CHAPTER 2:

LITERATURE REVIEW

1. Literature review

This contains the research and review work done by various authors in India and worldwide. Their findings were useful for guiding the current research. Such findings are described briefly in this chapter. Also, references from reviews have been used. Some findings have been highly supportive. However, some observations have been contradicting our findings as well.

2.1. Mining and Reclamation

Coal mining is an important activity as it is related to the development of a country. India currently ranks 3rd in the production of coal and lignite (6.8% of world production – US Dept Energy, 2011; Ministry of Coal, National Govt. of India, 2011) as well as contributing significantly to the production of other mined commodities such as mineral fuels, metallic minerals, industrial materials, and metal alloys (Kuo, 2005; Khullar, 2006). Coal exploration creates ecological imbalances and is a matter of concern especially as open cast mining gives rise to big hillocks called overburden dumps. These dumps are disturbed soil profiles which have loose rock and soil components. They often collapse and create lots of hazard in the mining area. They also cause river siltation and air pollution. The most serious impact of mining is the land degradation and habitat destruction of the ecosystem as a whole. Thus restoration activity is often required to curb the pollution effects. The reclamation procedure is cost and labor intensive. As the open cast mining is continued, for the same seam in the same area, dumps cannot be restored as the seam lying below has to be mined immediately one after the other. Thus problem becomes acute due to coal seam fire in Jharia Coalfields (Ferris, 2015).

Bradshaw (1996) defined the components of restoration with respect to chemical and physical aspects of the habitat and the species themselves. Each of these may require specific treatment, but natural restorative processes (succession) should not be neglected. The process of restoration being progressive, the criteria of success are not easy to define. The most important point is that ecosystem development should be on an unrestricted upward path. In Fig. 2.1, a different option for improvement of the degraded ecosystem is explained in terms of two major components of ecosystem structure (species composition and complexity) and ecosystem function (biomass and nutrient contents). When degradation occurs, both components are destroyed. Thus, the ecosystem must be brought back to its original state in terms of both structure and function as much as possible.

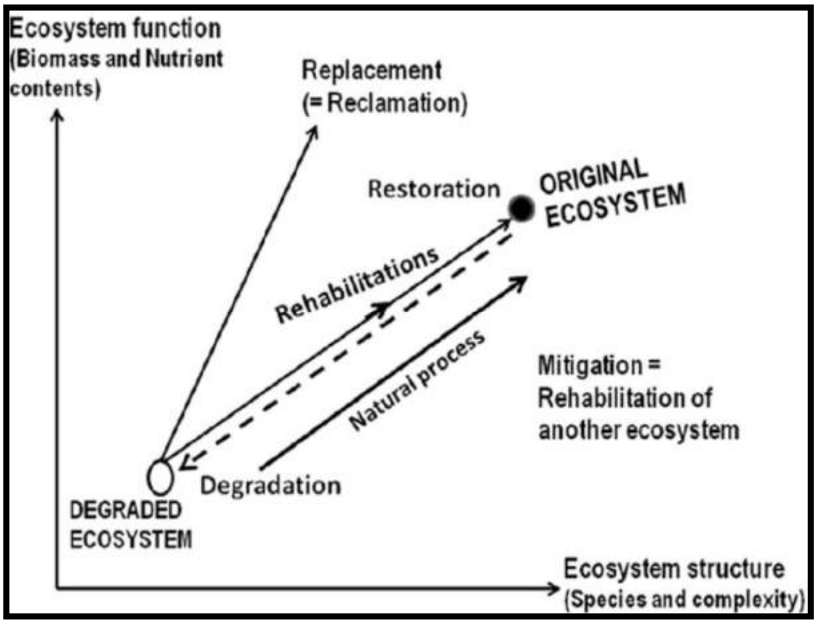

Fig. 2.1 Options for reconstruction of degraded ecosystem (Bradshaw, 1996)

With reference to mine reclamation, the ultimate land-use should be compatible with either the current land-use in the surrounding area or with the pre-mining environment (Soltanmohammadi et al., 2010). Opencast lignite mining, which requires removal of large areas of topsoil followed by the coal or lignite, the final landscape, can be topographically lower than the original. Opencast sites are therefore prone to flooding. Hence these dumps are to be reclaimed for making mining a sustainable activity. Reclamation is the process of getting back the lost properties of a system. The main goal of reclamation is to return affected areas as near as possible to their economical and ecological value. It does not aim to return them to the original state (UNEP, 1983). At the local scale, reclamation involves an examination of surrounding landscapes, in combination with determining predicted succession trends of vegetation communities appropriate to enhance local and regional ecosystems (Policy and Corporate Services Division Environmental Assessment Branch, 2009). Types of post-mining land use can include: land reverts to the initial state /agricultural activities /forest and wildlife sanctuaries and creating tourist attractions the industrial and residential settlements (Akbari et al., 2007). However, the initial stage is difficult as the spoils are not suitable for plant and microbial growth because of low organic matter content, unfavorable pH and drought arising from coarse texture or oxygen deficiency due to compaction (Agrawal et al. 1993). The other limiting factors for revegetation of mine spoil may be salinity, acidity, and poor water holding capacity, inadequate supply of plant nutrients and accelerated rate of erosion (Jha and Singh 1991, Dutta and Agrawal 2000). Restoring these dumps is initially tough. It requires suitable stress resistant plant species and also suitable soil environment for their establishment and growth.

The cycling of nutrients regulates the sustainability of plant community. Without cycling, nutrients will be lost or immobilized and the plant community will not be capable of regeneration. Berg and Barrau (1978) suggested that rapid reestablishment of the nitrogen cycle is important, but often difficult to achieve in mine spoil. Often soil amendments are required to speed up the restoration process. But choosing soil amendments is also a matter of concern. Soil amendment should always make restoration as economical as possible otherwise, the stakeholders will avoid the reclamation task. It is often necessary to establish and maintain a vegetative cover without the use of topsoils or other bulky amendments (Rimmer, 1982). Natural plant succession is also very slow on coal mine spoil land. The artificial raising of plantations may accelerate this process leading to a self-sustained ecosystem in a relatively short period of time (Singh and Singh, 1999).

Tordoff et al. (2000) reported that revegetation is considered to be the most suitable to achieve long-term reclamation. Vegetation can provide effective protection against the wind carried polluted particles. Research demonstrates that forest vegetation on surface coal mines can be productive. When properly reclaimed for reforestation, mine soils provide deeper rooting zones and are richer in the geologically derived nutrients Ca, Mg, and K than many native soils in steep mountain landscapes. Tree productivity on certain pre- SMCRA (Surface Mining Control and Reclamation Act of 1977) mine sites in the USA, has been documented as equivalent to, or better, than that of adjacent unmined forests. In an early study, Ashby et al. (1980) found high growth rates for many hardwood species planted on reclaimed coal mines in southern Illinois. Rodrigue et al. (2002) reported that forest growth on 12 out of 14 selected older coal mine sites in the eastern and mid-western US achieved productivities similar to local unmined forests. Once the vegetation is established, the improved soil condition, in turn, promotes plant succession. The degree of ecosystem development can be assessed by the level of vegetation recovery and nutrient status of the spoils (Banerjee et al., 2004).

The establishment of a stable plant cover is considered a suitable option to get long-term reclamation (Whiting et al., 2004; Simon, 2005; Conesa et al., 2007a). It is useful to search plants that have spontaneously colonized mining sites and therefore, are completely adapted to these polluted environments (Conesa et al., 2007b). Mummy et al. (2002) stated that after 20 years of reclamation, total plant cover can recover to pre-disturbance levels, but soil total microbial biomass (bacterial and fungal), biomarkers averaged only 20, 16 and 28%, respectively, of amounts found in undisturbed soil. Reclamation study done by Sadhu et al. (2012), on nearby Raniganj coal mines, compared the soil quality of native soil with mines spoil.

In many situations, true restoration may be unrealistic, and realistically, rehabilitation and replacement can be proper options. Replacement is a particularly interesting option since it may allow restoration of a component, such as productivity, to a higher level than that existed previously. The structural and functional ecosystem characteristics that are usually measured during ecorestoration process are given in Table 2.1.

Table 2.1 Ecosystem characteristics for consideration as ecological restoration objectives (Cooke and Jhonson, 2002)

Sl.N.	Ecosystem characteristics
1.	Composition of species presence and their relative abundance
2.	Structure: vertical arrangement of vegetation and soil components
3.	Pattern: horizontal arrangement of system components
4.	Heterogeneity: a variable composing of characteristics 1–3
5.	Function: performance of basic ecosystem processes (energy capture, water retention, nutrient cycling)
6.	Species interactions, for example, pollination and seed dispersal
7.	Dynamics and resilience: succession and state-transition processes, ability to recover from normal episodic disturbance events (e.g. drought, fire)

2.2. Factors affecting vegetation in mine spoil

Soil and site factors influence the speed of natural succession on mine sites. For example, use of excavated soils that contain living seeds and roots from the native forest in reclamation areas can accelerate natural succession. Groninger et al. (2007) observed that mined areas that are close to the unmined native forests are colonized by native forest species more rapidly than sites farther from unmined forests. Succession and invasion of native species over 47 years formed a forest on this mine site in eastern Tennessee. Succession occurred over the years and the pine forest was replaced with vegetation similar to the nearby native forest: yellow-poplar dominant in the overstory, red maple, sassafrass and northern red oak in the mid-story, and blueberries, ground pine, Virginia creeper and ferns in the understory.

