Problems and Prospects of Crop Production and Afforestation on Salt Affected Soils With Special Reference to India

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Introduction

The accelerated pace of degradation processes inflicting extensive areas and limiting crop production is causing a serious concern the world over. A highly disturbing situation is created in view of the fact that whereas more production is needed to meet the ever growing multiple demands of the rapidly expanding population, vast areas are going out of cultivation due to intense degradation. Indiscriminate and excessive deforestation, overgrazing, inadequate soil and water conservation measures, faulty cultivation methods, unplanned developmental activities relating to industrialization, urbanization, communication, hydro-electric projects, mining, etc., improper disposal of waste materials, defective use of irrigation water and such other factors are largely responsible for the deterioration of soil quality.

In India alone, nearly 175 million hectares (M ha) comprising 90 M ha due to water erosion, 60 M ha due to wind erosion, 6 M ha due to waterlogging, 8 M ha due to soil salinity and alkalinity, 4 M ha due to shifting cultivation and 7 M ha due to river action, mining, etc. are degraded to a greater or smaller degree. Land degradation of physical, chemical and biological nature resulting from these factors is affecting the welfare of millions of people, as numerous areas of once fertile lands are losing productivity and becoming wastelands. Sustained development is not possible without conservation of the natural resources.

Scenario of Indian Agriculture

Indian agriculture has made commendable progress after independence, especially after the mid 60's as reflected in tremendous increase in the production of foodgrains, sugarcane, cotton, fish, eggs, milk, fruits, vegetables and many other items. The total foodgrain production touched a record figure of 176.2 M

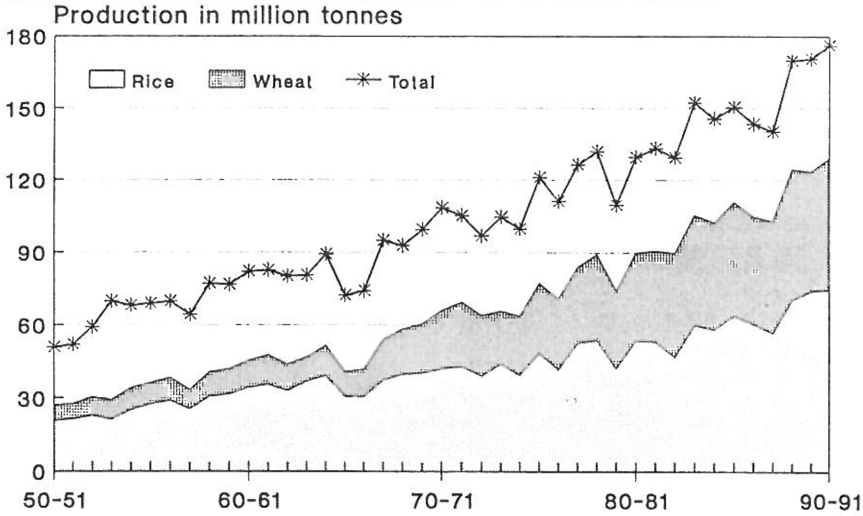

Fig. 1
Trend of total foodgrains, rice and wheat production in India during 1950-1951 to 1990-1991

in 1990-1991 as against merely 50.8 M t in 1950-1951, the bulk of the increase being attributable to a quantum jump in rice and wheat crops (Fig. 1).

Despite substantial increase in the net irrigated area (41.8 M ha being second in the world next to China), fertilizer consumption (12.5 M t being fourth in the world), area under high yielding cultivars (67 M ha) and the use of various other inputs including pesticides, weedicides and improved machinery beside

Table 1
Crop yields and input use in some countries in 1989

Country	Irrigated area, M ha	Fertilizer use, kg/ha	Paddy yield, t/ha	Wheat yield, t/ha	Maize yield, t/ha
Australia	1.8	3	7.7	1.6	4.2
China	44.5	61	5.5	3.0	3.7
Egypt	2.6	400	6.5	5.0	5.8
France	1.4	194	5.7	6.3	6.7
India	41.8	61	2.6	2.2	1.3
Japan	2.9	365	6.2	3.5	2.7
Korea Dem. Rep.	1.2	331	7.2	4.1	6.5
U. S. A.	18.1	41	6.4	2.2	7.0
U. S. S. R.	20.8	45	3.9	1.9	3.6
World	228.7	31	3.5	2.4	3.6

modern agronomic practices, not only the foodgrain production is marked by periodic peaks and troughs but also the yields of some crops per ha are lower than many countries (Table 1). In addition, wide imbalances exist in the input, use, cropping intensity and crop yields among different states and regions under different biophysical and socio-economic environments. With proper adoption of even currently available improved production technologies the yields of crops like rice, wheat, maize, sorghum and pearl millet can be enhanced by

