CHAPTER 2

REVIEW OF LITERATURE

The importance of minerals in the life of a nation as well as that of an individual is next to agriculture. Unless extracted, minerals are of no value and their extraction is one of the most valuable forms of land uses. Current economic dynamics would be hard to understand without mining. Although some may insist that modern economics derive a large portion of their revenue and prosperity from the service sector, primary sector activities form the economy’s real bed-rock. Without exaggerating, the World Bank confirms that the most significant progress towards satisfying human needs, including food, accommodation, health, education, employment and transport, relies on the increasingly efficient use of mineral resources. Furthermore, some studies suggest that activities such as manufacturing, construction and even agriculture, could not exist without mineral production. At its various stages, from exploration to production, it generates significant number of jobs and income for mankind. Due to rising demand for minerals by the world’s largest and growing economies, mining is becoming increasingly important.

However, mineral resources have certain distinctive characteristics which are unique to them. Minerals are site specific, fixed quantity and quality, and non-renewable. These peculiarities lead to some of the most challenging problems of the mineral industry. Juxtaposition of their below-ground occurrence with above-ground forest areas at almost all the places of their occurrence has made the exploitation of minerals more challenging activity. In view of the importance of the extraction of minerals and problem of their juxtaposition with forest areas, it is imperative to reclaim the mined out areas with utmost care and to its original landscape as far as possible. However, the waste rock dumps generated after surface mining have various problems of physical, chemical and biological properties, resulting into limiting the choice of species to be planted, and desired growth and success of such planted species for revegetation of mine spoil.
From the socio-political point of view, it is important that mining as an alternative use be accompanied by rehabilitation techniques which can demonstrate that the mined land can be successfully retuned to agriculture, preferably profitable grain production. Mining cannot be accepted as a land use alternative if it is seen as a terminal use; neither can erosion-inducing agricultural methods be tolerated (Russell and Roberts, 1986). Wali and Kollman (1977) have rightly pointed out that the unrehabilitated post mining physical, chemical and biological characteristics of the mine spoils create a specific ‘mining ecology’. The goal of restoration is usually to develop a long-term sustainable ecosystem native to the area where mining occurred and to accelerate natural successional processes so as to increase biological productivity, reduce rates of soil erosion, increase soil fertility and increase biotic control over biogeochemical fluxes within the recovering ecosystems (Parrotta, 1992; Young, 2000; Singh et al., 2002; Maiti and Das, 2004; Maiti and Ghose, 2005; Zedler, 2005; Grant, 2006; Maiti, 2006).

Following review of literature is not exhaustive but provides background information on certain ecological aspects of mine spoils.

2.1 PROBLEMS RELATED WITH REHABILITATION OF MINE SPOILS

The large-scale land disturbances associated with mining operations and related concerns about the environmental effects have triggered an increasing number of rehabilitation programmes which aim for the restoration of natural ecosystems disturbed by mining. Restoration of mine sites often entails amelioration of physical and chemical characteristics of substrate, ensuring the return of vegetation cover (Bradshaw, 1987). If specific problems hindering ecosystem redevelopment can be identified, a cure can be designed using or mimicking natural processes. According to Dobson et al. (1997), this process of identification and intervention is the essence of ecological restoration.

The most common response to land degradation has been abandonment or reliance on natural succession to restore lost soil fertility, species richness and biomass productivity (Parrotta et al., 1997a, b). However, the process of natural succession on
surface-mined soil is slow due to the removal of topsoil, resulting in elimination of soil seed bank and root stocks and due to soil profile disturbances (Parrotta et al., 1997 b).

It has been argued that if environmental change produced by disturbance is large, it may become lethal to greater number of established species than are, or can be, immediately replaced by immigrants (Sheil, 1999). Disturbance such as logging usually causes an immediate decline in biodiversity followed by a recovery, although not necessarily of the same species (Noble and Dirzo, 1997). Species richness of a site experiencing disturbance, therefore, will be a cumulative outcome of differential responses of species to disturbance. Some species may tolerate the disturbance and the other may disappear (Sagar et al., 2003). Ecosystem, in general, refers to the universal assemblage of soil, air, water, plants and animals along with many other components which are both biotic and abiotic in nature. It denotes the interactions of the biotic community with the abiotic environment. Bradshaw (1984) has stated that the characteristics of ecosystems can be decided by their two main parameters, namely the structure, i.e., species number and organizational complexity, and function, i.e., metabolism, interactions and resource recycling.

The open cast mining results into physically, nutritionally and biologically poor overburden. The establishment of vegetation cover on coal mine spoil is challenging task due to problems such as compaction, poor water-holding capacity, infertility, high acidity or salinity of soil and extreme temperatures (Joshi et al., 2006). Bradshaw (1983) has also opined that the devastated ecosystems in the aftermath of mining, if left to itself, could have recuperated along the normal natural trajectory of development, but due to extreme poverty of starting materials, the progress will be extremely slow. Soil or the substrate into which plants establish and root is the starting point which may be varied, and the problems they pose can be dependent on the specific site conditions. This starting material is usually extremely skeletal on derelict sites, and its properties and situation determine in a very crucial manner the degree to which an ecosystem can develop naturally on the site, how far this development will progress, and what treatments are necessary to assist its development. However, the very simple needs of plants are: (i) a medium into which they are physically able to root, (ii) an adequate
water supply, (iii) an adequate nutrient supply, and (iv) lack of toxicity (Bradshaw, 1987).

The main aim of any restoration process is to create sustainable plant communities representative of the composition and diversity of the surrounding natural plant communities (Jefferson, 2004). Restoration of the original natural or semi-natural vegetation, though often technically very difficult or impossible to achieve, is frequently the ultimate aim of rehabilitation programmes (Dickie et al., 1988.). Bending and Moffat (1999) have indicated that establishing vegetation on spoils often present challenging problems. These include compaction, salinity, acidity, poor water-holding capacity, hostile temperature regime and inadequate supplies of plant nutrients (Doubleday and Jones, 1977).

Other researchers have also emphasized that establishment of vegetation on abandoned mined lands is hindered by physical factors such as high temperature and low availability of soil moisture. Particularly, in arid and semi-arid areas, limited rainfall during the growing season and high surface temperatures often limit plant establishment and growth. In certain areas, the main factor in preventing vegetation from becoming established is acidity. If specific problems hindering ecosystem redevelopment can be identified, a cure can be designed using or mimicking natural process (Maiti, 2003; Singh et al., 2002).

Study by Doerr et al. (1983) has demonstrated the feasibility and potential problems involved in revegetating intensively disturbed sites. According to them, alkalinity and salinity of mine spoil, higher rates of litter accumulation, damages by insect and pathogens, and lower spoil nutrient contents are the usual problems affecting revegetation. Power and Bennett (1977) found nutrient deficiencies (N and P), toxicities (Mg, B and Mo), compaction and steep slopes as the major problems. Bradshaw (1987) concluded that the problems these derelict lands pose can be reduced to: (i) physical-structure, either too compact or too open, instability, and moisture level either too low or too high, (ii) low or negligible availability of macro- or micro-nutrients, (iii) toxicity-either too low or too high pH, too high salinity and too high level of heavy metals, and (iv) absence or slow colonization of wild plants and animals.
2.1.1 Properties of the mine spoil

In surface mining, when overburden is removed, the soil horizons get upside down and the unweathered ‘C’ horizon gets exposed. This contains unweathered clay with high cation exchange capacity (CEC) and high level of exchangeable bases. The major deficiency is lack of organic carbon and almost complete absence of nitrogen (Das et al., 1992; Mohanty, 2004). Fail Jr. and Wochok (1977) reported that coal spoils characteristically lack nitrogen primarily because of loss of top-soil with its organic matter, together with the fact that nitrogen availability rapidly drops with decrease in pH. A pre-requisite to any revegetation plan is the knowledge of physico-chemical properties of the mine spoils. According to Power (1978), the physico-chemical characters crucial to prediction of the plant growth potential for overburden include texture, pH, electrical conductivity, soluble Ca, Mg, Na, B, cation exchange capacity, exchangeable cations, gypsum and calcium carbonate equivalents, and carbonate, bicarbonate, sulphate, chloride and nitrate contents of the saturation extract. Water holding capacity and infiltration rate are other key variables.

Many obstacles, like low pH, soil compaction, elevated surface temperature, water stress and lack of nutrients, viz. N and P exist to establishing vegetation on previously mined sites. However, considering the stressful abiotic condition and minimal management efforts, the degree of resilience of these systems is encouraging (Holl and Cairns, 1994). Analyzing spoils of four coal-mine sites of Jharkhand, Prasad and Roy (2001) reported that the pH of coal-mine spoils was acidic (5 to 5.6). Those spoils were significantly poorer in available nitrogen, phosphorus, potassium and organic matter than the plant populated control area.

Coarse and medium textured overburden materials with low water holding capacity when compacted exhibit improvement in water holding capacity. However, when heavy clays are compacted they exhibit undesirably low water transmissivity characteristics. Shukla and Lal (2005) found that the soil disturbance due to mining operation increased soil bulk density at both depths of 0-15 cm and 15-30 cm. Soil quality improved with increase in reclamation duration as evidenced by decline in bulk density, increase in pH, and total nitrogen concentration of soil. With increase in bulk
density, water infiltration and movement decreases. Generally, low bulk densities in soils indicate high organic matter content, good granulation, high infiltration, and good aeration, resulting in a good rooting medium. Conversely, higher bulk density values generally indicate low soil aggregation, inhibited root penetration, and low infiltration and permeability rates.

Healthy plant growth is intimately related to the capacity of soil particles to group together into stable structures, i.e. aggregation property of the soil. A fine-textured, well-aggregated soil is ideal for growth, since it has the desirable properties of both a fine-textured soil, in its capacity for holding water and nutrients, and a coarse-textured soil, in its water permeability, aeration, and resistance to compaction. The binding colloids are derived from organic matter; therefore, a newly created surface generally lacks them. Aggregation will improve with time if suitable soil flora and fauna can be established and maintained (Jha and Singh, 1992a).

The most suitable soil texture for any site depends, to a large extent, upon the type of vegetation that is desired. The proportion of particles with diameters less than 2 mm (that is, sands, silts, and clays) is most significant to plant growth because small particles, with their greater surface area, contribute most to the water- and nutrient-holding capacity of the substrate (Ibid, 1992a). High temperatures and low moisture of surface mine spoil limit plant growth (Richardson, 1958; Richardson and Greenwood, 1967; Bradshaw et al., 1975; Bell and Ungar, 1981) and also reduce decomposer activity (Wieder et al., 1983). Root development is restricted due to changes in physical and chemical properties during spoil handling. Due to high sodium and low soluble salt content clays become dispersed, water movement is restricted and unfavourable conditions for root growth occur. Root growth is restricted in soils with a bulk density higher than 1.6 (Russell, 1977). Power et al. (1978b) have reported 10 to 30% lower bulk density for spoils compared to original undisturbed soil. The bulk density values of spoil and undisturbed soil typically range from 1.1 to 1.4 and 1.4 to 1.7 g cm$^{-3}$, respectively. When spoils are dry, the heavy machinery used for mining operations causes severe compaction, warranting ripping or other surface disturbances before seeding. Lyle (1987) and Zeleznik and Skousen (1996) suggested that bulk
density higher than 1.5 mg/m³ can severely restrict root growth of many species. A study by Fierro et al. (1999) found that bulk density of unamended mine soil was more or less equal to 1.7mg m⁻³.

EC is a common mine soil variable influencing plant productivity (Andrews et al., 1998; Torbert et al., 1988; McFee et al., 1981). High levels of soluble salts inhibit water and carbon dioxide uptake, and also inactivate enzymes affecting protein synthesis, C metabolism, and photophosphorylation. Regression analysis by Rodrigue and Burger (2004) indicated a decrease in site productivity with an increase in the soluble salt concentration.

2.1.2 Nutrient poverty in mine spoils

Soil fertility may be defined in terms of the capacity of the soil to supply essential nutrients and water for the growth of plants. In tropical forest areas with highly weathered soils, organic matter plays an important role in soil functioning and forest sustainability. When forests are clear-cut, the soil begins almost immediately to lose organic matter, triggering a series of soil degradation processes, the extent and intensity of which depends on soil management. Most tropical forests grow on highly weathered soils that contain low activity clays and have low natural fertility and pH. Because of this, these systems depend on efficient nutrient cycling based on litter deposition and decomposition. In addition, in these soils, soil organic matter (SOM) plays an important role in the soil cation exchange capacity (CEC), retention of base ion, soil aggregation and is directly related to nutrient availability, especially soil nitrogen. Studies indicate that nitrogen is probably the most important limiting factor to the reestablishment of forest communities (Macedo et al., 2008). Increased nutrient export from the system (Likens et al., 1970; Stark, 1977; O'Neill et al., 1977) and depletion of soil carbon pool, i.e., "energy currency" from the belowground ecosystem (Parkinson, 1979), cause ecosystem disruption. Mine wastes or sub-soils are unlikely to contain any significant quantities of nitrogen in particular, since in most ecosystems nitrogen accumulates in surface soils as a result of biological activity (Bradshaw, 1987). Mining activity alters the flow of N through a stable-plant-microbial system (Reeder and Sabey, 1987). It causes loss of litter layer, which is an integral storage and exchange site for nutrients.
Nutrient-holding capacity of mine spoil is drastically reduced and a major disadvantage of surface-mined sites is thus low inherent fertility of the spoil material (Bradshaw, 1983). Mine spoils are nutritionally and microbiologically impoverished (Visser et al., 1979) and soil-forming processes are confined to the top few centimeters even in older spoils (Smith et al., 1971; Anderson, 1977; Down, 1975; Rimmer, 1982). Schafer et al. (1980) also found that organic matter was present only in the upper few centimeters of a 53-year old spoil. Samples of overburdens from chromite and coalmines in eastern India have showed major deficiencies in nitrogen at all these sites, but not of other nutrients (Das et al., 1992).

Reduced nutrient availability was reported even in reclaimed sites compared to soils of natural sites by Toy and Shay (1987). Investigations suggest that nitrogen is usually the major limiting factor (Crocker and Major, 1955; Roberts et al., 1981). It is the only nutrient that changes significantly with ecosystem development and can be shown to be continually limiting (Marrs et al., 1983). Mine dumps usually lack biologically active nitrogen; however, exchangeable ammonium-N may be present which nitrifies to nitrate-N in a few months when exposed to atmosphere (Power et al., 1974). Other researchers have also found nitrogen accumulation as a major factor limiting the rate of vegetation development on mine wastes (Bradshaw et al., 1975; Dancer et al., 1977; Roberts et al., 1981). Bradshaw (1987) is of the view that the exact amount of soil nitrogen capital will depend on rates of decomposition and the particular type of vegetation considered and it will take some time to accumulate. Bradshaw (1987), supported by findings of Marrs et al. (1980) and Roberts et al. (1980), in well-managed kaolin mine waste reclamation projects in south-western England, concluded that the problem of nitrogen accumulation is reflected not only in the total amount of nitrogen accumulated, but also in the total amount mineralized compared with normal soils. Lack of mineralizable organic N and lower mineralization rates affect the availability of N to plants in mine spoils (Reeder and Berg, 1977). High levels of organic matter in mine soils improve aggregation and infiltration capacities and increase the availability of nutrients (Toy and Shay, 1987).
In a study of Neyveli Lignite Mining areas in India, Sengupta (1991) found that the huge Bucket Wheel Excavator cannot segregate and excavate the top 30 cm soil which has the plant nutrients, humus and microbes, separately. The excavated mine spoil is practically inert with very low organic matter and very poor in available N, P and K.

