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Community Structure, Diversity, Biomass and Net Production in a Rehabilitated Subtropical Forest in North India

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Gangetic alluvial plain in north India constitutes significant proportions of barren sodic lands. A representative site, where afforestation was carried out during 1960s to rehabilitate the site under forest ecosystem, was selected to assess the restoration success. Three stands (S1, S2, and S3) were selected in a semi-natural subtropical forest at Banthra, Lucknow (26˚45'N, 80˚53'E) on the basis of different vegetation morphology and basal area gradient. Species composition and their growth forms were studied in overstory, understory and ground layer vegetation, in which dominants were assorted. Among the dominants few species were common in the three stands as also in different strata, which perhaps indicate their natural regeneration. Classification of individuals among the different size classes indicated "L" shape distribution in which most of the individuals remained confined in younger groups. Biomass increased from the stand S1 to S3 stand in overstory, and vise versa for understory. Stand S2 consisted of predominance of ground layer biomass over the other stands. Biomass allocation in different plant components differed significantly between the overstory and understory for aerial woody components (stem and branch). Annual litter fall did not differ significantly among the stands, where as fine root biomass (up to 45 cm soil depth) decreased from S1 to S3 stands. Rainy and summer seasons contributed to two-third proportion of total annual fine root production. The state of this rehabilitated forest when compared with the degraded and reference forest of the region indicated that structural complexity, biomass and production levels have been achieved to 70% of the reference forest site even after having a different species composition.

Keywords: Diversity, Community Structure, Concentration of Dominance, Biomass, Production, Litter, Fine Root

Introduction

Tropical forests are disappearing at an alarming rate of 13.5 million hectare per year globally Kobayashi (2004). In India about 20% of the geographical area is under forest in which tropical forests contribute nearly 83% of the forest area. Almost half of the forest area is classified as degraded forest with poor population density and species abundance. Deforestation and forest degradation are widely recognized as major threats to environmental stability, economic prosperity and social welfare and also to perform the statutory function of biodiversity conservation and ecosystem services. Often the forest management considers primarily commercially important monoculture species and rehabilitation of site for ecosystem/landscape management/species conservation or societal services assumes secondary importance. When the degraded and desolated lands do not turn out an economic yield, many sites are abandoned where natural succession proceeds and over a period of time several biotic communities colonize there and perform a variety of ecosystem function (Jha & Singh, 1991). The widespread degradation of alluvial soil in the Indo-Gangetic plains affected by varying degree of sodicity or salinity has received priority attention for afforestation during past few decades. It has been emphasized in the Indian forest policy to enhance the forest cover, biodiversity conservation and to provide the multiple goods and services to the ever-increasing human population of the country. Forest area is shrinking day by day and new forests are not being developed proportionally. It is estimated that about 53% of the total geographical area of the country is subjected to erosion and land degradation problems. Intensive afforestation efforts are required to rehabilitate such sites under productive forest ecosystems. Both exotic and native species may be planted to rehabilitate degraded lands depending on site conditions (Singh et al., 2002; Datta & Agarwal, 2003; Singh et al., 2004; Singh & Singh, 2004; Shukla et al., 2011).

Natural succession remains arrested on sodic lands, and does not proceed automatically without some anthropogenic interventions. As a consequence, these sites do not have any significant vegetation growing on them except sporadic patches of some salt tolerant grasses. Creation of new forest on barren sodic land is therefore a critical task due to several soil constraints restricting the growth and development of plants. Mainly, an exotic *Prosopis juliflora* has been planted successfully (Bhojwaid & Timmer, 1998) which showed a fairly good adaptability to generate fuel wood quickly, but the drawback with this invasive alien species (exotic) is that *Prosopis julifora* does not accommodate the native species in their niche and overrides on the native species diversity. There is strong evidence that plantations can facilitate forest succession in their understories through modification of both physical and biological site conditions. Changes in light, temperature and moisture at the soil surface enable germination and growth of seeds transported to the site by wildlife and other vectors from adjacent forest remnants. It has been observed that at the stand level mixed species performed well for volume, basal area, biomass, and carbon sequestrations in comparison to pure monoculture stands (Piotto et al., 2003ab; Alice et al., 2004; Petit & Montazinimi, 2004, 2006). Economically viable and adoptable technology for afforestation of sodic land has been under experimentation for a long time (Sharma et al., 1992). Sandhu & Abrol (1981) studied the method of site preparation using augur holes and effect of establishment on *Eucalyptus tereticornis* and *Acacia nilotica* on sodic soil sites. Later on, these plantations suffered with the girdling, stress growth, and poor yield. Sodic soils contain exchangeable sodium in excess quantity which interferes with the growth of most crop plants and trees. The pH of such soils usually ranges from 8.5 to 10, which disturbs the ionic equilibrium of soil solution limiting to the growth of plants (Kelley, 1951). Such soils are generally poor in organic matter and nitrogen contents (Abrol & Bhumbla, 1971; Agrawal & Gupta, 1968; Khanduja et al., 1986; Pandey et al., 2011) and therefore its enhancement is vital for better growth and productivity (Shukla & Misra, 1993; Singh, 1996, 1998). Additionally the encrustation of calcium carbonate gravels and iron granules into a hard cemented bed in sub soil impedes not only root developments but water permeability too. Such characteristic properties resulting in root deformations, growth reductions and ultimately significantly lower yields do not support and pro- mote the extension of production forestry on sodic lands in commensuration with their inputs (Gupta & Abrol, 1990). However, (Abrol & Joshi, 1986) reported the economic viability of utilizing highly alkaline soil for the plantations of *Acacia nilotica*, *Eucalyptus tereticornis* but it could not gather enough momentum due to high initial investments and a large gestation period.

Afforestation with salt tolerant species was initiated from 1980 onwards (Sissay, 1986; Totey et al., 1987; Sharma, 1988). The afforestation trials those have been succeeded led to the identification and selection of tolerant species *in situ* on the basis of their growth performance (Khan & Yadav, 1962; Pandey, 1966; Srivastava, 1970; Yadav & Singh, 1970; Ahuja et al., 1979; Yadav 1980; Khoshoo 1987). Tolerance limit of several species was evaluated for sodic soils in pot culture experiments (Singh et al., 1994). Performance of trees at varying sodicity levels was also observed (Ashwathappa et al., 1986). Since the characteristics of salt affected soils vary greatly from place to place ranging from low to high ESP (exchangeable sodium percent) tolerant species were assorted accordingly (Yadav & Singh, 1970; Toth, 1981). Tolerance of *Dalbergia sissoo* in varying sodicity conditions was studied at different sites (Singh et al., 1990). Tree species are supposed to be more tolerant to adverse soil conditions, particularly *Prosopis* and *Acacias* (Garg & Jain, 1992). *Prosopis juliflora* can survive well on the calcarious soils which have on the average a maximum pH value of 9.5. *Acacia nilotica* was also found to be more resistant to soil salinity and sodicity (Yadav & Singh, 1970; Garg & Khanduja, 1979; Tomar & Yadav, 1980; Singh et al., 1986). Abrol (1986) suggested that, apart from identifying appropriate species and cultural practices, there is a need to evaluate the social and economic consequences of planting on saline land with fuel and forage species. A standardized silvicultural technology for afforestation on sodic lands was developed thereafter (Chaturvedi, 1985; Prasad & Sharma, 1990).

Earlier studies have been limited to the growth observations in height and diameter of the plants. Though some account is available for biomass and productivity of few trees grown on sodic soils (Chaturvedi, 1985; Dogra, 1989; Singh, 1991, 1998; Chaturvedi et al., 1991, Chaturvedi & Behl, 1996; Jain and Singh, 1998) that too pertains to juvenile stage of plant growth with a very little applicability to understand the community development process on a degraded land. Many previous trials failed to rehabilitate the sodic bare lands under tree cover due to lack of proven technology, proper financial support and dedication (Yadav, 1975, 1980; Abrol, 1986). A man-made forest developed on sodic land at Banthra Research Station of the National Botanical Research Institute, Lucknow, India is the oldest successful endeavor of afforestation with multiple species. Very little information is available to our understanding in restoration of sodic land under forest ecosystem. Srivastava (1987) described the occurrence of species in this forest in which some were introduced, while others invaded naturally and colonized by the induced succession. Verma et al. (1982) reported that a mixed canopy cover was more effective in the reduction of pH than that of individual species. This is a good indication to diversify the monocultures with various indigenous species which also aid to counter the effects of epidemic and allelopathy. A generalized impact of soil reclamation in this forest was assessed by (Singh, 1996, 1998).

