Leguminous Trees an Innovative Tool for Soil Sustainability

10

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Contents

Abstract
World food production is to some extent dependent upon biological nitrogen (N) fixation (about 100 million tons per year globally) in agroecosystem. Legumes reflect multidimensional activity towards developing soil nutrient pool and improving soil fertility. Increased level of CO_2 (0.04%) associated with addition of N in a system is dependent upon various abiotic (temperature, humidity, soil) and biotic (species interaction, resource partitioning, biotic interference) factors.

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As a consequence there may be a significant level of variation in the N cycle in different ecosystems. In comparison with cropland soils of Europe and North America, soils of India are strongly depleted of their N reserves. Such deficiency can be mitigated through the inherent N-fixing ability and improvement of soil condition by leguminous tree species. Such approaches also promote proper enhancement of forest floor biodiversity in terms of various living communities. Leguminous trees are often found to be a key instrument towards combating climate change due to their higher C sequestration potential and wide ecological amplitude at various conditions. Such potentiality often hampers the flourishment of legume trees in nature due to over exploitation and improper regeneration. Community-based natural resource management practices are the suitable solution for these problems. Exploration of areas with higher density of legumes and management of legumes in captivity and under natural condition needs to be prioritized. In this context appropriate research work should be aimed towards proper exploration of potentiality among leguminous vegetation in fixing atmospheric N. Wider application of such species has become a thrust area of research in modern science perspectives. All these issues are periodically reviewed with research-oriented database for the benefits of soil sustainability. The present chapter deals with the beneficial and multipurpose role of leguminous tree species towards soil sustainability and plant growth.

Keywords
C and N sequestration · N fixation · Nutrient pool · Tree species

Abbreviations

AMF	Arbuscular mycorrhizae fungi
BNF	Biological nitrogen fixation
C	Carbon
CO_2	Carbon dioxide
FACE	Free-air CO_2 enrichment
FAO	Food and Agricultural Organization
GHG	Greenhouse gases
INM	Integrated nutrient management
N	Nitrogen
NFP	Nitrogen-fixing potential
NFT	Nitrogen-fixing trees
OM	Organic matter
R&D	Research and development
SCP	Soil carbon pool
SNF	Symbiotic nitrogen fixation
SNP	Soil nitrogen pool
SOCP	Soil organic carbon pool
SOM	Soil organic matter

10.1 Introduction

Legumes show considerable promise for sustained supply of N into the soil systems for ready uptake of crop species along with checking soil health problems. Flowering plants are to some extent dominated by legumes. The Gramineae family which includes cereals and grasses while family Leguminosae (Fabaceae) includes legumes or the bean family has a wider contribution to the soil health and nutritional security in world agriculture. The Leguminosae family is represented by 750 genera and 19,000 species (Stevens 2001; Bargali 2016; Dhakal et al. 2016) and is divided as the Caesalpinioideae, Papilionoideae and Mimosoideae.

Among the flowering plants, members of Leguminosae family are providing a variety of products like food, gums, fodder, timber, etc. in various climatic regimes of the world (Rao and Husain 1993; Bargali 2016). In India, legumes are also widely adapted plant species under various environmental conditions and are represented by 1152 species under 179 genera (Husain and Kapoor 1990; Sanjappa 1991). The family comprises diverse growth form in terms of height, growth, life cycle and various life forms (Rao and Husain 1993; Bargali 2016). Symbiotic association of microbes with root system of legumes is often designated as nodular growth of root (Allen and Allen 1981).

Legumes provide good quality foods as well as produce lesser GHGs (five to seven times) when compared to other crops. They also sequester 7.21 g kg^{-1} DM, 23.6 versus 21.8 g C kg^{-1} year. In agricultural system, legumes can be widely grown in conservation system, low-input farming system as well as intercropping system (Stagnari et al. 2017; Varma et al. 2017a). Nitrogen fixer (mostly legumes) maintains harmony between productivity and sustainability (Rao et al. 2007). Legumes perform various ecological functions like improvement in the soil quality, reduction in N requirement for plant species for growth purpose and enrichment of wildlife habitat, improving land capability which stops further land degradation (Bargali and Bargali 2009). They can be successfully incorporated through practices such as crop rotation/intercropping to improve soil health with minimum amount of fertilizer application. Legume-rhizobium association stands to be the most promising N fixation system providing economic benefits in terms of lesser fertilizer application and soil sustainability (Crews and Peoples 2004; Kumar et al. 2013, 2014; Bhagat et al. 2014). Such potentialities promote ecological restoration of degraded land habitat. The biological N fixation (BNF) process is often dependent upon various abiotic factors as well as soil nutrient status which influence the rate of N fixation of legumes at molecular and functional level which regulates the N-fixing potential at a certain time interval in a certain area (Bommarco et al. 2013). Symbiotic process includes N fixation as a natural process that helps to maintain soil fertility along with crop productivity under semiarid tropical condition. From sustainable agriculture perspective, symbiotic N fixation (SNF) is a suitable strategy with growing dimension for future to boost up agricultural productivity. Qualitative assessment on SNF and its impact on crop and leguminous species indicated that leguminous SNF is highly susceptible towards environmental changes (Galiana et al. 2004), and therefore N fixation potential (NFP) can be hindered. Leguminous N-fixing trees

(NFT) often have multipurpose uses, e.g. *Leucaena* can be effectively utilized for fodder, fuel and fibre. Other species such as wattles (*Acacia* spp.) has been reported to produce gums and resins. Lesser nodulation was observed in Caesalpinioideae than the other subfamilies. The present chapter deals with the potential role of legumes in different directions towards environmental sustainability. Further, it addresses the ecofriendly roles of legumes towards soil sustainability under tropical condition of India.

10.2 Leguminous Trees and Their Role in Soil Sustainability

Nowadays, soil sustainability is a major challenge under the complex influence of various phenomena such as nutrient loss, soil erosion as well as agricultural pollution (Zentner et al. 2004). Legumes perform multifaceted activities in various spheres of agricultural sector as well as help fix atmospheric carbon and provide daily basic needs (Fig. 10.1). Legumes also promote soil carbon sequestration. They also serve as high-protein feeds and promote biodiversity and soil quality. Multifaceted role of legumes and their agro-productivity along with socio-economic upliftment of the farming community in different agroecological zones of the world should be emphasized in research and development activities.

Legume has the potential to stop the splashing action of rain drops to check soil erosion. *Rhizobium* colonizes the roots of legume plant in the form of symbiotic relationship (Bilyaminu and Wani 2016). Root nodule formation by *Rhizobium* species has a positive influence on rates of BNF under nutrient-deficient condition. *Rhizobium* bacterium performs the vital ecological role in solubilization of nutrient with vesicular-arbuscular mycorrhizae (VAM) association. Such type of association positively influences the root system to explore and gain more nutrients from the soil nutrient pool such as phosphorous under stress condition. As per earlier reports, it was observed that plant species reflects a significant level of variation over soil structure. Legumes are found to be much more promising in this context (Drury et al. 1991) because legume promotes higher mobilization of nitrate in the plant-soil ecosystem (Holtham et al. 2007; Meena et al. 2015a).

Presently throughout the world, half of the cultivated land is under the threat of degradation and future prediction reveals that present rate of land degradation would lead to huge area of agricultural area to become less productive by near future. Under tropical condition building up of SOM pool is an essential requirement under acidic condition by the elevated saturation of Al (aluminium) and lesser availability of P (phosphorus). OM condition is a key factor towards proper nutrient utilization by the crop plants on such type of surfaces. N and biotic constituents represent better relationship towards rate of mineralization which indicates quality of OM (Fox et al. 1990; Thomas and Asakawa 1993).