Potassium may also be deficient, either in terms of total or available amounts (Beaton, 1974; Bradshaw, 1987). Wittwer et al. (1981) found both N and P as limiting factors in southeastern Kentucky mine spoils. Safaya and Wali (1979) and Iverson and Wali (1982) observed P as a major limiting nutrient during colonization and early succession processes and found that when P was inadequate, plant growth was adversely affected. Power et al. (1978b) reported universal deficiency of P in arid mine spoils of United States. Prasad and Shukla (1985a) reported N, P and K deficiency in coal mine spoils at Dhanpuri, Madhya Pradesh, India; and Prasad and Pandey (1985) reported lack of nutrients and moisture retention capacity in bauxite mine spoils at Amarkantak, MP, India. Jha (1992) observed that the generic mine spoils of Jhingurda coal mines, MP, India were nutritionally sub-optimal for plant growth and responded positively to the addition of NPK fertilizers. Maiti et al. (2005), in a coalfield in Jharkhand, India, found that available N in the top 15 cm of overburden (OB) was 30 ppm as compared to 45 ppm in topsoil. They observed that the lower value of available N in the OB dumps can be attributed to lack of microbial activity and mineralization of organic matter. Available P was also found lower in comparison to topsoil, which may be due to the fixation of phosphorus by coal shell, and in acidic pH, it forms insoluble aluminium phosphate. Exchangeable potassium was found lower in reclaimed OB dumps than topsoil. According to Severson and Gouch (1983), rapid changes in chemical equilibrium are expected in spoils due to young stage of soil development. Kumar et al. (2005) also reported high pH (8.7) and high Na⁺ but low available N and P with no nitrification in lignite mine spoils of Rajasthan, India.

2.1.3 Soil erosion and reduced water conservation

Surface mining drastically changes the topography of the area and transfers relatively stable land forms into more erosive ones. In mine spoils, geomorphic system
is in disequilibrium due to destruction of the balance between landforms and processes which accelerate erosion rates (Soulliere and Toy, 1986). Down (1975) reported accelerated erosion even on very old (178 years) spoils (32-36° slope).

Hydrological data collected for eastern U.S. mine spoils showed that the potential for runoff and erosion on long slopes of 9% or greater was rather severe (Gilley et al., 1977). Archibold (1980) observed that slopewash due to rains easily moves seeds to the base of the slope. Fine clay particles are also moved through runoff. Therefore, soil erosion is one of the major problems in rehabilitating mine spoils. Properties of mine-spoils, such as texture, extent of fragmentation of rocks, exchangeable Na content, bulk density, compaction, degree, and length of slope influence infiltration, runoff and evaporation of water (Jha and Singh, 1992a). Pederson et al. (1980) found that spoils having high bulk density and low porosity had low infiltration rates. Most of the spoils retained only 25% as much plant available water as the water of a natural soil. The dumping and smoothing of spoils with equipments cause differential packing. The central axis of the piles is markedly packed, while packing is less on the outer slopes where materials are pushed or slide down the slope. Thus, the bulk density in the central axis of the piles becomes higher, and lower towards outer slopes. This causes uneven subsidence and differences in surface drainage (Jha, 1990). Mishra and Hota (1991) have opined that reclamation of mined areas having slope more than 14 degrees is rarely successful.

Formation of benches or terraces is a common method to reduce runoff and soil erosion. Terracing reduces the slope length and creates new base portion farther upslope. Armiger et al. (1976) are of the views that increase in the rate of infiltration, absorption of soil water by root, dry matter yield per unit water used, and decrease in rate of runoff, evaporation, and leaching of soil water depend on conservation and efficient use of limited precipitation.

2.1.4 Toxicity of the mine spoils

Extensive work on the mine spoils in Northern Great Plains has indicated that these materials are characteristically neutral to alkaline in pH, contain soluble salts with
sulphates of Ca, Mg and Na predominating, and appreciable amounts of CaCO$_3$ with very few readily soluble chlorides, carbonates or bicarbonate (Power et al., 1978a). Toxicity problems, usually associated with acidity, nutrient deficiency and physical conditions, have been reported by Rimmer (1982) in reclaimed mine sites in northern England. Mine spoils may also increase the amount of trace elements at surface of the spoil to potentially hazardous levels. Water soluble B, Cu, Fe, Li, Ni, Sr and Zn contents were greater in mine spoils compared to unmined sites in North Dakota (Wali and Freeman, 1973). Infiltration and storage of water in a soil is affected by exchangeable Na. Sodium adsorption ratio (SAR) values above 12 influence stability and dispersion of clay minerals, surface sealing, restriction in water infiltration, and increased rate of runoff. Thus, less water is stored in the soil for the vegetation use (Power et al., 1978a). According to Merrill et al. (1985), the low hydraulic conductivity of sodic mine spoil (SAR=30) was the dominant factor limiting plant growth. Sandoval and Gould (1978) reported that spoils of North Dakota and New Mexico had high exchangeable Na contents that resulted in deterioration of soil structure, reduced infiltration and greater crusting. Availability of water for plant growth is reduced by salinity (total dissolved salts) of mine spoils. More energy is required to extract water from saline soil which results in less growth per unit of water used. In sodic spoil, gypsum is used to replace Na on the cation exchange complex. Power et al. (1978a) reported that gypsum additions reduced exchangeable Na content by 30-50 per cent in the upper 30 cm of spoil within a few years.

Acidity in mine soils arises from two primary sources. Some spoils are inherently low in bases that are rapidly leached in humid environments and other spoils contain pyrites that oxidize and frequently lower mine soil pH values to < 4 (Roberts et al., 1988). Due to biochemical oxidation of pyrites, the pH values may decrease from 8.0 to 2.0 within 10 years, which is an important factor for plant growth in several mine spoils (Chadwick, 1973; Doubleday, 1974; Caruccio, 1975; Armiger et al., 1976; Bennett et al., 1976). Acidic spoils contain toxic levels of soluble elements such as Fe, Al, Mn and Cu, and inadequate supply of Mg, Ca and P; and seedling establishment in these spoils is difficult because of the lack of active organic matter (Jha and Singh, 1992a). Costigan et al., 1981 reported that dieback of well-established vegetation may result from
continued acidification for many years. After a study of active surface mines in Wyoming, Montana and North Dakota, Barth and Martin (1984) were of the view that acidic spoil was the most difficult to revegetate, while in the sodic spoil Na migrated subsequently into the replaced topsoil up to a depth of 14 cm in sodic spoil.

An exceptionally high concentration of total B (boron) was reported in limestone mine spoils (Sharma et al., 2000). Chemical analysis of the tin mine tailings indicated that deficiencies of P, K, Ca, Mg, S and trace elements, together with aluminate toxicity associated with high pH, might be responsible for the paucity of natural colonization (Phia et al., 1995).

The ecologically elegant solution for reclamation is to use metal tolerant plants and to supply fertilizers (Smith and Bradshaw, 1979). However, nutrient cycling is so much reduced by the heavy metal toxicity that growth is limited unless repeated fertilizer applications are given (McNeilly et al., 1984). Hence, Bradshaw (1987) is of the view that in case of metal contaminated sites, the nature of the toxicity is such that direct treatment is not completely satisfactory and for successful restoration, vegetation colonizing natural, undisturbed metal-contaminated areas is indicative. Strong negative relationship between tree growth and high concentration of magnesium has been drawn by Richardson and Evans (1987) and Bending and Moffat (1999). In manganese mine spoils in Central India, Juwarkar et al. (2001) informed that spoils had pH in the range of 6.9–7.4 with low soluble salts, N, P, K and organic carbon content (0.104–0.108%). Although, heavy metals like Cr, Pb, Cu, Mn and Zn were present, however, they were not of serious concern. In a study of a coalfield mine spoil in Jharkhand, India, Maiti et al. (2005) also found that acidic nature of mine spoil increases bioavailability of trace elements (micronutrients) but it is not going to cause any toxicity problem for the plants, except zinc. The average concentration of bioavailable zinc in the range of 5.8 to 6.2 mg/kg may cause toxicity problems. In four coalmine sites in Jharkhand, Prasad and Roy (2001) found that metals at high level in spoils could be toxic to plants and among them Ni, Mn, Zn and Cu are prominent. A decrease in total chlorophyll content was reported, in agreement with other similar findings, from various plant species grown on metal enriched soil from all over the world. The physico-chemical properties of the
metal-contaminated mine spoils tend to inhibit soil-forming processes and plant growth. Other adverse factors of mine spoil are absence of top-soil, absence of soil forming fine materials, shortage of essential nutrients, etc. (Wong, 2003).

However, in an experiment on evaluation of coal mine spoil as a medium for plant growth, Jha (1992) found that mine spoils were non-toxic and suitable, although sub-optimal medium, for plant growth.

### 2.2 CHANGES AFTER REVEGETATION OF MINE SPOIL

#### 2.2.1 Plant Succession

Plant succession following drastic disturbance due to mining is a subject of both practical and ecological interest. The classical view of ecological succession is that, following a disturbance, several assemblages of species progressively occupy site, each giving way to its successor until the community that is able to reproduce itself indefinitely finally develops. Egler (1954) termed this classical view of succession “relay floristic”. Hobbs and Legg (1983) concluded that in many situations it is the “initial floristic composition” (IFC) following disturbance that determines future shifts in dominance. In this type of community succession, the overall pattern of development of the stand will be introduced by the species composition that first establishes, and subsequent developments are merely changes in the relative abundance of species.

Succession can be defined as a “directional change in the composition, relative abundance and spatial pattern of species comprising communities” (Frankland, 1998). Succession is initiated by natural or human disturbances, where, over successional stages, nutrient resources are improved by the early successional organisms for the later colonizers in the later stage of succession (Connell and Slatyer, 1977). Surface mining so alters physical and chemical properties of soil that process of natural recovery of un-amended spoil is very slow (Marrs et al., 1981; Roberts et al., 1981). Understanding of various ecological parameters is fruitful when we can put them together in a post-mining scenario and make them work (Bradshaw, 1983). Information on the mechanism and course of natural re-vegetation is of profound assistance in planning a speedy
recovery of the land. If it is possible to accelerate the process of natural succession, a self sustaining ecosystem may develop in a short period.

In natural ecosystem development, species invade slowly and can take advantage of the developing environment produced by physical and chemical changes that occur during primary succession (Bradshaw, 1987). Wali and Freeman (1973) pointed out that an adequate understanding of natural re-vegetation processes should be included in all rehabilitation efforts without which no desired plant cover will be possible. Bradshaw (1983) reported that natural processes or ecosystem development on derelict lands are slow and stochastic; and that the ecosystem development on such lands is partly allogenic and partly autogenic. Thompson et al. (1984) argued that natural plant invasion and succession can be important part of the vegetation development of disturbed sites. Pickett (1997) has pointed out that the structure, function or composition, and for that reason the rate of nutrient cycling in an ecosystem, may change as a result of renewed succession during or in the aftermath of mining. Burger and Zipper (2002), during the course of coal mine restoration in Appalachian mixed-hardwood forests of South-West Virginia, have opined that after mining and reclamation, given several hundreds of years, the area will be restored of its complex forest with original structure and functions. Fierro et al. (1999) are also of the same view concluding that in the limiting conditions prevailing on the mine derelict lands, the succession will be autogenic which is more time consuming rather than allogenic. While making a quantitative analysis of the vegetation on the un-reclaimed coal strip mines in Oklahoma, Gibson et al. (1985) have revealed that species composition is largely a function of dispersal efficiency of the potential colonizing species, the location of individual sites, the natural distribution of native species and substratum condition. Austin (1971) also has shown that absence of a species at a particular site is not merely the intolerance of species to the environmental condition, but also its inability to reach the site due to dispersal inefficiency. Similar observations that mine spoil is typically colonized by plants adapted to long distance, or efficient seed dispersal have been made previously also on re-vegetating lead and zinc mine spoil in Pennsylvania (Bramble and Ashley, 1955), New Mexico (Wagner et al., 1978) and Great Britain (Brierly, 1956; Hall, 1957). Leisman (1957) has emphasized the importance of surrounding vegetation
and dissemination efficiency of propagules on spoil banks. Distance to seed source was the best predictor of tree recruitment on the reclaimed mine surfaces in Central Florida (McClanahan, 1986). A study conducted by Hiremath (1996) in Bicholin area of Goa, India revealed that floral abundance of iron ore dumps show natural re-colonization by flora from the adjoining disturbed area. They were mostly annuals and their density was found to increase with the age of the dumps. The species diversity on the dumps was more than undisturbed sites during monsoon because of invasion of barren land by different species and lack of competition. Rosiere et al. (1989) reported natural revegetation of abandoned quarries by native species with or without reclamation (i.e. succession occurs regardless of treatment and ends with climax vegetation).

Picket (1997) believes that the probable keys for restoration of profoundly disturbed mine sites lie in fluxes and influences exerted by adjacent undisturbed and moderately disturbed forest patches, because these are the potential sources for dispersal of seeds and other propagules to the fresh colonization areas after mining. Arnold and Gulumian (1984) observed that reclamation success depends on biological activity of the surface horizons in the long-term. Marrs et al. (1981) pointed out that studies in the developing ecosystems may indicate the nutrient concentrations which have to be reached in order to achieve a specific vegetation end-point in reclamation schemes. According to Fresquez and Lindemann (1982), available carbon source is a critical factor to stimulate spoil microflora in mine spoils. Skeffington and Bradshaw (1981) felt that a large pool of organic N and a high rate of ammonification were necessary to sustain vegetation and to prevent N immobilization. Woodmansee et al. (1980) estimated that it may take up to 2160 years of natural succession on overburden for N pool to grow large enough to support a stable self-sustaining plant-soil system.

The process of restoration actually involves setting the system on a new developmental trajectory towards its particular ‘target’, i.e., its former state. Many times the product will not be an exact replica of the former system, but rather will represent major change in trajectory towards the target. Many researchers found that it may be possible to produce restored ecosystems of high ecological quality on a larger scale because, a larger site has a more complete functional infrastructure, and can support
more species. It is believed that with a more complete understanding of the natural colonization of plants on mine waste, it should be possible to achieve restoration of visually acceptable, biodiverse and self-sustaining ecosystem quickly and cheaply by accelerating the natural succession process (Bradshaw, 1992, 1997; Dobson et al., 1997).

Post-disturbance succession in the un-mined jarrah forest is believed to conform more closely to the initial floristic composition model (Bell et al., 1989) than to the classical relay floristics model. In this model the composition of the vegetation in the first few years after disturbance controls the long-term floristics and functioning of the ecosystem. The similarity of restored sites to intact forest sites did not increase over 13 years. Sites restored in 2001 showed higher Bray-Curtis similarities to intact forest sites, which reflect changes in restoration practices designed to better represent the species composition and proportions of the intact forest flora. Due to disturbance of mining, restored sites have higher densities and species richness of re-seeder species and ephemerals, and lower densities and species richness of resprouter species than intact forest (Koch, 2007b). Raizada and Samra (2000) reported that two perennial grass species, viz. *Thysaloena maxima* and *Saccharum spontaneum* had high IVI values indicating clearly that site condition in top and upper middle reaches of the topography were conducive for their survival and niche occupation. Shade loving species, viz. *Murraya koeningii*, *Eupatorium odoratum* and *Woodfordia fruticosa* were found in the middle reaches of the topography. Dominance diversity curve of the rehabilitated area indicates that out of the total 31 species recorded; only eight species had IVI values in excess of 10, the remaining species showing a very poor distribution. In the rehabilitated area, while species richness of trees and shrubs were similar, richness of grasses was poorer, but their dominance was highest. The higher diversity of the shrub component in the rehabilitated area was primarily due to the open canopy, causing greater light to reach the substratum and encourage development of a prominent understory cover below the scattered tree. It is now well established that species diversity first increases as an ecosystem develops, but declines with maturity. The occurrence of leguminous species like *Acacia catechu* and *Leucaena leucocephala* in the rehabilitated area may, over time, result in improved surface soil layers that may
possibly permit the successful migration of late colonizers in the rehabilitated area, though this would take several decades (Ibid., 2000). The absence of many species in the reclaimed sites that were found in the hardwood sites is certainly due in large part to the stressful environmental conditions and the poor dispersal abilities of a number of native herbaceous species. Failure of establishment of some species found in the hardwood forest may also be due to the lack of canopy cover in these reclaimed sites, though the canopy is beginning to close in the oldest reclaimed sites. Finally, it is difficult for many native species to compete with the non-native species used for reclamation (Holl and Cairns, 1994).

Raizada and Samra (2000) reported that normal associate species of *Shorea robusta* had a very poor distribution in the rehabilitated area indicating that site edaphic conditions are not conducive enough to support seedling survival of these hardy species, and perennial grass species were quite aggressive in the area. Veeranjaneyulu and Dhanaraju (1990) recorded a total number of 81 plant species, belonging to 71 genera of 31 angiosperm families on copper ore deposits of Nallakonda Copper Mine, Andhra Pradesh. Among the families, Leguminosae showed the highest number of species with 9 genera. In monocots highest number of genera and species was observed in the family Poaceae. Four species, *Chrysopogon fulvus*, *Aristida adscensionis*, *Carissa spinarum* and *Cissus quadrangularis* have the highest percentage of presence values on copper ore deposits. High percentage of presence appears to be due to the narrowly specialized adaptation of these species to high metal content of the habitat. Out of these four species, *Chrysopogon fulvus* and *Carissa spinarum* have the highest frequency values.