The tolerant tree and shrub species made the soil hospitable for less tolerant species. Thus a portion of land that was once totally barren and desolate is now recognized as a functional forest ecosystem with a top story of trees, middle story of small trees and shrubs; and a ground layer of herbs and seedlings of the perennials. Structure and composition of overstory trees determine the understorey vegetation diversity and their complexity (Barbier et al., 2008). Basic changes in demography, tree size and growth comprise classic descriptors of stand development (Brinkley, 2004). Efforts were made to observe the relationships between vegetation productivity and species diversity (Sculze & Mooney, 1993; Huston, 1997; Chapin et al., 2000; Loreau et al., 2003; Liang et al., 2007). Such forest inventories are useful to rehabilitate the other barren sites in an efficient way as well as to ensure a desired composition and structure of the developing forest which could be self sustainable even after rational extraction or mild disturbances from environmental perturbations.

This study was carried out in a 40-yr-old rehabilitated forest on sodic land to identify the development of community structure and productivity levels, their diversity, dominance and compatibility with natural forest of the region. An attempt was made to characterize the various species performance and their interrelations in the constitution and development of new “biotope”.

Methods and Materials

Site

The forest was established on abandoned sodic soil during the 1960s at Banthra, Lucknow, situated in a subtropical, semiarid region of north India (26˚45'N, 80˚53'E). Geographically, this region is classified as Gangetic alluvial plains of the Uttar Pradesh state due to transported deposition of minerals from the Himalayan rocks by the Ganga River. A large tract of this region consists of cultivated land interspersed with barren sodic land measured about 1.3 million hectares (Figure 1). The prehistoric natural forests in this region were sparse and most of them were replaced by Sal (*Shorea robusta* Gaertn. f.) and Teak (*Tectona grandis* L. f.) forests in the middle of the nineteenth century. A few patches of those forests are still available in Katarniaghat Wildlife Sanctuary, in Behraich (lat 27˚55'N, long 81˚25'E) district of U.P. The natural dry tropical forests of Varanasi (lat 24˚55'N, long 83˚3'E) and Mirzapur (lat 24˚55'N, long 82˚32'E) were compared as degraded forest sites. Average annual rainfall at Lucknow ranged from 840 to 980 mm during the past 10 years, which is slightly less than that at the

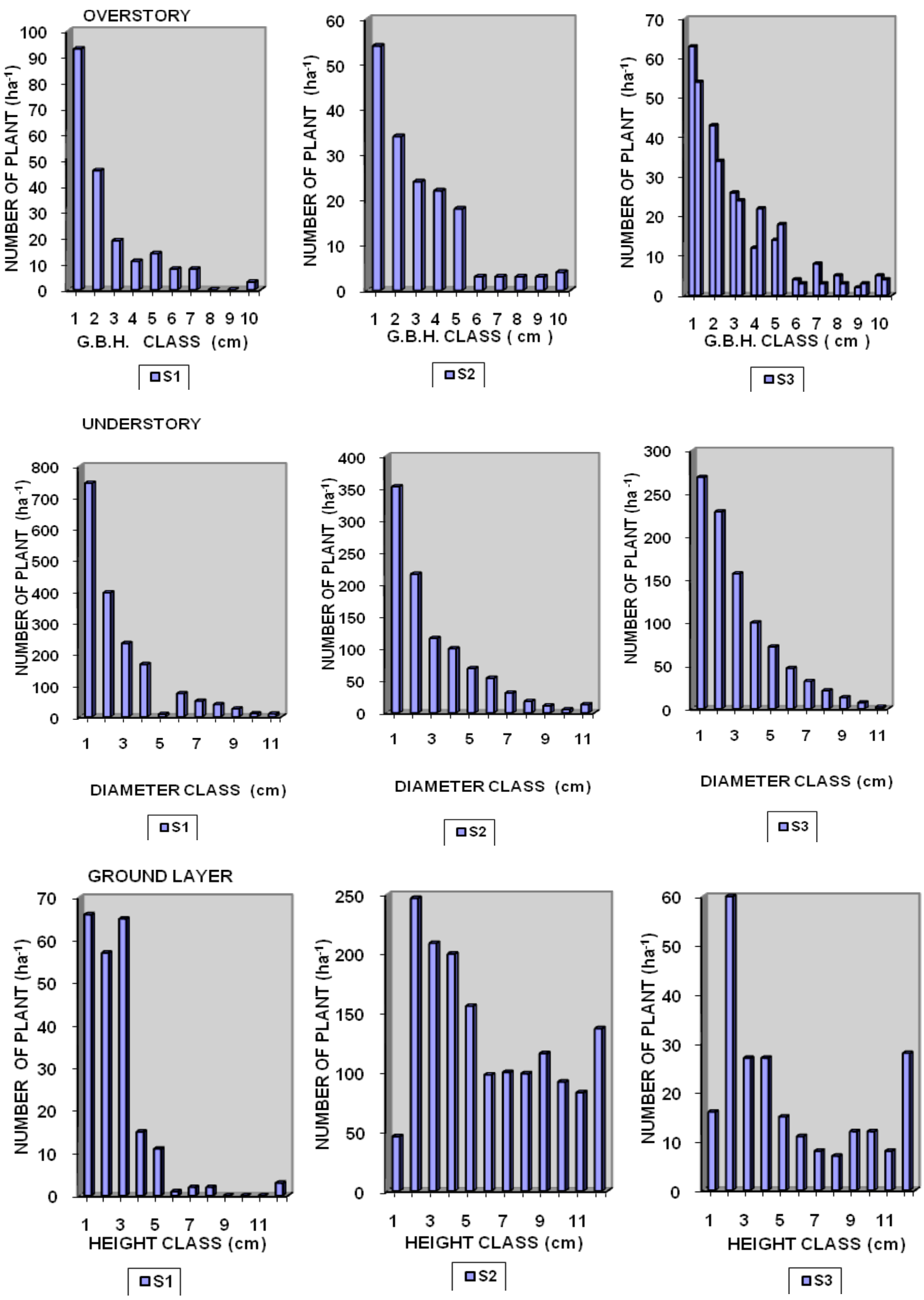

Figure 1.
Distribution of plant population in different size classes in three vegetation layers in three stands of 40 *yr old man-made forest*. *Overstory classes Girth* (*cm*): 1 =20 - 40, 2 = 40 - 60, 3 = 60 - 80, 4 = 80 - 100, 5 = 100 - 120, 6 = 120 - 140, 7 = 140 - 160, 8 = 160 - 180, 9 = 180 - 200, 10 ≥ 200. *Understory classes Diameter* (*cm*): 1 = 0 - 1, 2 = 1 - 2, 3 = 2 - 3, 4 = 3 - 4, 5 = 4 - 5, 6 = 5 - 6, 7 = 6 - 7, 8 = 7 - 8, 9 = 8 - 9, 10 = 9 - 10, 11≥ 10. *Ground layer classes Height* (*cm*): 1 = 0 - 10, 2 = 10 - 20, 3 = 20 - 30, 4 = 30 - 40, 5 = 40 - 50, 6 = 50 - 60, 7 = 60 - 70, 8 = 70 - 80, 9 = 80 - 100, 10 = 100 - 110, 11 ≥ 110.

reference site (1057 mm/year). More than 80% of the precipitation occurs in the monsoon season (July-September), and the remainder of the year is dry. Average minimum and maximum temperature differ significantly from winter (8˚C, night; 20˚C, day) to summer (27˚C, night; 40˚C, day), indicating a seasonally distinct climate. Average relative humidity was 63% during the last 10 years.

The site soil is an Inseptisol (Typic Natrustalf) with silty clay loam texture. A compact layer of indurated pan comprising $CaCO_3$ gravels and iron granules exists between 0.4 m and 0.8 m depths in these sodic soils. Structural degradation of the heavy (high bulk density) and impervious soil leads to crusting in winters and waterlogging condition during rainy seasons. During summer, efflorescence of $NaCO_3$ salt occurs as a powdery layer on the soil surface. Consequently, suspended particulate matter is quite high in the atmosphere during the day. The soil was characterized by a high pH (>10) and exchangeable sodium percentage (ESP) (>50) and low electrical conductivity (EC) (<1.0 dS/m) and organic carbon content (<0.2%) prior to planting (Garg, 1987). Carbonate and bicarbonate of Na and Ca were the dominant ions. When the content of soluble salts (EC) is low and exchangeable Na high, the physical condition of the soil is usually unfavorable for the tillage as well as establishment and growth of desired plants. As a consequence, only a few grasses, viz *Sporobolus* and *Desmostachia*, are found sporadically under natural conditions. Attempts were made to rehabilitate such barren land through afforestations as well as other land use systems over an area of about 50 ha acquired during the 1960s. The entire area was demarcated with barbed wire fencing and designated as Banthra Research Station (BRS). Some of the native tree species commonly occurring in tropical forests of north India (*Acacia nilotica*, *Albizia lebbeck*, *Albizia procera*, *Bauhinia variegata*, *Ficus bengalensis*, *F. rumphii*, *Syzygium heyneanum*, *Syzygium cumini*, *Terminalia arjuna*, *Derris indica*) were planted in plantation pits of 1 m^3 that had been filled with a mixture of soil, compost manure, and decomposed leaf litter in 2:1:1 proportion on a 5-ha site. They were also planted along the marked boundary of the BRS. The initial population density was around 1,000 trees/ha. A drainage channel 1.5 m deep and 2 m wide was developed around the plantation site to prevent water logging, which was intensively observed during the rainy season for a proper drainage of stagnating water. Mortality during the initial years was greater than 50%, and trees were replanted in consecutive years. Several species invaded and colonized this area over time through natural succession process due to changes in microrelief. Seed dispersal and natural regeneration of trees and many other species gradually extended to cover about 17 ha of total forest area in the 2010.

