Grain Legumes: Impact on Soil Health and Agroecosystem

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Abstract

Legumes are one of the richest sources of proteins, minerals, and fibers for animals and human being. They also have a great role in maintaining soil fertility through biological nitrogen fixation (BNF). Legumes help in solubilizing insoluble phosphorus (P) in soil, improving the soil physical environment, and increasing soil microbial activity and also have smothering effect on weed. Due to these positive roles in improving soil health and excellent adaptability to marginal environment, legumes are now considered as one of the important components of a cropping system. To reduce poverty, hunger, malnutrition, and

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environmental degradation, legume crop can be a substitute for cereal crop in marginal lands. Rediscoveries in genetics and genomics now open up new opportunities for improving productivity and quality in grain legume research. The carryover of nitrogen (N) derived from legume grain either in crop senescence or in intercropping system for succeeding crop is important. The necessitate of the interdisciplinary study on grain legumes to address their important role on soil health. Thus, the maximum beneficial effect in modern agriculture as the optimization of fertilizer N use is an essential not only to maintain and restore soil organic carbon (SOC) but also to minimize the nitrate pollution from agricultural source.

Keywords
Grain legumes · Nitrogen yield · Protein yield · Biological nitrogen fixation

Abbreviations

AM	Arbuscular mycorrhizal fungi
BNF	Biological nitrogen fixation
CED	Chronic energy deficiency
ISFM	Integrated soil fertility management practices
PEM	Protein energy malnutrition
PGPR	Plant growth-promoting rhizobacteria
SMB	Soil microbial biomass
SOC	Soil organic carbon

16.1 Introduction

Among the cultivated crops of the world, grain legume occupies an important position. The pods (matured, ripen, or unripen) of the grain legumes (family, Fabaceae) are used as human food as well as animal feed. In terms of production, grain legumes rank third after cereal and oilseed, but its importance is more in terms of agriculture and the environment due to the supplement of protein to human and livestock and the ability to fix atmospheric nitrogen (N) (Mantri et al. 2013). With the expanding world's population, from the current 7.5 billion to 11 billion by the end of the twenty-first century, about 70% more food will be needed (UN 2017; Alexandratas 2009). The cultivation of grain legume will play an important role in the food security of this growing world population. Among the grain legumes, the main sources of dietary protein for vegetarians come from chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), grass pea (*Lathyrus sativus*), lentil (*Lens culinaris*), mung bean (*Vigna radiata*), urad bean (*Vigna mungo*), pea (*Pisum sativum*), pigeon pea (*Cajanus cajan*), and soybean (*Glycine max*). Though rich in protein and known as poor man's meat, some grain legumes like soybean and groundnut are also good sources of vegetable oil (Bellaloui et al. 2013; Meena and Yadav 2015). The ability to fix N biologically makes the legume crop an important candidate for cropping sequence to maintain the N fertility in agricultural soil and thus to improve soil physical condition and sustain the environmental balance (Courty et al. 2015). Cultivation of legume can significantly mitigate the agricultural contribution to climate change by reducing the energy use, emission of greenhouse gasses, and maintaining positive soil carbon balance. The presence of high soluble and insoluble fiber, oligosaccharide, and phenolics and essential nutrients such as vitamins, antioxidants, and bioactive compounds in food legume can provide several health benefits to human and the livestock (Shimelis and Rakshit 2005; Meena et al. 2015a).

Legumes are cultivated in diverse climates ranging from semiarid to subtropical and temperate region. Being shorter in crop duration, any changes in climatic parameters lead to drastic reduction of legume yield (Fang et al. 2010). They are more sensitive to various abiotic and biotic stresses than cereals and have higher cultivation risk and lower yield over competing cereal crops. Environmental factors such as water stress, temperature stress, salinity, high CO_2 concentration, and heavy metal pollution affect its growth, yield, and the quality of the produce (Wani et al. 2007; Varma and Meena 2016). Farmers also use their marginal lands to grow grain legume leading to reduced productivity. In a modeling approach, Cooper et al. (2009) predicted that 3 °C rise in temperature will reduce current average peanut production in Zimbabwe by 33% and pigeon pea in Kenya by 19%, due to shorter growing period and early maturity. Legume crops are slow grower at early stages of growth and susceptible to weed competition due to low soil N uptake at this period, which can reduce the yields by 25–40% (Pandey et al. 1998). To cope with the changing climate, legume breeding for stress resistance is very essential. Several grain legume genotypes have been identified with the ability to decrease the stomatal conductance with the soil drying – making them a perfect candidate to grow under water-limited situation (Zaman-Allah et al. 2011; Devi et al. 2009). Therefore, it is the need of the hour to give emphasis on enhancement of the grain legume production through agronomic and molecular breeding approach. Compared to natural ecosystem, soil health in an agroecosystem has to face many challenges owing to rapid disturbances from various agricultural operations during cultivation. Therefore, a holistic approach is needed to maintain the soil physical, chemical, and biological characteristics of an agroecosystem. Reduced soil disturbances in terms of tillage practices and keeping an organic soil cover are proved helpful in this regard (Meena et al. 2015b). This can be achieved by introducing a legume crop in an agroecosystem since they can grow under reduced tillage and be used as an organic cover.

Legumes can be grown in marginal land with less availability of macro- and micronutrient. Due to the presence of nitrogen-fixing ability, legumes can support their own growth and development at even soil with less fertility. With the process of growth, they accumulate good amount of biomass through photosynthetic carbon (C) fixation. These biomass finally enrich the soil with C by net exudation. Thus, the legume can maintain the SOC component. Once the soil is enriched with C, it improves the soil physicochemical properties. For succeeding crop, legumes can thus improve the soil quality through their biomass incorporation – this is the basic hypothesis of this chapter. In this chapter we discussed about the impact of legume cultivation on soil health (in terms of both biological and chemical health) and the role of legume crop in agroecosystem – with reference to modern agriculture.