Legumes further promote checking soil erosion by stabilizing ravines and gullies. Legumes have the potential to reduce N pollution through chemical fertilizer which subsequently reduces fossil fuel consumption (Zentner et al. 2001, 2004). Without crop rotation, productivity of agroecosystem decreases under various biotic

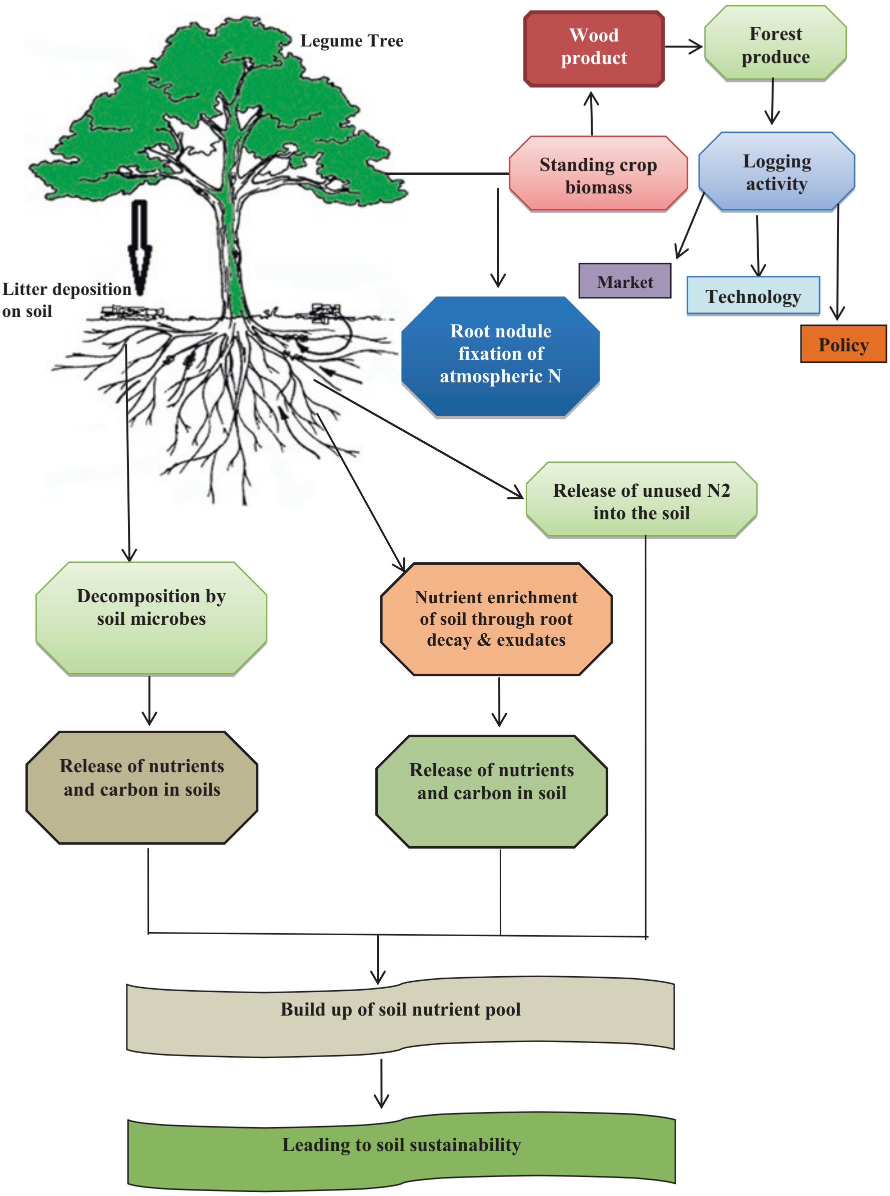

Fig. 10.1 Role of tree towards soil sustainability and meeting human needs

and abiotic factors. Non-judicious crop rotation practices lead to decline in productivity, the yield of crops with subsequent degradation of the soil quality with the gradual invasion of various biotic factors (Dumanski et al. 1998; Jhariya and Yadav 2017). Studies on mixed cropping on long-term experimental tenure in specific cropping sequence reported higher productivity and higher biomass turnover in

Table 10.1 Legume biomass (t/ha) in tropics of Chhattisgarh, India (Jhariya et al. 2014)

Species	Bole	Branch	Leaf	Root	Total
Tree stage					
Cassia fistula Linn.	0.59–0.98	0.64–1.18	0.06–0.10	0.22–0.37	1.52–2.63
Dalbergia paniculata Roxb.	0.64	0.62	0.07	0.24	1.57
Ougeinia oojeinensis (Roxb.) Hochr.	3.59–5.49	3.90–7.94	0.40–054	1.34–2.06	9.23–16.03
Sapling stage					
Butea monosperma (Lamk) Taub.	0.016–0.03	0.007–0.01	0.003–0.005	0.006–0.01	0.03–0.07
Cassia fistula Linn.	0.03	0.01	0.05	0.01	0.07
Dalbergia paniculata Roxb.	0.16	0.09	0.02	0.06	0.32
Ougeinia oojeinensis (Roxb.) Hochr.	0.11–0.36	0.066–0.21	0.01–0.05	0.04–0.14	0.23–0.76
Seedling stage					
Cassia fistula Linn.	0.24	0.05	0.047	0.087	0.42
Dalbergia paniculata Roxb.	0.06	0.01	0.01	0.02	0.11
Ougeinia oojeinensis (Roxb.) Hochr.	0.28	0.06	0.056	0.10	0.50
Shrubs					
Bauhinia racemosa Lam.	0.02	0.01	0.10	0.010	0.15
Bauhinia vahlii (W.) A.	0.03	0.02	0.17	0.02	0.24
Butea superba Roxb. ex Willd.	0.53	0.28	1.81	0.09	2.71
Spatholobus roxburghii Benth.	0.007	0.005	0.034	0.003	0.05

annual rotation system instead of monoculture (Drinkwater et al. 1998). This, therefore, revealed lower C/N ratio in the USA, which has increased C pool that promotes a certain amount (1–2%) of emission reduction of carbon in atmosphere through burning of fossil fuel (Marland and Boden 1997; Yadav et al. 2017a).

10.3 Leguminous Trees and Soil Biomass

BNF is an effective process towards supplying N in soil nutrient pool due to their capability to fix atmospheric N into the soil. Legume can be effectively utilized in this case due to their fast-growing nature, drought resistancy as well as the ability to fix atmospheric N. *Acacia* species has a high potential for N fixation, which grows very fast in the wasteland and agroforestry systems throughout India. Legumes such as *A. nilotica* have a significant stimulatory impact over paddy cultivation regarding N-fixing potential as well as higher organic matter (OM) accumulation which promotes its development in rice-cultivated area (Jhariya et al. 2015). The species have been found to have higher carbon-sequestering potential when compared to other plants which are nonleguminous in nature. These species have substantial potential to produce higher biomass and carbon storage (Tables 10.1 and 10.2) supports to build high soil organic biomass depending upon the age, site quality and successive stage. *A. nilotica* approximately fixes 228.45 kg per tree biomass carbon which is added to

Table 10.2 Legume C storage (t/ha) potential in tropics of Chhattisgarh, India (Jhariya et al. 2014)