Vegetation Analysis

Three stands were selected in this forest according to gross morphology and a basal area gradient within the original 5-ha revegetated area. Sample plots, each 1 ha, were marked in all three stands denoted as S1, S2, and S3. Vegetation analysis was carried out on belt transects (10 m wide). The method and quadrat size were standardized using a species–area-curve relationship. Thirty-four quadrats of 10 × 10 m along three transects spaced 10 m apart were laid out contiguously in each stand. Plants were enumerated and measured for growth parameters. Ninety-five percent of the species were identified through the use of the National Botanical Research Institute's herbarium records. Girth of trees (>20 cm·gbh) was measured at 137 cm above the ground for overstory species, whereas diameter of young trees and shrubs occupying less than 10 cm dbh was measured 50 cm above the ground, using an electronic vernier caliper. These were classified as understory species. Height of small seedlings less than 50 cm and of herbaceous species were measured and placed in the ground layer community. Species structure (frequency, density, abundance, basal area/cover, importance value index (IVI), etc.) was determined from the field data (Misra, 1968). The cross-sectional area of the stem at measured levels is the basal area of all woody species. Leaf area cover (basal cover) for the ground layer was computed by specific leaf area ratio, which is defined as area per unit weight of the leaf (Misra, 1968). Species having greater than 10 IVI or >10% of the total basal area were considered dominant species in each stratum.

Species Diversity Index

Species diversity index (H) for overstory, understory, and ground layer vegetations were determined separately from the Shannon Wiener's information function (Shannon & Weaver, 1963).

$$H = -\sum(ni/N)\overline{\log}_2(ni/N) \qquad \text{OR} -\sum pi\log_2 pi$$

where: ni = importance value for each species, N = total of importance values

pi = importance probability for each species = ni/N

Concentration of Dominance

Concentration of dominance (Cd) was measured by Simpson's index which is also known as index of dominance (Simpson's 1949).

Index of dominance (Cd) = Σ $(ni/N)^2$

where: ni = importance value for each species, N = total of importance value

Equitability or Evenness (e)

Equitability refers to the degree of relative dominance of each species in that area. Following Pielou (1966), equitability or eveness index was calculated as:

Equitability (e) = H/logs

Where: S = number of species and H = Shannon Wiener index

Productivity Assessment

All the stems were classified in 7 girth/diameter classes in overstory and understory vegetations and 7 height classes in ground layer. Overstory biomass was estimated by a common regression equation already developed from 13 tree species in a MAB project at BHU, Varanasi, because the permission for harvesting of green trees was not granted by the UP Forest Department in view of the felling restrictions on the trees planted under restoration programmes. Harvesting of sample plants of the understory could be possible and therefore three representatives from each size classes were sampled for stem, branch, and leaf and root biomass. Species of ground layer were sampled according to the height classes for stem, leaf and root components. Regression equations were developed with the help of data of sample plants for diameter (cm) on "x" axis and oven dry weight (g) of the particular component on "y". The form of regression was:

$$\ln Y = a + b \ln x$$

A software programme "SYSTAT 9.0 SPSS" was used for regressions. With the component biomass, total biomass of all species per unit area was computed as per their respective population density. The ground layer species biomass was computed with their equation where "x" variable was heights of plant in cm. Net productions were obtained as the differences in biomass during the two consecutive years (2007 to 2009. Biomass of ground layer was assumed to net production in view of their little contribution in total forest ecosystem productivity.

Litter

Litter fall was collected monthly in 1 m^2 trays during the year. Four trays were placed in each of the three stands. Components of litter were separated out as leaf, twig, flower-fruits and bark. Apart from, six quadrats of 1 m^2 were laid on underneath each stand to sample forest floor litter layers as L, F and H fractions.

Fine Root

Fine root biomass was extracted by wet sieving of ten soil cores of 100 cm^3 in each stand at two depths (0 cm - 15 cm and 15 cm - 30 cm) in five seasons. Similarly fine root production was estimated by establishment of root free in-growth cores in each season and extraction of root by wet sieving. These roots were classified into three diameter classes (<0.5, 0.5 mm - 1 mm and 1 mm - 2 mm). The live and dead roots were separated on the basis of gross morphology and degree of cohesion between cortex and periderm according to Vogt and Persson (1991). Both fractions were oven-dried at 80˚C to constant weight.

Results

Community Structure and Diversity

There were only a few species which contributed more than 10% of the total basal area in each stand; therefore, dominants were assorted including >10 IVI (Table 1). On the basis of IVI and relative basal area, S1 stand constituted more dominant species in comparison to other two stands. Among the dominants few species were common in all the three stands such as *Syzygium cumini*, *Syzygium heyneanum*, *Streblus asper*, *Azadirachta indica*, *Albizia lebbeck* in overstory vegetations. In understory the common dominants among the stands were *Lantana camara*, *Streblus asper*, *Syzygium cumini*. Besides, some of the species were found common in all the three vegetation strata viz. *Leucaena leucocephala*, *Sterculia alata*, *Streblus asper*, *Syzygium cumini*, *Syzygium heyneanum. But Clerodendrum vescosum*, *Ichnocarpus frutescens*, and *Putranjiva roxburghii remained confined to under stay & ground layer vegetation.*

Species distribution pattern and their natural associations provide the clues for rehabilitation of barren sodic land under forest ecosystems. Basal area increased from S1 to S3 stand in overstory, whereas in understory it was decreased in same order. In ground layer, maximum basal cover was found in S2 stand. In overstory vegetation of S1 stand, dominant species covered 44.2% of the total basal area which indicates that other species have no less importance in organization of plant communities occupying rest of the 56% of the total basal area. In S2 stand other species contributed relatively less with the proportions of dominants contributing to 72% of the total basal area of overstory vegetation. S3 stand had almost similar value to that of S1 stand. In S1 stand, *Albizia lebbeck* and *Azadirachta indica* had 30% of the total basal area. In S2 stand *Albizia lebbeck*, *Syzyum heyneanum* and *Terminalia arjuna* hold about 51% of the total basal area. In S3 stand *Albizia lebbeck*, *Albizia procera*, *Ficus rumphii* consisted of about 45% of the total basal area. In understory vegetation, *Leucaena leucocephala* had greatest IVI in S1 stand. Dominant understory vegetation constituted 61%, 72% and 52% of the total understory basal area of the respective S1, S2 and S3 stands. In ground layer vegetation, S1 stand had more dominant species in comparison to other stands with greatest IVI in S2 stand. In S1 stand ground layer vegetation of the dominants occupied 87% of the total basal cover. S2 and S3 stands had 89% and 95% basal cover of dominants.

Population size of overstory and understory trees was largest in S1 stand, whereas S2 stand consisted of the greatest number of individuals of the ground layer (Table 2). However, population size on the basis of number of individuals per unit area does not contribute much in ecosystem function, as it does not give any additional weight to the size of individuals. Basal area is a composite function of the number and size of the individuals

Table 1.
Classification of species as a percent of the total species represented by their populations from unit to thousands in respective vegetation strata.

