

PHYTOREMEDIATION OF A SODIC FOREST ECOSYSTEM: PLANT COMMUNITY RESPONSE TO RESTORATION PROCESS

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Abstract. The creation of a new biotope on degraded lands is the focused objective nowadays, on a global level. An attempt was made to rehabilitate sodic waste lands through the establishment of plant cover, with diverse plant communities within Banthra Research Station of the National Botanical Research Institute, Lucknow, India (80°45' - 53°53' E and 26°40' - 26°45' N) for the last three decades. A rehabilitated forest ecosystem developed in this way consists in a number of herbs, shrubs and trees. *Derris indica*, *Dalbergia sissoo*, *Azadirachta indica*, *Cassia siamea*, *Terminalia arjuna*, *Syzigium cumin* were the dominant species in this rehabilitated forest, whereas *Sporobolus*, *Desmostachya* and *Dactyloctenium* were a common genera of grasses /forbs on a barren land. This study showed that species diversity and productivity significantly influenced the soil amelioration process. A comparison of three afforested sites with a varying degree of productivity and diversity indicated that some soil properties were influenced by diversity while others by productivity. Individual effects of diversity and productivity were classified as 42% and respectively 58%, in soil reclamation. A combined effect of both biomass productivity and species diversity contributed about 92% towards amelioration. There was an appreciable reduction in soil pH and ESP (exchangeable sodium percentage) and an increase in organic C and N contents showing that sodicity has receded in the forested soil. This experience can be tried out on similar sites of arid and semiarid regions of the world for the bioreclamation of sodic lands.

Key words: soil amelioration, diversity, rehabilitated forest, productivity, degraded wastelands

INTRODUCTION

Salt affected soils are wide spread on many continents of the world, constituting about 831 million ha (Martinez-Beltran and Manzur, 2005). There are two major types of salt affected soils, namely saline and alkali soils. Saline soils include solonchak/white alkali and sodic soils also called solonetz/black alkali. Alkali soils, also termed sodic, due to the presence of excessive exchangeable Na⁺. Such soils possess bad physical conditions. Soil particles are dispersed; and as a consequence, the movement of water and air is restricted. In general, soil sodicity is a more widely spread form of land degradation occupying >2 billion ha throughout the world (Grainger, 1988). Reclamation and revegetation of degraded lands under productive ecosystems are currently global priority issues (Winjum et al., 1992). Proven afforestation techniques have been employed to control land degradation, as for example, enhancing the forest cover *vis-a-vis* biodiversity conservation and pollution abatement. Restoration/rehabilitation of degraded waste lands has attracted worldwide attention in view of the shrinking arable land, particularly in developing countries (Barrelt-

Lennard et al., 1986; Singh, 1989; Brown and Lugo, 1994; Garg, 1999). Most of the developing countries in Asia are facing the daunting challenge of managing their ever increasing human and cattle population, to meet the requirement of food, fuel wood and fodder etc. There is fragmentary information available regarding the restoration of productivity and fertility of degraded sodic soils through tree plantation (Bhojvaid et al., 1996). However, the development of mixed forest tree species on sodic wastelands, apart from providing diverse needs and services to the society, ameliorates the soil to various degrees. This appears as a function of species diversity, productivity and decomposition process (Garg, 1998; Singh, 1998). Hence, the present study reports the influence of plant diversity and dominance on afforested sites, during the past three decades. Different forested sites with varying degrees of productivity and diversity were evaluated for the changes in soil characteristics.

MATERIAL AND METHODS

SITE AND CLIMATE

The study was carried out within the Banthra Research Station of the National Botanical Research Institute, Lucknow, India (80°45' to 80°53' EL and 26°40' to 26°45' NL). The site belongs to the Gangetic alluvial plain region in the subtropical biogeographical zone of India. Average annual rainfall is measured as 872 mm. More than 80% of the precipitation occurs in a monsoon season (July-September), while for the rest of the year, it remains almost dry. Mean minimum and maximum temperature differ significantly from winter (8°C, 22°C) to summer (27°C, 40°C) indicating a seasonally distinct climate.

