Sustainable Rehabilitation of Sodic Soils Through Biolgical Means—A Case Study

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Abstract: Growing of efficient genotypes of crops and trees that could endure sodicity were experimented for rehabilitation of once barren sodic landscape in the middle part of the Gangetic alluvial plain at Banthra Research Station of National Botanical Research Institute, Lucknow, India (80° 45′ –53′ E, 26° 40′ –45′ N). The results showed the anthropogenic effect on alteration of surface texture in soils of Typic Natrustalfs. The soils of Inceptic Haplustalfs markedly improved. The soils of Aeric Endoaquepts supporting the stands of forest trees are now devoid of sodicity to about 0.5 m depth, whereas the soils of Aeric Halaquepts though under cultivation have mild sodicity. Strategies for sustainable management of sodic wastelands suggested are maintenance of ground water level in safe zone and follow intensive cropping using biological treatments to get desired and long lasting results.
Keywords: Bio- treatments, sodic soil, sustainable management, rehabilitation

1 Introduction

Sodic soils are wide spread throughout the world (Bui *et al.,*1998). In general genetic causes of soil sodicity identified are climate, hydrology, soil type and irrigation practices (Sharma, 1998). In India and elsewhere various soil amendments were used to tackle the problem of sodic soils (Mc Bride, 1994). However the reclamation process is location specific. Generalization of any technique could be unrealistic because the condition of sodicity differs from place to place. The problem of resalinization/ resodification was observed when large-scale reclamation project was undertaken in the State of Uttar Pradesh, India through World Bank Group initiated in the year 1993. Essentially there could be two approaches for the rehabilitation of sodic lands. The first could be improving soil properties through suitable chemical amendments or otherwise by growing efficient genotypes of crops/trees which could tolerate the existing sodic soil stress conditions. In any case the main objective in rehabilitation of such land is to reduce its exchangeable sodium content to a level that permits conditions for plant growth. The present study provides a comprehensive account of rehabilitation using biological means at Banthra Research Station, which was once a barren sodic land in the middle part of Gangetic alluvial plain in north India.

2 Materials and methods

2.1 Description of the study area

The study was conducted at Banthra Research Station of the Institute situated beside the Lucknow - Kanpur highway at an elevation of about 129 m above m.s.l. It stretches from longitude 80° 45′ to 80° 53′ E and latitude 26° 40′ to 26° 45′ N). The meteorological parameters indicate that the climate of the site is semiarid subtropical and monsoonic. It receives an average annual rainfall of about 872mm. Mean maximum temperatures of 39.1℃ found in the month of May and the mean minimum temperature of 7.6℃ observed in the month of January. Soil temperature regime is hyperthermic. Soil moisture regime varies from ustic to aquic depending upon the physiographic position of the study area. A vast tract of this alluvium constitutes abandoned sodic soils. It was subjected to periodic submergence and evaporation turned to sodic when natural drainage was impeded. Some physical and chemical properties of original soil profile are given in Table (1). Dedicated efforts were made to rehabilitate these inhospitable soils planted with crops/ trees in the past three decades (Khoshoo, 1987).

Table 1 Physico-chemical properties of original soil profile at Banthra Research Station, Lucknow, India

Depth Cm	Sand %	Silt %	Clay %	Texture	W.H.C.* g kg^{-1}	Permeability cc hr^{-1}	pH	EC dsm^{-1}	OC g • kg^{-1}	$CaCO_3$ g • kg^{-1}	Ca (c mol (+) kg^{-1})	Mg (c mol (+) kg^{-1})	Na (c mol (+) kg^{-1})	CEC	ESP
0—20	43.4	30	26.6	sil	3.4	Nil	9.6	2.18	1.9	8.2	16.2	1.0	9.26	12.6	73.5
20—56	33.4	30	36.6	sicl	3.9	Nil	10.2	3.43	0.8	10.3	11.8	4.2	15.26	12.3	124.0
56—78	29.4	28	42.6	sicl	3.7	Nil	10.2	3.12	1.0	5.7	5.6	12.4	15.5	14.1	110.0
78—110	23.4	36	40.6	sicl	3.8	Nil	9.6	1.72	1.1	5.0	5.8	7.2	11.16	15.1	74.0
110—152	39.7	26	34.3	sicl	3.3	Nil	9.1	1.25	1.1	62.8	6.4	9.2	4.36	14.2	31.0