2.2.2 Species composition

The accumulation of soil organic carbon and nitrogen to a critical level is a vital prerequisite for subsequent colonization of the site by suitable plants (Singh et al., 2006). Few studies have investigated successional processes in areas returning towards native forest ecosystems after mining. Johnson et al. (1994) have observed that major emphasis has been in investigating techniques for ameliorating waste materials to allow immediate establishment of a vegetation cover, whereas little attention has been paid to
the processes of soil development and natural recruitment in these new and disturbed environments. Nichols and Michaelsen (1986) have opined that species richness and diversity are inadequate measures of biological successional processes. Rather Sorensen’s similarity indices compare the species composition of plant communities in two habitats.

Factors controlling vegetation development on mine spoils are microclimate, spoil properties, surrounding flora, nutrient-holding capacity (Russell and La Roi, 1986); and dissemination efficiency of propagules (Gibson et al., 1985; Leisman, 1957). The substrate conditions on individual mine sites act as environmental sieve (Harper and White, 1970; Hulst, 1978). Davidson et al. (2004) also found that the availability of higher concentrations of N in course of ecological succession promotes an increase in the number of tree species.

In a survey of 6-17 years old coal mined sites in New Mexico, Wagner et al. (1978) demonstrated that those sites tended to be dominated by pioneer annuals and short-lived taxa. Comparisons have been made of species richness, diversity, equitability, similarity and litter cover values between bauxite mined areas and un-mined forest areas (Glossop, 1980; Tacey and Glossop, 1980). McMahon (1981) found that no mined areas were very similar to the forest site in terms of species richness, and pointed out that natural succession in a disturbed forest is a very slow process. Most suited species are able to establish and become an important component of the community. Brierley (1956), Wali and Freeman (1973), Alverez et al. (1974), Glenn–Lewin (1979), Jonescu (1979), Russell (1985) and Prasad and Pandey (1985) have reported the prevalence of Asteraceae, Poaceae and Fabaceae on mine spoils. Croxton (1928), Bramble and Ashley (1955), Schramm (1966) and Schuster and Hutnik (1987) noted that spoil characteristics affect the rate and composition of community development. Sindelar (1979) reported an increase in species diversity with increase in age in seeded coal mine spoils at Colstrip, Montana. Tryon and Markus (1953) found that forest composition on 70-to 100- yr- old iron ore mine spoils in West Virginia was similar to adjacent un-mined areas.
Gibson *et al.* (1985) studied species composition of 49 reclaimed coal strip mines ranging in age from 10 to 70 years. They reported that structural characteristics of the vegetation were similar to mature upland forests on the older and favourable sites. As many as 80 per cent of the tree species of the upland forests and 50 per cent of the floodplain forest were found on average Oklahoma mine spoils by Johnson *et al.* (1982).

Species richness increased and equitability declined with age from 5-yr-old to 16-yr-old community with an increase in the 20-yr-old community in Singrauli coalfield, India (Jha and Singh, 1990a). The age pattern of species diversity was similar to that of evenness of species. Evidently evenness has a greater influence on species diversity than species richness. In contrast to species diversity and evenness of species, concentration of dominance increased up to 16 years of age and then declined in the 20-yr-old community (*Ibid*, 1990a). Several workers, on the other hand, have reported a consistent increase in species diversity during succession (Odum, 1960, 1969; Tagawa, 1964; Margalef, 1963; Monk, 1967; Reiners *et al.*, 1971).

Iverson and Wali (1982) observed an increase in species richness with age in reclaimed coalsmine spoils in western North Dakota. In coal mine spoil in Alberta, Canada, Russell and La Roi (1986) noted higher species richness on fine-textured spoil than on coarse-textured spoils. They found low plant cover (usually < 10 per cent) in rocky coal mine spoils. The species richness increased substantially in finer textured spoils with higher water and nutrient-holding capacities. Plant species of later successional stages are found from the beginning on mine spoils but they only grow rapidly after soil development, in terms of nitrogen accumulation, has occurred (Leisman, 1957; Bradshaw, 1983).

Jha and Singh (1992b) studied change in species composition with time on mine spoils of Singrauli coal fields, India. *Aristida adscensionis*, which is adapted to grow in stressed habitats, was the most predominant species as it was the dominant or the co-dominant species in 7 out of 9 communities recognized (Jha, 1990). *Bothriochloa pertusa*, a species of high successional order growing naturally under better soil conditions, participated in the community formation on mine spoils with *A.*
adscensionis, which is a major species of degraded grasslands. This indicated the possibility of revegetating the mine spoils with desirable species of higher successional order. Singh et al. (2001), in a study of limestone mine-spoil after agro forestry interventions in Mussoorie hills, found that after establishment of planted species, invasion of other native species started. After seven years of succession, twenty seven plant species (five tree species, nine shrub species and thirteen herbs and grasses species) were recorded.

On a 10-year-old coal mine spoil, 97 wild species from 67 genera and 21 families, mostly Compositeae and grasses, successfully invaded the reclaimed area (Li, 2006). Natural colonisation of plants on the five lead/zinc tailings studied by Shu et al., 2005 was slow. Of 54 species belonging to 51 genera colonizing five lead/zinc mine tailings, 13 dominant species belonged to the Gramineae and 10 to the Asteraceae (Compositeae). Legume and non-legume nitrogen fixation have been identified as the critical components of the process of soil and vegetation development (Roberts et al., 1981). O’Neill et al. (1998) reported leguminous species, Trifolium repens, Vicia sepium, and Lotus pendunculatus, with Trifolium repens the most common, on pyrite tailings in Ireland, 8 years after rehabilitation. Mars et al. (1980) reported low species diversity even after several years of succession. Poor abundance and density with sparsely scattered plants were reported by Game et al. (1982). In some spoils, even no vegetation development occurred (Glen-Lewin, 1979; Wali and Freeman, 1973). Norman et al. (2006) found that species with good dispersal mechanisms are usually exotic or have weed-like behavior, both of which are undesirable as dominant life forms on a rehabilitated site.

Prakasam and Banerjee (2001), from Malanjkhand copper mine spoils (Madhya Pradesh, India) reported that Poaceae was the largest family followed by Fabaceae and Asteraceae. Presence of Poaceae family was a good sign as they improve the soil nutrient status of the sites by fixing atmospheric nitrogen. Shrubs like Casia tora, Colotropis procera and Woodfordia fruticosa were present in almost all the dump sites of this copper mine. Achyranthes aspera, Alternanthera ficoides, Celosia argentea, Calotropis procera, Crotalaria prostrata, Cynodon doctylon, Desmodium triflorum,
Emilia sanchifolia, Evolvulus nummularius, Saccharum spontaneum and Tridax procumbens were present on all the spoil sites. The late colonizing species were Ageratum conyzoides, Ampelocissus latifolia, Cassia pumila, Chrysopogon fulvus, Crotalaria calycina, Digitaria ciliaris, Dioscorea bulbifera, Hyptis suaveolens, Olax scandens, Sida cordata, Sida acuta, Phyllanthus urinaria and Setaria pumila. They observed that only four species, viz. Celosia argentia, Crotalaria prostrata, Tridax procumbens and Saccharum spontanum participated in community development as dominants or co-dominants. Out of the above four species, Tridax procumbens and S. spontanum are very common in coal-, iron-, limestone-, and manganese-mine overburderns of Madhya Pradesh and Chhattisgarh. But, the other two species were identified only in the copper mined areas and in the forest area just adjacent to copper mines. Hence, they concluded that Celosia argentia and Crotalaria prostrata may be considered as the indicator species for copper mined areas.

2.3 POSSIBLE INTERVENTIONS

2.3.1 Topsoil replacement

Soil disturbed by the surface mining are highly susceptible to erosion and difficult to stabilize by vegetation. For restoring the productivity, and for protection of soil and water resources, many authors have advocated covering the spoil with topsoil of variable depth. In opencast mining, it is accepted that removal, storage and replacement of the original topsoil is essential to the restoration process (Dickie et al., 1988). Topsoil replacement is a common method in enhancing physical and nutrient status of spoils in Northern Great Plains. Several soil properties, e.g., water holding capacity, nutrient supplying capability, buffering capacity, and plant root depth are affected by the thickness of the respread A and B horizon materials. These factors affect plant growth, plant composition and nutritional quality of the vegetation (Jha and Singh, 1992a). Topsoil, particularly fresh topsoil, is the major contributor to plant diversity on rehabilitated bauxite mines. The majority of the plant species (72%) on rehabilitated areas came from seed stored in the topsoil. Many of these topsoil species are smaller understory or annual species. Nevertheless, they are an important part of the jarrah
forest ecosystem, so rehabilitation procedures must be developed to maximize their establishment (Ward et al., 1996).

In progressive mining operations, it is becoming mandatory for surface soils to be conserved and replaced. In the restoration of small, existing degraded areas, the use of layer of topsoil to cover up whatever is wrong beneath is common (Bradshaw, 1987). Parrotta and Knowles (2001), from bauxite mined areas of Brazil, reported that tree basal area, canopy height and crown cover percentages were significantly lower in the mixed native species treatment plots with inadequate topsoil application than in plots in which the prescribed site preparation protocols were followed. In the former plots, rates of litter accumulation and humus development were relatively poor and individuals more than 2 m tall were relatively absent.

Soil handling, stockpiling, and soil mixing can impact on nutrients, biology and organic matter contained in the soil. The concentrations of many nutrients in the forest are greatest in the surface soil and may decrease rapidly with depth. Restoration operations can cause these nutrient rich upper layers of soil to become diluted with soil from deeper in the profile (Ward, 2000; Grant et al., 2007).

Torbert et al. (1988) found a significant relationship between EC and finely textured soils derived from shales and siltstones, with EC increasing with finely textured shales. To minimize adverse effects of EC, they recommended placing coarse-textured, sandstone on the surface instead of finely textured, reduced overburden. Their field descriptions also showed that the finely textured C horizons had the highest EC. Soluble salt concentrations > 1000 to 300 µS cm\(^{-1}\) were found to be detrimental to plant growth, reducing tree survival and crop yields (McFee et al., 1981).

Carlson et al. (1961) have suggested that P concentration in several crops could be enhanced by returning topsoil or adding manure. Power et al. (1982) have evaluated the effect upon various parameters of crop quality after four years of topsoil and subsoil replacement. Higher plant P concentration was reported where spoil was covered with 20 or 60 cm thick topsoil layer. Gilley et al. (1977) have reported greater runoff and erosion when the smoothed spoils had steep slopes. When such a steep slope (9-10 per
cent) was covered with 25 cm topsoil without revegetation the soil loss (36 t ha\(^{-1}\)) was greater compared to uncovered spoil (7.8 t ha\(^{-1}\)). Thus the replaced topsoil would be quickly eroded from steep slopes in absence of vegetation. Power et al. (1978b) found that addition of straw reduced the erosion and runoff from the respread topsoil.

From a modeling exercise, Parton et al. (1979) indicated that increasing the topsoil depth from 5 cm to 60 cm increased plant production by 20 to 28 per cent as a result of increased N uptake. Application of N fertilizer caused a six fold increase in primary production and when combined with irrigation the production increased by 100 per cent compared to fertilization alone.

A study of coalmine overburdens in India reveals that stockpiling of soil material has been found to degrade soil quality continually. Topsoil should be removed in a separate layer and stockpiled only when it is not feasible to promptly redistribute on degraded areas. The stockpiled materials should be selectively placed on a suitable area and protected from erosion, compactness and contaminants which will lesser the capability of materials to support vegetation. The dumps height and slope should be maintained properly (Ghose and Kundu, 2001). Other researchers (Moffat and Boswell, 1997; Bending and Moffat, 1999) have also suggested for careful spoil and soil placement in order to prevent compaction during post-mining landform design. Bradshaw (1987) has also opined that it is commonly found that the performances (measured as yield) of ecosystem reconstructed on topsoil are inadequate. Experimentation shows that soil used is unable to sustain vigorous growth unless supplied with extra nitrogen (Bloomfield et al., 1981). This can be due either to deterioration of the soil during storage between gathering and respreading, or to excessive amount of sub-soil being included in ‘topsoil’. Sandoval and Gould (1978) and Merrill et al. (1980a; 1983), have reported that since in some spoils sodium moves upwards into topsoil from the spoil causing a decrease in plant yield in later years, a small layer of topsoil replacement cannot maintain the productivity for long. Doll et al. (1984) have suggested more exacting guidelines for soil replacement based upon spoil properties such as texture, electrical conductivity and sodium adsorption ratio. Careful site preparation practices, particularly judicious topsoil handling and re-application
prior to tree planting, are essential for the establishment of forest cover, elimination of competing grasses, and acceleration of natural forest succession on reclaimed bauxite mine sites in Amazonia (Parrotta and Knowles, 2001). It is reported that the soil seed bank of the stored topsoil can be maintained throughout the store, so long as the storage period is no longer than a few months (Dickie et al., 1988).

2.3.2 Chemical amendments and fertilization

The sodic and acidic spoils may require chemical amendments in order to speed up the process of rehabilitation and to reduce the cost associated with topsoil replacement. To reach a productively level equivalent to the pre-mining forest, an input of nutrients to the system is required (Ward and Koch, 1996; Ward, 2000).

Bradshaw (1983), Kendle and Bradshaw (1992), Moffat and Buckley (1995) and Bending and Moffat (1999) have suggested that without inorganic or organic nitrogen amendment, reclamation of coal spoils to forestry is unrealistic. Merrill et al. (1980b) reported that for the sodic spoils of Northern Great Plains the three requirements associated with chemical reclamation are: (i) Ca or Mg salt, (ii) sufficient water to transport the Ca-ions to the cation exchange sites to displace the Na-ions, and (iii) sufficient hydraulic conductivity so that Na-ions are transported out of the root zone. Power et al. (1978a) have reported that under the climate prevailing in most mine areas of Northern Great Plains, gypsum additions reduce exchangeable Na content by 30-50 per cent in the upper 30 cm of material within a few years after treatment.

The need for nutrient additions, when ecosystems are being reconstructed on skeletal material, is obvious. Ecosystems, even in a juvenile condition, do need considerable amounts of nutrients for growth, and these substances are likely to be limiting in most of the skeletal materials found on severely degraded land. It is easy to provide the necessary nutrients by means of ordinary agricultural fertilizers containing nitrogen, phosphorus and potassium. Practical experience shows that these nutrients must be provided repeatedly or growth is substantially reduced (Bradshaw, 1987). Mine overburdens may be excellent materials for plant growth provided that the deficiencies in organic matter and nitrogen can be remedied (Das et al., 1992).
Application of fertilizer has proven highly successful in replacing nutrient pools lost through the mining and restoration process, particularly P (Ward, 2000; Grant et al., 2007). Day et al. (1979) observed in growth chamber experiments that even with adequate irrigation but without proper fertilization, plant growth in spoils and top soil materials was extremely poor. Jha (1992) found significant difference in shoot growth for NPK treated plants compared to those grown in mine spoil only and in mine spoil with forest soil. Singh et al. (2000a), from a fertilizer treatment experiment in Singrauli Coalfields, India, found that NPK fertilization of mine spoils with seeded ground cover promotes growth, particularly in non-leguminous woody species, consequently leading to potentially increased biomass production. The response of tree species to nutrient amendment is variable, however. The impact of fertilization in most species was more on diameter growth than on height growth.

Norman et al. (2006) concluded that fertilizing sites with N is beneficial for increasing growth and establishment in newly rehabilitated sites, but there appears to be no long-term floristic benefits over unfertilized sites. Despite this, fertilizer application is considered a necessary component of the rehabilitation process to increase nutrient stores and encourage nutrient cycling. Although, in the short term, fertilizers can be applied to restored areas, in the long term the demand for nutrients must be met principally from nutrient cycling supplemented by inputs in rain fall, dry deposition, rock weathering, and for nitrogen, by biological fixation of atmospheric N (Grant et al., 2007). Koch (2007a) reported use of diammonium phosphate with potassium and micronutrients at the rate of 280 kg/ha to newly restored areas for restoration of bauxite mined areas of South Western Australia.

