Chapter

Grass-Legume Seeding: A Sustainable Approach Towards Reclamation of Coalmine Degraded Lands in India

Sneha Kumari and Subodh Kumar Maiti

Abstract

Most of the ecosystem services undergo significant degradation during coal mining activities with negative impacts on ecology, biodiversity and local people's livelihoods. The cumulative effect of such large scale environmental changes is reflected in rising pollution load, earth's temperatures and deforestation. There is no eloquence to it that coal is and will continue to be the primary fossil fuel in global energy production, there is a need to embrace sustainability as a key aspect throughout all phases of mining. The cheapest, easiest and eco-friendly approach to accelerate the trajectory of ecological restoration towards a reference state is the introduction of versatile and pioneering plant life forms like grasses and legumes. These species works on basic scientific principles based on ecological theories and incorporating them in post-mined landscapes provides multitudinous environmental benefits coupled with economic and social development. Keeping this in mind the chapter aims to emphasize the importance of grass-legume seeding during ecological restoration of mine degraded lands concerned with the concepts of sustainability.

Keywords: Coal mining, Ecological restoration, Grass-legume seeding, Sustainable development

1. Introduction

In coal powered India, a paradigm shift towards mining sector for energy needs has tremendous negative repercussions in environmental and socio-economic arenas. The idea of '*more hole more coal*' without any conservative measures leaves atrocious footprints on the landscapes like abandoned quarries and discarded dumps devoid of vegetation, including plant stocks and seeds capable to re-germinate. Mining is linked to all the Sustainable Development Goals (SDGs) in many ways. A multi-objective approach towards ecological restoration of mining areas keeping with the principles of sustainable development is the need of the hour [1]. "Pioneer" plant species like grasses and legumes are cost-effective and use basic scientific principles based on ecological theories therefore, incorporating them in post-mined landscapes (**Figure 1**) has shown multitudinous environmental benefits coupled with economic and social development [2]. There is no eloquence to it that coal is and will continue to be the primary fossil fuel in global energy production,

Figure 1.
Ecologically restored coal mine dumps under Bharat Coking Coal Limited (BCCL), India showing (A) growth of grasses on the overburden dump slope near Bhowra area (B) closer view of grass (Pennisetum pedicellatum) and tree growth in the Gokul Park dump of Lodna area, (C & D) distant view of dense and diverse vegetation cover and closer view of legume (Stylosanthes hamata) growth on the Chandan opencast project dump.

there is a need to embrace sustainability as a key aspect throughout all phases of mining (**Figure 2**). Keeping this in mind the chapter aims to emphasize the importance of grass-legume seeding during ecological restoration of mine degraded lands concerned with the concepts of sustainability.

Figure 2.
Criterias for sustainable mining practices.

1.1 Current scenario of coal mining in India

The 'Coal Vision 2025' brought out by the Ministry of Coal, Government of India (GOI), has flagged coal as an essential commodity. It reports an increase in coal production from 777.7 million tonnes (MT) in 2020 to 1.2 billion tonnes (BT) in 2025. In addition data suggests that 67% of India's energy demands depend on fossil fuel, out of which coal makes up to approximately 59%. The major outcomes of the vision are:

1. The annual growth in demand for coal is expected to increase 1147 MT (7% GDP growth) and 1267 MT (8% GDP growth) till 2025.

2. The total production of domestic coal is predicted to increase to 1086 MT in 2025, out of which 83% (902 MT) will consist of open-cast production.

3. The coal vision 2025 would double the land requirement from 1,47, 000 to 2,92, 500 hectares adversely affecting 1,70, 000 families and increasing the need for rehabilitation.

4. The requirement of forest land would increase three-folds from current 15–25% of the projected total land requirement.

As per the vision outcomes and past records, the demand of coal will increase (**Table 1**) and also predicted land degradation escalating environmental complications. There is no data available on how much post-mined lands has been reclaimed in India, however the MONGABAY 2020 article on land reclamation for the year (2018–2019) states that the 52 open-cast coal mines projects of Coal India Limited (CIL) constitutes a total excavated area of 255 square kilometers (sq km) out of which 61 sq. km has been biologically reclaimed, 100 sq. km is under technical reclamation and 95 sq. km is under active mining. The National Mineral Policy (2019) which regulates mining activities in India has therefore stressed about the importance of land reclamation to bring back mined out landscapes to the pre-mining state.

Production Year	Total Coal Demand	
	Domestic production (MT)	Import (MT)
2010–2011	532	76
2011–2012	540	105
2012–2013	556	141
2013–2014	566	169
2014–2015	609	212
2015–2016	639	200
2016–2017	651	191
2017–2018	689	208
2018–2019	734	235
2019–2020	729	248
2020–2021	716	196

Table 1.
Total coal demand in India for the last 10 years (in million tons).

1.2 Multi dimensional impact of coal mining

Coal can be mined through open-cast and underground extraction methods based on the site specific geological condition [3]. An open-cast mining operation affects the ecosystem services as a whole (**Figure 3**). It involves generation of huge mass waste (overburden materials) due to mining activities like blasting, drilling etc. [4]. Coal mining is usually associated with land degradation and the excavated toxic waste materials create serious environmental and socio-economic problems in the adjoining areas. The most severe post-mining impact on the ecosystem are environmental damage such as deforestation, air and water pollution, detoriation of topsoil quality, loss of biodiversity and landscape destruction by invasive species [5–8]. Coal mining activities in Nokrek Biosphere Reserve, India adversely affected the native vegetation and greatly reduced the density of trees and shrubs [9]. The phenomenon of spontaneous heating through interconnected oxidative and thermal process affects various coal mines in the country leading to mine fires. Data estimates report that 10% of total national coal resources are in the fire affected regions. Mine fires give rise to several ecological problems besides safety hazards and economic losses [10]. Coal mining activities puts tremendous pressure on economic–socio-cultural aspects of the people residing around mine areas. Mining induced displacement and rehabilitation is accompanied by loss of social assets including income earning resources, networking, cultural identity, homes and productive land etc. [11, 12]. Coal combustion releases dangerous levels of toxic gaseous pollutants including coal bed methane and dust particles adversely affecting human health, local and global environment as well [13]. The negative effects of mining over large stretch of lands persist for years and can get the better of by relevant planning and policy making ensuring sustainable development. An ongoing challenge for the coal mining industries is sustainable development owing to rising demand for coal in the energy sector. Overcoming these challenges will require ecological resolution pertaining to technical, economic, environmental and social performances.