*****Water holding capacity

2.2 Management of the land

Provision of assured supply of irrigation was accomplished by boring of low cost cavity wells up to 30m—35 m depth. These wells gave a discharge of about 13,000 l • hr $^{-1}$ water. The trenches (2m × 3m) were excavated throughout the periphery of land to regulate the flow and harvest the rainwater. These trenches were also used as drainage channel and ultimate water was stored in a pond for use during the dry periods. Before the land was brought under cultivation it was leveled well. Organic matter and several weeds and unwanted phytomass were incorporated into the soil. Initially high water demand crop of paddy (*Oryza sativa*) and dhaincha (*Sesbanea aculeate*) followed by wheat/barley were cultivated as being the most tolerant and adaptable in such stress conditions. This was followed by other sodic - tolerant plant species e.g. annuals, herbs including medicinal and aromatic, shrubs, fruit trees and fuelwood trees. Following crop and crop sequences were adopted in the rehabilitation of sodic soils.

(1) Paddy—shrubs—bulbous plants
(2) Paddy—fruit trees—bulbous plants
(3) Paddy—shrubs—annual crops
(4) Paddy—mono & mixed culture tree cropping
(5) Paddy—uncultivated (control)

In order to monitor soil chemical changes that occurred during the past thirty-five years of bioreclamation, soils were classified into five soil groups. These are Typic Natrustalfs, Typic Haplustalfs, Aeric Halaquepts, Aeric Endoaquepts and Typic Halaquepts. Garg *et al.* (2000) has reported the characteristics of these soils in detail. To test the hypothesis in rehabilitation of sodic soils by trees a separate study was also conducted where monoculture tree plantation of *Acacia nilotica*, *Dalbergia sissoo*, *Prosopis juliflora* and *Terminalia arjuna* were planted for about a decade period (1990—2000). The rate of nutrient flux was ascertained by analyzing the soil samples for different depths (15 cm interval) every year. The physical parameters such as bulk density (BD), particle density (PD) and water holding capacity (WHC) were determined following standard methods (Jackson, 1967, Richards, 1954). The tree root system (Bohm, 1979) and soil mycoflora in planted and unplanted sites were estimated by dilution plate technique. The representative colonies of fungi isolated from each type were authenticated from Commonwealth Agricultural Bureau, International Mycological Institute in Oxford.

3 Results and discussion

Soil chemical changes observed in different soil profile following different crop sequences for over three decades are presented in Table (2).

3.1 Improvement in typic natrustalfs

In general, *Sesbanea aculeate* was grown as green manuring crop during summer initially. Thereafter, paddy (*Oryza sativa*) was cropped in kharif and wheat in rabi each year since the reclamation programme was launched. Farmyard manure and other organic material were applied frequently. The cropping sequence adopted was: paddy—bougainvillea—bougainvillea—tuberose. The sturdy root system of paddy markedly increased hydraulic conductivity (Garg, 2000). The rate of sodium removal enhanced by mass flow rather than by diffusion caused by paddy cultivation (Mc Neal *et al.*, 1968). Bougainvillea grew well on sodic soil and helped in scavenging of sodium through their foliage accumulating higher concentration of Na 7 g • kg^{-1} (Jain *et al.*, 1981). This led to cultivation of *Polianthes tuberosia* a ornamental crop able to withstand sodic stress (Singh, 1972). During practicing of above cropping sequence, application of sand (river) and FYM in bulk amount led to the build up organic matter status and also brought about changes in surface texture from silt loam to sandy loam.

Table 2 Chemical changes in soil profile following different cropping sequences at Banthra Research Station, Lucknow, India