Strata	Unit	Tens	Hundreds	Thousands	Total
Overstory	37	38	23	2	100
Understory	36	36	23	5	100
Ground layer	25	37	25	13	100

Table 2.
Population size and plant diversity in a 45-*yr old rehabilitated forest community developed on barren sodic land.*

Parameter	Form	Stands			Mean ± SE
		S1	S2	S3	
Population density (No. ha^{-1})	Overstory	610	517	535	554 ± 28
	Understory	5554	2871	2759	3728 ± 913
	Ground layer	2190	15930	2320	6813 ± 4558
Basal area ($m^2 \cdot ha^{-1}$)	Overstory	25.8	30.5	33.6	29.9 ± 1.9
	Understory	7.25	3.13	2.31	4.20 ± 1.2
	Ground layer	5.39	271.5	58.18	111.6 ± 66.4
Species richness (number)	Overstory	35	27	28	30 ± 2
	Understory	38	40	30	36 ± 1.6
	Ground layer	15	17	13	15 ± 0.47
Equitability (e)	Overstory	1.29	1.0	1.09	1.1 ± 0.07
	Understory	0.72	1.06	0.99	0.9 ± 0.08
	Ground layer	0.65	0.52	0.87	0.7 ± 0.08
Shannon Wiener's index (H)	Overstory	3.99	3.25	3.64	3.6 ± 0.17
	Understory	2.65	3.80	3.35	3.3 ± 0.27
	Ground layer	1.76	1.45	2.24	1.8 ± 0.19
Concentration of dominance	Overstory	0.11	0.18	0.13	0.14 ± 0.02
	Understory	0.40	0.14	0.15	0.23 ± 0.07
	Ground layer	0.45	0.46	0.29	0.40 ± 0.05

per unit area (1 ha) which shows the relative contribution of the species in structure and function of the forest ecosystems. On the basis of basal area, three stands contributed in different proportions for each vegetation types. The predominance of overstory basal area in S3 stand and understory in S1 stand and a relatively large basal cover of ground layer vegetation in S2 stand differentiates these stands each other in the community structure and its organization during developmental process. However, these sites differences do not appear to be significant in species richness. It is because of the fact that various tree species planted initially are now representing presently the overstory. Whereas, understory and ground layer mainly consist of the progeny of same species along with the few natural invaders.

Measurement of biodiversity in a specific area (local scale) on the basis of richness does not provide a complete understanding about the individuals of the species as it suffers from the lack of evenness or equitability (e). Richness index decreased from overstory to understory by 50% followed by the ground layer. It ranged from maximum 2.47 (S1 stand) in overstory, to minimum 0.43 (S2 stand) in ground layer vegetation. Equitability (e) was greatest in S1, S2 and S3 stands, for overstory, understory and ground layer vegetations respectively. Both indices decreased from overstory to ground layer on average of stands. The species were more evenly distributed in ground layer showing lowest in comparison to the overstory vegetation, so it was decreased from overstory to ground layer vegetation. Shannon Wiener's index (H) is one of the most popular measures of general species diversity in a forest. This index decreased from overstory to ground layer in accordance with the richness index. In this forest, Shannon Wiener's diversity index ranged from 3.99 (S1 stand) in overstory, to least 1.45 (S2 stand) in ground layer vegetation (Table 2). Although S2 stand had greatest ground flora even then their diversity index was lowest for the ground flora which indicates that the ground flora consisted of only few abundant species such as *Barleria prionitis*, *Blepharis maderaspatensis* and *Clerodendrum vescosum*. Concentration of dominance (c) = Σ pi^2 indicates that the dominance was more concentrated with fewer species in the ground layer in comparison to overstory vegetation where dominance was shared by multiple species. It showed an opposite pattern with the diversity index among the three vegetation types.

Entire plant population of the three vegetation strata were classified over a range of size classes according to girth (overstory), diameter (understory) and height for ground layer (Figure 2). In general, these stands appear to be still immature and ecosystem has not yet reached equilibrium. Their configuration and structure indicate a "L" shape positively skewed asymmetrical distribution of plant populations with increasing size of girth and diameter for both overstory and understory vegetation, respectively. Population of the understory vegetation was nearly half in S2 and S3 stands in comparison to S1 stand, whereas S2 stand predominated in ground layer vegetation. Population of ground layer vegetation was almost evenly distributed across the height class in S2 and S3 stands, whereas in S1 stand most of the population was confined to first few groups only. It was observed that the number of species decreased with increasing plant size in each of the three vegetation forms. In overstory, maximum number of species occurred in initial girth class (20 cm - 40 cm) in all the three stands. Similarly in understory species richness was greatest in initial diameter class. Such types of species composition depicted that species diversity reduced among older individuals with the growth and developments of plants. The pattern of species area relations was almost similar for each of the three stands.

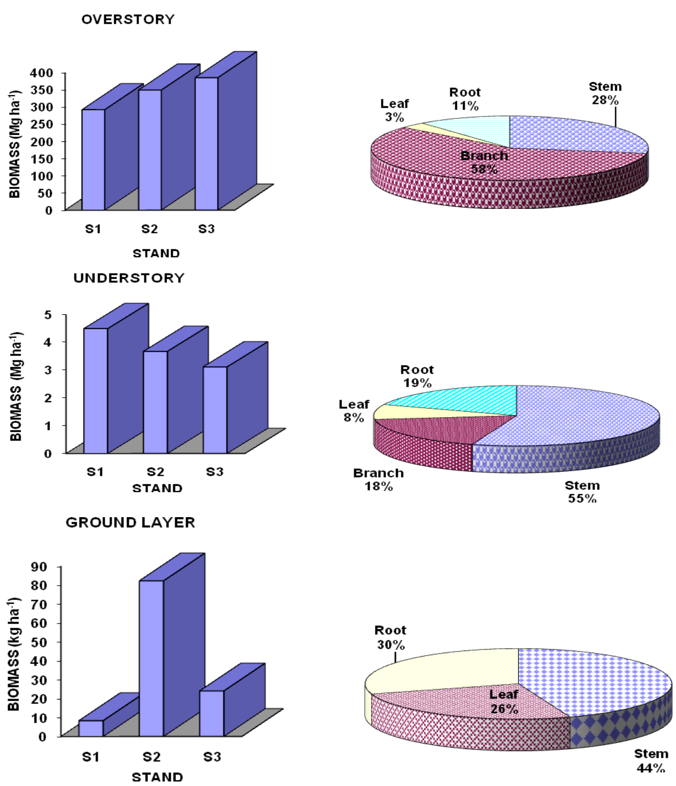

Figure 2.
Biomass of three vegetation layers along with proportional contribution in different components in three stands of 40 *year old man made forest.*

Stand Biomass

Overstory biomass increased from 292.8 Mg·ha^{-1} (S1 stand) to 386.2 Mg·ha^{-1} (S3 stand) corresponding to increase in 30% basal area from S1 stand to S3 stand (Figure 3). The contribution of plant components in total biomass was 28% stem, 58% branches, 3% leaf and 11%root. Typically branches cover more biomass than boles in most of the tropical forests. The contribution of root in this forest was relatively low in comparison to an average root proportions of about 20% of total biomass found in most of the natural forests. It may be due to the soil compactness and presence of a calcic compact (calcium carbonate gravels) layer in subsoil. As a consequence roots do not spread and proliferate freely. The understory biomass slightly decreased from 4.5 Mg·ha^{-1}, (S1 stand) to 3.12 Mg·ha^{-1} (S3 stand) corresponding to decrease in basal area (Figure 3). The percent contribution of the total biomass in different components of understory vegetation showed about 55% in stem, 18% in branches, 8% in leaf, and 19% roots. Biomass distribution pattern among the components in understory vegetation changed to that of overstory vegetation. Besides, pattern of stand biomass also reversed among stands showing a decrease from S1 to S3 stand. Total biomass of ground layer vegetation decreased from 82.3 kg·ha^{-1} (S2 stand) to 8.4 kg·ha^{-1} (S1 stand) corresponding to decrease in basal cover from 271.49 m^2·ha^{-1} (S2 stand) to 5.39 m^2·ha^{-1} (S1 stand). The percent contribution of different components of ground layer vegetation in stem, leaf and root was 44%, 26% and 30% respectively. The root/shoot ratio increased considerably from overstory (0.12) to understory (0.23) and ground layer (0.42) vegetations.

Net Production

Mean annual increment in biomass (MAI) of overstory vegetation had little difference within stands, but current annual increment (CAI) and net primary production (NPP) were greatest in S2 stand (Figure 3). Thus, a stand superior in total biomass (S3) could not succeed as well in net production although with minor reduction, which may be due to the fact that S3 stand would have been optimized maximum production during 45 yr. However, at the same time MAI, CAI and NPP of understory vegetation were in the order of S1 > S2 > S3 stand in accordance with their biomass. Overstory production contributed to 95% of total forest production in a year. Understory and ground layer contributed to 4% and 1% of the total forest production, respectively.