Nutrient recycling and its availability on reclaimed sites are reflected by the rate of decomposition of plant material. Litter decomposition in mined land versus unmined land is often retarded during the initial months after reclamation (Lawrey, 1977). The presence of heavy metals which reduce soil pH and the lack of an existing litter layer create an unfavorable microclimate for soil microbes (which are responsible for breaking down organic matter). Decomposition rates begin to equalize after six months indicating increased microbial activity, but the initial dearth of recycled nutrients could impede the establishment of new plants. Williamson and Johnson (1990) reported that soil organic carbon content recorded during their study was low in comparison to that reported in the topsoil stock piles of four years old mounds at Cumbria and Staffordshire, U.K. The lower level of organic carbon in mine spoil soil might be due to the disruption of ecosystem functioning (Stark, 1977), depletion of soil organic pool (Parkinson, 1979) and loss of litter layer during mining which is an integral storage and exchange site for nutrients. Biological restoration is the ultimate method to stabilize the spoils. Landscape position is a combination of site aspect and topography, so the direction of slope, slope steepness, and location on the slope are the primary factors to consider when selecting tree species for planting (Davis et al., 2012). Indigenous species are preferable because they are more likely to fit into the fully functional ecosystem and are climatically adapted (Li et al., 2003; Chaney et al., 2007). Grasses are considered as a nurse crop for an early vegetation purpose as they provide a protective mat over the soil. Although many crop tree species provide wildlife benefits, tree and shrub species of lesser commercial value but important to wildlife value also occur in natural forests. Such plant species can also be introduced at reclamation sites.

Topography is an important factor, which is described as the surface shape, relief or terrain, and elevation of a site’s position on the land surface. Topography influences soil moisture availability. Steep slopes are drier than more gentle slopes because they shed more rainfall as runoff, allowing less water to infiltrate the soil (Maiti, 2013).

2.3. Soil structure and particle size

Soil structure is the aggregation of soil particles in a particular fashion depending on the relative proportion of the soil particles, organic matter, and other cementing elements. Soil aggregation affects the degree to which oxygen, water, and nutrients flow through the soil (Lindemann et al., 1984) and may reduce erosion potential (Elkins et al., 1984). Aggregate structure breaks down as successive layers of soil are removed and stockpiled elsewhere on the site when mining begins. The water holding capacity and aeration depend on the soil aggregates. The loose subsoil is very important to plant root systems. The extent of the root system determines a plant's ability to maximize its surface area and access a greater volume of water and soil nutrients. McSweeney and Jansen (1984) reported that the plants grown in fritted subsoil have extensive vertical and lateral penetration in rooting patterns. Root growth in compacted soils are limited to cracks occurring in the substrate and achieve little additional soil penetration. Particle size distribution is a major factor in governing a successful revegetation on reclaimed land as it influences water holding capacity, bulk density, soil moisture availability and nutrient contents as well as availability. Dutta and Agrawal (2002) reported that the values obtained for bulk density of reclaimed soil higher than the native forest soil, but lower than the fresh mine spoil.

If the volume of stones is more than about a third of the volume of the soil, then it likely has a strong effect on water storage and nutrient availability to the plant. The effect will be particularly severe if stones are close in contact with one another, which reduces the volume of soil available for roots to explore for water and nutrients (Down, 1974). They have an important effect on water storage capacity in seasonally dry climates and mine soil (Rimmer, 1982). The stoniness fraction in overburden dump materials is generally found between 40 and 60%, sometimes as high as even 80–85% (Maiti 1995, 2007). The low moisture retention of about 25% was reported for most of the coal mine spoil in Pennsylvania (Pederson et al., 1988).

The soil moisture content as observed in a study by Jha and Singh (1991) was higher in comparison to the five years old naturally revegetated mine spoil soil of nearby area (4.6%). Their research also depicted a positive relationship between soil moisture content and height of the tree species (*Acacia auriculiformis* Benth., *Casuarinas equistifolia* L., *Cassia siamea* Lam., *Eucalyptus hybrida* Maiden, *Grevillea pteridifolia* Knight). Maiti et al., (2002) worked on the particle size distribution versus depth in one of the overburden dump and mined-out area of Jharia coalfield. They observed that in the top 15-cm layer had 56–65% fractions of particle size more than 5.6 mm which is a very coarse and big fraction of the soil. Maiti et al. (2006) concluded that the average percentage of sand, silt and clay reported for some of the Indian coal mine spoils was as follows: 12–20%, 25–30% and 52–60% (Parej Opencast Project, Central Coalfields Limited); 25, 31 and 44% (Bina, Northern Coalfields Limited).

In the majority of cases, mine spoils have very low moisture contents (3.4–4.4%), and in dry summer, it comes down to less than 3% (Maiti, 2003). In a 5-year-old overburden dump of Jingurda mine of Northern Coalfields Limited, Jha and Singh (1992) reported moisture contents to range between 2.6–5.4%. In the case of Bina mine OB dump (Northern Coalfields Limited), it was found only 4.4%. In OB dumps of Bharat Coking Coal Limited area (Rajapur dumps), it was found only 2.3–6% during lean seasons (Maiti, 1995). In other land use, like a forest, grassland, and cultivated land, this value was found 12–15%, 13–16% and 10–12%, respectively. The moisture contents in different dumps of Jharia coalfields were found to range between 2.3–6%.

2.4. Soil pH

The general range of pH for plant growth is 5.5–7.5. Soil acidity is common in the regions where precipitation is high enough to leach appreciable quantities of exchangeable base-forming cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) from the surface of soils, while alkalinity occurs when there is a comparatively high degree of saturation with base-forming cations (Brady, 2000). The effect of pH on spoil plays a role on solubility and availability of metals and other ions, which lead to deficiencies or toxicities. Maximum availability of the primary nutrients, Nitrogen, Phosphorus, and Potassium, as well as secondary nutrients, Sulphur, Calcium and Magnesium, is at a pH range of 6.5–7.5. The availability of minor elements Iron, Manganese, Boron, Copper, Chlorine and Zinc is more in the acidic range than in the neutral or alkaline range (Lyle, 1987).

In the case of coal mine land, it is also important to consider soil pH because acidic soils are a common by-product of mining. Mining typically exposes sulfur-containing pyrites that oxidize to sulfuric acid when exposed to oxygen, water, and certain aerobic bacteria, leaving soil pH at 2.2-3.5 (Gitt and Dollhopf, 1991; Gould et al., 1996). Most plants achieve optimal growth in soil at neutral pH. Acidic mine soils can be effectively neutralized after they have been respread at the reclamation site by applying either cement kiln dust (CaO) or limestone ($CaCO_3$) (Gitt and Dollhopf, 1991). Lime application rates must account for both past and future pyrite oxidation in order to maintain neutral soil pH levels over time or inhibited altogether in acidic environments. High soil acidity inhibits plant root growth by limiting a number of nutrients available for uptake (Lawrey, 1977; Gitt and Dollhopf, 1991). Richart et al. (1987) observed that the change in pH of opencast spoil was directly related to the tree growth.

Maiti (1995) studied the role of natural succession process on the improvement of pH in various dumps of Jharia Coalfields and found that pH improved due to leaching of H^+ ions and accumulation of organic matter. Maiti and Ghose (2005) reported that the pH varies from 4.9 to 5.3 in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area in the Ranchi district of Jharkhand State of India and thus indicated the acidic nature of the dumps. This acidic nature arises due to the nature of geology of the rock present in the area. It has been reported earlier that when pH is less than 5, along with Fe, the bioavailability of toxic metal such as Nickel, Lead, and Cadmium increases (Maiti, 2003). In the majority of cases, pH of mine spoil is found acidic to neutral range. However, in some spoil dumps, like Block-II, BCCL and Ghanashyam OCP, ECL are slightly alkaline pH was found to range from 7.8- 8.5 (Maiti, 1995). It was observed that the pH of the reclaimed soil in Singrauli Coalfields, a subsidiary of Coal India Limited, Madhya Pradesh, was found to increase from 6.30 in OB plantation of the year 2003-04 to 6.68 in OB plantation in the year 2000-01. Against this, the value of pH in the plain plantation of 2000-01 was found to be 6.30, however, in 1990-91 and 1995-96, the pH was found to be 5.49 and 5.45 respectively, as reported by Chaubey et al. (2012). Mukhopadhyay and Maiti (2011) studied pH of reclaimed (4.18–5.35) and unreclaimed dump (4.21–4.92) of Kusunda Opencast Project, Jharia Coalfields and observed that pH goes towards neutral as reclamation process accelerates.

2.5. Selection of plant species

Early research focused on the selection of species for their ability to withstand difficult site conditions (e.g., low pH and organic matter, and high levels of certain elements). Much of the objective was simply to vegetate the site in order to reduce erosion. However, recent research on the restoration of abandoned lands has been focusing on evaluations of commercial timber plantations as initiators of forest succession (Parrotta et al., 1997). Thus, they represent a low-cost method of restoring the native forest vegetation using the succession model of floristics, with a sequential establishment of species (Dobson et al., 1997). This facilitates to create conditions those are conducive to the natural regeneration of understory species. Most importantly, rhizosphere of different plant species affects nutrient cycling (Garcia et al., 2005).

