past planting)	Foliage M_1	Foliage M_2	Foliage M_3	Foliage M_4	Foliage Mean	Foliage LSD (0.05)	Woody matter M_1	Woody matter M_2	Woody matter M_3	Woody matter M_4	Woody matter Mean	Woody matter LSD (0.05)
						Iron						
0	40.00	40.00	40.00	40.00	40.00	NS	12.32	12.32	12.32	12.32	12.32	NS
1	38.36	36.46	34.84	35.65	36.33	1.06	11.68	12.04	11.48	10.96	11.54	NS
3	32.32	26.79	20.71	20.54	25.09	2.24	9.46	10.36	9.46	9.29	9.64	NS
5	10.18	9.29	7.14	7.68	8.57	1.65	4.46	5.36	3.93	4.29	4.51	NS
9	11.07	14.11	11.25	13.21	12.41	2.04	4.29	4.64	3.93	4.11	4.24	NS
12	13.21	10.71	8.39	11.43	10.94	2.22	3.93	4.29	3.21	3.04	3.62	NS
15	11.68	9.88	6.36	7.44	8.84	2.18	4.16	4.74	4.56	3.68	4.29	NS s
18	10.35	9.64	7.59	6.36	8.49	1.88	4.54	4.92	4.77	4.65	4.72	NS
21	9.64	8.36	7.14	6.84	8.00	2.64	3.98	4.16	4.28	4.26	4.17	NS
24	8.36	7.48	6.26	6.66	7.19	1.92	3.65	3.88	4.06	4.38	4.12	NS
27	9.14	8.32	6.18	5.68	7.33	1.96	3.44	3.56	3.84	4.16	3.75	NS
30	8.58	7.16	6.20	5.92	6.97	1.84	3.82	4.12	3.98	4.38	4.08	NS
Mean	16.91	15.68	13.51	13.95	15.01	1.55	5.81	6.20	5.82	5.79	5.92	NS
						Manganese						
0	2.08	2.08	2.08	2.08	2.08	NS	1.04	1.04	1.04	1.04	1.04	NS
1	2.22	2.38	2.16	2.22	2.25	NS	1.00	1.00	0.96	0.94	0.98	NS
3	3.51	3.26	2.09	2.04	2.73	1.14	0.98	1.00	0.93	0.84	0.94	NS
5	4.55	3.64	2.26	2.08	3.13	1.26	0.94	0.95	0.87	0.84	0.90	NS
9	4.51	2.89	2.16	2.27	2.96	1.32	1.69	1.02	0.96	0.80	1.12	0.36
12	2.29	1.44	1.69	1.42	1.71	NS	2.76	1.00	1.07	0.82	1.41	0.48
15	2.84	1.90	1.46	1.28	1.87	1.16	1.92	0.96	0.84	0.76	1.12	0.52
18	2.72	1.65	1.52	1.36	1.81	1.22	1.82	0.87	0.88	0.66	1.06	0.44
21	3.36	1.45	1.26	1.09	1.79	1.36	1.64	1.12	0.76	0.48	1.00	0.36
24	2.64	1.58	1.38	1.28	1.72	1.16	1.78	1.14	0.94	0.60	1.12	0.48
27	2.32	1.14	1.46	1.32	1.56	1.06	1.64	1.32	0.88	0.66	1.13	0.50
30	2.66	1.18	1.26	1.16	1.57	0.90	1.52	1.26	0.96	0.72	1.12	0.46
Mean	2.98	2.05	1.73	1.63	2.10	1.12	1.56	1.06	0.92	0.76	1.08	NS

Table 73. Effect of selected posthole filling mixtures on the periodic concentration (mmoles x 10^3 kg-1) of Zn and Cu in foliage and woody matter of <u>Casuarina</u> <u>equisetifolia</u> L.

Growth stage (months past planting)	Foliage						Woody matter					
	M_1	M_2	M_3	M_4	Mean	LSD (0.05)	M_1	M_2	M_3	M_4	Mean	LSD (0.05)
						Zinc						
0	462	462	462	462	462	NS	246	246	246	246	246	NS
1	452	438	448	438	444	NS	238	246	238	246	242	NS
3	385	400	400	323	337	42	231	231	231	246	235	NS
5	292	338	308	292	308	30	215	231	215	231	222	NS
9	260	262	246	200	242	38	138	154	154	154	150	NS
12	262	277	246	215	250	45	123	092	62	108	96	40
15	248	284	238	202	243	40	126	088	56	076	87	44
18	272	296	214	224	252	52	132	076	48	076	083	56.
21	256	282	238	240	253	48	118	102	62	062	086	52
24	244	286	216	228	244	50	126	092	56	0.62	84	55
27	232	274	216	228	238	48	112	088	56	56	78	46
30	246	265	216	236	241	44	112	088	48	56	76	52
Mean	301	322	287	274	296	38	160	145	123	135	140	NS
						Copper						
0	125	125	125	125	125	NS	156	156	156	156	156	NS
1	125	125	125	125	125	NS	156	156	156	141	151	NS
3	125	141	125	125	129	NS	141	156	156	141	149	NS
5	125	141	125	112	126	16	125	156	141	125	137	NS
9	141	141	112	112	127	20	94	94	078	078	86	NS
12	78	125	103	112	105	20	47	31	031	047	39	NS
15	78	125	78	86	92	16	47	47	031	47	43	NS
18	64	086	64	64	70	16	31	47	047	31	39	NS
21	56	086	64	78	71	20	31	31	47	31	35	NS
24	64	078	56	64	66	20	31	47	31	47	39	NS
27	56	078	56	78	67	20	47	31	47	47	48	NS
30	64	064	56	56	60	NS	47	31	31	47	39	NS
Mean	92	110	91	95	97	NS	79	82	79	78	80	NS

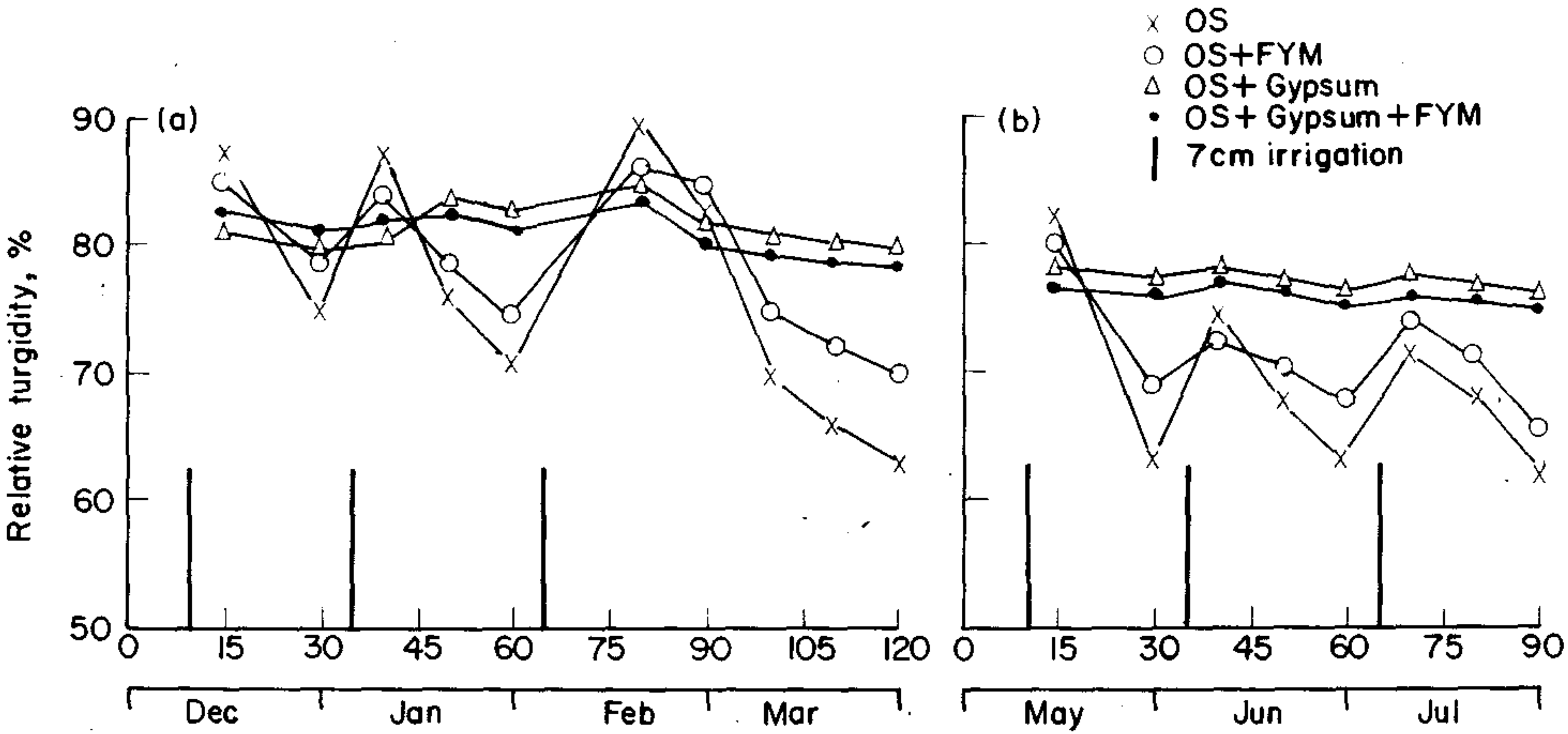


Fig. 21. Effect of watering on changes in relative turgidity of Casuarina foliage during winter of 1982-83 (a) and summer of 1983 (b)

plants in postholes receiving an application of their gypsum or gypsum plus FYM indicated little fluctuations with time during both the seasons. But there was a marked irregularity in the RT of foliage of plants growing in postholes refilled by the OS alone or OS plus FYM and response to watering was observed maximum in that treatments. This implies that the addition of the OS alone or OS plus FYM did not ameliorate the soil to an extent favourable for the growth of roots to horizons of ensured water availability as did the application of either gypsum alone or gypsum plus FYM. Plants in case of the former treatments, thus, suffer water stress and responded to watering. High soil sodicity throughout the entire depth of postholes refilled with the OS alone or OS plus FYM is the cogent cause that restricted root growth. Such observations were made by other workers (Abrol and Acharya, 1975; Acharya et al., 1979) in case of field crops. Application of either gypsum alone or gypsum plus FYM resulted in greater degree of amelioration of soil which not only helped in fast proliferation of roots but also higher infiltration and in turn storage in the root zone. During winter season, RT of plants growing in postholes containing no application of gypsum was observed to increase with watering than those having gypsum treated mixtures. But this was not the case in summer season. This is ascribed to the low evapotranspiration demands during the winter season and relatively poor growth of plants in postholes containing the OS alone or OS plus FYM. Irrespect of other factors, the RT is reported to decrease with growth and high atmospheric evapotranspiration demands (Zahner, 1968; Kozlowski, 1979).

6.5 Evaluation of Selected Tree Species for Their Tolerance to Sodicity and Mechanical Impedance in a Highly Sodic Soil.

<u>Introduction</u>: Soil sodicity is one of the important constraints which make the soil environment inhospitable and impairs the growth of the plants being demesticated by the mankind. Therefore, most highly sodic soils are devoid of greenery possessing much economic significance. Afforestation of these desertified lands appears promising for not only maintaining the healthy ecological balance that has been severely disturbed due to indiscriminate large scale cutting of wood in the past but also to create resources to meet additional future needs of firewood, forage and other products. Considering the vast scope that sodic soils hold for afforestation, only a few efforts have been made in this direction. This is so because limited research work has been done on the field scale. Thus, lack of experimental evidences have a serious bearing on formulation of plans and programmes to afforest such soils.

In view of adverse properties of the sodic soils, establishment of trees requires a correct choice of species in addition to any special treatment for site preparation. Choice of a promising species for such soils depends upon the local agroclimate, soil conditions, potential availability of species and purpose of the plantation i.e. industrial uses (firewood, pulpwood, saw timber and panel products) domestic uses (firewood, poles, stakes), environmental protection, amenity, shade, shelter, food, forage and browse and amelioration of the soil through leaf fall, N fixation and accompanying physico-chemical phenomena. This experiment was conducted to investigate the tolerance of selected tree species when planted through newly developed posthole technique in a highly sodic soil.

Methodology: To evaluate the performance of selected eight tree species namely Albizia lebbec L. Benth (Siris), Azadirachta indica Juss. (Neem), Dalbergia sissoo Roxb. (Shisham), Morus indica var. alba L. (Shahtoot), Populus deltoides Bartr. (Poplar), Prosopis juliflora (Sw.) DC. (Mesquite), Syzygium cuminii Wall. (Jaman) and Syzygium fructicosum DC. (Jamoa) in a highly sodic soil, this experiment was carried out at Gudha Farm of the institute. Details about physico-chemical characteristics of the experimental site are presented in Part-I of the current chapter.

Robust and uniformly looking saplings each of the given species were planted on March 31,1980 in shallow and deep postholes. Shallow postholes were 30 cm wide (dia.) and 60 cm deep and were dug out mechanically using a soil auger run by tractor power (Plate 2). Deep postholes were prepared by deepening of shallow postholes (30 cm X 30 cm) dug out with tractor operated auger to 120 cm depth with 15 cm dia. (15 cm X 61-120 cm) manually operated soil augers. Approximate volume of the soil dug out in shallow and deep postholes was calculated to be 42412 cc (74.2 kg) and 53014 cc (= 92.8 kg) respectively. Each posthole was refilled with a mixture comprising surface (0-30 cm) soil collected from a patch supporting natural vegetation within the experimental field, 8 kg FYM of good quality (Table 74) and 3 kg agricultural grade gypsum of 70 per cent purity, 25 g N (27.8 kg ha^{-1}) as urea and rice husk with soil in a ratio of 3:2 by volume. Another dose of same amount of N was applied to each plant with irrigation water 180 days after planting.

Table 74. Chemical composition of the FYM used in the posthole filling mixture.

Item	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(mol kg^{-1})						(mmol kg^{-1})			
Concentration	0.27	0.10	0.31	0.21	0.22	0.14	45.4	5.2	0.48	0.44
	g								mg	
Amount added through 8 kg FYM	39	16	62	43	27	23	2.5	0.3	31	28

*FYM at the time of use had 32-40 per cent moisture (fresh wt. basis).

Experiment was replicated four times in a factorial (eight tree species planted in two types of postholes) randomized block design layout. Each replicate included four plants. Distance between row to row and plant to plant was maintained at 3 m (1111 plants ha^{-1}). Age of the saplings of <u>Siris</u>, <u>Neem</u>, <u>Shisham</u>, <u>Shahtoot</u>, Poplar, Mesquite, <u>Jaman</u> and <u>Jamoa</u> at planting time was about 8, 6, 18, 18, 12, 6, 8 and 9 months respectively. Plants were watered on the need felt basis for about four months past planting to aid their establishment.

Periodic observations on per cent survival and growth indices (maximum height and stem girth diameter at 5 and 30 cm height above the ground level) were recorded after 15, 45, 75, 210, 360, 540 and 720 days of planting. Experiment was terminated 720 days past planting to evaluate the surviving species in terms of their (a) primary biomass yield. (b) Chemical composition of various plant components (c) root growth behaviour and (d) intensive analyses of soil profiles in the vicinity of growing trees to study mechanical impedance and identification of salient soil characteristics which may modify the tree growth directly or indirectly. Procedures followed to accomplish

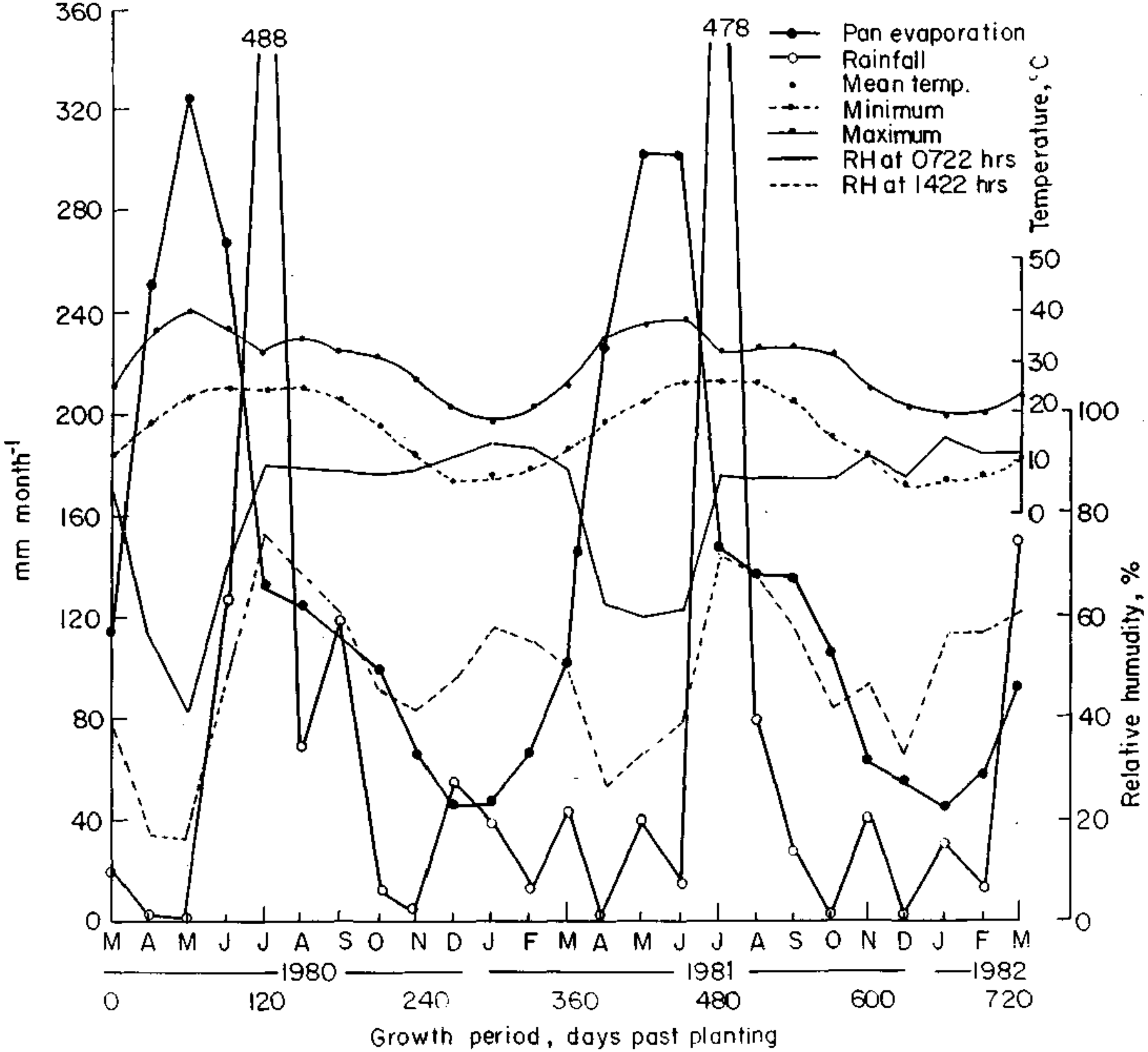


Fig.22. Salient agro-climatological conditions prevailed during the observed growth period.

and quantify the given observations are presented in Chapter III. Some of the important agro-climatological conditions that prevailed during the observed growth period are depicted in Fig. 22.

Results and Discussion: The experimental results on various aspects of this investigation are presented and discussed below under various heads:

A. Per Cent Survival: Data (Table 75 and Appendix III) showed an increase but varying mortality among selected species subsequent to planting except Shisham. Mortality occurred more frequently until 360 days of planting than later on when per cent survival of given species tended to stabilize. The species which survived hostility of the soil sodicity hazard differently demonstrated no change in per cent survival after 540 as well as 720 days of planting.

All Poplar plants died just 45 days after planting but they indicated growth and survival up to 30 days. Rest of the species showed cent per cent survival during this period, however, significant differences were developed among them until 75 days growth (Appendix III). Following complete mortality of Poplar, per cent survival of Jaman and Shahtoot decreased periodically to extinction after 540 days of planting when rest of the species were noticed to indicate little variation.

Effect of the two types of postholes on the per cent surival was also significant. Irrespect of the tree species, per cent survival was more in shallow than in the deep postholes throughout the noted growth period but statistical significance was computed to occur at only three growth stages i.e. 75, 210 and 360 days after planting (Fig.23). Occurrence of mortality in deep postholes was not only of high order but

Table 75. Periodic per cent survival of selected tree species in a highly sodic soil.

Tree species	Growth period, days past planting						
	15	45	75	210	360	540	720
Siris	100	100	93	93	87	69	69
Neem	100	100	100	75	63	63	63
Shisham	100	100	100	100	100	100	100
Shahtoot	100	100	100	75	25	0	0
Poplar	100	0	0	0	0	0	0
Mesquite	100	100	100	87	87	87	87
Jaman	100	100	75	18	12	0	0
Jamoa	100	100	100	68	56	50	50
LSD (0.05)	NS	10	13	23	25	23	23

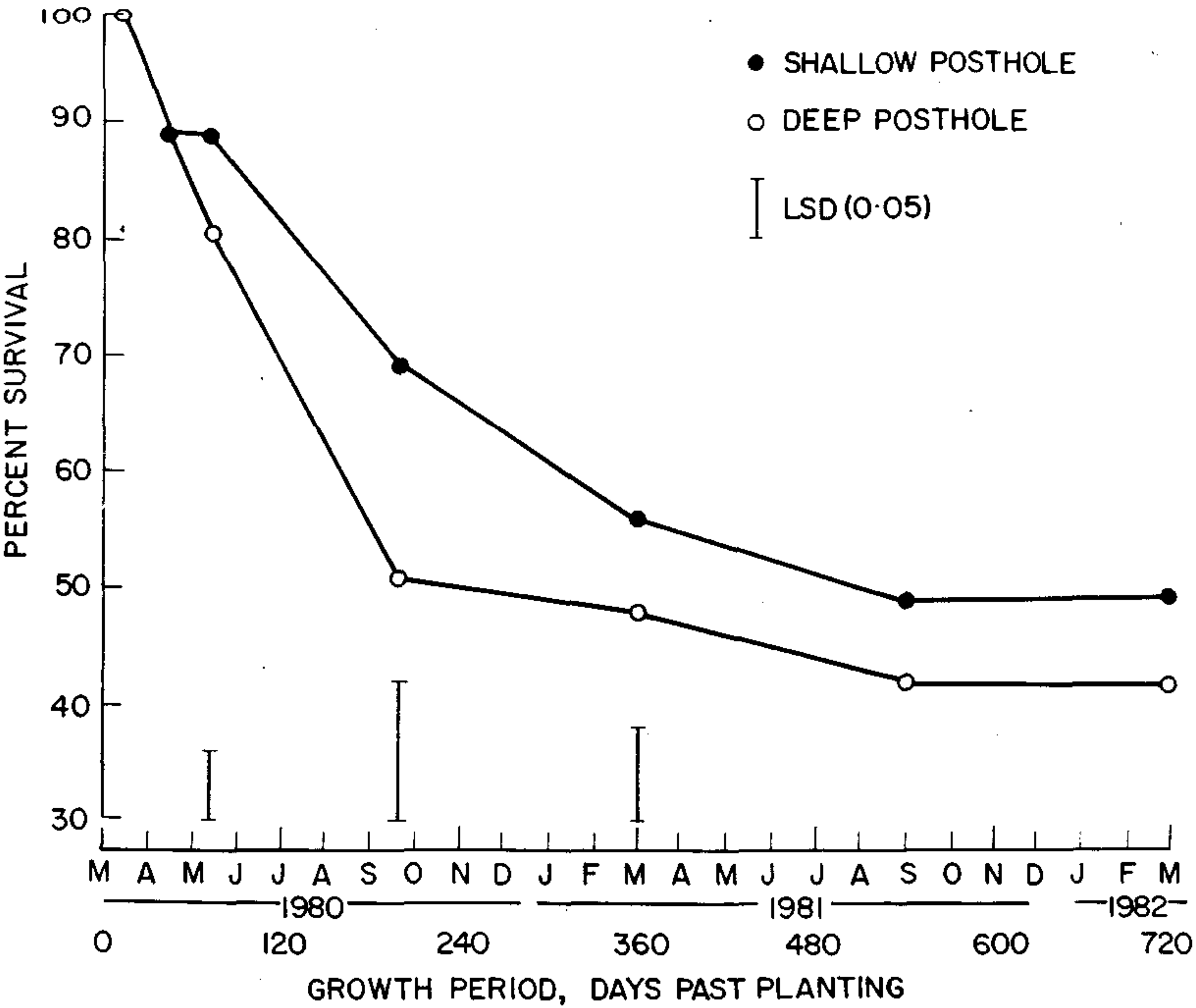


Fig.23. Changes in periodic percent survival of selected species planted in shallow and deep postholes.

was also enhanced considerably. But this was not so in Mesquite and *Shisham*. Per cent survival data (Table 75), thus show that mortality of the selected species occured differently but mostly between 75 to 360 days past planting. Differences among the given tree species were remarkable throughout the growth period. Of the eight species studied, Poplar, *Jaman* and *Jamoa* met complete mortality whereas per cent survival of *Shisham*, *Mesquite*, *Siris*, *Neem* and *Jamoa* was 100, 87, 75, 75 and 50 in shallow and 100, 87, 62, 50 and 50 in deep postholes after 540 as well as 720 days of planting, respectively.

Relatively high per cent survival of *Shisham* and Mesquite irrespect of the type of posthole used to prepare the planting site may be attributed to their greater tolerance to high soil sodicity than *Siris*, *Neem* and *Jamoa*. The latter species indicated moderate tolerance whereas Poplar, *Jaman* and *Shahtoot* were found poorly tolerant and failed to survive. Similar survival each of Mesquite and *Shisham* in both types of postholes further indicate their greater relative tolerance than of Siris and Neem whose per cent survival in the shallow postholes was more than in deeper ones. This brings out that application of same dose of gypsum and FYM caused amelioration of the soil in shallow postholes to a greater degree than in the deep postholes with comparatively larger volume of the soil. This may be termed dilution effect of applied amendments. The btter performance and survival of Mesquite, *Siris*, *Shisham* and *Neem* was reported by other workers as stated in a review by Yadav (1980). But contrary reports about all of the said species except Mesquite are also reported in literature.

B. Growth Indices

(a) Height Growth: Data on periodic height growth of tree species with different survival per cent indicated significant variations.

Poplar did not grow in height before complete mortality (Appendix IV). Jaman and Shahtoot showed an increase in height though slight until 75 days of planting. But all the plants of both the species were dead after 75 and 360 days of planting respectively.