Species	Bole	Branch	Leaf	Root	Total
Tree stage					
Cassia fistula Linn.	0.49	0.59	0.05	0.18	1.32
Dalbergia paniculata Roxb.	0.32	0.31	0.04	0.12	0.79
Ougeinia oojeinensis (Roxb.) Hochr.	2.74	3.97	0.27	1.03	8.01
Sapling stage					
Butea monosperma (Lamk) Taub.	0.02	0.01	0.003	0.01	0.03
Cassia fistula Linn.	0.02	0.01	0.003	0.01	0.03
Dalbergia paniculata Roxb.	0.08	0.04	0.01	0.03	0.16
Ougeinia oojeinensis (Roxb.) Hochr.	0.18	0.11	0.03	0.07	0.38
Seedling stage					
Cassia fistula Linn.	0.118	0.026	0.024	0.044	0.21
Dalbergia paniculata Roxb.	0.032	0.007	0.006	0.012	0.06
Ougeinia oojeinensis (Roxb.) Hochr.	0.139	0.030	0.028	0.052	0.25
Shrubs					
Bauhinia racemosa Lam.	0.01	0.01	0.05	0.005	0.07
Bauhinia vahlii (W.) A.	0.02	0.01	0.08	0.008	0.12
Butea superba Roxb. ex Willd.	0.26	0.14	0.90	0.044	1.35
Spatholobus roxburghii Benth.	0.01	0.005	0.03	0.003	0.05

the soil organic carbon (SOC) stock rendering higher fertility of the soil. Carbon content sequence appears to be *Eucalyptus tereticornis* = *Azadirachta indica* = *Acacia nilotica* = *Butea monosperma* > *Albizia procera* = *Dalbergia sissoo* > *Emblica officinalis* = *Anogeissus pendula*. *Albizia procera* were most efficient in CO_2 fixation, and *Anogeissus pendula* were least in these aspects (Rajendra Prasad et al. 2010).

10.4 Leguminous Trees' Role in Carbon Sequestration

Leaves of leguminous trees add a considerable level of SOC due to decomposition by soil microorganisms (Fig. 10.2). Trees have the potentiality to entrap atmospheric carbon which leads to carbon sequestration in forests (Tables 10.3 and 10.4). Legume tree like *Acacia nilotica* can fix substantial level of C which leads to enhancement of SOC pool (SOCP) as well as soil fertility. Different plant parts of aged trees reported the variable level of carbon concentration. A sum of stored carbon in different plant parts varied from 1.36 to 3.08 t/ha (Dhruw et al. 2009; Datta et al. 2017). Maximum amount (70%) of stored carbon were represented in the above ground parts, and lesser amount (30%) were obtained from below ground.

A higher level of carbon sequestration in soil leads to increased biomass which further promotes soil fertility. Increasing level of soil fertility adds more C to the soil. *Leucaena leucocephala* recorded fixation of carbon up to 0.575 t/ha annually and a higher level of C storage in legume-based tropical pastures in comparison to grassland. Some earlier works (Cadisch et al. 1998) reported major contribution of N-fixing species towards gradual building up of SOM in tropical soil.

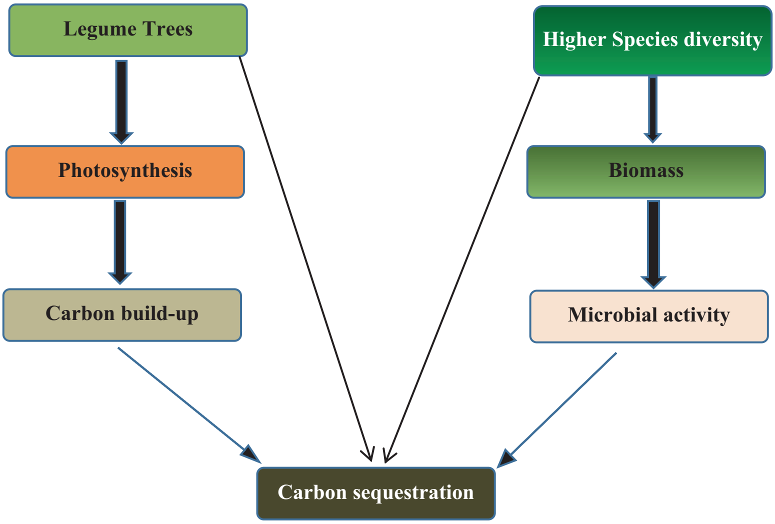

Fig. 10.2 Role of legumes trees in soil carbon sequestration

Table 10.3 Carbon storage potential of some legume species

Tree species	Carbon storage	Author
Dalbergia sissoo	151.84 t/tree	Bilyaminu and Wani (2016)
Acacia nilotica	86.52 t/tree	
Leucaena leucocephala	71.27 t/tree	
Albizia lebbeck	158.20 t/tree	
Bauhinia variegata	19.54 t/tree	
Leucaena leucocephala	13.660 kg/tree	Deka et al. (2016)
Bauhinia variegata	26.020 kg/tree	
Mixed plantation of *D. sissoo* and *L. leucocephala*	93.47 ± 0.67 t/ha	Sheikh et al. (2015)
Dalbergia sissoo	74.54 ± 0.53 t/ha	
L. leucocephala	53.98 ± 1.21 t/ha	

L. leucocephala along with *D. sissoo* promoted higher carbon sequestration potential instead of the separate plantation of each. Such strategies may lead to greater reduction of the atmospheric CO_2 level and thus will be helpful to combat climate change (Sheikh et al. 2015; Kumar et al. 2016). Inclusion of leguminous trees within *Eucalyptus* plantations promoted carbon sequestration in the vegetation stand (Kaye et al. 2000). The presence of NFT within forests accelerates the higher level of carbon sequestration in soils (Resh et al. 2002) and therefore improves the level of SOM and carbon. As per earlier reported works, 1 g N is associated with fixation of 12–15 g C (Binkley and Menyailo 2005). To promote higher absorption of light and CO_2, mobilization of carbon in the upper canopy part of a plant body from roots and the mycorrhizal association is connected with nutrient availability (McConnaughay and Coleman 1999). The amount of carbon and N level were proportional to the carbon content in lithospheric zone of forested area (Macedo et al. 2008).

Table 10.4 Carbon sequestration potential of some legume species

Tree species	Carbon sequestration	Author
Mixed plantation of *D. sissoo* and *L. leucocephala*	34.30 ± 0.24 t/ha/year	Sheikh et al. (2015)
Dalbergia sissoo	27.35 ± 0.19 t/ha/year	
L. leucocephala	19.81 ± 0.44 t/ha/year	

Table 10.5 Various sources of N fixation (Dashora 2011)

N fixation source	N fixed (10^6 tons/year)
Land	155
Legume	40
Nonlegume	10
Others	105
Sea	40
Total biological	195
Lightning	10
Industry	85
Total non-biological	95

10.5 Leguminous Trees' Role in N Sequestration

Several works on different legume species have emphasized the importance of mixed culture system in comparison to monoculture plantation of legumes for BNF. N_2-fixing potential (NFP) refers to the relative capability of species to fix atmospheric N_2 in the absence of limiting factor (Table 10.5). The presence of limiting factor influences N_2 fixation negatively, and, therefore, measurement of actual fixation of N_2 was measured (Galiana et al. 2004). Hereditary characteristics of both the symbionts (host plant and associated bacterial strain) influence NFP of legumes. Species such as *Leucaena leucocephala*, *Calliandra* spp., *Acacia mangium*, *Acacia auriculiformis*, *Acacia crassicarpa*, *Acacia mearnsii*, *Gliricidia sepium*, *Sesbania spp*., *Casuarina equisetifolia* and *Casuarina cunninghamiana* have high NFP (60–100 kg/ha annually); *Prosopis juliflora* and *Acacia saligna* (syn.: *A. cyanophylla*) are reported to have medium NFP, and *Acacia raddiana*, *Acacia senegal*, *Acacia cyclops* and *Faidherbia albida* have low NFP (Ganry and Dommergues 1995).