The successful restoration program attempts to accelerate the natural recovery processes to restore the soil fertility and to enhance the biological diversity (Dobson et al., 1997; Khurana and Singh, 2001). In the recent times, increased ecological awareness among researchers, have resulted in search for innovative approaches for revegetation of coal mine area in India and abroad (Zak and Parkinson, 1983; Prasad and Mahammad, 1990; Gupta et al., 1994; Dugaya et al., 1996; Kumar and Jena, 1996; Pandya et al., 1997; Sonkar et al., 1998). The use of native and indigenous plant species has been emphasized in re-vegetation programs with a view to maintaining essential processes, life support system, preservation of genetic diversity and to ensure sustainable utilization of species and ecosystem (Soni et al., 1989; Jha and Singh, 1993; Banerjee et al., 1996).

Since mine spoils lack nutrients so the plant's species selected for restoration must be preferably local, easily available, resistant to water and nutrient stresses, fast growers, having less dormancy etc. Plant species should be compatible with each of the cases mentioned above. Species selection and implant are one of the important steps (Xia and Zhen, 2008). Monterroso et al. (1998); Chen et al. (1998); Maiti and Ghose (2005); Tafi et al. (2006) and Carrick and Kruger (2007) have evaluated the factors limiting plant growth on mined soils and also mentioned the most serious soil limitations. As a result, only species that are coordinated with the type of post-mining land use comply. The second factor for primary selection of plant types is regional climate condition. So at this stage, the types that are accorded with local climatic conditions are selected. The indigenous types have the capability in terms of the compatibility with the climate. Regional Climate includes lighting and sunlight, weather, moisture, temperature, the wind, air pollutants. Then comes the soil quality also which is the third element of primary consideration that among the selected types based on the first and second factors are sometimes rejected (Bangian and Osanloo, 2008). Osanloo (2001) observed that the soil is also considered on the basis of the existence of acid or alkali, salinity, heavy metals, organic materials.

Alavi et al. (2011) reported other factors for plant species selection are the perspective of the region, resistance against disease and insects, strength and method of growth, availability to plant type, economic efficiency, protection of soil and storing water, prevention of pollution. In mined out areas winds are strong because the area is bare so during the first stage of succession some hardy plants species should be selected otherwise the plants will be uprooted and the reclamation process will fail. *Abies* *balsamea* (L.) is especially suitable for the higher elevations because of its tolerance to the wind. Makineci et al. (2011) suggested that plant species on abandoned open coal mine spoils which have no reclamation techniques, show the resistance and survival capability and such species can be selected as target species for coal mine restoration. The native species like *Abies balsamea* L., *Alnus incana* L. *Moench, Populus deltoids* W. Bartram ex Marshall, *Populus tremuloides* Michx., were used for the reclamation of the Usibelli Coal Mine near Fairbanks, Alaska (Bidwell, 1996). These trees tolerate poor, gravelly moist and polluted soils.

Since the ecological restoration of natural ecosystems attempts to recover as much historical authenticity as can be reasonably accommodated, the reduction or elimination of exotic species at restoration project sites is highly desirable. However, there are studies on reclamation using such exotic plant species. Exotic fast-growing species were tried in view of their large scale use in afforestation schemes in the country in a study by Dutta and Agrawal (2003), namely *Acacia auriculiformis* Benth., *Casuarina equisetifolia* L., *Cassia siamea* Lam., *Eucalyptus x hybrida* Maiden and *Grevillia pteridifolia* Knight., in northern coalfields. They concluded that exotic species may be especially recommended for primary rehabilitation on bare coal mine spoil due to their fast growth. Some species like *Alnus incana* (L.) Moench is valuable because of its nitrogen fixing properties.

However, it is better not to use exotic species as they may sometimes create a threat to the indigenous species in terms of their vigor and non-recognition of the herbivores as food sources. This leads to proliferated growth of exotic species. Eucalyptus and Acacia are two types of usually used pioneer trees for land reclamation in tropical and subtropical regions like China, due to some excellent characteristics, such as rapid growth and relatively strong resistance to harsh environments. But eucalyptus has lots of negative ecological effects. It has a huge water absorbing capacity, which makes ground water level decrease drastically. Some kinds of eucalyptus, such as *E. exserta* F. Muell. and *E. urophylla* S.T. Blake, have strong allelopathic effects, or have significant inhibitions on seedlings growth of other plants, thus making the undergrowth vegetation sparse (Zeng and Li, 1997).

Zhou (1997) gave an important revealation that Eucalyptus hardens the soil surface. *Acacia mangum* Willd. or *Acacia aurifuliformis* Benth. has also been utilized extensively in the tropics and subtropics for the identical goal. As a pioneer, it takes good effect for land reclamation and ecological restoration, but its ecological effects decrease gradually after about twelve years. Another drawback often encountered with *A. mangium* is that the branches are brittle and prone to shatter in the case of strong winds or typhoons as reported by Hengchaovanich (1999). Apart from this, the dribbling water drops from leaves of broad-leaved trees generally have a larger diameter, they increase the dash of waterdrops to the forest land, especially in the situation of low intensity of rainfall. Therefore, the canopy of the broad-leaved forest without understory generally hampers the topsoil conservation on forestland as concluded by Zhou (1997 a, b). The primary consideration in the selection of plant species is also based on the nature of mine spoil as well as future land use plan of the eco-restored site have been listed by Maiti (2006) as given in Table 2.2.

Table 2.2 Selection criteria of plant species based on spoil characteristics and future land use pattern (Maiti, 2006).

Primary consideration	Plant species selected
1. Nature of spoil	Metal-tolerant plants
2. Toxic metals at high	Unpalatable species Fencing with spiny shrubs around site perimeter
3. Extreme acidity/alkalinity	Natural invaders of acidic or alkaline conditions
4. High level of salts	Salt-tolerant species Natural invaders of salty area
5. Drought conditions	Drought-tolerant species Certain-metal-tolerant cultivars
6. Poor nutrient status	Legumes or other nitrogen fixer Species that grow in nutrient-poor areas
Based on land use	
1. For wildlife propagation	A variety of native and naturalized species that provide seeds, fruits, palatable herbage, nesting site, etc.
2. For aboriginal or tribal	use Native Species Timber, medicinal or food crops Species that regenerate after practices such as burning of forest
3. For amenity and recreation	Low productivity

Maiti (2013) reported that grasses are more tolerant to adverse soil pH and moisture stress than legumes, therefore, grasses are easier to establish on mine spoils. Trees and shrubs are desired where a windbreak is required or where the visual shield is required. They are also suitable to steep or rocky terrain and coarse waste. The successful vegetation establishment of waste dumps also depends on micro- and macroclimate, disease and insect resistance, competition, growth pattern and propagation ability of the species.

Grasses and herbaceous legumes are generally the first choices because they have strong vitality and infertility-enduring ability (Xia and Shu, 2001); furthermore, the latter can fix nitrogen. However, compared to grasses, the resistance of legumes to adverse conditions is limited. These cannot survive in very harsh habitats. As to grasses and other creepers, many of them have strong resistance and huge biomass and therefore some of them can be used effectively to reclaim degraded land. However, there are still many species of grasses that are not very suitable to be as land stabilization. For example, *Miscanthus floridulus* (Labill.) Warb. Ex K. Schum. & Lauterb. and *Miscanthus sinensis* Andersson), and *Arundinella nepalensis* Trin. generally grow on rocky mountains, but their roots are neither so massive nor strongly penetrative. Another example, *Wedelia trilobata* can produce a very quick and good covering effect on a barren land surface, but it has an allelopathy to other plants, and furthermore it is easy to prone to become a weed. Today, the application of vetiver technique is increasingly extensive. *Vetiveria zizanioides* (L.) Nash, a perennial grass, has been widely accepted as a better alternative for land reclamation in the past twelve years due to its following excellent features:

1. Strong resistance to adverse conditions
2. Strong ability to remove pollutants, which makes it rehabilitate the polluted land rapidly.
3. Huge biomass, including shoots and roots, which make it effectively ameliorate the degraded soil and cover barren land rapidly.

A typical reclamation strategy for selecting species is given in Fig. 2.2. Ecorestoration in mine-degraded site seeks to stimulate natural succession processes leading to the forest. All vegetation types are established at the initial stage (grass and legume seeds are sown in the interspacing of tree rows) of reclamation.

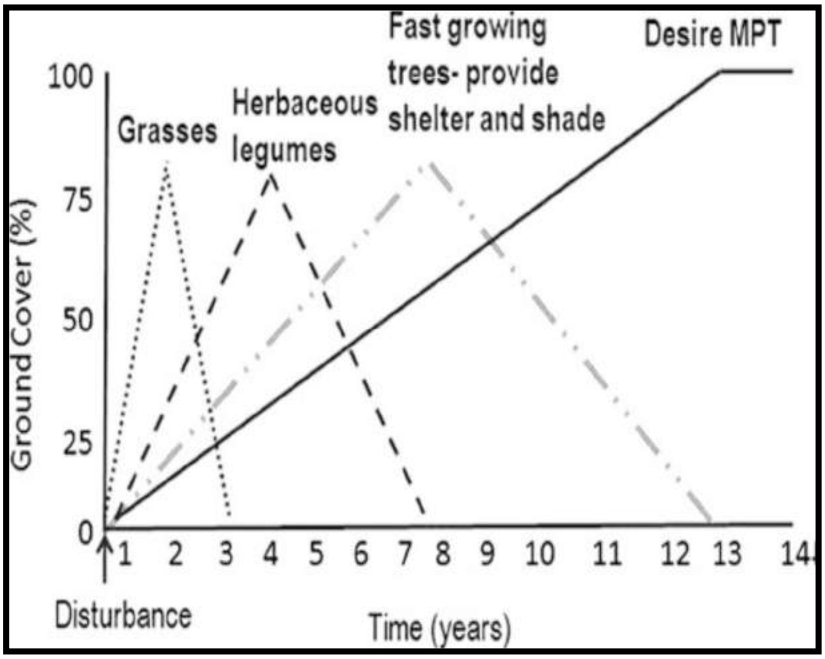

Fig. 2.2: As time passes, grass and legume covers enhance the yield of organic matter and nitrogen for the fast-growing trees and desire multipurpose trees (MPT), which gradually mature and develop forest (Burger and Zipper, 2002).