During the observed growth period, maximum height growth was recorded for Mesquite and it was followed by Siris, Shisham, Neem and Jamoa (Fig. 21). In the initial stages, height growth rate was very slow. Average increase in height of Mesquite, Siris, Shisham, Neem and Jamoa 45 and 75 days past planting was 43 (16 cm), 3 (1 cm), 6 (3 cm), 7 (2 cm), 6 (3 cm) and 81 (30 cm), 52 (16 cm), 25 (13 cm), 27 (8 cm), 6 (3 cm) per cent respectively over the initial height recorded 15 days after planting. Subsequently, Mesquite and Siris showed a relatively faster height growth than Shisham, Neem and Jamoa. Average height of Mesquite increased from 67 cm after 75 days to 385 cm (475 per cent) after 720 days of planting. Height growth of Siris during the same period was 205 cm (436 per cent). Height growth of Shisham, Neem and Jamoa was relatively very slow. Jamoa showed no height growth in the initial years of planting although it attained height increments of 18 (9 cm), 43 (22 cm) and 65 (33 cm) per cent over the initial height at planting. Per cent increase in height 45, 75, 210, 360, 540 and 720 days past planting for Shisham and Neem were 6 (3 cm), 25 (13 cm), 73 (37 cm), 82 (42 cm), 108 (55 cm), 157 (80 cm) and 7 (2 cm), 33 (10 cm), 153 (46 cm), 197 (59 cm), 263 (79 cm), 313 (94 cm) respectively. Growth during winter (Nov. to Feb.) marked with considerably low temperature (Fig. 22) was almost negligible. This may be ascribed to adverse effect of low temperatures on plant metabolism. Except Siris and Shisham (deciduous), rest of the surviving species were of evergreen nature. Height growth equations

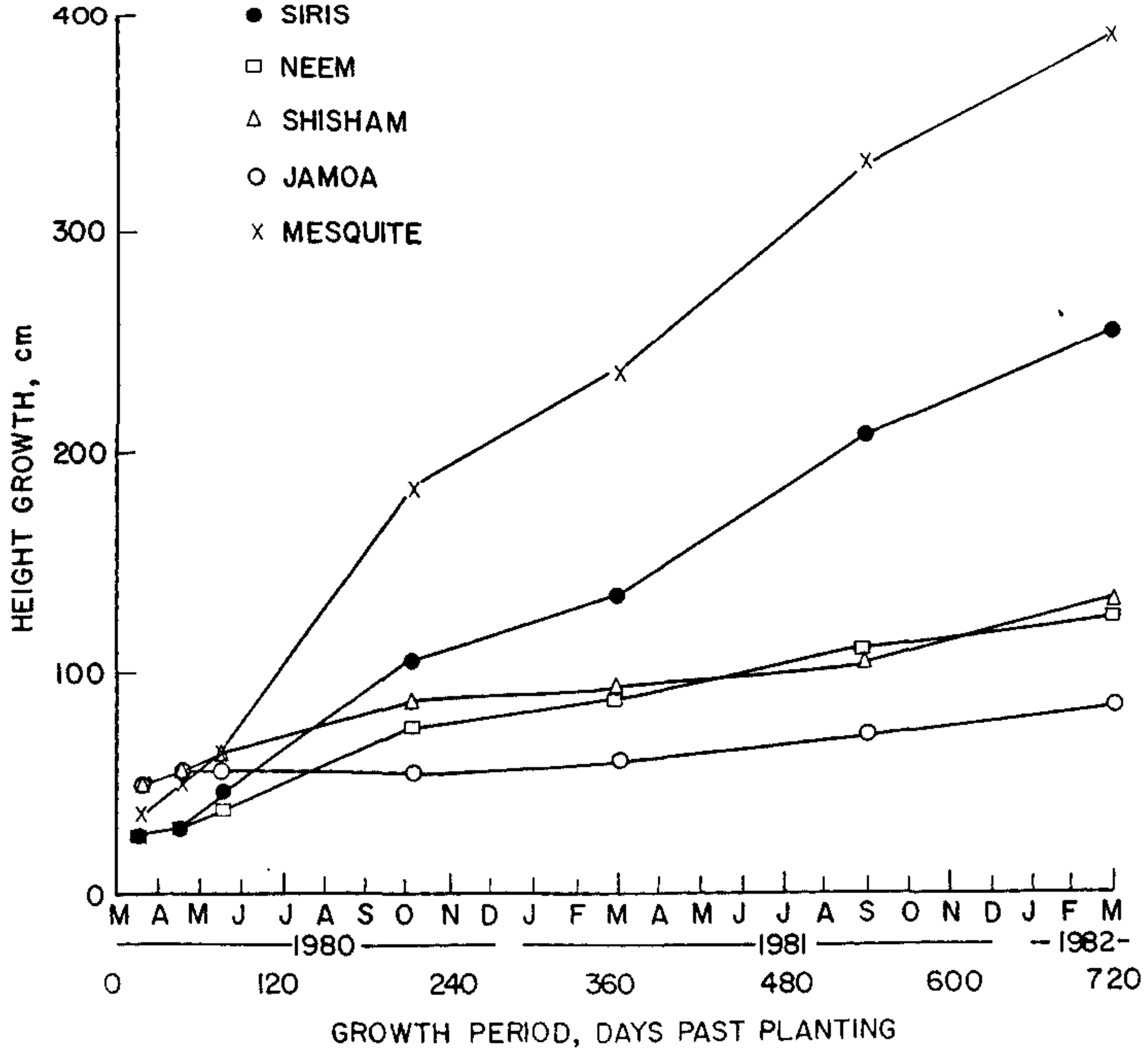


Fig. 24. Periodic height growth of selected species irrespect of posthole depths.

Table 76. Height growth curves of the tree species in a highly sodic soil.

Tree species height (cm)	Growth equation	R^2
	Shallow posthole planting	
Siris	$19.5 + 0.481\ d - 1.60 \times 10^{-4}\ d^2$	0.995**
Neem	$22.2 + 0.294\ d - 1.93 \times 10^{-4}\ d^2$	0.992**
Shisham	$48.7 + 0.211\ d - 1.63 \times 10^{-4}\ d^2$	0.977**
Mesquite	$20.1 + 0.884\ d - 6.50 \times 10^{-4}\ d^2$	0.992**
Jamoa	$53.1 + 0.004\ d + 7.08 \times 10^{-5}\ d^2$	0.986**
Mean	$44.9 + 0.262\ d - 8.24 \times 10^{-5}\ d^2$	0.991**
	Deep posthole planting	
Siris	$22.4 + 0.294\ d + 1.28 \times 10^{-5}\ d^2$	0.988**
Neem	$26.9 + 0.183\ d - 9.19 \times 10^{-5}\ d^2$	0.981**
Shisham	$53.5 + 0.067\ d + 7.12 \times 10^{-5}\ d^2$	0.954**
Mesquite	$23.2 + 0.648\ d - 7.70 \times 10^{-5}\ d^2$	0.993**
Jamoa	$51.0 + 0.006\ d + 5.31 \times 10^{-5}\ d^d$	0.980**
Mean	$48.9 + 0.119\ d + 1.35 \times 10^{-4}\ d^2$	0.989**

d denote days past planting.

of the surviving five species in the two types of posthole planting are presented in Table 76.

Effect of the two posthole types on height growth was marked although statistically significant difference prevailed only at two growth stages (210 and 360 days past planting) (Fig. 25). The height growth of Siris, Neem and Shisham planted in shallow postholes was significantly more than in the deep ones throughout their growth period except in the initial 75 days (Fig. 26). Similar observations were made in Mesquite in the early growth period but the reverse was noticed after 360 days of planting. Height growth of Mesquite in deep postholes between 360-720 days of planting occurred at a rate which not only recouped the lag but also established a considerable lead over the average height of Mesquite planted in the shallow postholes. During the later stages of growth period, Mesquite growth in height was slow but more biomass productivity in terms of branching on the main stem was observed. Therefore, absolute height as a measure of growth and biomass productivity may have a limitation.

(b) Girth Growth: Periodic changes in the stem girth diameter at 5 cm (DSH) height (Fig. 27a) above ground level showed that girth growth was almost negligible until 75 days of growth. But subsequently the significant differences developed among the growing tree species. The DSH of Mesquite and Siris was almost tantamount at 210 days growth stage. But later on increase in Mesquite occured at a faster rate than in Siris though girth growth of both was significantly more than rest of the species throughout the noted growth period. Poplar, Shahtoot and Jaman died after 45, 210 and 360 days of planting respectively (Appendices V and VI). A gradual decline in their stem girth with time after planting was evident. The cogent cause may

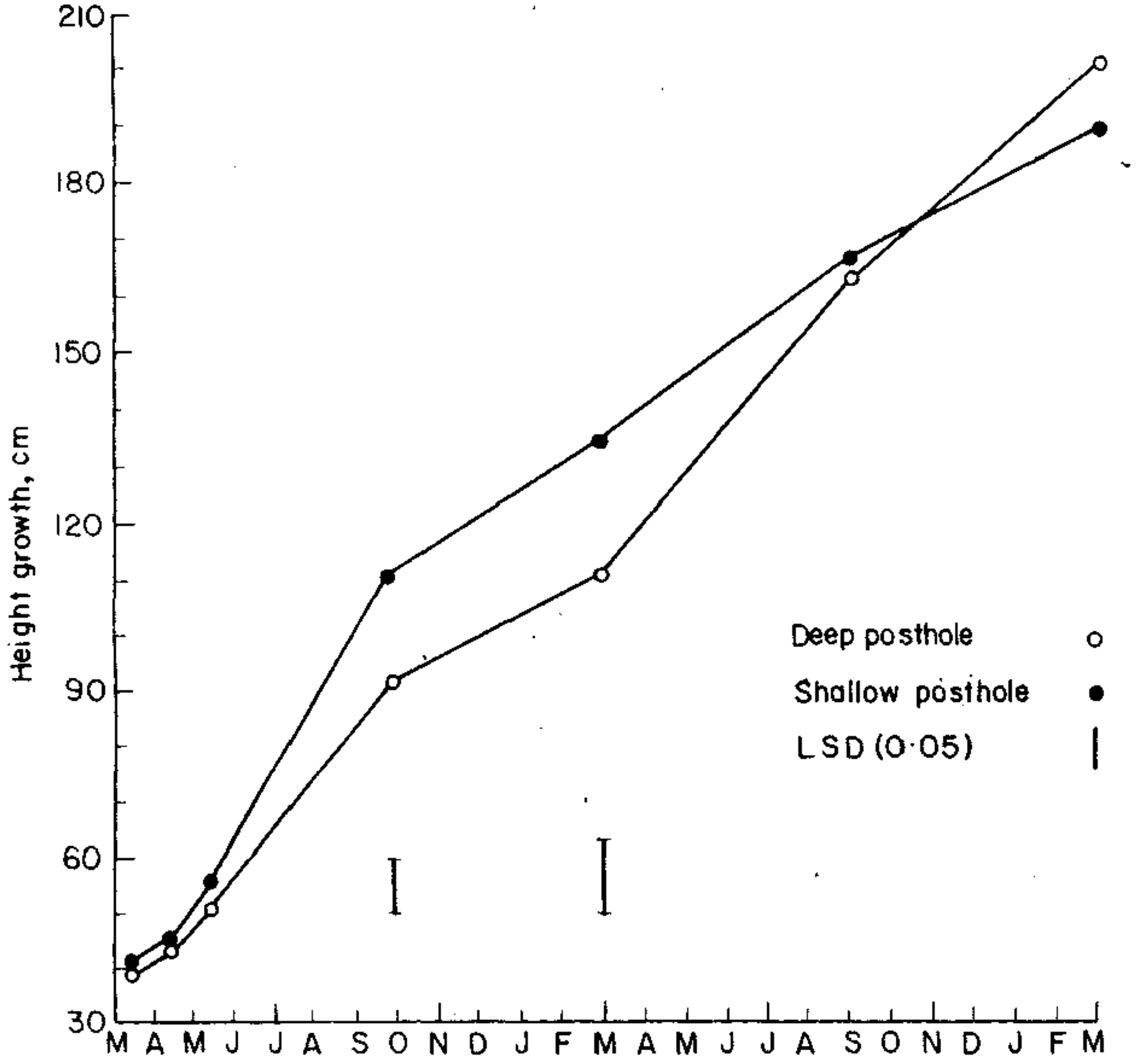


Fig. 25. Effect of posthole depth on the periodic height growth of surviving species.

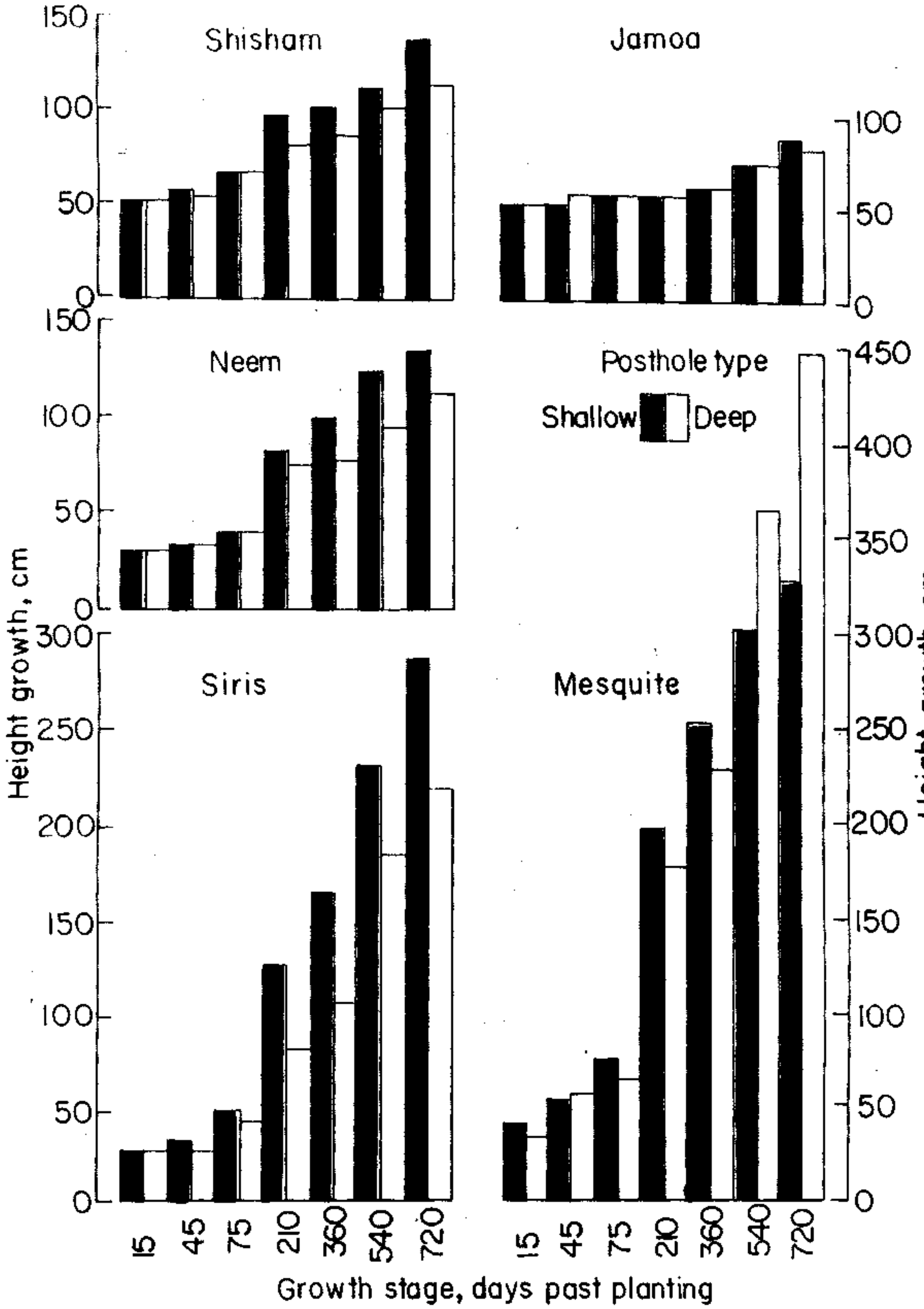


Fig. 26. Effect of posthole depth on height growth of given trees at selected growth stages.

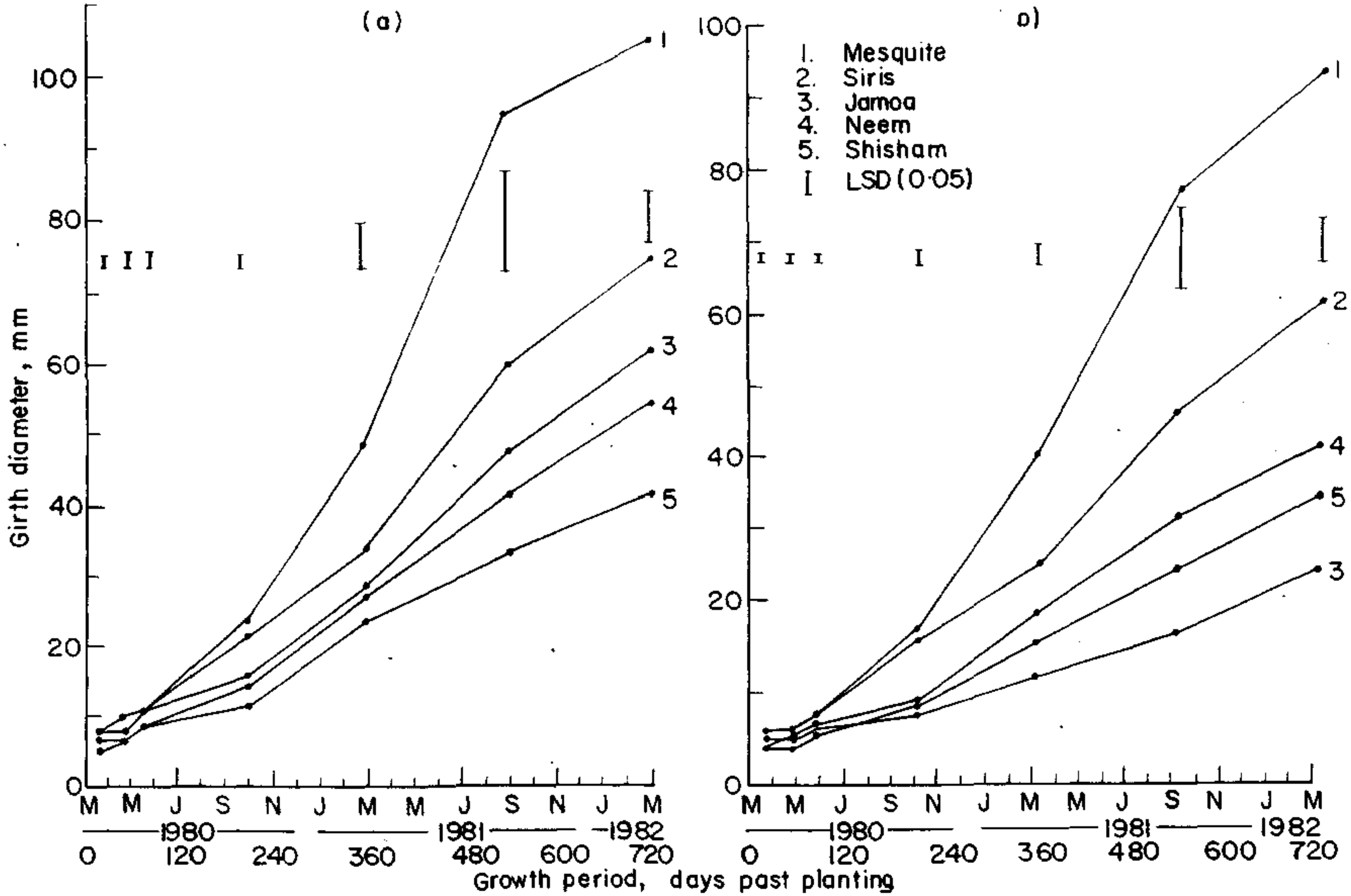


Fig.27. Periodic girth growth of selected species irrespect of posthole depths as measured by DSH (a) and DBH (b).

be the breakdown and mobilization of stored energy for continual survival once the plant system ceased synthesise food because of impending soil sodicity stress. Similar were the observations on girth growth at 30 cm height (Fig. 27b) except that girth diameter values were lower than DSH in all the species.

The DSH of Mesquite increased from 11 mm after 75 days to 104 mm (845 per cent) after 720 days of planting. Increase in Siris during the same span was 63 mm (573 per cent). But increase in the girth diameter of Mesquite and Siris at 30 cm height between 75-720 days of planting was 87 mm (1243 per cent) and 54 mm (675 per cent) respectively (Fig. 27b). Girth growth of Shisham, Neem and Jamoa occured at a relatively slower rate than either of Mesquite or of Siris. Girth growth of Neem was more consistent and girth diameter at 5 cm and 30 cm height recorded after 45, 75, 210, 360, 540 and 720 days past planting was 7, 99, 14, 28, 42, 54 and 4, 6, 9, 18, 32, 42 mm respectively. This indicated an overall increase of 47 mm (671 per cent) and 38 mm(950 per cent) in diameter at 5 and 30 cm height during 720 days of growth. Corresponding values for Shisham and Jamoa were 500 (35 mm) and 580 (29 mm) per cent and 589 (53 mm) and 367 (22 mm) per cent respectively. Girth growth equations of the given tree species planted in shallow and deep postholes are presented in Table 77.

Effect of the two posthole types was also significant on the girth diameter at 5 and 30 cm stem height of the surviving species throughout the noted growth period except first 75-210 days (Fig.28). Stump girth diameter in both types of posthole planting was at par until 210 days of planting irrespect of the given species. However,

Table 77. Girth growth equations of the given tree species

Girth diameter (mm) of species	Growth equation	R^2
(a) Girth diameter at 5 cm height of stem when planted in shallow postholes.		
Siris	$3.6 + 0.100\ d + 2.89 \times 10^{-5}\ d^2$	0.986**
Neem	$3.4 + 0.084\ d + 3.69 \times 10^{-6} d^2$	0.989**
Shisham	$4.7 + 0.050\ d - 4.11 \times 10^{-6} d^2$	0.983**
Mesquite	$6.6 + 0.063 + 1.97 \times 10^{-5} d^2$	0.981**
Jamoa	$2.2 + 0.107 + 2.68 \times 10^{-5} d^2$	0.987**
Mean	$4.3 + 0.0734 + 2.61 \times 10^{-5} d^2$	0.982**
Girth diameter at 5 cm height of stem when planted in deep postholes		
Siris	$7.2 + 0.038\ d + 5.15 \times 10^{-5} d^2$	0.991**
Neem	$4.2 + 0.078\ d - 3.59 \times 10^{-5} d^2$	0.935**
Shisham	$6.7 + 0.028\ d + 4.04 \times 10^{-5} d^2$	0.997**
Mesquite	$8.8 + 0.015\ d + 8.67 \times 10^{-5} d^2$	0.997**
Jamoa	$-1.1 + 0.169\ d + 2.68 \times 10^{-5} d^2$	0.987**
Mean	$6.0 + 0.050 + 5.30 \times 10^{-5} d^2$	0.987**
(b) Girth diameter at 30 cm height of stem when planted in shallow postholes.		
Siris	$4.3 + 0.40 + 7.78 \times 10^{-5} d^2$	0.991**
Neem	$2.0 + 0.046 + 3.45 \times 10^{-5} d^2$	0.982**
Shisham	$4.2 + 0.022 + 2.47 \times 10^{-5} d^2$	0.997**
Mesquite	$4.3 + 0.033 + 6.38 \times 10^{-6} d^2$	0.990**
Jamoa	$0.5 + 0.086 + 4.17 \times 10^{-5}$	0.985**
Mean	$2.5 + 0.051 + 3.19 \times 10^{-5}$	0.985**
Girth diameter at 30 cm height of stem when planted in deep postholes.		
Siris	$6.5 + 0.008 + 6.74 \times 10^{-5}$	0.978**
Neem	$3.8 + 0.015 + 3.61 \times 10^{-5}$	0.994**
Shisham	$4.8 + 0.016 + 3.55 \times 10^{-5}$	0.999**
Mesquite	$5.0 + 0.019 + 1.77 \times 10^{-5}$	0.995**
Jamoa	$-1.5 + 0.121 + 5.09 \times 10^{-5}$	0.980**
Mean	$3.7 + 0.034 + 4.47 \times 10^{-5}$	0.992**

d denote days past planting.

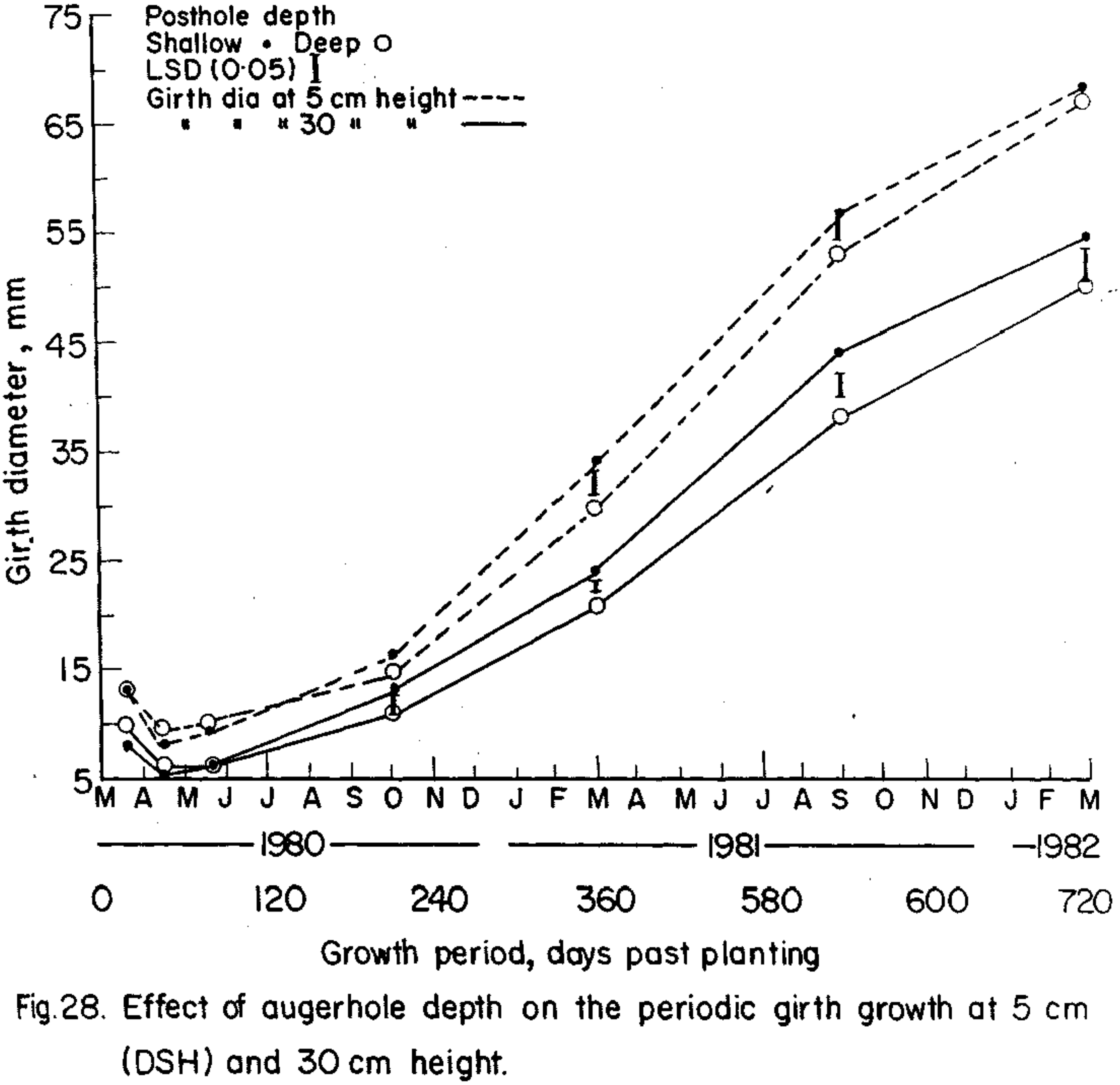


Fig. 28. Effect of augerhole depth on the periodic girth growth at 5 cm (DSH) and 30 cm height.

girth diameter at 30 cm height differed significantly with the two types at this growth stage. Subsequently, the average girth diameter at both the heights remained significantly greater in shallow than in the deep posthole planting. But this differences in stem height girth diameter at 720 days growth stages attained almost parity. This may be attributed to different growth behaviour of the given tree species when planted in the two types of postholes. Girth diameter at 5 cm (Fig. 29) and 30 cm (Fig. 30) stem height of *Siris* and *Neem* was significantly greater in shallow than in the deep posthole planting at all the growth stages beyond 210 days of planting. But opposite was true for Mesquite. Such an effect was, however, unmarked in *Shisham* and *Jamoa*. Data further showed that the absolute girth diameter at 5 cm height was markedly higher than at 30 cm of the five species throughout the recorded growth period.

The height and girth growth data, thus, clearly indicated relatively greater tolerance of Mesquite and *Siris*. Mesquite showed rapid early growth in the deep postholes whereas *Siris* and *Neem* in shallow ones despite their considerable mortality. This brings out that the latter two need sodic soil amelioration to a greater degree for their establishment caused by application of same dose of gypsum and FYM in shallow than the deep postholes with a larger volume. Cent per survival of *Shisham* was an interesting observation but its growth of height and girth was quite slow. *Jamoa* also showed very slow growth. The results corroborate the reports of several authors compiled by Yadav (1980). However, there is no evidence in literature to compare growth and per cent survival of the given tree species in view of the physico-chemical characteristics of different planting sites with the one under this experiment.