C. S* No.	Name of soil group	Depth (cm)	Texture	pH	EC (ds • m^{-1})	Org. C. (g • kg^{-1})	$CaCO_3$ (g • kg^{-1})	Exchangeable cations (c mol (+) kg^{-1})				CEC (c mol(+) kg^{-1})	ESP
					1:2 soil ratio			Ca^{++}	Mg^{++}	K^{+}	Na^{+}		
1	Typic Natrustalfs	0—10	Sl	9.4	0.91	4.74	8.4	9.2	4.8	0.50	3.48	15.65	22.24
		10—22	sil	10.0	1.0	1.03	7.2	6.0	2.8	0.40	9.57	18.26	52.41
		22—40	sicl	10.2	1.2	0.91	9.3	2.8	0.4	0.50	14.78	20.00	73.90
		40—65	sil	10.5	1.2	0.71	10.4	1.6	0.4	0.46	15.65	20.00	78.25
		65—100^{+}	sil	10.7	1.8	0.84	12.0	2.4	0.4	0.40	15.65	21.74	71.99
2	Typic Haplustalfs	0—10	Sil	7.8	0.48	6.05	0.13	11.2	4.8	1.02	0.61	18.26	3.34
		10—25	sil	8.1	0.34	2.58	0.09	10.8	6.0	0.46	0.52	18.26	2.85
		25—40	sil	8.0	0.29	1.60	0.22	10.0	3.6	0.40	0.52	17.39	3.00
		40—60	sil	8.1	0.27	1.68	0.26	9.2	5.2	0.40	0.43	20.87	2.06
		60—80	sil	8.0	0.30	1.05	0.08	10.4	4.8	0.40	0.43	20.00	2.15
		80—100^{+}	sil	7.9	0.22	0.96	0.10	8.8	5.2	0.40	0.52	19.13	2.75
3	Aeric Halaquepts	0—16	Sil	8.6	0.27	5.74	2.8	10.0	10.0	1.41	1.52	18.15	8.39
		16—45	cl	10.0	0.63	1.32	4.0	9.3	8.8	0.78	11.41	18.47	61.76
		45—61	cl	10.3	0.85	1.32	7.6	6.4	3.1	0.89	14.78	16.84	87.60
		61—74	cl	10.4	0.74	0.58	5.4	4.6	4.9	0.89	14.02	14.78	90.27
		74—90	cl	9.6	0.66	0.30	4.8	5.0	4.0	0.89	14.13	15.43	90.55
		90—110^{+}	cl	9.8	0.71	0.30	4.5	4.4	6.1	1.03	14.89	15.22	90.85
4	Aeric Endoaquepts	0—9	Sil	8.3	0.27	9.7	Nil	11.6	14.8	2.18	0.54	22.28	2.44
		9—19	sil	8.3	0.23	1.17	2.9	14.8	15.6	1.98	1.63	14.48	8.82
		19—35	sil	8.5	0.19	0.44	0.1	10.4	13.1	1.28	0.87	15.10	5.75
		35—48	sil	8.9	0.20	0.44	Nil	9.8	13.1	0.77	1.95	16.74	11.68
		48—66	sil	9.3	0.27	0.14	Nil	8.3	9.6	0.64	3.80	14.35	26.51
		66—95	sil	9.6	0.37	0.14	Nil	6.8	10.6	0.51	4.78	12.50	38.25
5	Typic Halaquepts	0—16	Sil	9.5	0.47	2.20	3.9	6.0	8.0	0.77	3.80	11.95	31.82
		16—39	sicl	10.6	0.81	0.44	8.3	3.6	7.8	0.77	13.04	12.50	90.34
		39—56	cl	10.9	1.27	0.29	8.0	2.3	2.3	0.83	14.67	14.78	90.26
		56—72	cl	10.9	1.94	0.29	1.1	2.7	2.3	1.02	19.56	20.10	90.33
		72—94	cl	11.0	2.47	0.14	1.1	3.0	1.5	0.89	19.02	18.15	91.33
		94—100^{+}	cl	11.0	2.52	0.14	1.0	3.3	3.3	0.89	14.67	21.74	67.49

*Cropping sequence

3.2 Improvement in inceptic haplustalfs

The cropping sequence of paddy—grape—grape—gladiolus was followed. The results observed were similar to the improvement of Typic Natrustalfs by growing rice crop for about a decade. The roots of deep-rooted fruit crop of grape probably acted as bio drain and helped further in reducing the sodicity of soil (Garg, 2000). This crop resulted in an appreciable decrease in exchangeable Na and created favourable conditions for successful cultivation of gladiolus crop.

3.3 Improvement in aeric halaquepts

The cropping sequence practiced was: paddy—rose—matricaria—amaranth; since these soils remain submerged for most of the year, the reclamation process was slow. However, the cultivation of rose brought about a marked decrease in soil pH and Exch. Na. The salt uptake studies indicate that this plant removed Na about 9 $g \cdot kg^{-1}$ of plant material (Singh, 1970a). Whereas cultivation of *Matricaria Chamomilla* proved to be greater scavenger of Na than *Rosa damascena* removing about 28 $kg \cdot ha^{-1}$ Na from the soil in one crop cycle (Singh, 1970a). Thus, the status of exch. Na was declined sufficient to a level permitting the cultivation of other less tolerant crops like amaranth.