SOILS

The soil of the site is characterized as Aquic Natrustalfs, having silt loam to silty clay loam surface texture at the afforested site. Soils were non-saline sodic, structureless, with a calcic horizon and having extremely low permeability. The soil matrix had a predominantly yellow (2.5 y 5/4) hue. Soils had a pH of 10-11, which increased with depth. The specific conductance of the soil was generally $<2 \text{ dSm}^{-1}$. A compact layer of indurated pan consisting of CaCO_3 concretions and iron hydroxide granules is encountered between 0.20-0.90 m depth, coinciding with the illuviation zone. The soil profile had restricted subsurface drainage with mottling of MnO_2 and roundish granules of iron coating, varying from 3-5 mm in size. These soils become very hard, form a thin crack and turn cloddy during dry, hot summers. When wet, particularly during rains, they become waterlogged, sticky and plastic, consequently plant growth is impaired and soil functions restricted by the adverse effect of oxygen stress.

METHODS

Several tree species were grown on an abandoned sodic land (pH >10) from 1956 to 1962 through repeated revegetation attempts. These were planted in the pits of 1m^3 size filled with a mixture of compost manure and leafmold, covering an area of about 15 ha. About 22 tree species could have been established, out of 50 species tried (Table 1). These species led to the development of a secondary succession and formation of a terrestrial ecosystem inhabiting local wild life such as monkey, jackal, rabbits, reptiles, foxes, blue bulls and birds. Community structure and species abundance were quantified by laying out several quadrats following line transect method (Singh et al., 2004). With these field data Importance Value Index (IVI) and Shannon-Wiener's Index of diversity were calculated. Three sites with diverse species composition and basal area were selected and designated as site I, II, III. A control (non-forested site) was also studied with 20 quadrats of relatively small size ($1\text{x}1 \text{ m}$), laid-out randomly on barren sodic land. Three replicated plots of about 0.1 ha were marked on each treatment site. All 30 quadrats ($10\text{m} \times 10\text{m}$) were studied to measure IVI, species

richness, basal area, population density, by employing Shannon Wiener's index of diversity and productivity per unit area on each site.

Table 1

Tree species grown from 1956 to 1962 on a barren sodic soil at Lucknow, India

<i>Acacia auriculiformis</i> A. Cunn ex Benth.	<i>Diospyros montana</i> Roxb.
<i>A. catechu</i> Willd.	<i>D. peregrine</i> Montana Roxb.
<i>A. lenticularis</i> Buch. Ham.	<i>Eucalyptus terericornis</i> Sm.
<i>A. leucophloea</i> (Roxb.) Willd.	<i>Lagerstroemia speciosa</i> Pers.
<i>A nodusa</i> Wall.	<i>L.thorelii</i> Gagnep.
<i>A. Senegal</i> Willd.	<i>Madhuca indica</i> J.F. Gmel.
<i>A. nilotia</i> var. <i>indica</i> Hill.	<i>M.longifolia</i> (Koenig) Mach.
<i>Adina cordifolia</i> (Roxb.) B. et. Hoof. F. ex Brandis	<i>Markhamia stipulata</i> Seem.
<i>Albizia lebbeck</i> (L) Benth.	<i>Melaleuca leucadendron</i> Linn.
<i>A. procera</i> Benth.	<i>Melia indica</i> A. Juss.
<i>Anogeissus pendula</i> Edgew.	<i>Millingtonia hortensis</i> Linn.
<i>Azadirachta indica</i> A. Juss.	<i>Mimosa rubicaulis</i> Lam.
<i>Barringtonia acutangula</i> (Linn) Gaerth.	<i>Morus laevigata</i> Wall.
<i>Bauhinia spp</i>	<i>Peltophorum pterocarpum</i> Bach.
<i>Bombax ceiba</i> Linn.	<i>Pithecellobium dulce</i> Bench.
<i>Borassus flabellifer</i> Linn.	<i>Prosopis spicigera</i> Linn.
<i>Caesalpinia coriaria</i> (N.J. Jaiquin) Willd.	<i>Soymida febrifuga</i> Juss.
<i>Callistemon lonceolatus</i> Sweet.	<i>Streblus asper</i> Lour.
<i>Casia fistula</i> Linn.	<i>Syzygium cumini</i> (L) Skeels.
<i>C. siamea</i> Lam.	<i>Tabebuia argentea</i> Briton.
<i>Casuarina equisetifolia</i> Linn.	<i>Tamarindus indica</i> Linn.
<i>Cordia dichotoma</i> Forst.	<i>Terminalia arjuna</i> (Roxb ex DC) Wight & Arn
<i>Dalbergia sissoo</i> Roxb. ex DC	<i>T. belerica</i> Roxb.
<i>Delonix regia</i> Rafin.	<i>T. chebula</i> Retz.
<i>Derris indica</i> Bennet.	<i>Thespesia populnea</i> Soland. ex Correa.