BNF is an effective mechanism to improve soil N status through the cultivation of leguminous crops under N-deficient soil condition. These species have the inherent capability to fix atmospheric N to be utilized by both plant and soil system (Fig. 10.3). During summer leguminous species like *Cajanus*, *Crotalaria*, *Gliricidia*, *Sesbania* and *Tephrosia* have been used as intercrop which promoted 100–200 kg N/ha biannually in African subcontinent (Rao et al. 2007).

Leguminous plants may fix 15–200 kg N/ha annually (Dakora and Keya 1997; Unkovich and Pate 2000), which renders them to be utilized as an intercrop or as cover crops (Table 10.6). As per earlier reports, it can be formulated that higher ambient concentration of CO_2 will promote addition of more N into the soil through

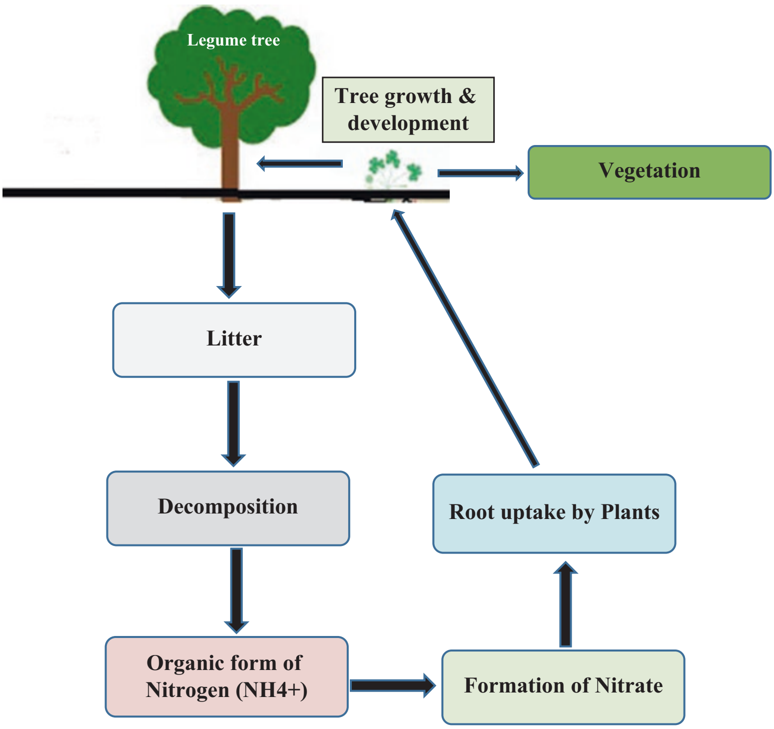

Fig. 10.3 Nitrogen fixation cycle in trees

BNF mechanism. Within agricultural ecosystems, biologically fixed N is mainly contributed towards different vegetative parts, but the fewer amount of N is emitted to the soil (Hardarson et al. 1987). Various scientific reports revealed that climate change has its influence upon BNF species, but lacunae in scientific knowledge still prevail about the increased level of CO_2 upon ecosystem influencing nutrient cycle. Recent development regarding free-air CO_2 enrichment (FACE) approach (Miglietta et al. 2001; Okada et al. 2001) reveals the elevated level of CO_2 without altering other environmental, climatic elements and other living biological organisms. FACE experiments are now exploring the role of various climate change segments altering addition of N in ecological systems through BNF technology. A comparative account was prepared under various treatment systems which includes CO_2 and lower atmospheric O_3 are applied in a specific crop rotation system, and addition of CO_2 and fertilizer was done as treatments of N on pasture land comprising of clover and ryegrass (Miglietta et al. 2001; Okada et al. 2001; Meena et al. 2013a, b). Swiss FACE experiment appears to be the primary source of information about the role of elevated CO_2 on N dynamics in the ecosystem. Proper extrapolation needs to be done for Swiss FACE results in comparison to other agricultural systems due to various factors such as higher density of these plant species are pasture grown, mixed vegetation with clumpy planting and without crop rotation. Zak et al. (2000)

Table 10.6 Biological N capture in different ecological systems

Common name	Scientific name	Amount of N fixed (kg/ha/year)	References
Agri-pastoral component			
Soybean	*Glycine max*	15–140	Unkovich and Pate (2000)
Common bean	*Phaseolus vulgaris*	17–85	
Peanut	*Arachis hypogaea*	30–175	
Chickpea	*Cicer arietinum*	60	
Field pea	*Pisum sativum*	105–200	
Lentil	*Lens culinaris*	80	
Faba bean	*Vicia faba*	90	
Narrow-leaf lupin	*Lupinus angustifolius*	230	
Cowpea	*Vigna unguiculata*	24–200	Dakora and Keya (1997)
Bambara groundnut	*Vigna subterranean*	40–65	
Agriculture with forestry component			
Leucaena	*Leucaena leucocephala*	110–550[a, b]	Danso et al. (1992) and Dakora and Keya (1997)
Australian pine	*Casuarina equisetifolia*	43–60[a, b]	Danso et al. (1992)
Sesbania	*Sesbania rostrata*	505–601[a, b]	
Egyptian riverhemp	*Sesbania sesban*	45–100[a, b]	
Siris	*Albizia lebbeck*	94[a, b]	
Soapbush wattle or strap wattle	*Acacia holosericea*	36–110[a, b]	Dakora and Keya (1997)
Gliricidia	*Gliricidia sepium*	108[a, b]	Danso et al. (1992)
Naturally occurring components			
Hawaii ashflow	*Myrica faya*	20	Vitousek et al. (1987)
SE coastal plain	*Myrica cerifera*	<2–10	Permar and Fisher (1983)
Appalachian oak forest	*Robinia pseudoacacia*	30–75	Boring and Swank (1984a, b)
Sonoran desert	*Prosopis glandulosa*	25–35	Rundel et al. (1982)
Massachusetts peatland	*Myrica gale*	35	Schwintzer (1983)
Pacific northwest	*Ceanothus velutinus*	0–100	Tarrant (1983)
	Alnus rubra	40–160	Luken and Fonda (1983)
Alaskan boreal forest	*Alnus incana*	155–360	Van Cleve et al. (1971)

[a]Above ground only
[b]Using total N-difference methods

reported the influence of CO_2 enrichment has got significant influence over N cycle and mineralization as well as over dry wet of microbes.

Pueraria phaseoloides or *Centrosema pubescens* are frequently used as leguminous cover crops. These species can fix up to 150 kg/ha/year of ambient N (Giller

Table 10.7 N capture by woody leguminous species in various regions

Scientific name (English name)	Region	N fixed (kg/ha/year)	References
Leucaena leucocephala (Leucaena)	Tanzania	110	Hogberg and Kvarnstrom (1982)
	Nigeria	305	Danso et al. (1992)
Sesbania sesban (Egyptian riverhemp)	Senegal	43–100	Ndoye and Dreyfus (1988)
	Kenya	52	Gathumbi et al. (2002)
Gliricidia sepium (Gliricidia)	Nigeria	110	Danso et al. (1992)
	Brazil	110	Apolinário et al. (2016)
Cajanus cajan (pigeon pea)	Kenya	90	Gathumbi et al. (2002)
Calliandra calothyrsus (Calliandra)		25	
Mimosa caesalpiniifolia (Sabia)	Brazil	160	Apolinário et al. (2016)

and Wilson 1991), act as a weed suppressant and stimulate the activity of soil dwelling forms (Agamuthu and Broughton 1985; Sanginga et al. 1992). Plant species used as cover crops often requires labour inputs in terms of initiation and progression to facilitate protection to woody species from aerial legumes. During summer season considerable competitions were observed among various cover crops with the woody crops for physiological requirements (Lehmann et al. 2000).