Chaulya et al., (2000) reported that Sisum and Subabool have been observed to be the dominant tree species in most of the mine spoil sites both in terms of plant height and diameter increment after two years of growth. Sisum contributed the most plant biomass (4.23 kg/plant) while Subabool contributed comparatively very low biomass (0.8 kg/plant). Singh et al. (2004a) studied the influence of mine spoils age on herbaceous biomass yield in a dry tropical environment. Naturally revegetated mine spoils selected were 1-, 5-, 10-, 15- and 20-year-old. The biomass yield increased with increasing age of the spoils. The root, shoot and total biomass were significantly greater on 5-, 10-, 15- and 20-year-old spoils compared to 1-year-old young spoil.

Hazarika et al. (2006) conducted a study on coal mine spoils at Tikak Colliery, Assam and found that 24 naturally occurring plant species were observed in different mine spoils.

In one-year-old mine spoil, 12 plant species were recorded, of which, *Macaranga denticulata* (Blume) Mull.Arg. was a tree, 8 were herbs and 3 kinds of grass. No shrub was observed on this dump. In the 5-year-old mine spoil, out of 13 plant species recorded, 1 was a tree, *Schima wallichii* (Choisy), 1 shrub, 5 herbs, 3 ferns and 3 grass species. In 10-year-old spoil the 15 plant species included 2 tree species (*Macaranga denticulata* and *Schima wallichii*), 1 shrub, 8 herbs, 1 fern and 3 grass species.

The reclamation strategies adopted in the Kurasia opencast mines in Chirimiri area of SECL was studied during July 2005 and April 2006 (Maiti, 2007). The overburden dumps and mined-out areas were reclaimed by a plantation of tree species. The plantation was carried out by Chhattisgarh Van Vikas Nigam at the rate of Rs.50/tree sapling, which includes digging of pits and overall maintenance for 3 years. Thus reclamation was cost effective. In the reclaimed overburden dumps of Singareni coalfields (Maiti and Reddy, 2003), tree species comprised of, *Melia azedarach* L., *Prosopis juliflora* (Sw.) DC., *Gmelina arborea* Roxb., *Cassia siamea* Lam., *Acacia auriculiformis* Benth., *Dendrocalamus strictus* (Roxb.) Nees, *Ailanthus excelsa* Roxb., *Albizia lebbeck* (L.) Benth. and *Eucalyptus x hybrida* Maiden were planted, and satisfactory growth was found for *Prosopis juliflora, Cassia siamea, Dalbergia sissoo, Acacia auriculiformis, Dendrocalamus strictus and Eucalyptus hybrida*. The survey of vegetation in the reclaimed areas of Jharia coalfield by Maiti (1995, 2003, and 2006) suggested that a large number of species found to be growing well on the reclaimed overburden dumps and other mined-out areas. Those are *Melia azedarach, Gmelina arborea, Prosopis juliflora, Cassia siamea, Dalbergia sissoo, Ailanthus excelsa* Roxb., *Acacia auriculiformis, Pongamia pinnata* (L.) Pierre, *Albizia lebbeck*, Leucaena leucocephala, Dendrocalamus, etc. Out of these, the growth of *Leucaena, Melia, Prosopis, C. siamea, C. fistula, D. sissoo, Acacia auriculiformis, Alstonia and Eucalyptus* were found satisfactory. These tree species are relatively easier to establish and more useful for revegetation of mine spoil. Central Pollution Control Board, New Delhi, (CPCB, 2000) has also suggested plants species for revegetation of mine spoil and degraded areas which are depicted in Table 2.3.

Table 2.3 Suggested multipurpose tree (MPTs) for revegetation of mine spoil (CPCB 2000)

Acacia catechu (L.f.) Willd.	*Acacia nilotica* (L.) Delile	*Acacia tortilis* (Forssk.) Hayne
Albizia procera (Roxb.) Benth.	*Albizia lebbeck* (L.) Benth.	*Azadirachta indica* A.Juss.
Casuarina equisetifolia L.	*Dalbergia sissoo* DC.	*Dendrocalamus strictus* (Roxb.) Nees
Gmelina arborea Roxb.	*Holarrhena antidysenterica* (Roth) Wall. Ex A. DC.	*Holoptelea integrifolia* Roxb.
Leucaena leucocephala (Lam.) de Wit	*Madhuca indica* J.F. Gmel.	*Melia azedarach* L.
Phyllanthus emblica L.	*Pongamia pinnata* L. Pierre	*Prosopis cineraria* Roxb.
Sesbania sp.	*Shorea robusta* Gaertn.	*Syzygium cumini* (L.) Skeels
Tamarindus indica L.	*Tectona grandis* L.f.	*Terminalia arjuna* Roxb. ex DC.
Terminalia bellerica Wall.	*Ziziphus mauritiana* Lam.	

Kumar et al. (2011) studied biodiversity in Ranigunj coalfields. The authors studied biodiversity in differently aged dumps and concluded that coal surface mines in this region can recover a diverse native community quickly if appropriate conditions are present. Chaubey et al. (2012) reported that the species found on reclaimed overburden dumps were mainly *Dalbergia sissoo* Roxb., *Pongamia pinnata* L.Pierre, *Gmelina arborea* Roxb., *Azadirachta indica* A. Juss., *Terminalia belerica* (Gaertn.) Roxb., *Phyllanthus emlica* Gaertn.*, Peltaphorum ferruginium* Benth.*, Prosopis juliflora* (Sw.) DC*, Grevillea pteridifolia* Knight*, Holoptelea integrifolia* (Roxb.) Planch*, Ziziphus jujuba* (L.) Gaertn. auct*, Acacia catechu* (L.f.) Willd*, Tectona grandis* L.f.*, Bauhinia variegata* L. and *Dendrocalamus strictus* (Roxb.).

2.6. Microbial activity and ecological significance of soil enzyme

The term 'soil microbial activity' implies to the overall metabolic activity of all microorganisms inhabiting soil, including bacteria, fungi, actinomycetes, protozoa, algae and other microfauna (Nannipieri, 1990). The microbial activity plays a vital role in soil productivity sustainability, as it underpins a number of fundamental soil properties such as fertility and structure. The turnover and mineralization of organic substances, nutrient transformations, and cycling of organic wastes in soil are all dependent on the metabolic functions of soil microorganisms (Lee and Pankhurst, 1992). Therefore, the role of microbial activity in the development and functioning of soil ecosystem is inevitable, and changes in soil microbial activity may be an indicative of, and extremely sensitive to changes in the soil health as reported by Pankhurst et al. (1995).

When soil layers are removed and stockpiled, the soil microbes inhabiting the original upper layers end up on the bottom of the pile under compacted soil. A flush of activity occurs in the new upper layer during the first year as bacteria are exposed to atmospheric oxygen (Williamson and Johnson, 1991). Microbial activity decreases with depth and time as topsoil continues to be stored during mining operations (Harris et al., 1989). After two years of storage, there is little change in bacterial number at the surface, but less than one-half the initial populations persist at depths below 50 cm. Microbial activity, measured in ATP concentrations, plummets to very low levels within a few months. Microbial respiration and microbial biomass carbon at deeper levels of a stockpile may not be significantly reduced. Response to glucose is slower by microbes at all depths, suggesting that metabolic rates decrease with time (Visser et al., 1984). Rhizobium is single-celled bacteria, belonging to the family of bacteria Rhizobiacea, form a mutually beneficial association with legume plants. These bacteria take nitrogen from the air (which plant cannot use) and convert it into a form of nitrogen called ammonia (NH_4^+) used by plants (Gil-Sotres et al., 2005).

Free-living as well as symbiotic plant growth promoting rhizo-bacteria can enhance plant growth directly by providing bioavailable phosphorus (P) for plant uptake, fixing N for plant use, sequestering trace elements like iron for plants by siderophores, producing plant hormone-like auxins, cytokinins and gibberlins, and lowering of plant ethylene levels (Glick et al., 1999; Khan, 2005). Topsoil contains carbon, but it is often in the form of coal or other humic material mixed during soil replacement and is not readily usable (Moynahan et al., 2002). Enzyme assays are used as indicators of microbial biomass or microbial activity for monitoring the effects on soils due to chemicals, disturbance, or other environmental changes (Tabatabai, 1994). A variety of enzymes has been examined with varying degrees of success for evaluating relationships with soil microbial biomass, including dehydrogenase, urease, phosphatase, protease, cellulase and hydrolases of fluorescein diacetate (Hankin et al., 1982; Schurner and Rosswall, 1982). A simple and useful assay is that for catalase. It has been widely utilized for this purpose in a variety of habitats including wood (Line, 1983) and soil (Trevors, 1984).