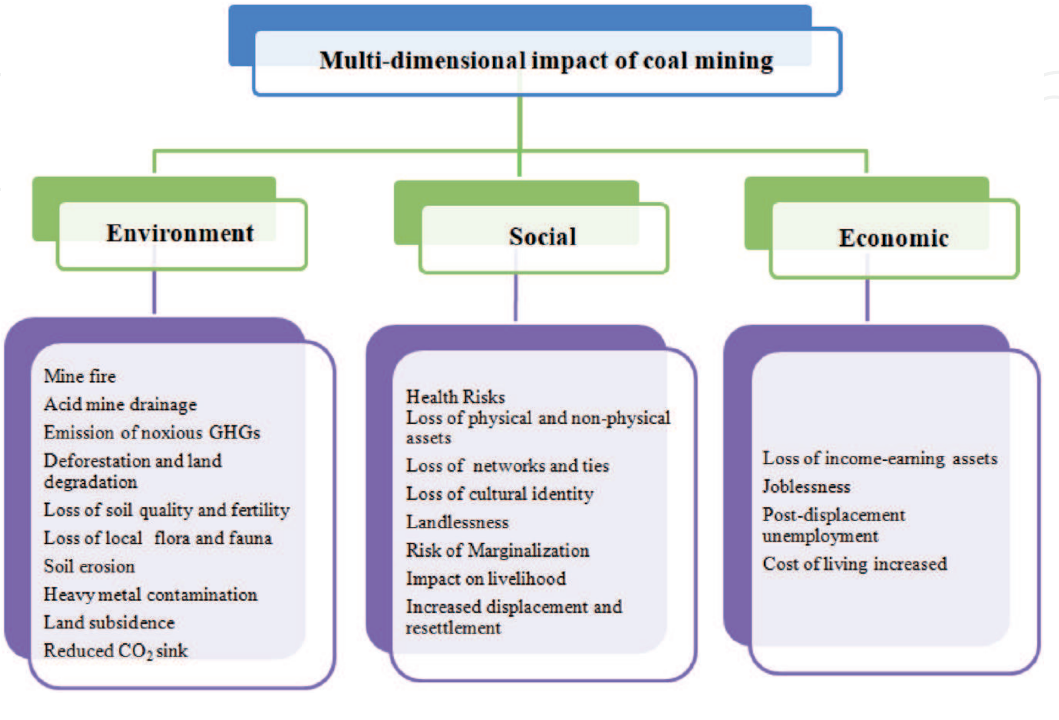

Figure 3.
Multi-dimensional impact of coal mining activities.

2. Ecological restoration

Abrupt changes in natural environment have become an indispensable part of mining activities, still mining cannot be ignored nor can environmental protection be sidelined. Therefore, a balance has to be worked out between mining and environment for sustainable development. Ecological restoration ultimately aims to attain a self-sustainable ecosystem by reconstructing ecosystem functions and structures and may be regarded as identical to secondary succession after the site recovers sustainably on its own [3]. Furthermore, following coal excavation, besides the environmental detoriation, result in a series of social and economic issues. Thus the ecological restoration in mined out lands not only means ecosystem reconstruction but should also include enhancement of environment as well as social and economic development [14]. Ecological restoration provides a solution for sustainable resource management and environmental protection in mining industry through ecological interventions [15–17]. Primary steps involved in ecological restoration are shown in **Figure 4**.

2.1 Reclamation approaches during ecological restoration

Reforestation/revegetation of barren mined out lands over time can bring it to a more or less pre-mining state. The main challenges faced during re-establishment of vegetation on hostile mine lands that has lost their upper soil horizon is finding plant species that will grow under harsh conditions. The success of reclamation depends on the adaptive potential of plant species to the highly variable and newly formed reclaimed mine soils. Surface Mining Control and Reclamation Act (SMCRA) of 1977 have recommended the use of native grass and legume species in mine degraded areas. Forage mixtures containing legumes plays an expanded role

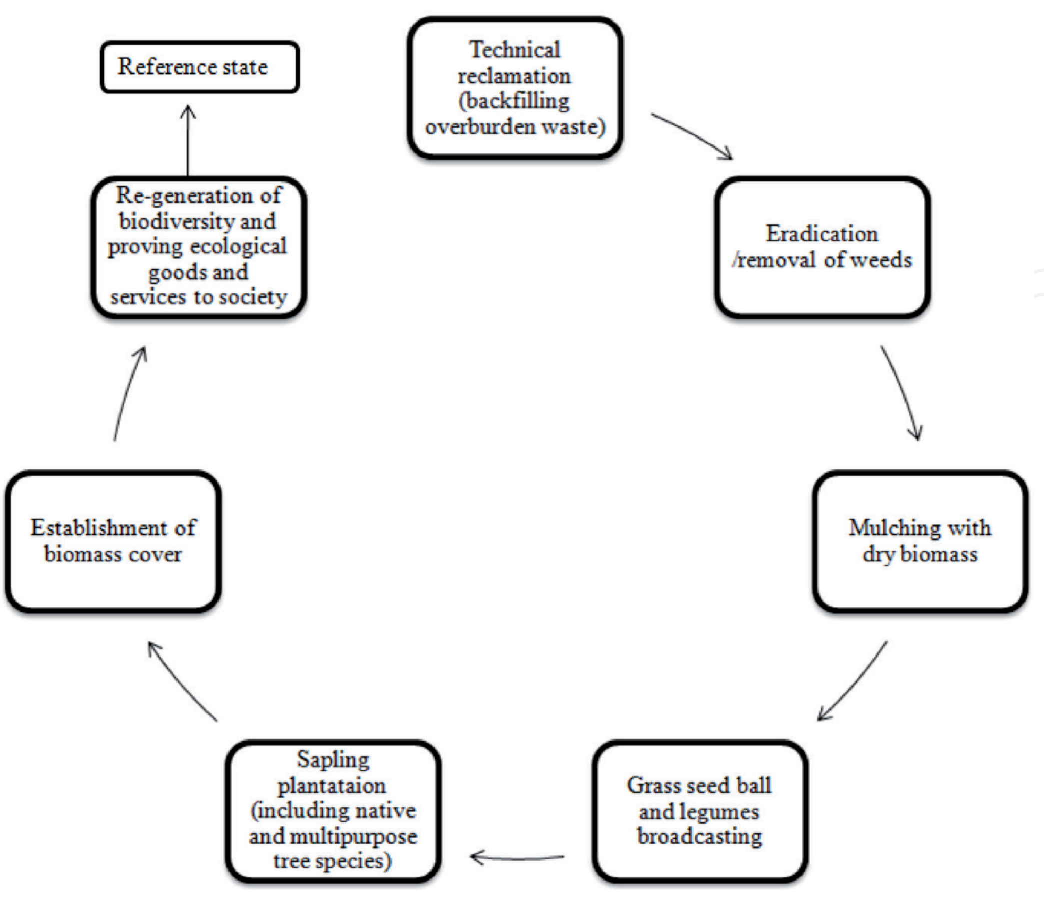

Figure 4.
Primary steps involved in ecological restoration process towards a reference state.

in the nitrogen (N) economy, lowers carbon (C) footprints and out-yield monocultures [18]. Native trees and a more species/genetic diversity accelerate the recovery to a self-sustaining ecosystem (forest) [19, 20]. The development of forest and the trajectory with which it develops on mine degraded sites depends upon geo-climatic conditions and reclamation practices. Successful and sustainable reclamation practices must focus on bringing the disturbed ecosystem back to normalcy leading to restored ecological, aesthetical, and socioeconomic functioning of the post-mining area [21]. Different reclamation approaches have been proposed for various disciplines like forestry, archeology, mining, landscape architecture etc. [22]. The reclamation approaches for mining sector has been discussed below

2.1.1 Forestry reclamation approach

The forestry approach (FRA) has been promoted as a desirable method to reclaim productive forest in coal mined land under the SMCRA act of 1977 [23]. The main features of the approach are:

1. Creating a suitable rooting medium with appropriate available material up to a depth of 4 feet for growth of deep rooted tree species. Preferred rooting medium can be topsoil, weathered rock materials etc. with pH range of 5 to 7, soluble salts less than 1 mmhos cm^{-1}, low pyritic sulfur (S) concentration, and good texture for proper drainage.

2. Excessive soil compaction due to heavy operating equipments on mine soils reduces the growth of planted trees. To re-establish productive forest post-mining, growth medium (topsoil or its substitutes) should be loosely graded to minimize compaction and favor growth.

3. Support groundcover vegetation compatible with growing trees. Groundcover species should include slow growing legumes and grasses that are tolerant to a wide range of soil conditions. This groundcover will ensure balance between erosion control and competition for resources (light, water, and space) required by trees over long-term to form a mature forest

4. Planting diverse tree species for early succession, supporting wildlife and soil improvement, over commercially valuable crop tree species.

5. Proper tree plantation techniques should be adopted. Improper planting of tree seedlings leads to poor survival rate. Tree seedlings should be dormant and stored in a cool environment away from direct sunlight until planted.