N has its origin in the ecosystem by means of BNF includes biomass decomposition in terms of litter and root turnover. Prediction of effect on climate change on ecosystems reveals a reduction in litter quality and its decomposition rate promoting higher mobility of nutrients from plant parts to litter in terms of high ratio of C and N (Strain and Bazzaz 1983). N-fixing and non-N-fixing plant species have not supported the findings above with sufficient consistency (Norby et al. 2001). As per Ross et al. (1996), in New Zealand within pasture land, ecosystem has higher CO_2 due to higher decomposition rates promoted by the production of CO_2 in soils, with least effect on N content in soil. Treatments of CO_2 and fertilizer to promote N input in soil revealed nutrient content in dried plant parts reflected unchanged in pasture under a higher level of CO_2 as a result of higher N fixation by plant community (Hartwig et al. 2000).

There is a significant level of variation in N_2 fixation (Table 10.7) under the influence of biotic and abiotic factors. BNF by tree legumes has got higher potentiality for making economic gains in the agricultural sector regarding lesser fertilizer inputs as well as minimizing C footprint of the agroecosystem. Synthetic N fertilizer contributes mostly C to the agroecosystem. Natural gas is the driving energy source for synthetic N fertilizer production. As per earlier report (Lal 2004) C emission for manufacturing, allocation of synthetic nitrogenous fertilizer appears to be approximately as high as up to 2 kg of C per kg N which is proportionate to amount of N fixed. From sustainability perspective, BNF seems to be promising in comparison to synthetic N fertilizers which creates multi-facets of environmental hazards (Crews and Peoples 2004; Yadav et al. 2017b).

Legumes often undergo a close association with soil bacteria and utilize the biologically fixed N for their growth. Peoples et al. (2012) reported that in leguminous system when grass was added, the level of symbiotic association changes from legume bacteria to other understorey vegetation. From productivity perspectives, combination of grass and legume is much more productive than legume alone due to bimodal N uptake in legume-grass association (Nyfeler et al. 2011). N transfer in ecosystem occurs in various ways. Recycling of N to soil takes place through cattle excreta with a minute amount added as animal products (Dubeux Jr et al. 2007). As per Cantarutti et al. (2002) litter deposition aids N transfer in sward, transfer within soil compartment through exudates of roots, various anatomizing network systems which include common fungal networks along with turnover from root system (Sierra et al. 2007; Verma et al. 2015a).

Few reports are available regarding mobilization of N from N fixer to non-N fixer species. It appears to be difficult approach for measuring the indirect nutrient transfer process through litter recycling under field conditions due to the utilization of N for this purpose for N-fixing species. As per Dommergues et al. (1999), in situ mobilization of N by mycorrhizal involvement is yet to be explored. A quantitative estimation of fixed N from a N fixer to a non-N fixer were done through radio isotopic study of natural sources of isotopic N (Van Kessel et al. 1995). 15N radio isotope in *Leucaena leucocephala* and its associated vegetation reflected a declining pattern of fixation of N on a long time basis (1–6 year) due to litter deposition by the leguminous tree species. Recycling of N from leaf litter and roots of trees is mediated by soil microorganisms. Mobilization of nutrients within different plant parts needs to incorporate N. As per some earlier works, recycled N level in N fixer is less in amount in comparison to non-N fixer (Wheeler 1991). Trees usually excavate N in the form of nutrients from the deeper part of the soil and uplifted in the surface soil (Dupuy and Dreyfus 1992).

From Indian perspective, Garg and Jam (1992) reported the increment of the level of soil N in case of *Acacia nilotica* and *Prosopis juliflora* plantation. In Senegal, soil N content was found to be 309 kg ha^{-1} under *Casuarina equisetifolia*. Areas without the establishment of legume trees have much lower soil N content (Dommergues 1963). Different conditions soil and other abiotic factors reflect significant level of variation in productivity along with N balance in plantation schemes. Macedo et al. (2008) reported the increment in the level of N due to BNF is associated with carbon assimilation in the sites. NFP of legumes has promoted them to be cultivated in the various ecosystems such as pastures (Tarre et al. 2001), zero tillage land (Boddey et al. 2010), woody plantations (Balieiro et al. 2008) and agriculture with forestry (Handayanto et al. 1995) which have increased soil N and SOCP. SOM maintains soil fertility and quality under tropical conditions (Six et al. 2002). BNF activity of N-fixing legumes positively promotes carbon stock in degraded areas (Boddey et al. 2009; Meena et al. 2015b). As per Banning et al. (2008), litter of leguminous species is very much beneficial for stimulating humification process along with biogeochemical cycling (Costa et al. 2004).

10.6 Leguminous Trees' Variable Traits for Soil Improvement

Legumes have the phenomenal trait of developing root nodules in the presence of soil *rhizobacteria*. Such type of symbiotic association often may act as limiting factor for their potential to be used as biological N fixers. Root nodule formation takes place between host and its symbiont species based on proper cell signalling mechanism. The mechanism involves induction of transcription by *nif* genes present in *rhizobacteria* through stimulation obtained from the root exudates of legume species. Induction of *nif* genes leads to the formation of lipochitooligo-saccharide molecules which promotes nodule formation in host plants (Long 1996). The event of nodulation involves hundreds of genes present in legume species and its rhizobial counterpart (Vance 2002).

Woody plants capable of fixing atmospheric N are utilized in terms of cover crops for other agricultural plantation crops (Beer et al. 1998). Earlier research reports suggest multifaceted uses of legume species in relation to fruits and firewood (*Inga* spp.); 'service functions', such as BNF; and production of nutrient-rich litter and shade (*Gliricidia sepium* and *Erythrina* spp.). Beer (1988) reported the N-fixing ability of legume shade trees as high as 60 kg N/ha/year in smallholder plantations with deficiency of N fertilization. According to a research report in Latin American country (Brazil), enhanced level of N pool were recorded with respect to certain distance from specific tree species (*Erythrina glauca* and *E. poeppigiana*) which grow under shade condition when compared to adjacent crop species. As per Santana and Cabala-Rosand (1982), lower level of total N in soil under cacao plantation in comparison to *Erythrina* inhabitates habitat. In the coastal sandy region of Cote d'Ivoire, regeneration of coconut plantation was promoted by N_2-fixing trees (Zakra et al. 1996). Shoot pruning is an effective measure to increase N capture process among N fixers along with N mobilization within associated crop species (Beer et al. 1998; Schroth et al. 2000; Dhakal et al. 2015).

N_2 fixation by legume is a subsidy for cropping plants under N scarce condition. Research reports reveal unscientific approach of a higher rate of application of N fertilizer (e.g. up to 270 kg N/ha/year in specific agricultural plantation crop species in Costa Rica) leads towards lower N_2 fixation due to wrong screening of low-economic potential plants growing under shade condition (Beer 1988). According to Giller and Wilson (1991), the higher rate of application of N fertilizer increases nitrate levels in the soil which hinders the BNF activity (Giller and Wilson 1991). Further, plantation of legume under shade conditions is an effective strategy due to their ease of pruning and rapid regrowth as well as higher biomass production that leads to maintaining adequate SOM levels which are good for soil health and fertility (Beer 1988).

N distribution in different plant parts of different crops reflects significant contributions in terms of N assimilation and accumulation in the residual parts of legume crops which may be used by the next successive cropping sequence as well as applicable for nonlegume in intercropping systems. BNF has its two principle sources which include decomposed plant parts of legume species as well as from excreta of domestic animal. The root-mediated deposition process adds more N to the soil through root system (Herridge et al. 2008; Fustec et al. 2010). Therefore, N fixers are effective machinery towards sustainable agricultural practices and promote lesser use of chemical fertilizer.