To study the response of diversity and productivity, soil sampling was carried out from 3 replicated plots in each site, along with a control (non forested site). There were no distinct horizons, therefore soil samples were taken at 0.15 m intervals, up to 0.90 m depth from nine soil profiles of barren land. Standard methods were applied for the determination of soil pH, organic carbon, total N, and exchangeable sodium percentage (ESP) (Jackson, 1967; Richards, 1954).

RESULTS AND DISCUSSION

TREE POPULATION DENSITY AND DOMINANCE

As far as the present study is concerned, 6 species viz. *Derris indica*, *Dalbergia sissoo*, *Azadirachta indica*, *Syzygium cumuni*, *Cassia siamea* and *Terminalia arjuna* have a larger number of individuals, while other species were represented by one or two individuals. Considering the distribution of species in the area, *Azadirachta indica* exhibited maximum dispersion (65%) followed by *Dalbergia sissoo* (60%) and *Syzygium cumuni* (40%). *Terminalia arjuna* and *Derris indica* showed 30% spread. However, other species showed a frequency distribution of about 5 percent only. High frequency values showed a greater uniformity of species spread and dispersion, while poorly-spread species have a few occurrences. The most promising dominant species, on the basis of the IVI value >40, were *Derris indica*, followed by *Cassia siamea*, *Dalbergia sissoo*, *Azadirachta indica*, *Tectona grandis*, *Prosopis juliflora*, *Terminalia arjuna*. However, *Syzygium cumuni*, *Cassia fistula*, *Bauhinia accuminata*, *Delonix regia*, *Peltophorum pterocarpum* and *Acacia nilotica*, with IVI

above 28, may be considered as co-dominant species. The basal area is also considered as one of the indices for identifying dominant species. The species constituting more than 10% of the total basal area in a forest are generally considered the dominant species of that forest. As such, *Dalbergia sissoo*, *Azadirachta indica*, and *Terminalia arjuna* stand for dominants (Table 2).

Table 2
Species occurrence and community structure on a rehabilitated site at Lucknow, India