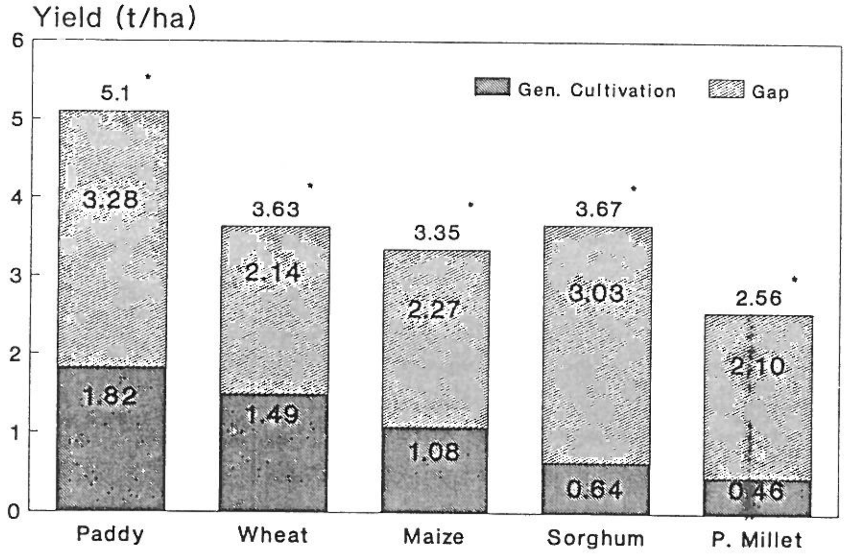

Fig. 2

Gap in the yield levels of some important crops between national demonstration plots and general cultivation in India (1971-1972 to 1983-1984)

about three to six times as evidenced by the gap recorded between the average national yields obtained in the demonstration plots on the farmers' fields and in the traditional farming (Fig. 2). The requirement of foodgrains by 2000 A.D. is estimated at 225-240 M t and will be much higher in the next century.

Land Resources and Severe Stress

The mounting pressure of fast swelling population on the land resources is a global concern. The human population in the world is expected to become 6.1 billion in 2000 A.D., 10 billion in 2050 and 11.6 billion in 2150 A.D., the growth rate being much higher in the developing than in the developed countries. The total population is increasing by 88 million every year, the largest share at present being that of India (21.5%). In India, the population is likely to become 1 billion in 2000 A.D., 1.45 billion in 2025 A.D., and may even exceed that of China by 2050 if the present growth rate is not checked.

India supports roughly 1/6th of the world's population on only 2.24% of the land area, with more than 70% population depending on agriculture. On an average, 72.6% of farmers possess operational land holdings of less than 2 ha. The per capita availabiltiy of arable land has gone down from 0.46 ha in 1951 to 0.26 ha in 1981 and is likely to decline further to 0.15 ha by 2000 A. D. Thus, greater number of people have to be supported from a much smaller area. This necessitates most efficient and wise management of the finite land resources.

Irrigation Induced Soil Salinity and Sodicity

Irrigation with canal water

Expansion of irrigation resources to augment crop production has received priority focus in the developmental programmes of many countries of the world. However, irrigation water has proved to be a blessing or a curse depending upon how it is used. According to SZABOLCS (1975) about half of the irrigated land in the world has either become salinized, or has the potential danger of secondary salinization in future. According to some other workers, approximately one-third of the irrigated land is suffering from soil salinity, and every year more and more additional areas are engulfed by this malady with increase in irrigation expansion. According to FRAMJI (1987) productivity of about 200,000 to 300,000 ha of irrigated land is lost due to salinization and waterlogging, and this is causing a reduction of about 1 million tonnes of foodgrain production every year.