Natural enzymatic activity is an informative index of fertility and productivity of the soil. It is multi-factor dependent and shaped by the type of soil, intensity of cultivation, plant cover, vegetative period as well as by many other factors (Bremner et al., 1971; Cieśla et al., 1990; Kobus et al., 1995; Nowak et al.,1999**)**. The activity of enzymes is disturbed almost immediately after metals join the matter circulating in the soil. Though usually, the enzymatic activity returns to its initial level with time, for high concentrations of heavy metal elements a solid inhibition resulting in a disturbed dynamic balance of soil transformations may occur (Nowak et al., 1997, 2001).

An important role is also played by environmental and soil factors, including temperature, pH, moisture, soil type, organic matter content, fertilization and count and activity of soil microorganisms (Pedziwilk, 1995; Kızılkaya, 1997; Wyszkowska, 2002). An assay of the enzymatic activity of soil, especially the activity of enzymes involved in the conversion of C, N, and P, can be regarded as a good indicator of the effect of pesticides on soil metabolism, and also soil enzyme activities are very sensitive to both natural and anthropogenic disturbances, and show a quick response to the induced changes (Dick, 1997). Therefore, enzyme activities can be considered effective indicators of soil quality changes resulting from environmental stress or management practices (Kızılkaya et al., 2012).

Dehydrogenase is an enzyme that occurs in all viable microbial cells. These enzymes function as a measurement of the metabolic state of soil microorganisms (Watts et al., 2010). Dehydrogenase activity is commonly used as an indicator of biological activity in soil (Burns et al., 1978). Dehydrogenase enzymes play a significant role in the biological oxidation of soil organic matter by transferring protons and electrons from substrates to acceptors. These processes, being a part of respiration pathways of soil microorganisms, are closely related to soil-air-water conditions (Glinski et al., 1985). Dehydrogenase activity (DHA) is one of the most adequate, important and one of the most sensitive bioindicators, relating to soil fertility (Wolinska and Stepniewska, 2012). Its activity depends on the same factors, which influence on microorganisms abundance and activity. Besides, it is well known that pesticides have inhibiting effects on DHA (Karaca et al., 2011; Wolinska and Stepniewska, 2012). Dehydrogenase enzyme is known to oxidize soil organic matter by transferring protons and electrons from substrates to acceptors. These processes are the part of respiration pathways of soil microorganisms and are closely related to the type of soil and soil-air-water conditions (Glinski and Stepniewski, 1985; Kandeler, 1996). Since these processes are the part of respiration pathways of soil microorganisms, studies on the activities of dehydrogenase enzyme in the soil are very important as it may give indications of the potential of the soil to support biochemical processes which are essential for maintaining soil fertility as well as soil health.

A study by Brzezinska et al. (1998) suggested that soil water content and temperature influence dehydrogenase activity indirectly by affecting the soil redox status. After flooding the soil, the oxygen present is rapidly exhausted so that a shift of the activity from aerobic to anaerobic microorganisms takes place. Such redox transformations are closely connected with respiration activity of soil microorganisms. They may serve as indicators of the microbiological redox systems in soils and can be considered a possible measure of microbial oxidative activity (Tabatabai, 1982; Trevors, 1984). For instance, lack of oxygen may trigger facultative anaerobes to initiate metabolic processes involving dehydrogenase activities and the use of Fe (III) forms as terminal electron acceptors (Bromfield, 1954; Galstian and Awungian, 1974), a process that may affect iron availability to plants in the ecosystem (Benckiser et al., 1984). Additionally, dehydrogenase enzyme is often used as a measure of any disruption caused by pesticides, trace elements or management practices to the soil (Reddy and Faza, 1989; Wilke, 1991; Frank and Malkomes, 1993), as well as a direct measure of soil microbial activity (Trevors, 1984; Garcia and Herna´ndez, 1997). It can also indicate the type and significance of pollution in soils. For example, dehydrogenase enzyme is reported to be high in soils polluted with pulp and paper mill effluents (McCarthy et al., 1994) but low in soils polluted with fly ash (Pitchel and Hayes, 1990). Similarly, higher activities of dehydrogenases have been reported at low doses of pesticides, and lower activities of the enzyme at higher doses of pesticides (Baruah and Mishra, 1986).

The enzymes with dehydrogenase properties are distributed in a number of diverse prokaryotic and eukaryotic organisms (Iddar et al., 2005; Noor et al., 2005; Grochowski et al., 2006; Nojiri et al., 2006; Saito et al., 2006). Amino acid dehydrogenases have been studied widely because of their potential applications in biosensors or diagnostic kits, synthesis of L- amino acids for use in production pharmaceutical peptides, herbicides and insecticides and development of coenzyme regeneration systems for industrial processes (Ohshima et al., 1990; Brunhuber et al., 1994). The dehydrogenase activity (DHA) has been proposed as a measure of overall microbial activity and used as an index of the soil microbial biomass (Mukhopadhyay and Maiti, 2010a). In the reclaimed land, it has been seen that soil enzyme activities could also be used as an index of evaluating soil fertility and soil health (Mukhopadhyay and Maiti, 2010a). In opencast coal mine restored sites, dehydrogenase activities are generally found low due to damage of soil microflora and lack of organic matter. The addition of organic amendments increases enzyme activity in mine soil.

Their finding highlighted that incorporation of organic amendments to soil stimulate DHA because the added material contains intra- and extracellular enzymes and may also stimulate microbial activity in the soil. However, the enzyme activity of polluted soils was restored; after 15–20 years, it was quite similar to the enzyme activity of natural soils. Sinha et al. (2009) reported 92.3 mg TPF g^{-1}dry soil 24 h^{-1} of DHA in rhizosphere samples of degraded sites of a coal mine, Dhanbad, India. In a previous study (Rodriguez and Truelove, 1970), the catalase activity of a cultivated soil in Alabama was correlated with bacterial and fungal counts, cation exchange capacity, dehydrogenase activity, and cotton yield. The Catalase is sensitive to oxygen level and shows a quick response to induced changes. Also, it may be affected by cast formation by earthworm in anaerobic condition. The Catalase is based on the rates of oxygen release from the added hydrogen peroxide and may be related to the metabolic activity of aerobic organisms (Kizilkaya et al., 2004; Kizilkaya and Hepşen, 2007).

Catalase is an intracellular oxidoreductase associated with the aerobic microbial activity. It is considered as an indicator of the overall microbial activity of soil (Rodriguez-Kabana and Truelove, 1982; Gracia et al., 1994; Masciandaro et al., 2000). Soil enzyme activity depends, to a certain extent, on the number of soil microorganisms (Sun et al., 1997). The catalase activity is a dynamic indicator of the self-cleaning capacity of the soil to remove contaminants. The function of catalase is to regulate the formation of highly active oxygen, which is used by microorganisms in oil degradation (Khaziev, 1967). Catalase activity was measured to assess microbiological activity in the soil by Beck (1971) which makes it an important enzyme of study. As can be seen from the study of Gang et al. (2009), conducted in Qinling Mountains, China, the correlation between the soil converting enzymes; and urease and catalase was highly significant. This shows that there are close ties between these soil enzymes when they take part in different biochemical processes at the same time. Fuxu and Ping (2004) found that catalase activity was positively correlated with the soil pH value (r = 0.854, 0.804, 0.078 and 0.082, respectively), and was negatively correlated with total N (r = –0.201, –0.529, –0.221 and –0.821, respectively), total P (r = –0.143, –0.213, –0.362 and –0.751, respectively) and available P (r = –0.339, –0.351, –0.576, and –0.676, respectively). The catalase was affected by salinity and alkalinity. The catalase activity was repressed by alkaline soil and reduced conversion of organic matter. The quantities of microorganisms were significantly positively correlated with the organic matter content, total N, total P, available P, available K, pH, electrical conductivity, total salt content, catalase, in another important study by Wu et al. (2006).

It was seen that the soil contamination causes a drop in the catalase and dehydrogenase activities, the cellulolytic capacity, the number of *Azotobacter* bacteria, and the characteristics of the plant germination (Kolesnikov et al., 2009). A worth mentioning study was conducted to determine the responses of soil enzymes (invertase, polyphenol oxidase, catalase, and dehydrogenase) to long-term CO_2 enrichment at the Research Station of Changbai Mountain Forest Ecosystems (Xin et al., 2007). The activity of catalase at elevated CO_2 increased by 16% compared to that in the ambient control chamber.

In autumn, the activities all enzymes except dehydrogenase measured at all sampling dates were lower under elevated CO_2 than those in the ambient control chamber. Tan et al. (2008) observed that water logging decreased activities of superoxide dismutase and catalase in both wheat cultivars. The enzyme catalase is found in all aerobic organisms and is thought to play a role in the protection of these organisms from the toxic effects of hydrogen peroxide (Elstner et al., 1983). Activities of catalase and various other enzymes in soils have been correlated with soil variables such as particles size, carbon content, nitrogen content, numbers of micro-organisms and fertility.

2.7. Mycorrhizal association with plants

Rock spoils usually contain little N and P in plant available forms. Thus, N and P are commonly applied as fertilizer during reclamation, but these additions do not approach native forest soil nutrient pool quantities; if larger quantities were applied, the mine soils would be unlikely to retain most as plant available forms (Zipper et al., 2011). Carbon and nitrogen cycles, in particular, are disrupted as soil microbe populations decline and must be re-established during reclamation.