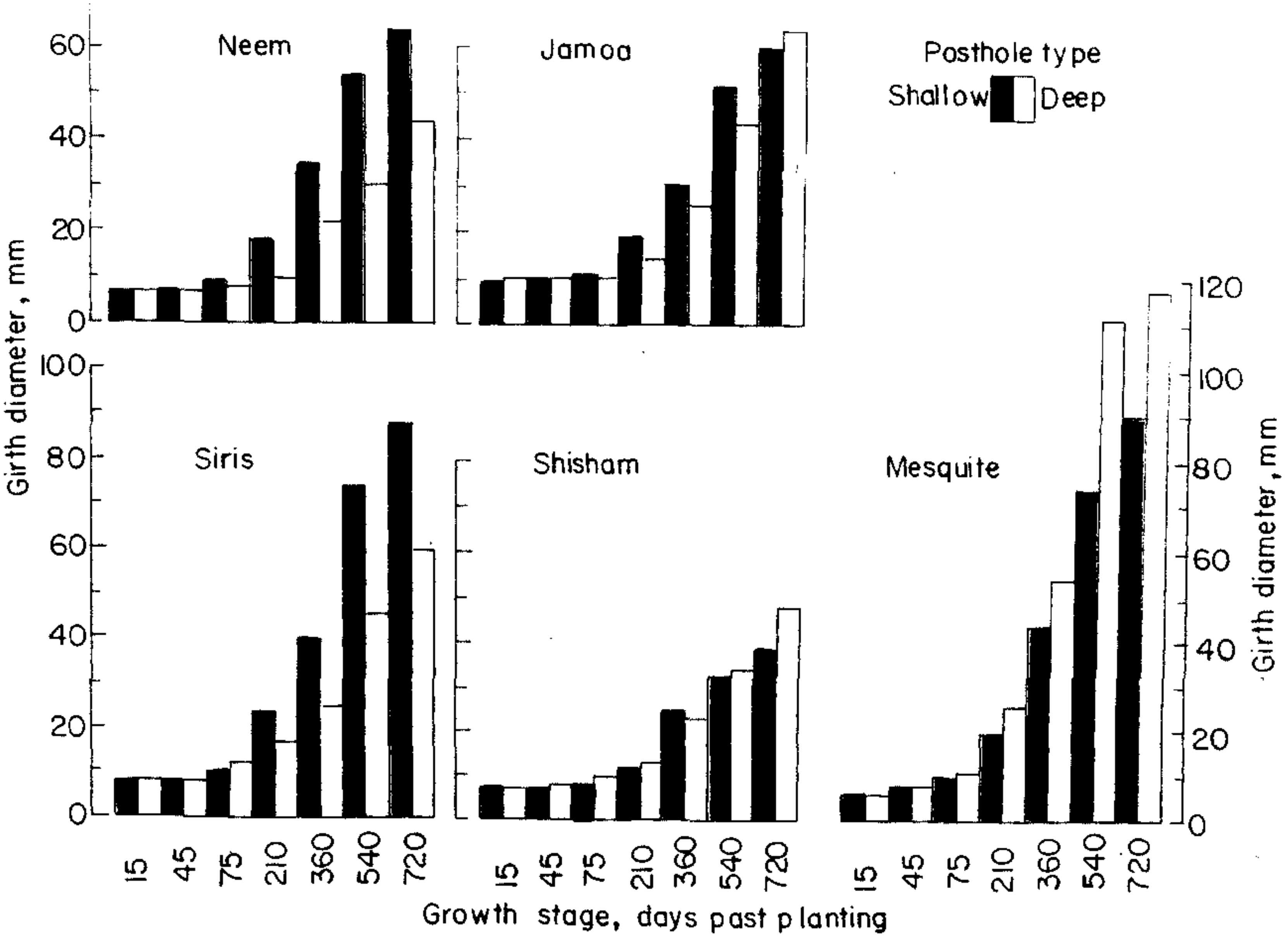


Fig. 29. Effect of posthole depth on DSH of given trees at selected growth stages.

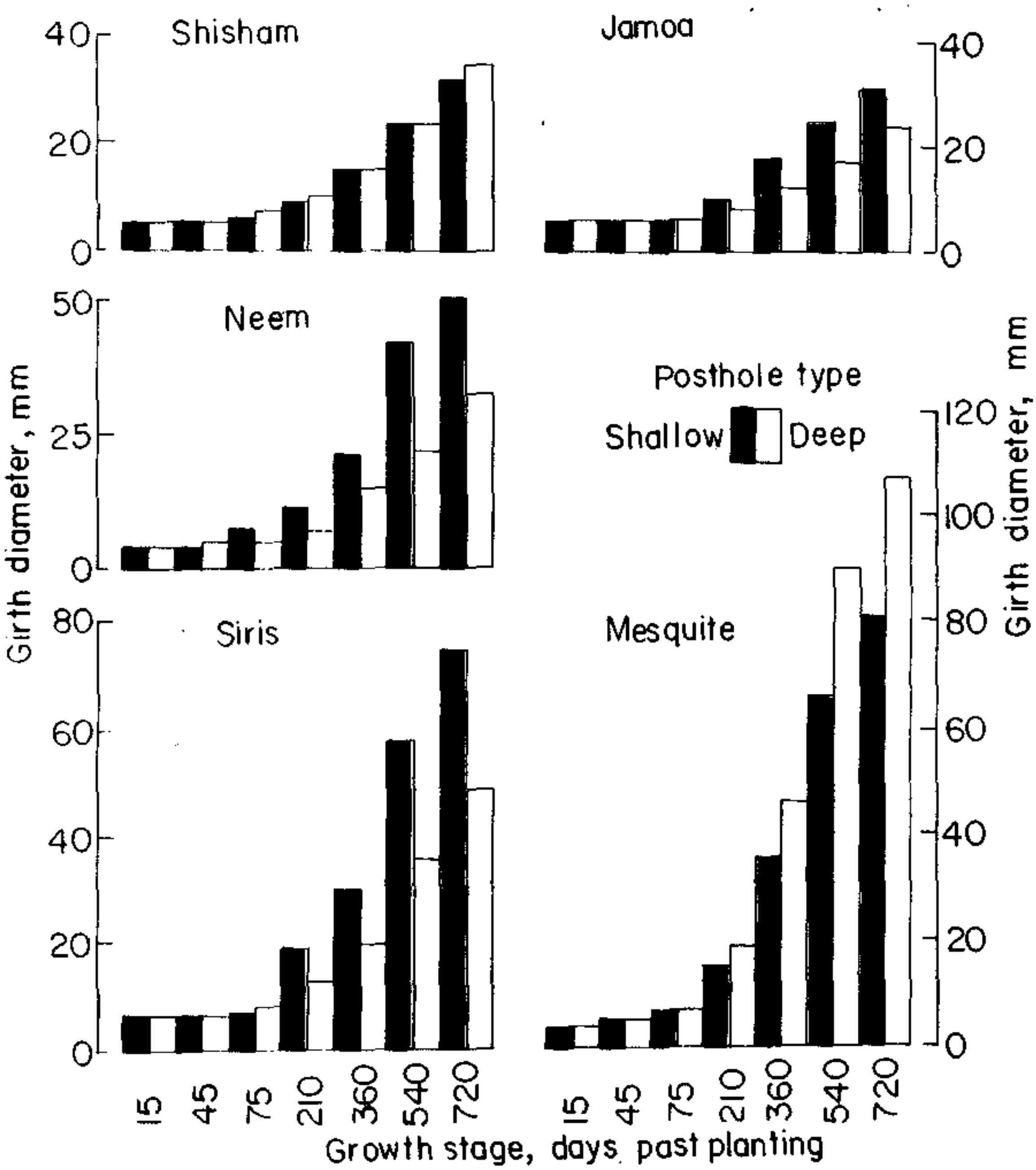


Fig. 30. Effect of posthole depth on DBH of given trees at selected growth stages.

C. Primary Biomass Production: Data (Table 78) on average biomass yield per plant of the five tree species in a growth period of 720 days indicate huge differences among themselves. Mesquite yielded the highest amount of dry matter whereas it was the lowest in the case of Jamoa. The mean total of a Mesquite plant was measured 17718 and was several folds the per plant yield of Siris (5577 g), Neem (654 g), Shisham (349 g) and Jamoa (293 g). Similar order was observed for the aerial (foliage and woody matter) biomass yield (Table 78), roots (Table 79) and the woody matter (Table 80) components of the total biomass production of these species. In case of foliage, Shisham interchanged its rank with Jamoa (Table 80). Bioass yields recorded on fresh weight basis of all the components of these species were considerably high due to the moisture content. Mean moisture content of roots, woody matter and foliage was determined to vary between 52-65, 54-67 and 56-72 per cent respectively.

Results also show the significant effect of two types of post-holes on the total biomass yield (Table 78) as well as the different components namely roots (Table 79); foliage and woody matter in the form of stem and twigs or billets (Table 80). Mesquite produced significantly higher biomass when planted in deep (23252 g plant^{-1}) than in shallow (12183 g plant^{-1}) postholes. Trend was contrary to Siris. This type of effect was not significant in Neem, Jamoa and Shisham. However, relative yields of different plant components, and in turn, the total biomass was more in the deep postholes whereas Neem and Jamoa gave more yield in the shallow postholes. Shoot-root relations of these species typify the greater efficiency of the root syst of Mesquite in producing significantly higher aerial biomass comprising foliage and woody matter (stem and secondary branches). This is clear

Table 78. Biomass yield (g $plant^{-1}$) after 720 growth days of the given species planted in shallow and deep postholes in a highly sodic soil.

Species	Oven dry basis			Fresh weight basis		
	Shallow	Deep	Mean	Shallow	Deep	Mean
			Aerial biomass (Foliage+ stem and twigs)			
Siris	4983 (5537)	2212 (2458)	3598 (3998)	11918 (13242)	5268 (5853)	8593 (9548)
Neem	584 (649)	316 (351)	450 (500)	1350 (1500)	702 (780)	1026 (1140)
Shisham	156 (173)	265 (294)	211 (234)	554 (616)	770 (856)	662 (736)
Mesquite	10532 (11702)	19699 (21888)	15116 (16796)	26297 (29219)	47298 (52553)	36798 (40887)
Jamoa	199 (221)	150 (167)	175 (194)	608 (676)	464 (515)	536 (596)
Mean	3291 (3656)	4528 (5032)	3910 (4344)	8145 (9050)	10900 (12112)	9523 (10581)
LSD (0.05):	Species		218 (242)			264 (293)
	Postholes		222 (247)			252 (280)
	Interaction		276 (307)			323 (359)
			Total (Foliage + Stem and twigs + Roots)			
Siris	8538 (9487)	2616 (2907)	5577 (6197)	19783 (21981)	6330 (7033)	13057 (14508)
Neem	901 (1001)	406 (451)	654 (727)	2186 (2429)	990 (1100)	1588 (1764)
Shisham	282 (313)	415 (461)	349 (388)	869 (966)	1232 (1369)	1051 (1168)
Mesquite	12183 (13537)	23252 (25836)	17718 (19687)	29983 (33314)	54532 (60591)	42258 (46953)
Jamoa	326 (362)	258 (287)	293 (326)	921 (1023)	717 (797)	819 (910)
Mean	4446 (4940)	5389 (5988)	4918 (5464)	10748 (11943)	12760 (14178)	11755 (13061)
LSD (0.05):	Species		1320 (1467)			1460 (1622)
	Postholes		684 (760)			1296 (1440)
	Interaction		1868 (2076)			1964 (2182)

Figures in parentheses denote corresponding values in kg ha^{-1}

Table 79. Root biomass production (g plant^{-1}) after 720 growth days of the given species planted in shallow and deep postholes in a highly sodic soil.

Species	Oven dry basis			Fresh weight basis		
	Shallow	Deep	Mean	Shallow	Deep	Mean
Siris	3555	404	1980	7865	1062	4464
	(3950)	(449)	(2200)	(8739)	(1180)	(4960)
Neem	317	90	204	836	288	562
	(352)	(101)	(227)	(929)	(320)	(624)
Shisham	126	150	138	315	462	389
	(140)	(167)	(153)	(350)	(513)	(432)
Mesquite	1651	3553	2602	3686	7234	5460
	(1834)	(3948)	(2891)	(4096)	(8038)	(6067)
Jamoa	127	108	118	282	228	255
	(141)	(120)	(131)	(313)	(253)	(283)
Mean	1155	861	1008	2597	1855	2226
	(1283)	(957)	(1120)	(2686)	(2061)	(2473)
LSD (0.05)	Species		304			368
			(338)			(409)
	Postholes		192			284
			(213)			(316)
	Interaction		430			562
			(478)			(624)

Figures in parentheses denote corresponding values in kg ha^{-1}.

Table 80. Biomass yield (g plant^{-1}) after 720 growth days of the given species planted in shallow and deep postholes in a highly sodic soil.

Species	Oven dry basis			Fresh weight basis		
	Shallow	Deep	Mean	Shallow	Deep	Mean
			Foliage			
Siris	736 (818)	425 (472)	581 (646)	2654 (2949)	1428 (1587)	2041 (2268)
Neem	153 (170)	135 (150)	144 (160)	388 (431)	338 (376)	363 (404)
Shisham	35 (39)	46 (51)	41 (46)	128 (142)	168 (187)	148 (164)
Mesquite	2308 (2546)	4177 (4641)	3243 (3603)	7665 (8517)	13462 (14958)	10564 (11738)
Jamoa	70 (78)	56 (62)	63 (70)	242 (269)	182 (202)	212 (236)
Mean	660 (733)	968 (1076)	804 (893)	2235 (2483)	3116 (3462)	2676 (2973)
LSD(0.05): Species			104 (116)			206 (229)
Postholes			65 (72)			112 (124)
Interaction			146 (162)			218 (242)
			Woody matter (Stem and twigs excluding foliage)			
Siris	4247 (4718)	1787 (1986)	3017 (3352)	9264 (10293)	3840 (4267)	6552 (7280)
Neem	431 (479)	181 (201)	306 (340)	962 (1069)	364 (404)	663 (737)
Shisham	121 (134)	219 (243)	170 (189)	426 (473)	602 (669)	514 (571)
Mesquite	8224 (9138)	15522 (17247)	11873 (13192)	18632 (20702)	33836 (37596)	26234 (29149)
Jamoa	129 (143)	94 (104)	112 (124)	366 (407)	282 (313)	324 (360)
Mean	2630 (2922)	3561 (3957)	3096 (3439)	5930 (6589)	7785 (8650)	6857 (7619)
LSD(0.05): Species			765 (850)			878 (976)
Postholes			563 (630)			614 (682)
Interaction			1082 (1202)			1282 (1424)

Figures in parentheses denote corresponding values in kg ha^{-1}.

from the data (Table 81) showing widest shoot:root ratio of Mesquite. Shoot:root ratios of Siris and Neem grown up in shallow postholes were also noted to be considerably wide. But their absolute yields of the aerial biomass (shoot) were markedly less than that of Mesquite. Shisham and Jamoa had narrow shoot: root ratios as well as unsatisfactory growth of both the roots and shoots.

Table 81. Shoot:root ratios of biomass produced by different species in a growth period of 720 days.

Species	Oven dry biomass			Fresh		
	Shallow	Deep	Mean	Shallow	Deep	Mean
Siris	1.40	5.48	1.82	1.52	4.96	1.93
Neem	1.84	3.51	2.21	1.62	2.44	1.83
Shisham	1.24	1.77	1.53	1.76	1.67	1.70
Mesquite	6.38	5.54	5.81	7.13	6.54	6.74
Jamoa	1.57	1.39	1.48	2.15	2.04	2.10
LSD (0.05)	Species		1.08			1. 22
	Postholes		1.18			1.07
	Interaction		1.28			1.32

In Mesquite, per cent contribution of roots, foliage and aerial woody matter towards total biomass yield was computed to about 14, 29 and 67 per cent in both types of postholes (Fig.31). Similar values for both types of postholes indicate its high tolerance to sodicity hazard because these postholes otherwise effected significant differences in its biomass productivity. These differences may have resulted from the different mechanical impedence experienced by the roots of Mesquite in shallow and deep postholes during initial growth stages. Fractionation of total biomass yield of Siris in shallow postholes among different

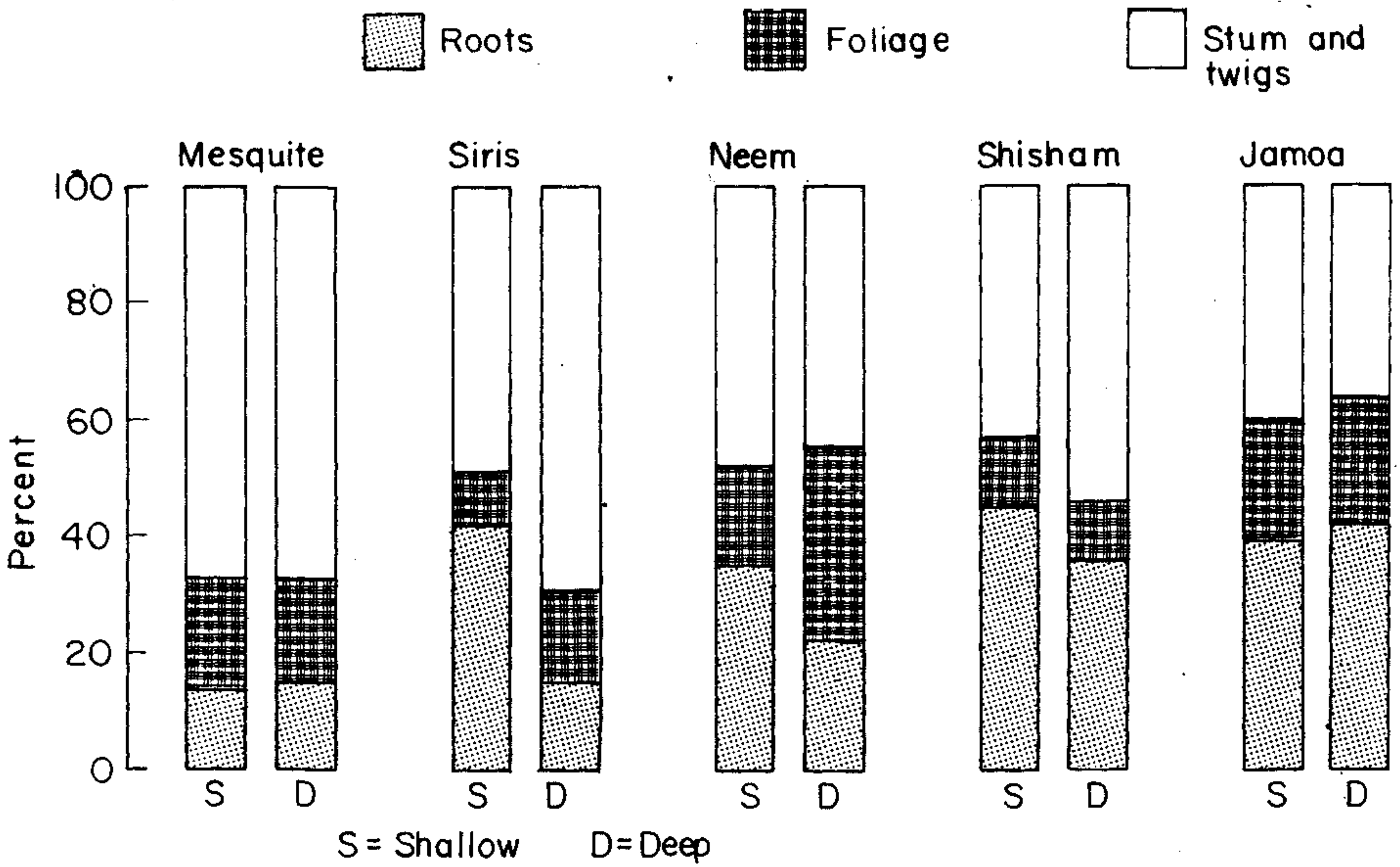


Fig.31. Percent contribution of root, foliage and woody matter towards average total biomass (dry) yield of given species in two types of postholes.

components was similar. Aerial woody matter component of Neem, Shisham, Jamoa and Siris in deep postholes showed little variation among themselves and it was significantly less than that of Mesquite and Siris in the shallow postholes. Foliage of Neem in deep postholes made relatively greater contribution than in the shallow ones towards its total yield. On the basis of these results it may be deduced that Mesquite is tolerant to extremely high soil sodicity. It produced a dense growth of roots in soil layers whose ESP was measured above 90, however, root and shoot biomass was significantly less in shallow than in the deep postholes owing to the greater mechanical impedance faced by its roots during downward growth. Its high tolerance to soil sodicity is also evident from greater efficiency of the root system i.e. production of more aerial biomass per unit biomass of the roots. Siris followed by Neem performed better in shallow than in deep postholes. They were found able to penetrate their roots across the calcic horizon, a severe physical impediment in the soil profile. This implies that both are fairly tolerant to the mechanical impedance of the calcic horizon and high soil sodicity. But they may require more careful management during the initial stages and amelioration of the sodic soil of the planting pit or posthole to a greater extent. Since the tolerance of plants to stress environments vary with growth stages, this aspect relating to these species needs carrying out more research work. Shisham and Jamoa did not grow satisfactorily though the survival of the former species was cent per cent throughout the growth span of 720 days past planting.

Data on primary biomass production, thus, bring out that hazards of high soil sodicity and mechanical impedance greatly modify the growth behaviour of different tree species. A highly tolerant species like Mesquite may require amelioration of the sodic soil of the planting pit to a lesser degree. But its biomass production may be enhanced markedly by limited perforation of the calcic horizon. Siris and Neem may need more care and amelioration for establishment in the initial stages only. Mesquite and Siris were also reported by Yadav et al. (1975) to perform well when planted in pits, 90 cm each in depth to perform well when planted in pits, 90 cm each in depth and diameter. Good performance of these species when planted through posthole technique was also a promise to make planting operation economical and less troublesome. In view of their life span and potential yields (NAS, 1980) under diverse situations of agroclimate and soil types, Mesquite may be ranked a highly tolerant, Siris and Neem moderately and Shisham and Jamoa poorly tolerant of highly sodic soil conditions.

D. Chemical Composition of Plant Components: Concentration of Na in the foliage of different tree species (Table 82) was observed generally higher than in roots and in aerial woody matter (stem and twigs). Foliage and roots of Mesquite showed significantly higher Na than other species. Sodium in foliage and woody matter of Siris was notably less. But it indicated relatively greater accumulation in roots than Neem, Shisham and Jamoa. Effect of posthole depth on Na concentration of the three plant components was not significant. However, foliage of Mesquite in deep postholes contained more than double the Na content in shallow ones. It was contrary in the case of Neem. Roots of Siris and Neem in shallow postholes had significantly less Na accumulation than in deeper ones. But the trend was opposite in Mesquite. The variation in Na concentration of the given plant components may be due to different mechanisms of its absorption as well as translocation. Better growth of Mesquite despite high Na accumulation infers its tolerance to

Table 82. Na, K, Ca and Mg concentration (mmol kg^{-1}) of foliage, roots and aerial woody matter of different tree species.

Species	Foliage			Stem and twigs			Roots		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
Sodium									
Siris	78	61	70	48	35	41	74	165	117
Neem	396	100	248	100	100	100	74	109	91
Shisham	139	143	141	78	91	85	87	83	85
Mesquite	96	213	160	78	96	87	139	117	128
Jamoa	109	152	130	104	104	104	109	104	107
Mean	165	135	148	83	87	85	96	113	104
LSD(0.05)	Species		43			22			9
	Postholes		NS			NS			4
	Interaction		61			NS			13
Potassium									
Siris	172	354	262	185	138	164	205	167	185
Neem	228	267	249	174	200	187	279	251	267
Shisham	305	251	277	192	190	192	156	156	156
Mesquite	428	305	367	97	44	72	236	136	192
Jamoa	143	131	138	87	64	76	110	108	110
Mean	256	261	259	146	133	141	197	164	179
LSD(0.05)	Species		21			15			26
	Postholes		NS			10			15
	Interaction		35			23			43
Calcium									
Siris	767	425	595	150	150	150	148	270	210
Neem	457	662	560	143	188	168	100	100	100
Shisham	650	632	640	208	220	215	140	150	145
Mesquite	507	500	502	200	195	198	220	275	248
Jamoa	387	375	382	300	228	265	198	200	199
Mean	555	520	535	200	195	198	160	200	180
LSD().05)	Species		58			25			20
	Postholes		35			NS			13
	Interaction		83			35			30
Magnesium									
Siris	750	504	625	221	208	215	175	271	221
Neem	462	362	412	187	162	175	212	229	221
Shisham	358	421	387	196	212	204	225	300	362
Mesquite	492	383	437	100	108	104	208	171	187
Jamoa	417	375	396	258	212	235	292	267	279
Mean	496	408	450	192	179	187	221	246	233
LSD(0.05)	Species		54			21			12
	Postholes		37			12			8
	Interaction		79			33			21

sodicity. Poor performance of Siris and Neem in deep postholes may be due to the greater concentration of Na in roots itself.

Relative concentration of K among different plant components was about 2-4 times higher than of Na (Table 82). Its accumulation like Na was also more in foliage followed by roots (except in Shisham) and woody material. Foliage of Mesquite contained significantly more K (367 mmol kg^{-1}) than Shisham (277 mmol kg^{-1}), Siris (262 mmol kg^{-1}), Neem (249 mmol kg^{-1}) and Jamoa (138 mmol kg^{-1}). Effect of posthole depths was not significant on K concentration of different species in general. But accumulation of K in the foliage of Siris and Neem was more with deep than in shallow postholes. It was the opposite in case of Mesquite. This may be attributed to the dilution effect of better growth of Mesquite in deep and Siris and Neem in shallow postholes. Potassium concentration in woody matter of Shisham and Neem was significantly more than in Siris. It was the lowest in Mesquite and Jamoa. However, Neem followed by Mesquite and Siris showed significantly greater accumulation in roots than Shisham and Jamoa. Results, thus, show that relatively greater concentration of K in roots of Siris and Neem may help to counter the entry of Na in plant system. But in Mesquite, difference in K concentrationof roots in deep and shallow postholes appears to be due to differential growth.

Accumulation of Mg and Ca in different components of given (Table 82) tree species was also more in foliage than roots followed by aerial woody matter. But concentration of Ca in twigs and billets of Neem, Shisham and Jamoa was more than of its roots. Relative concentrations of Ca and Mg in the three components of different species were more than those of Na and K. But a few exceptions in roots were noted. Accumulation of Ca was maximum in Shisham followed by Siris, *Neem*, Mesquite and *Jamoa*. But this order was observed to change for Ca concentration in woody matter to *Jamoa*, *Shisham*, Mesquite *Neem* and *Siris*. In respect of Ca accumulation in roots it was Mesquite, *Siris*, *Jamoa*, *Shisham* and *Neem*. This shows that Ca concentration may be associated with the ability of the root systems of different species to check entry of Na in roots because growth and survival of these species also followed this ranking. Concentration of Mg (mmol kg^{-1}) in foliage of *Siris* (625) was significantly more than Mesquite (437), *Neem* (412), *Jamoa* (396) and *Shisham* (387). Concentration of Mg in woody matter of Mesquite was significantly less than in *Neem* followed by *Shisham*, *Siris* and *Jamoa*. Accumulation of Mg in roots of *Siris* and *Neem* was nearly equal but significantly higher than in Mesquite and lower than in *Jamoa* and *Shisham*. Data (Table 82) on relative concentration of Na, K, Ca and Mg in foliage, woody material and roots, thus show that their relative accumulation in roots and foliage gave more information in determining tolerance mechanism of different species beside absorption and translocation of these elements.

Results on concentration of P, S and N (Table 83) in foliage, aerial woody matter and roots also show that their accumulation was more in the foliage followed by roots and woody branches. Differences in the concentration of N were more pronounced than those of P and S due to tree species. Accumulation of P in the foliage of Mesquite was significantly more than *Neem*, *Siris*, *Shisham* and *Jamoa* indescending order. Similar trend was observed for S accumulation in foliage. But concentration of P in the woody material and roots of Mesquite was significantly less than in *Siris*, *Neem* and *Shisham*. Sulphur accumulation in woody matter did not vary markedly among the species.

Table 83. P, S and N concentration (mmol kg^{-1}) of foliage, roots and aerial woody matter of different tree species.