6. The revegetation method under FRA commonly used for coal mining areas involves planting bare root tree seedlings and secondly hydro seeding grass and legume seeds. The method suggests use of less competitive and tree compatible grass and legume species. This will minimize competition with the growing tree seedlings and help to establish a tree compatible ground cover. Further it also suggests using fewer amounts of seeds and N fertilizers.

2.1.2 Holistic reclamation approach

Holistic approach has been promoted by Dan Dagget in mining areas. Local environmental microclimatic conditions sometimes prevent forest succession, therefore in such areas establishment of rangelands may be a better option. A holistic approach requires necessary knowledge of ecological (biotic and abiotic) components along with good drainage patterns. The main features of the approach are:

1. Grade the best available material according to the required topography for establishment of vegetation cover. If topsoil is not available as growth medium than topsoil substitutes can be prepared on site using early succession species like native grass biomass combined with livestock residues.

2. Propagating early succession native species like grasses and other plants

3. Mulching the area to provide the initial forage required for livestock.

4. Establishing paddocks or livestock with managed grazing techniques to heal the land by balancing production and forage use.

5. If the aim is to establish a wildlife area/natural park, as the keystone species returns via ecological succession or are introduced into the system, livestock can be reduced gradually or eliminated.

2.1.3 Integrated reclamation approach (three-tier plantation)

Several countries have opted for plantation of fast-growing exotic tree species during reclamation of post-mined areas. Such single-tier plantation is successful to provide green canopy cover but remains unsuccessful in controlling erosion, groundwater recharge and re-establishing biodiversity. Moreover, the selections of exotic species are not considered to meet socio-economic requirement of the local community. In view of all such drawbacks an integrated approach was proposed which favored plantation by three-tier method [24]. The objective is to replicate natural forest with native species and biodiversity revival as existed prior to mining. The main features of the approach are:

1. Vegetation/plantation should comprise of native species (native to nearby forest) and must consider meeting socio-economic requirement locally.

2. Mine dumps are amply invaded by invasive/exotic weeds like *Parthenium hysterophorus*, *Xanthium strumarium*, *Lantana camara* etc. Removal of weeds from mine degraded land creates better opportunity for the native species to germinate and re-establish biodiversity.

3. The three-tier plantation involves native species consisting of herbs and grasses (lower level), understory vegetation including shrubs/bushes (middle level) and trees (top level).

4. The lower level vegetation will provide nutrients to the soil and habitat for micro-organisms and arthropods. Overall the three-tier plantation system will improve local climate and attract flora, fauna and other organisms to re-establish biodiversity. At last completely developed forest with food chain and food web shall establish along with improved socioeconomic condition.

3. Sustainability aspects of grass and legume species

Both grasses in woody bamboo forms while legumes as shrubs and trees have their origin from the tropical forests. The grasses belong to the Gramineae family of monocotyledons with around 780 genera and 12,000 species [25]. The fifth largest flowering plant family currently appears to be most widespread throughout the world and adapted to conditions from rain forest to dry deserts and seashores to cold mountain tops. Grasses are the most versatile and pioneering plant life forms. Grasses have greater digestible fiber compared to legumes. Their adaptability to a diverse ecosystem is due to the fact that they grow very close to soil surface therefore safe from environmental damage including grazing and fire. Grass species recommended for reclamation of coal mine degraded lands are listed in **Table 2**.

Legumes belong to the Fabaceae family that comprises almost 770 genera and more than 19,500 species. It is the third largest family of flowering plants that comprises economically important trees and shrubs adapted to a wide variety of ecological and climatic regime [27]. Research on legume nodulation started in the mid 1960 [28]. Legumes are rich in nutrient composition including crude protein, energy and micronutrients compared to grasses. Legumes contain symbiotic N-fixing bacteria (*Rhizobia*) within root nodules structures hence, a key component in crop rotation. Legumes are often referred to as "green manure" and alternating between legumes and grasses during rotational cropping produces good results by providing ample amount of N compounds [29, 30]. Legume species recommended for reclamation of coal mine degraded lands are listed in **Table 3**.

3.1 Forage production

A grass and legume mixture represents prime example of diversification and adaptation in plant community. Incorporating grasses and legumes as a forage in mine degraded lands started from the early 70's [31]. The main aim of grass-legume mixed seeding in any system is to produce higher yields and improve natural resource use efficiency than monoculture. Legumes (*Stylosanthes hamata*) and grass (*Cenchrus ciliaris*) seeding offer great potential to cope with the prominent challenge of mine reclamation to produce adequate biomass cover where no commercial N-fertilizer is applied [2]. It is generally accepted in studies that the grass species have a competitive advantage over legumes and therefore can dominate pastures. A balance between grasses and legumes is advisable to maintain high biomass productivity [33]. Grass (*Miscanthus sinensis)* and legumes (as a functional group) enhance diverse plant communities, greater biomass and less toxic forage for rapid reclamation of mine degraded lands [34]. This is because legumes improve the functioning of soil systems through bacterial symbiosis [29]. Irreversible changes due to coal mining activities threaten the economy and sustainability of local livelihood such as agriculture and livestock production [35]. Improved animal productivity is associated with the lower fiber contents and higher ruminal rates of passage which are characteristic feature of legume forages compared to grass forages [36]. Forage legumes can overcome the insufficient dietary problem that limits animal production. Grass-legume mixtures produce more forage biomass and feed with less resources therefore improving resource use efficiency in animal production. The high proportion of protein and soluble carbohydrates in legume foliage enables digestion by ruminants (herbivorous mammals). These nutritional benefits of legumes will be most evident with young and lactating ruminants, because their requirements for crude protein are higher than mature ruminants [37]. The quantity of milk produced was significantly higher in livestock's feeding on forage legume (*Stylosanthes)* supplements compared to natural pasture. Experimental results suggested that 3 kg of *Stylosanthes* dry matter (DM) was the optimal level of supplement for the milk production of 1.8 L day^{-1} [38]. Multipurpose forage legumes like *Stylo* spp. is a potential environment-friendly feed strategy to supply crude protein to grazing livestock's during drought conditions when availability of protein rich

Grass species	Distribution	Climate/Annual rainfall	Yield (t ha^{-1})	Type	Characteristic features
Brachiaria brizantha (Palisade grass)	Native to Africa	Warm and humid	GF:120	Warm season	Remains green throughout the year Compatible with legume species if adequate phosphorus concentration is maintained
Brachiaria mutica (Buffalo grass)	Native to Brazil	Warm and humid/ 900 mm.	GF: 1950–2755	Warm season	Shows rapid growth. Compatible with legume species Tolerant to saline salinity
Cenchrus ciliaris (Buffel grass) *Cenchrus setigerus* (Dhaman grass)	Native to South Africa, south Asia (east to India)	Arid and semi-arid /125 to 1250 mm	DM:6–11 GF:35–40	Warm season	Drought tolerant Suitable for soil conservation
Chloris gayana (Rhodes grass)	Native to South Africa	Warm and moist	DM:17	Warm season	Early establishment in soil Compatible with legume species Adapted to a range of soil and climatic conditions
Chrysopogon fulvus (Dhwalu grass)	Native to India and East Africa	Arid and semi-arid /250 to 850 mm	DM:4–10		Acts as good soil binder Can grow on gravel and stony soils Shows luxurious growth during summers when other grasses dry out
Cynodon dactylon (Bermuda grass)	Native to India	Semi arid/ 300 to 2000 mm	DM:4–5 GF:16	Warm season	Drought resistant Tolerant to salinity and alkalinity Controls erosion Ensures stabilization of slopes Compatible with legume species