3.4 Changes in aeric endoaquepts

In the beginning, the paddy crop was grown as described earlier. There after different species of trees were planted in a mono as well as mixed cropping system. Mixed tree species included *Acacia nilotica*, *Albizia procera*, *Emblica officinale*, *Ficus bengalensis* and *Syzygium cumini*. An appraisal of data revealed that afforestation of sodic soil by mixed tree cropping was found far better than mono tree cropping (Verma *et al*., 1982). However, in another set of experiment growing them separately in monoculture tested the efficacy of tree in rehabilitation of sodic soils. Tree species of *Acacia nilotica, Dalbergia sissoo, Prosopis juliflora,* and *Terminalia arjuna* were afforested for about a decade to rehabilitate sodic soils. Results showed a marked improvement in physical properties by way of decreasing bulk density and increasing of water holding capacity (Table 3).

Table 3 Changes in some physical properties of sodic soil (0 cm—15 cm depth) under a decade old tree stands planted at Banthra Research Station, Lucknow, India

Tree species	Bulk density ($10^3\ g \cdot m^{-3}$)	Porosity (%)	Water holding capacity ($g \cdot kg^{-1}$)
Acacia nilotica.	1.61	45	3.7
Dalbergia sissoo	1.50	48	4.5
Prosopis juliflora	1.43	51	5.4
Terminalia arjuna	1.55	45	4.0
Unplanted site	1.80	40	2.9

The microbial activity enhanced at site planted under the tree than in the control unplanted site (Table 4). The pioneer mycoflora found associated with the root zones of afforested trees were *Aspergillus flavus* Link, *A. fumigatus* Fres, *A. niger* V. Tieghem, *Cunninghamella echinulata* (Thaxter) Thaxter ex Blakeslee, *Paecilomyces lilacinus* (Thom) Samson, *Penicillium, Rhizopus* and *Trichoderma.*

Table 4 Mean microbial population of surface soil covered with different trees and without tree (control) at Banthra Research Station, Lucknow, India

Site type		Fungi × 10^6	Total count × 10^6	
			Bacteria	Actinomycetes
Acacia nilotica.	(R)	12.0	30.3	4.5
	(D)	10.0	18.6	7.9
Dalbergia sissoo	(R)	19.3	28.8	9.2
	(D)	10.0	26.2	8.2
Prosopis juliflora	(R)	15.0	42.0	11.0
	(D)	12.0	36.0	8.3
Terminalia arjuna	(R)	8.0	15.0	4.0
	(D)	8.3	13.0	2.0
Control		6.5	9.8	3.2

R = rhizosphere soil; D = metre away from tree base

The potential extent of biological rejuvenation of sodic soil was found related to the distribution of roots in the soil profile. Results showed that the horizontal spreading of roots with bulk of fibrous and fine feeder root and downward penetration of roots attributed amelioration of sodic soils (Fig.1).

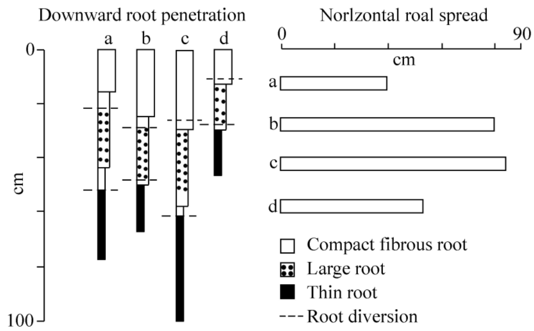

Fig.1 Downward and horizontal root spread of (a) *Acacia nilotica*; (b) *Dalbergia sissoo;* (c) *Prosopis juliflora* and; (d) *Terminalia arjuna*

3.5 Changes in typic halaquepts

Since paddy was the pioneer crop some improvement observed due to its special cultural practices. However, this area acted as control as it was not under continuous cultivation, thus, did not show any marked changes in exchangeable Na.

Presently, the forest site is comprised of subtropical mixed deciduous tree species. It is supporting the habitat of animals like monkey, jackals, rabbits, foxes and birds (peacock, partridges etc.) and reptiles.

3.6 Strategy for sustainable rehabilitation of sodic land

- Water is the cause of the soil sodicity and water is also a remedy of rehabilitation.
- Use ground water for intensive irrigation.
- Follow conjunctive use of surface and ground water to maintain water level in safe zone.
- Harvest rainwater to use in dry periods or where other source of irrigation is unavailable.
- Heavy irrigation in clay dominant lithology area should be avoided.
- Intensive cropping system should be followed using biological treatments.

Acknowledgements

The author is grateful to Dr. P. Pushpangadan, Director, National Botanical Research Institute, Lucknow for his keen interest and providing necessary facilities during the course of study.

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