Species	Foliage			Stem and twigs			Roots		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
				Phosphorus					
Siris	95	117	106	47	37	42	77	108	93
Neem	117	129	123	30	56	43	33	45	39
Shisham	86	95	90	35	36	35	56	57	57
Mesquite	153	130	141	24	17	21	36	24	30
Jamoa	96	81	88	30	21	25	85	84	85
Mean	109	110	110	33	33	33	57	64	61
LSD (0.05)	Species		14			6			5
	Postholes		NS			NS			3
	Interaction		20			9			7
				Sulphur					
Siris	80	115	97	38	49	44	78	130	104
Neem	131	97	114	49	59	54	90	78	83
Shisham	86	94	90	37	53	45	60	60	60
Mesquite	195	157	176	74	44	59	111	110	111
Jamoa	72	68	70	56	44	50	88	87	88
Mean	113	107	110	51	50	50	86	93	89
LSD (0.05)	Species		13			6			8
	Postholes		NS			NS			7
	Interaction		18			8			14
				Nitrogen					
Siris	878	1014	946	464	510	487	512	555	534
Neem	564	612	588	284	306	295	322	338	330
Shisham	1276	1094	1235	568	572	570	594	626	610
Mesquite	992	826	909	444	404	424	556	518	537
Jamoa	590	636	613	296	326	311	372	414	393
Mean	860	856	858	411	424	418	471	490	480
LSD (0.05)	Species		214			116			128
	Postholes		120			NS			NS
	Interaction		278			134			159

But its concentration (mmol kg^{-1}) in roots of Mesquite (111) was more than in Siris (104), Jamoa (88) and Neem (83). Relative accumulation of P and S were many times less than that of N. Concentration of N (mmol kg^{-1}) in the foliage of leguminuous species namely Shisham (1235), Siris (946) and Mesquite (909) were considerably more than the non-leguminuous species i.e. Jamoa (613) and Neem (588). Similar trend was observed for accumulation of N in roots and woody mass of these species. Effect of posthole depth on the concentration of N, P and S in the woody matter, P and S in foliage and N in roots of different species was not significant. However, accumulations of N in foliage and that of P and S in roots of these species varied significantly. These differences are the outcome of the differential dilution effects resulting from different growth rates of these species and the ability of leguminuous species to fix atmospheric dinitrogen symbiotically. Viewing the concentration of N, P and S in plant components of these species in association with their growth and biomass production, it may be deduced that the species able to fix atmospheric dinitrogen were able to tolerate sodic conditions better than the others. Concentrations of these nutrients in foliage conform to the observations of other workers (Ayoub, 1975; Rouhani and Bassiri, 1976; Garg and Khanduja, 1979).

Data (Table 84) on the concentration of Fe, Mn, Zn and Cu in the three components of the plants showed significant variation due to the species and among the components of a given species. Accumulation of Fe in roots of Siris (94.2 mmol kg^{-1}) was significantly more than in Mesquite, Jamoa, Neem and Shisham. Concentration of Fe in roots of Siris, Neem, Mesquite and Jamoa was notably more than in foliage followed by woody material. Effect of posthole depth on the concentration of Fe in the foliage and in woody matter was not

Table 84. Fe, Mn, Zn and Cu concentration (mmol kg^{-1}) of foliage, roots and aerial woody matter of different tree species.

Species	Foliage			Stem and twigs			Roots		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
				Iron					
Siris	7.75	6.55	7.15	5.36	2.53	3.95	140.32	48.24	94.20
Neem	5.82	5.82	5.82	7.05	4.38	5.71	19.42	25.62	22.52
Shisham	7.82	10.18	9.00	6.16	6.64	6.40	9.82	9.89	6.65
Mesquite	10.55	6.73	8.64	10.44	15.11	12.78	27.46	25.82	26.68
Jamoa	8.18	8.73	8.45	6.42	7.93	7.16	24.92	22.66	23.74
Mean	8.02	7.60	7.80	7.09	7.33	7.20	44.42	26.44	35.43
LSD (0.05)	Species		2.14			1.44			4.32
	Postholes		NS			NS			2.70
	Interaction		2.06			2.04			6.08
				Manganese					
Siris	2.13	1.79	1.95	4.16	3.05	3.61	6.25	4.57	5.41
Neem	1.43	0.89	1.16	4.91	3.23	4.07	9.64	8.45	9.04
Shisham	3.75	2.86	3.30	4.57	5.05	4.80	4.66	4.82	4.75
Mesquite	2.02	1.79	1.89	4.71	5.25	4.98	10.61	16.36	13.48
Jamoa	2.50	2.14	2.32	4.29	4.54	4.41	23.73	21.77	22.75
Mean	2.29	1.89	2.09	4.54	4.23	4.38	10.98	11.20	11.09
LSD (0.05)	Species		0.41			0.89			0.80
	Postholes		0.25			NS			0.50
	Interaction		0.57			1.27			1.13
				Zinc					
Siris	0.23	0.25	0.23	0.31	0.25	0.28	0.26	0.62	0.43
Neem	0.43	0.49	0.46	0.14	0.12	0.12	0.20	0.18	0.18
Shisham	0.42	0.43	0.43	0.19	0.15	0.17	0.15	0.15	0.15
Mesquite	0.51	0.45	0.48	0.09	0.11	0.10	0.22	0.34	0.28
Jamoa	0.31	0.28	0.30	0.11	0.12	0.11	0.20	0.20	0.20
Mean	0.38	0.38	0.38	0.17	0.15	0.16	0.20	0.29	0.25
LSD (0.05)	Species		0.05			0.05			0.03
	Postholes		NS			NS			0.02
	Interaction		0.07			NS			0.05
				Copper					
Siris	0.14	0.14	0.14	0.08	0.06	0.08	0.17	0.38	0.27
Neem	0.13	0.14	0.14	0.09	0.06	0.08	0.13	0.14	0.13
Shisham	0.17	0.14	0.16	0.09	0.08	0.08	0.09	0.09	0.09
Mesquite	0.20	0.17	0.19	0.08	0.08	0.08	0.16	0.19	0.17
Jamoa	0.11	0.13	0.12	0.08	0.08	0.08	0.16	0.16	0.16
Mean	0.16	0.14	0.15	0.08	0.08	0.08	0.14	0.19	0.16
LSD (0.05)	Species		0.02			NS			0.03
	Postholes		NS			NS			0.02
	Interaction		NS			0.01			0.03

significant. However, Mesquite showed significantly higher Fe concentration in foliage with shallow postholes. The trend was opposite for aerial woody matter. *Siris* and *Neem* grown in deep postholes accumulated more Fe than the plants grown in shallow posthole was the highest (140.32 mmol kg^{-1}). In case of Mn, concentration in roots was higher than in the woody matter followed by the foliage. Differences in composition due to the species were pronounced more with respect to their roots and the foliage than them and branches. Relative accumulation of Mn was less than of Fe in all of the species. Posthole depth significantly affected Fe concentration of foliage and of roots. Accumulation of Zn unlike Mn and Fe was more in the foliage than in roots followed by the woody material in general. But *Siris* showed less accumulation of Fe in the foliage than the other two components. Differences in concentration of Zn and Cu of the foliage and woody matter due to posthole depths were not pronounced. Relative concentration of Zn and Cu in the given components of these species were considerably higher than Fe and Mn. Concentration of Cu in foliage of Mesquite (0.19 mmol kg^{-1}) was the highest and significantly more than in the other species. Highest Cu accumulation in roots was in *Siris* (0.27 mmol kg^{-1}). Copper accumulation in woody matter of these species was nearly the same. In view of slow nutrition rate of trees in general (Kramar and Kozlowski, 1960) and the critical limits reported by several workers compiled in a review (Kanwar and Randhawa, 1978) the concentrations of Fe, Mn, Zn and Cu observed may be termed adequate for normal growth of these species in a highly sodic soil.

E. *Root Studies of Tree Species:* Root systems of the species which survived and grew at different rates during initial 720 days after planting were studied intensively. Pertinent results are presented below:

(a) *Root Penetration Depth:* Data (Table 85) showed that roots of Mesquite penetrated to a greater depth than other species. In deep postholes roots were observed growing to a depth of 222 cm whereas in shallow postholes, the root penetration was reduced significantly to 189 cm depth. Next to Mesquite, it was *Siris* whose roots penetrated down to 184 cm in shallow (Plate 7) and 188 cm in deep postholes. Root penetration of *Shisham* and *Jamoa* was significantly greater in deep than in shallow postholes. But in case of *Neem*, the effect of postholes on root penetration depth was not evident. Results, thus, indicate that species greatly differed in respect of their root penetrability under similar conditions of planting site modification. This may be attributed to differences in their tolerance to soil sodicity and mechanical impedance at different depths of the profile. For example, Mesquite showed greater root penetration and shoot growth in deep than in shallow postholes whereas reverse was true for *Siris* (Plate 7).

Table 85. Effect of posthole depth on root penetration depth (cm) of different tree species.

Species		Posthole depth		Mean
		Shallow	Deep	
Siris		184	188	186
Neem		127	119	123
Shisham		86	135	111
Mesquite		189	222	206
Jamoa		132	168	150
LSD () .05)	Species			15
	Posthole depths			10
	Interaction			22

Plate 7

A Siris (720 days old) plant in deep posthole with limited root and shoot growth.

A Mesquite plant (720 days old) in deep posthole with promising root and shoot growth.

(b) Site Modification Technique and Root Growth Behaviour: Different species showed (Table 86) significant differences to produce fine and large roots in the two types of postholes. Fine roots biomass of Mesquite in shallow postholes (417.6 g plant^{-1}) was significantly less than in deeper ones (1243.8 g plant^{-1}). It was reverse in the case of large roots. However, the total biomass was also about double in deep than in the shallow postholes. In case of Siris, large roots in shallow and deep postholes constituted 97 and 86 per cent of the total biomass respectively. Effect of two types of postholes on fine root biomass was not significant, however, large root biomass in shallow postholes was about 7-8 times more than in the deep ones. Root system of Siris in shallow posthole was observed stoutly developed whereas in the deep type the roots were observed mostly confined to the ameliorated soil volume of the posthole (Plate 8). This indicates that the application of more amendments per unt volume (or mass of OS) in shallow posthole favoured development of a resolute root system of Siris than the dilution of same amount of amendments in a larger volume of deep postholes. Fine root biomass of Shisham and Jamoa was notably more than of other species but their root systems were observed (Plate 9) to be poorly developed. Neem produced more fine roots in deep than in shallow postholes. Data showed that deep postholes favour growth of finer roots. This is ascribed to the tillage effect which increased porosity of the soil mass. This has been reported favourable for root growth because it reduces soil strength (Taylor and Bruce, 1968; Rogers and Jhurlow, 1973; Grives et al., 1975). In Mesquite and Siris it was noted that roots in shallow postholes became thicker when penetrated to depths beyond that of shallow postholes.

Table 86. Effect of posthole depth on per plant biomass of fine and large roots of different tree species in a highly sodic soil.

Species	Fine roots			Large roots			Total		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
Siris	69.4	57.9	63.6	2622.5	347.3	1484.9	2691.9	407.3	1549.6
	(3)	(14)	(8)	(97)	(86)	(92)			
Neem	23.0	13.3	18.1	328.4	76.4	202.4	351.3	89.7	220.5
	(7)	(15)	(11)	(93)	(85)	(89)			
Shisham	29.9	53.3	41.6	85.7	128.5	107.1	116.1	181.7	148.9
	(26)	(29)	(28)	(74)	(71)	(72)			
Mesquite	417.6	1243.8	830.8	1233.2	2094.5	1663.9	1650.8	3348.1	2499.5
	(25)	(37)	(31)	(75)	(63)	(69)			
Jamoa	48.5	33.0	40.7	78.6	74.7	76.6	127.1	95.0	111.0
	(38)	(30)	(34)	(62)	(70)	(66)			
Mean	117.7	280.3	199.0	869.7	544.3	707.0	987.4	824.4	905.9
	(20)	(25)	(23)	(80)	(74)	(77)			
LSD (0.05)	Species		53.9			271.2			293.7
			(1)			(2)			
	Posthole depths		34.1			171.5			185.7
			(8)			(1)			
	Interaction		76.2			383.5			415.3
			(2)			(3)			

Figures in parentheses stands for respective percentage of the total.

(c) Cation Exchange Capacity of Roots of Tree Species: Data (Table 87) indicate that RCEC of leguminuous trees i.e. Mesquite, Siris and Shisham was significantly more than that of Neem and Jamoa. The RCEC of all the species was observed decreasing with increasing thickness or woodiness. This may be due to decreased activity on suberization (Kramar and Kozlowski, 1960) and proportionate reduction in the root surface per unit mass with increasing thickness. Considerably higher RCEC in case of leguminuous trees may be associated with higher N supply which generally increases RCEC of plant roots. Root zone was also found to have a bearing on changes in RCEC of a given species. The RCEC values for different species were noticed to decrease with depth. But the rate of decrease was more with species whose RCEC was markedly high. High RCEC of Mesquite and Siris may cause greater uptake of polyvalent cations i.e. Ca and Mg relative to the monovalents (Na and K). Dicots with higher RCEC values have been reported to take up polyvalent cations more efficiently than the monocots, which as a group have roots with low CEC values (Heintze, 1961). Should an essential polyvalent cation like Ca in sodic soil be in critically short supply, species with higher RCEC values would be more competitive than with low RCEC values (Bear, 1964). Decrease in RCEC of species with depth may be ascribed to the effect of soil environment. The RCEC is reported to correlate with the composition of the suite of cations taken up by some species (Heintze, 1961; Bear, 1964). It is concluded that high RCEC may help a species in sodic soils to avoid assimilation of Na or assist in greater absorption of polyvalent cations like Ca and Mg, the absorption of which counters the deterimental effects of Na in the metabolism, if any.

Table 87. RCEC of differently thick roots of different species.

Species	Root thickness (dia., mm)	Root zone, per cent of root penetration				Mean
		0–25	25–50	51–75	76–100	
Siris	Less than 2	36.4	32.8	30.4	26.7	31.6
	2– 5	21.5	20.4	18.7	16.3	19.2
	5– 10	13.2	14.2	12.3	10.2	12.5
	10– 20	8.8	9.6	8.2	6.6	8.3
	20– 40	5.9	4.8	3.6	3.5	4.5
	more than 40	3.6	3.5	3.8	3.8	3.7
	Mean	14.9	14.2	12.8	11.2	13.3
Neem	Less than 2	16.2	14.8	14.2	12.2	14.4
	2– 5	14.6	12.7	11.9	10.8	12.5
	5– 10	9.3	8.2	7.6	7.7	8.2
	10– 20	5.5	4.4	3.8	3.2	4.2
	20– 40	2.8	2.6	3.3	3.4	3.0
	Mean	9.7	8.5	8.2	7.5	8.5
Shisham	Less than 2	32.3	31.3	30.4	26.7	30.3
	2– 5	28.4	26.3	24.7	22.8	25.6
	5– 10	22.6	20.8	20.2	18.6	20.6
	10– 20	15.7	13.9	12.2	10.9	13.2
	20– 40	10.8	9.2	7.7	6.5	8.6
	Mean	22.0	20.4	19.7	17.1	19.6
Mesquite	Less than 2	38.4	36.2	32.6	30.8	34.5
	2– 5	34.3	32.7	30.8	29.2	31.8
	5– 10	26.5	22.9	21.1	20.4	22.7
	10– 20	14.3	12.6	10.7	11.2	10.7
	20– 40	8.2	7.2	6.8	7.8	7.5
	More than 40	5.7	4.8	5.2	5.0	5.2
	Mean	21.2	19.4	17.9	17.4	19.0
Jamoa	Less than 2	14.8	13.3	14.5	13.6	14.1
	2– 5	11.3	10.8	11.2	10.8	11.0
	5– 10	9.4	8.3	8.8	8.0	8.6
	10– 20	5.2	4.9	5.0	4.6	4.9
	20– 40	3.0	3.2	2.8	2.6	2.9
	Mean	8.7	8.1	8.5	7.9	8.3

(d) Layer-wise Root Distribution of Tree Species:

(i) Siris: Data (Table 88) show that root system of Siris was more well developed in shallow than in deep postholes. Total root biomass in each layer was significantly more in the shallow type. The concentration of large roots accounted for more than 96 per cent of the total biomass. But in deep postholes, amount of large as well as fine roots was relatively less though these penetrated the profile depth as in case of shallow postholes (Plate 8.). Maximum root diameter showed a decrease with root penetration but it was significantly more of Siris plants growing in shallow postholes. Biomass of fine as well as large roots was high in the surface layer and it showed a decrease with depth. The characteristic feature of the root system of Siris was pronounced growth of relatively larged sized roots in shallow postholes. There was profuse nodulation of Siris roots in the upper (0-30 cm) layers.

(ii) Mesquite: This species developed extensive root system (Table 88). Mesquite produced significantly higher root biomass in deep than in shallow postholes, however, root penetration depth in both types was almost the same. The amount of fine root biomass was particularly high in Mesquite. It was more in deep postholes. This indicates that perforation of the soil during digging and refilling of the postholes with ameliorated sodic soil favoured the growth of fine roots. Amount of large roots in the surface layer was more than in Siris. But in soil layers between 16-75 cm it was considerably less than Siris in shallow postholes. Despite Mesquite being a leguminuous tree, nodulation was not observed in any of the soil layers. Amount of fine as well as large roots decreased with depth down to 135-150 cm depth. Beyond this depth, roots were noted to proliferate away from the base of plant. This may be due to congenial soil conditions for root growth. Roots of

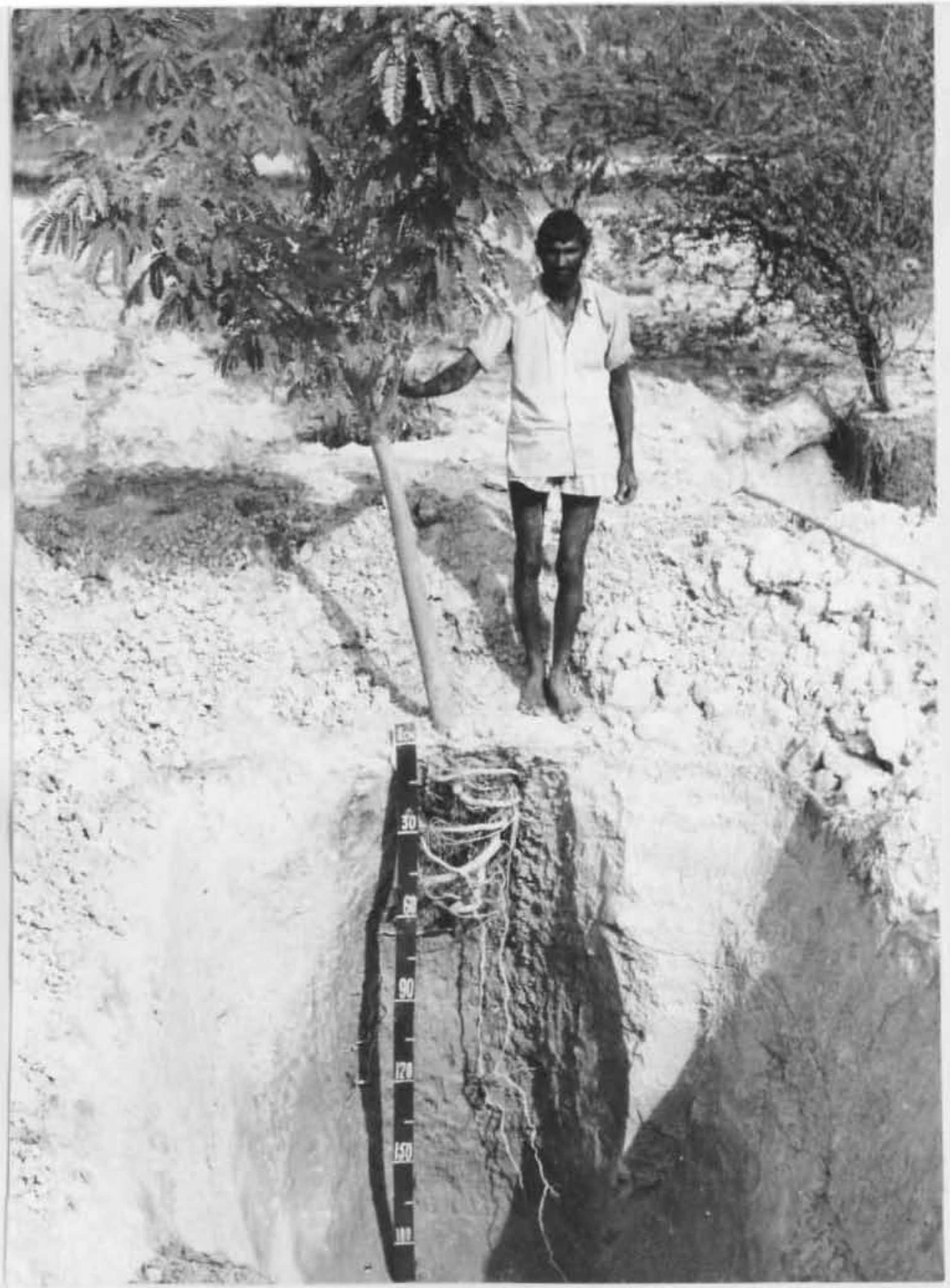
Table 88. Layer-wise root biomass (g) distribution of Mesquite and *Siris* planted in shallow and deep postholes.

Soil layer (cm)	Fine roots			Large roots			Total (Fine+Large)		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
					Siris				
0- 15	15.20	22.58	18.89	952.3	183.4	567.7	967.5	203.4	585.5
16- 30	19.85	8.70	14.27	967.3	84.4	525.9	987.3	93.1	540.2
31- 45	11.10	4.79	7.94	336.6	26.3	181.4	346.4	31.1	188.7
46- 60	8.06	5.66	6.84	239.1	16.8	128.0	247.1	22.5	134.8
61- 75	4.07	4.20	4.14	50.9	11.1	31.0	55.0	15.3	35.2
76- 90	2.72	4.11	3.41	25.0	7.2	16.1	27.7	11.3	19.5
91-105	2.10	3.83	2.96	16.6	4.8	10.7	18.7	8.6	13.6
106-120	1.76	2.44	2.10	10.1	3.7	6.9	11.8	6.2	9.0
121-135	1.83	1.83	1.83	8.3	3.6	6.0	10.1	5.5	7.8
136-150	1.82	0.89	1.36	7.8	2.2	5.0	10.3	3.3	6.8
151-165	1.38	0.61	1.00	5.2	3.2	4.2	8.2	2.6	5.4
166-180	1.25	0.47	0.86	4.1	1.1	2.6	5.3	1.5	3.4
181-195	0.62	0.29	0.43	2.3	0.6	1.4	2.9	0.9	1.9
196-210	0.45	0.28	0.36	1.1	0.6	0.8	1.5	0.9	1.2
					Mesquite				
0- 15	108.80	275.97	192.39	485.2	1000.7	743.0	594.0	1274.4	934.2
16- 30	85.31	202.91	144.11	348.6	574.2	461.4	434.0	778.3	606.1
31-45	70.28	153.11	111.70	71.2	107.4	89.3	141.5	270.2	205.8
46- 60	61.87	138.64	100.25	61.8	93.0	77.4	123.6	230.7	177.1
61- 75	16.62	110.68	63.65	32.8	53.7	43.2	49.4	164.4	106.9
76- 90	10.96	91.18	51.07	23.5	41.8	32.7	34.5	133.0	83.8
91-105	5.50	58.80	32.15	21.9	33.1	27.5	27.4	91.9	59.6
106-120	4.97	49.72	27.34	19.8	31.8	25.8	24.7	81.5	53.1
121-135	4.83	41.63	23.23	17.1	30.2	23.7	22.0	76.9	49.4
136-150	6.59	35.91	21.25	24.1	35.7	29.9	31.0	66.0	48.5
151-165	8.36	35.65	22.00	18.2	30.3	24.2	37.6	64.9	51.2
166-180	9.85	23.18	16.52	34.3	21.7	28.0	44.2	44.9	44.5
181-195	10.27	13.87	12.07	33.0	18.0	25.5	43.2	31.9	37.5
196-210	8.59	8.41	8.50	20.2	15.4	17.7	28.7	23.8	26.3
211-225	4.80	4.06	4.43	10.3	11.0	10.6	15.1	15.0	15.0

Plate 8

A *Siris* (720 days old) plant in shallow posthole with stout development of root system and shoot.

A close up of the root system of 720 days old *Siris* in a shallow posthole.


30
60
90
120
150
180

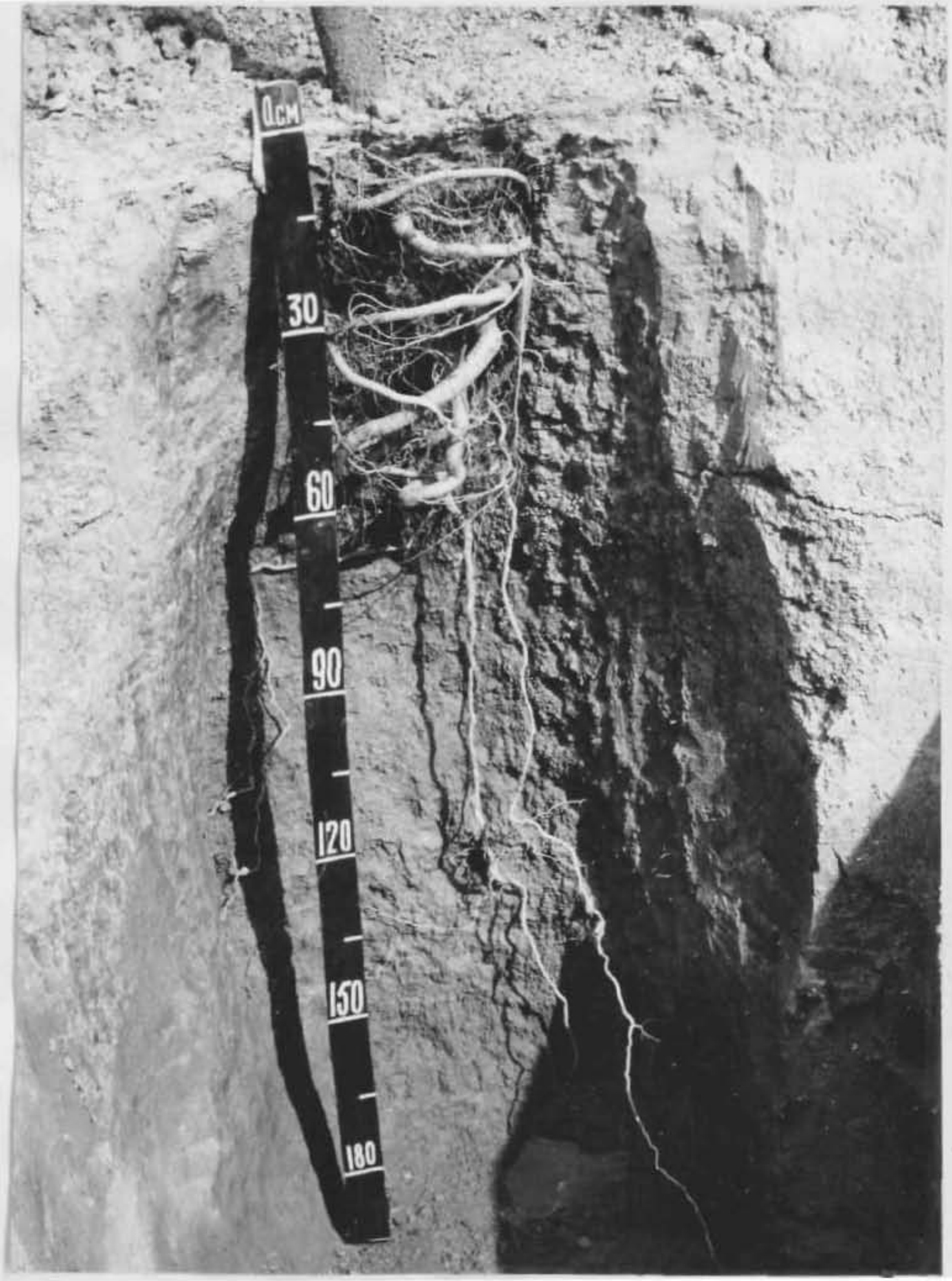

0 cm
30
60
90
120
150
180

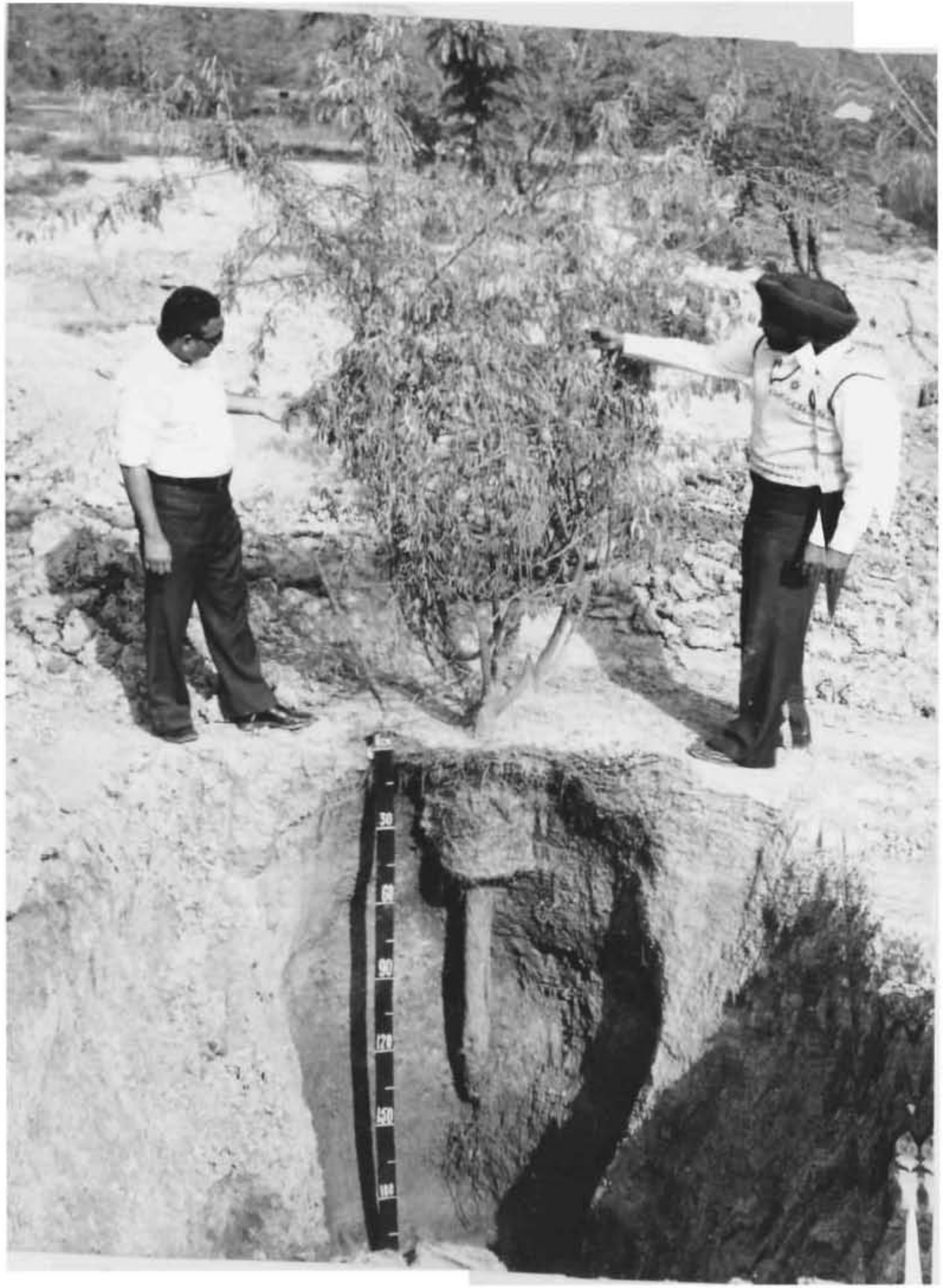
Table 89. Layer-wise root biomass (g) distribution of <u>Shisham</u>, <u>Neem</u> and Jamoa planted in shallow and deep postholes.