Mining also affects many soil factors, such as pH, fertility, toxicity, bulk density, and soil moisture, which, in turn, reduce the VAM propagules in the soil that would be necessary for mycorrhizal-dependent plants to thrive (Fuge, 1986) so mychorrhizae may be inoculated manually at rhisosphere soil to improve propagule density and enhance proper restoration. Mycorrhizae are found naturally in soil but not in coal polluted soil (Bureau of Mines, 1990). The hyphal network established by mycorrhizal fungi breaks when soils are initially moved and stockpiled (Gould et al., 1996). However, Miller (1987) reported that seedlings infected with mycorrhizae have a better chance of survival. It is well documented that mycorrhizal associations stimulate plant growth (Clark, 1969; Mosse, 1973; Furlan and Fortin, 1973; Daft and Hacskaylo, 1974) and plant uptake of phosphorus and nitrogen (Daft and Hacskaylo, 1976; Khan, 2005). Mycorrhizal propagule densities remain low immediately after reclamation on uninoculated sites but reestablish themselves after a period of two years (Williamson and Johnson, 1991; Gould et al., 1996). Thus the addition of mycorrhizae becomes necessary.

Mycorrhizal association with plants are most preferred. Ninety percent of the plants form mychorrhizal association. Mycorrhiza support plant growth by increasing the plant's ability to survive in a nutrient poor and water deficient environment. They increase plant hormones act as barriers for the plant pathogens and filters out the heavy metals. Five types of mycorrhiza are recognized namely ectomycorrhiza (ECM), vesicular arbuscular mycorrhiza (VAM), ericoid, orchid, ectendomycorrhiza (Sturges, 1997). Endomycorrhiza is known as VAM (vesicular arbuscular mycorrhiza) fungi where as, Zygomicotina and Ascomycotina group, do not form the sheath. VAM is the most non-specific among the five types. VAM penetrates the cell walls of the roots of the plants and forms vesicles (lipid storage sites) and arbuscules lie outside the roots (fine hair like structures for nutrient absorption). VAM is host obligate while ectomycorrhiza can live without a plant host, but needs one to complete its life cycle. Both ECM and VAM can be found on mined-out sites, but VAM has been found to colonize mine spoils more than ECM (Danielson, 1985). Also, ECM is found in the colder region so its application in tropical countries is restricted. Therefore, VAM is the best option in this case. It has been reported to grow in disturbed and polluted soil.

They appear to serve as an organ of storage and transfer of carbon compounds and mineral nutrients between the fungal hyphae and host plant. VAM fungi are the most widespread and important root symbionts of all mycorrhizal association. The member of Cruciferae and Chenopodiaceae are devoid of VAM infection. About 80% of all land plants form VAM. Hosts include most families of angiosperms and gymnosperm including Rosaceae, Gramineae and Leguminosae. These VAM species are also found on mine OB dumps, namely, Glomus spp., Gigaspora, *Scutellospora gregari* and *Acaulospora laevis*.

Many of the plants that grow on reclaimed coal mine overburden (OB) dumps or naturally colonized invariability have mycorrhiza colonizations which increase the growth and survival rate of these plants. Maiti (1997) reviewed the important mine spoil properties that affect the natural colonization in the tree species growing on overburden dumps. Recovery of disturbed area in terms of mycorrhizal infection and spore population can be controlled by a number of factors, like (a) initial spore count, (b) soil nutrients, (c) texture, (d) moisture, (e) host plant genotype and (f) plant cover age of revegetated site (Norland, 1993).

Mycorrhizal fungi act as providers and protectors for plants. Nitrogen, phosphorus, and potassium are deficient in mine soils and tailings and can be increased in plant intake by mycorrhizae. Govindarajulu et al. (2005), did a beautiful study on the pathway of nitrogen transfer in the mychorhiza. Other essential nutrients such as calcium, magnesium, sulfur, iron, zinc, aluminum, and sodium have shown an increase in plant intake with mycorrhizal fungi (Daft and Hacskaylo, 1976). Higher concentrations of metals (such as aluminum, arsenic, barium, boron, cadmium, copper, iron, lead, manganese, nickel, selenium, and zinc) which can be harmful to plants, can exist on mined sites and, at the same time, be filtered to tolerable amounts by the fungi for the plant. Increasing plant hormones and acting as a barrier to plant pathogens are other benefits provided by mycorrhizae (Fuge, 1986). Mycorrhizae can also alleviate the stress of higher surface temperatures and acidity that mined sites may have (Danielson 1985). Not only can mycorrhizae improve plant growth, but provide some resistance to drought and salinity as well (Duvert et al., 1990).

Juwarkar et al. (1994) studied that in Nayveli Lignite spoil, maximum VAM infection was noticed in *Albizia lebbeck* (90%), *Cassia siamea* (60%) and *Tamarindus indica (*45%). Spores from 23 VAM species were found but Glomus species dominated. In virgin dumps, *G. globuliferum* was found. Juwarkar et al. (1994) also studied VAM infection in two overburden dumps in Kamptee and Chandrapur areas of WCL where the rate of VAM infection was *Dalbegia sissoo*, *Eucalyptus hybrida* (50%) > *Cynodon dactylon* (L.) Pers. (40%) > *Tectona grandis* L.f. (20%) > *Albizia procera* (Roxb.) Benth. (15%) > *Delonix regia* (Hook.) Raf. (10%). The research concluded that VAM population on OB dumps depends on the age of revegetated site, the degree of surface soil disturbance and the amount of topsoil and presence of susceptible root material.

An important arbuscular mycorrhiza genus is Glomus, which colonize a variety of host species, including sunflower (Marschner, 1995). There is a little decrease in viable mycorrhizal inoculum potential during the first two years of storage (Miller et al., 1985). The viability of mycorrhizas in stored soils decreases considerably and possibly to the levels 1/10 those of the undisturbed soil (Rives et al., 1980). Miller et al. (1985) also indicated that soil water potential is a significant factor affecting mycorrhizal viability. It is important to use indigenous arbuscular mycorrhizal fungus strains which are best adapted to actual soil and climatic conditions to produce site-specific arbuscular mycorrhizal fungus inocula (Mummey et al., 2002b; Khan, 2004).

Nine species of VAM fungi belonging to the 3 major genera *viz., Acaulospora*, *Glomus* and *Gigaspora* were identified from a rehabilitated coal mine spoil at Bisrampur, Madhya Pradesh (Dugaya et al., 1996). *Acaulospora*, *Glomus* and *Gigaspora* species were commonly found, while *Scutellospora* and *Sclerocystis* species were scarce in the coal mine overburden spoils at Kusmunda in Bilaspur district of Madhya Pradesh (Chandra and Jamaluddin, 1999). Only *Glomus globiferum* was present in the recently revegetated lignite mine spoil (1-2 years old) of Neyveli, while the adjacent undisturbed area possessed 23 VAM species (*Entrophospora colombiana, Gigaspora albida, Gi. gigantea, Gi. margarita, Glomus albidum, G. aggregatum, G. ambisporum, G. citricoloum, G. claroidium, G. clarum, G. constrictum, G. deserticola, G. dimorphicum, G. etunicatum, G. fecundisporum, G. heterosporum, G. intraradices, G. macrocarpum, G. maculosum, G. mosseae, G. pustulatum, G. tenue, Sclerocystis coremioides, Sc. papillosa, Scutellospora aurigloba* and *S. pakistanica*). Only *G. aggregatum* and *G. pustulatum* were present in the oldest (25 years) disturbed mine spoil site (Ganesan et al., 1990).

Glomus was the most dominant genus isolated among the various mine spoils and mine spoil dumps in India (Ganesan et al., 1990; Dugaya et al., 1996; Selvam and Mahadevan, 2002; Mukhopadhyay and Maiti, 2010). *G. aggregatum* was present in the coal, lignite and magnesite mine spoils, while *G. ambisporum* was common in the calcite, coal and lignite mine spoils. The other dominant species colonizing the mine spoils in their decreasing order of magnitude were *G. deserticola, G. fasciculatum, G. heterosporum* and *G. intraradices. Entrophospora colombiana* was the only species in the genus *Entrophospora* to be found in the mine spoils and dumps. It was commonly present among the coal and lignite mine spoils (Mehrotra, 1998). Some of the other species commonly found in various mine spoils and dumps were *Acaulospora scrobiculata, Gigaspora gigantea, Gigaspora margarita, Sclerocystis microcarpus, Sc. pachycaulis, Scutellospora aurigloba, S. erythropa* and *S. Persica.*

Natural VAM colonization in the tree species growing the reclaimed overburden dumps of Jharia coalfield was studied by Maiti and Shee (2003), Maiti et al. (2003) and Mukhopadhyay and Maiti (2010). Out of ten tree species studied, roots of Dalbergia sissoo contain maximum infection (99%), followed by *Prosopis juliflora* (Sw.) DC. (95%), *Acacia auriculiformis* Benth. and *Tectona grandis* L.f. (93%), *Melia azedarach* L. (83%), *Alstonia scholaris* (L.) R. Br. (78%), *Polyalthia longifolia* (Sonn.) Thwaites (66%), *Cassia siamea* Lam. (44%) and *Azadirachta indica* A. Juss. (35%). However, in Eucalyptus, no VAM infection was recorded. Here also, Glomus was the most predominant genus found in the mine area. But the number of spores found in the rhizosphere of mine area of different species was higher (425–600 spores/5 g of soil) than the rhizosphere of non-mining area 300 spores/5 g of soil (garden soil of ISM campus control area). The details of their study are given in Table 2.4.