The problems of waterlogging and soil salinity are more common in the irrigated areas of the arid and semi-arid regions, largely because of disturbance in the hydrologic equilibrium and rise in groundwater table resulting from excessive groundwater recharge. Though water is the key factor for crop production, a lack of appreciation of its importance as an input like seed and fertilizer has led to a neglect of its wise use and has resulted in the development of waterlogging and soil salinity. The problem is accentuated more in the areas where low water requiring crops are replaced by high water requiring crops such as sugarcane and rice. The chief factors responsible for the ill-effects of irrigation are:

- poor land development;
- seepage from the unlined canals and other water courses;
- over irrigation and deep percolation from the field;
- inefficient water management including improper irrigation method;

- inappropriate cropping system;
- non-conjunctive use of surface and groundwaters;
- impeded drainage and lack of outlet.

Owing to high priority assigned to irrigation by the government of India in the various Five Year Plans, the irrigation potential increased from 22.6 M ha in 1950-1951 to 67.9 M ha in 1984-1985, showing one of the highest annual rates of irrigation development in any country almost next to China. About 31% of the gross cropped area is now under irrigation. However, the incidence of waterlogging and soil salinity has assumed alarming proportion in several irrigation projects in the country and extensive areas of once fertile land (Table 2) are affected seriously by this twin problem (JOSHI & AGNIHOTRI, 1984). The problem becomes evident within few years of introduction of canal irrigation.

Table 2

Development of waterlogging and soil salinity in some irrigation projects in India (in thousand hectares)

Irrigation project	State	Water-logging	Soil salinity
Sriramsagar	Andhra Pradesh	60.0	1.0
Tungabhadra	Andhra Pradesh and Karnataka	4.7	24.5
Gandak	Bihar and U. P.	211.0	400.0
Ukai-Kakrapar	Gujarat	16.3	8.3
Mahi-Kadana	Gujarat and Rajasthan	82.0	35.8
Chambal	Madhya Pradesh and Rajasthan	98.7	40.0
Tawa	Madhya Pradesh	-	6.6
Indira Gandhi Canal	Rajasthan	43.1	29.1
Sharda Sahayak	Uttar Pradesh	303.0	50.0
Ramganga	Uttar Pradesh	195.0	352.4

At the research farm of the Haryana Agricultural University, Hisar, the water table has risen at an average annual rate of 90 cm after introduction of Bhakra canal system in 1963 and has come up from 15.3 m depth in 1967 to 1.56 m depth in 1982 (Fig. 3), likewise, such degradation phenomenon has occurred in many irrigation projects and has caused reduction in agricultural production. The average crop yield in irrigated areas is only about 2 t/ha, though with judicious water management it is not difficult to obtain 5-6 t/ha of foodgrains.

A survey carried out by AGARWAL et al. (1957) in the salt affected patches in some districts of Uttar Pradesh 40 years after LEATHER (1914) had surveyed them initially, revealed an appreciable increase in the extent and intensity of

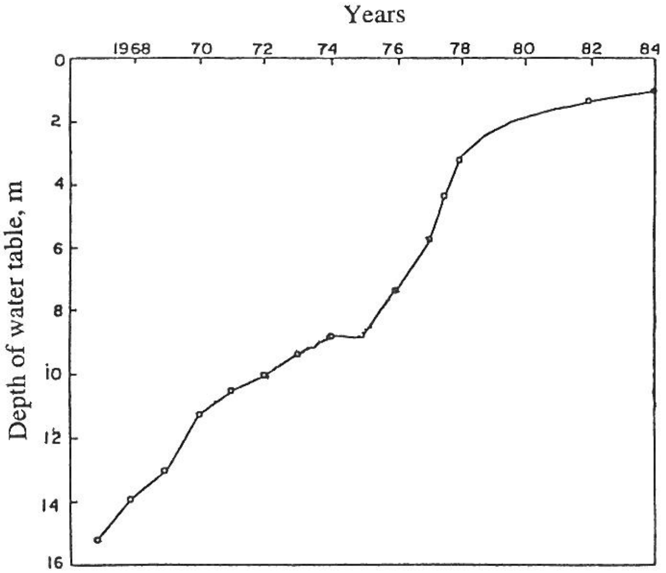

Fig. 3
Periodic rise in water table in Hisar (India) after introduction of canal irrigation

majority of these patches in the canal irrigated tracts. Therefore, continuous monitoring of the changes taking place as a result of canal irrigation is essential to assess the dynamics of the problem and to mitigate degradation of the irrigated areas.