Soil layer (cm)	Fine roots			Large roots			Total (Fine+Large)		
	Shallow	Deep	Mean	Shallow	Deep	Mean	Shallow	Deep	Mean
				Shisham					
0- 15	5.51	12.27	8.89	40.7	67.6	54.1	46.1	79.8	63.0
16- 30	5.46	8.66	7.06	19.9	27.4	23.6	25.3	36.1	30.7
31- 45	5.93	6.43	6.18	10.8	12.9	11.9	16.7	19.3	18.0
46- 60	4.93	5.82	5.37	7.8	8.0	7.9	12.7	13.8	13.3
61-75	4.53	5.35	4.94	4.1	4.8	4.4	8.6	10.1	9.4
76- 90	3.54	4.33	3.93	6.0	7.6	6.8	6.0	7.6	6.8
91-105	-	3.98	3.98	-	2.3	2.3	-	6.3	3.2
106-120	-	3.24	3.24	-	1.2	1.2	-	4.4	2.2
121-135	-	2.27	2.27	-	0.8	0.8	-	3.1	3.1
136-150	-	1.86	1.86	-	0.4	0.4	-	2.3	2.3
				Neem					
0- 15	3.66	2.96	3.31	82.3	43.1	62.7	86.0	46.1	66.0
16- 30	6.22	3.60	4.91	89.5	13.8	51.6	95.7	17.4	56.6
31- 45	3.84	2.49	3.16	45.4	9.7	27.5	49.2	12.2	30.7
46- 60	2.87	1.56	2.21	39.2	3.9	21.6	42.2	5.5	23.8
61- 75	2.30	1.03	1.67	26.6	2.8	14.7	28.9	3.8	16.3
76- 90	1.65	0.79	1.22	18.6	1.6	10.0	20.2	2.4	11.3
91-105	1.13	0.55	0.84	13.0	1.0	7.0	14.1	1.5	7.8
106-120	0.76	0.32	0.54	7.6	0.5	4.0	8.3	0.8	4.6
				Jamoa					
0- 15	13.24	5.54	9.39	22.3	22.9	22.6	35.6	28.5	32.0
16- 30	11.54	5.31	8.43	19.9	17.0	18.4	31.4	22.3	26.9
31- 45	9.71	4.19	6.95	17.1	15.4	16.3	26.8	19.6	23.2
46- 60	8.71	4.17	6.44	14.9	8.8	11.9	23.6	13.1	18.4
61- 75	5.26	3.27	4.27	4.3	4.5	4.4	9.5	7.8	8.7
76- 90	-	2.39	1.21	-	1.8	0.9	-	4.2	4.2
91-105	-	2.13	1.08	-	1.6	1.6	-	3.7	3.7
106-120	-	1.96	1.00	-	1.0	1.0	-	2.9	2.9
121-135	-	1.71	1.71	-	1.0	1.0	-	2.7	2.7
136-150	-	1.03	1.03	-	0.9	0.9	-	1.9	1.9
151-165	-	0.62	0.62	-	0.9	0.9	-	1.5	1.5

Plate 9

A 720 days old Mesquite plant with promising growth of root and shoot in a deep posthole.

A close up of the extensively developed root system of a 720 days old Mesquite plant in a deep posthole.


30
60
90
120
150
180

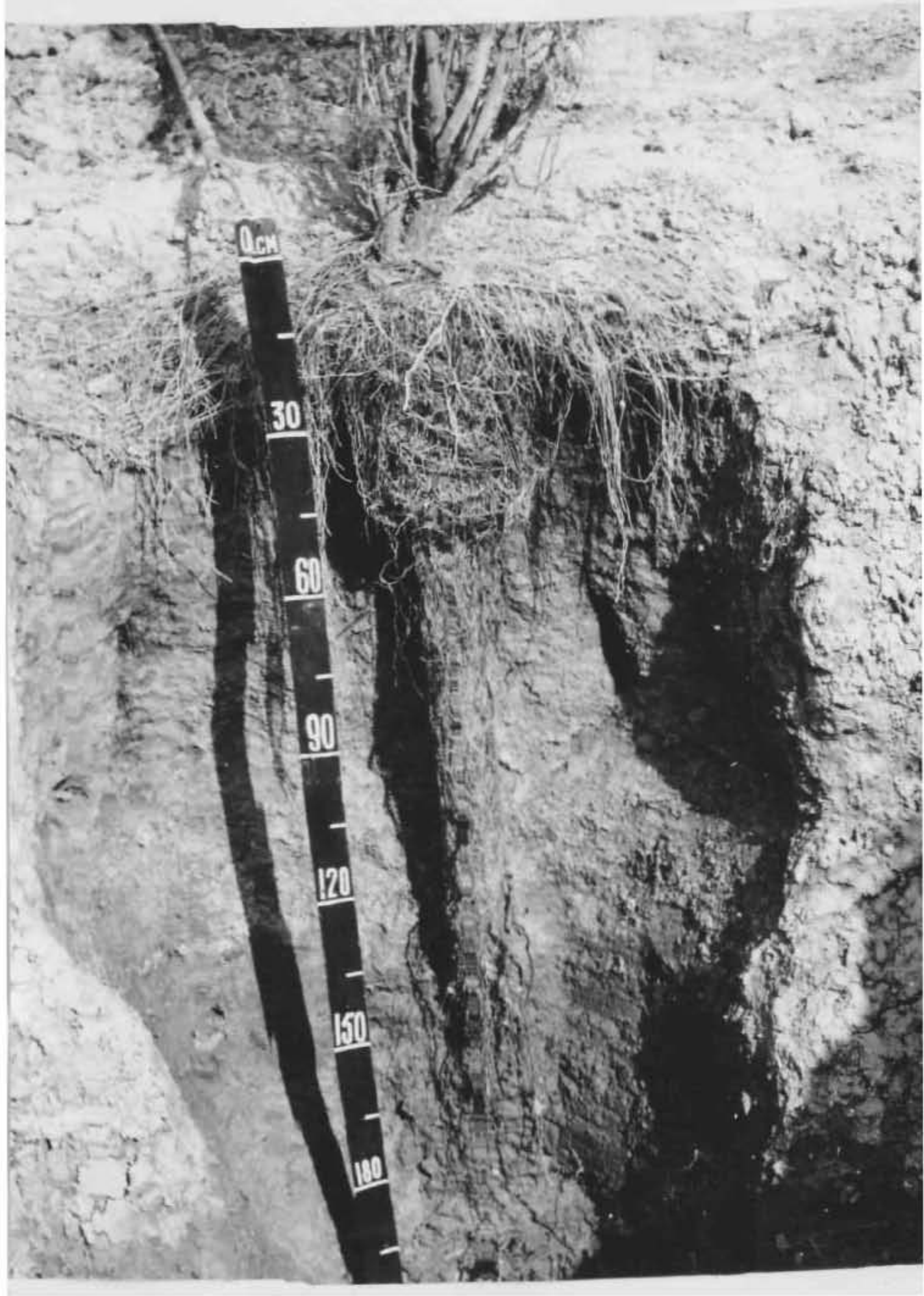
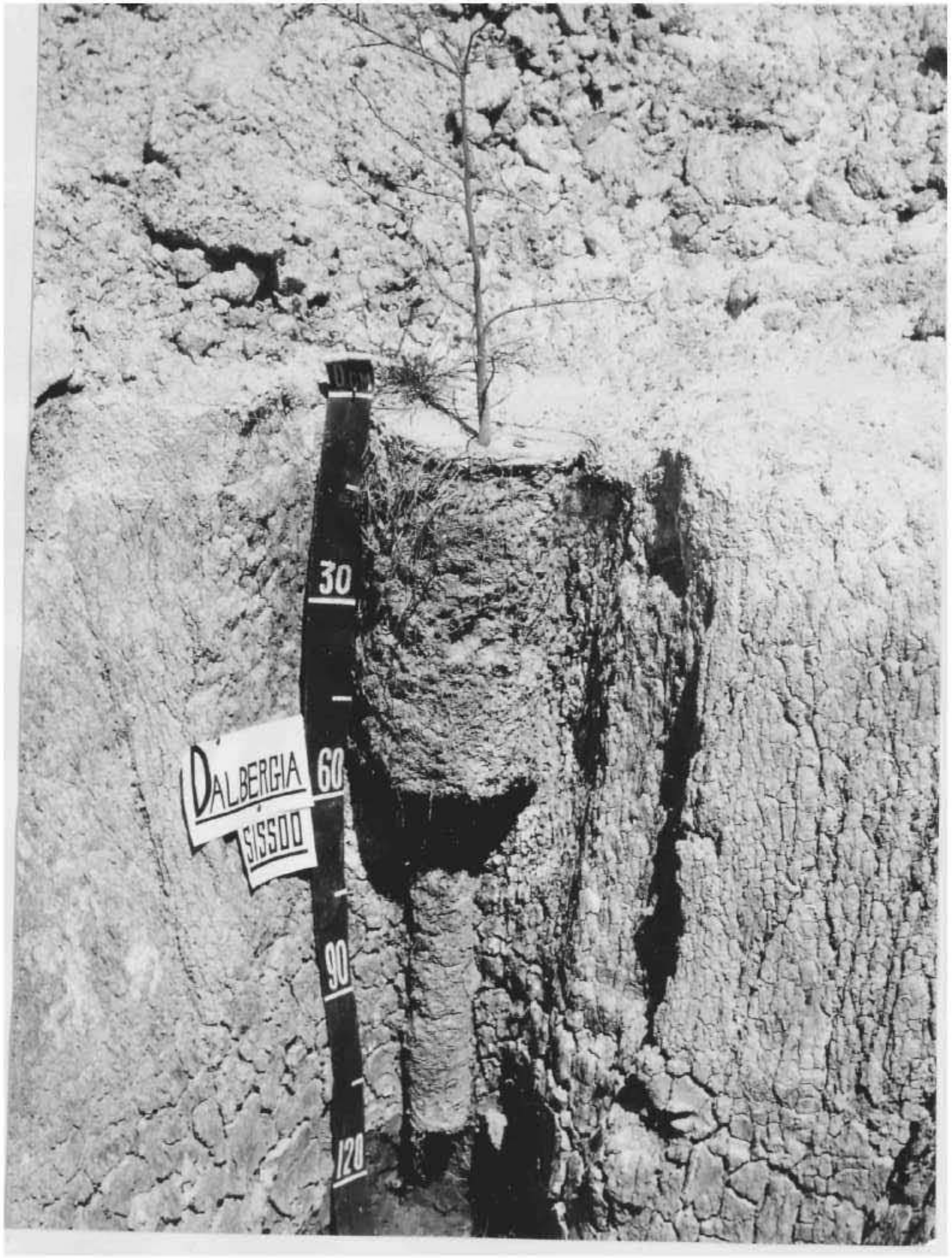

0 cm
30
60
90
120
150
180

Plate 10

A 720 days old *Jamca* plant in deep posthole.

A 720 days old *Shisham* plant in deep posthole.


SYZYGIUM
FRUTICOSUM
0 cm
30
60
90
120
150


DALBERGIA
SISSOO
0 cm
30
60
90
120

Mesquite were dark brown in colour as compared to pale white of Siris. These were extensively branched and beared profuse growth of fine root hairs on fine roots. Maximum root diameter was more in deep postholes than the shallow ones and it decreased with depth in both the cases. Plate 9 shows extensive growth of Mesquite roots in soil layers whose ESP was more then 90. This proves its high tolerance to highly sodic soil conditions.

(iii) Neem: Root growth as measured by production of biomass of fine and large roots of Neem showed (Table 89) that the amount of fine roots in both types of postholes was about same. But in shallow postholes, biomass in large roots and, in turn, total root biomass was significantly more than in the deep postholes. Roots were dark coloured in both types of the postholes and were brittle in nature in comparison to those of Mesquite.

(iv) Shisham and Jamoa: Root systems of Shisham and Jamoa were observed poorly developed (Plate 10). Biomass of their fine and large roots in the profile was almost equal in different layers. Shisham roots were found profusely nodulated owing to its ability to fix atmospheric dinitrogen in symbiosis with Rhizobium species.

4.6 Physico-Chemical Factors Influencing Mechanical Impedance in a Highly Sodic Soil Profile.

Introduction: Mechanical impedance (MI) or compactness has been reported (Barley and Greacen, 1967) to have widespread influence on root growth and penetration. It was suggested by Taylor et al. (1966) that soil strength should be recognised and evaluated in most experiments dealing with the plant-soil interactions. This is because some workers concluded that soil strength and not the bulk density (Db) was the critical factor in controlling root penetration. The range of MI which stopped root growth was reported (Barley and Greacen, 1967; Greacen et al., 1968) at 0.8 - 5.0 MPa. The mode of measurement probably influenced the difference. The factors which influence resistance of soil to metal penetrometers are soil bulk density, moisture content, texture, organic matter contents and the management practices. Studies were carried out to identify and model the role of some of these factors in a highly sodic soil under experiments on tree species.

Methodology: A static tip penetrometer was first used to quantify the MI of highly sodic soil. But in view of its inconsistency and poor repeatability under relatively dry conditions of the soil profile, an impact penetrometer was fabricated. Details regarding its fabrication, use to measure MI and calculation of energy in Kilojoules (KJ) are given in Chapter-III. To evaluate the influence of moisture content on MI, mechanical impedance of each layer of the soil profile was measured at five different moisture contents for computing the relationships between the two. The MI was calculated in SI units i.e. KJ.

Results and Discussion: The equational models which explain the influence of soil moisture on MI show a high degree of reciprocal relationship between them in different layers of a highly sodic soil profile (Table 90). With an increase in moisture content of the soil, there occurs a decrease in MI. But with a given increase in moisture content of the soil, the decrease in MI varies greatly among different layers of the profile. A fall in MI with a given increase in moisture content of the soil (Fig.32) was observed markedly greater for silty loam (0-90 cm) and loam (91-150 cm) layers than those of the loamy sand (151-210 cm) in the soil profile. Data also show that with decreasing moisture content of different soil layers, coefficient of variation showed a general increase. This was so more incese of

Table 90. Relationship of the mechanical impedance (KJ) with moisture content (v/v) in different layers of a highly sodic soil.

Depth (cm)	Equational model	Texture	N	R^2	Coefficient of variation at three soil moisture (%, v/v) ranges		
					Low (5-12)	Medium (13-25)	High (26-35)
0- 15	MI = 1886-46.5 M	sil	52	0.95***	8	5	3
16- 30	MI = 2532-62.4 M	sil	52	0.96***	10	8	5
31- 45	MI = 2676-65.6 M	sil	48	0.96***	14	8	6
46- 60	MI = 2576-60.7 M	sil	52	0.95***	13	10	7
61- 75	MI = 2708-59.8 M	sil	44	0.94**	12	9	6
76- 90	MI = 2694-58.2 M	sil	40	0.95***	18	10	7
91-105	MI = 2646-60.7 M	l	40	0.92***	31	21	12
106-120	MI = 2676-58.2 M	l	40	0.89***	41	22	15
121-135	MI = 2574-55.5 M	l	36	0.90***	40	23	16
136-150	MI = 2232-52.6 M	l	32	0.88***	20	18	12
151-165	MI = 1574-36.4 M	ls	32	0.97***	11	7	6
166-180	MI = 1195-27.8 M	ls	26	0.97***	10	8	5
181-195	MI = 1082-26.2 M	ls	26	0.97***	8	6	4
196-210	MI = 1136-29.5 M	ls	22	0.97***	9	7	4

MI and M stands for mechanical impedance and per cent moisture content on volume basis.

relatively heavy textured horizons of the soil profile. Values of coefficient of variation for layers between 91-150 cm, a zone of solid granules of calcium carbonate accumulation, indicated a wide variation probably due to limitation of the use of penetrometer for measuring MI. During measurements, it was observed that by chance or otherwise placement of the penetrometer tip on solid granules greatly enhanced the MI. The results, thus, clearly show that MI increases with the profile depth. But it varied little between 16-150 cm depth of the soil profile. Although MI showed a linear decrease with increase moisture content of the soil but in practice high sodicity of the surface soil and calcic horizon between 91-150 cm depth of the profile do not let the given zone of high MI have adequate moisture that lessen the soil strength. This may be the possible season for rapid root growth of several tree species when planted in deep postholes. A few trees were also found capable of growing roots across this zone at their own. This clearly pinpoints the necessity of evaluating tree species for their tolerance to the MI of a highly sodic soil. Mesquite, Siris, Neem, Casuarina and Babul were observed to show their capability in doing so.

These findings, thus, show that to modify MI of the soil for favourable root growth, irrigation is an important practice. Thus, irrigation in initial stages of planting tree species in a highly sodic soil may serve as an impetus to grow an extensive root system that will aid their establishment by increasing tolerance due to growth and utilizing a larger volume of the soil for absorption of water and essential plant nutrients. The reciprocal relationship of soil moisture and MI is reported (Barley and Greacen, 1967) to be a universal. But MI of a highly sodic soil was found much higher than values reported by Greacen et al. (1968) at which root growth stopped. This implies that MI is a major factor that check root growth and in turn the shoot

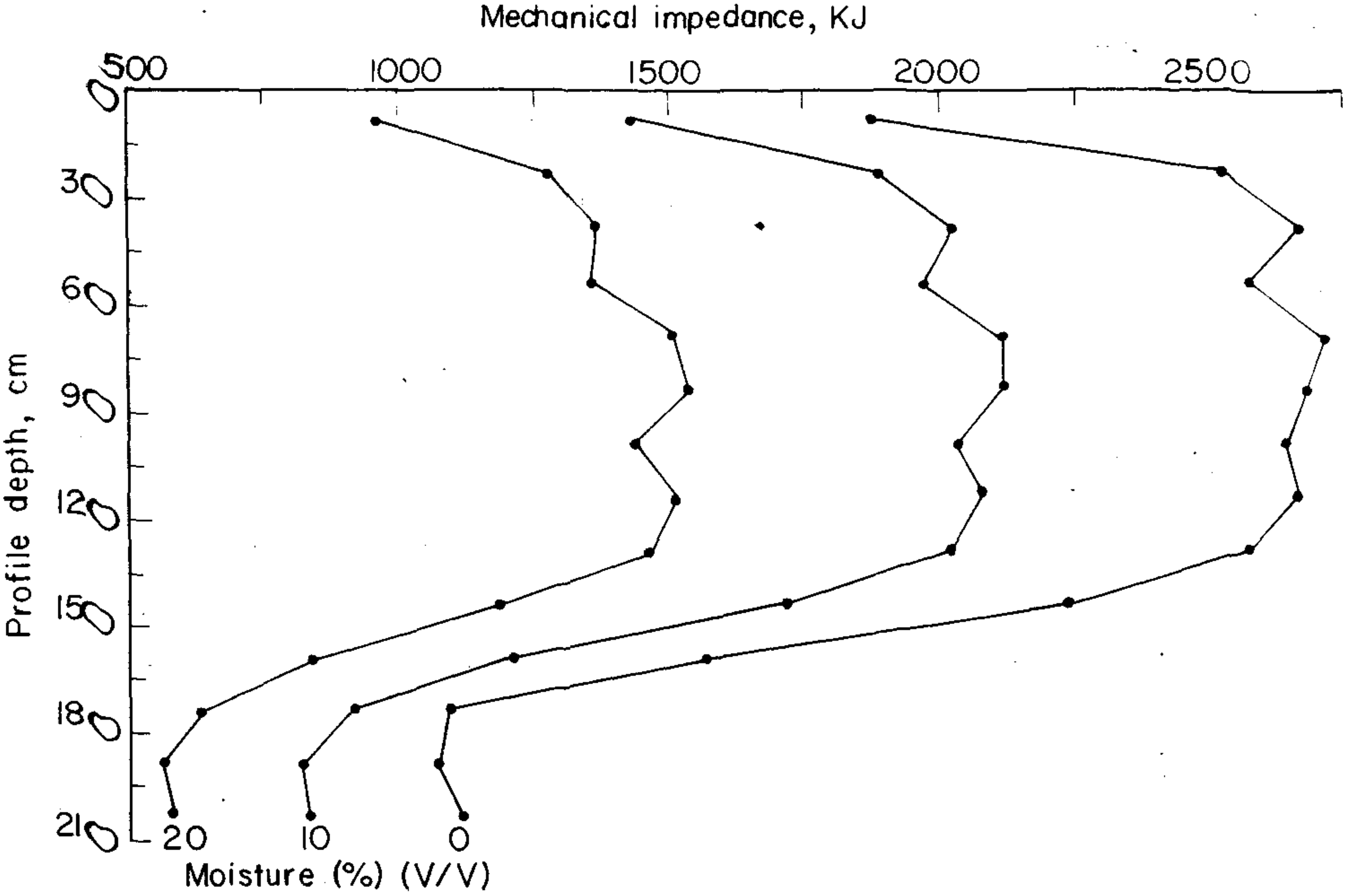


Fig. 3~~3~~2. Effect of moisture content on the mechanical impedance of different layers of the highly sodic soil.

growth of plants. For favourable growth, MI needs modification through tillage or irrigation or addition of organic matter to the root zone. Factors

Factors Affecting Mechanical Impedance:

To identify factors that affect soil strength irrespect of different layers of the soil profile, linear relationships of MI with clay, clay plus silt (finer fractions of the soil), Db, concretions (per cent, w/w), pH and ESP were worked out. The MI was observed closely related to the changes in finer fractions of the soil. Its relationship with per cent clay was highly significant (R^2 = 0.88**) and it showed (Fig. 33) further improvement with clay+silt. This may be responsible for a considerable increase in MI of the soil layers between 16-90 cm depth of the profile. As clay particles are negatively charged and a major fraction of charge occupied by sodium ions, their dispersion and transloca-tion to may also result in an increase in compactness. Dispersion ratio of the soil profile was also found highly related (r = 0.91**) to the soil strength (MI).

The relationship of soil Db with MI (Fig. 34) was also significant (R^2 = 0.73**) although at relatively low values, there was a considerably variation in MI of the soil. This may due to large variations in MI due to other factors i.e. clay, silt, ESP, void ratio etc. Such a variation in MI led to a poor relationship (R^2 = 0.11) of concretions per cent (w/w) with MI though the zone of concretion accumulation in the profile was actually observed exhibiting a high mechanical impedance (Table 90, Fig. 32). This was so due to an equivalent MI of soil layers containing less concretions between 0-90 cm and those having a very high content of concretions between

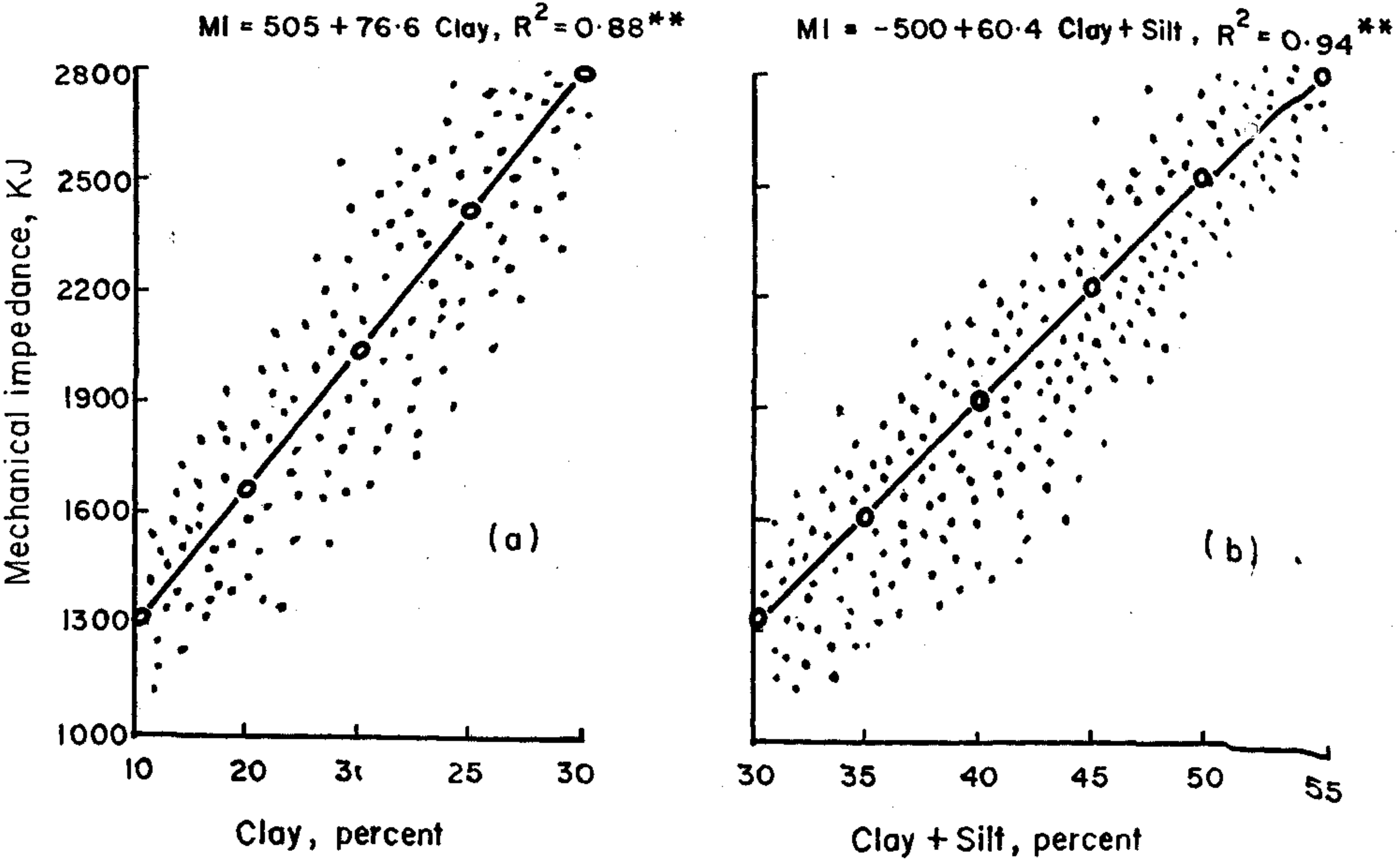


Fig. 33. Effect of clay (a) or clay + silt (b) on the mechanical impedance of a highly sodic soil.