Singh et al. (1996a) studied the effectiveness of amendments on growth of P. dulce in coal mine overburden. Singh (2004) studied the influence of NPK fertilization on N and P resorption efficiency in nine native tropical tree species planted on coal mine spoil. Of these, Acacia catechu, Albizia lebbeck, Dalbergia sissoo and Pongamia pinnata were legumes, while Azadirachta indica, Gmelina arborea, Phyllanthus emblica, Tectona grandis and Terminalia bellirica were nonlegumes. The N and P resorption efficiencies dropped in fertilized plots in all the species. Nonleguminous tree
species had exhibited greater efficiency for N resorption than leguminous species. The study indicated that nutrient enrichment reduced internal cycling of nutrients thus facilitating greater amount of nutrient return to soil, which in turn would enhance the reclamation process by allowing the colonization of more species due to increased habitat fertility. For the ten tropical tree species, Singh and Singh (2001) and Singh and Singh (2006) reported that the impact of fertilization was comparatively more on non-leguminous tree species than on the leguminous tree species. Nitrogen-fixing species may overcome the nitrogen deficiency by virtue of their nitrogen fixing ability; hence they may remain unaffected by N fertilization but may respond to P fertilization (Singh et al., 2000a; Singh and Singh, 2001). The impact of fertilization in most species was more on diameter growth than on height growth (Singh et al., 2000a).

2.3.3 Seedbank, seeding and planting

Seed and propagule dissemination plays a key role in community dynamics during plant succession (Noble and Slatyer, 1980). Forest topsoil, which contains seedbank, has been used to revegetate disturbed lands (Johnson and Bradshaw, 1979; Tacey and Glossop, 1980). The effect of seed size on depth of burial and subsequent emergence has been well documented in the literature. Generally, the larger the seed the greater will be the seedling’s capacity to emerge from deeper locations in the soil (Grant et al., 1996). The extent to which one can rely on seed-bank germination (from applied topsoil) to establish species-rich forest cover is largely unknown, although studies of forest succession following natural disturbances and agricultural abandonment can provide some guidance and generally suggest that early successional tree species, need not be planted due to their abundance in the soil seed-bank and adaptability to degraded site conditions (Parrotta and Knowles, 1999). Hodder (1977) has reported that the top 5 cm soil layer contains sufficient number of seeds to revegetate the areas beyond their original densities, though the type of vegetation may be altered because most of the seedlings emerging from the seedbank may be of pioneer species. Many viable seeds and propagules from a large number of species were present in forest topsoil associated with surface mining in Tennessee and practically all plants emerging from these propagules survived on typical mine soils and were well established by the end of one
growing season (Farmer et al., 1982). In topsoil stored for several years, than months, the overall viable seed population will be significantly reduced except near the surface of the store. In addition, the longer the stores remain, the more will the surface be subjected to invasion by widely dispersed and undesirable ruderal and weed species. These will then add their seeds to the bank unless they are effectively controlled. Sole reliance on buried viable seed from redistributed topsoil would not guarantee rapid establishment of closed vegetation, with further opportunities for undesirable species to enter the consequent gaps. There may be a reduction in total number of viable seeds, and any potential for a reduced diversity would be unwelcome in a conservation context (Dickie et al., 1988). However, contrary to the above findings, from a coalmine in USA, Johnson and West (1989) reported that the greatest number of seeds occurred in the oldest topsoil stockpiles. Inversion of soil layers during soil handling processes cause a reduction in seed numbers and seeds of most prevalent colonizers after reclamation were not present in top soil, rather they emigrated from surrounding areas (Iverson and Wali, 1982). Positive response of the role of soil seed bank in natural restoration of degraded areas has been reported by Liu et al. (2009) also.

The topsoil in areas of the jarrah forest mined for bauxite commonly contains about two-thirds gravel by weight (Ward, 2000). Approximately 90% of seeds in topsoil pass through a 5-mm screen (Murphy and Loneragan, 2000). Study by Koch and Ward (1994) indicated that 77% of species found in rehabilitated pits germinate from seed of the topsoil rather than from the applied seed, indicating the importance of topsoil in any site rehabilitation. However, the efficiency of use of seed in the topsoil for bauxite mine rehabilitation appears to be low. The highest efficiency of establishment of seedling from topsoil stored seed appears to be about 2%. The loss of seed was attributed to a number of factors, including physical damage during soil handling procedures, loss of seed while soil is stockpiled, dilution of seed when soil is respread, and burial of seed at a depth too deep for emergence (Grant et al., 1996).

Top-soil can be collected, the gravel sieved out, and the remaining much smaller volume of seed-rich source can be re-spread on post-mine areas. Spreading a thin layer of this seed-rich soil after ripping ensures that very little of the seed is buried too deeply
to germinate. If the soil is collected and sieved in summer, when seed stores are highest, the effectiveness of this seed store is maximized (Koch, 2007a). Study by Koch et al. (1996) indicated that there were large reserves of seeds in the soils of jarrah forest, but substantial losses of seed can occur during soil handling activities, particularly if the soil is stockpiled. For effective use of these seeds, they recommended to respread topsoil to a lesser depth than it was collected from.

Seeding or planting of suitable species speeds up succession that fulfils the revegetation goal (Jha and Singh, 1992a).

Sindelar (1979) reported that seeded species, initial seeding success, cultural practice, and weather influence plant succession on mine spoils. Davidson (1980) favoured direct seeding for revegetating surface mine spoils because this is easier and cost-effective than spot-seeding or drilling. In Northern Great Plains, seeding of native grasses yielded favourable results (Ries et al., 1978; Ries and DePuit, 1984). Barth (1986) recommended sod-forming grasses for surface protection and erosion control in mine spoil. Direct seeding of trees into more normal site is a promising approach (Zarger et al., 1973; Luke et al., 1982) but careful attention is essential.

Wittwer et al. (1981), Creighton et al. (1983) and Cunningham and Wittwer (1984) found that direct spot-seeding at a proper rate is a better and cost-effective method of revegetation for oaks, pine black walnut and black locust, compared to planting of bare-root seeding on mine spoils. Direct seeding results in a more complete occupation of the site. Seeding through drilling or broadcast with judicious inputs of N and P and proper timing with, respect to rainfall regime and temperature conditions has proved successful for establishment for mono- and mixed stands of grasses and legumes (Ries and DePuit, 1984). Initially seeded rehabilitated sites had higher native species richness than unseeded rehabilitated sites. The unseeded treatment achieved species richness values equivalent to those of the seeded treatments at 8 and 14 years of age, but still had lower diversity and lower evenness. This is undesirable because although the same number of species may be present, the vegetation community is dominated by large number of individuals of a few species. Although there was no effect of the different seed mixture on exotic species density in 1-year-old rehabilitated site,
unseeded sites had significantly higher exotic species density and richness than seeded sites at 5 and 8 years of age, respectively (Norman et al., 2006). Rehabilitated sites had higher exotic species richness, density and cover than forest sites (Ross et al., 2004; Norman et al., 2006).

Floristic enrichment of the reforestation areas through natural regeneration of 'colonizing' tree species (i.e. those not planted or present in the applied soil seed bank) is largely dependent on seed-dispersing wildlife, mainly bats, birds and terrestrial mammals. The conservation status of the surrounding old-growth forest and an effective ban on hunting greatly facilitated this process. Restoration managers need to be cognizant of the critical role of wildlife in forest re-development, actively encourage wildlife conservation in the surrounding landscape, and design restoration treatments that will provide suitable habitats for a variety of target wildlife species (Parrotta and Knowles, 2001).

Natural restoration of mine spoil is a slow process. Numerous studies have demonstrated that land rehabilitation benefits from plantations because it acts as a catalyst to succession. The catalytic effects of plantations are due to changes in understory microclimatic conditions (increased soil moisture, reduced temperature, etc.), increased vegetational-structured complexity, and development of litter and humus layers that occur during the early years of plantation growth. Artificial revegetation is often used to facilitate the generally slow natural rehabilitation process (Bradshaw, 1983). Artificial seeding of grasses and legumes or both has been a commonly used method to stabilize unconsolidated mine tailings and to encourage natural invasion of tree and shrub seedling. This ultimately improves site fertility and moisture retention capacity. Once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use has begun and offsite damages are minimized. In addition, establishment of the vegetation on an abandoned mine land also improves the aesthetics of the area (Singh et al., 2002).

Forest plantations are commonly used to ameliorate harsh mineland soil and microclimatic conditions and speed establishment of native temperate and tropical vegetation. Plantings of native forest species combined with topsoil recovery and
careful site preparation has been shown to reduce soil compaction, promote mycorrhizal symbiosis, and facilitate colonization of a species-rich forest community on Amazonian bauxite mines (Parrotta et al. 1997b; Parrotta and Knowles 1999). Throughout the tropics, forest plantings containing either native or non-native species have been promoted as “foster ecosystems” that can modulate microclimatic extremes and improve soil nutrient availability.

Plantations have an important role in protecting the soil surface from erosion and allowing the accumulation of fine particles. They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter, lower soil bulk density, moderate soil pH and bring mineral nutrients to the surface and accumulate them in available from (Chakraborty and Chakraborty, 1989). Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients and re-deposit them on the soil surface in organic matter, from which nutrients are much more readily available by microbial breakdown (Singh et al., 2002).

The development of a plantation canopy can alter the under story microclimate and soil's physical and chemical environment to facilitate recruitment, survival and growth of native forest species. Otherwise, native species would only very slowly, if ever, regenerate on degraded site. Thus, plantations may act as ‘foster ecosystems’, accelerating development of genetic and biochemical diversity on degraded site (Singh et al., 2002). However, for reclamation works, proper selection of the species that will adapt with the climatic and local soil condition is a critical step (Maiti et al., 2006).

Afforestation of mine spoils with fast growing tree species accelerates the revegetation process and fulfils the restoration goal (Singh, 2008). Follow-up plantings are a possible method of increasing species richness in rehabilitation sites over a period of time (Norman et al., 2006). Enrichment plantings of shade-requiring species, about 5 years after rehabilitation, occur successfully in the Brazilian Amazon (Parrotta and Knowles, 1999). Planting in a 10- to 13- year old rehabilitated sites in the jarrah forest of Western Australia following thinning and burning operations was successful and may be used to increase the species richness of rehabilitation of this age (Grant and Norman,
2006). However, it is generally believed that introduced species pose a formidable problem in successional management. These species have greater potential for out-competing the less aggressive natives thus resulting in reduction in species and habitat diversity and formation of monospecific stands (Masoodi et al., 2003). The tendency of spread by native species on infertile soils must be an important feature of conservation because it speeds up the direction of change and rate of ecosystem development. The species with such characteristics have a high adaptive efficiency and hasten the process of natural succession on developing lands (Ibid., 2003).

Achievement of an early vegetation cover and high biomass production can be approached though proper selection and planting of early successional native tree species because such species are able to exist under harsh soil conditions and require less long term maintenance. Preference should be given to local leguminous species because they can survive in unfavourable conditions and will reduce initial nitrogen requirement and also fix the nitrogen required for the subsequent successional species (Singh and Singh, 1998).

Developing species selection and establishment guidelines to ensure rapid revegetation of harsh planting site is a universal challenge among mine revegetation projects. Unlike restoration of less severely degraded land, the use of non-native plants remains an acceptable option for mineland revegetation (D’ Antonio and Meyerson, 2002; Li 2006) if they fulfill a temporary successional role to colonize and ameliorate severely degraded sites and facilitate colonization and eventual dominance by native flora (Seo et al., 2008).

The choice of plant species depends on the characteristics of spoil, climatic conditions and ultimate land use. The goal of plant species selection model is to provide a method to identify the suitable tree/plant species for reclamation of land contaminated from mining activities. A better understanding of the tree properties on restored mine spoils can lead to beneficial changes in reclamation practice and renewed the prospect of commercial forestry on these restored land. These plantations can provide fuel, timber, and non-wood forest products to local people (Dutta and Agrawal, 2003). Jefferies et al. (1981) are of the view that legumes are an effective means of improving
the nitrogen status of derelict land, with mineralization allowing substantial transfer to companion species.

Vasistha et al., (1995) recommended *Trema politoria* for mine spoil rehabilitation. This species is a middle sized tree and is commonly distributed in sub-Himalayan ranges from Punjab to Bengal, Assam, Bihar, Orissa, Rajasthan and Madhya Pradesh. The species mostly comes up in profusion on landslips, mined out areas and other places where the soil is exposed. Owing to its capacity to grow on landslips and mined degraded areas as a primary colonizer, it is suitable for afforestation of such degraded areas. This plant is also used as a source of green fodder during lean period in sub-Himalayan tract. The species is capable of providing above ground protection and underground soil binding to the degraded loose substrate. The species has effective soil binding capacity and thus it is a very suitable soil conserving species for degraded mined lands. Besides being fast growing and of soil binding value it is socio-economically very useful.

Hossner and Hons (1992) reported that bauxite spoils are highly erodible and a minimum ground cover of 80% is recommended. Because tailings are so variable, those parameters that limit successful reclamation are expected to be site specific and must be evaluated on case by case basis. Acid-tolerant and nodulated legume trees were used to revegetate the bauxite dumps in Amazon (Franco and De Faria, 1997).

When selecting plants for the reclamation, indigenous species are most preferred over exotic species because they are likely to fit into a fully functional ecosystem and to be climatically adopted but most to the native species in the region are slow growing species. Exotic fast-growing species were therefore tried in view of their large scale use in afforestation schemes in the country (Parrotta, 1999). Exotic species may be especially recommended for primary rehabilitation on bare coal mine spoil due to their fast growth and establishment as observed in the present study. Care is, however, needed so that introduced exotic species may not become a problematic weed to local flora (Dutta and Agrawal, 2003).
Current reclamation and rehabilitation efforts often make use of exotic species. These practices include afforestation or plantation programmes, which include large-scale introduction of fast growing exotic species such as *Leucaena leucocephala*, *Acacia auriculiformis*, *Grevillea robusta*, *Eucalyptus* species, etc., and species of commercial importance such as *Tectona grandis*, *Casuarina equisetifolia*, etc. The success of any biological reclamation depends on; climatic conditions, nature of spoils, types of plant species, nature of dumps, proximity to seed banks (nearby vegetation) and types of amendments used (Maiti and Singh, 2007).

Kuusipalo *et al.* (1995) suggested using a fast-growing exotic species as a “sacrifice fallow” to aid in restoring degraded forest lands invaded by the large fire-enhancing native grass *Imperata cylindrica* in the humid tropics of Southeast Asia. *Imperata* creates conditions of soil compaction, nutrient deficiency, and hydrologic instability, and the susceptibility of the grass to fire prevents natural succession by destroying propagules and root symbionts. To prevent further cutting of rainforest, Kuusipalo *et al.* (1995) suggested planting introduced *Acacia* spp. into *Imperata* stands. The rationale behind this is that topsoil can be improved and desired woody vegetation will then be favoured at the expense of more light-demanding grasses and a more heterogeneous light environment is created, favouring a higher degree of biodiversity (D’Antonio and Meyerson, 2002).

The selection of tree species that are capable of rapid early growth under stressful conditions is essential for rapid occupancy of the reforestations site and suppression of grasses that can very often be a severe barrier to regeneration of all but a very limited number of pioneer tree and shrub species. A mixture of both fast growing pioneer species and slower growing (and longer-lived) native species is recommended to provide greater canopy habitat diversity within the reforestation area, increase structural and biochemical diversity of redeveloping forest floor and soil humus layers. The planting density of nursery-grown seedlings, stumped saplings and / or large seeds should be adequate to minimize the early mortality resulting from competition with grasses and thus facilitate rapid site capture; the planting density of 2500 trees/ha used at Trombetas appears to be an acceptable minimum (Parrotta *et al.*, 1997b).
Evidence presented from the study by Alexander (1989b) suggests that the long-term effect of eucalypt plantations on the spoil soils of the Jos Plateau may be detrimental rather than ameliorative. Although the eucalypts increase both the content of organic matter and some of the bases of the spoil soils, these potentially-beneficial effects has to be balanced against the progressive decrease in base saturation and pH brought about by an increase in cation exchange capacity, a situation, which if continues, will render the soil progressively less productive, rather than more productive as had been the intention of the planting scheme.