Legume species associated with mycorrhizal species along with nodulation proved to be most effective to colonize substrate without OM (Franco and Faria 1997). Franco and Faria (1997) reported the effectiveness of rhizobial species with legumes to utilize for land reclamation purposes which include various *Acacia* species, *Albizia* and other species.

Legumes' association with arbuscular mycorrhizae fungi (AMF) reflect their potential to be utilized in the land reclamation process. The fungal increases the root anchorage potential for better absorption of nutrients and water (Siqueira 1996). A significant level of variation was observed in case of soil rhizobial or arbuscular fungi activity in relation to nutrient mobilization in plant species and reflects a combined effect of both. In the case of *Leucaena leucocephala* grown in greenhouse under latossol, the mycorrhizal activity was greater in comparison to rhizobia, reflecting phosphorous as a growth-limiting factor instead of N.

Plant colonization is a natural process which is regulated by the availability of nutrients in soil regarding N, but SOM may impose its impact over the invasion of colonizing plants. In this context, legumes have the advantage of depositing more OM regarding biomass in comparison to other nonlegumes. As per reports, tissues of leguminous vegetation have higher N content in comparison to nonleguminous species which adds more N into soil N pool (SNP). Such available N can be effectively used by non-N fixer. Indigenous and inherent SNP often acts as a major influencing issue, promoting optimum crop proliferation. Therefore, utilization of N-fixing species within the cropping pattern in a cultivation system can be an effective strategy to overcome such limitations.

In northwestern part of India, soil with higher pH value (10.2) and trees with fodder crop such as *Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora* along with herbs and grasses reflected improvement of soil conditions (Kaur et al. 2002). Positive influence of woody vegetation including *Acacia* upon soil conductivity as well as good rhizospheric development for next crop has been reported (Yunusa et al. 2002). Under dry or saline condition, *Acacia* and *Prosopis* have been found to enhance soil nutrient status (Zuzana and Ward 2002; Meena 2013).

10.7 Leguminous Trees Improve Forest Flora

Biodiversity of an area can be promoted through legume plantation on wider dimension. Woody leguminous species reflects better ecological adaptability in terms of species interaction for fulfilling basic needs for survival with respect to other species. Benefits received from the woody leguminous species under various climatic zones are yet to be scientifically explored. As per Franco and Faria (1997), NFT legumes with mycorrhizal association promote phosphorous in organic form in the soil and revegetation of altered pedon with lesser agrochemical addition.

Legume root, shoot and leaf biomass acts as a nutrient source for above- and belowground fauna. Surface litter and incorporated SOM serve as a nutrient source for the decomposer community and soil microorganisms after senescence and recombination (Mattson 1980).

Species interactions at various trophic levels of a food chain influence the distribution of N resources under the presence of legume trees. Other forest flora such as insect-feeding organisms, herbivores and other associated organisms are influenced by N-fixing legumes. The diverse functions include vegetation diversity-productivity gradients, vegetation community invisibility, natural enemy dynamics, soil structure and functioning, ecology and conservation of avifauna, emissions of GHG from agriculture and soil C sequestration (Drinkwater et al. 1998; Bullock et al. 2001; Birkhofer et al. 2011). Legume ecology reflects significant promise to mitigate the problems of biodiversity crisis and change in global climate.

Legumes can promote diversity in some plant community (Tilman et al. 1997; Fargione et al. 2007). Legumes have a positive impact on the growth of nonleguminous plant species, reduce the competition within vegetation communities, increase ecological invasion and maintain vegetational diversity (Smith and Gross 2007). Newer methods are being developed to assess the functional role of ecosystems (Mace et al. 2012; Bommarco et al. 2013; Meena et al. 2013).

Legume often competes for resources and food with non-crop plant species. Legume canopy with broad leaves reduces the infiltration of sunlight to understorey stratum which promotes ground vegetation with higher leaf area index (Bilalis et al. 2010). N can be effectively mobilized by legume crops through reducing N uptake from soil supplemented by their own biologically fixed N as well as direct supply to other neighbouring plants. Resource partitioning in such way leads to higher diversity over a geographical area within a specified time (Tilman et al. 1997). Legumes have wide dimensions of advantages regarding having a positive influence over vegetation communities through the betterment of soil structure along with high seed bank (Albrecht 2003). Legumes have a significant impact on weed community and bring significant level of changes.

Leguminous tree species has significant influence over pollination of flowering plants which proliferates the diversity of forest flora (Ghazoul 2006). In legume-supported system, it has been observed that legumes have significant influence over the associated vegetation which is dependent upon the interaction between them.

Legumes may promote herbaceous vegetation of the forest through proper transportation of water from deeper soil layers. Such type of relationship may not be visible for legumes and its associated species which might be attributed towards moisture regimes of the soil (Gea-Izquierdo et al. 2009). Among the various plant families, Fabaceae is the dominant representative in the forest of Neotropics and Africa (including Madagascar). As per Ter Steege et al. (2006), prevalence was reflected by legumes at Amazon rain forest, neotropical dry forests (Pennington et al. 2006; Sarkinen et al. 2011) as well as savannas (Ratter et al. 2006). Higher density of legumes is an important factor towards carbon and N sequestration in forest ecosystem (Knops and Tilman 2000). Sequestering higher N in the soil of the forest legume promotes canopy structure and differentiation which leads to higher biomass accumulation (Spehn et al. 2002). Further N fixer such as legumes (Sprent 2009) is the common habitant on several continents (Lewis et al. 2009) and oceanic islands (Caetano et al. 2012), including savanna and grassland ecosystems (Chaneton et al. 2004). Slow-growing trees such as *Dalbergia* can sequester carbon storage up to significant level due to low decomposition rate (Weedon et al. 2009; Varma et al. 2017b).

10.8 Leguminous Trees' Key Players to Mitigate Climate Change

Higher ambient CO_2 level along with other factors contributing climate change significantly influences the N-fixing process, its associated species and amount of fixed N along with addition into soil. Various anthropogenic activities and changes in the land-use pattern have raised the CO_2 level from the time period before industrialization to recent time frame, which may further double in the upcoming century. As per current updates, human-mediated emission of CO_2 reached 32 (±2.7) $GtCO_2$/year in 2010 and progressed further by about 3% between 2010 and 2011 and by about 1–2% between 2011 and 2012 (IPCC 2014). CO_2 happens to be a main driving force for global warming phenomenon in comparison to other GHGs. CO_2 may promote a considerable level of increase in global-mean temperature (IPCC 2014), which may influence the regional rainfall pattern throughout the world (Rind et al. 1990). Three of the important factors such as CO_2, temperature and water may cause alterations in plant growth and development on a spatial basis. Carbon sequestration by plants can affect the factors influencing the climate change. From future perspectives, exact quantification of CO_2 inputs in various ecosystems along with the release from the biosphere needs to be explored.

Tropospheric ozone imposes negative influences over legume species (Morgan et al. 2003). A higher level of N in plant tissues and the soil often inhibits N capture (Hunt and Layzell 1993). NFP is not very much compatible with soil N uptake in comparison to non-fixing plants. Several natural and human-made issues influence the output of symbiotic association of N fixer in context of climate change. Root nodule formation and enzymatic activity related to BNF reflect significant level of variation under environmental factors. Supply of required resources for N fixation is regulated by carrying capacity of environment. As per source control hypothesis, availability of light influences photosynthetic rate which in turn regulates the level of carbohydrate required for N_2 fixation in nodules, thereby hindering nodulation and nitrogenase activity.