Grass species	Distribution	Climate/Annual rainfall	Yield ($t\ ha^{-1}$)	Type	Characteristic features
Digitaria decumbens (Pangloa grass)	Native to Transvaal	Humid /1015 mm	GF:7–13	Cool season	Controls erosion Compatible with legume species Insect resistant
Eragrostis curvula (Weeping love grass)	Native to India and Tanzania	Mild temperate/500 to 1000 mm	GF:20–30	Warm season	Good soil binding capacity Controls erosion Highly tolerant of soil acidity
Panicum antidotale (Sudan grass)	Native to Australia	Arid and semi-arid/100to 1000 mm	GF:20	Warm season	Suitable for pasturage Shows fast re-growth
Panicum maximum (Guinea grass)	Native to Africa	Warm and moist/ variable rainfall	GF:50–60	Warm season	Suitable for soil conservation
Paspalum notatum (Bahia grass)	Native to Brazil	warm and moist/ 1500 mm.	GF:20–40	Warm season	Good soil binder Suitable for soil conservation
Pennisetum pedicellatum (Dinanath grass)	Distributed in West Africa and India	warm climate/ 800 to 1250 mm.	GF:55–60 DM:14	Warm sseason	Suitable to grow on nutrient poor soil Very tall, robust grass Rapid growth under moist, warm conditions Useful windbreak species
Setaria sphacelata (Golden timothy grass)	Native to Africa	warm climate/1500 mm	GF:24	Warm season	Good soil binder Compatible with legume species
Vetiveria zizanoides (Vetiver grass)	Native to Asia	semi-arid /500–5000 mm.		Warm season	Tolerant to extreme drought conditions Suitable for soil conservation

Adapted from Trivedi [26]; DM = Dry matter, GF = Green forage.

Table 2.
Grass species recommended for reclamation of coal mine degraded lands.

forages is scarce. Several forage legumes also possess tannins and polyphenoloxidase (plant secondary metabolites) [39]. Tannins protect proteins degradation in the rumen, and subsequently ruminants excrete less urinary N and greater fecal N.

Legume species	Distribution	Climate/ Annual rainfall	Yield (t ha^{-1})	Type	Characteristic features
Calopogonium mucunoides (Calopo)	Native to South America	Hot humid tropical /1525 mm	GF:56	Warm season	Good Nitrogen (N) fixer Well adapted to grow in acidic soil
Centrosema pubescens (Centro)	Native to South America	Hot humid/ 1525 mm.	GF:15–20	Cool season	Good N fixer and increases soil N content Compatible with grasses like *Panicum, Pennisetum, Digitaria, Brachiaria* etc.
Stylosanthes guianensis (Stylo) *Stylosanthes hamata* (Carribean stylo) *Stylosanthes humilis* (Townsville stylo) *Stylosanthes scabra* (Shrubby stylo)	Native to Brazil	Warm humid tropical/ 500–1270 mm	GF:15–41 DM:5–10	Warm season	High quality forage Drought resistant Provide permanent vegetation cover N-fixation capability Improves soil quality by adding organic matter and N Compatible with grasses like *Cenchrus, Pennisetum* and *Chloris gyana* etc
Medicago sativa (Alfalfa)	Native to South West Asia	Temperate and tropical	GF:150 DM: 9	Cool season	Pest and insect resistance Drought and salt resistant. High N-fixation capability
Desmodium intortum (Green leaf desmodium)	Native to South America	Sub-tropical / 900 to 1275 mm	GF:19 DM:6–13	Warm season	Builds the soil organic matter Conserves soil moisture It contributes large quantity of N to soil Compatible with grasses
Desmanthus virgatus (Dashrath grass)	Native to Argentina	Hot climate/ 250 to 2000 mm	GF:15–25	Warm season	Tolerant to soil salinity Drought resistant Good N fixer
Trifolium repens (White clover) *Trifolium pretense* (Red clover)	Native to Europe	Temperate climate /750–1200 mm	DM:7–18	Warm season Cool season	Used as green manure Excellent N-fixation capability Increases soil fertility Compatible with grasses like *Lolium prenne, Cynodon dactylon, Pennisetum* etc.

Adapted from: Trivedi [26]; DM = Dry matter, GF = Green forage.

Table 3.
Leguminous species recommended for reclamation of coal mine degraded lands.

This is environmentally beneficial because it reduces the conversion of urinary N to ammonia and nitrous oxide, a potential greenhouse gas (GHGs). In addition, several studies have reported that high quality forage can also reduce enteric methane emissions, other powerful GHGs [39, 40]. Livestock grazing legume (*Medicago sativa)*-grass mixture reported 25% reduced enteric methane emissions compared to only grass pastures [41]. Adopting strategic use of grass-legume mixtures in ruminant's diet can be beneficial for health of livestock, sustainable use of resources and environment by mitigating GHGs in addition to benefits like enhanced productivity and reducing shift towards N fertilizer. The linkage between mining and engagement of local communities in mining activities is not only complex but also contentious. However, legume inclusive mining systems can turn in line with sustainability principles at food, animal, human and environmental level.

3.2 Soil fertility

Grass-legume mixture is widely accepted for restoration of coal mine dumps (**Table 4**). Grass-legume mulch residues act as soil conditioner to enhance soil physical properties via moisture conservation, reducing soil erosion and moderating soil temperature. The branching fibrous roots of grasses lowers the bulk density of compacted mine soil which accelerates the recovery of soils physical conditions at surface 10 cm depth [48]. Under drought stress conditions, root length and root area of grasses are more than legumes at the 30–60 cm depth of soil, therefore grass-legume mixture having different water use strategies can be opted for restoration of fragile areas [49]. The aggressive taproot system of legume species penetrates to a depth of 6–8 feet into soil. The N rich high protein legume residues stimulates earthworm burrows which in turn increases soil porosity, movement of air and water to deeper soil depths. Furthermore, legumes have extended value because they are naturally high quality forage that could enhance the quality and productivity of associating species specially grasses by biologically fixing atmospheric N [50]. Legumes can furnish up to 90% of their own N therefore when associated with grasses legume can regulate soil nutrient balance. When legumes are grown with grasses, the amount of atmospheric N fixed depends on three factors (1) available soil N, (2) legume proportion in mixture, and (3) the rate of biological N fixation (BNF). Soils that are N-deficient, legumes will out-compete grasses to grow and produce greater biomass/forage due to their N-fixing ability. Moreover in such situations BNF may be very similar to monoculture. In contrary if the soil contains adequate amount of available N to support grasses they will usually out-compete legumes for available soil N (**Figure 5**). In such situation the leguminous species will be stimulated and BNF will be greater compared to monoculture however, the total atmospheric N fixed will be lower in mixture because of lower legume biomass accumulation and competition with grass species. Adding grasses as an intercrop can increase the competitive aspects between grass and legume plant species but will continue to retain and recycle more total N than their pure strands (**Figure 6**). Non-competitive interferences may be the direct stimulation between species, for example the N fixed by a legume species becoming available to non-legumes. Grass-legume mixtures can yield more N than legumes monocultures due to mutual stimulation of N uptake via symbiotic and non-symbiotic rhizospheric micro-organisms and endophytic association as illustrated in (**Figure 7**) to sustainably improve the soil processes [51, 52]. Soil N management is necessary to reduce negative environmental impacts. The unused or excess N can lead to eutrophication in surrounding water bodies and nitrate poisoning in livestock. The concept of using mixture of N scavenging grasses with N addition legume will maintain the N balance under proper management strategies.