Sl. No.	Species	Family	IVI	Basal Area (m ² ha ⁻¹)	Diversity Index
1.	<i>Acacia nilotica</i>	<i>Leguminosae</i>	28.21	1.55	0.065
2.	<i>Albizia lebbbeck</i> Benth.	<i>Leguminosae</i>	8.90	0.32	0.065
3	<i>Azadirachta indica</i> Juss.	<i>Meliaceae</i>	63.04	6.83	0.131
4	<i>Bauhinia spp.</i>	<i>Leguminosae</i>	32.20	0.40	0.145
5	<i>Cassia siamea</i> Lamk.	<i>Leguminosae</i>	77.73	0.38	0.156
6	<i>Cassia fistula</i> Linn.	<i>Leguminosae</i>	33.95	0.04	0.040
7	<i>Cordia dichotoma</i> Forst.f	<i>Boraginacea</i>	12.66	0.78	0.152
8	<i>Dalbergia sissoo</i> Roxb.	<i>Leguminosae</i>	77.04	0.75	0.097
9	<i>Delonix regia</i> Rafin.	<i>Leguminosae</i>	31.32	0.42	0.123
10	<i>Erythrina indica</i> Lamk.	<i>Leguminosae</i>	5.12	0.08	0.065
11	<i>Emblcia officinalis</i> Gaertn.f.	<i>Euphorbiaceae</i>	19.74	1.25	0.123
12	<i>Eucalyptus tereticornis</i> Syn.	<i>Myrtaceae</i>	7.55	0.36	0.040
13	<i>Holoptelea integrifolia</i> Planch.	<i>Ulmaceae</i>	11.40	0.13	0.065
14	<i>Leucaena leucocephala</i> de Wet.	<i>Leguminosae</i>	13.21	0.23	0.120
15	<i>Pithecellobium dulce</i> Benth.	<i>Leguminosae</i>	21.57	0.18	0.065
16	<i>Derris indica</i> Bennet.	<i>Leguminosae</i>	84.09	1.98	0.130
17	<i>Peltophorum pterocarpum</i> B. ex Heyne.	<i>Leguminosae</i>	39.41	0.21	0.121
18	<i>Prosopis juliflora</i> DC.	<i>Leguminosae</i>	41.53	0.16	0.065
19	<i>Psidium guajava</i> Linn.	<i>Myrtaceae</i>	11.28	0.09	0.065
20	<i>Syzygium cumini</i> Skeels.	<i>Myrtaceae</i>	33.19	1.95	0.159
21	<i>Terminalia arjuna</i> W & A.	<i>Combretaceae</i>	41.25	4.53	0.154
22	<i>Tectona grandis</i> Linn.f.	<i>Verbenaceae</i>	45.41	0.39	0.112

DIVERSITY INDEX

The tree species diversity index (H) was assessed as 2.3 in our study, according to Shannon Weiner's formula (Table 2). As not all the trees grew at the same rate, not even the individuals of a single species, variation in the population size resulted into a different plant community structure. The diversity index (H) in our forest was relatively low, in comparison to the natural forest of the Vindhyan region, India (Singh and Singh, 1991). Similarly lower H values have been reported in three rain forests of Brazil (Scarano et al., 1998). The tree species established on sodic site showed their ability to tolerate and adapt to the adverse edapho-climatic conditions. In due course of time, a new functional forest ecosystem was developed, with the associations of natural invaders.

RESPONSE OF DIVERSITY AND PRODUCTIVITY AT DIFFERENT SITES

There were a few species common among the dominants of forested sites, such as *Terminalia arjuna* (I, II, III), *Bauhinia variegata* (I & II) and *Holoptelea integrifolia* (I & II) as listed in Table 3.

Different indices of community structure for the 3 afforested sites indicated a decreasing pattern of IVI, diversity index, population density and basal area from site I to site III (Table 4). As a consequence, phytomass also declined accordingly. The control site, containing a few sparse grasses of *Sporobolus* and *Desmostachya*, had a modest range of IVI and tillers, but its diversity index and phytomass values were lowest among all sites.

However, these species also varied in size and growth stage. All these sites were not apparently different in soil texture, as the proportions of sand, silt and clay were almost similar and the soils were classified as salty clay loam. Soil pH and ESP decreased considerably corresponding to productivity and diversity of species (Figure 1).

Table 3

Dominant species of the three afforested sites in comparison to non forested control (Site IV)

Site I	Site II	Site III	Site IV (control)
<i>Acacia nilotica</i>	<i>Azadirachata indica</i>	<i>Bauhinia variegata</i>	<i>Sporobolus coromandeliaus</i>
<i>Bauhinia spp</i>	<i>Albezia lebbek</i>	<i>Eucalyptus tereticornis</i>	<i>Desmostachya ipinnata</i>
<i>Daldergia sissoo</i>	<i>Holoptelea integrifolia</i>	<i>Terminalia arjuna</i>	<i>Chloris barbata</i>
<i>Holoptelea integrifolia</i>	<i>Streblus asper</i>		<i>Desmodium triflorum</i>
<i>Lantana camara</i>	<i>Syzygium heyneanum</i>		<i>Dactyloctenium aegyptium</i>
<i>Peltoforum pterocarpum</i>	<i>Terminalia arjuna</i>		
<i>Syzygium cumminii</i>			
<i>Terminalia arjuna</i>			