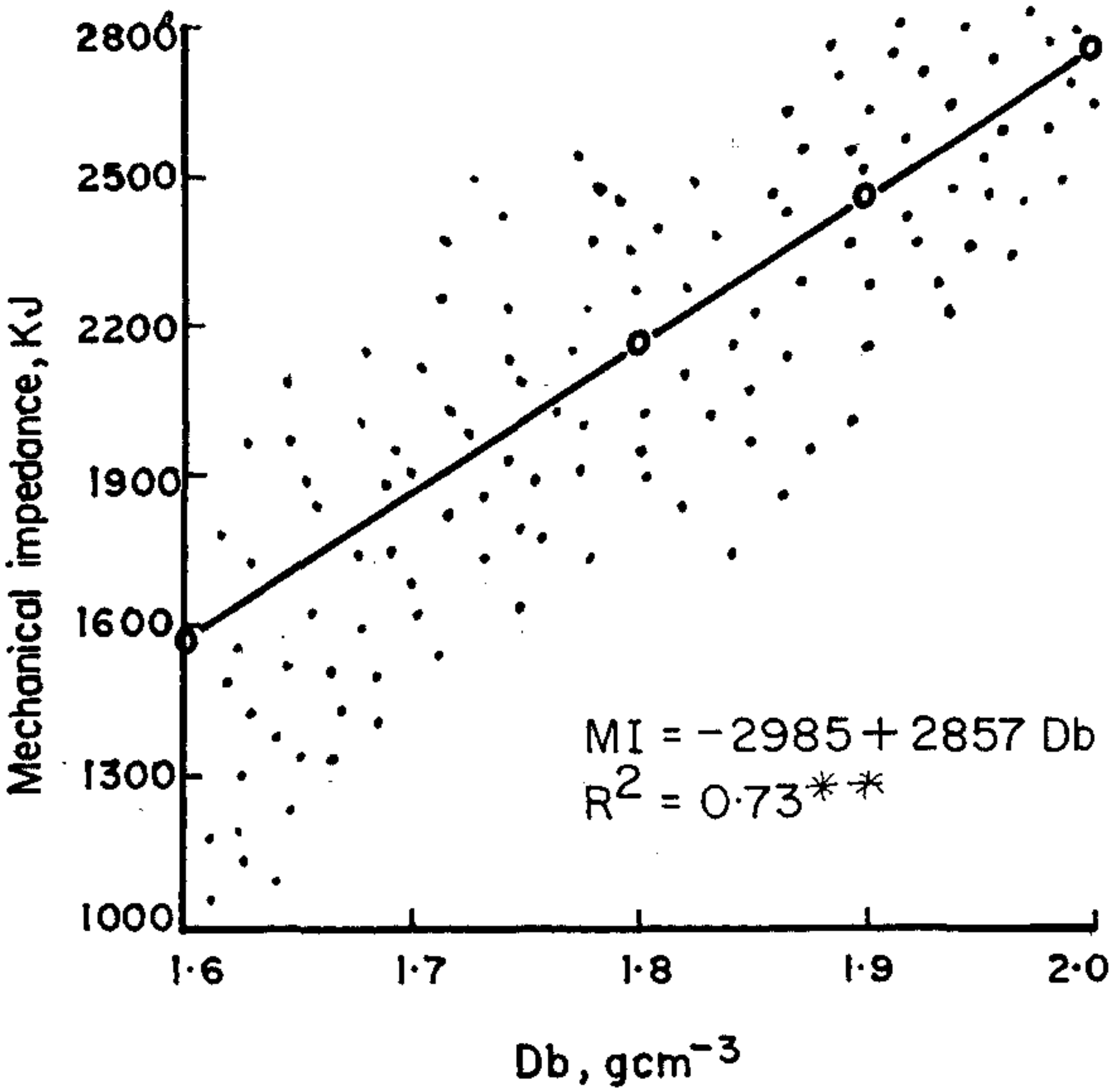


Fig. 34. Effect of Db of the soil mass on the mechanical impedance of a highly sodic soil.

91-150 cm depth. When MI values only for 91-150 cm depth were included, the relationship turned out to be highly significant ($R^2 = 0.90^{**}$). This shows that in addition to clay, silt and Db, concretions added to the MI of the soil. These concretions are chiefly composed of calcium carbonate. Their dissolution yields calcium carbonate which cements the soil particles to effect greater compactness. During excavation in root studies, it was experienced that uniform distribution of fine granules of calcium carbonate in the calcic horizon were more difficult and troublesome to work with than irregularly spread large sized concretions.

The relationships of MI with ESP ($R^2 = 0.92^{**}$) and pH ($R^2 = 0.87^{**}$) was also found highly significant. These bring out the role of dispersion in causing compactness. It may, thus, be presumed that in addition to important physical factors i.e. texture, moisture content, Db, concretions, dispersion of the soil due to high sodicity or alkaliness also contributed to the high MI of a sodic soil. The effect of high ESP or pH may be indirect through their influence on soil-water relationships of the soil. Experimental data, therefore, show that clay, texture, soil Db, concretions, pH and ESP are the important physico-chemical factors which affected MI in a highly sodic soil. These results corroborate the findings reported in a review by Bowen (1981).

SUMMARY

Considering a total lack of systematic experimental evidences which pose a severe restriction for successful raising of plantations on sodic soils and unequivocal emphasis of the Government of India to devise programmes for afforestation of waste lands especially the salt affected soils in the country, this investigation was carried out to evaluate selected tree species for their tolerance to sodicity and mechanical impedance in a highly sodic soil with particular reference to root growth behaviour. Six field trials were conducted on a highly sodic experimental farm of Central Soil Salinity Research Institute near village Gudha of Karnal district of Haryana. High soil sodicity hazard of the experimental site classified as aquic Natrustalfs is a representative of the sizeable chunk of sodic soils occurring in the Indo-Gangetic plains of Haryana, Punjab, Uttar Pradesh, Bihar, Madhya Pradesh and Rajasthan. The pertinent findings are summarized below experiment wise.

5.1 Analysis of Soil Profile for the Identification and Intensity of Constraints for Growth of Trees in a Highly Sodic Soil

Management of sodic soils for afforestation because of deep rooted system of tree species requires amelioration of the root zone to deeper depths of the soil profile. The soil profile (0-240 cm) analyses of a highly sodic soil was conducted to quantify and identify salient physico-chemical constraints which may impair growth of different tree species in such soils.

A. <u>Physical Properties</u>: Texture of the soil for all layers of 15 cm each between 0-90 cm, 91-150 cm and 151-240 cm was found to be silty loam, loam and loamy sand respectively. Clay content was less in the surface 15 cm layer but it increased gradually with depth down to 60 cm. It varied between 20.3 and 32.3 g $100g^{-1}$ soil in 61-120 cm and then declined to vary between 10.2 and 13.8 g $100g^{-1}$ soil among various layers between 151-and 240 cm. Amount of silt in the surface layers was slightly less than in the 16-45 cm layers. It also showed a decrease with depth but varied less between 121 and 240 cm of the profile. Sand fraction in the surface 15 cm layer and between 121 and 135 cm depth was about same. However, its amount was considerably more in the layers between 151 and 240 cm.

Water retention at 0.03 MPa (field capacity) and 1.5 MPa (permanent wilting point) was observed closely associated with the textural class, more for layers of silty loam (0-90 cm), followed by loam (91-150 cm) and loamy sand (151-240 cm) portions of the profile. The organic matter content of the soil was very low and its amount indicated a regular decrease with profile depth. Average amount of concretions (g $100g^{-1}$ soil) was less than unity in layers between 0-45 cm but increased to 1.30, 4.80, 8.28 and 10.64 in 46-60, 61-75, 76-90 and 91-105 cm layers respectively. Between 106-150 cm, concretions were more with a content of 24.23 g $100g^{-1}$soil. But beyond 150 cm depth, each succeeding layer exhibited a decrease in its content. Soil bulk density (Db) varied between 1.70-1.85 g cm^{-3} throughout the soil profile. Relative values of Db were relatively high for soil layers between 16-120 cm than the surface 15 cm and horizons beyond 120 cm depth. Similar trend was observed when soil mass (including concretions) was taken as such but then Db values were a little high. The particle density (g cm^{-3}) of different profile layers ranged between 2.54-2.76 for the soil, 2.82-2.98 for the concretions and 2.62-2.94 for the soil plus concretions.

B. Chemical Properties: High pH of the soil throughout the profile showed that the experimental area was extremely alkali. Soil pH was the highest in the surface layer and decreased with depth. Soluble salts were also more in the surface layer and decreased with depth. EC of all the soil layers below 90 cm depth of the profile was comparatively low and, thus, were relatively non-saline. Among the four principal cations (Na^+, K^+, Ca^{++} and Mg^{++}), concentration of sodium in the saturation extract of soil exhibited its predominance. Its concentration was maximum in surface (0-15 cm) soil and decreased regularly with depth of 150 cm. But its content was almost constant for soil layers between 151-240 cm. Potassium indicated less marked variation in the profile, however, its relative concentration was higher in layers between 0-135 cm than in 136-240 cm depth of the profile. Concentration of both calcium and magnesium was very low and less than unity for layers down to 105 cm. Concentrations of both were observed increasing with depth but their relative concentrations were very low despite the large quantities of calcium carbonate content of the soil. The average $CaCO_3$ content of the soil ranged 1.18-3.26 g $100g^{-1}$ soil for layers between 0 and 60 cm. But the middle portion (91-165 cm) of the profile indicated its accumulation between 5.26-15.62 g $100g^{-1}$ soil. The content of $CaCO_3$ equivalent was increased appreciably on inclusion of concretions in the soil and its distribution within profile showed dependence on the amount of concentrations in different layers of the profile.

Among the anions, carbonate and bicarbonate were predominant particularly in the surface layer. Their amount decreased with depth down to 180 cm. But variation between 181 and 240 cm was not notable. Concentrations of chloride and sulphate were relatively low and declined with profile depth. Their accumulation was also maximum in the top layer (0-15 cm). The CEC of different layers varied between 7.00-12.68 me $100g^{-1}$ soil. It was relatively higher for horizon between 16-135 cm depth than for lower layers and the surface one. Sodium was determined to be a predominant cation on the exchange complex and its content ranged from 4.36 to 11.94 me $100\ g^{-1}$ soil for the different layers. Exchangeable sodium also showed a decrease with depth. But exchangeable calcium and magnesium indicated an increase with depth although their relative amount was low in all of the 16 layers. Amount of K on the exchange complex ranged from 0.22-0.89 me $100g^{-1}$ soil but it followed no particular trend like other cations. Computed ESP, ESR and SARe of the soil profile also decreased with depth. ESP exhibited good correlation with $pH_{1:2}$, pHe, ESR and SSP than with SARe. SARe also showed comparatively weaker relationship with $pH_{1:2}$, pHe and ESR.

Available N of the soil profile was low as a whole. Its content was maximum (25.2 mg kg^{-1}) in the surface soil and decreased with depth. Available P in the surface layer was high (37.4 mg kg^{-1}) but it decreased to 23.0, 16.2, 9.6, 8.6, 6.2 and 5.2 mg kg^{-1}) soil in the deeper layers in descending order. Its content showed further decline beyond 105 cm and all of these layers were poor in available P. Amount of available K, though decreased with depth, its overall content in 0-120 cm of profile was high and medium in rest of the profile. Available contents of Fe, Mn and Cu were high. Their accumulation was also maximum in the surface layer and it declined with profile depth. Depth wise distribution of available Zn was similar to other micronutrients but its average amount was low throughout the soil profile.

5.2 Evaluation of Selected Site Preparation Techniques on the Performance of *Eucalyptus tereticornis* Sm. and *Acacia nilotica* (L.) Willd. ex. Del. in a Highly Sodic Soil

To achieve satisfactory performance of a tree species planted in a highly inhospitable sodic soil, planting techniques suited for normal soils require an appropriate modification. In view of a few intrinsic bottlenecks of recently suggested technique i.e. pit planting, this experiment was carried out to bring a refinement in the planting technique. The hyopthesis of proposed technique was that in tree plants, management of the root zone by modifying the sodic soil environment with limited amount of amendments in the profile to a deeper depth has a vital role in their successful establishment.

A. Per Cent Survival and Growth: Survival of both Acacia and Eucalyptus planted in postholes of considerably limited width (10-15 cm) but greater depth (120-180 cm) and pits of large volume (90 cm each in dia. and depth) was noted to be cent per cent during 72 months of initial growth period. Effect of postholes refilled with limited amounts of gypsum (3 kg) and FYM (4-12 kg) mixed sodic soil and pit using comparatively more gypsum (12 kg) and FYM (24 kg) did not reflect significant differences on periodically recorded growth of the two species. Periodic height, DSH and DBH, thus, did fail to exhibit significant differences owing to posthole and pit planting techniques. Among postholes of different dimensions, diameter of postholes was observed having no bearing on the growth whereas their depth to 180 cm effected a clear edge over that of 120 cm at some stages of growth particularly in Eucalyptus. Response of Acacia to different posthole types was indifferent. Its growth in pits had an edge over the postholes. It was proved that use of limited amount of amendments in a limited volume (with greater profile depth and narrow diameter of planting pit i.e. posthole) has a vital role in establishment of plantations of selected tree species in highly sodic soils.

B. Biomass Production on Lopping Acacia trees: Woody matter and foliage yields resulted from lopping of Acacia after 16 and 42 months of planting did not vary markedly due to different planting techniques. However, yields obtained were the highest in T_5. Total yield of oven dry foliage and billets from both the loppings ranged 1921-2828 and 5306-7616 kg ha^{-1} respectively. Different site preparation techniques effected no significant change in the concentration of Na, K, Ca, Mg, N, P, S, Fe, Mn, Zn and Cu in both of the components of biomass. Their relative accumulation was more in foliage lopped after 16 than 42 months of planting. The mean total removal of Na (241 mol ha^{-1}) through the lopped biomass was less than that of K (1827 mol ha^{-1}), Ca (1618 mol ha^{-1}) and Mg (781 mol ha^{-1}). Amounts of given elements removed were greater with biomass lopped after 42 than 16 months growth stage and were more in treatments which yielded higher biomass. Woody matter though showed low accumulation of the said nutrient elements but their removal occurred more through this component of biomass.

C. Firewood Value of Acacia and Eucalyptus Billets: The firewood value of Acacia was determined to be more than that of Eucalyptus by 200-300 KCal kg^{-1} of dry wood. Heat value of both the species showed improvement with increasing thickness of the billets. An increasing moisture content of differently thick branches of both the trees effect drastic reduction in their heat value. Thickness of branches also affect their seasoning or drying pattern.

D. Biomass Production Underneath the Tree Canopies: Effect of site preparation techniques on biomass yielded from natural growth of vegetation, primarily sodicity tolerant grasses, was not significant. However, canopies of Acacia and Eucalyptus influenced the yield significantly. Biomass yield was more underneath the former canopy in a relatively dry year (1982). But in 1983 and 1984 when normal monsoon rains occurred, opposite was true. Concentration of Na, K, Ca, Mg, P, S, Fe, Mn, Zn and Cu of the biomass did not vary with site preparation techniques in 1982-1984. Their concentration decreased with successive years. Same was true for N in biomass harvested from Eucalyptus plantation but contrary was observed in case of Acacia. Average removal of these elements exhibited the role of biomass yield rather than their concentration. Thus, their removal was more in 1982 than in 1983 and 1984.

E. Amelicrative Effect and Micro-Climate Modifications: Per cent moisture content (w/w) of different layers of soil profile (0-120 cm) under Eucalyptus plantation was observed to be low at all the sampling stages than under Acacia plantation. Fluctuations with seasons were pronounced in 0-15, 16-30 and 31-45 cm layers than rest of the deeper horizons and moisture content of different soil layers under Acacia was found higher by 2-3 per cent than under Eucalyptus plantation.

Air temperature under Acacia canopy during summer was observed lower (sheltering effect) by 3-5°C and higher (blanketing effect) during winter by 2-4°C than the neighbouring open area. Impact of Eucalyptus canopy on modification of air temperature was less marked. Modifying effect of the two canopies on soil temperature was more at 5 than at 15 cm depth. The effect was that of blanketing during summer and sheltering during winter months. Acacia and Eucalyptus plantations effected considerable amelioration of highly sodic soil with time by lowering pH and EC of the soil and increasing organic carbon content and water infiltration rate. Amelioration was more in surface layer (0-15 cm). Acacia plantation resulted in greater increase in organic carbon of the soil than Eucalyptus.

Litter production of Acacia was more than Eucalyptus plantation and was observed to increase with growth years. Such an increase was not noted with Eucalyptus. Winter season (Nov. - Feb.) accounted for more than 40 and 50 per cent of the total litter production of Acacia and Eucalyptus respectively.

F. Nutrients Recycled through Litter: Concentration of Na, K, Ca, Mg, N, P, S, Fe, Mn, Zn and Cu in the litter produced by Acacia and Eucalyptus during different growth seasons of 1982-1984 did not vary significantly. However, there were notable differences with the litter of the two species and the amount of these elemts recycled through litter of the two species varied significantly with different growth periods in 1981-1984. Their amounts recycled during winter were more for both the species and increased with successive growth years only in Acacia. Distribution of the total amount of each nutrient recycled through litter produced during different growth

Kozlowski, T.T. 1979. *The Tree Growth and Environmental Stresses.* 192 p. University of Washington Press, Seattle.

Kozlowski, T.T. and J.C. Cooley. 1961. Root grafting in northern Wisconsin. J. Forestry 59: 105-107.

Kramer, P.J. 1969. *Plant and soil water relationships - a modern synthesis.* McGraw-Hill Book Co., 482 p., New York.

Kramar, P.J. and T.T. Kozlowski, 1960. *Physiology of trees.* McGraw-Hill, New York.

Kretinin, V.M. 1967. Effect of shelterbelts on soils of the pale chestnut sub-zone. Pochvovedenie 12: 124-132.

Kulkarni, D.G. 1959. Some special features of afforestation in the arid regions of Saurashtra and Kutch (Bombay state). Proc. Symp. Dry Zone Afforestation in India, Technical Paper, Dehra Dun.

Kulkarni, D.G. 1961. Use of brackish water for irrigation and its effects on soils and crops. Proc. Tehran. Symp. on Salinity Problems of Arid Zones, pp. 267-271. UNESCO, Rome.

Kumar, A. and I.P. Abrol. 1983. Effect of gypsum on five tropical grasses in normal and extremely sodic soil. Expt. Agric. 19: 169-177.

Kunkel, G. 1978. *Flowering trees in subtropical gardens.* Dr.W.Junk b.v.Publishers, The Hague, pp.8.

Kumkle, S.H. 1974. Water - its quality often depends on the forester. Unasylva 105: 10-16.

Kunkle, 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.

Kutilek, M. 1973. The influence of clay minerals and exchangeable cations on soil moisture potential. *In.* Hadas, A.T. (Ed.), *Physical aspects of soil water and salts in the ecosystem,* Chapman and Hall, London.

Lahiri, A.N. and Y.D. Gaur. 1969. Germination studies on arid land plants. V. The nature and role of germination inhibitors present in leaves of *Prosopis juliflora* (Sw.) DC. Nat. Inst. Sci. India Proc. 35 B; 60-71.

Laitakari, E. 1929. The root system of Pine (*Pinus silvertris*). A morphological investigation. Acta. For. Fenn. 33: 1-380.

Lanly, J.P. and J.Clement. 1979. Present and future natural forest and plantation areas in the tropics. Unasylva 123: 12-20.

Leather, J.W. 1893. Reclamation of *Reh* or *Usar* soils. Agric. Ledger, 12,13.

Leather, J.W. 1897. Reclamation of *Reh* or *Usar* soils. Agric.Ledger,7.9. 37.

periods of 1982-1984 showed close association with quantity of litter rather than the concentration of a nutrient in the litter. Litter of Acacia recycled considerably greater amounts of N to the soil greatly deficient of this nutrient and important from biomass productivity purposes.

5.3 Evaluation of the Growth Response of Eucalyptus tereticornis Sm. and Acacia nilotica (L.) Willd. ex. Del. to Composition of Selected Posthole Filling Mixtures in a Highly Sodic Soil

Excessof exchangeable Na and high pH impart sodic soils poor physico_chemical properties which affect adversely the growth of most plants. In order to alleviate/overcome these problems, the devised posthole technique was tested with five filling mixtures in a replicated randomized block design with two tree species, Eucalyptus and Acacia.

A. Per Cent Survival and Growth: Irrespect of the filling mixtures, per cent survival of Eucalyptus (55-60) was less than of Acacia (78-81) during 24-72 months of growth. However, for optimum survival of both the species use of amendments was noticed to be absolutely essential. Survival of Eucalyptus increased when filling mixtures comprising 3 kg gypsum in combination with 8 kg FYM posthole^{-1} was used and was superior to gypsum alone even applied at higher rate (6 kg). But response of Acacia to use of 3 or 6 kg gypsum alone or 3 kg gypsum and 8 kg FYM in combination with sodic soil or sand was indifferent.

The height and girth growth data showed greater tolerance of Acacia than of Eucalyptus to sodicity of the soil. Height and girth responses of Acacia were similar for mixtures containing gypsum alone at a rate of 3 kg or 6 kg or 3 kg gypsum and 8 kg FYM mixed with sodic soil (OS) or sand. But in case of Eucalyptus, use of gypsum alone at both the rates was inferior to its combined application with FYM. Results suggest that for identifying species suited to afforestation programmes on salt affected soils, due weightage be given to per cent survival and early growth.

B. Biomass Production on Lopping of Acacia Trees: Canopy growth of Acacia excelled over Eucalyptus in a highly sodic soil. Acacia yielded considerable biomass on lopping of trees 16 and 42 months past planting. Foliage and woody matter yields were significantly higher for postholes refilled with a mixture of 3 kg gypsum and 8 kg FYM with OS or sand than gypsum alone irrespect of its rate for both of the loppings. Biomass yield resulted from first lopping was lower than the second by 3-4 times. Effect of filling mixtures on the chemical composition of lopped woody material was not noticeable. But chemical composition of foliage harvested from the control (OS) different significantly with that from mixtures having an application of amendment. Concentration of all the elements except Na was notably less in foliage collected from the second than from the first lopping although not significantly for K, Mg and P. Mean total removal (mol ha^{-1}) of Na, K, Ca and Mg through lopped biomass was 265, 2251, 1483 and 790. This showed less Na in the plant system of Acacia and its ability to recycle Ca, Mg and K. Mean total removal of N (2697 mol ha^{-1}) was about four times more than that of P and S. Foliage accounted for more than 89 per cent of its removal. Combined use of FYM and gypsum caused considerably more removal of N, P, S, Fe, Mn, Zn and Cu than use of gypsum alone at both the rates.

C. **Biomass Production Underneath the Tree Canopies:** Biomass productivity underneath the canopies of Eucalyptus and Acacia showed no effect of posthole filling mixtures during 1982-1984 but it varied significantly between the two canopies. Biomass yields underneath Acacia trees in all the plots were more than double than under the Eucalyptus plantation in 1982. But in 1983 and 1984, biomass yielded under Eucalyptus canopy was significantly more than that under Acacia canopy. These observations established the relationship of biomass production of natural growth of vegetation underneath the canopies of Eucalyptus and Acacia with the agro-climatological conditions prevailing during the observational years (1982-84). This relationship prompts to conclude that under relatively dry conditions, Acacia would favour higher biomass productivity under its canopy.

Concentration of Na, K, Ca, Mg, N, P, S, Fe, Mn, Zn and Cu in the biomass harvested from underneath the canopies of Acacia and Eucalyptus and their removal in 1982-1984 did not vary much due to different posthole filling mixtures. But changes were more due to variations in the biomass yield during different years rather than the differences in concentration of nutrient elements in the biomass harvested from both the plantations. Concentration of Na and its removal through biomass yield of the underneath vegetation exceeded that of K, Ca and Mg. But this was not so for lopped biomass of Acacia. Significantly different chemical composition of grass cover under Acacia from its lopped biomass indicates that the role of grasses and trees are complimentary rather than competitive in respect of their nutrition. Thus, the double storey system of plants may enhance improvement of soil physico-chemical properties by greater biomass production and nutrients recycling.

5.4 Evaluation of *Casuarina equisetifolia* L. for its Tolerance to a Highly Sodic Soil

A field experiment was carried out to investigate performance of Casuarina planted through newly devised posthole technique in a highly sodic soil. A replicated trial within the purview of Randomized Block Design included planting of the said species in deep postholes (25 cm dia. upto 80 cm depth and 15 cm dia. from 81-180 cm depth) refilled with four filling mixtures (a) original sodic soil (OS), M_1; (b) OS mixed with 8 kg FYM, M_2; (C) OS mixed with 2 kg gypsum, M_3; (d) OS mixed with 2 kg gypsum and 8 kg FYM, M_4.

A. Per Cent Survival and Growth: Per cent survival at the end of 24 months was 67 per cent in control (M_1). Mixing of FYM improved survival significantly but for best results application of gypsum alone or in combination with FYM was imperative. Influence of posthole filling mixtures on the periodic height and girth increments during initial 36 months of the growth period was significant. Absolute height and girth growth measured as DSH and DBH and in turn magnitude of height and girth increments were almost equal in M_4 and M_3. These were markedly less in M_2 and M_1. Height and girth growth occurred more in summer and lower in winter. After 36 months of planting, M_4, M_3 and M_2 gave height increase by 154, 144 and 110 per cent over M_1 respectively. Respective per cent increase in DSH was 154, 144 and 89 and in DBH it was 195, 152 and 78. Per cent survival height and girth growth data thus indicated that Casuarina is a highly tolerant and promising tree species to meet requirement for afforestation of sodic soils.

B. Changes in Periodic Chemical Composition: Concentration of Na in foliage and woody components was refilled by posthole filling mixtures being minimum in M_4. Sodium accumulation was more in foliage than wood. But K content was the highest for M_4 or M_3 and minimum for M_1. These observations point to antagonistic role of Na and K. In control (M_1) Na accumulation was 3-5 times more than K on whole plant basis. This trend was not so with other filling mixtures. Foliage contained more Ca and Mg than woody parts. Relative accumulation of Ca was more than Mg. At all selected growth stages, it was opposite of the foliage composition except in very early growth stages.

Phosphorus concentration was minimum in M_4 and the highest in M_1 mainly due to dilution effect. Accumulation of P was only marginally more in foliage than in woody branches. But S content of foliage was 2-3 times more than the casuarina branches and its accumulation was more than P at all growth stages. Filling mixtures having gypsum caused greater accumulation of S in the plants. The concentration of N in the biomass produced by Casuarina in sodic soils indicate ability of this species to fix N even under most hostile soil environmental conditions having little native N suggesting effectiveness of the role of actinomycetes, <u>Frankia</u>. Concentration of micronutrients was more in foliage than woody material and followed the order Fe Mn Zn Cu. Due to dilution effects, concentrations were lower in filling mixtures treatments that effected greater growth or biomass i.e. M_4 and M_3. Results also show that accumulation of micronutrients in the woody portion varied little with different posthole filling mixtures.