Sl. no	Study type	Vegetation type	Country	Type of soil	Positively affected parameters	Reference
1	Field experiment	Grass-legume mixture with leguminous and non leguminous tree species	India	Coal mine soil	Soil fertility Biomass yield Carbon sequestration	[19]
2	Field experiment	Grass-legume mixture	India	Coal mine soil	Soil fertility Forage/ biomass yield CO_2 flux	[2]
3	Field experiment	Multipurpose tree species and leguminous trees	India	Coal mine soil	Soil fertility	[42]
4	Field experiment	Grasses with leguminous and non leguminous tree species	India	Coal mine soil	Soil fertility N mineralization Biomass yield	[43]
5	Field experiment	Grasses with leguminous and non leguminous tree species	India	Coal mine soil	Soil fertility Reduction in air pollutants Water conservation potential Improved esthetic view	[44]
5	Field experiment	Grasses with leguminous and non leguminous tree species	India	Coal mine soil	Soil fertility and soil quality Biomass yield Soil CO_2 flux Soil enzymatic activity	[45]
6	Field experiment	Grass-legume mixture	India	Coal mine soil	Soil fertility Forage/biomass yield	[46]
7	Field experiment	Grasses, shrubs with leguminous and non leguminous tree species	India	Coal mine soil	Soil fertility Heavy metal reduction	[47]

Table 4.
Various field experiments in India using grass-legume mixture and the positively affected mine soil parameters post- reclamation.

A grass-legume association potentially accumulates high quality organic substrates in soil with soil organic carbon (SOC) and N pool accretion and promoting beneficial soil micro-organisms [53–55]. The difference in the chemical composition of grass-legume mixture incorporated in soil shifts the nutrient cycling via mineralization which stimulated the soil microbial activities [56]. Soil microorganisms are a necessary link between plant–soil interaction for productivity, nutrient availability and cycling thus, legumes are one of the necessary components to increase soil microbial activity accelerating the process of ecological restoration in mined areas [29]. Legumes add high quality of soil organic matter (SOM) because of their low biomass C:N ratio that can be readily decomposed by soil microbes improving soil biodiversity, deep taproot system and high water infiltration [57]. Also, legumes provide additional benefits to strengthen ecosystem services like (1) protection from pests

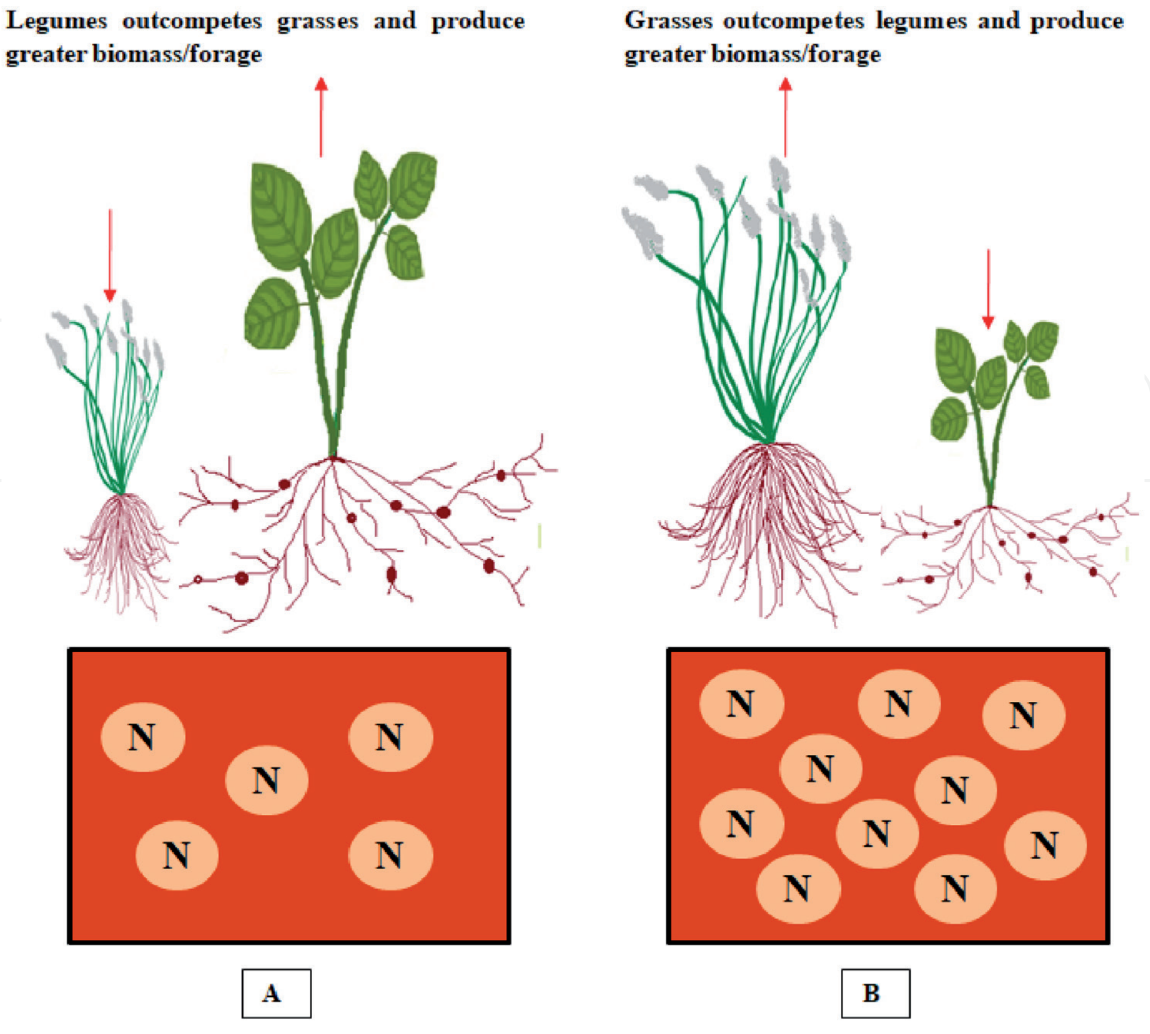

Figure 5.
Competitive aspects of grass-legume mixture under varying soil nitrogen (N) concentration.

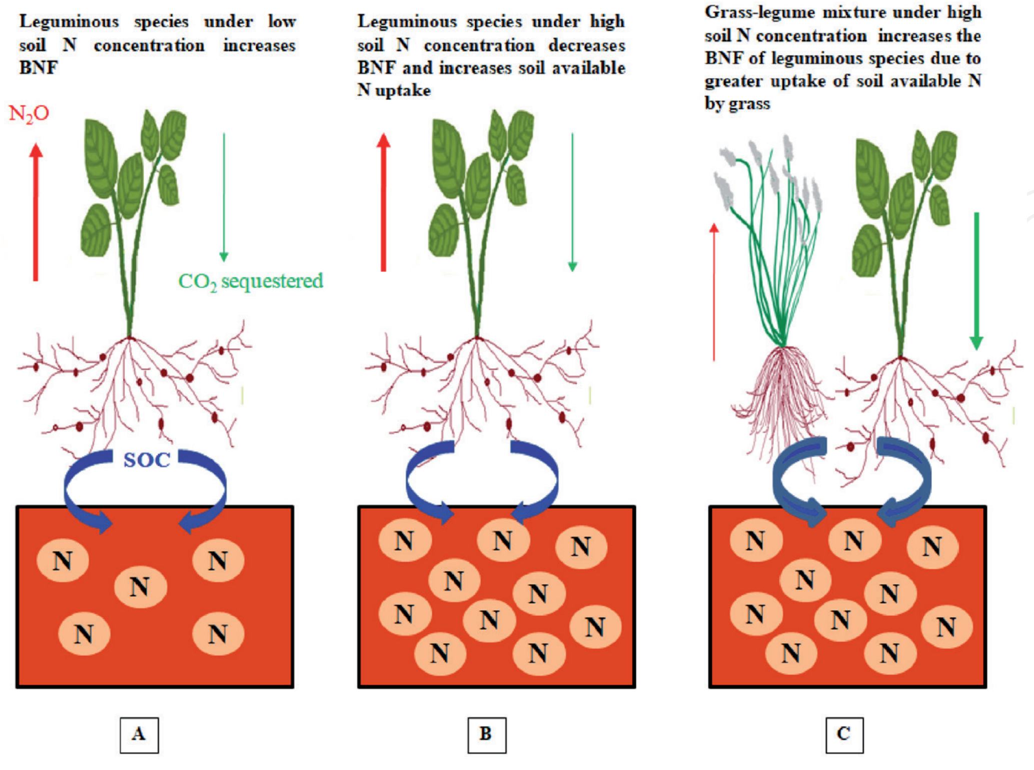

Figure 6.
Potential benefits of diverse species mixture in comparison to monoculture under varying soil nitrogen (N) concentration in binary nitrogen fixation (BNF), nitrous oxide emission (N2O), carbon sequestration and soil fertility.