The rate of succession may also depend on the species planted first. Larson (1984) found low tree invasion rates on white pine plots and significantly higher invasion rates on black locust plots, for 30-yr old strip mine plantations in Ohio. Schuster and Hutnik (1987), while studying community development on 35-yr old planted mine spoil banks in Pennsylvania, observed delayed succession on white and red pine plots and accelerated succession on black locust and green and white ash plots. Most importantly, some species can fix and accumulate nitrogen rapidly in sufficient quantities to provide a nitrogen capital, where none previously existed, more than adequate for normal ecosystem functioning. Once the soil characteristics have been restored, it is not difficult to restore a full suit of plant species to form the required vegetation (Dobson et al., 1997). Other advantages are that establishment of desirable tree species capable of maintaining the site will slow or prohibit invasion of less desirable weedy species, will provide economic returns in the long term, will aid in developing wildlife habitat and will promote hydrologic balance in the watershed (Singh et al., 2002).

Improvement of soil conditions promoted plant succession and sustained stable, productive plant communities (Schafer and Nielsen, 1979). Climax and subclimax native and introduced plant species accelerate soil development processes (Ries et al., 1977). Successional rate may also depend on the species planted first. Larson (1984) found low tree invasion rates on white-pine plots and significantly higher invasion rates on black locust plots in a 30-yr old strip mine plantation in Ohio. Schuster and Hutnik (1987), while studying community development on a 35-yr- old planted mine spoil
banks in Pennsylvania, observed delayed succession on white- and red-pine plots and accelerated succession on black locust, green- and white-ash plots.

Norman et al. (2006) carried an experiment with diverse seed treatments – legume and under-storey mix (major plus minor [MM] mix), under-storey mix only (minor [M] mix), and no seed (NS) – and sites were fertilized with N & P or P only. They found that the species composition of M and NS sites were more similar to that of the forest than to MM sites. The vegetation structure of M sites at 14 years was more similar to the forest structure than were the other treatments. The M treatment produced a lower fire-hazard, and more forest-like appearance and accessibility, due to lack of tall, fast growing legumes in the seed mix. The multivariate analysis of cover showed that seeded sites were more similar to the forest than to unseeded sites due to the establishment of mid-storey and over-storey structure. An MM site with reduced abundance of large legume species appears to be the most appropriate seeding treatment to implement in rehabilitated areas to increase similarity to the forest. Although the M mix alone produced a vegetation structure and floristic composition most similar to the forest, a similar result could be achieved by reducing the abundance of the large legumes in the MM mix, while still retaining some beneficial effects of nitrogen fixation. Reducing the amounts of large legumes can increase the presence of under-storey species in rehabilitated sites and reduce the fire risks. The dominance of annual species in unseeded treatments means that not applying seed is not a viable rehabilitation option. Applying nitrogen fertilizer increased the richness, density and cover of exotic species. They also recommended to immediately establishing all the plant species that are desired in the target community.

2.3.4 Selection of species for revegetation

Establishment of a mat of vegetation that is both self-sustaining and amenable to predetermined end uses is usually an important element in a rehabilitation program for waste disposal areas. Silvicultural knowledge is required to select species and establishment techniques appropriate to local site conditions and long-range restoration objectives. In many tropical regions, including the Amazon basin, restorationists lack basic, essential information on seed availability, propagation techniques, growth rates
and site adaptability for the hundreds of candidate tree species present in the natural forests (Knowles and Parrotta, 1995).

Improper selection of plant species is the most common problem associated with revegetation failure. The choice of plantation species is likely to greatly influence both the rate and the trajectory of rehabilitation processes (Parrotta, 1992). Forest restoration programs operated by mining companies in Brazil, Australia and other tropical countries have, therefore, usually relied on the artificial regeneration of either native or exotic forest species to rapidly establish tree cover on reclaimed minesites and thereby facilitate natural forest succession (Parrotta and Knowles, 1999).

In an study of 3 coal mines dumps of eastern India, Singh et al. (1998) observed that Dalbergia sissoo was the fastest growing species followed by Leucaena leucocephala at one site. At another site D. sissoo was followed by Delonix regia and at the third site L. leucocephala had the highest growth and Acacia nilotica the lowest.

The seeding of leguminous herbs, Stylosanthes hamata, and grass Pennisetum pedicellatum and Heterpogon contortus in the experimental plots of flat and sloppy areas enhanced the colonization of a large number of plant species. Seeding with native grasses and legumes (nitrogen fixing plants) is an inexpensive method to quickly cover a site. Grasses like Dinanath grass (Pennisetum pedicellatum) and legumes (Stylosanthes humilis) have been successfully used for mine reclamation (Maiti and Singh, 2007). Where phytotoxicity is suspected, it is particularly important to include plant material from populations growing naturally on mine sites and other areas likely to contain similar toxic factors (Phia et al., 1995).

Study by Dadhwal and Singh (1993) reveals that in degraded abandoned limestone mined land Leucaena leucocephala and Bauhinia retusa among trees, are the plant species suitable for rehabilitation of degraded mine sites because of presence of many root nodules in Leucaena leucocephala and soil binding factors of both these species.

Many studies document the positive role of grass cover as a nurse crop (Bramble and Ashley, 1955). Grasses may have both positive and negative effects on restoration
of mine lands. They are frequently needed to stabilize soils during the restoration process, but they may compete with woody regeneration. Grasses have fibrous roots that can slow erosion and their sod-forming tendencies eventually produce a layer of organic soil. They are useful in restoration of mined land because they stabilize soil, conserve soil moisture, and may compete with weedy species. This initial cover must allow the development of diverse, self-sustaining plant communities (Singh et al., 2002).

Trees can potentially improve soils through numerous processes, including maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below the reach of roots of understory herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil biological properties, reduce and leaching, improve soil biological activity. Given time, new self-sustaining topsoils are created by trees (Filcheva et al., 2000). However, impact of trees on soil fertility depends on their nutrient-cycling characteristics such as litter chemistry and decomposition. In addition to the nutrient sink function due to mass accumulation, same plantation species exhibit high nutrient use efficiency and may be more effective nutrient sink than the other species (Singh et al., 2002). In temperate environment, slower-growing, broad-leaved native trees are regarded as better for amenity, but less efficient for timber production (Filcheva et al., 2000). Lei and Duan (2008) concluded that in general, pioneer plant would be the ideal species for phytostabilization of mine tailings. However, Bendfeldt et al. (2001) observed that after 16 years, there appeared to be no lasting soil quality improvements due to addition of organic amendments to the mine soil. Amendments improved short-term production, but there cost of transport and application may be difficult to justify based on long-term soil quality improvement. Singh and Vasistha (2004) observe that positive impact on hydrological attributes of mined degraded watersheds was mainly due to the effect of silvi-pastoral interventions that may play a vital role in the development of mined degraded watersheds in lower Himalayas.

The role of exotic or native species in rehabilitation needs careful consideration, because we may have to use species combinations (native, exotic or combination
thereof) that are capable of surviving into new conditions (Singh et al., 2002; Singh et al., 2004a). Alexander (1989c) found that native *Acacia albida* had more beneficial effect on the spoil soils than the exotic eucalypts in tin-mine spoils of Jos Plateau of Nigeria. Woody legumes perform best on tin (Sn) mine tailings and pulverized fuel ash waste sites, because, apart from being N-fixing, their roots can penetrate into deeper, moist layers (Phia et al., 1995). In the study by Zhang et al. (2001), root nodules were formed in *Leucaena leucocephala* derived from the soil seed bank. The lead-uptake pattern of *L. leucocephala* revealed that considerable Pb was accumulated in the root, branch, stem bark, and xylem, accounting for more than 80% of total metal in this plant. Therefore, such woody legumes may have a greater advantage in metal-phyto-remediation than herbaceous plants. The shoots of herbaceous plants, which contained rather higher Pb concentration, would become litter during their growth (Ibid., 2001).

For soil reclamation, the difficulty is not in finding a system that fixes enough N to supply the plant needs, but in managing the system and finding species that will grow under the harsh conditions common in degraded soils. Low soil pH is characteristic of most weathered degraded soils of the humid tropics. It is even more of a problem in mining spoils that generate acidity (Franco and De Faria, 1997).

Many literatures are available for selection of suitable species for rehabilitation (Singh et al., 2002; India, 2004 a; Dubey, 2007). Careful selection of species is needed, as newly introduced exotics may also become pests in other situation. Exotic species are believed to negatively impact site conditions, escape into pristine habitats and displace native species (Lugo, 1997). Therefore, candidate plantation species should be screened for their potential to become problematic weeds in relation to local and regional floristics (Parrotta et al., 1997a). As a part of revegetation efforts, selection of desirable species adapted to the local environment has been emphasized. For artificial introduction, use of species that are well adapted to the local environment should be emphasized (Dobson et al., 1997; Wali and Freeman, 1973; Gibson et al., 1985). Indigenous species are preferable to exotics because they are most likely to fit into a fully functional ecosystem and to be climatically adapted (Phia et al., 1995).
On mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation, and hence, an alternative approach might be to introduce legumes and other nitrogen-fixing species (Singh et al., 2002). Dobson et al. (1997) emphasized that the use of nitrogen-fixing species requires good knowledge of their biology, both their soil preferences and their interactions with other species. Nitrogen-fixing species can have dramatic effect on soil fertility through the production of readily decomposable, nutrient-rich litter and turnover of fine roots and nodules (Singh et al., 2002). Mineralization of N-rich litter from these species will allow substantial transfer to companion species and subsequent cycling, thus enabling the development of a self-sustaining ecosystem (Jefferies et al., 1981). It should be emphasized that leguminous species also differ in their soil enrichment capabilities. In a study done for restoration of damaged coal mine areas in India, Singh et al. (1996b) reported that compared to native non-leguminous species, native leguminous species show greater improvement in soil fertility parameters. Also native legumes are more efficient in bringing out differences in soil properties than exotic legumes in the short term (Ibid, 1996b). Jha and Singh (1993) from coal mine rehabilitation site in Madhya Pradesh reported good performance of Bothriochloa pertusa, Bothriochloa intermedia, Chrysopogon fulvus and Cenchrus setigerus. Comparing the survival and growth of three species on coal mine spoil, Singh et al. (2004c) observed that high survival rate was observed in Albizia procera and lowest in Tectona grandis. At the age of six years, height was maximum in Albizia lebbek and minimum in Tectona grandis, whereas diameter was maximum in A. procera and minimum in T. grandis. Similar findings were recorded for two Albizia species by Singh et al. (2004b). Singh and Singh (1999a) have studied the effect of mulches on nutrient uptake of A. procera planted in coal mine overburden.

Moreover, vegetative material used in reclamation should consist of trees, which is consistent with site capabilities and should be designed to provide a cover consistent with the stated land-use objective and which does not constitute a health hazard. It should fulfill the demand of the local people (Dubey, 2007). Gupta and Singh (2005) observe that Albizia lebbek was the best-adapted plant species for a mine site of Eastern Coalfield Limited, followed by Dalbergia sissoo. A. lebbek and D. sissoo can be
considered as early successional tree species and might have atmospheric nitrogen fixing capacity to cope up with the impoverished, slightly alkaline overburden mine spoil of the area.

Bending and Moffat (1999) have suggested that landform design, selection of suitable soil or soil-forming materials, spoil placement technique and appropriate species choice are central to future success of forestry on restored mined area in South Wales. A suitable species for planting on mine spoils should possess the ability: (i) to grow on poor and dry soils; (ii) to develop the vegetation cover in a short time and to accumulate biomass rapidly; (iii) to bind soil to arrest soil erosion and check nutrient loss; and (iv) to improve the soil organic matter status and soil microbial biomass, thereby enhancing the supply of plant nutrients available (Singh and Singh, 1999b); and in addition, the species should be of economic importance (Singh et al., 2006). Bradshaw (1997) is of the view that current methods of reclamation may lead to the establishment of a limited number of plant species only, resulting in the production of ecosystem of low diversity with restricted land use potential and wildlife conservation value. Phyto-stabilization is the use of metal-tolerant plant species to immobilize heavy metals through absorption and accumulation by roots, adsorption onto roots, or precipitation within the rhizosphere. This process reduces metal mobility and also reduces bioavailability for entry into the food chain. By using metal tolerant plant species for stabilizing mine spoils, it could also provide improved conditions for natural attenuation. The normal practice is to choose drought-resistant, fast-growing species which can grow in metal-contaminated and nutrient-deficient soils (Wong, 2003).

Most investigations on vegetation of man-made mine wastes especially emphasize the selection of metal-tolerant species, and few are related to initial stages of primary succession of plants on these wastelands (Gibson, 1982; Ernst, 1988; Chambers and Siddle, 1991). For reclaimed coal mine spoils of West Central New Mexico, Sanchez and Wood (1989) reported that revegetation species were selected for their ability to withstand environmental stress from severe climatic conditions and shallow, infertile soils; ability to stabilize the ground surface of redistributed soil material; and
ability to withstand grazing pressure. Seed mixtures used in the reclamation project were composed of warm season and cold season grasses, forbs and shrubs.

Since spoils usually lack nitrogen, legumes appear to be a logical choice for quick cover (Maiti and Banerjee, 1993; Maiti, 1997; Vajpayee et al., 2000). On the other hand, legumes face severe difficulties both in growth and nodulation on acid spoils since many studies of legumes seeded on acid soils indicate that poor growth under acid condition often can be attributed to toxicities caused by excess manganese and aluminium brought into solution by the acid conditions (Fail Jr. and Wochok, 1977). Legumes are commonly planted, since the bacteria associated with their root nodules have the capacity to fix atmospheric nitrogen. In a study, Macedo et al. (2008) also found that due to their association with arbuscular mycorrhizal fungi, leguminous tree species were selected that not only can establish under harsh conditions, but also produce high biomass yields of low C:N ratio. Soil N increase is very important in degraded land rehabilitation projects, since, it enhances the capacity of the system to support a more complex community.

Doubleday and Jones (1977) pointed out that spoils may be reclaimed by directly establishing grass but the grass swards often deteriorate over a number of years and show signs of moisture stress in summer months and sometimes water-logging in the winter (Doubleday, 1974). Armiger et al. (1976) found that steep slopes (≥60%) in some situations can be stabilized by seeding and transplanting leguminous species with phosphorus application. Stabilization of spoils and reduction in erosion can be effected by seeding the spoil with sod-forming grasses. Grasses have ameliorative effects on both physical and chemical properties of spoils. Alexander (1989 a, b) has compared the beneficial effect of Acacia albida and Eucalyptus camaldulensis on the tin-mine spoil in Jos Plateau, Nigeria, and recommended that A. albida has an ability to improve both the nutrient status and physical conditions in the top 20 cm of the soil beneath its canopy, whereas E. camaldulensis caused a progressive increase in the soil acidity and reduction of base content, although organic C increased. Robinia pseudoacacia, a N-fixing legume, raised soil N levels considerably more than the other non-leguminous species in Ohio coalmine spoil, U.S.A (Vimmerstedt et al., 1989).
As well as fixing atmospheric N, fast-growing legumes provide rapidly established vegetative cover (reducing erosion), increase soil organic matter, modify the microclimate at the soil surface, provide a resource for fauna, and favorably affect soil physical properties (Ward et al., 1996; Ward, 2000). However, there are a number of disadvantages including increased competition leading to a restoration in plant species richness, dense vegetation making areas less accessible, and increased rate of fire-fuel load accumulation, and hence, the density of legumes needs to be controlled to limit competitive exclusion of other species. Therefore, low-biomass nitrogen-fixing species should be used in restoration programme to assist in the re-accumulation of micronutrients following initial fertilizer application (Grant et al., 2007). Wong (2003) has reported successful establishment and colonization of several pioneer plant species, e.g., Vetiveria zizanioides, Sesbania rostrata and Leucaena leucocephala on Pb-Zn mine spoils in China. Vetiver grass (Vetiveria zizanioides) has a massive finely structured and deep root system capable of reaching 3-4 m. in the first year. Due to its unique morphological and physiological characteristics, it has been commonly known for its effectiveness in erosion and sediment control, and has also been found to be highly tolerant to extreme soil conditions including prolonged drought, flood, submergence, extreme temperature (-10°C to 48°C), and a wide range of soil acidity and alkalinity (pH from 3 to 10.5). This species is highly tolerant to soil salinity, sodicity, Al, Mn and heavy metal (such as As, Cd, Cr, Ni, Pb, Zn, Hg, Sc and Ce) toxicities in the soil. Several workers from Pb-Zn mine spoils of China reported that vetiver grass was found to be the best plant spices (in terms of biomass production and coverage) when compared with other three grass species, namely Paspalum notatum, Cynodon dactylon and Imperata cylindrica used for revegetating Pb-Zn mine tailings in South China (Ibid, 2003). Sesbania rostrata, which possesses stem as well as root nodules, can be used to modify properties of mine spoils, by supplying the much needed N and organic matter. Apart from having a very high growth rate, it is also tolerant to toxic metals and low nutrient status, and therefore, will be an ideal pioneer species to accelerate ecological succession of the man-made habitats (Ibid, 2003). Ye et al. (2001) also found that S. rostrata is a better choice as a pioneer species for revegetation of lead/zinc mine tailings than S. cannabina.
Themeda australis (kangaroo grass) was found suitable for use in large-scale mine rehabilitation and it was planted for mine site restoration in the Central Tablelands of New South Wales Australia (Windsor and Clements, 2001). Calcareous bauxite mining spoils on Ghiona Mountain, Central Greece was revegetated by seeding of woody species (Brofas and Karetsos, 2002). From a study of coal mine spoil in Madhya Pradesh, Dutta and Agrawal (2002) reported that among different plant species, the physical characteristics are maximally improved by Eucalyptus hybrid, Acacia auriculiformis and Casuarina equisetifolia. In soil texture, maximum silt and clay was found in the plots of Eucalyptus hybrid. Bulk density was higher in Casuarina equisetifolia followed by Acacia auriculiformis and lowest in Gravellia pteridifolia plots. WHC was also highest in the plots of Eucalyptus hybrid. Moisture content also followed a similar trend. In chemical characteristics, total N content was higher for Acacia auriculiformis, a nitrogen-fixing species, whereas Cassia siamea showed lowest N content in soil. Organic C and total P also had a similar trend. These characteristics can be due to the lower growth and poor nodulation of Cassia siamea plants. Casuarina equisetifolia, a non-leguminous nitrogen fixing species showed highest available P content and a higher N level in the soil.