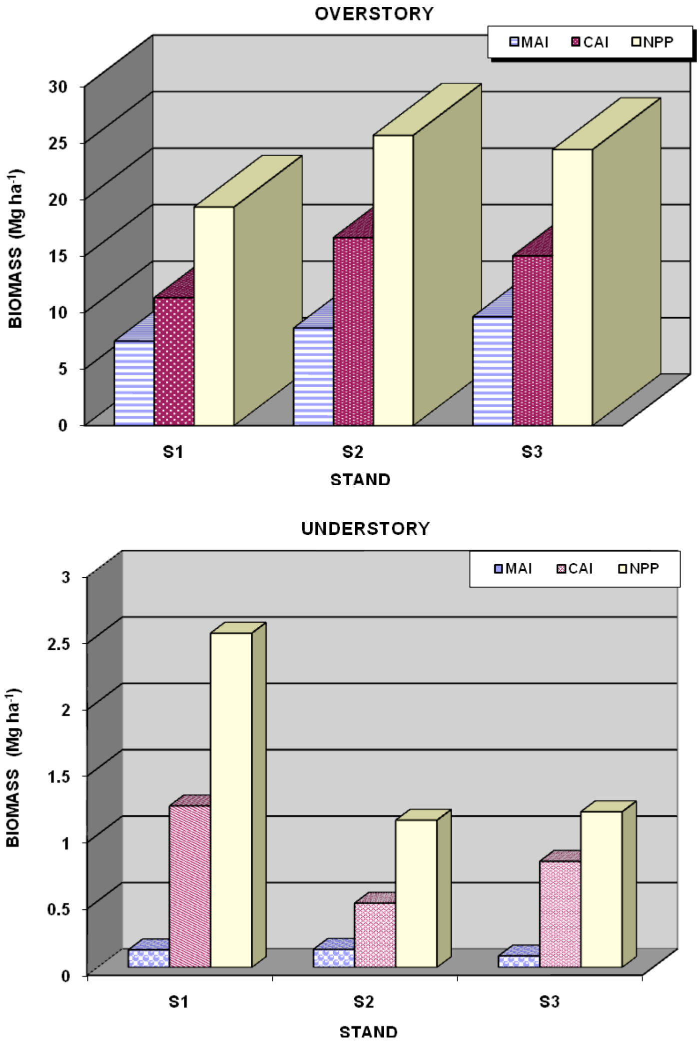

Figure 3.
Annual increment in dry matter of overstory and understory in three forest stands. MAI = mean annual increment, CAI = current annual increment, NPP = net primary production.

Litter and Fine Root

Litter Fall

Litter fall is an important flux to transfer the organic matter and nutrients from trees to the soil which maintains soil sustainability in general and reclamation of sodic soils in this particular case. About 8 $Mg \cdot ha^{-1} \cdot yr^{-1}$ - 9 $Mg \cdot ha^{-1} \cdot yr^{-1}$ litter fall occurred among the stands of the 40 yr-old forest under study (Table 3). Maximum input of litter to the soil was recorded in S2 stand and minimum in S3 stand although these were not significantly different. In all stands, litter was separated in four components in varying proportions. On stand mean basis leaf, twig, flower-fruits and bark contributed to 68%, 20%, 9% and 3% of the total litter fall, respectively. Earlier, a relatively high annual litter fall of 11.2 $Mg \cdot ha^{-1} \cdot yr^{-1}$ was reported in the same forest (Singh, 1996). Thus annual litter fall decreased slightly with further maturity of forest. Since the forest constituted both deciduous and evergreen species, litter fall occurred throughout the year with its maximum quantity in March due to more deciduous species. Seasonal variation in litter fall indicated a relatively high proportion in summer and spring seasons, each about 25% of the annual flux. Generally the wind velocity increases in these seasons which promote the abscission of mature and old leaves and dead twigs and branches. Least amount of litter fall was observed in autumn season (12% of annual).

Forest Floor Litter

Although litter fall and decomposition are instantaneous proc esses but entire litter fall during one year does not decompose completely during the next year and a substantial amount remains to be decomposed in subsequent years. The residue accumulated on the forest floor was estimated as 6.3 $Mg \cdot ha^{-1}$ under different stage of decay forming ecto-organic layers (L, F and H) on mineral soil. The magnitude of forest floor was relatively large in S3 stand corresponding to their standing biomass and small in S2 stand (Table 3). The distribution of organic matter in these layers varied in different proportions such as 38% (L), 29% (F) and 33% (H) of the total forest floor litter on the basis of seasonal mean. This litter serves as 'nutrient bank', checks evaporation and conserves soil moisture to optimize the microbiological activity in the underlying mineral soil.

Fine Root Biomass

Fine roots play a crucial role in water and minerals uptake and moisture retention in the soil. On account of their ephemeral nature, fine roots may also contribute to soil organic matter and carbon sequestration. Besides, fine roots act well in reclamation of sodic soil by reducing the pH, improving the soil structure, porosity and water permeability of heavy impervious sodic soils. Fine root biomass in different season (rainy, autumn, winter, spring and summer) was extracted with respect to soil depth, intermittently at 15 cm intervals up to 45 cm. Total fine root biomass (live and dead) was 532 $g \cdot m^{-2}$ up to 0 cm - 45 cm depth in which live and dead proportions were classified as 93% and 7% respectively (Table 4). Fine root biomass decreased with depth up to 45 cm. Total fine root biomass varied significantly ($P < 05$) between the stands with maximum in S1 stand and minimum in S3 stand. About 47% of total fine root biomass occurred in superficial 0 cm - 15 cm depth. Fine root biomass decreased significantly from rainy to summer season. Total fine and small roots were classified into 5 diameter classes from < 1 mm to 25 mm. Biomass of fine roots increased with size class in all the three stands accounting maximum in 10 mm - 25 mm size class ranging from 27% (S3 stand) to 42% (S1 stand) and minimum in the 1 mm - 2 mm class with 7% (S1 stand) to 12% (S2 stand).

Table 3.
Annual litter fall in a rehabilitated forest on sodic land at Banthra, Lucknow ($Mg \cdot ha^{-1}$).

Components	**Stands**			
	S1	**S2**	**S3**	**Mean ± SE**
Leaf	6.18	5.43	5.57	5.73 ± 0.230
Twig	1.49	2.02	1.71	1.74 ± 0.154
Flower and Fruits	5.70	1.23	4.70	7.57 ± 0.238
Bark	1.00	1.30	4.60	2.30 ± 0.115
Total	8.34	8.81	8.21	8.45 ± 0.182
Forest floor litter	6.00	5.40	7.50	6.30 ± 0.28

Table 4.
Fine root biomass in a rehabilitated forest on sodic land ($g \cdot m^{-2}$).

Depth (cm)	**State**	**Stands**			
		S1	**S2**	**S3**	**Mean ± SE**
0 - 15	Live	273 ± 88.67	195 ± 51.5	210 ± 71.39	226 ± 23.89
	Dead	17 ± 2.63	33 ± 17.14	17 ± 8.15	22 ± 5.33
15 - 30	Live	283 ± 134.7	223 ± 84.73	140 ± 55.14	215 ± 41.45
	Dead	5 ± 1.53	16 ± 9.57	4 ± 1.24	8 ± 3.84
30 - 45	Live	93 ± 37.3	47 ± 13.14	30 ± 11.22	57 ± 18.8
	Dead	6 ± 3.5	2 ± 0.36	3 ± 0.95	4 ± 1.2
Total (0 - 45)	Live	649	465	380	498 ± 79.38
	Dead	26	51	24	34 ± 8.68
	Total	675	516	404	532 ± 79.22

Fine Root Production

Fine root production was less than half (233 $g \cdot m^{-2} \cdot yr^{-1}$) to that of their biomass up to a depth of 30 cm (Table 5). About two third i.e. 67% of the annual fine root production was measured during rainy and summer season. Corresponding to biomass, fine root production was also less in lower strata of 15-30 cm depth (101 $g \cdot m^{-2}$) in comparison to surface soil of 15 cm (132 $g \cdot m^{-2}$). It appears that about 70% of the total annual production of fine roots undergoes to mortality. However, in the periodic in-growth core extractions, fractions of dead roots were found to only 20% of the total annual production during different seasons, but cumulative mortality during the year would be many more times. Fine root production differed significantly between the stands and it decreased from S3 to S1 stand.

Discussions

Rehabilitation of barren sodic land under forest almost performs the same ecological functions to that of their natural allies despite of in different species composition plant community structure and species abundance might be different, yet the degraded state was renewed to an extent where life support systems could be operated by the several tropical biotas. However, the process was enough difficult to create a healthy ecosystem on account of many soil constraints commonly found in sodic soils which inhibit the establishment and growth of plants (Gupta & Abrol, 1990; Sumner, 1993; Naidu & Rengasami, 1993; Garg, 1998), nevertheless it was successful effort to accommodate a wide range of species in the new biotope. Knowledge of the species adaptation to such sites and process involved in succession can be utilized for rehabilitating the other similar sites in general and sodic ones in particular. This study, however, does not indicate temporal changes, yet it examines the diversity of a rehabilitated forest from several angles which exerts a strong influence to restore stability and resilience of rehabilitated ecosystem. Forest developed in such a way under protection forestry programs is important to determine the rate of restoration, structural and ecological diversities, establishment of steady state in biogeochemical cycle and patterns towards the climax communities. Any major disturbances may destabilize the building of niche (composition, aggregation and organization) which may extend the restoration process.