Table 4

Diversity and productivity of the three rehabilitated sites compared with a control (Site IV)

Site	IVI	Diversity Index**	Population Density (ha ⁻¹)	Basal Area (m ² ha ⁻¹)	Phytomass (Mg ha ⁻¹)
I	320	1.85	1501	57.3	506
II	301	1.80	391	35.5	245
III	150	1.37	350	7.6	48
IV (control)	259	0.56	586*	-	18

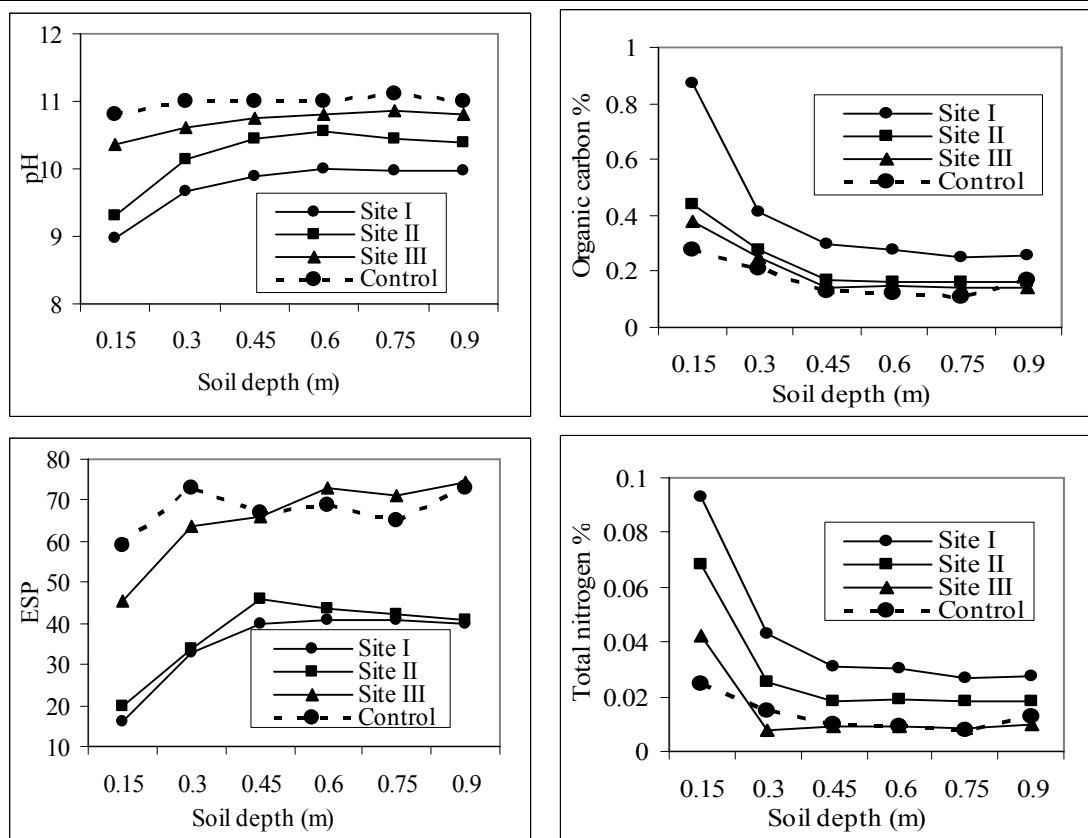


Figure 1. Increasing pattern of pH & ESP and decreasing trend of organic C & N with soil depth on three afforested and a control sites