A higher level of CO_2 promotes higher nutrient uptake from soil (Berntson 1994). Earlier works reveal that elevated CO_2 level may change the structural configuration of the root (Berntson and Bazzaz 1996) and nutrient uptake ability of fine roots (Jackson and Reynolds 1996). Symbiotic associations of root with symbiont species positively influence nutrient uptake through CO_2 enrichment (Thomas et al. 2000). The proliferation of N fixers in a higher level of CO_2 reveals unending availability of N through BNF (Lee et al. 2003). Under the condition of limited availability of N in the soil, the N fixers are much more promising in comparison to non-fixing plants (Poorter and Navas 2003; Meena et al. 2016).

The beneficial effects of CO_2 enrichment in the ambient environment contribute towards a higher level of N content in the whole plant body. Thomas et al. (2000) reported the relationship between higher CO_2 level and enriched N content in plant body might be attributed towards increased carbohydrate content in the nodule as well as in the roots (Cabrerizo et al. 2001). By using radioactive isotopes of carbon, Tissue et al. (1997) reported a higher rate of photosynthesis with higher carbon assimilation and transport within the plant body in commonly used agroforestry tree species such as *Gliricidia sepium*. Elevated CO_2 also promotes higher microbial growth in soil rhizosphere zone of N_2-fixing plants (Marilley et al. 1999) and found to promote the soil rhizosphere microbial population in aquatic condition (Dakora and Keya 1997). Higher level of CO_2 promotes lesser availability of soluble N compounds, which may otherwise inhibit N capture process (Serraj and Sinclair 2003).

Dixon and Wheeler (1983) reported that species with BNF activity includes N-fixing legumes along N_2-fixing microbes display a wide variability in activity under variable environmental conditions. Research reports revealed that in the case of *Alnus incana* and other N_2-fixing species show their growth in Arctic range and on the other hand *Casuarina* spp. occur above 30 °C or more and found in developed regions. Mulder et al. (1977) reported that wider thermal regime prevails from a development perspective in comparison to optimal N_2 capture. Present scenario such as climate change would have the least impact on tropical legumes as reflected through prevailing rates of BNF.

Enzyme activity for N fixation reflects wide thermal spectrum with an optimum temperature range between 20 and 30 °C. As per Waughman (1977) within this wide temperature spectrum, temperate legumes prefer the lowest range, and species of tropics prefer highest range. Furthermore, Ryle et al. (1989) reported that *Trifolium repens* reflected elevated Nase activity linearly within 25 °C. Further increase in temperature leads to have no effect on enzyme activity. As per earlier reports, elevated Nase activity within temperature range above 18 °C and below 28 °C was reported for specific species (Crush 1993).

Fungal species inhabiting rhizosphere have shown variability in Nase activity due to variation in temperature. Hensley and Carpenter (1979) reported various temperate zone species reflect optimum temperature range between 20 and 25 °C. Species of subtropics such as *Casuarina* species, optimum temperature was reported to be above 30 °C or more (Bond and Mackintosh 1975). Enzyme activity for N fixation reflects variability under various temperature ranges along with species (Waughman 1977) and temperature conditions used for growing plants (Gibson 1976).

Research reports reveal that increment of the CO_2 level associated with water stress condition helps to combat such abiotic form of stress through increasing photosynthetic activity as well as efficient water use during photosynthetic. Very few reports are there regarding the interrelationship between elevated CO_2, water stress and N fixation. The increment in the level of CO_2 has partially mitigated the problem of drought-mediated reduction in N fixation through stimulation of mass nodule along with nodular activity (Serraj et al. 1999). The proposed mechanism behind such type of process includes biosynthesis of some nonstructural carbohydrates promoting a reduction in the level of soluble N compounds thereby reducing N fixation process (Serraj and Sinclair 2003; Meena et al. 2015c).

Ecosystem services refer to the processes which are beneficial to mankind. These includes services from various angle dimensions such as resource-based functions such as fulfilling basic needs, ecological and environmental services, social and spiritual functions which include multi-facets of benefits to mankind and other sustainable ecological functioning (Millennium Ecosystem Assessment 2005). N fixer facilitates such services on a sustainable basis from environmental perspectives. Legumes perform mitigating changes in global climate which includes a reduction of GHG emissions in comparison to N fertilizer-based cropping system, reduction in fossil fuel energy, sequestering carbon in soil and providing biomass as biofuel (Jensen et al. 2012). Several research reports reveal cycling of carbon is associated with N cycle, C to N ratios in various pedons. Therefore, woody BNF can promote sequestering of C in the soil through BNF (Nair et al. 2010; Kirkby et al. 2011).

10.9 *Acacia nilotica*: A New Promise of Legume-Based Agroforestry

Babool (*Acacia nilotica*) is a BNF species having its wider distribution throughout Asia, Africa as well as in southern America, Australia and Mexico. *A. nilotica* comprises of nine varieties/subspecies, of which majority (six) of species are native to tropical Africa and remaining (three) species are native to the Indian subcontinent.

Genus *Acacia* is represented by numerous species in the tropical part of the world. One-fourth of the area of the world under subtropical and semiarid condition was found to be represented dominantly by genera *Acacia*. Mixed interpretations have been suggested by several workers towards the management of arid ecosystems. On one hand, woody legumes should be eliminated to promote herbaceous growth for livestock feeding (Fisher 1977) and on the other hand higher possibility of output regarding arid forestry (Felker 1998). A comparative assessment has been shown by several workers between N fixer and non-N fixer tree leading to the higher availability of N in top soil from deeper layers (Barth and Klemmedson 1982). A significant level of benefits can be harvested from *Acacia* in terms of environmental, social and economic benefits associated with C and N sequestration under tropical condition, and therefore approaches need to be designed for sustainable management of these species. Besides improving soil condition, *Acacia* also provides diverse nature of NTFPs like gum, fodder and small timber. Although the fact that trees promote higher N fixation and thus help to maintain the productivity under tropical system is widely known, very few research approaches have been oriented towards this direction.

Agroforestry is a time-oriented concept of sustainable agriculture which promotes production in various spheres aiming towards optimum utilization of resources in a sustainable manner. Agroforestry appears to be a holistic approach involving multistrata plantation along prevailing cultivation system and livestock promoting agricultural productivity. Moreover, agroforestry can enhance the population of beneficial soil microorganism by increasing the SOM through litter production (Raj et al. 2016; Singh and Jhariya 2016; Varma and Meena 2016). Chhattisgarh plain within the central part of India is characterized by traditional agroforestry systems which are a widely practiced land-use system. The farming system needs to be integrated with the plantation scheme in judicious manner to boost up the agricultural productivity. *A. nilotica* represents mostly in agroforestry systems of Chhattisgarh plains due to its hardy nature and adjusting with diverse environmental condition giving agro-products of diverse nature. Therefore, *A. nilotica* with rice cultivation system is prevalent in Chhattisgarh (Jhariya et al. 2015).

Soil productivity in the modern perspective is a major challenge due to nutrient loss, soil erosion as well as non-judicious approach in the field of agricultural productivity. N-deficient soil condition can be effectively managed using plantation or integration of leguminous crop plants through BNF activity. Leguminous species have their inherent capability to fix atmospheric N to be used in soil and plant systems. In such conditions *A. nilotica* shows significant promise due to higher growth rate, stress tolerant along BNF ability. It has higher growth rate in degraded lands and important components of agroforestry practices for its multipurpose uses in India along with BNF activity. *A. nilotica* has a positive impact over paddy cultivation regarding addition of N and OM in soil under paddy cultivation.