Community Structure

A semi natural forest developed on sodic soil constituted 74 species belonging to 35 families. These species were classified in overstory (44), understory (19), ground layer (8) and climber (3). Several species of overstory are also found in understory and ground layer vegetation which are supposed to be offspring of the parents at different growth stage. Several parameters of this rehabilitated forest have been compared with a degraded and reference forest of the region (Table 6). Plant population density decreased from degraded, rehabilitated to reference forest, respectively for overstory species but understory population in our rehabilitated forest was exceedingly high due to biotic protection.The average basal area (30 $m^2 \cdot ha^{-1}$) of the forest studied lies in between the degraded (Jha & Singh, 1990, Singh & Singh, 1991) and reference (Tripathi & Singh, 2009) forests. It appears that the carrying capacity for supporting the tree stock on sodic soils differs with species ranging from 12 to 38 $m^2 ha^{-1}$ basal area in *Acacia nilotica* and *Eucalyptus camaldulensis* plantations at same age (Singh et al., 2000). These values compare fairly well with 17 $m^2 \cdot ha^{-1}$ - 40 and 20 $m^2 \cdot ha^{-1}$ - 75 $m^2 \cdot ha^{-1}$ for dry and wet forests of the world, respectively (Murphy & Lugo, 1986b). The basal area of our rehabilitated forest is also well comparable to that of deciduous and evergreen forest (16 $m^2 \cdot ha^{-1}$ - 33 $m^2 \cdot ha^{-1}$) of Brazil (Haase 1999), beech forest 28 $m^2 \cdot ha^{-1}$ of Japan (Nagaike et al., 1999). Basal area of hardwood forest in USA was relatively high in the range of 40 $m^2 \cdot ha^{-1}$ - 45.5 $m^2 \cdot ha^{-1}$ (Gilliam et al., 1995) which might be expected with better silvicultural management on a good soil type.

The species richness of overstory vegetation was relatively high from understory and ground layer. Number of species in overstory can also be compared well with rainforest (43), moist forest (45), temperate forest (45) in one hectare plot area (Brockway, 1998). The classification of species as a percent of the total species in respective vegetation strata according to their population in numerals revealed that there were only a few species representing their populations in thousands and a high percent of total species had their individuals either in units or tens as under (Table 1).

Table 5.
Fine root production in a 45-yr old rehabilitated forest on sodic soil ($g \cdot m^{-2}$).

Depth (cm)	State	Rainy (%)	Autumn (%)	Winter (%)	Spring (%)	Summer (%)	Total annual
0 - 15	Live	35(33)	11(10)	8(8)	10(9)	43(40)	107
	Dead	7(28)	5(20)	2(8)	3(12)	8(32)	25
15 - 30	Live	31(38)	13(16)	6(8)	6(8)	24(30)	80
	Dead	3(14)	10(47)	2(10)	2(10)	4(19)	21
Total (0 - 30)	Live	66(35)	24(13)	14(7)	16(9)	67(36)	187
	Dead	10(22)	15(32)	4(9)	5(11)	12(26)	46
Grand total		76(33)	39(17)	18(7)	21(9)	79(34)	233

Table 6.
Comparative evaluation of vegetation structure and productivity in degraded, rehabilitated and reference forest.

Parameters	Vegetation strata	Degraded forest*	Rehabilitated forest**	Reference forest***
Population density (No/ha)	Overstory	1055 ± 68.7	554 ± 28	49 ± 45
	Understory	343 ± 121	3728 ± 913	245 ± 116
	Ground layer	-	6813 ± 456	4015 ± 730
Basal area ($m^2 \cdot ha^{-1}$)	Overstory	16.53 ± 0.82	29.9 ± 1.9	35.22 ± 6.54
	Understory	1.34 ± 0.47	4.2 ± 1.2	14.00 ± 8.20
	Ground layer	-	112 ± 66.4	274 ± 61
Species richness	Overstory	9 ± 0.24	44 ± 3.1	16 ± 1.76
	Understory	8 ± 0.28	18 ± 1.6	25 ± 2.5
	Ground layer	-	12 ± 0.72	21±5.78
Richness index	Overstory	0.39 ± 0.11	2 ± 0.1	1.74 ± 0.29
	Understory	0.67 ± 0.09	1 ± 0.1	1.50 ± 0.57
	Ground layer	-	0.8 ± 0.1	0.91 ± 0.21
Equitability	Overstory	0.72 ± 0.11	1.1 ± 0.07	0.93 ± 0.03
	Understory	1.06 ± 0.05	0.9 ± 0.08	0.77 ± 0.02
	Ground layer	-	0.7 ± 0.08	0.73 ± 0.06
Shanna Wiener's Index	Overstory	1.07 ± 0.32	3.6 ± 0.17	1.84 ± 0.14
	Understory	1.98 ± 0.09	3.3 ± 0.27	2.27 ± 0.17
	Ground layer	-	1.8 ± 0.19	2.23 ± 0.18
Concentrate of dominance	Overstory	0.58 ± 0.107	0.14 ± 0.02	0.18 ± 0.02
	Understory	0.31 ± 0.04	0.23 ± 0.07	0.15 ± 0.02
	Ground layer	-	0.40 ± 0.05	0.186 ± 0.01
Biomass ($Mg \cdot ha^{-1}$)	Overstory	89.87 ± 8.62	343±27	480 ± 37
	Understory	4.28 ± 0.34	3.8 ± 0.4	70 ± 5
	Ground layer	0.82 ± 0.15	0.04 ± 0.02	5 ± 0.2
Net production ($Mg \cdot ha^{-1} \cdot yr^{-1}$)	Overstory	12 ± 1.2	23±2.1	35 ± 2.5
	Understory	0.9 ± 0.15	1.2 ± 0.15	15 ± 1.6
	Ground layer	1.1 ± 0.17	0.05 ± 0.01	7 ± 1.1

*After Singh and Misra (1979) and Singh and Singh (1991). **Present study. ***Tripathi and Singh (2009).

About 28 species were found naturally regenerating in this forest which was about 64% of the total species listed in the forest. All these species may be considered to be well adopted in sodic soils viz. *Aegle marmelos*, *Alangium salvifolium*, *Albizia lebbeck*, *Azadirachta indica*, *Bauhinia variegata*, *Cassia siamea*, *Cassia fistula*, *Cordia dichotoma*, *Callistemon lanceolatus*, *Dalbergia sissoo*, *Dryopteris embryopteris*, *Ficus glomerata*, *Holoptelea integrifolia*, *Leucaena leucocephala*, *Mangifera indica*, *Phoenix sylvestris*, *Pithecellobium dulce*, *Derris indica*, *Putranjiva roxburghii*, *Streblus asper*, *Sterculia alata*, *Syzygium cumini*, *Syzygium heyneanum*, *Tamarindus indica*, *Thevetia peruviana*, *Terminalia arjuna*, *Ziziphus nummularia* etc.

Importance value index (IVI) of this forest in general ranged from 10 to 77 including 10 to 48 for overstory species. These values match with the range of 11 to 52 for sub-tropical tree species of a wet hill forest, India (Rao et al., 1990). The IVI of tree species of a protected forest in Orissa (India) ranged from 12 to 55 (Verma et al., 1997), and trees of dry tropical forest of Vindhyan region constituted 3 to 32 IVI (Singh & Singh, 1991). Thus, our estimate for a rehabilitated forest compares fairly well with the natural forests in India. Shannon Wiener's index (H) of general diversity obtained from 1.8 (ground layer) to 3.6 (Overstory vegetation) indicated that the variability of trees was apparently higher in comparison to ground flora. Since many tree species were planted in this forest, tree diversity index exceeded from dry tropical forests of India, whereas ground layer diversity was almost similar to that of other native forests (Jha, 1990; Singh & Singh, 1991). Shannon Wiener's diversity index of this forest was relatively low from tropical rainforests (3.8 to 4.8) of Silent Valley, India, (Singh et al., 1984). A more generalized relation of the species diversity is derived when stands were pooled together for certain correlations. For instance, the Shannon Wiener's index increased positively with the increase in IVI and the correlation was highly significant (P < 01). The Shannon Wiener's index was negatively correlated with the concentration of dominance, and redundancy, whereas; it had a direct relation with equitability and richness index.