However, the difference in ESP between site I and site II was negligible, which showed that productivity could not influence the significant reduction of ESP. A similar effect of diversity, as observed between control and site III, was also not apparent on the reduction of soil ESP. A decrease in soil pH, with respect to secondary succession on any rehabilitated site, is a common phenomenon due to the leaching and accumulation of weak organic acids as vegetation development proceeds (Crowley, 1986). As such, the maximum improvement was noticed on site I; however, at lower depth below 0.3 m, soil amelioration was relatively less. Site III at lower depth (below 0.3 m) did not show any improvement in soil ESP. On an average, good forested site reclaimed such sodic soils significantly up to 0.5 m depth (Garg, 2000). Soil fertility increased 3 times from the control to site I as evident by its C and N contents in surface soil (0.15 m). A high population density of monoculture plantations (*Prosopis juliflora*, *Dalbergia sissoo*) may increase the C and N contents, up to 6 times in surface soil (0.15 m) in 8-yr old plantations (Garg and Jain, 1992; Garg, 1998), but soil amelioration below 0.3 m depth could not be found under these plantations. Conversely, our forested site I & II indicated a significant change in the C and N content from the control, even up to 0.75 m depth. Nevertheless, amelioration in the sub soil was relatively small in comparison to the surface. So the process of humus incorporation in the sub soil takes considerable time to offset the adverse effect at lower depth. These results showed that a high productivity and diversity of site I & II contributed to soil amelioration up to deeper level. At site III, where productivity and diversity were very low, only a superficial layer of soil (0.15 m) was reclaimed. Consequently, there was no difference between control and site III below 0.3 m depth. Since the soil properties are largely influenced by the dynamics of litter and fine roots in forest ecosystems, both fluxes are equally important. Litter performs a major role in soil fertility; fine roots contribute substantially in improving soil structure, pH, resource acquisition and water permeability (Singh, 1996; 1998).

Several studies have suggested that soil C, N, P and moisture contents may influence the successional dynamics and community structure (Lloyd and Pigott, 1967; Walker et al., 1981; Tilman, 1986). Studies of the primary and secondary succession both reveal N as the major limiting nutrient, which increases with successional age (Tilman, 1987). On N poor sites, N fixers initially colonize, which later on promotes to accommodate other species, when N levels are enhanced to some extent. Litter decomposition and fluxes of nutrient cycling proceed more efficiently in older rehabilitating stands, due to the feed back processes of soil-plant interactions (Vitousek and Waker, 1989; Wedin and Tilman, 1990). The community structure of the three sites constituted variable diversity and productivity indices. Site I had the maximum and site III least values for both the aspects. Site II is intermediate between the two and its diversity is not significantly different from site I, but phytomass was less than half to that of site I. Thus, the differences in soil properties between site I and II would reflect the effect of productivity. In contrast, the diversity between control and site III appears to be quite high, but biomass does not differ as much, and thus the differences in the soil of these two sites may explain the effect of diversity. The other two sites i.e. I & II when compared with control showed the combined effect of diversity and productivity, both in response to the soil amelioration process.

EFFECT OF PRODUCTIVITY ON SOIL PROPERTIES

Productivity influenced soil properties, by reducing pH and ESP; however, it could not influence much on the whole reclamation process, even at the cost of a relatively high standing biomass. However, soil fertility has increased considerably in site I, as compared to site II due to a relatively high productivity and the difference between these two stands in C (98%) and N (35%) were significant. On the basis of certain significant differences between

site I & II in seven properties out of the 12 studied, it can be assessed that productivity contributed to about 58% in soil amelioration.

EFFECT OF DIVERSITY ON SOIL PROPERTIES

Diversity influenced a marginal decrease in soil pH and ESP suggesting their partial role in the amelioration process. Similarly, organic C (18%) and total N (71 %) increased in the surface soil on site III from the control, showing a significant difference in N only due to species diversity. Thus in overall assessment, site III differed significantly from the control in five of the 12 parameters studied, which revealed about 42% contribution of this factor in soil amelioration.