C. <u>Water Relations</u>: Water relations adjudged by RT of Casuarina plants in postholes receiving an application of either gypsum alone or gypsum plus FYM indicated very less fluctuations with time during winter and summer unlike control (M_1) and to some extent M_2. Plants responded more to watering in M_1 and M_2. Better maintenance of RT in M_3 and M_4

suggest that application of gypsum favour proliferation of plant roots in zones of easy water availability which in turn ensure supply of moisture requirements of Casuarina plants.

5.5 Evaluation of Selected Tree Species for Their Tolerance to Sodicity and Mechanical Impedance in a Highly Sodic Soil.

Establishment of trees on sodic soils greatly depends upon a correct choice of species in addition to any special treatment for site preparation. This experiment was conducted to evaluate tolerance of eight selected species to a highly sodic soil when planted in shallow (30 cm X 60 cm) and deep (30 cm X 60 cm + 15 cm X 61-120 cm) postholes refilled with a mixture of original sodic soil, 8 kg FYM and 3 kg gypsum. Experiment was replicated four times within the purview of factorial Randomized Block Design.

A. <u>Per Cent Survival</u>: Of the eight species, Poplar <u>Jaman</u> and <u>Shahtoot</u> met complete mortality whereas per cent survival of <u>Shisham</u>, Mesquite, <u>Siris</u>, <u>Neem</u> and <u>Jamoa</u> was 100, 87, 75, 75 and 50 in shallow and 100, 87, 62, 50 and 50 in deep postholes after 540 as well as 720 days of planting respectively. Occurrence of mortality in deep postholes was of higher order than in shallow ones throughout the noted growth period of 720 days when surviving species were harvested for estimating biomass production and root growth behaviour.

B. <u>Height and Girth Growth</u>: During the observed growth period of 720 days, maximum height growth was occurred in Mesquite (385 cm) followed by <u>Siris</u> (252 cm), <u>Shisham</u> (131 cm), <u>Neem</u> (124 cm) and <u>Jamoa</u> (84 cm). Height growth in initial stages and winter was very little. Increase in height of <u>Siris</u>, <u>Neem</u> and <u>Shisham</u> was significantly more in shallow than deep posthole planting. Similar was the observation on Mesquite in the early growth period but it was reverse after 360 days of planting. Girth growth of Mesquite (104 mm) as measured by DSH was also more than Siris (74 mm), Shisham (42 mm), Neem (54 mm) and Jamoa (62 mm). Height and girth growth data, thus, clearly indicated relatively greater tolerance of Mesquite and Siris. Comparative growth of Mesquite was more in deep postholes. But Siris and Neem showed more growth in shallow ones despite their considerable mortality.

C. Primary Biomass Production: Mesquite yielded the highest amount of dry matter and it was the lowest in the case of Jamoa. Mean total of a Mesquite plant was 17718 g and was several folds the per plant yield of Siris (5577 g), Neem (654), Shisham (293 g) and Jamoa (293 g). Similar was the order for the aerial biomass yield, roots and the woody matter components of total biomass production of these species. Mesquite produced significantly higher biomass when planted in deep (23252 g plant^{-1}) than in shallow (12183 g plant^{-1}) postholes. Trend was contrary to Siris and not evident in Neem, Jamoa and Shisham. Shoot: root ratio of Mesquite was the widest followed by Siris and Neem which tupify greater efficiency of the root systems of these species. Fractionation of total biomass yield into different components varied with species and type of postholes. On the basis of these results it may be deduced that Mesquite is tolerant to extremely high soil sodicity.

D. Chemical Composition of Plant Components: Accumulation of Na, K, Ca and Mg was more in foliage followed by roots (except in Shisham) and woody material of different species. Foliage and roots of Mesquite contained high Na than other species. Concentration of Na in foliage and woody matter of Siris was notably less but it showed relatively greater accumulation in roots than Neem, Shisham and Jamoa.

Relative content of K in different components of said species was about 2-4 times higher than of Na. Type of posthole showed no influence on accumulation of Na and K in general. Relative concentration of Mg and Ca in different components of given species was considerably more than that of Na and K. Differences in the concentration of N were more pronounced than those of P and S due to tree species. Relative accumulation of P and S was many times less than that of N in various plant components of different species. Accumulation of P and S in foliage of Mesquite was more than Neem, Siris, Shisham and Jamoa in descending order. But P content in woody material of Mesquite was less than in Siris, Neem and Shisham. Data on the concentration of Fe, Mn, Zn and Cu in the three components of plants showed marked variation due to the species. The differences in chemical composition of plants may be ascribed to (a) differential dilution effects resulting from different growth rates (b) ability of leguminuous species to fix atmospheric dinitrogen symbiotically and (c) metabolic adjustments owing to their growth in a stress environment.

E. Root Studies of Tree Species: Roots of Mesquite were found penetrated to depths of 222 and 189 cm in deep and shallow postholes. Roots of Siris penetrated down to 184 cm in shallow and 188 cm in deep postholes. Relative root penetration of Shisham, Neem and Jamoa was significantly less.

Different species showed marked differences to produce fine and large roots in the two types of postholes. Fine roots biomass of Mesquite was significantly less in shallow (417.6 g plant^{-1}) than in deep (1243.8 g plant^{-1}) postholes. It was not so in the case of large roots, however, total biomass of roots was also about double in deep than in the shallow postholes. In Siris, large roots in shallow and deep postholes constituted 97 and 86 per cent of the total biomass of roots respectively. Large roots biomass of Siris was about 7-8 times more in shallow than in deep postholes. Fine roots biomass of Shisham and Jamoa was notably more but their root systems as a whole were observed to be poorly developed. Neem produced more fine roots in deep than in shallow postholes. Results showed that deep postholes favour growth of finer roots.

Root cation exchange capacity (RCEC) of leguminuous trees i.e. Mesquite, Siris and Neem was significantly more than that of Neem and Jaoma. The RCEC of all the species showed decrease with increasing thickness or woodinees. The RCEC values for these species were noticed to decrease with depth. But rate of decrease was more with species having high RCEC.

Data on layer-wise root distribution of roots of tree species proved that root system of Mesquite was stout and extensively developed in deep as well as shallow postholes in comparison to those of Neem, Shisham and Jamoa. Root system of Siris was well developed in shallow than in deep postholes.

5.6 Physico-Chemical Factors Influencing Mechanical Impedance in a Highly Sodic Soil Profile.

Studies were carried out to identify and model the role of important physico-chemical factors which influence mechanical impedance of soil to metal penetrometers. For this purpose, an impact penetrometer was fabricated following inconsistency and poory repeatability of a static tip penetrometer under field conditions. Results showed a high degree of reciprocal relationship between soil moisture and mechanical impedance (MI) of different horizons of a highly sodic soil profile. Decrease in MI with a given increase in moisture content of the soil was observed to be markedly greater for silty loam (0–90 cm) and loam (91–150 cm) layers than those of the loamy sand (151–210 cm) in the soil profile. The MI was observed closely related to the finer fraction of the soil. Its relationship with per cent clay was highly significant ($R^2 = 0.88^{**}$). It showed further improvement with clay plus silt. Relationship of soil Db with MI was also significant ($R^2 = 0.73^{**}$). Zone of accumulation of concretions in the soil profile i.e. 90–150 cm exhibited high MI. Changes in MI of the different layers showed association with depth of the profile. Results, thus, showed increase in MI of the sodic soil with increase in clay, clay plus silt, bulk density of the soil and its content of concretions.

REFERENCES

Abrol, I.P. 1977. Exchangeable sodium and soil water behaviour. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp. 103-109, CSSRI, Karnal.

Abrol, I.P. 1982. Technology of chemical, physical and biological amelioration of deteriorated soils. Paper presented at the Meeting of Panel of Experts on Amelioration and Development of Deteriorated Soils in Egypt, May 2-6, 1982, Cairo.

Abrol, I.P. and C.L. Acharya. 1975. Soil water behaviour and irrigation frequencies in soils with physical constraints. Proc. 2nd World Cong. Intern. Water Resources Assoc. 1: 335-342, New Delhi.

Abrol, I.P. and D.R. Bhumbla. 1971. Saline and alkali soils in India - their occurrence and management. World Soil Resources Rep.No. 41: 42-51. Food and Agriculture Organization, Rome.

Abrol, I.P. and D.R. Bhumbla. 1977. Paper presented at FAO Expert Consultation on identification and reclamation of salt affected soils and secondary salinization. Food and Agriculture Organization, Rome.

Abrol, I.P. and D.R. Bhumbla. 1978. Some comments on terminology relating to salt affected soils. Proc. meetings of the sub-commission on salt-affected soils "Dryland Saline Seep Control" at the 11th Intern. Soil Sci. Cong. pp. 6-19 to 6-27, Edmonton.

Abrol, I.P. and D.R. Bhumbla, 1979. Crop responses to differential gypsum application in a highly sodic soil and the tolerance of several crops to exchangeable sodium under field conditions. Soil Sci. 127: 79-85.

Abrol, I.P., K.S. Dargan and D.R. Bhumbla, 1973. Reclaiming alkali soils. Bull No.2, 58 p, CSSRI, Karnal.

Abrol, I.P. and M. Fireman. 1977. Alkali and saline soils, identification and improvement for crop production. Bull.No.4, 32 p. CSSRI,Karnal.

Abrol, I.P., R.Chhabra and R.K. Gupta. 1980. A fresh look at the diagnostic criteria for sodic soils. Proc. Intern. Symp. on Salt Affected Soils, pp. 142-147, CSSRI,Karnal.

Acharya, C.L. and Abrol, I.P. 1978. Exchangeable sodium and soil water behaviour under field conditions. Soil Sci. 125: 310-319.

Acharya, C.L., S.S. Sandhu and I.P. Abrol. 1979. Effect of exchangeable sodium on the rate and pattern of water uptake by Raya (*Brassica juncea* L.) under field condition. Agron J. 71: 936-941.

Agarwal, R.R. and J.S.P. Yadav. 1954. Saline and alkali soils of the Indian Gangetic alluvium in Uttar Pradesh. J. Soil Sci. 5: 330-336.

Agarwal, R.R., J.S.P. Yadav and R.N. Gupta. 1979. Saline and alkali soils of India, 286 p. ICAR, New Delhi.

Anderson, H.W., M.D. Hoover and K.G. Reinhart. 1976. Forests and waters: effects of forest management on floods, sedimentation and water supply. Pacific Southwest Forest and Range Expl. Sta. Rep. PSW – 18/1976, US. Forestry Service.

Anonymous. 1938. *Usar* Land Reclamation Committee U.P., Report (1938-39) 1: 118p. Superintendent, Printing and Stationery, Allahabad.

Anonymous. 1982. Indian agriculture in brief. Ministry of Agri., Govt. of India, New Delhi.

Antipov-Karataev, I.N., I.A. Yurin, L.A. Frolkina. 1957. Reclamation of solonetz in the chermozen zone. Pochvouedenie No.2: 1-17.

Aggal, P. 1978. Role of wood energy in the rural economy of India. Proc. 8th World Forestry Cong. FRC/3-8, Jakrta.

Arkin, G.F. and H.M. Taylor (eds.) 1981. Modifying the root environment to reduce crop stress. ASAE, 407 p., Michigan.

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

Aycub, A.T. 1975. Sodium and cation accumulation by *Senna* (*Cassia acutifolia*). J. Expt. Bot. 26: 891-896.

Azeuedo, J. and D.L. Morgan. 1974. Fog precipitation in coastal California forest. Ecology 55: 1135-1141.

Bakhshi, S.R. 1946. Roadside avenue in Punjab. Proc. VII Silva. Conf., pp. 139-146, FRI, Dehra Dun.

Bangash, S.H. 1977. Salt tolerance of forest tree species as determined by germination of seeds at different salinity. Pakistan J. For. 27: 93-97.

Bannan, M.W. 1940. The root systems of northern Ontario conifers growing in sand. Amer. J. Bot. 27: 108_114.

Barley, K.P. and E.L. Greacen. 1967. Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Adv. Agron. 19: 1-43.

Barrs, H.D. 1968. Determination of water deficits in plant tissues. pp. 236-368. In. Kozlowski, T.T. (ed.) *Water Deficits and Plant Growth* Vol.I. Development, control and measurement. 390 p. Academic Press Inc., New York.

Barton, H., W.G. McCully, H.M. Taylor and J.E. Box. 1966. Influence of soil compaction on emergence and first-year growth of seeded grasses. J. Range Mgt. 19: 118-121.

Bear, F.E. 1964. *Chemistry of the soil*. 2nd ed. Reinhold Publishing Corp., New York.

Bell, T.I.W. 1973. Erosion in the Trinidad teak plantations. Commonw. For. Rev. 52: 223-233.

Bene, J.G. 1974. Sawlogs from 10-yr. rotations in the tropics. World Wood 15: 12-16.

Bernal, C.T., F.T. Bingham and J. Oertli. 1974. Salt tolerance of Mexican wheats. II. Relation to variable sodium chloride and length of growing season. Soil Sci. Soc. Amer. Proc.38:777-780.

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Annu. Rev. Alytopathol. 13: 295-312.

Bernstein, L., L.E. Francois and R.A. Clark. 1972. Salt tolerance of ornamental shrubs and ground covers. J. Amer. Soc. Hortic. Sci. 97: 550-556.

Bethlahamy, N. 1962. First year effects of timber removal on soil moisture. Intern. Assn. Sci. Hydrol. Bull. 7: 34-38.

Bhargava, G.P. 1977. Classification of salt affected soils - some problems. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp. 31-46, CSSRI,Karnal.

Bhargava, G.P. and I.P. Abrol. 1978. Characteristics of some typical salt-affected soils of Uttar Pradesh. Report No. 6, 33p., CSSRI, Karnal.

Bhargava, G.P., I.P. Abrol and D.R. Bhumbla. 1976. On the nomenclature of some salt affected soils in the Indo-Gangetic plains. J. Indian Soc. Soil Sci. 24: 81-83.

Bhargava, G.P., R.C. Sharma, D.K. Pal and I.P. Abrol. 1980. A case study of the distribution and formation of salt affected soils in Haryana state. Proc. Intern. Symp. on Salt Affected Soils. pp. 83-91, CSSRI, Karnal.

Bhargava, G.P., S.K. Singhla and I.P. Abrol. 1972. Characteristics of some typical saline-sodic soils occurring in Karnal district, Haryana state. Rep. No.2, 46 p., CSSRI, Karnal.

Bhargava, O.P. 1948. Saline and alkaline soils and their afforestation problems. Indian Forester, 303-306.

Bhargava, O.P. 1956. An experiment to afforest alkaline areas in Madhya Pradesh. Proc. 8th Silv. Conf. 2: 103-106, Dehra Dun.

Bhumbla, D.R. 1977. Alkali and saline soils of India. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp.14-20, CSSRI,Karnal.

Bhumbla, D.R. and I.P. Abrol. 1978. Saline and sodic soils. <u>In</u>. <u>Soils and Rice</u>, pp. 719-738, IRRI, Los Banos.

Bhumbla, D.R., I.P. Abrol, G.P. Bhargava and S.K. Singhla. 1972. Soils of the experimental farm, Karnal. Bull.No.1 42 p. CSSRI,Karnal.

Bidner-BarHava, N. and B.Ramati. 1967. The tolerance of some species Eucalyptus, Pinus and other forest trees to soil salinity and low soil moisture in the Negev. Israel. J. Agric. Res. 17: 65-76.

Black, C.A. (ed.-in-chief). 1965. *Methods of soil analysis*. Agron.J. Part I (Physical properties) and II (Chemical and microbiological properties), ASA, Madison.

Bloodworth, M.E., C.A. Burleson, W.R. Cowley. 1958. Root distribution of some irrigated crops using undisturbed soil cores. Agron. J. 50: 317-320.

Bohm, W. 1979. *Methods of studying root systems*. 186 p. Springer-Verlag, New York.

Bol'shakov, A.F. and S.D. Erpert. 1956. Experiment with forest plantations on semi-desert soils of a solonetz complex. Soils and Fertil. abstr. 19: 380.

Bovey, R.W. and J.D. Diaz-Colon. 1969. Occurrence of plant growth inhibitors in tropical and subtropical vegetation. Physiol. Plant. 22: 253-259.

Bowen, H.D. 1981. Alleviating mechanical impedance. pp.21-57. *In.* Arkin, G.F. and H.M. Taylor (eds.), *Modifying the root environment to reduce crop stress*. Mono.No. 4, 407 p. ASAE, Michigan.

Bower, C.A., W.G. Harper, C.D. Moodie, R. Overstreet and L.A.Richards. 1958. Report of the nomenclature committee appointed by the board of collaborators of the US Salinity Lab. Soil Sci. Soc. Amer. Proc. 22: 270.

Boyko, H. and E.Boyko. 1966. *Salinity and aridity*. pp. 214-282. Dr.W. Junk Publishers, The Hague.

Brawn, G., A.Von Schonborn and E.Weber. 1978. Investigations on the relative resistance of woody plants to de-icing salt (sodium chloride). Allgemeine Forest-and-Jagdizer-tung.149: 21-35.

Bray, J.R. 1963. Root production and the estimation of net productivity. Can. J. Bot. 41: 65-72.

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

Brunig, E.F. 1977. The tropical rain forest - a wasted asset or an essential biospheric resource. Ambio 6: 187-191.

Bucl, S.W. 1965. Present soil-forming factors and processes in arid and semiarid regions. Soil Sci. 99: 45-49.

Burnett, E. and V.L. Hauser. 1968. Deep tillage and soil-plant-water relationships. *In.* *Tillage for greater crop production*, ASAE Publication Proc. 168: 47-52.

Cairns, R.R. and W.E. Bowser. 1977. Solonetzic soils and their management. Canada Dept. Agric. Pub. 1391, 37 p.

Carlson, C.W. 1966. Problems and techniques in studying plant root systems. Proc. 9th Intern. Grassland Cong. 9: 1491-1493.

Carter, D.L. 1975. Problems of salinity in agriculture. In. Poljakoff-Mayber, A. and J.Gale (eds.), Plants in saline environments pp. 25-35. Springer Verlag, Berlin.

Carter, L.M., J.R. Stockton, J.R. Tavernetti and R.F. Colwick. 1965. Precision tillage for cotton production. Transactions of the ASAE (2): 177-179.

Chaney, W.R. and T.T. Kozlowski. 1971. Water transport in relation to expansion and contraction of leaves and fruits of Calamondin orange. J. Hortic. Sci. 46: 71-81.

Chaturvedi, A.N. 1984. Firewood crops in areas of brackish water. Indian Forester. 110: 364-366.

Chhabra, R., I.P. Abrol and M.V. Singh. 1981. Dynamics of phosphorus during reclamation of sodic soils. Soil Sci. 132: 319-324.

Chopra, R.S. 1939. Tree planting in the punjab. Bull. 31 p. Forestry Pavillion, All India Exhibition, Lahore.

Chopra, R.S. 1945. The technique and problems of irrigated planations. Proc. VI Silva.Conf. pp.143-150, FRI, Dehra Dun.

Crooke, W.M. 1964. The measurement of the cation-exchange capacity of plant roots. Plant and Soil 21: 43-49.

Cruz-Romero, G. and N.T. Coleman. 1975. Reactions responsible for high pH of Na-saturated soils and clays. J. Soil Sci. 26: 169-175.

Darling, F.F. 1969. Wilderness and plenty. Reith lectures, Ballantine, London.

Davidson, D.T. 1965. Penetrometer measurements. pp. 472-484. In.Black, C.A. (editor-in-chief), Methods of Soil Analysis, Agronomy Monograph 9, Part II, ASA, Madison.

Davis, R.M., P.E. Martin, A.W. Fry, L.M. Carter, M.B. Zahara and R.M. Hagan. 1968. Plant growth as a function of soil texture in the Hanford series. Hilgardia 39: 107-120.

Day, P.R. 1965. Particle fractionation and particle size analysis. In. Black, C.A. (ed.in-chief), Methods of Soil Analysis, Part I (Physical Properties), Agron. J. pp. 65-66, Amer. Soc. Agron. Madison.

Donahue, R.L., R.W. Miller and J.C.Shickluna. 1977. Soils: An introduction to soils and plant growth, 626 p. Prentice Hall, Inc. London.

Duthie, J.F. 1896. Reclamation of Reh or Usar land. Agric. Ledger 13: 1-8.

Easu, K. 1943. Vascular differentiation in the Pear root. Hilgardia 15: 299-313.

Eck, H.V. and R.G. Davis. 1971. Profile modification and root yield, distribution and activity. Agron. J. 63: 934-937.

Eck, H.V. and H.M. Taylor. 1969. Profile modification of a slowly permeable soil. Soil Sci. Soc. Amer. Proc. 33: 779-783.

Eckholm, E. 1979. Planting for the future: forestry for human needs. World watch Paper 26, Worldwatch Institute, Washington DC.

Eis, S. 1972. Root grafts and their silvicultural implications. Can. J. For.Res. 2:111-120.

Elkins, C.B., R.L. Haaland and C.S. Hoveland. 1977. Grass roots as a tool for penetrating soil hardpans and increasing crop yields. Proc. 34th Southern Pasture Forage Crop Improvement Conf. pp. 21-26, Auburn.

FAO, 1962. Forest influences. Food and Agriculture Organization, Rome.

FAO, 1967a. Actual and potential role of man-made forests in the changing world pattern of wood consumption. Secretariat Note. Proc. World Symp. man-made forests and their industrial importance. pp. 1-50. Food and Agriculture Organization, Rome.

FAO, 1967b. International source book on irrigation and drainage of arid lands in relation to salinity and alkalinity. Food and Agriculture Organization, Rome.

FAO. 1973. Man's influence on the hydrological cycle. Irrigation and drainage paper, special issue 17 p. Food and Agriculture Organization, Rome.

FAO. 1978a. China: forestry support for agriculture. Forestry paper No.12, Food and Agriculture Organization, Rome.

FAO 1978b. Implementing forestry programmes for local community development. Proc. 8th World Forestry Cong. FRC/4-0, Jakarta.

Ford-Robertson, F.C. (ed.). 1971. Terminology of forest science, technology, practice and products. IUFRO/Society of American Foresters, Washington, D.C.

Foth, H.D. 1962. Root and top growth of Corn. Agron.J. 54: 49-52.

Freitag, D.R. 1971. Methods of measuring soil compaction. pp.47-103. In.Barnes, K.K. (ed.) Compaction of Agricultural Soils. ASAE, Madison.

Fritschen, L.J. and P.Doraiswamy. 1973. Dew: An addition to the hydrologic balance of Douglas. Water Resources Res.9: 891-894.

Kanwar, J.S. 1961. Clay minerals in saline alkali soils of the Punjab. J. Indian Soc. Soil Sci. 9: 35-40.

Kanwar, J.S. 1977. Crop production in arid and semi-arid tropics with particular reference to salt affected soils. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp.219-221, CSSRI, Karnal.

Kanwar, J.S. and D.R. Bhumbla. 1960-1962. Reclamation of alkaline and saline soils in the Punjab. Report ICAR, New Delhi.

Kanwar, J.S. and D.R. Bhumbla, 1969. Physico-chemical characteristics of sodic soils of the Punjab and Haryana and their amelioration by the use of gypsum. Agrokemia es Talajtan Suppl. 18: 315-320.

Kanwar, J.S. and J.L. Sehgal. 1962. Classification of saline sodic and normal soils of Kamal district. J. Indian Soc. Soil Sci. 10: 19-26.

Kanwar, J.S. and N.S. Randhawa. 1978. *Micronutrient research in soils and plants in India (A review)*. ICAR Tech. Bull (Agric.) No.50, 185 p. New Delhi.

Karschon, R. 1966. Environment and tree growth in the Rift. Valley Oasis of Ein Hatseva, Suppl. 2, La. Yaaron.

Kassas, M. 1979. Competition is not imperative. Ceres. 12: 14-18.

Kaushik, R.C., I.M. Qureshi, J.S.P. Yadav and Jai Parkash. 1969. Suitability of soils for *Eucalyptus hybrid* in Haryana and Punjab. Indian Forester 95: 377-388.

Kelley, W.P. 1951. *Alkali soils, their formation, properties and reclamation*. Reinhold Publishing Corporation, New York.

Khan, M.A.W. and J.S.P. Yadav. 1962. Characteristics and afforestation problems of saline alkali soils. Indian Forester 88: 259-271.

King, K.F.S. 1975. It's time to make paper in the tropics. Unasylva 109: 2-5.

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

Kovda, V.A. 1961. Principles of the theory and practice of reclamation and utilization of saline soils in the arid zones. Proc. Tehran Symp. on Salinity Problems of Arid Zones, pp.201-212, UNESCO, Rome.

Kovda, V.A. 1965. Alkaline soda-saline soils. Agrokemia es Talajtan. Suppl. 14: 15-48.

Kovda, V.A. 1971. *Origin of saline soils and their regime*. US Dep. Commerce, National Tech. Inf. Service, Springfield, 509, New York.

Kozlowski, T.T. 1971. *Growth and development of trees*. Vol. II. Academic Press, New York.

Greacen, E.L., K.P. Barley and D.A. Farrel. 1968. The mechanics of root growth in soils with particular reference to the implications for root distribution. pp. 256-269. In. Whittington, W.J. (ed.). Root Growth, Butterworth, London.

Griffith, A.L. 1945. The afforestation of dry areas. proc. VI. Silva. Cong., pp. 126-132, FRI, Dehra Dun.

Griffith, A.L. 1946. The Punjab arid areas afforestation plots. Proc. VII Silva. Conf. pp. 113-117, FRI, Dehra Dun.

Grimes, D.W., R.J. Miller and P.L. Wiley. 1975. Cotton and Corn root development strength characteristics. Agron. J. 67: 519-523.

Gupta, R.K., R.Chhabra and I.P. Abrol. 1981. Relationship between pH and exchangeable sodium. Soil Sci. 131: 215-219.

Hartley, A. 1977. The establishment of Eucalyptus tereticornis on tailings of the Bougainville copper mine, Papua New Guinea. Commonw.For. Rev. 56: 239-245.

Heintze, S.G. 1961. Studies on cation-exchange capacities of roots. Plant and Soil 13: 365-383.

Hoffman, G.J. 1981. Alleviating salinity stress. pp. 305-343. In. Arkin, G.F. and H.M. Taylor (eds.), Modifying the root environment to reduce crop stress, ASAE, Michigan.

Holland, T.H. and W.A.K. Christie. 1909. The origin of the salt deposits of Rajputana. Rec.geol. Surv. India 38: 154-186.

Hoon, R.C. 1955. Land reclamation. Publ. Cent. Bd. Irrig. India 2: 160-178.

Hoon, R.C. and M.L. Mehta. 1936. A study of the soil profiles of the Punjab plains with reference to their natural flora. Punjab Irrigation Res. Instt. Pub. 3.

Huber, B. 1937. Wasserumsatz und staffbewegungen, H. Fortschr. Bot. 7: 197-207 (C.f. Kramer and Kozlowski, 1960).

IUCN(International Union for the Conservation of Nature and Natural Resources). 1977. UN Conference on desertification, Nairobi.

Jackson, M.L. 1967. Soil chemical analysis. Asia Publishing House, New Delhi.

Jackson, J.K. 1977. Irrigated plantation, "Savanna afforestation in Africa" Forestry Paper No.11, FAO, Rome.

Johnston, D.R. 1976. Forestry in a changing world. Forestry 49: 29-44.

Joshi, M.J. 1982. Social forestry.Bhagirath 29: 1-5.

Joshi, M.J. 1957. Problems of afforestation for the immobilization of the catchment in the Banaskantha division, Bombay state. Proc. Symp. Dry Zone Afforestation in India, Technical Papers, Dehra Dun.

Kanwar, J.S. 1961. Clay minerals in saline alkali soils of the Punjab. J. Indian Soc. Soil Sci. 9: 35-40.

Kanwar, J.S. 1977. Crop production in arid and semi-arid tropics with particular reference to salt affected soils. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp.219-221, CSSRI,Karnal.

Kanwar, J.S. and D.R. Bhumbla. 1960-1962. Reclamation of alkaline and saline soils in the Punjab. Report ICAR, New Delhi.

Kanwar, J.S. and D.R. Bhumbla, 1969. Physico-chemical characteristics of sodic soils of the Punjab and Haryana and their amelioration by the use of gypsum. Agrokemia es Talajtan Suppl. 18: 315-320.

Kanwar, J.S. and J.L. Sehgal. 1962. Classification of saline sodic and normal soils of Kammal district. J. Indian Soc. Soil Sci. 10: 19-26.