Table 2.4 Spore density in different rhizosphere of host plant in overburden dumps (Maiti and Shee, 2003).

Name of host plant	Spore density/5 g soil
Azadirachta indica A. Juss.	425
Cassia fistula L.,	445
Alstonia scholaris (L.) R. Br.	456
Melia azadirachta L.	467
Tectona grandis L.f.	500
Acacia auriculiformis Benth.	585
Prosopis juliflora (Sw.) DC.	595
Dalbergia sissoo DC.	600

The density of VAM spores in the rhizosphere of three commonly used tree species, namely, *Dalbergia sissoo, Cassia siamea* and *Acacia auriculiformis*, used for biological reclamation of overburden dumps were studied by Maiti and Singh (2006). Samples were collected from the rhizosphere of these three species growing in different aged dumps of KD Heslong, Piparwar and Jharia coalfields. In all the dumps, total VAM spore density was found highest in *C. siamea*, followed by *D. sissoo* and *A. auriculiformis.*

Many plant species, particularly those that are mycorrhizal (e.g. *Sericea lespedeza*), are able to draw P from difficulty available sources (Sheoran et al, 2010). Considering the significance of mycorrhizal fungi, Chaubey et al. (2012) studied the status of VAM, root colonization with VAM and microbial biomass in different species planted in different years old OB dumps and plain plantations at Jhingurdah OCP projects of NCL Singrauli.

In older plantations, all five genera of VAM fungi including *Acanlospora, Glomus, Gigaspora, Scutellospora* and *Sclerocystis* were recorded. Out of these *Acanlospora* and *Glomus* were in high frequency.

A significant study conducted in KD Heslong project (NK area, CCL) showed that VAM spore density in the rhizosphere of *C. siamea* (27–204 spores/5 g soil) was higher than that found under *Dalbergia sissoo* (17–112 spores/5 g soil) (Maiti, 2013). Logaprabha and Tamilselvi (2014) concluded that enriching the soil with AM fungi by planting of legumes can be the one of the best approaches for the reclamation of mine spoils. Sengupta and Anshumali (2013) conducted plot experiments in which VAM, as tablets, was added as a soil amendment and the plants showed positive growth response.

2.8. Litter decomposition

The accumulation and decomposition of plant litter are one of the most important processes in the initiation of nutrient cycling in the establishment of the self-sustaining ecosystem in the reclaimed sites. The mine spoil largely comprises of unweathered parent materials, which set the extremely adverse conditions for plant growth. Litter decomposition in mine spoils is a slow process due to high temperature, low moisture, small litter volume and low microbial activity (Richardson, 1958; Bell and Ungar, 1981). Plant residues with different chemical composition show variable mineralization potential and decomposition behavior (Mtambaengwe and Kirchman, 1995). Thus, it is the process of plant litter decomposition that ultimately links plant production to most long-term changes in the physical and chemical properties of mine spoil (Roberts et al., 1981; Wieder et al., 1983).

Litter deposition and decomposition are the two major processes responsible for nutrient enrichment in many terrestrial ecosystems. Litterfall serves three main functions in the ecosystem (i) energy input for soil microflora and fauna, (ii) nutrient input for plant nutrition, and (iii) material input for soil organic matter development (Swift et al., 1979; Moore et al. 2006; Berg and McClaugherty, 2008). The first two functions are completed through decomposition and mineralization, and the third through decomposition and humification. The balance between plant litter deposition and decomposition controls the turnover of detrital organic matter and nutrient fluxes in most terrestrial ecosystems (Olson, 1963; Yadav et al., 2008).

The rate of litter decomposition is strongly influenced by climatic conditions and initial chemical composition of the litter (Horward and Horward, 1980; Van Vuuren et al., 1993; Couteaux et al., 1995). Among the climatic variables, rainfall and air temperature determine the rate of decomposition while microbial diversity constitutes a significant part of the soil biomass (Lee, 1974; Jonsson and Wardle, 2008). However, some other parameters like litter quality with high nitrogen (N) content mostly enhance decomposition (Swift et al., 1979; Prescott, 1995; Couteaux et al., 1995). Therefore, this information provides an opportunity to predict the timing of nutrients' release (Das and Chaturvedi, 2003), which is useful in species selection for restoration of coal mine spoil which is the thrust of our study.

Extensive studies have been carried out on litter dynamics in India (Yadav et al., 2008). Singh et al. (1999) have worked on nutrient release patterns on coal mine spoils in Northern Coal Field, Singrauli. Barbhuiya et al. (2008) studied nutrient dynamics in

Nandapha National Park, Arunachal Pradesh and found that the initial N and P content were significantly correlated with decay rates, however, Arunachalam et al. (1998) found that initial lignin, nitrogen (N) and lignin/N ratio were negative correlations with decay rates. Litter decomposition studies have been carried out on various forest and agro-ecosystems but such studies on mine spoils is, however, rare (Singh et. al., 1999). Isaac and Nair (2005) discovered that the litter of *Mangifera indica* with a half-life period of 3.2 months showed the fastest decay as compared to other two species, *Artocarpus heterophyllus* and *Anacardium occidentale* in the warm humid tropics of Kerala.

The accumulation of plant litter depends on the type of tree species, the age of plantation, density and seasons, whilst decomposition depends on climatic conditions, soil moisture, microbial activity and physicochemical properties of the mine soil (Mukhopadhyay and Maiti, 2010b). The study of litter decomposition is also an important part of the most intensively studied nutrient cycling processes in forest ecosystems. The rate of litter decomposition is largely a determining factor for productivity or biomass of every terrestrial ecosystem in general and of forest ecosystems in particular. The average litter accumulation of five tree species growing in a reclaimed coal mine overburden dumps was studied by Mukhopadhyay and Maiti (2010b). Maximum litter accumulation under a tree with broad leaves (*G. arborea*), whilst analyzing the composition of litter, only 35% consists of fresh leaves of *G. arborea*, 25% woody fractions, and 40% belongs to other category. Higher litter accumulation also observed under *C. seamea*, which consists of fresh leaves of *C. seamea* (60%), A. auriculiformis (15%), leaves woody parts (15%) and other (10%) (Mukhopadhyay and Maiti 2010 a, b). The litter accumulation and their decomposition rate under different tree canopies are given in Table 2.5.

Table 2.5 Litter accumulation and decomposition rate in a reclaimed coal mine overburden dumps (all weights in g dry wt/m^2) (Mukhopadhyay and Maiti, 2010).

Sl.N.	Tree Cover	Fresh litter	Partially decomposed litter (>2 mm) (A)	Decomposed litter (<2 mm) (B)	Total decomposed (A + B)	%decomposition
1.	*Cassia siamea* Lam.	510.03	45.09	64.45	109.54	17.57
		(429–578)	(31–66)	(45–82)	(84–148)	(15–20)
2.	*Dendrocalamus strictus* (Roxb.) Nees	437.41	65.11	63.95	129.05	22.77
		(418–453)	(61–76)	(61–69)	(121–138)	(121–138)
3.	*Prosopis juliflora* (Sw.) DC.	390.90	27.40	48.60	76.00	16.24
		371–405	(32–59)	(33–46)	(70–105)	(15–20)
4.	*Ficus religiosa* L.	388.42	43.13	38.57	81.7	17.26
		(372–410)	(25–31)	(43–56)	(67–88)	(15.3–17.6)
5.	*Gmelina arborea* Roxb.	652.08	99.76	82.44	182.19	21.77
		(631–704)	(89–119)	(73–99)	(162–218)	(20–24)

2.9. Soil phosphorus and its fraction

The total quantity of P and plant-available P often differ greatly in soils of the tropics, which typically range in weathering intensity. Nevertheless, inappropriate P fertilizer management coupled with increasing cropping intensity with modern high yielding varieties (HYV) causes P depletion in soils and thus, P deficiency occurs in many alluvial soils (Ali et al., 1997). Soil P is dynamically affected by chemical, physical, and biological processes (Russell, 1977; Stevenson, 1986). Soil P status is frequently studied by sequential extraction methods (Chang and Jackson, 1957; Hedley et al., 1982). The Hedley approach, for example, has been widely used to separate soil P into eight fractions of varying availability for plants (Tiessen and Moir, 1993; Schmidt et al., 1996), and to characterize their transformation (Tiessen et al., 1984; Agbenin and Tiessen, 1994; Cross and Schlesinger, 1995).

Guo and Yost (1998) compared the dynamics of an individual soil P fraction and cumulative crop P uptake. Their results indicated that P fractions in different soils varied in availability and that some fractions were related to plant availability in some soils but not in other soils. Linquist et al. (1997) studied the relationship between soybean-P uptake and soil P fractions. In these studies, the transformations and dynamics among the P fractions could not be characterized. Path analysis was used to study the interactions among P pools (Turner and Stevens, 1959; Tiessen et al., 1984; Beck and Sanchez, 1994). The sequential extraction of soil P is a relatively complicated, time-consuming, and expensive procedure. Some fractions have no contribution to crop growth and are not greatly influenced by added P fertilizer, and hence are redundant from the point of view of fertilizer recommendations. It is important, therefore, to identify the kind and a minimum number of P fractions necessary to characterize plant–soil P dynamics and to determine whether the same fractions should be quantified in soils that vary in P sorption capacity.