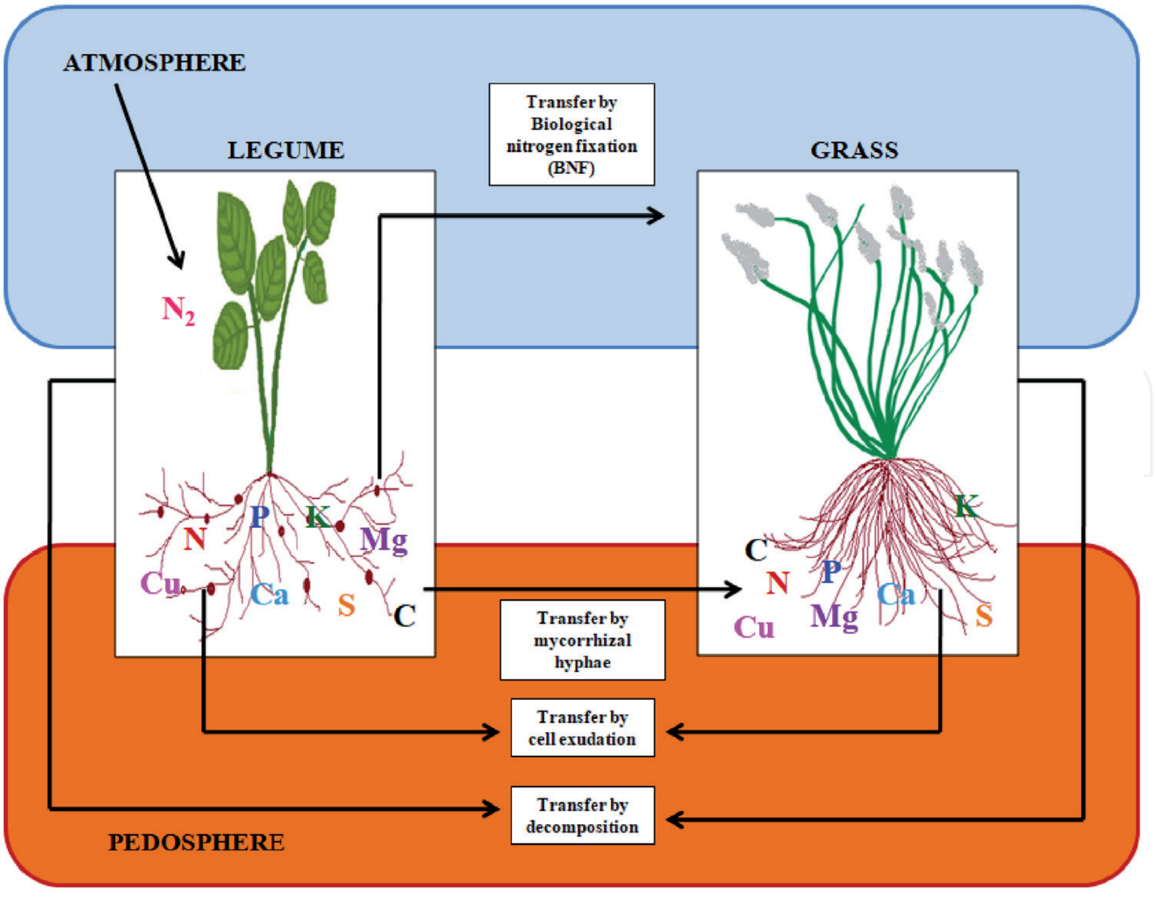

Figure 7.
Pathways of soil nitrogen (N) and other nutrients transfer between associating grass and legume species.

and diseases (2) *Rhizobium*-legume symbiosis accelerates the removal of soil pollutants. *Rhizobium* is a burgeoning component of the degrading microcosm in polluted soil and controlling tool for hazardous metal bioremediation reclaiming soil fertility [58, 59]. Some of the promising leguminous species used to remediate soil pollution are *Dalbergia sisso, Acacia auriculiformis, Albizia lebbeck,* and *Pongamia pinnata* while grasses are *Vetiveria zizanoides* and *Cymbopogon flexuosus* [44].

3.3 Carbon sequestration

Carbon sequestration is the natural process of capturing atmospheric CO_2 into the soil C pool through conversion of biomass residues into stable humus forms. It is one of the most important determinative biological factors of soil quality, productivity, and fertility [60]. Nearly 80% of total terrestrial C accounting to 2500 gigatons (GT) is found in soil out of which 1550 GT is organic C and 950 GT is inorganic C. The amount of C found in living plants and animals is relatively very small (560 GT) compared to soil C [61]. Plant biomass residues increase C sequestration through decomposition of their residues which links soil C sequestration to elevated biomass production and hence to soil fertility. Increasing soil fertility is the most effective way of rapidly accelerating SOC storage and can be accomplished through addition of soil N fertilizers. In contrast the role of legumes in supplying eco-friendly N through fixation is being favored more because of co-benefits like GHGs stability by reducing emissions. Grass-legume based vegetation system contributes to accelerate biomass production which improves the SOC stock and maintains a high amount of sequestered soil C [19, 29, 62]. The potential of C sequestration varies between different species depending on rate of decomposition and rate of conversion of soil liable C to recalcitrant C [57]. Perennial legumes like *Medicago sativa, Lespedeza davurica* and *Astragalus adsurgens* growing on arable lands increased the soil C sequestration by 79, 68 and 74% respectively [63]. Several practices have been reported to increase forage biomass yields, including better pasture management, fertilization, organic amendments, improved irrigation, grass-legume mixture, reduced tillage and crop rotations. All these techniques are associated with reduced C loss and increased C input however, the rates of C sequestration vary with different management practices and inclusion of legumes or N sources. Land degradation due to coal mining disturbs the ecological processes of photosynthesis, decomposition and soil respiration and consequently to depletion of SOC pool. These anthropogenic activities negatively affect the global climate by rapid inputs of CO_2 and other GHGs to the atmosphere [64]. The French "4 per mile" initiative signed by more than 100 countries at Conference of parties (COP21) states that increase in soil C by 4% (0.4%) a year we can halt the annual CO_2 increase in the atmosphere. A Grass-legume mixture management strategy provides an opportunity for sequestering C back into soil reducing exacerbation of GHGs and climate change.