Kanwar, J.S. and N.S. Randhawa. 1978. Micronutrient research in soils and plants in India (A review). ICAR Tech. Bull (Agric.) No.50, 185 p. New Delhi.

Karschon, R. 1966. Environment and tree growth in the Rift. Valley Oasis of Ein Hatseva, Suppl. 2, La. Yaaron.

Kassas, M. 1979. Competition is not imperative. Ceres. 12: 14-18.

Kaushik, R.C., I.M. Qureshi, J.S.P. Yadav and Jai Parkash. 1969. Suitability of soils for Eucalyptus hybrid in Haryana and Punjab. Indian Forester 95: 377-388.

Kelley, W.P. 1951. Alkali soils, their formation, properties and reclamation. Reinhold Publishing Corporation, New York.

Khan, M.A.W. and J.S.P. Yadav. 1962. Characteristics and afforestation problems of saline alkali soils. Indian Forester 88: 259-271.

King, K.F.S. 1975. It's time to make paper in the tropics. Unasylva 109: 2-5.

Kittredge, J. 1948. Forest influences. McGraw Hill, New York.

Kovda, V.A. 1961. Principles of the theory and practice of reclamation and utilization of saline soils in the arid zones. Proc. Tehran Symp. on Salinity Problems of Arid Zones, pp.201-212, UNESCO, Rome.

Kovda, V.A. 1965. Alkaline soda-saline soils. Agrokemia es Talajtan. Suppl. 14: 15-48.

Kovda, V.A. 1971. Origin of saline soils and their regime. US Dep. Commerce, National Tech. Inf. Service, Springfield, 509, New York.

Kozlowski, T.T. 1971. Growth and development of trees. Vol. II. Academic Press, New York.

Lieth, H. 1977. Biological productivity of tropical lands. Unasylava 114: 24-31.

Lieth, H. and R. Whittacker. 1975. Primary productivity of the biosphere. Ecological Studies No.14, New York.

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, Iron, Manganese and Copper. Soil Sci. Soc. Amer. J. 42: 421-428.

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

Long, C.H. 1959. Root studies on some farm crops in Tennessee. Univ. of Tennessee, Agric. Exp. Sta. Bull. 301, 41 p.

Lowery, F.E., H.M. Taylor and M.G. Huck. 1970. Growth rate and yield of cotton as influenced by depth and bulk density of soil pans. Soil Sci. Soc. Amer. Proc. 34: 306-309.

Lundgren, B. 1978. Soil conditions and nutrient cycling under natural and plantation forests in Tanzanian highlands. Rop. Forest Ecology and Forest Soils No. 31. Dep. Forest Soils, Swed. Univ. Agric. Sci., Uppsala.

Lutz, J.F. (Chairman). 1965. Glossary of soil science terms, Committee report. Soil Sci. Soc. Amer. Proc. 29: 330-351.

Lyr, H. and G. Hoffmann. 1967. Growth rates and growth periodicity of tree root. Intern. Rev. Forestry Res. 2: 181-236.

Maas, E.V. and G.J. Hoffman, 1977. Crop salt tolerance - current assessment. ASCE J. Irrig. and Drainage Div. 103: 115-134.

Mathur, H.N., R. Babu, P. Joshie and B. Singh. 1976. Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. Indian Forester 102: 219-226.

McColl, J.J. 1977. Retention of soil water following forest cutting. Soil Sci. Soc. Amer. J. 41: 984-988.

McNeal, B.L. and N.T. Coleman. 1966. Effect of solution composition on soil hydraulic conductivity. Soil Sci. Soc. Amer. Proc. 30: 308-312.

Mech, S.J., G.M. Horner, L.M. Cox and E.E. Cary. 1967. Soil profile modification by backhoe mixing and deep plowing. Transactions of the ASAE 10: 775-779.

Menzel, R.G., H.V. Eck and D.F. Champion. 1967. Effect of placement depth and root inhibiting chemicals on uptake of strontium-85 by field crops. 59: 70-72.

Menzel, R.G., H.V. Eck, P.E. James and D.E. Wilkins. 1968. Reduction of Strontium-85 uptake in field crops by deep plowing and sodium carbonate application. Agron. J. 60: 499-502.

Merwin, H.D. and M.Peech. 1950. Exchangeability of soil potassium in the sand, silt and clay fractions, as influenced by the nature of the complimentary exchangeable cations. Soil Sci. Soc. Amer. Proc. 15: 125-128.

Migunova, E.S. 1972. Desalinizing action of tree plantations of solonchakous and solonetz-like soils. Pochvovedenie 2: 123-135.

Migunova, E.S. 1976. The root systems of woody species on saline soils in the South Ukraine. Lesovedenie 6: 27-36.

Mikola, P. 1978. The role of forestry in the fight against desertification. Proc. 8th World Forestry Cong. 000/0-9, Jakarta.

Musa, O.S. 1977. Der grungurtel von Khartoum (The green belt of Khartoum). Beitr. Forstwirtsch. 11: 95-97.

Nambiar, E.K.S., G.D. Bowen and R. Sands. 1979. Root regeneration and plant water stress of *Pinus radiata* O. Don. seedlings transplanted to different soil temperatures. J. Exptl.Bot. 30: 1119-1131.

Narayana, V.V.D., S.K. Gupta and A.K. Tiwari. 1978. Rainfall and run-off analysis for rain water management in agriculture. Proc. Symp. *Hydrology of Rivers with small and medium Catchments*, Vol. II, pp. 43-53, New Delhi.

NAS (National Academy of Sciences). 1980. Firewood Crops, shrub and tree species for energy production. Vol. I. 237 p. Washington, D.C.

NAS (National Academy of Sciences). 1983. Firewood crops, shrub and tree species for energy production. Vol. II, 92 p. Washington, DC.

Nash, V.E. and V.C. Baligar. 1974. The growth of Soyabean (*Glycine max* L.) roots in relation to soil micromorphology. Plant and Soil. 41: 81-89.

National Commission on Agriculture. 1976. Ministry of Agriculture. Govt. of India, New Delhi.

Noble, M.K. 1950. Report on irrigation and allied research, Poona.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus by extraction with sodium carbonate. Circ. USDA No. 939, 19 p., Washington, DC.

Ovington, J.D. 1965. *The role of forestry*. The Aust. Natn. Univ., Canberra.

Ovington, J.D. 1972. The biological and economic considerations of forest production in the tropics with particular reference to tropical rain forests. Forest Resources Div., Forestry Dep., Food and Agriculture Organization, Rome.

Pal, B.P. 1984. Environmental conservation and agricultural production. Indian J. agric. Sci. 54: 233-250.

Pande, D.C. 1956. A short note on the introduction of tree species in mil usar lands of U.P. Proc. 9th Silv. Conf. 1: 337-342.

Pande, G.C. 1967. Afforestation of usar lands. Proc. 11th All India Silv. Conf. FRI, Dehra Dun.

Pandey, S.L., A.K. Sinha and P. Mahendra. 1972. Water-table fluctuations and its interpretation. CBIP No.118, Vol.1: 55-64.

Panse, V.G. and P.V. Sukhatme. 1978. Statistical methods for agricultural workers. ICAR, New Delhi.

Pant, M.M. 1980. The impact of social forestry in the national economy of India. The International Tree Crops J. 1: 69-92.

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

Pearson, G.A. 1960. Tolerance of crops to exchangeable sodium. U.S. Dept. Agric. Inf. Bull. 216, Washington, DC.

Pereira, J.S. and T.T. Kozlowski. 1978. Diurnal and seasonal changes in water balance of Acer saccharum and Betula papyrifera. Physiol. Plant. 43: 19-30.

Peters, D.B. 1965. Water availability. In. Black, C.A. (ed.-in-chief), Methods of Soil Analysis, Agron, 9. Part I, Physical and Mineralogical Properties, ASA, Madison.

Pillai, V.N.K. Bringing forests closer to your farmstead. Intensive Agri. 20: 5-6.

Piper, C.S. 1950. Soil and plant analysis. Hans Publishing Co.,Bombay.

Puri, G.S. 1960. Indian forest ecology. Vol.1 and 2. Oxford Book and and Stationery, New Delhi.

Raja Singh, G.J. 1965. Dry zone afforestation in selected countries. Fellowship Report, FAO, Rome.

Rao, D.L.N. and S.K. Ghai. 1985. Urease and dehydrogenase activity of alkali and reclaimed soils. Aust. J. Soil Res. 23 (in press).

Rasmussen, W.W.,G.C. Lewis and M.P. Fosberg. 1964. Improvement of the Chilcott-Sebree slick spot soils in Southwestern Idaho. USDA-ARS 41-91, 39 p.

Reeve, R.C. 1965. Modulus of rupture. pp. 466-471. In. Black, C.A. (ed.-in-chief), Methods of Soil Analysis, Agronomy Monograph 9, Part I, ASA, Madison.

Rege, N.D. and R.V. Tamhane. 1964. Standards for reclamation of saline and alkali soils. Proc. 5th NSSA Conf. , pp. 289-304, FRI, Dehra Dun.

Reisenauer, H.M. 1976. Soil and plant-tissue testing in California. Div. of Agric. Sci., Univ. of California Bull.1879, 54 p.

Rice, E.L. 1974. Allelopathy. Academic Press, New York.

Rice, R.M. 1978. The effects of forest management on erosion and sedimentation due to landslides. Proc. 8th World Forestry Cong., FFF/5-10, Jakarta.

Richards, L.A. (ed.). 1954. Diagnosis and improvement of saline and alkali soils. Agri. Hand Book No.60, 160 p. U.S. Dep. Agric. Washington, DC.

Richardson, S.D. 1978. The role of Asian Development Bank in forestry and forest industries development. Proc. 8th World Forestry Cong. FID-11/21-18, Jakarta.

Rogers, H.T. and D.L. Jhurlow. 1973. Soyabeans restricted by soil compaction. High lights of Agr. Res. 20: 10, Auburn Univ. Agril. Expt. Sta., Auburn.

Rogerson, T.L. 1976. Soil water deficits under forested and clearcut areas in northern Arkansas. Soil Sci. Soc. Amer. J. 40: 802-805.

Rouhani, I. and Bassiri, A. 1976. Sodium and potassium distribution in Crassulacean Acid Metabolism plants as related to salt concentration. J. Amer. Soc. Hortic. Sci. 101: 270-273.

Sallberg, J.R. 1965. Shear strength. pp. 431-447. In. Black, C.A. (ed.-in-chief), Methods of Soil Analysis, Agronomy Monograph 9, Part I, ASA, Madison.

Sandhu, S.S., C.L. Acharya and I.P. Abrol. 1980. The effect of exchangeable sodium on the water retention and transmission of modulus of rupture of a soil. Intern. Symp. Salt Affected Soils, pp. 185-194, CSSRI, Karnal.

Sandhu, S.S., C.L. Acharya and I.P. Abrol. 1982. Water utilization pattern of Cowpea fodder crop as affected by the sodicity. J. Indian Soc. Soil Sci. 30: 6-12.

Sandoval, F.M., J.J. Bond and G.A. Reichman. 1972. Deep plowing and chemical amendment effect on a sodic claypan soil. Transactions of the ASAE 15: 681-684, 687.

Sands, R., E.L. Greacen and C.J. Gerard. 1979. Compaction of sandy soils in radiata pine forests. I. A penetrometer study. Aust. J. Soil Res. 17: 101-113.

Sangar, C., G.Lessard and G.Poulsen. 1977. Trees for people. International Res. Dev. Centre, Canada.

Sehgal, J.L., G.F. Hall and G.P. Bhargava. 1975. An appraisal of the problems in classifying saline-sodic soils of the Indo-Gangetic plain in NW India. Geoderma 14: 75-71.

Sen, A. 1958. Influence of climatic factors on the salinity of Indian soils. Indian J. agric. Sci. 28: 61-72.

Shah, S.A. 1957. Propagation of Mesquite (letters to the editor) Indian Forester 83: 472.

Shah, R.K. and J.C. Vora. 1965. Prosopis juliflora (SW.) DC. for improving saline soils. J. Guj. Univ. 8: 210-214.

Shah, R.K., J.C. Vora and A.M. Trivedi. 1958. Possibilities of reclamation of the alkali soils of the Little Rann of Kutch. Indian J. appl. Chem. 6: 133-137.

Sharma, [illegible].K. 1978. Forestry support for agriculture through watershed management and windbreaks in India. Proc. 8th World Forestry Cong., FFF/5-14, Jakarta.

Sigmond, A.A.J. de. 1924. The alkali soils in Hungary and their reclamation. Soil Sci. 18: 379-381.

Singh, B. 1975. Role of forestry in mitigating the energy crisis in India. Indian Forester 101: 589-596.

Singh, K. 1960. Farm forestry in Rajasthan. Proc. Farm Forestry Symp. ICAR, New Delhi. pp. 246-251.

Slatyer, R.O. 1957. The influence of progressive increases in total soil moisture stress on transpiration, growth, and internal water relationships of plants. Aust. J. Biol. Sci. 10: 320-336.

Smith, S.T. 1961. Reclaiming salt land with blue bush J. Agric. W. Australia. 14th Ser. 57-59.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. Oxford and IBH Publishing Co., New Delhi.

Spears, J.S. 1979. Can the wet tropical forest survive? Commonw. For. Rev. 58: 165-180.

Stout, B.B. 1956. Studies of the root systems of deciduous trees. Black Rock Forest Bull. 15: 1-45.

Subbiah, B.V. and G.L. Arija. 1956. A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25: 259-260.

Sumbur, G.N. 1963. Mobility of exchangeable sodium and determination of rates of application of gypsum during reclamation of solonetzes. Pochvovedenie 11: 35-46.

Swaminathan, M.S. 1980. Indian forestry at the cross roads. Intern. Tree Crops J. 1: 61-67.

Szabolcs, I. 1965. Salt affected soils in Hungary. Agrokemia es. Talajtan. Suppl. 14: 275-290.

Szabolcs, I. 1977. Salinity and alkalinity of soils - extension, classification and main properties. Proc. Indo-Hungarian Semin. on Management of Salt Affected Soils, pp. 20-30, CSSRI,Karnal.

Szabolcs, I. 1980. Saline and alkali soils - commonalities and differences. Intern. Symp. on Salt Affected Soils, pp. 1-6, CSSRI,Karnal.

Talati, R.P. 1941. Damaged lands in the Daccan and their classification. Indian J. agric. Sci. 11: 959-987.

Talati, R.P. 1947. Field experiments on the reclamation of salts lands in Baramati of Bombay Deccan. Indian J. agric. Sci. 17: 153-174.

Taylor, H.M. and B. Klepper. 1973. Rooting density and water extraction patterns for Corn (*Zea mays* L.). Agron. J. 65: 965-968.

Taylor, H.M. and E.Burnett. 1964. Influence of soil strength on the root-growth habits of plants. Soil Sci. 98: 174-180.

Taylor, H.M., G.M. Roberson and J.F.Parker, Jr. 1966. Soil strength-root penetration relations for medium-to coarse-textured soil materials. Soil Sci. 102: 18-22.

Taylor, H.M. and H.R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content and strength of soil. Soil Sci. 96: 153-156.

Taylor, H.M., L.F. Locke and J.E. Box. 1964. Pans in southern great plains soils. III. Their effect on cotton and grain sorghum. Agron. J. 56: 542-545.

Taylor, H.M. and R.R. Bruce. 1968. Effects of soil strength on the root growth and crop yield in the southern United States. Transactions 9th Intern. Cong. Soil Sci. 1: 803-811, Adelaide.

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

Tejwani, K.G. 1979. Soil fertility status, maintenance and conservation for agroforestry systems on wasted lands in India. *In*. Soils Research in Agroforestry, pp. 141-174.

UNESCO/FAO. 1973. Irrigation, drainage and salinity - An Intern. source book. UNESCO, Paris.

Uppal, H.L. 1962. Reclamation of saline and alkali soils. Proc. Semin. on Soil Salinity and Alkalinity Problems, pp. 86-92, IARI, New Delhi.

Vadiunina, A.F. 1957. Experiments on the biological amelioration of solonetses by means of shrubs. I. Improvement of the moisture-physical properties of solonetses under shrubs. Vestn. moskov. Univ. Ser. biol. Pochvoved Geol. Geogr. No.4: 75-87.

Vadiunina, A.F. 1964. Ameliorative effect of forest shelter belt on the soils of semi-desert. Proc. 8th Intern. Cong. Soil Sci. 8: 955-960, Bucharest.

Van-Ollenbach, A.W. 1978. Planting guide too the Middle East. 154 p. The Architectural Press, London.

Waisel, Y. 1960. Ecological studies on *Tamarix aphylla* (L.) Karst. 2 The water economy. Phyton (Buenos Aires) 15: 19-28.

Waring, R.H. and S.W. Running. 1976. Water uptake, storage and transpiration by confiers: A physiological model. *In*. Lange, O.L., L.Kappen and E.D. Schulze (eds.) *Water and Plant Life*, pp. 189-202, Springer-Verlag, New York.

Watson, G.A. 1983. Development of mixed tree and food crop systems in humid tropics: A response to population pressure and deforestation. Exptl. Agric. 19: 311-332.

Went, F.W. 1952. Fire and biotic factors affecting germination. Ecology 33: 351-364.

Went, F.W. and M. Westergaard. 1949. Ecology of desert plants. II. Development of plants in the Death Valley National Monument, California, Ecology 30: 26-38.

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

Wilcox, H. 1954. Primary organization of primary and dormant roots or noble Fir, *Abies procera*. Amer. J. Bot. 41: 812-818.

Wilcox, H. 1962. Growth studies of the root of incense cedar, *Libocedrus decurrens* L. I. The origin and development of primary tissues. Amer. J. Bot. 49: 221-227.

Wilcox, L.V. 1960. Boron injury to plants. US Dept. Agr. Bull.211,7p.

Wilson, B.F. 1964. Structure and growth of woody roots of *Acer rubrum* L. Harvard For. Pap. No.11: 1-14, Harvard, Univ. Petersham, Mass.

Wolf, B. 1982. A comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. Commun. in Soil and Plant Anal. 13: 1035-1059.

Wood, P.J. 1975. The world situation as it will affect the U.K. Scott. For. 29: 25-38.

World Bank. 1978. Forestry. Sector Policy Paper. World Bank, Washington, DC.

Yadav, J.S.P. 1956. *Usar* soils, their characteristics and exploitation in forestry. Proc. 9th Silv. Conf. Part I: 347-352.

Yadav, J.S.P. 1958. Prospects of farm forestry on barren spots in agricultural lands. Proc. Farm Forestry Symp., pp. 282-287, FRI, Dehra Dun.

Yadav, J.S.P. 1980. Salt affected soils and their afforestation. Indian For. 106: 259-272.

Yadav, J.S.P., D.R. Bhumbla and O.P. Sharma. 1975. Performance of certain forest species on a saline sodic soil. Proc. Symp. New Dev. in the Field of Salt Affected Soils, pp. 683-690, Intern. Soc. Soil Sci., Cairo.

Yadav, J.S.P. and H.M. Mathur. 1962. Soil pH tolerance of Sal (Shorea robusta Gaertn.) seedlings. Indian Forester 88: 694-700.

Yadav, J.S.P. and K. Singh. 1970. Tolerance of certain forest species to varying degree of salinity and alkali. Indian For. 96: 587-599.

Yadav, J.S.P. and T.C. Pathak. 1957. Study of saline and alkaline soils and their possible improvement by afforestation. J. Soil and Water Cong. India 5: 24-29.

Zahner, R. 1968. Water deficits and growth of trees. In. Kozłowski, T.T. (ed.), Water Deficits and Plant Growth, pp. 191-254, Academic Press, New York.

Zelenin, A.V. 1976. Afforestation of saline soilsin the Salskaya steppes. Lesnoe Khozyaistva 9: 79-81.

Zimmermann, M.H. and C.L. Brown. 1971. Trees, structure and function. Springer, New York.

Appendix I. Effect of selected posthole filling mixtures on the periodic per cent survival of casuarina equisetifolia L. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures				Mean	LSD (0.05)
	M_1	M_2	M_3	M_4		
0 (July, 1982)	100	100	100	100	100	NS
1	100	100	100	100	100	NS
2	100	100	100	100	100	NS
3	100	100	100	100	100	NS
4	100	100	100	100	100	NS
5	100	100	100	100	100	NS
6	100	100	100	100	100	NS
7	100	100	100	100	100	NS
8	100	100	100	100	100	NS
9	100	100	100	100	100	NS
10	100	100	100	100	100	NS
11	100	100	100	100	100	NS
12	100	100	100	100	100	NS
15	92	100	100	100	98	NS
18	84	92	100	100	94	NS
21	75	92	100	100	92	15
24	67	92	100	100	90	21
27	67	92	100	100	90	21
30	67	84	100	100	90	17
33	67	84	100	100	90	17
36	67	84	100	100	90	17
39	67	84	100	100	90	17

Appendix II. Effect of selected posthole filling mixtures on the periodic height of *Casuarina equisetifolia* L. in a highly sodic soil.

Growth stage (months past planting)	Posthole filling mixtures				Mean	LSD (0.05)
	M_1	M_2	M_3	M_4		
0	29	30	28	29	29	NS
1	36	46	53	58	48	7
2	44	55	71	79	62	11
3	59	72	95	103	82	20
4	82	102	122	125	108	22
5	91	114	135	142	120	28
6	95	120	143	158	128	27
7	95	129	148	164	134	30
8	103	141	158	172	143	29
9	112	148	179	185	156	32
10	126	180	197	206	177	37
11	139	196	237	248	205	40
12	156	240	303	316	254	62
15	198	280	352	371	300	55
18	215	330	385	417	337	63
21	227	347	400	428	351	52
24	247	376	471	486	395	84
27	258	480	576	620	484	90
30	262	540	632	666	525	101
33	268	572	652	682	544	108
36	275	577	670	698	555	100
39	284	592	696	735	577	102

Appendix III. Periodic per cent survival of selected tree species planted in shallow and deep postholes in a highly sodic soil.

Tree species	Type of posthole	Growth period, days past planting						
		15	45	75	210	360	540	720
Siris	Shallow	100	100	100	100	87	75	75
	Deep	100	100	87	87	87	62	62
	Mean	100	100	93	93	87	68	68
Neem	Shallow	100	100	100	100	75	75	75
	Deep	100	100	100	50	50	50	50
	Mean	100	100	100	75	62	62	62
Shisham	Shallow	100	100	100	100	100	100	100
	Deep	100	100	100	100	100	100	100
	Mean	100	100	100	100	100	100	100
Shahtoot	Shallow	100	100	100	75	25	0	0
	Deep	100	100	100	0	0	0	0
	Mean	100	100	100	0	0	0	0
Poplar	Shallow	100	0	0	0	0	0	0
	Deep	100	0	0	0	0	0	0
	Mean	100	0	0	0	0	0	0
Mesquite	Shallow	100	100	100	87	87	87	87
	Deep	100	100	100	87	87	87	87
	Mean	100	100	100	87	87	87	87
Jaman	Shallow	100	100	87	25	12	0	0
	Deep	100	100	62	12	12	0	0
	Mean	100	100	74	18	12	0	0
Jamoa	Shallow	100	100	100	62	62	50	50
	Deep	100	100	100	75	50	50	50
	Mean	100	100	100	68	56	50	50
LSD (0.05)	Species	NS	NS	13	23	25	23	23
	Postholes	NS	NS	6	12	13	NS	NS
	Interaction	NS	NS	18	32	NS	NS	NS

Appendix IV. Periodic height growth of selected tree species planted in shallow and deep postholes in a highly sodic soil.

Tree species	Type of posthole	Growth period, days past planting						
		15	45	75	210	360	540	720
Siris	Shallow	31	34	51	127	165	231	285
	Deep	30	30	44	83	108	185	218
	Mean	31	32	47	105	136	208	252
Neem	Shallow	30	32	39	82	101	123	135
	Deep	29	32	40	70	77	95	113
	Mean	30	32	40	76	89	109	124
Shisham	Shallow	51	55	64	94	101	111	119
	Deep	50	53	63	81	86	100	144
	Mean	51	54	64	88	93	106	131
Shahtoot	Shallow	121	124	123	126	*	*	*
	Deep	126	130	134	*	*	*	*
	Mean	124	127	128	–	*	*	*
Poplar	Shallow	215	*	*	*	*	*	*
	Deep	215	*	*	*	*	*	*
	Mean	215	*	*	*	*	*	*
Mesquite	Shallow	40	52	72	196	250	299	324
	Deep	34	54	62	175	225	362	447
	Mean	37	53	67	186	238	330	385
Jaman	Shallow	29	31	32	44	42	*	*
	Deep	28	30	27	35	35	*	*
	Mean	29	31	30	39	39	*	*
Jamoa	Shallow	51	54	55	56	59	73	87
	Deep	50	53	53	52	60	72	82
	Mean	51	54	54	54	60	73	84
Mean	–	71	55	60	93	109	165	195
LSD (0.05)	Species	14	6	6	17	20	29	30
	Postholes	NS	NS	NS	10	13	NS	NS
Species X Postholes		NS	NS	9	NS	28	41	42

*Denote cent per cent mortality.

Appendix V. Periodic girth growth, stem diameter (mm) at stump height (5 cm from ground level) of selected tree species planted in shallow and deep postholes in a highly sodic soil.

Tree species	Type of posthole	Growth period, days past planting						
		15	45	75	210	360	540	720
Siris	Shallow	8	8	10	24	40	74	88
	Deep	8	8	12	17	25	46	60
	Mean	8	8	11	21	33	60	74
Neem	Shallow	7	7	9	18	34	54	64
	Deep	7	7	8	10	22	30	44
	Mean	7	7	9	14	28	42	54
Shisham	Shallow	7	7	8	12	24	32	38
	Deep	7	8	10	13	23	34	48
	Mean	7	7	9	12	24	33	42
Shahtoot	Shallow	8	9	8	8	*	*	*
	Deep	12	12	10	*	*	*	*
	Mean	10	10	9	-	*	*	*
Poplar	Shallow	38	*	*	*	*	*	*
	Deep	38	*	*	*	*	*	*
	Mean	38	*	*	*	*	*	*
Mesquite	Shallow	6	8	10	20	44	74	90
	Deep	6	8	11	26	54	112	118
	Mean	6	8	11	23	49	93	104
Jaman	Shallow	8	8	8	6	*	*	*
	Deep	8	8	7	5	*	*	*
	Mean	8	8	8	5	*	*	*
Jamoa	Shallow	9	10	11	18	30	52	60
	Deep	10	10	10	14	26	44	64
	Mean	9	10	11	16	28	48	62
Mean	-	12	8	10	15	32	55	67
LSD (P.05)	Species	1	2	2	2	4	14	7
	Postholes	NS	NS	NS	2	2	NS	NS
	Interaction	NS	NS	2	3	5	20	9

*Denote complete mortality.

Appendix VI. Periodic girth growth, stem diameter (mm), at a 30 cm height from ground level of selected tree species planted in shallow and deep postholes in a highly sodic soil.

Tree species	Type of posthole	Growth period, days past planting						
		15	45	75	210	360	540	720
Sirim	Shallow	5	5	7	19	30	58	75
	Deep	6	6	8	13	20	36	49
	Mean	6	6	8	16	25	47	62
Neem	Shallow	4	4	6	11	21	42	51
	Deep	4	5	5	7	15	22	33
	Mean	4	4	6	9	18	32	42
Shisham	Shallow	5	5	6	9	15	24	32
	Deep	5	5	7	10	15	24	35
	Mean	5	5	7	9	15	24	34
Shahtoot	Shallow	7	7	7	7	*	*	*
	Deep	10	10	9	*	*	*	*
	Mean	8	8	8	*	*	*	*
Poplar	Shallow	28	*	*	*	*	*	*
	Deep	28	*	*	*	*	*	*
	Mean	28	*	*	*	*	*	*
Mesquite	Shallow	4	5	7	15	36	66	81
	Deep	4	5	7	19	46	90	107
	Mean	4	5	7	17	41	78	94
Jaman	Shallow	5	5	5	3	*	*	*
	Deep	5	5	3	2	*	*	*
	Mean	5	5	4	3	*	*	*
Jamoa	Shallow	6	6	6	10	18	25	31
	Deep	6	6	6	8	12	17	24
	Mean	6	6	6	9	15	21	28
Mean	–	9	5	6	12	23	41	52
LSD(0.05)	Species	1	1	1	2	3	11	6
	Postholes	NS	NS	NS	1	1	2	3
	Interaction	NS	NS	1	3	4	17	8