EFFECT OF PRODUCTIVITY AND DIVERSITY BOTH ON SOIL PROPERTIES

The combined effect of productivity and diversity has resulted into a drastic decrease in soil pH and ESP of the surface soil in site I & II, as compared to the control. Thus, the aggregate effect of diversity and productivity showed a speedy reclamation. On the basis of significant differences between the control and the mean of site I & II in 11 out of the 12 properties studied, these effects contributed to about 92% in the soil amelioration process. The accumulation of organic C and total N was also greater, due to the integrated effect, rather than the individual role. Even then, these soils have not yet offset the degraded conditions completely compatible to managed forests of this region (Sharma and Pandey, 1989) and have achieved the status of the degraded tropical deciduous forests of India (Singh and Singh, 1991). These results infer that, while rehabilitating sodic wastelands through afforestation, several potential species should be tried so that different types of canopy, root systems & litter dynamics accelerate the process of speedy recovery during minimum period. This approach for increasing the resiliency of disturbed ecosystems would be equally important to all hospitable sites in general and sodic land in particular.

CONCLUSIONS

The study thus concluded that the new forest created on sodic wastelands had a modest Shanon-Wiener's diversity index (2.3). Importance value index (IVI) indicated that *Derris indica*, *Cassia siamea*, *Dalbergia sissoo*, *Azadirachta indica*, *Tectona grandis*, *Terminalia arjuna*, and *Syzigium cumuni* were the major dominant species. These species, in due course of succession, developed their association and niche with natural invaders, by accommodating varying levels of diversity and productivity status. Both have contributed to the soil restoration process significantly. The role of diversity was measured as 42% and productivity 58% on the basis of the diagnostic soil properties studied. The combined effect of diversity and productivity was assessed to 92% in soil amelioration.

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REZUMAT

FITOREMEDIEREA ECOSISTEMELOR FORESTIERE SODICE: REACȚIA PLANTELOR LA PROCESUL DE RESTAURARE

Crearea de noi biotipuri adecvate terenurile degradate are o importanță deosebită în remedierea ecosistemelor forestiere, fiind în prezent un obiectiv urmărit la nivel global. Cercetări în acest sens au fost efectuate în ultimele trei decade la Stațiunea de Cercetare Brantha, din cadrul Institutului Național de Cercetare Botanică, Lucknow, India ($80^{\circ}45' - 53^{\circ}53'E$ și $26^{\circ}40' - 26^{\circ}45'N$), cu scopul de a reabilita terenurile sodice, prin asigurarea unui înveliș de plante adecvat. Un ecosistem forestier reabilitat și îmbunătățit este constituit dintr-un număr diferit de ierburi, arbuști și arbori, într-o asociere optimă. *Derris indica*, *Dalbergia sissoo*, *Azadirachta indica*, *Cassia siamea*, *Terminalia arjuna*, *Syzigium cumini* au fost speciile dominante în aceste ecosisteme forestiere reabilitate, unde *Sporobolus*, *Desmostachya* și *Dactyloctenium* au fost ierburile obișnuite pe terenurile sterile din arealul propus. Studiile au arătat că diversitatea și productivitatea speciilor influențează semnificativ procesul de ameliorare a solului. O comparație între trei amplasamente cu variate grade de productivitate și diversitate, a evidențiat faptul că unele proprietăți ale solului au fost influențate de productivitate, iar altele de diversitate. Efectele individuale ale diversității și productivității au fost clasificate ca având o pondere cuprinsă între 42% și 58% în recuperarea solului. Efectul combinat al productivității biomasei și diversității speciilor au contribuit cu 92% în ameliorare solului. S-a înregistrat o scădere apreciabilă a pH-ului și a procentului de sodiu schimbat și o creștere a carbonului organic și a azotului, demonstrându-se că sodicitatea a fost îndepărtată în solurile forestiere. Se consideră că experimentul poate fi încercat și în alte amplasamente din regiunile aride și semiaride ale lumii, în scopul recuperării terenurilor sodice.