3.4 N fertilizer and N_2O emission

Legumes owing to their N fixation capabilities have little exogenous fertilizer requirement except the starter dose of application depending on site-specific conditions. The effect of previous legume in rotational cropping also reduces the need for fertilization in succeeding plant cover. Without fertilization legumes like *Trifolium* spp. have reported N fertilizer savings of (160–310 kg ha^{-1}) through BNF [65]. At current times when the chemical inputs like fertilizer application is not a viable option for environment along with increased cost of natural gas-based N fertilizers we need to consider legume as an eco-friendly option to sustain fertility and yields over longer time periods compared to fertilizer [29]. Nitrous oxide (N_2O), powerful GHG is 300 times more potent compared to CO_2 in relation to global warming potential. Nutrient poor or degraded soil requires greater amount of N fertilization to sustain biomass cover and increase yields. The emission of soil N_2O increases linearly with the quantity of N fertilizer applied to soil thus, BNF via legumes will become an essential aspect in all systems. Diverse mixture with legume addition improves biomass yield, in some cases equivalent to mineral N fertilization at the rate of 33–150 kg ha^{-1} and reduce soil N_2O emissions by 30–40% [66]. The study of [67] also showed consistent lower N_2O emissions in binary grass-legume mixtures compared to only grass with N fertilization. The reduced emission rate is associated with species complementarities between grasses and legumes which creates a synchrony in the timing of N mineralization and N demand. Soil systems including grass-legume mixture significantly lower the annual N_2O emissions saving N fertilizers and thus GHGs and a considerable potential for climate change mitigation [50].

3.5 Weed control

Weed invasion on post-mined lands negatively affects plant survival and biomass yield and therefore needs to be fully eradicated. Use of herbicides for weed removal can be effective at times but not environmental friendly and induces GHGs emission. Plant diversity (grass-legume mixture) can effectively suppress weed invasion. Sanderson et al., [68] found consistently lower weed abundance in legume-dominated mixtures compared to monocultures. Weed management system should be consistent with the principle of control, prevention and eradication. Organic mulches including grass and legume mulch residues can suppress the invasion of weeds [69] in several ways like (1) blocking germination by intercepting light (2) lowering soil temperature (3) greatly humidified day and night temperature fluctuations (4) thick mulch layer lowers weed seeds to germinate than non-mulched soil (5) organic mulches enhances competition of resources, favors plant growth eradicating weeds. Study on weed suppression reported 52% less weed biomass across mixtures varying in species proportions. Weed invasion can be lowered via forage species combination and plant diversity and persistence traits in systems designed to reduce reliance on N fertilizer [70]. Nitrogen is not required for legumes or grass-legume mixture establishment. Application of N in such conditions can deter N fixation by legumes and in turn will accelerate competitive growth of grasses and weeds.

4. Case study: a successful case study promoting sustainable mining in India

Objective of the study: To conserve and enhance the biodiversity along with generating natural resources to cater the needs of local community and better esthetic view of the mined area.

4.1 Study area description

Ecological restoration (using 3-tier plantation model) of Tetulmari coal mine dump under Bharat Coking Coal Limited (BCCL), India was carried out to reverse the environmental degradation post-mining. The total area cover was 8–10 hectares located at 23°48′210" N and 86°20'527" E and at an elevation of 704.9 m above mean sea level. Prior to restoration the mined out area was 14 years old and fully invaded by exotic weeds (*Lantana camara, Eupatorium odoratum, Heptis suaveolens*). The area was completely devoid of grass cover and native tree species.

4.2 Restoration approaches

- Based on the geological condition of post-mined sites, various restoration approaches were applied. Biological reclamation approach by fast growing single tier species plantation was the first effort of BCCL to restore the coal mine dump. This approach was not suitable for ecological restoration. The monoculture plantation method failed to develop on nutrient deficient rocky structure of mine dumps and also did not allure animals, birds and micro-organisms etc.

- Following the above scenario an ecological restoration approach based on three tier plantation model using grasses, herbs shrubs and trees was developed during three years (2011–2014) time period. A total of 13,000 plants of different species including grasses, legumes and horticulture species were planted in the coal mine dump (**Table 5**). The species were propagated through direct seeding, culms, seed balls, stem cutting, bulbils and seedling planting. Further, for attaining a sustainable and more stable ecosystem at the mine degraded area, a biodiversity enhancement initiative was carried out from 2016 to 2018. The initiative includes steps such as weed eradication, mulching, topsoiling, pitcher irrigation technique.

4.3 Results

Re-vegetation status: The ecological restoration approach was successful in establishing dense and diverse vegetation (trees, shrubs, herbs and grasses) cover on the mined dump within three years of restoration. Vegetation analysis during the course of restoration showed that among planted species *Dalbergia sissoo* was the most successful at the site with a maximum density of 514.3 tree ha^{-1}. The total

	Seed mix (sown)		Seed mix (soil balls)		Species planted	
Sl. No	**Species**	**Family**	**Species**	**Family**	**Species**	**Family**
1	*Acacia nilotica*	Mimosaceae	*Bamboosa bambos*	Poaceae	*Albizia lebbeck*	Fabaceae
2	*Aegle marmelos*	Rutaceae	*Cenchrus ciliaris*	Poaceae	*Albizia procera*	Fabaceae
3	*Albizia lebbeck*	Mimosaceae	*Cenchrus setigerus*	Poaceae	*Azadirachta indica*	Meliaceae
4	*Albizia procera*	Mimosaceae	*Cynodon dactylon*	Poaceae	*Bamboosa bambos*	Poaceae
5	*Bauhinia purpurea*	Caesalpiniaceae	*Panicum nitidum*	Poaceae	*Bombax ceiba*	Bombacaceae
6	*Bombax ceiba*	Bombacaceae	*Saccharum benghalense*	Poaceae	*Cassia fistula*	Fabaceae
7	*Cassia fistula*	Caesalpiniaceae	*Stylosanthes hamata*	Fabaceae	*Dalbergia sissoo*	Fabaceae
8	*Dalbergia sissoo*	Fabaceae	*Trifolium repens*	Fabaceae	*Madhuca indica*	Sapotaceae
9	*Melia azaderach*	Meliaceae			*Mangifera indica*	Anacardiaceae
10	*Moringa oleifera*	Moringaceae			*Emblica officinalis*	Euphorbiaceae
11	*Crotalaria juncea*	Fabaceae			*Pongamia pinnata*	leguminoceae
12	*Pongamia pinnata*	Fabaceae			*Psidium guajava*	Myrtaceae
13	*Dodonaea viscosa*	Sapindaceae			*Syzygium cumini*	Myrtaceae
14	*Indigofera trita*	Fabaceae			*Terminalia arjuna*	Combretaceae
15	*Mimosa pudica*	Mimosaceae			*Zizyphusnummularia*	Rahmnaceae
16	*Mucuna pruriens*	Fabaceae				
17	*Withania somnifera*	Solanaceae				

Table 5.
Species composition under the three-tier plantation method during ecological restoration of Tetulmari coal mine dumps, India.

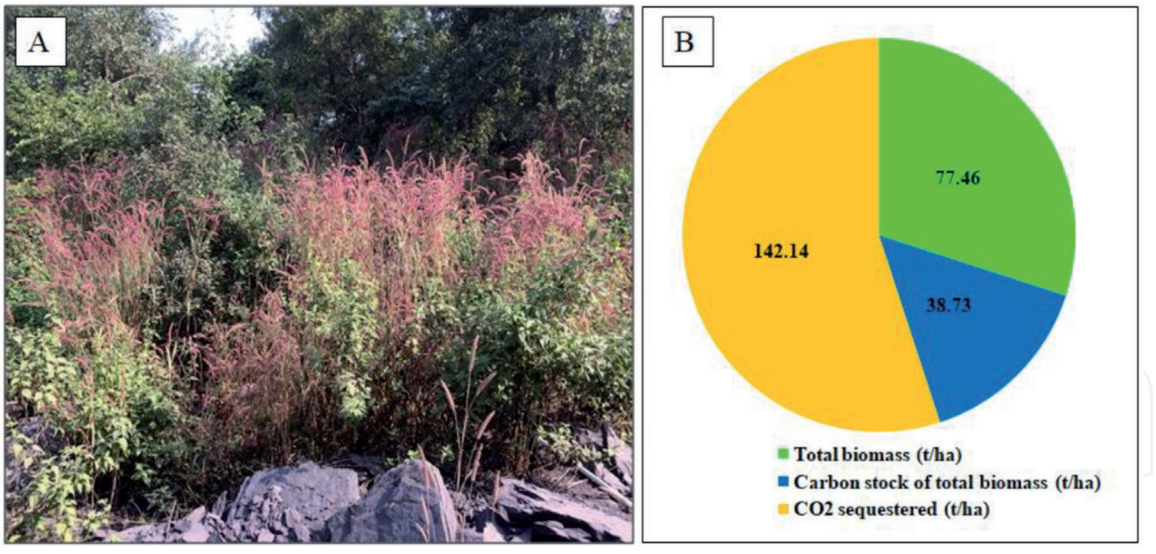

Figure 8.
(A) Closer view of dense and diverse vegetation cover of understory biomass and tree growth (B) biomass carbon stock and CO2 sequestered after ecological restoration of Tetulmari coal mine dumps, India.