Lajtha and Schlesinger (1988) found that primary source of phosphorus in terrestrial ecosystems is the weathering of minerals found in parent rock materials. It is well documented that mycorrhizal associations are essential for survival and growth of plants and plant uptake of a nutrient such as phosphorus and nitrogen, especially P-deficient derelict soils (Khan, 2005). Soil phosphorus uptake has been studied by Saha et al. (2014) in agricultural soil impregnated with phosphorus fertilizer. Phosphorus distribution in the soil of Chottanagpur Plateau, West Bengal, has been studied by Sarkar et al. (2013). Singh et al. (2015) observed that majority of phosphorus is buried in sediments with less than 1% being available for recycling within the mangrove ecosystem of India.

The primary source of phosphorus (P) in terrestrial ecosystems is the weathering of minerals found in parent rock materials. P can ultimately control net primary production (NPP) and the decay of organic matter either directly or through interactions with nitrogen (N) in P-deficient ecosystems. The distribution of soil phosphorus (P) among different fractions changes during the course of soil formation, as leaching and the gradual geochemical transformation of P, reduce the amount of labile P. This process can eventually limit net primary production (NPP) and other processes of terrestrial ecosystems. Thus it is very important to find out the P-pools in mine spoils. Phosphorus (P) is one of the major limiting nutrients in various newly established coal sites, which limit the establishment and proper growth of vegetation. Although low solubility and slow cycling control P circulation in a wide range of ecosystems, most studies that evaluate the bioavailability of soil P use only indices of short-term supply. The phosphorus can ultimately control net primary production (NPP) and the decay of organic matter either directly or through interactions with nitrogen (N) in P-deficient ecosystems (Walker and Syers, 1976; Cole and Heil, 1981; Pastor et al., 1984; Tate and Salcedo, 1988; Crews et al., 1995; Herbert and Fownes, 1995). Many studies highlighted that ecosystem process of lowland tropical rainforests in some deeply weathered skeletal soils are limited by P (Vitousek, 1984; Vitousek and Sanford, 1986; Tiessen et al., 1994; Raaimakers et al., 1995; Sollins, 1998). However, the extent of such P-deficient rainforests is still unknown. Vitousek and Sanford (1986) demonstrated that soil fertility can vary considerably with soil type in the lowland tropics. Moreover, in comparison to lowland tropical rainforests, upland rainforests are believed to be limited by N due to slow mineralization of organic matter (Grubb, 1977; Vitousek and Sanford, 1986). These results imply that the pattern and control of nutrient cycling in tropical rainforests vary in a landscape context, but on old substrates, the nutrient limitation shifts from P to N with increasing altitude on single mountain slopes (Tanner et al., 1998). Evidence to support these hypotheses is, however, circumstantial, and has been obtained mainly from the element concentration in litter fall supported by the work of Vitousek (1984) and Tanner et al., (1998).

The distribution of soil phosphorus (P) among different fractions changes during the course of soil formation (Walker and Syers, 1976), as leaching and the gradual geochemical transformation of P reduce the amount of labile P. This process can eventually limit net primary production (NPP) and other processes of forest ecosystems (Chadwick et al., 1999). When Vitousek and Sanford (1986) examined patterns of litter production and the mineral concentrations, they concluded that NPP in tropical rain forests on old soil is indeed limited by P. As per the research of Herbert and Fownes (1995, 1999) and Vitousek and Farrington (1997), fertilization experiments in Hawaiian montane rain forests on deeply weathered oxisols have provided direct evidence of the P limitation of aboveground net primary production. Microbial P is highly variable and one of the smaller fractions in most soils (Guo et al., 2000). Microorganisms deeply affect soil P in for turnover through mineralization–immobilization processes (Stevenson, 1986). The resultant labile Pi and Po pools were mainly affected by nutrient sources, suggesting that the changes in soil labile P forms in the 0- to 30-cm soil layer depended more on nutrient sources than on crop rotations (Zheng et al., 2002). The agricultural soil of Iran was studies by Adhami et al. (2013) for soil phosphorus fraction and found that inorganic fractions were more due to the addition of inorganic fertilizers. Walker and Syers (1976) put forth a model of soil phosphorus transformation during the soil development that provides a useful starting point for investigating P dynamics and C-N-P interactions at different stages of the soil development (Fig. 2.3). The model depicts that all the soil P is in the primary mineral form (mainly as calcium apatite minerals) at the beginning of the soil development which coincides with the onset of primary succession.

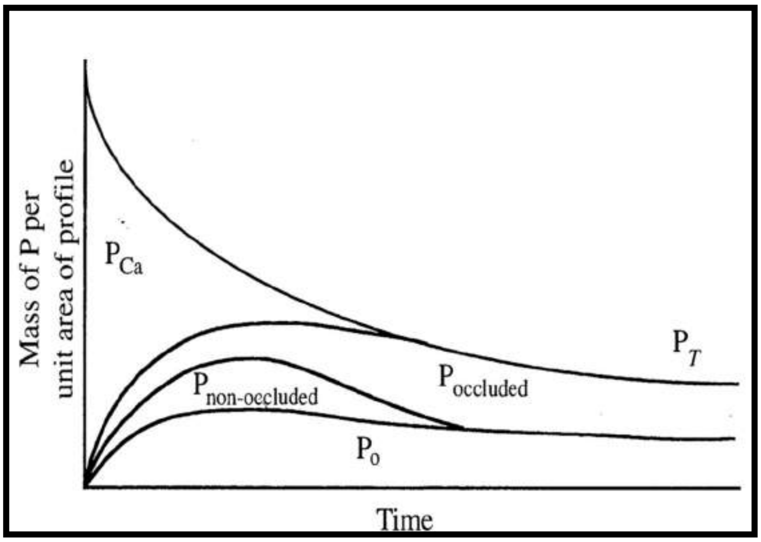

Fig. 2.3 P transformations with time. P_{Ca} = calcium phosphates, P_T= total P, P_o= P bound to organic matter

The Hedley fractionation method has been widely used to characterize soil P availability. The procedure, in its original (Hedley et al., 1982) or modified forms (Tiessen et al., 1983, 1984; Sharpley et al., 1987; Tiessen and Moir, 1993; Beck and Sanchez, 1994), removes the readily available P from the soil first with mild extractants, then the more stable P forms with stronger extractants. The Hedley procedure has been used to study P fractions in both slightly weathered (Tiessen et al., 1983; O'Halloran, 1993; Richards et al., 1995) and highly weathered soils (Ball-Coelho et al., 1993; Agbenin and Tiessen, 1994; Beck and Sanchez, 1994; Schmidt et al., 1996). Phosphorus fraction changes due to organic amendments have also been reported (Hedley et al., 1982; Iyamuremye et al., 1996). Ruttenberg (1992) developed a fractionation method. Procedures typically begin with dilute extractants, which remove the most loosely bound P forms, and they proceed stepwise toward stronger extractants, attacking P forms more strongly bound to the solid phase. The P forms commonly separated include soluble and loosely sorbed (labile) PO_4-P, redox-sensitive iron (Fe)-bound P, and P bound to hydrated oxides of (Al) and nonreducible Fe (surface-bound), calcium (Ca)-bound P (apatite-P), and organic P. The organic P is sometimes divided into refractory and labile fractions. In addition to organic P, the refractory fraction is assumed to contain some inorganic P, possibly as occluded P forms.

As nearly all soil P is unavailable for immediate use by soil microbes and plant roots, therefore relationships between labile and recalcitrant P is an important topic for study (Chang and Jackson, 1957; Thomas and Peaslee, 1973). Even though, most research and management studies that evaluate bioavailable P continue to characterize P availability using only extractants designed to correlate with yields of P-fertilized agricultural crops grown in the same year as that of the soil sampling and analysis (Bray and Kurtz, 1945; Mehlich, 1978; Olsen et al., 1954).

A wide variety of extraction procedures for soil and sediment P have been developed, varying with the aim of the study and the P fractions targeted (Bostrom et al., 1982, Van

Eck, 1982; Pettersson et al., 1988; Ruban et al., 1999). The P forms commonly separated include soluble and loosely sorbed (labile) PO_4-P, redox-sensitive iron (Fe)-bound P and P bound to hydrated oxides of Al and non-reducible Fe (surface-bound), calcium (Ca)-bound P (apatite-P), and organic P. Maiti (2013) reported extractable P to be low in OB material ranging from 0.01 to 0.05 ppm or one-tenth of P concentration observed in topsoil. The concentration of extractable P was reported in coal mine spoil in the order of 8.6 kg/ha (Dhanpuri OB), 10.8–15.3 kg/ha (Heslong, CCL) and 19 Kg/ha (Bina OB). The average concentration of P for optimal plant growth should be in the order of 20 ppm (45 kg/ha). Although the total phosphorus content of some mine spoils may equal or exceed those of the unmined soils, the plant-available phosphorus in almost all the spoils is invariably in the deficiency range (Yamamoto, 1975). However, there has been a lack of literature about phosphorus fractionation in fresh OB dumps. It is very important to know which fraction of phosphorus is present in such disturbed fraction so that if the application of phosphorus is at all required it can be done judiciously. Since phosphorus is a limiting factor for plant growth in such dumps, hence, the study of the phosphorus fraction is highly desired. It will also enlighten whether the fraction present in the dumps can be extracted or not. Therefore, the vital information can be drawn out. Subsequently, the reclamation process can be made more economic.