A. nilotica reflects the positive influence on soil physical attributes by reducing the splashing action of raindrops over top soil particles. Roots of *A. nilotica* are very much colonized by *Rhizobium* species. Higher number of root nodule formation by *Rhizobium* species significantly promotes a higher rate of N fixation to nutrient-deficient soils. *Rhizobium* bacterium plays the secondary role of nutrient solubilization in association with vesicular-arbuscular mycorrhizae. Such relationship helps higher adherence and accessibility of roots towards soil nutrients such as phosphorous and also mobilizes unavailable form of nutrient into available form.

This legume tree is a boon for the resource-poor farming community in the context of Chhattisgarh who have age old practice of cultivating different tree species along with agricultural crops. *A. nilotica* contributes gum (Das et al. 2014; Raj 2015a) which has its diverse use for the pharmaceutical purpose, calico-printing, sizing paper, cloth and textiles, encapsulation, etc., and tapping of gum would promote the socio-economic upliftment of the local community stakeholders as well as implementation of conservative measures towards environment and bio-resources (Raj 2015b; Meena et al. 2015d). Moreover, the species has a higher potential for fuelwood production in tropical climatic conditions.

It has been reported that the species have higher carbon-sequestering potential in comparison to other nonlegume plant species. Some earlier works reported that *A. nilotica* is capable of fixing 228.42 kg/tree biomass carbon which may be later on added to the soil to improve the SOCP leading to improvement in soil fertility. *A. nilotica* will help in stabilizing ravines and gullies and checking their spread.

10.10 Threats to Legumes

Due to multi-facets of utilization potentiality, abuse of legume species is often over-exploited. In India, different types of human-made perturbances have created a significant loss in the legume species. Legumes can be considered as a reservoir of various valuable resources having diverse distribution pattern in different regions. Mostly they are used by the local community stakeholders for maintaining their daily livelihood as well as to economic gains. Improper way of collection due to lack of knowledge, technical expertise also leads to the destruction of the legume species without appropriate regeneration which renders the species under severe threat of extinction.

Wild relatives of legumes cultivated in tribal area are being replaced by high-yielding legume varieties which may lead to degeneration of the genetic base of the wild relatives. Habitat degradation of wild relatives of legume species leads to the destruction of natural stock of legume species under high population pressure accompanied by climate change (Rao and Husain 1993). The problem of loss of genetic resource base of wild relatives of legume is further aggravated with limited distribution along with the rapid rate of urbanization and unprecedented growth of grazing activity. As per Lane and Jarvis (2007), such activities have generated their possibilities of extinction within the next upcoming future.

10.11 Legumes and Their Conservation Perspectives

Equitable and sustainable use of biodiversity is a new challenge under modern era (Reid 1992). The West Himalayan region is enriched with endemic plants which include endemic legumes which required conservation priority (Rao and Husain 1993).

Conservation includes appropriate strategies which include identifying species under potential threat of extinction and their subsequent conservation along with their habitat. Community-based natural resources management practices along with the optimum use of legumes need to be prioritized. Areas with the higher abundance of leguminous species need to be explored, and proper care should be taken for their protection and conservation. Traditional knowledge-based plant-resource management should be emphasized by the scientific community. Local community stakeholders should be promoted for plant collection in various regions for efficient management of plant resources. The barren land area is commonly associated with low fertility. Leguminous species can be effectively planted to build up the SNP through BNF for their growth and development (Bargali 2011; Verma et al. 2015b). Utilization of BNF species for conservation of soil nutrient status as a part of INM (integrated nutrient management) as well as eco-restoration of degraded land is an effective strategy towards maintaining the sustainability of the ecosystem.

Under semiarid and tropical ecosystems production of cattle, fuel wood and small timber, wood often hampers N balance in the ecosystem which could be ameliorated through a plantation of tree legume species. Suitable approaches need to be focussed to assess the carbon sequestration potential of legume species. Land degradation is a major environmental problem in present days which hampers the soil fertility to a great extent. Eco-restoration is a serious challenge under the arena of land degradation. Rejuvenation of soil fertility through legume plantation is a major step as they can supply extra N through BNF process apart from SNP.

10.12 Future Prospectus of Leguminous Trees

Despite the advantages reflected by BNF technology, it has got some inherent problems such as transfer of technology from lab to field conditions. In developing nation farming community is very much reluctant to cope with such type of technology considering the economical output of such technologies. Besides the multifaceted sustainable role of legume tree species, they have always been treated as minor crops. In this context the quantification of N inflow and outflow from the system is an essential prerequisite to harmonize BNF potential of legume trees. Several advanced methods are available to quantify these dimensions of measurement of N input. To measure the N input in any ecosystem, various advanced methods are available nowadays such as isotopic methods (isotopic dilution, natural abundance in '15N, A-value method), nodulation observation, ureides and amides in xylem sap and acetylene reduction method (Danso et al. 1992). The combination of these various methods can determine the N input into the ecosystem much more accurately. Isotope study appears to be the most appropriate methods for quantification of BNF activity. Characteristics of tree species as well as other sources of variation can significantly influence the evaluation of BNF activity (Boddey et al. 2000; Meena et al. 2017). The amount of N fixed significantly varies upon variable climatic and soil conditions.

Maintaining N balance in a natural ecosystem is an essential prerequisite (Ganry et al. 2001). N balance can be maintained through optimum N fertilizer dose application as well as BNF activity. In the present perspective, very few works have been reported regarding utilization of agroforestry system to maintain soil N balance. However, biotechnology shows significant promise to improve the potential of BNF species fixed atmospheric N on long-term basis. In this context use of BNF inoculation in the nursery, application of clones of N fixer having higher NFP is a stimulatory approach under lab condition.

Acceptability of BNF technology in the farming community is the major challenge for Third World countries. Low economy, political influences as well as the lack of adequate scientific knowledge often hinder this process. Unknown facts such as identification of host legume species, screening of efficient rhizobial strains as well as their interactions often influence the applicability of the process. BNF appears to be a key element of INM system which produces products on a sustainable basis. Huge potential of N fixation may increase the importance of legumes on biosphere perspective. To combat soil pollution as well as depletion of land resource plantation of legumes is a suitable ecofriendly approach. Such process due to its lower cost has got wider acceptability throughout the world which sustains the food productivity and security. Under tropical conditions, maintenance of food production level and quality is a big challenge due to ever-increasing population growth. Good quality foods with optimum nutrient supplements are also a bigger challenge for poor people of the Third World nation. Subsequently, the impact of climate change would further aggravate the problem in areas such as South Asia and sub-Saharan Africa, where optimum conditions for cultivation are not available. Under these circumstances BNF technology and legume trees seem to be a suitable tool in the hand of mankind to combat various dimensions of environmental perturbances.

10.13 Conclusion

Plantation of leguminous tree species under agroforestry systems would promote optimum fixation of nitrogen into the soil environment. Leguminous plants also have the potentiality to fix carbon at higher rate which contribute towards gradual build-up of SOC pool through biomass accumulation. Legumes have been reported to undergo close association with vesicular-arbuscular mycorrhizae and other soil bacteria which promote improvement in the fertility status of the soil. Therefore, legumes can be effective in wasteland reclamation process. Legumes have also been reported to promote forest floor biodiversity through nutrient build-up mechanism. Higher photosynthetic rate of leguminous species under elevated CO_2 level helps to combat climate change. Due to its multifaceted use, there is a progressive threat of abuse and overexploitation of legumes. From this perspective effective conservative measures in terms of exploring areas with high density of legume along with community-based conservation system need to be properly implemented. Overall the BNF potential of legume species needs to be fully explored for better future into a sustainable world.

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