Irrigation with poor quality groundwater

In many arid and semi-arid regions of the world, groundwater which is generally of poor quality is the major source of irrigation. The nature and distribution of groundwaters in some parts of India is reported by YADAV (1982). Continuous use of these waters causes salinity or sodicity in the soil, the effects being more pronounced in slowly permeable heavy clay soils dominated by montmorillonite mineral than in light textured soils dominated by kaolinite or illite mineral (YADAV, 1977), though the climatic conditions, drainability and calcareousness of soil, management practices and kind of crops grown are also important in modifying the effect of irrigation water. Since the crops differ greatly in their tolerance, the limits of salt concentration of irrigation water in causing 10, 25 and 50% reduction in the yields of different crops vary according to soil texture (Table 3; GUPTA & YADAV, 1986).

Besides, many of the poor quality groundwaters possess higher proportion of magnesium than calcium, their ratio increasing with an increase in salinity of

Table 3

Tolerance limits of some crops in saline water irrigation for a given yield reduction

Crop	Limit of EC_{iw} * for yield reduction					
	Sandy loam soil at Agra			Black clay soil at Dharwad		
	10%	25%	50%	10%	25%	50%
Wheat	9.0	12.9	17.6	2.7	7.4	18.0
Sorghum	8.3	12.8	17.8	2.4	6.5	13.4
Safflower	6.2	11.4	-	4.9	12.2	24.7
Mustard	7.9	10.9	14.6			
Pigeon pea	1.8	3.3	6.2			
Cotton				3.3	7.7	15.1
Cowpea				2.0	4.6	8.8

* EC: electrical conductivity in dS/m; iw: irrigation water

water. The prolonged use of irrigation water with high Mg:Ca ratio creates adverse effects on the physical properties of soil like sodium as reflected in an increase in the degree of dispersion and a decrease in hydraulic conductivity (YADAV & GIRDHAR, 1981). The adverse effect is of much greater magnitude in non-calcareous than in calcareous soils. Depending upon the degree of salinity or sodicity of the irrigation water appropriate management practices have been worked out under an all India Coordinated Research Project on Use of Saline Water in Agriculture in recent years.

Problem of Salt Affected Soils

The problem of salt affected soils is widespread in the world (SZABOLCS, 1977) and constitutes one of the most serious factors limiting crop production due to several unfavourable physical, chemical and biological properties. In India, several million ha are inflicted by this malady though some workers put this figure as high as 26.1 M ha. The nature and intensity of the problem varies from region to region according to the variations in the topographical situation, hydrologic and climatic conditions, drainage availability and land use, and therefore, the methods of their management have to be location-specific.

Though the problem is reported to exist from ancient times, some systematic research was initiated towards the end of the Nineteenth Century. The work done on different aspects of salt affected soils in India has been reviewed comprehensively by AGARWAL, YADAV and GUPTA (1979). With the establishment of the Central Soil Salinity Research Institute at Karnal in 1969 under the Indian Council of Agricultural Research, the research activities were intensified and strengthened in a more coordinated manner at the national level. From the management standpoint the salt affected soils are grouped into two broad classes having distinct physical and chemical characteristics:

1. Alkali (sodic) soils, and
2. Saline soils.

The *sodic* soils have high exchangeable sodium, preponderance of carbonate and bicarbonate salts of sodium, high pH values often exceeding 10, deficient amount of available calcium, nitrogen and zinc, impaired physical condition including extremely low infiltration rate, hydraulic conductivity and poor moisture transmission characteristics. Absence of gypsum is conspicuous, but the presence of $CaCO_3$ in amorphous or nodular form or both is a common feature, at times forming a cemented pan in the subsoil which acts as a physical barrier to the growth of deep rooted crops. Because of an inhospitable environment and nutritional disorder, these soils in highly deteriorated condition remain deserted.

The *saline* soils possess excessive concentration of neutral salts of chlorides and sulphates, low exchangeable sodium and pH values, toxicity of specific ions, better physical condition and satisfactory permeability. Generally, the water table is high and the quality of groundwater is poor. Excessive salt concentration is highly injurious to plant growth, and the extent and intensity of bare spots gives an indication of the degree of soil salinity.

In view of the tremendous multiple demands and limited land resources, it has become inevitable to utilize the vast stretches of once productive lands now affected by soil salinity and sodicity for crop production and afforestation.