Successional patterns on plant species diversity during rehabilitation of barren land in India are not known and thus the species recruitment/replacement rate is yet to be understood with temporal scale from the initial establishments. The way through which the succession approaches to attain equilibrium, alike to that of natural forests of this region and is stabilized might be interesting to understand for creating a new biotope of our own choice. Manipulation at time to time may be made to divert the ecological processes in the best interest of the entire organism associated with the forests. However, most of the natural forests are disturbed to various degrees on account of a high population pressure for timber, industrial pulp and fuelwood which affect the species diversity significantly. For instance a dry tropical forest of Vindhyan region in India consisted of lower species diversity and basal area in comparison to our study due to several biotic disturbances (Singh and Singh, 1991). However, if a forest is not disturbed during the development of dominant species, then also the species richness is reduced (Odum, 1960). Therefore moderate disturbance may be in favor of high species richness. The studies made elsewhere on species diversity with succession reported the conflicting patterns. McCormick (1968) and (Nicholson & Monk, 1974) found that diversity increased with succession, while Shafi and Yarantan (1973) reported decline in diversity with age. A few noted the highest diversity in the early stages of succession (Habeck, 1968; Long, 1977; Peet, 1978), whereas, several others have depicted a polynomial increase followed by a decrease during succession (Margalef, 1963, 1968; Loucks, 1970; Auclair & Goff, 1971; Schoonmaker & Mackee, 1988). In some cases diversity may show multiple peaks during succession as found by (Halpern & Spies, 1995). Therefore, no generalized trend is maintained and such variations if examined along the site quality gradients would be useful in modeling of diversity patterns.

The different theories of the community organization stated that the diversity is a structural concept which relates to stability, maturity, productivity and evolutionary time, predation pressure and spatial heterogeneity (Hill, 1973). Species diversity (richness) and dominance (Simpson index) were inversely related to each other in agreement with Zobel et al. (1976). Most of these studies suggest that major diversity changes occur during early forest formation and time of species saturation during succession varies greatly in different forests (Nicholson & Monk, 1974). The trends of equitability with succession has not been yet resolved as the high diversity of undisturbed tropical forest implies high equitability levels for mature tropi- cal forest communities (Janzen, 1970; Shafi & Yaranton, 1973), whereas other data indicate a strong decrease in equitability with forest age in USA (Loucks, 1970; Auclair & Goff, 1971; Nicholson & Scott, 1972). It might be possible that a high scale catastrophic perturbation would have reduced the equitability in mature forest vegetation. In general diversity indices (richness, Shannon Wiener's and equitability) tend to stabilize from ground layer to overstory vegetation. Nicholson & Monk (1974) expressed a basic change in the strategy of the plant communities in initial forest formation from a low to high equitability. The young communities (0 yr - 20 yr.) are characterized by plentiful resources and growing space with low equitability, whereas older communities, highly competitive in space and resource, exhibited a high equitability. Thus rapid increase and stabilization of plant equitability early in succession is viewed as a necessary adjustment to resource scarcity. These findings entail that the community structure and species diversity are related to several environmental factors which lead to specific changes at various scale (region, landscape, biome).

Productivity

Standing biomass and net primary production (NPP) are the aggregate response of the plant species in a particular set of environmental conditions. Climatic and edaphic factors across the region along with the species intrinsic potential determine the limits of ecosystems productivity. Forest productivity differs considerably with environmental conditions from arid to humid climates (8 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$ - 40 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$), standing biomass and net primary production are generally found to be closely associated with each other. Forest established on degraded land tends to acquire the climate based yield in a particular habitat.

Biomass

Total biomass of the three stands varied about 12% - 14 % from their mean in this rehabilitated forest. Our mean value (347 $Mg{\cdot}ha^{-1}$ ± 27 $Mg{\cdot}ha^{-1}$) is supposed to be far better from the other dry tropical forests (degraded) of India, however it is yet to achieve the status of a reference forest of this region (Table 6). Murphy & Lugo (1986b) have reported the global pattern of biomass of dry tropical forests (78 $Mg{\cdot}ha^{-1}$ - 320 $Mg{\cdot}ha^{-1}$), in which the biomass of this rehabilitated forest was relatively higher, but it was lower to that of wet tropical forest (269 to 1186 $Mg{\cdot}ha^{-1}$) The total biomass of our rehabilitated forest was less than half of the humid sal forest of India (Singh & Singh, 1989). It was also below by 24% and 37% from the tropical rain forest of Sarawak and Karnataka, India (Proctor et al., 1983; Rai & Proctor, 1986). In a particular habitat biomass depends much on the composition of the tree species in a forest because species to species variations, even on the sodic soil sites have been found to be quite high ranging from 202 (*Acacia nilotica*) to 405 $Mg{\cdot}ha^{-1}$ (Eucalyptus) on the same site at same age (Singh et al., 2000). The average biomass of our rehabilitated forest was less (43%) than the mixed dry deciduous forest at Haryana India (Gupta & Bhardwaj, 1993). Such variations may be considered as the proportional responses of the site quality interactions to various species in order to perform the forest ecosystem functioning as efficiently as it can optimize the climate based yield.

Biomass Allocation

Above ground biomass in this study was low in comparison to some tropical forests including wet forests. Biomass in above ground plant parts was 88% of the total (stem 28%, branch 57% and leaf 3%), indicating that allocation in root was below the average of 20% observed in most of the natural forests. This might be expected due to soil compactness and presence of "Kankar pan" (a stony layer of $CaCO_3$ gravels) in sub soil. As a consequence, root could not spread and proliferate freely. In this rehabilitated semi-natural forest the mean root biomass contributed about 12.4% of total forest biomass in which coarse root contributed 11% and fine roots contributed to 1.4% of total forest biomass. The contribution of roots in total forest biomass was comparatively low from dry tropical forests supporting 12% - 18% of total biomass (Singh & Misra, 1979; Murphy & Lugo, 1986a; Singh & Singh, 1991). The contribution of coarse root in present forest was comparable to lower range of value (8% - 50%) reported for a number of dry forests (Murphy & Lugo 1986b). It was also slightly less from the average contribution of 16% in 33 moist and wet tropical forests cited by Brown & Lugo (1982).

In global pattern, below ground biomass was 10 Mg·ha^{-1} - 45 Mg·ha$^{–1}$ for dry tropical forest and 11-135 Mg ha^{-1} for tropical wet forest (Murphy & Lugo, 1986b). However, tropical rain forest in India consisted of a relatively low root biomass of 14 Mg·ha^{-1} - 20 Mg·ha$^{–1}$ (Rai & Proctor, 1986). The root/shoot ratio in our forest (0.124) was slightly less than that of global pattern (0.181) of dry tropical forest (Murphy & Lugo, 1986b). This forest had a very less root/shoot value in comparison to other subtropical forests ranging from 0.39 - 0.42 (Jordan 1971a; Vyas et al. 1977). The understory biomass in our rehabilitated forest (3.76 Mg·ha^{-1}) contributed a very little proportion of 1.2% of total biomass of the forest, which is far less from dry tropical forests of India, in which about 13 % - 40% of total biomass was shared by understory (Singh & Singh, 1991). However, (Singh & Misra, 1979) reported only 2% - 7% of total biomass in understory of dry tropical forests on a different site in same geographical region.

Net production of this rehabilitated forest was estimated to 25 Mg·ha$^{–1}$·yr$^{–1}$, which appears to be better than dry tropical forests of India, but it is less than the reference forest (Singh & Misra, 1979; Singh & Singh, 1991; Tripathi & Singh, 2009). Net production of this forest compares fairly well at higher level in the global pattern of 13 Mg·ha$^{–1}$ - 28 Mg·ha$^{–1}$ and 8 Mg·ha$^{–1}$ - 21 Mg·ha$^{–1}$·yr$^{–1}$ for wet and dry tropical forests, respectively (Murphy & Lugo, 1986a, b). The net production of present forest was also within the range (10.3 to 28.6 Mg·ha$^{–1}$·yr$^{–1}$) of montane rain forest of Puerto Rico and tropical rain forest of Thailand (Kira et al., 1967; Jordan, 1971b). Managed plantations may generate a relatively high yield from the rehabilitated forests as observed in case of *Eucalyptus saligna* and *Albizia falcataria* species at north east cost of Island Hawai (Binkley & Ryan, 1998). Therefore the net production of tropical forest plantations is considered to be one of the most productive eco- systems in the world, showing 40 Mg·ha$^{–1}$·yr$^{–1}$ of above ground net primary production (Lugo et al., 1998; Evans, 1992; Binkley et al., 1997). The enhanced productivity has been found to be closely associated with the environmental factors and generic potential.