Sengupta (1991) reported that for stabilization of Neyveli lignite mine slopes, Brachiaria mutica and Cynodon dactylon are planted before going for tree plantation. Mathur (1978) and Gupta (1979), for overburden of semiarid to subhumid regions in India, suggested for seeding/planting of Acacia auriculiformis, Cassia siamea, Albizia lebbek, Dalbergia sissoo, Prosopis juliflora, Terminalia arjuna, Syzygium cumini, Pongamia pinnata, Madhuca latifolia, Alstonia scholaris, Pterocarpus marsupium, Cleistanthus collinus, Vitex negundo, Ipomoea carnea, Tephrosia candida, Sesbania aegyptiaca, Pennisetum pedicellatum, P. purpureum, Cenchrus ciliaris and Chrysopogon fulvus. Saxena (1979) suggested Cenchrus ciliaris, Cenchrus setigerus, Cynodon dactylon, Dichanthium annulatum, Sehima nervosum, Sporobolus marginatus and Eleusine compressa as grasses, and Prosopis cineraria, Zizyphus nummularia, Acacia tortilis, A. senegal, Calotropis procera, Salvadoria oleoides, Indigofera oblongifolia, Grewia tenax and Prosopis juliflora among shrubs and trees for revegetation of gypsum and bentonite mines of Rajasthan, India.
Biological reclamation on 10-year-old mine spoil at Alkusha-Gopalpur, Raniganj Coalfields in Eastern India was carried out during 1992. It was observed that after five years of reclamation, out of 14 plant species selected for reclamation, *Acacia auriculiformis*, *Acacia arabica*, *Albizia lebbeck*, *Leucaena leucocephala* and *Gmelina arborea* were successful. Organic carbon, available major nutrients (N, P and K), pH, exchangeable cations and cation exchange capacity increased whereas trace elements decreased. A progressive richness in species diversity in natural vegetation was observed indicating rejuvenation of the ecosystem (De and Mitra, 2002). After study of revegetation program of Jharia Coalfields, India, Singh et al. (2005) found that *Pterocarpus ascerifolium*, *Bauhinea variegata*, *Eucalyptus* spp. and *Zizyphus zuzuba* attenuate sulphur dioxide and nitrous oxide, whereas bamboo spp., *Dalbergia sissoo* and *Cassia siamia* are good attenuaters of sulphur dioxide only. *Syzygium cumini*, *Mymosops elengi* and *Madhuca indica* attenuate oxides of nitrogen and particulate matters. For restoring gypsum mine spoil, Rao and Tarafdar (1998) found that *Acacia senegal*, *Acacia tortilis*, *Azadirachta indica*, *Cenchrus ciliaris*, *Colophospermum mopen*, *Dichrostachys nutans*, *Pithecellobium dulce*, *Prosopis juliflora*, *Salvadora oleoidis* and *Zizyphus nummularia* can be used. Among these plant species, *Azadirachta indica*, *Colophospermum mopen* and *Z. nummularia* showed better exploitation of micro nutrients on mine spoils than normal soil; and *Salvadora oleoidis*, *Colophospermum mopen* and *Pithecellobium dulce* were identified as calcium-loving plants. The significantly higher availability of micro-nutrients in gypsum mine spoil compared to the normal cultivated soil of the surroundings may be the reason for higher concentration in plants. Growth of most of the selected plant species in gypsum mine spoil was equal to or more than that observed in normal soil. Gupta et al. (2004 b) reported that *Bambusa pallida*, *Dendrocalamus hamiltonii*, *Bambusa nutans*, *Bambusa multiplex* and *Phyllostachys reticulate* exhibited 60-80% survival on mine spoil slopes, whereas *Bambusa tulda* failed to survive. Growth parameters of the above survived bamboo species were also almost comparable to these species growing in natural habitat.

Muzzi and Fabbri (2007) tested the comparative performance of 24 shrub and tree species on a revegetated mineral clay soil in Italy and found that the best
performing shrub species were Spartium junceum, Ligustrum vulgare and Cotinus coggygria followed by the substrate adaptive but less developed Rahmnus cathartica, Pinus spinosa and Crataegus monogyna. The tree species that responded best were Sorbus domestica, Pyrus pyraster, Fraxinus ornus and Fraxinus angustifolia followed by the adoptive but underperforming Ulmus minor, Fraxinus excelsior and Acer campestre. Pot experiments were carried out to find out the growth potential of the native plant species and some exotic species, a total of 40 plant species were selected. Nursery raised sapling in polyethylene bags were transported to the site and transplanted in wasteland areas at the Jharia coalfields. The study of plant growth performance with respect to increment in height and girth indicated that the growth potential was maximum in case of Dalbergia sisoo, followed by Gmelina arborea, A. indica, Albezia lebbeck, Tectona grandis, P. enormi, Alstonia scholaris among the selected plant species (Pal et al., 2005). A series of experiments was conducted on the rehabilitation of mine spoils in a dry tropical region of India for determining the suitability of tree species and impact of the plantations on the restoration of biological fertility of the mine spoils. It was found that the growth of the majority of the species could be improved by amending the mine spoil with NPK fertilizer.

Direct seeding showed the greatest height of Zizyphus jujuba and Pongamia pinnata on the flat surface and Terminalia arjuna on the slope. The plantation of trees significantly accelerated the soil redevelopment process on the mine spoil (Singh and Singh, 2006). Singh et al. (2000 b), from a study of rehabilitated limestone mined land near Mussoorie, reported that agroforestry interventions with establishment of trees, shrubs and grasses on mine spoil have improved the soil conditions significantly. Boulder percentage decreased and the soil fraction below 2mm size increased in rehabilitated mined area in comparison to unrehabilitated control plot. The sand percentage decreased and silt and clay increased significantly after agroforestry interventions. Water holding capacity increased while bulk density decreased after plantation.

For lead/ zinc mine tailings of China, Shu et al. (2005) suggested that artificially accelerating the colonization would be necessary to create self-sustaining vegetation on
the tailings. Relatively cost-effective methods for revegetation of the tailings might include: (1) using organic wastes for buffering metal toxicities and improving physicochemical properties; (2) applying top soil from adjacent areas as seed resources and also providing favourable microsites for plant colonization; and (3) introducing seeds of some nature rhizomatous, perennial grasses that might have high colonization potential.

For bauxite-mined lands in Brazilian Amazon, the most productive treatment in terms of basal area development and height growth was the mixed commercial species treatment, followed by the natural regeneration, direct seeding and mixed native species treatments. Tree basal areas in the restoration treatments ranged from 18% (in the mixed native species plots) to 33% (in the mixed commercial species plots) of that in the primary forest plots (Parrotta and Knowles, 1999).

Analyses of basal-area dominance among restoration treatments clearly show that it will take at least several decades before the species that presently dominate the primary forest, though often present in the understory of the restoration stands, will assume a significant structural role (Ibid, 1999).

The mixed commercial species treatment, dominated by *Eucalyptus* spp., *Sclerolobium paniculatum* and *Acacia mangium* stands out clearly at the most productive as indicated by data on basal area and tree height growth. The abundance, mean height and species richness of trees and shrubs regenerating in the understory were significantly lower, however, than in either the direct seeding or mixed native species treatments. The relatively low regeneration density in this treatment is most likely due in part to the rapid growth rates of the planted trees, to relatively high understory light levels and to increased grass and herb densities all of which result in increased root competition among germinating woody species. The significantly lower understory species richness in treatments also suggests possible limitations on seed-bank germination and/or seed inputs by birds, bats and other mammals that are the main agents of seed dispersal from the primary forest (Ibid, 1999).
Notwithstanding the merits of planting mixed stands of native hardwood species attempts to establish plantations of indigenous species have often been either difficult or unsuccessful owing to the lack of adequate knowledge on their biology, ecology and silviculture (Leopold et al., 2001). Conversely, plantation establishment using exotic species has increased due to (i) readily available information on propagation techniques, silvicultural behaviour and management practices, and (ii) at least initially fast growth rates, and production of wood that can be used for various purposes in a relatively short period of time. However, exotic tree plantations are meanwhile widely considered to have serious adverse effects on the environment, which include (i) harmful changes in the physical, chemical and biological conditions of the soil; (ii) competition with agronomical land use for monetary reasons; (iii) displacement of the local flora, the native vegetation and, in part, the native fauna; and (iv) enhancing problems of susceptibility of the exotic species to epidemic diseases and pests (Feyera et al., 2002).

Despite the various benefits that accrue from reforestation with exotic species, growing concern regarding the disadvantages of such ventures and reluctance or even resistance of local people to the introduction and establishment of exotic species is observed. It is claimed that fast-growing exotic trees, once established in a plantation, may exert higher competitive strength for water, nutrients, and light than indigenous plants. Some may also hamper germination, establishment and growth of other, in particular indigenous, plants by releasing allelopathic chemicals. As a result, environmental changes beneath and around the plantation may take place that are detrimental to the normal functioning of the habitat (Ibid, 2002).

However, the impact of plantations of exotic species on the site conditions and on the possible regeneration of indigenous species under that canopy depends not only on the planted species but also on the history of the site, the forest management practices employed, such as planting density and coppicing. Moreover, quality and quantity of light penetrating through the canopy, microclimatic conditions, composition of the seed bank in the soil, and availability of recent seed sources in the vicinity of the plantation are important. Therefore, generalizations are at least risky since they may lead to inappropriate conclusions and recommendations. Potentially, in addition to
production of wood as an economic resource, exotic tree plantations may also have advantages, such as improving microclimatic conditions, protecting degraded lands against soil erosion, stabilizing soil development, thereby enhancing soil nutrient status and increasing soil organic matter through enhancement of litter and humus production and supporting water catchment values. In addition, such plantation may foster the regeneration of native species under their canopy and provide a habitat for wildlife (Keenan et al., 1997). Thus, exotic tree plantation potentially may greatly improve physical and biological site conditions catalyzing subsequent succession processes towards a natural forest (Parrotta, 1992; Parrotta et al. 1997b).

Several recent studies in different parts of the world have shown that tree plantations can have a nurse effect and thus be an effective means for rehabilitation of degraded sites and catalyzing the restoration of native vegetation beneath their canopy (Parrotta, 1992; Parrotta et al., 1997a). In many sites and with various exotic species, substantial numbers of indigenous woody species regenerate beneath the canopy of the plantations, thus showing an increase in their biodiversity (Feyera et al., 2002).

The establishment of a permanent cover of vegetation involves not only growing plants, but it necessitates bringing into a plant community that will maintain itself indefinitely without attention or artificial aid, and support native fauna. The presence of certain tree species in a productive system can result in better soil structure and increased soil nutrient availability. Such performance could be achieved by selecting species adapted to grow, spread and reproduce under severe conditions provided both by the nature of the dump material and the exposed situation on the dump surface (Singh et al., 2002).

In an experiment with the N$_2$-fixing legume-tree, *Albezia lebbek* was used as a plantation tree in Puerto Rico. It was found that seedling mortality of the plantation tree itself under the canopy was much larger (47% in a 1.3 year period) than that of secondary forest species (23-26%) underlining the role of the plantation as a “foster ecosystem” for successional development of secondary forest (Parrotta, 1993). While most species appear to act as catalysts for ecosystem rehabilitation, broadleaf species seem to give better results than conifers (Parrotta et al., 1997a). Of these, fast-growing
species that represent lower successional stages should have preference, particularly those known to establish and grow well on degraded sites.

With the appropriate management, reforestation with exotic trees can foster under-growth. Tree planting may facilitate the process of forest succession by providing a nurse effect for colonizing native species. This nurse effect is attributed to a protective microenvironment under the canopies of tree plantation which rhythmically changes upon coppicing of the nurse tree. Intermittent changes of the light and microclimate obviously increase germination and growth rates as well. In addition, the associated increase in vegetation structural complexity, and the production of multi-component litter and the concomitant enrichment of humus layers bring about improvement of forest floor conditions. In turn, these changes facilitate seedling establishment by suppression of grasses that normally prevent tree seeds germination and growth of the seedlings (Feyera et al., 2002).

Feyera et al. (2002) concluded that objection against the establishment of exotic species cannot be warranted, especially in countries where, on the one hand, there is a desperate and urgent need of expanding the forest resource base to meet the ever-increasing demand for timber, firewood and non-timber products and, on the other hand, remaining natural forests need protection and regenerative extension of stands of native trees is highly desirable.

D’ Antonio and Meyerson (2002) opined that in some degraded sites it may be necessary to introduce an exotic species to assist with the restoration process. At many places fast-growing but sterile exotic grasses were used to quickly establish cover. These grasses do not seed and presumably give way to native species. In other places where land uses, such as mining, have resulted in loss of soil fertility, fast-growing exotic N-fixing trees have been used to ameliorate harsh site conditions. Gupta et al. (2005) reported better growth of *D. sissoo* and *M. azedarach* than *Casia fistula* and *Tectona grandis* on coal mine spoils due to atmospheric N-fixation into the soil pool together with higher litter decomposition rate which in turn increase the biomass.
Parrotta (1992) found that an Asian N-fixing tree could grow well in degraded pastures in Puerto Rico and eventually accelerate regeneration of native rain-forest. Lugo (1988) provided observational evidence that non-indigenous trees can ameliorate harsh environmental conditions on barren sites, eventually facilitating the establishment of native tree species.

In a study by Kumar et al. (2004) on vetiver grass (Vetiveria zizanioides) planted on coal overburden dumps, it was found that it added nutrients by its biomass and improved the physico-chemical properties of the dumps to support other species to come up. It was concluded that selecting vetiver grass species is the economical bio-reclamation approach for the coal overburden dump. Gupta et al. (2004 a) reported that Amaranthus caudatus, regarded as pseudo-cereal, is an under-utilized plant and can be a promising plant species to be used for restoration of coal mine spoils. This species can be used as vegetable, cereal and even as fodder and its establishment will not only help restriction of degraded land but also be useful for people living around mine area. In a study of coal-mine overburden rehabilitation by four species, Singh et al. (2006) concluded that a non-legume (Dendrocalamus strictus) can also play a significant role in restoring mine-spoil habitats, in the same way that has been especially reported for leguminous species. Aber (1987) was also of the view that several non-leguminous species, particularly in genera of woody plants associated with wetlands (e.g., Alnus spp.) have different but also effective N-fixing microbial associations.