Utilization for Agricultural Production

Sodic soils

Successful reclamation includes a package of practices comprising proper land levelling and bunding, correct addition of amendment, adequate application of fertilizers and manures including zinc, selection of tolerant crops, their varieties and cropping sequence, appropriate agronomic and water management practices. Availability of good quality irrigation water is an essential prerequisite. Besides, replacement of exchangeable sodium by calcium through the use of an appropriate amendment is a primary requirement for satisfactory reclamation. Amongst the amendments, indigenously available gypsum is by far the most popular and is being used on a large scale.

During the last few years a number of experiments relating to the reclamation of sodic soils have been carried out at the Central Soil Salinity Research Institute, Karnal. The work has shown that initial improvement of only surface 0-15 cm soil is adequate to grow successfully shallow-rooted and tolerant crops like rice and wheat, thereby reducing the dose of amendment application as well as the cost of reclamation. Since crops differ widely in their tolerance, proper selection depending upon the stage of soil deterioration is cri-

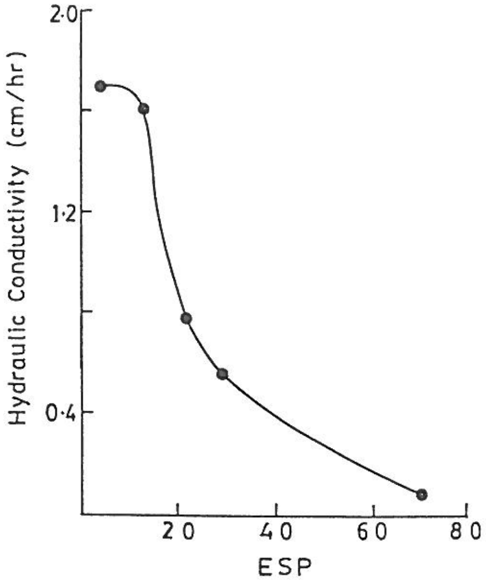

Fig. 4.
Effect of different ESP levels on the saturated hydraulic conductivity of soil

tical. AGARWAL and YADAV (1956) proposed a salinity and alkali scale to evaluate the saline alkali soils of the Indo-Gangetic plain for crop responses. Rice-wheat-*Sesbania aculeata* crop rotation has been found very useful. Inclusion of rice crop in the cropping system has proved extremely beneficial in hastening the reclamation process because of its greater tolerance and its effective role in reducing ESP and pH values under submerged condition of cultivation. Since in the initial stages of reclamation the ESP values still remain relatively higher, the hydraulic conductivity is lower (Fig. 4, SAHA et al., 1971). Under such conditions light and frequent irrigations result in better growth of wheat crop which is sensitive to prolonged water stagnation. Green manuring with *Sesbania aculeata* not only improves soil condition but also benefits the succeeding rice crop equivalent to about 60-80 kg applied nitrogen per ha. In the first few years application of P and K is not generally required, but application of nitrogen 20-25% more as compared to the normal soils is highly beneficial.

In a large number of demonstration trials conducted on the farmers' fields, average yields of 4-5 tonnes per ha of paddy and 1.5-2.0 tonnes per ha of wheat grain were obtained in the very first year. The results of an Operational Research Project implemented in seven villages of Karnal district revealed that with proper adoption of the technology evolved at the institute not only a substantial improvement in soil properties occurred but also a progressive increase in crop yield was recorded in subsequent years (Table 4, MEHTA et al., 1980). As a result of follow-up action undertaken by the state governments of Punjab, Haryana and Uttar Pradesh by establishing land development corporations,

Table 4

Average grain yield of rice (t/ha) (unhusked) on farmers' fields in successive years (I-IV) following reclamation in Karnal district

Year of starting reclamation	I.	II.	III.	IV.
1975	4.0	4.8	5.4	6.0
1976	5.8	5.4	5.6	
1977	4.8	5.1		
1978	4.1			

more than 450,000 ha of hitherto barren sodic soils have already been brought under reclamation.

DHRUVANARAYANA (1977) reported that consequent to reclamation, the infiltration rate of the sodic soil increased tenfold and out of a total monsoon rainfall of 57 cm, runoff of only 8 cm occurred as against 46 cm from the unreclaimed soil. This enhances groundwater recharge, minimizes drainage need and creates a favourable water balance.

Saline soils

For amelioration of saline soils, adequate drainage to lower the water table below the critical limit and to bring about efficient leaching of soluble salts, proper choice of crops and varieties, suitable agronomic methods including plant density, fertilizer application and water management are crucial. The essentiality of drainage for permanent reclamation of saline and waterlogged soils is adequately recognized the world over and is well documented.