shrub and herbs density was 1114 Ind ha^{-1} and 6.79 Ind m^{-2}. Similarly *Cenchrus ciliaris, Cenchrus setigerus* were found to be the promising grass species whereas *Pennisetum pedicellatum* was the first grass species to colonize the site. Successful horticultural species includes *Emblica officinalis, Mangifera indica Syzygium cumini* and *Psidium guajava.* Horticulture and grasses-legume species besides providing ecological stability were able to cater the needs of local communities and adjoining societies by providing food, fodder, timber resources and livelihood opportunities.

Nutrients status: Besides successful vegetation establishment, a notable change is soil physicochemical and biological properties were also observed in the span of three years. The soil pH increased from 6.0 to 7.1. SOC and total N concentration increased by 46% and 180% respectively after ecological restoration. The total biomass (77 t ha^{-1}) accumulated on the dump surface accumulated 39 t ha^{-1} C stock in soil equal to 141 t ha^{-1} CO_2 sequestered (**Figure 8**). The ecological restoration of mine degraded land considerably increased the ability of biomass and soils to sequester C. The development of terrestrial C sinks reduces ill-effects of polluting gases (GHGs) caused to the climate change.

Biodiversity status: The diverse vegetation started attracting different types of faunal species including birds, butterflies, insect, reptiles and naturally re-colonizing animals like foxes, rabbits, jackals etc. The enhanced biodiversity also facilitates to support food chains and better esthetics at the eco-restored area.

5. Conclusions

The mining process is not only ecological and socially devastating but also extremely demanding on natural resources like water land and energy. The post-mined areas are highly susceptible to weed invasion and prone to erosion that can cause mine waste to pollute adjoining soil and water resources. The rising demand of coal is likely to escalate ecosystem damage in several ways. The agronomic benefits' of grass and legume species has lead us to recognition of its environmental and socioeconomic advantages in mined-out landscapes (**Figure 9**). Sustainable mining is essential for the survival of humankind. The review of literature presented here in ascertains that grass-legume based management practices hold a vast potential to advance mine sustainability owing to benefits of BNF, soil

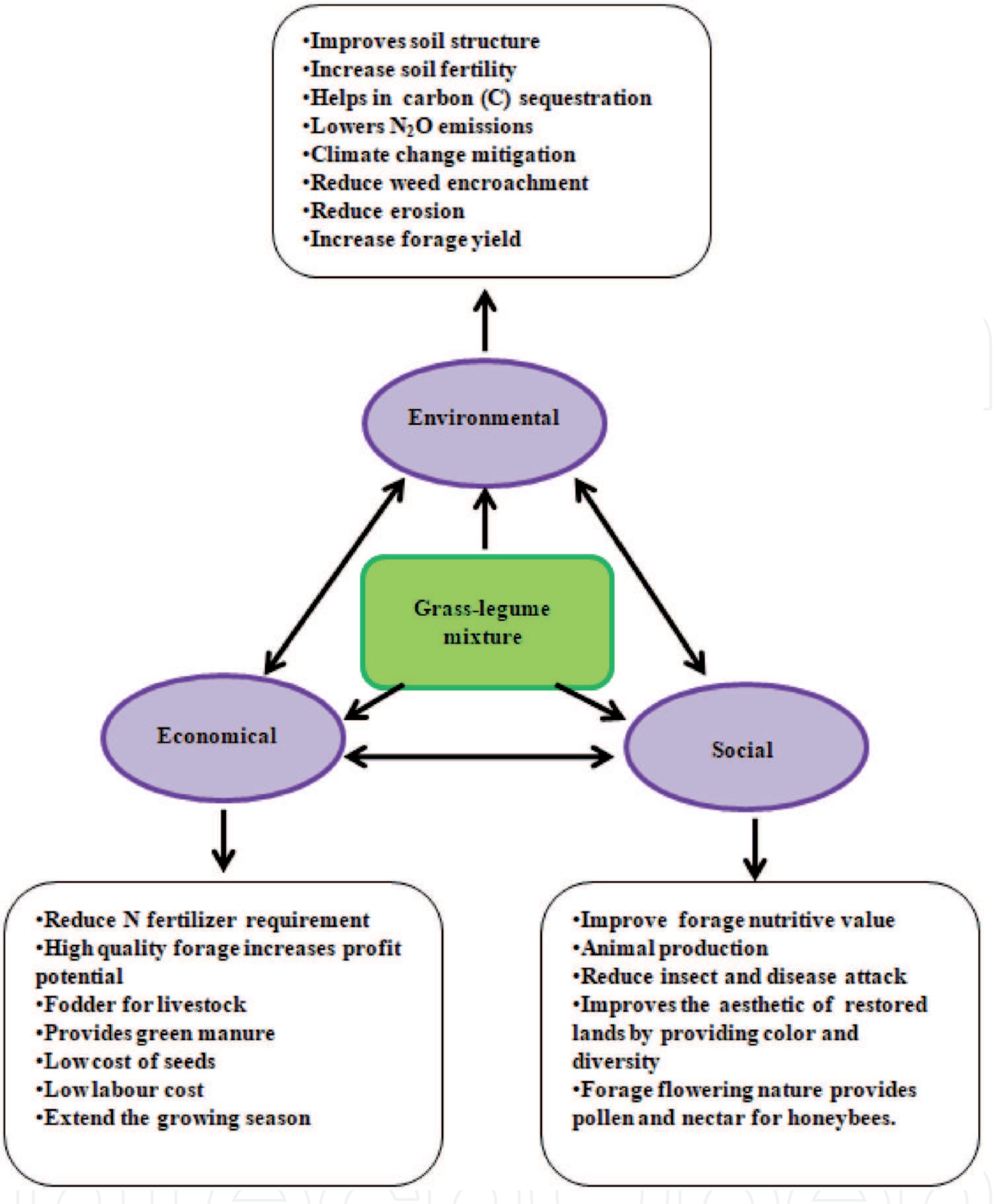

Figure 9.
Sustainability aspects of grass-legume mixture in environmental, social and economic arenas.

regeneration, creating terrestrial C sinks, weed control, reducing GHGs emissions and socioeconomically viable by increasing profit potential. Future perspective ascertains the need of ecological restoration using grass-legume seeding aimed towards sustainable intensification of mine degraded lands besides supporting livelihoods of millions.

Acknowledgements

The first author is grateful to Indian Institute of Technology (Indian School of Mines), Dhanbad, and Ministry of Human Resource Development, Government of India for providing fellowship and other research facilities to support the research work.

Declaration of competing interest

The authors do not have any conflict of interest.

Author details

Sneha Kumari and Subodh Kumar Maiti*

Department of Environmental Science and Engineering, Center of Mining Environment, Indian Institute of Technology (Indian School of Mines), Dhanbad, India

*Address all correspondence to: subodh@iitism.ac.in

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