Singh (2006), in a study of mixed plantations raised on mine spoil, found that the effect of N$_2$-fixing species as neighbour is not always beneficial for the growth of non-N$_2$-fixing species. Tectona grandis exhibited poor performance when grown with legumes Dalbergia sissoo and Leucaena leucocephala but its growth was significantly greater when planted with the non-legume Dendrocalamus strictus. In contrast to result obtained for T. grandis, the growth of non-legumes Gmelina arborea and Terminalia bellirica was greater when these species were grown with the legume Pongamia pinnata than when grown with non-legumes. This suggested a positive effect of N$_2$-fixing legumes on growth of non-legumes. Joshi and Singh (1998) reported better growth in oak in the presence of N$_2$-fixing alder than when the oak was grown alone.
Benefits from N$_2$-fixation are more likely to occur on sites that are less fertile (Binkley, 1983). This may be the reason behind better growth of non-legume *G. arborea* and *T. bellirica* in combination with N$_2$-fixing legume because mine spoils are nutrient-poor habitats. On degraded soil, N$_2$-fixing woody species could have long-term effects on improvement in growth of non-N$_2$-fixing woody species (Singh, 2006).

Singh (2006) found that the legume *Pongamia pinnata* exhibited better growth with non-legume in mixed plantations. This suggests that the legume and non-legume companionship is not only beneficial to non-legume but is also advantageous for legume. The poor performance of *Pongamia pinnata* with *Acacia catechu* suggests that perhaps both the legumes competed for the same resource, hence the growth of *Pongamia pinnata* was reduced when planted with *Acacia catechu*. Competition for resource is a dominant process influencing performance of species in mixed plantations (Shainsky and Radosevich, 1992). Pairs of species which have both a large competitive effect and response to one another, probably use the same resources, and hence, are limited by those resources (Miller and Werner, 1987). In mixed plantation, nitrogen may mediate interaction between and within species in at least two different ways. First, because the nitrogen fixer utilizes a different source of nitrogen (the atmosphere) form that of the non-fixer (the soil), potential exists for reduced competition between species through resource partitioning. Second, facilitation may occur through the addition of fixed nitrogen to the system, and enhanced availability to the non-fixer. *A. catechu* planted with legumes, showed better growth with *Pongamia pinnata* than with *Albizia lebbeck*. Greater N$_2$-fixation rate has been reported in *P. pinnata* than in *A. lebbeck*. The significantly greater N concentration in *Gmelina arborea* and *Terminalia bellirica* grown with leguminous trees suggests that N$_2$-fixing leguminous species have ability to improve the foliar N status of the companion species in mixed plantation. On the other hand, N$_2$-fixing legumes *Dalbergia sissoo* and *Leucaena leucocephala*, as neighbouring species, reduced the foliar N concentration in *Tectona grandis* suggesting that N$_2$-fixers may not always have a positive effect on foliar N status of non-N$_2$-fixing companion species in mixed plantation. Therefore, Singh (2006) concluded that in mixed plantation, effect on and response to one another will differ from species to species and
this aspects needs to be evaluated before recommending a particular species combination for mixed plantation.

Mine spoils need to be recreated before the mature plant community will function. Altering soil condition through plants has a potential problem that plants that have unusual physiological mechanisms (e.g., symbiotic N-fixation) and are, therefore, more likely to survive and to ameliorate soil conditions are often exotics. The role of exotic species in restoration has often been looked with concern due to their negative impact on soil fertility and biodiversity (Lugo, 1997). The available literature, however, do not support this (Parrotta, 1999). Aber (1987) cited an example of reclamation of mine wastes in the humid eastern parts of the USA where Robinia pseudoacacia, a N-fixing legume and Populus spp. a highly productive cation pump species are often planted first and concluded that once the function and structure are restored, then the exotic community can be removed. Dutta and Agrawal (2003) are of the view that exotic species may be recommended for primary rehabilitation on bare coal mine spoil due to their fast growth and establishment. Care, however, is needed so that introduced exotic species may not become a problematic weed to local flora. They reported that among the tested exotic species, viz. Acacia auriculiformis, Casuarina equisetifolia, Cassia siamea, Eucalyptus hybrid and Gravellia pteridifolia, the most suitable species for coal mine spoils were E. hybrid, A. auriculiformis and C. equisetifolia. E. hybrid showed the highest growth, biomass and net primary production followed by C. equisetifolia and A. auriculiformis. G. pteridifolia ranked fourth with respect to all the studied parameters while C. siamea did not show good growth and biomass accumulation on coal mine spoils.

Among species that may be considered suitable for a given degraded site, there may be considerable variations in their capacity to stabilize soils, increase soil organic matter and available soil nutrients, and facilitate understorey development. These variables include susceptibility to pests and diseases, patterns of aboveground and root biomass accumulation, nutrient utilization and allocation, nutrient use efficiency, nutrient retranslocation, litter decomposition, and the presence of secondary compounds that may inhibit the activity of decomposing organisms (Singh et al., 2002).
Selection of suitable species is extremely important for the development of self-sustaining ecosystem. Selection of the species must be determined by the fact as to what will grow best in the particular soil and climate of the area.

2.4 GROWTH OF PLANTED SPECIES

Self supporting plants that allocate too little biomass to stems may buckle under their own mass or break due to wind stress or other loads (O’Brien et al., 1995). According to Singh and Singh (2001), tree architecture (height-diameter, crown mass-trunk relationships) is, therefore, of considerable importance in selecting species for plantation on mine spoils. The constant stress model of tree growth is based on the assumption that trunk taper is such that stress produced by wind pressure along the stem is equalized (Dean and Long, 1986). In this model, the scaling exponent $b$ between diameter and height is equal to 0.5. Growth of 5 species, viz., Dalbergia sissoo, Azadirachta indica, Albizia procera, Delonix regia and Acacia nilotica over coal-mine OB material in Eastern India was studied by Singh et al. (1997). They observed that D. sissoo was the best early and late successional plant species for that study area. D. sissoo indicated 2.76 m height and 46 mm diameter after two years. D. sissoo has wide range of tolerance and contains root nodule bacteria which have nitrogen-fixing capacity. Singh et al. (2000a) reported that height growth in fertilizer treated Acacia catechu, D. sissoo and Pongamia pinnata did not differ from the control, i.e., without fertilizer input.

Singh and Singh (2001) reported that the legume Pongamia pinnata and the non-legume Phyllanthus emblica were found to follow this constant stress model of growth. This model is the most generally accepted model in a windy habitat. They also reported that legumes Acacia catechu and Dalbergia sissoo and the non-leguminous Azadirachta indica and Gmelina arborea followed the elastic similarity model of tree growth.

According to Singh and Singh (2001), average height, diameter and volume increments for leguminous species were greater than those for non-leguminous species, suggesting that the leguminous species have a greater capacity for growth in nutrient-
poor habitats. This may be due to the nitrogen fixing ability of leguminous species. Height growth of jarrah trees can be halved if the restored sites are not adequately deep ripped (Szota et al., 2007).

2.5 PLANT SPECIES FOR VARIOUS USES BY THE LOCAL PEOPLE

Although, the land under mining activities in India occupy an insignificantly small area, the impact of mines and mineral based industries in tribal areas is significant. A superimposition of forest-, tribal areas- and mining-maps of India will testify the fact that the tribals are mainly residents of forested tracts, and that major mining activities and mineral based industries are located in tribal areas of India. Due to mining operation, the local population is generally translocated; and in almost all the cases is deprived of the usufructs of the pre-mining ecosystems. Opening of mines and mineral based industries in their areas has suddenly exposed them to changed physical, chemical and biotic environmental stress, alteration of diet (Chaudhary, 1992) and living style. The highlanders mostly depend for their sustenance upon the limited resources available in their surroundings. The shelter-environment with its resource-base and constraints influences their socio-economic and cultural life (Sahoo et al., 1994). In the process of evolution, the highlanders gathered knowledge about the biological resources and their uses for different purposes such as fuel, medicines, and construction materials for their huts and agricultural implements, fodder for their livestock, and their many cultural beliefs.

In recent times, the concept of ethnobotany has been focused almost entirely on the applications and economic potential of plants by native people (Misra, 1998). Martin (1995) defined ethnobotany as ‘all studies (concerning plants) which describe local people’s interaction with the natural environment’. However, detailed studies have been done in past on the ethno-medicinal uses of various plant parts by these highlanders.

Knowledge and use of medicines in India dates back to Rigveda period, which is perhaps the oldest repository of human knowledge. Plants have been used to cure diseases since antiquity. All systems of traditional Indian medicine had their roots, in
one way or the other, in folk medicines and household remedies, whereas some of those earliest remedies and prescriptions became wide spread and were subjected to certain refinement, revision and improvement through practices, and thus got incorporated in organized system of medicine (Misra and Dash, 1997). But a major bulk of folk-medicines remained endemic to certain regions or people in the country. Due to lack of communication of intermingling, breeding of ideas and varying way of life, many of these earlier remedies survived only by words of mouth from generation to generation. The lack or absence of acculturation has in many instances held in preservation of this knowledge in almost original form (Jain, 1981).

Several workers had done study on the ethno-medicinal aspects of various parts of Orissa. Saxena and Dutta (1975), Saxena et al. (1981), Jain et al. (1973), Das and Misra (1987, 1988a, 1988b) are the main contributers in this regards. Nayak and Misra (1991) concluded that now-a-days traditional beliefs and practices followed by the tribals are given less importance due to influence of western culture; however, forest resources play an important role in the survival of tribals. They enlisted various parts of 18 species, viz, Aegle marmelos, Bauhinia vahlitii, B. purpurea, Buchanania lanzan, Carissa spinarum, Cacculus hirsutus, Dendrocalamus strictus, Dioscorea bulbifera, Diospyros melanoxydon, Flacourtia jangomas, F. sepiaria, Manilkara hexandra, Mangifera indica, Premna latifolia, Semecarpus anacardium, Syzygium cumini, Tamarindus indica and Ziziphus mauritiana to be used as food; sap of Caryota urens and Phoenix sylvestris, and fermented flowers of Madhuca indica as stimulants; various parts of Abrus precatorius, Aegle marmelos, Ageratum conyzoides, Andrographis paniculata, Argyreia nervosa, Asparagus racemosus, Azadirachta indica, Caesalpinia decapetala, Careya arborea, Clerodendron infortunatum, Cuscuta reflexa, Phyllanthus emblica, Hemidesmus indicus, Holarrhena antidysenterica, Lagerstroemia speciosa, Rouvolgia serpentina, Semecarpus anacardium, Soymida febrifuga, Streblus asper, Terminalia bellirica and T. chebula to be used as medicines. In addition to these uses, minor forest produces such as ‘mahua’ flower and seeds, myrobalan fruits, tamarind fruits, ‘karanj’ seeds, ‘siali’ leaves and bark, hill broom, and gooseberry are collected for own consumption and as economic source also.
Misra and Dash (1999) studied the conservation and utilization of minor forest resources in three villages of Phulbani district of Orissa. They found bamboo (*Dendrocalamus* and *Bambusa* spp.), hill broom (*Thysanolaena maxima*), ‘karanj’ seed (*Pongamia pinnata*), ‘mahua’ flowers and seeds (*Madhuca longifolia*), sap of *Caryota urens*, sal leaves (*Shorea robusta*), ‘siali’ leaves and bark (*Bauhinia vahlii*), wild date palm leaf (*Phoenix sylvestris*), thatch grass (*Imperata cylindrica*) and tamarind fruits (*Tamarindus indica*) were collected as NTFP; consumption of wild fruits of *Aegle marmelos*, *Alangium salvifolium*, *Artocarpus heterophyllus*, *Bauhinia purpurea*, *Diospyros melanoxylon*, *Feronia elephantum*, *Ficus racemosa*, *Flacourtia indica*, *Mangifera indica*, *Phoenix humilllis*, *P. sylvestris*, *Semecarpus anacardium* and *Syzygium cumini*; consumption of leaves of *Amaranthus spinosus*, *Bauhinia purpurea*, *B. vahlii*, *B. variegata*, *Cassia tora*, *Celosia argentea*, *Commelina benghalensis*, *Hibiscus sabdariffa*, *Indigofera cassioides*, *Moringa oleifera*, *Oxalis corniculata*, *Polygala arvensis*, *Portulaca oleracea* and *Sphaeranthus indicus*; and various parts of *Abus precatorius*, *Acalypha indica*, *Adhatoda zeylanica*, *Alstonia scholaris*, *Ammania baccifera*, *Centella asiatica*, *Cissus quadrangularis*, *Curculigo orchioides*, *Datura metel*, *Eclipta prostrata*, *Elephantopus scaber*, *Gloriosa superba*, *Mimosa pudica*, *Pavetta indica*, *Phyllanthus fraternus*, *Sida rhombifolia*, *Strychnos nux-vomica*, *Vanda tesselata*, *Vitex nigundo* and *Woodfordia fruiticosa* to be used as medicines for various diseases.

Discussing the plant diversity and sustainable development in a tribal village of Eastern Ghats of Orissa, Dash and Misra (1999) reported that the plant resources (wild and cultivated) available in and around the villages almost met the day-to-day requirements of the people for their subsistence. Except for a few commodities, these tribals depend on the biodiversity resources of the area. The plants yielding edible fruits in the studied villages were *Aegle marmelos*, *Alangium salvifolium*, *Anacardium occidentale*, *Annona reticulata*, *A. squamosa*, *Artocarpus heterophyllus*, *Carissa carandas*, *Diospyros melanoxylon*, *Feronia limonia*, *Ficus racemosa*, *Flacourtia indica*, *Lantana camara*, *Mangifera indica*, *Phoenix sylvestris*, *Phyllanthus emblica*, *Semecarpus anacardium*, *Syzygium cumini*, *Tamarindus indica*, *Ziziphus mauritiana* and *Ziziphus oenoplia*. Plants used as leafy vegetables are *Amaranthus spinosus*, *A.
viridis, Bauhinia purpurea, B. variegata, Borreria articularis, Canthium parviflorum, Cassia tora, Celosia argentea, Commelina benghalensis, Glinus oppositifolius, Hibiscus subdariffa, Indigofera cassioides, Marsilea minuta, Moringa oleifera, Murraya koenigii, Oxalis corniculata, Polygala arvensis, Portulaca oleracea and Sphaeranthus indicus. The flowers of Bauhinia purpurea, B. variegata and Moringa oleifera were used as food. The villagers used 18 timber yielding tree species, viz., Anogeissus acuminata, Careya arborea, Dalbergia lanceolaria, D. latifolia, D. paniculata, D. sissoo, Gmelina arborea, Haldina cordifolia, Lagerstroemia parviflora, Lannea coromandelica, Mangifera indica, Mitragyna parvifolia, Phoenix sylvestris, Pterocarpus marsupium, Shorea robusta, Tectona grandis, Terminalia alata and Toona ciliata for construction and/or repair of thatched houses and for making agricultural implements. Three plants were used as stimulant. Sap of Caryota urens was extracted from the plant and consumed as such or after fermentation as liquor. It was observed that some of the villagers live on the sap for days together without food. Rolled dried leaves of Diospyros melanoxylon were smoked as ‘bidi’. Flowers of Madhuca longifolia var. latifolia were used for preparation of country liquor through traditional method. Seventeen plants worshipped by the people, particularly during different socio-religious functions, were Aegle marmelos, Anisomeles indica, Azadirachta indica, Butea superba, Dendrocalamus strictus, Phyllanthus emblica, Ficus racemosa, F. religiosa, Madhuca longifolia var. latifolia, Mangifera indica, Mimosa pudica, Martynia annua, Ocimum basilicum, Saraca asoca, Sesbania grandiflora, Tamarindus indica and Terminalia bellirica. This mode of preservation of natural vegetation over a long period of time reflects the social and ecological stability of the region. Apart from grasses, 13 plants were useful as fodder. In these villages stall feeding is not a common practice. Thus cattle are left free to the nearby forests for grazing. In absence of sufficient or no rangeland/grazing land, the adjacent forest plays a vital role in solving the fodder problem of the villages. The principal fodder plants are: Ailanthus excelsa, Artocarpus heterophyllus, Cipadessa bacifera, Desmodium gangeticum, D. triflorum, Flacourtia indica, Garuga pinnata, Indigofera cessoides, Mitragyna parvifolia, Symplocos racemosa, Tamarindus indica, Ziziphus mauritiana and Z. oenoplia. For fuel, the villagers mainly depend on wood biomass which was collected from the nearby forest.
In addition, a substantial amount of commercial fuel wood was also exported from the village ecosystem. Sixteen plant species were used in the villages as fuel wood, viz., Ailanthus excelsa, Alangium salviifolium, Albizia procera, Anogeissus acuminata, A. latifolia, Bridelia retusa, Buchanania lanzan, Careya arborea, Carissa carandas, Cassia fistula, Celtis occidentalis, C. sophera, Cassia glauca, Cipadessa basifera, Clerodendrum viscosum and Garuga pinnata. The whole plant or parts of the plant used as medicines were Achyranthus aspera (tooth-ache), Andrographis paniculata (cattle wound), A. paniculata (skin diseases), Asperagus racemosus (urinary discharge), Azadirachta indica (skin diseases and worm), Breynia vitis-idea (eye diseases), Centella asiatica (madness), Cissus quadrangularis (rheumatism and bone fracture), Grangea maderaspatana (stomach diseases), Madhuca longifolia var. latifolia (dysentery), Mucuna prurita (worms), Phyllanthus fraternus (jaundice and liver diseases), Pergularia daemia (toothache), Pongamia pinnata (toothache), Sida cordifolia (fracture and swelling), Tamarindus indica (injuries), Tridax procumbens (antiseptic), Vanda tessellata (otitis) and Woodfordia fruticosa (unconsciousness). Leaves of Acalypha indica (mouth infection), Adhatoda zeylanica (cold and cough), Ammannia baccifera (stomach diseases), Barleria prionitis (ringworm and rheumatism), Eclipta prostrata (jaundice and live diseases), Holarrheana pubescens (rheumatism), Jatropha gossypifolia (purging), Leucas aspera (sinusitis), Pavetta indica (skin diseases), Plumbago zeylanica (snake bite), Polycarpea corymbosa (boils and inflammatory swelling), Solanum nigrum (constipation), Tribulus terrestris (body ache) and Vitex nigundo (fever and toothache) were used as medicine. The roots/underground parts of Caesalpinia bondu (dysentery), Curculigo orchioides (gonorrhea), Datura metel (pimples), Elephantopus scaber (pimples infants), Gloriosa superba (abortion), Hemidesmus indicus (dysentery and diarrhea), Mimosa pudica (urinary diseases), Oldenlandia corymbosa (liver diseases), Polygala arvensis (fever), Sida rhombifolia (bile complaint in children) and Tephrosia purpurea (toothache) were used as medicine. The barks of Alstonia scholaris (fever), Diospyros melanoxylon (diarrhea and dyspepsia), Erythrina variegata (dysentery and indigestion), Lagerstroemia parviflora (wounds), Lannea coromandelica (dysentery and indigestion), Mangifera indica (rheumatism) and Syzygium cumini (food poisoning and snake bite) were used as
medicine. The seeds/fruits of *Abras perotorius* (ophthalmic diseases), *Cassia fistula* (constipation), *Pongamia pinnata* (oil against rheumatism), *Sapindus emergenatus* (pain), *Semecarpus anacardium* (cattle foot and mouth diseases), *Solanum surattense* (toothache), *Strychnos nux-vomica* (pale), *Terminaliabellirica* (cold, constipation and acidity), and *T. chebula* (cooling agent and skin diseases) were used as medicine.