The results of a statistically designed experiment started in 1984 by the scientists of the Central Soil Salinity Research Institute in a highly saline sandy loam soil (EC_e ranging from 25-80 dS/m in 0-15 cm layer) with a high water table of poor quality groundwater (EC varying from 10-40 dS/m) in village Sampla in Haryana state, show that the subsurface tile drainage installed at 1.75 m depth brings about considerable salt removal and increased crop yields

Table 5

Effect of subsurface (tile) drainage on salt removal and crop yield in a saline sandy loam soil in India

Drain spacing, m	Salts removed from 0-2 m, t/ha	Crop yields, t/ha				
		Pearl millet	Mustard	Barley	Wheat	Cotton
25	63.6	0.8	2.5	4.2	4.9	1.9
50	52.2	0.7	2.1	3.0	4.1	1.6
75	40.4	0.4	0.9	2.1	2.5	1.6

(Table 5). Likewise, introduction of tile drainage at 1.2 m depth and 12-18 m spacing in a saline heavy clay soil in Karnataka state yielded very encouraging results. The use of vertical drainage in lowering the water table and in ameliorating soil salinity has given good results in some countries like Pakistan.

Despite the voluminous literature on the usefulness of subsurface drainage, its large scale adoption in the field is seriously constrained because of several socio-economic, administrative and organizational difficulties, especially when a group of farmers on a regional or watershed basis is involved. Safe disposal of salty drainage effluent entails additional complex problem which still awaits a workable and economic remedy. Consequently, the efforts made so far to prevent rise of water table and development of soil salinity in irrigated agriculture have been very scanty considering the magnitude of the problem. Time-bound massive programmes are required to be undertaken possibly with the assistance of international agencies if the problem of soil salinity is to be tackled as a measure of permanent solution.

Need and Prospects of Afforestation

Consequent to an unending excessive deforestation a wide gap has occurred between the demand and supply of various tree products and there has been deterioration of environmental ecology. Approximately 11 million ha of tropical forests are lost every year in the world. In India alone, 1.5 million ha of forests have been lost annually in the recent years, and therefore, only 17 M m^3 of fuelwood was available against the requirement of 184 M m^3 in 1980, which is expected to become 225 M m^3 by 2000 A.D. Similarly, only 9.1 M m^3 of industrial wood was available against the demand of 16.3 M m^3 in 1970, which may increase to 47.1-64.4 M m^3 by the turn of the century. The present fodder production is hardly adequate to meet even one-third requirement of 448 million livestock. Considering the acute deficit of forest products and unabated environmental degradation, it has become absolutely essential to afforest the degraded lands including the salt affected soils.

Certain salt affected lands belonging to the village community, educational institutions, government, etc. and also those lying along the roads, canals and railway lines and such other situations, wherein production of agricultural crops is neither feasible nor economical, offer immense possibilities of alternate uses like growing of trees and grasses. Since reclamation measures as adopted over the entire area for production of agricultural crops is too costly for forestry purpose, selection of tolerant species and suitable planting techniques should receive high priority. In highly deteriorated sodic soils it is more economical to improve only the soil of the planting site such that proper establishment of the planted seedlings is ensured. In some soils perforation of the impervious subsoil is necessary to permit adequate root development. These differential factors are reflected in varied response of the trees, sometimes of the same species, to different soil salinity and sodicity levels.

In general, the actual efforts to determine the tolerance of the forest species and suitability of the planting techniques for varying soil sodicity/salinity conditions have been very limited though the different forest species differ greatly in their tolerance. Nevertheless, based on the available data, some species are arranged in the descending order of their tolerance (Table 6). The presence of compact indurated layer/pan in the subsoil seriously limits the tolerance.