Fine Root Biomass and Production

Fine roots perform some principal physiological functions in absorption and conduction of solute, nutrient uptake, transpiretion, water retention in soils and on the death and decay, contribute to soil organic matter. Fine roots also act well in reclamation of sodic soils by reducing the pH, improving the soil structure and water permeability of heavy impervious sodic soils. In general fine root biomass and production in afforested sodic soils was relatively less in comparison to many other forests of India and abroad. This may be due to the high soil compactness, low rainfall, high pH, and poor water permeability in sodic soils, which adversely affected the fine root development in hostile conditions. Total fine root biomass (live + dead) measured as 532 gm$^{–2}$ up to 0 cm - 45 cm depth, was comparatively low in the present study from the of tropical deciduous forest up to 30 cm depth (Singh & Misra, 1979). The variation in fine root biomass among the different stands was 14% (S1) to 20% (S3) from their mean value .Fine root biomass was relatively high from the three plantation forests on same site (Singh et al., 2000). In an earlier study, fine root biomass (live + dead) was estimated as 222 g·m$^{–2}$ up to 30 cm depth in the same forest under the canopy of few species (Singh 1998). Thus various estimates of fine root biomass on the same site differ significantly from each other corresponding to species and soil depth considered in their studies. Fine root biomass of this forest compares fairly well with that of dry tropical forest (2.9 to 5.3 Mg·ha$^{–1}$) in India (Singh & Singh, 1991). The contribution of fine roots to total dry matter turnover in the forest including litter was about 59% which lies within the range 20% - 77% reported for a variety of forests (Vogt et al., 1986). However in some dry tropical forests, fine roots contribution was relatively low about 40% of the total dry matter turnover (Singh & Singh, 1991).

Biomass of fine root was estimated as low as 0.5 Mg·ha$^{–1}$ (Gower, 1987) and as high as 39.5 Mg·ha^{-1} from the rain forest (Cavelier, 1992). The fine root biomass and production both depend on environmental condition and community structure. A high precipitation zone (10372 mm·a$^{–1}$) showed significant seasonal difference (Khewtan & Ramakrishnan, 1993). Fine root biomass of a hard wood forest estimated as 4.71 Mg·ha^{-1} by Fahey & Hughes (1994) compared well with this forest, but it was quite less in comparison to a semi-deciduous rain forest at Panama (9.45 Mg·ha$^{–1}$) observed by Cavelier (1992). In some Indian tropical evergreen forests including eucalypt plantations fine root biomass varied from 0.32 to 3.65 Mg ha$^{–1}$ respectively (Bargali et al., 1992; Vasalakshi, 1994), and our estimates compared fairly well with some natural forests of the arid and semiarid regions of India cited by Singh (1996). Fine root biomass of our forest decreased with soil depth and about 47% of total fine root biomass is accommodated in superficial layer (0-15 cm). Decrease in fine root with soil depth is observed in many forests occupying most of the proportion's (43% of the total) in floor horizon alone (Fahey & Hughes, 1994). Simmons (1993) measured a much high value of fine root biomass (3.9 Mg·ha$^{–1}$) in the thicker forest floor (10 cm) of a mature northern hardwood forest. Fine root mortality (necromass) have been observed as 10% - 15% of total fine roots in various forests (Singh, 1998; Singh et al., 2000) and our estimate belongs to lowest end of this range.

Seasonal fluctuation in fine root biomass varied from 42% (summer) to 62% (rainy) of the yearly mean in our forest. Maximum fine roots were extracted in rainy season and minimum in summer season. However, Singh (1998) observed minimum fine root biomass in winter season. Seasonal variation has been observed to 22% of the yearly mean in small roots in the tropical dry deciduous forests in India (Singh & Singh 1981). The same for fine roots varied from 12 % - 17% from their seasonal means in two dry tropical evergreen forests (Vasalakshi 1994). Fluctuations of 50% or more have commonly been found in many other forests (Grier et al., 1981; McClaugherty et al., 1982; Persson, 1978, 1979, 1980). However, several oak and pine forests did not show any marked seasonal variations and had almost stable biomass pools (Keyes and Grier 1981; Aber et al. 1985). Comparing fine root biomass between forests is difficult because of differences in measuring techniques, soil depth and root diameter classes considered. In most Indian forests of dry zone it has varied from 32 to 340 gm$^{–2}$ for <2 mm diameter to a depth of 30 cm (Parthasarthy, 1988; Vasalakshi, 1994). In our forest, fine roots of < 2 mm diameter were categorized to 20% of total fine roots, which was comparatively less than other Indian dry zone forests. Different soils, vegetation intensity and climatic factors constitute variable quantities of fine roots, nevertheless our forest compared fairly well with some natural forests of the arid or semi arid zone of India (Singh 1998).

Fine root production was measured as 2.33 Mg·ha^{-1}·yr^{-1} in this forest, which was nearly half to that of fine root biomass to a depth of 30 cm. Live fine root production ranged from 2.5 Mg·ha^{-1}·yr^{-1} in chir pine forest to 3.61 Mg·ha^{-1}·yr^{-1} in banj oak evergreen forest (Usman & Rawat, 1999). According to Satoo (1971) the fine root production in evergreen broad leaved forest ranged between 3.7 to 5.3 Mg·ha^{-1}·yr^{-1}. The fine root production in this study lies within the range of 1.4 to 11.5 Mg·ha^{-1}·yr^{-1} reported for various tropical and temperate forests (Keys & Grier, 1981; Fogel, 1985; Santantonio & Hermann, 1985; Santantonio & Santantonio, 1987; Adhikari, 1992; Garkoti, 1992; Fahey & Hughes, 1994). In Indian forests, fine root production ranged from 0.5 Mg·ha^{-1}·yr^{-1} of tropical dry deciduous forest to 3.2 Mg·ha^{-1}·yr^{-1} in humid tropical forest (Singh & Singh, 1981; Khewtan & Ramakrishnan, 1993). Fine root production in tropi- cal evergreen forest in India ranged from 1 to 1.17 Mg·ha^{-1}·yr^{-1} Vasalakshi (1994). Fine root production differed with seasons and maximum production occurred during rainy season and summer season of about 67% of the annual production. Fine root production of <2 mm diameter occurred about 90% of total size classes studied which decreased with increasing root size in this forest.

Litter

Litter fall is an important flux of nutrient cycle to maintain the soil sustainability for perpetual production. Besides, it also contributes significantly in reclamation of sodic soil. Litter constitutes several parts i.e. leaves, twigs, bark, dead branches, flower, fruits, seed etc in which leaf litter generally contributes more than 50% of the total litter. Littoral and swamp forest and tropical moist deciduous forest had the highest total as well as leaf litter fall, while tropical dry deciduous forest had lowest total and leaf litter fall. While comparing in four contrasting forest types in India, Singh et al. (1992) also reported that dry deciduous forest had lower litter fall than other types. The relatively low net primary productivity of dry deciduous forests might be one of the reasons. The litter quantity also depends on the population density, age and species of the forest. Since most of these forests are degraded ones, the litter fall was relatively low. Annual litter fall of 8.5 Mg·ha^{-1}·yr^{-1} was estimated in the rehabilitated forest which was greater than the litter fall (5.8 Mg·ha^{-1}·yr^{-1}) of dry tropical forest in India (Singh & Misra, 1979; Singh & Singh, 1991). Mean litter fall of 6.4 Mg·ha^{-1}·yr^{-1} was reported for tropical montane forests (Vitousek & Sanford, 1986). A review of 44 published studies of Indian forests documented total and leaf litter fall in the range of 4.3 to 8.5 Mg·ha^{-1}·yr^{-1} and 3.4 to 6.9 Mg·ha^{-1}·yr^{-1} respectively (Dadhwal et al., 1997). Vogt et al. (1986) compiled a range of 2.44 to 9.44 Mg ha^{-1}yr^{-1} for various forest types of the world. The range of litter for a variety of tropical and dry forests of the world was reported to be 0.8 Mg·ha^{-1}·yr^{-1} - 15.3 Mg·ha^{-1}·yr^{-1} (Vitousek, 1984; Murphy & Lugo, 1986b; Dantas & Phillipson, 1989). So our data lie in the middle of the said range. Leaf litter in the present study contributed 68% of total litter fall which is comparable to that of (75%) tropical dry deciduous forests of India (Singh & Misra, 1979). In our forest, of the total annual litter fall, summer season contributed maximum (25%) and autumn minimum (12%). Corresponding figures in deciduous forest may reach to 42% of the total annual in summer and 18% in rainy season (Singh & Misra, 1979).

The data generated here with on plant community students, species diversity, biomass, net production, litter fall and fine roots indicated that the restoration of barren sodic land in a new forest ecosystem has acquired most of the characteristics properties of natural forests of this region, even after differing in species composition. This case study suggests the adoption of the most successful species for the restoration of other identical sites in amore efficient way. If we could control the fire, livestock grazing and invasive alien species, organization of new plant communities, succeeds with the little anthropogenic efforts. Mixed plantation with native species, particularly leguminous, has become more successful. It would be better to introduce the medicinal herbs, found in natural forests to develop amore useful and compatible ground layer in the rehabilitated forest.

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