Girach *et al.* (1996) reported, from Bhadrak district of Orissa, that various plant parts of 37 plant species, viz., *Abutilon indicum, Achyranthes aspera, Annona squamosa, Caesalpinia bonduc, Capparis zeylanica, Cassia sophera, Cayratia pedata, Cocos hirsutus, Cuscuta reflexa, Ficus hispida, Hemidesmus indicus, Ipomoea sepriaria, Mimosa pudica, Solanum trilobatum, Plumbago zeylanica, Tridex procumbens*, etc. were being used by local tribals for headache, boil, antidote for fish sting, sneezing and cold, earaches, as purgative, against malarial fever, diarrhea, dysentery, etc. Girach *et al.* (1997) discussed plant species being used as food by the tribals of Bhadrak district of Orissa. Consumption of sap of wild date palm is very common among tribals, and distillation of mahua (*Madhuca latifolia*) liquor and molasses liquor using barks of *Terminala tomentosa, Cassia fistula, Semecarpus anacardium* and *Hemidesmus indicus* root have been reported by Naidu and Misra (1998). Misra and Das (1998) reported 23 plant species for veterinary use by the ‘Sabar’ tribe of Ganjam district of Orissa. Girach *et al.* (1998) reported 29 veterinary prescriptions based on 25 plant species being used by tribals of Bhadrak district of Orissa. In the above two reports on veterinary uses, only 3 species viz. *Abras precatorius, Cissus quadrangularis* and *Paederia scandens* were common. However, the uses of these three plant species were not for the same proposes by the tribals of Ganjam and Bhadrak districts of Orissa. Girach *et al.* (1999) reported use of various plant parts of 37 plant species to be used in curing skin diseases by the tribals of Bhadrak district of Orissa. Mainly leaves, either crushed or made into paste, were used. However, crushed seeds, seed oil, stem bark and latex are also sometimes used. Girach *et al.* (2001) reported 25 plant species being used by ‘Unani’ physicians in Bhadrak district of Orissa and they suggested that four species, viz., *Crataeva magna* (in removing stone from the bladder), *Martynia annua* (in dermatitis), *Paederia foetida* (in rheumatic joint’s pain) and *Streblus asper* (in filariasis) needed immediate attention.
Senapati et al. (2001) listed 16 plant species being used by tribal healers in Mahendragiri Hill Ranges of Eastern Ghats. They informed use of jelly of *Aloe varvadensis* for burn injuries, paste of dried roots of *Nyctanthus arvortristis* with garlic for malaria, grains of *Eleusine coracana* to reduce blood pressure, leaves of *Calotropis gigantea* for abortion, dried roots of *Ferula asafetida* for treatment of ovary problems, roots of *Carica papaya* to cure jaundice, rhizomes of *Nymphaea nouchalli* for diabetes, paste of root of *Cicca acida* for treating goitre, leaves of *Calotropis procera* for boils, powder of the seeds of *Laportea iterrupta* to inhibit hairfall, roots of *Hemidesmus indicus* for jaundice, dried roots of *Plumbago zeylanica* with bark of *Plumeria acuminata* for abortion, root paste of *Lawsonia inermis* for curing jaundice, flower and bark of *Moringa oleifera* for treating abdominal pain of women and root of *Rauwolfia serpentina* for snake bite. Misra and Dash (2002) recorded uses of various parts of 108 plant species for curing 44 diseases by the tribals of Koraput district of Orissa.

Misra et al. (1993) discussed the medico-ethnobotany of *Calotropis gigantea* and *Calotropis procera* and reported that these two species of *Calotropis* hold a pride of place in Indian ethnobotany largely because of their other uses and economic values. The fiber extracted from the bark of the stem is white, silky, strong, flexible and durable, and is used to make rope for cots, gunny bags, fishing nets and bow strings. It is even considered superior to cotton and jute. The wood is used as cheap fuel and the seed hair is used for stuffing mattresses and pillows (Mitte, 1981). Latex is used in tanning industries, a source of hydrocarbons and as a fish poison (India, 2006). Almost all parts of these species, viz., fruit, flower, root, bark and latex are used by the tribal’s to cure various diseases. They reported that *C. gigantia* is more in medicinal uses than *C. procera*.

Misra (2004) discussed the use of plant or plant parts for various diseases by the rural and tribal people of Orissa. He reported medicinal uses of 358 taxa against the diseases the people of Orissa suffer from. Ninety agiospermic families (78 dicotyledons and 12 monocotyledons) and five pteridophytic families represented these 358 medicinal plants under use. These included 313 dicotyledon (236 genera), 40 monocotyledons (33 genera) and 5 pteridophyts (5 genera). Ten dominant angiospermic
families were Euphorbiaceae (31 species), Fabaceae/Papilionaceae (23), Asteraceae (20), Rubiaceae (17), Lamiaceae (13), Verbenaceae (10), Acanthaceae (10), Caesalpiniaceae (10), Malvaceae (9) and Solanaceae (9). These 10 families represented 152 species and 99 genera. Under monocots, Orchidaceae, Zingiberaceae and Poaceae represented 9, 8 and 7 taxa, respectively. Monocotyledons represented 40 species under 33 genera. Pteridophytes were represented by five taxa under five genera and five families.

Koraput district of Orissa is rich in plant wealth, but the natural vegetation is depleting at an ever increasing rate due to anthropogenic interference. In past, several attempts have been made to study the medico-ethno-botanical aspects from various regions of Koraput district. Rai Chaudhary et al. (1975) reported 26 medicinal plants from this district. Patnaik et al. (1986) discussed some useful plants among Dongrias of Kurli hill of this district. While dealing with flora of undivided Koraput district, Das (1991) and Das and Misra (1987, 1988a, 1988b) studied the ethno-botanical aspect of the district with particular reference to Chandrapur and Deomali hills of Koraput district.

After a study of the use of medicinal plants by the tribals of Deomali and adjacent areas of Koraput district, Orissa, Das and Misra (1987) reported that people of these areas were mostly dependent upon ‘Padhans’ (Village doctors), who were aware of most of the treatments for various diseases. They reported use of Ardisia solanacea fruits’ paste and leaf paste of Oxalis corniculata for headache, rhizomes of Angiopteris evecta, twig of Cissampelos pareira, bark of root and small roots of Hollarrhena antidysenterica for body ache, roots of Glossogyne pinnatifida and leaf of Vitex negundo for toothache, plant juice of Tephrosia purpurea and rhizome of Zingiber zerumbet for rheumatism, tender twigs of Murraya koenigii for fever, boiled flowers of Leucas aspera with cow milk for anemia, twig of Carum strictocarpum for enlarged spleen, root juice mixed with garlic juice being given to ladies immediately after delivery as a tonic, underground parts of Curculigo orchioides and Tephrosia purpurea to cure gonorrhea, juice of plants and rhizomes of Costus speciosus for filariasis, latex of Euphorbia hirta for eye sore, tender twigs of Euphorbia heyneana
boiled in cow milk to nourishing mothers and to cattle also to yield more milk, bark juice of *Hollarrhena antidysenterica* to cure excessive bleeding after delivery, plant of *Oxalis corniculata* for skin disease, leaves of *Pergularia daemia* to cure eye disease of cattle and leaves of *Erythrina suberosa* to cure wounds of cattle affected by larvae of housefly. They also reported that powder of dried plants of *Leucas aspera* is fumed in the house to ward off evil spirits and stem piece of *Woodfordia fruticosa* is tied on the neck of patient suffering from unconsciousness. In this list, some more plants were added by Das and Misra (1988a) while studying the use of medicinal plants by Kondhas in Koraput district. They reported use of root of *Achyranthus aspera* for toothache, root of *Asparagus racemosus* to check excessive bleeding, juice of stem bark of *Azadirechta indica* for diabetes, bark of *Cassia fistula* for headache, *Centella asiatica* for madness, tuberous root of *Curculigo orchioides* to cure enlarged spleen, root paste of *Crotalaria bialata* for epilepsy, rhizome of *Costus speciosus* for dysentery, root of *Datura metel* for boils and pimples, root of *Jasminum roxburghianum* to cure rheumatism, vegetative bud of *Madhuca longifolia* together with *Diospyros melanoxylon* to cure dysentery, root of *Plumbago rosea* to cause abortion, root of *Naringi crenulata* with root of *Strychnos nux-vomica* to cure stomachache, root of *Rauvolfia serpentina* for snake bites and scorpion sting and for relief from pain after menstrual cycle, entire plant of *Solanum xanthocarpum* with bark of *Adhatoda vasica* to cure cough, stem bark of *Strychnos nux-vomica* to cure skin disease and complaints due to excess acidity, etc.

Dealing with some medicinal plants of undivided Koraput district, Das and Misra (1988 b) informed that there are mainly three different types of herbal healers found in the district; first, the druids (as Jani, Dohari, Disari or Majhi) of the regional Gods and Goddesses who perform various religious rites followed by the medication to the patients, second, the village headman or the head of the community, who prescribes various plants available in the area along with the method of their uses, and third, the kaviraj, who collects different plant parts during various seasons, stores them after processing and supplies to the patients in the form of decoction, tablets, paste or powder. They reported 33 species to be used for cure of 22 diseases including child crying. They also reported that use of liquid forms as ear or nasal drops for various aches is rare among Indian tribes, which is common among African tribes.
Dash and Misra (1996) reported that various parts of 32 plant species were being used for medicinal purposes by tribals of Narayanpatna region of Koraput district of Orissa. Decoction of *Acalypha indica* is used as a laxative; paste of *Aerva lanata* is used for herpes; root paste of *Amaranthus spinosus* is applied around boils and carbuncle for speedy burst and its leaves are eaten as vegetable; crushed leaves of *Andrographis paniculata* with turmeric is used for skin infections; leaf paste of *Annona squamosa* is applied to cattle to cure cuts and wounds; leaf juice of *Argemone mexicana* is applied on eye corners to cure eye infections; paste of stem of *Bambusa bambosa* is used to stop excessive bleeding and young shoots are consumed as vegetable; paste of *Cissus quadrangularis* along with ragi is baked and is used to cure rheumatic pain; leaf paste of *Curcuma angustifolia* is used for constipation; latex of *Ficus racemosa* with salt is used for bodyache; bark paste of *Helicteres isora* as a remedy for scabies; root paste of *Hemidesmus indicus* with milk is used to cure dysentery and diarrhea; stem juice of *Ipomea carnea* used as antiseptic to small cuts; paste of flower ash of *Leonotis nepetaefolia* is applied to burns; paste of whole plant of *Mimosa pudica* is applied on the body during collection of honey to avoid wasp and decoction of root is used for urinary complaints; whole plant of *Mollugo pentaphylla* is dried and its paste is applied on skin diseases; smokes of *Ocimum basilicum* is used as insect repellant; latex of the stem of *Pedilanthus tithymalodies* with castor oil is externally applied to alleviate pain; in case of eye inflammation or eye infection in cattle, the leaf paste of *Phoenix sylvestris* is used; fresh root decoction of *Phyllanthus fraternus* is taken orally to cure jaundice and paste of whole plant is used for skin diseases; leaf paste of *Plumbago zeylanica* is used as antidote in snake bite and decoction of bark is taken orally to cure dysentery; decoction of bark of *Pterocarpus marsupium* is taken orally in stomachache; oil extracted from nuts of *Semecarpus anacardium* is applied for cough and pharyngitis; paste of boiled plant of *Sida cordifolia* is applied on fractures and swellings; dried fruit powder of *Solanum nigrum* is used to alleviate toothache; decoction of fruit of *Solanum surattense* is taken orally to cure cough; fruits and leaves of *Strychnos nux-vomica* are crushed and mixed with water as fish poison and its fruits are sold also; bark powder of *Strychnos potatorum* is applied on cuts or wounds as antibiotic; bark paste of *Syzygium cumini* with common salt is taken orally for food poisoning and bark paste and seed
paste are used as an antidote for snake or scorpion bite; bark charcoal powder of *Tamarindus indica* is applied on bone injuries; whole plant of *Tephrosia purpurea* is crushed and applied on cattle to ward off fly and lice; and latex of fruit of *Thevetia peruviana* is used as an antiseptic.

Misra and Dash (1997) reported 89 plant species to be used by the tribes of Koraput district of Orissa for their day to day medicinal requirements.

Many more literatures on ethnobotany may also be available and many more information on ethnobotanical knowledge held by tribals across the country may not be reported yet, and it is a fact that most of the uses are endemic to the community or a tribe only. It is very difficult to judge the effectiveness of the traditional medicines. The magico-spiritual and religious beliefs may not have a scientific basis, but it has great impact on the psychology of the patient (Misra, 1999). The tribals use the medicines only through the traditional healers with a strong spiritual belief. Gelfand (1970) has rightly stated that the spiritual and magical aspects of this practice cannot be ignored. However, further research on these medicinal plants will provide an insight to improve the quality and effectiveness of these traditional medicines. The recent interest in traditional medicines arose not only from the fact that some of the prescriptions of the traditional healers may be of benefit to the mankind, when thorough research is conducted into their properties, but also from the complications caused by some of the medications used by the same healers (Arnold and Gulumian, 1984). The remedies traditionally used in the developing countries may prove helpful for different diseases found in developed countries. Realising the potentiality of plants to serve as diverse source of new drugs, action should be initiated for their conservation (Misra, 1999). Misra and Dash (2002) reported that mining and various other developmental activities along with ‘Podu’ and preparation of charcoal from wood are the main causes of deforestation in Koraput district of Orissa; and due to this alarming situation, conservation of medicinal plants is very important, as most of these species have been reduced to a greater extent, and even some of them have disappeared from the district.