Table 6

Relative tolerance of some forest species in descending order

Soil sodicity	Soil salinity
Prosopis juliflora	*Prosopis juliflora*
Acacia nilotica	*Casuarina equisetifolia*
Eucalyptus hybrid	*Tamarix articulata*
Butea monosperma	*Salvadora oleoides*
Pongamia Dinnata	*Acacia nilotica*
Terminalia arjuna	*Eucalyptus hybrid*
Casuarina equisetifolia	*Azadirachta indica*
Azadirachta indica	*Pongamia pinnata*
Dalbergia sissoo	*Dalbergia sissoo*
Albizia lebbek	*Cassia siamea*

Sodic soils

From the results of a field experiment started in 1970 on a calcareous sodic soil with pH above 10 at Karnal, YADAV et al. (1975) reported that the height performance of *Prosopis juliflora, Acacia nilotica* and Eucalyptus hybrid in the soil treatment of the planting pit with gypsum + FYM five years after planting was almost at par with the treatment where the original soil was replaced by normal soil. Most of the planted seedlings died in the untreated sodic soil. Addition of N and P fertilizer in a small dose boosted the height growth. The presence of indurated calcic pan in the subsoil is more harmful to *Acacia nilotica* than to *Prosopis juliflora.* The growth of *P. juliflora* results in a decrease in the values of pH and salt content, and an increase in the amount of organic matter and nitrogen especially in the upper 15 cm layer (Table 7; YADAV & SINGH, 1970).

Table 7
Effect of Prosopis juliflora growth on the properties of sodic soil in Uttar Pradesh, India

Depth, cm	Organic matter, %	N, %	pH	Soluble salts, %
		Original soil		
0 - 5	0.54	0.057	10.6	1.24
5 - 25	0.21	0.032	10.6	1.24
25 - 57	0.18	0.017	10.5	0.90
57 - 95	0.08	0.010	10.4	0.67
		Under P. juliflora		
0 - 3	2.87	0.140	8.2	0.26
3 - 15	0.31	0.043	9.8	0.38
15 - 71	0.23	0.036	10.5	1.31
71 - 100	0.15	0.015	10.8	1.05

Saline soils

In a sand culture study, JOSHI et al. (1987) noticed tolerance of *Salvadora persica* and *Avicennia maritina* to high soil salinity and advocated the use of these species for forage production on the saline wastelands. JAIN et al. (1985) found that *P. juliflora* and *Tamarix articulata* are tolerant to soil salinity levels as high as 27-40 dS/m. According to TOMAR & GUPTA (1984) planting on the raised ridges resulted in higher survival percentage and height growth of *Acacia nilotica, P. juliflora* and *Tamarix articulata* in a highly saline soil (EC_e of surface soil ranging from 20-160 dS/m) having high water table of salty groundwater (EC ranging from 20-40 dS/m). *Casuarina equisetifolia* and *Parkinsonia aculeata* also showed good survival.

A number of direct and indirect benefits accrue from afforestation of salt affected soils. The tree growth not only provides economic returns, generates employment opportunities and supplies fuel, food, fodder, fertilizer, timber and other products, but also improves soil conditions, helps divert the use of animal dung as organic manure and maintains environmental ecology.

Conclusions

Heavy pressure of fast expanding population, declining land:man ratio, inefficient and inadequate use of various inputs, weather aberrations, incomplete transfer of improved technology and degradation of land, water and environment are the chief constraints to agricultural development. Resource inventories of degraded lands and their potentials to respond to wise management for productive purposes will facilitate optimum land use for sustaining rural economy. Widespread occurrence of soil salinity and sodicity resulting from poor water management and other factors is limiting crop production. With adoption of appropriate technologies these problem soils offer enormous scope for crop production and afforestation. A large area of sodic soils has been already brought under reclamation for crop production in India. The results obtained on the farmers' fields amply demonstrate the distinct possibility of achieving at least 5-6 tonnes of rice and wheat yields per ha in a year on the highly deteriorated sodic soils where nothing could be grown in the past. Similarly, the research findings of the Central Soil Salinity Research Institute, Karnal clearly favour the prospects of growing multipurpose trees on the saline and sodic soils with the use of suitable planting techniques, soil working methods and tolerant species.

Enhancement of agricultural production to feed the burgeoning population, and efficient utilization of the land resources to meet the growing other multiple demands related to tree products with due regard to environmental protection are the most pressing challenges facing the mankind today. With rapid changes in the socio-economic setting and in environmental ecology in the recent years, we have to face numerous challenges of more complex nature in future than in the past. Therefore, the new technologies should be tolerant to various stresses and should aim at increased productivity, profitability, stability and sustainability.

The following strategies merit priority attention;

- Intensification and diversification of agriculture
- Sustainability of high productivity

- Greater use efficiency of various inputs
- Modification of plant type and soil condition
- Development of economically viable, locally adaptable and socially acceptable technologies
- Adequate processing, marketing, distribution and credit facilities.

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