16.2 Role of Grain Legumes in Food Security

With the superior grain composition and multi-nutritional benefits, grain legumes may help to reduce the malnutrition and to meet the dietary demands of the increasing global population. Food security is achieved when all people have access to enough food to live a healthy and active life. In most of the cases, malnutrition is caused by undernutrition diet with inadequate protein and calories. Protein energy malnutrition (PEM) and chronic energy deficiency (CED) are two most common nutrient deficiency diseases in India. Legumes are rich sources of plant protein and play a significant role in food security of the society. Malnutrition can be overcome by production of enough legumes which is cheap compared to animal protein, and poor ones can easily purchase it for their dietary protein need. The agricultural production has to increase by 70% by 2050 to deal with an estimated increase of 40% in the world's population (Burinsma 2009). To cope with the increasing food demand, it is necessary to adopt sustainable and improve technologies for ensured developments in food productivity and thereby food security (Gruhn et al. 2000; Landers 2007; Ashoka et al. 2017). Along with the human dietary need, legumes are also essential for intensive animal and milk production, where grain crops are used as a major feed source and forage legumes are needed to maintain animal health as medicine (Wattiaux and Howard 2001). These make legumes as an integral component of the modern agriculture.

Food legumes are the best sources of dietary proteins more particularly in developing countries and provide 20–40% of dietary protein requirements (Kudapa et al. 2013). They are the rich sources of carbohydrates, vitamins, and minerals (Wang et al. 2011). Essential nutrients (macro and micro), vitamins, dietary minerals, good quality dietary fibers, antioxidants, and other bioactive compounds are the important sources of grain legumes (Prakash and Gupta 2011; Wang et al. 2011). But, compared to cereal crops, the yield of grain legumes is substantially low due to its shorter life cycle and requirement of higher photosynthate to convert to protein. They have numerous health benefits such as lowering and preventing some forms of cardiovascular diseases, obesity, certain cancer, and diabetes mellitus (Goni and Valentin-Gamazo 2003) due to their high soluble and insoluble fiber, oligosaccharide, and phenolic contents. In many countries, grain legumes serve as a vital part of the daily diet and thus deliver a larger share of plant protein in human diet. Legume accounts for 27% of world primary crop production and contributes 33% nutritional protein needs of human diet (Vance et al. 2000). Legume seeds are rich in protein, containing 20–30% protein with high level of lysine (Duranti and Gius 1997), one of the essential amino acids which cannot be synthesized by mammals. Because of this higher protein content and increasing price of animal protein, the cultivation of legume in modern agriculture is highly essential. Large variation exists in the protein content of food legumes in different studies and across different region and ranges from 26% to 57% in soybean (Iqbal et al. 2006), 21% to 29% in common bean (Costa et al. 2006), 16% to 32% in pea (Costa et al. 2006), 22% to 36% in faba bean (*Vicia faba*) (Iqbal et al. 2006), 19% to 32% in lentil (Costa et al. 2006), 16% to 28% in chickpea (Iqbal et al. 2006), 16% to 31% in cowpea (Duranti 2006), 21% to 31% in mung bean (Duranti 2006; Dhakal et al. 2015), and 16% to 24% in pigeon pea (Duranti 2006). Genotypes from the same crop species, environmental conditions, and crop husbandry practices adopted during cultivation play an important role in protein content of grain legume. Major storage proteins present in grain legumes are globulins (70%) and albumins (20%), whereas prolamins and glutelins are some minor proteins (Duranti 2006). Legumin and vicilin are the major protein fractions of globulin and albumin. All food legumes contain more vicilin, and the relative proportion of legumin and vicilin varies with genotype.

In addition to the digestible proteins, many essential amino acids such as lysine, leucine, valine, isoleucine, and phenylalanine (Javaid et al. 2004) are also found in grain legumes. Among the grain legumes, soybean and peanut contain an excellent source of vegetable oils and contribute more than 35% to global processed vegetable oil production. The higher vitamins and mineral contents along with the antioxidant property increase market demand of the vegetable oil. The carbohydrate content in grain legumes ranges from 30% in soybean to 63% in chickpea. Legume starch has a higher proportion of amylopectin than amylose. However, the amylose content of legume starches tends to be slightly higher than that of cereal starches (Arab et al. 2010). Grain legumes are also the vital sources of minerals such as P, potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn). Some essential fatty acids such as omega fatty acids (omega-3 and omega-6) are not synthesized in the human body, so they must be obtained through nutrition or as supplements. Replacing animal products in the diet with plant products such as soybean provide benefits in cardiovascular health (Sirtori et al. 2009) through lowered cholesterol (Harland and Haffner 2008). Consumption of both soybean and lupin was found to decrease cholesterol in animals and humans, and it also helped in managing diabetes (Bertoglio et al. 2011).

16.3 Necessity of Grain Legumes in Modern Agriculture

Cultivation of crop and raising of livestock for food, fiber, biofuel, medicine, and other day-to-day needs of human life are agriculture. Crops provide the major part of human nutrition, fodder, and the most important requirement, medicine. Thus, agriculture is essential for survival, food, growth, health, productivity, and development of world economic system (Ram and Meena 2014). Legume-based farming brings the sustainability to the farming system. Legumes deserve a prominent role in the present cropping systems of both developed and developing agriculture

(Dhakal et al. 2016). Along with the human dietary need, legumes are also essential for intensive animal and milk production, where grain crops are used as a major feed source and forage legumes are needed to maintain animal health as medicine (Wattiaux and Howard 2001). The primary goal of incorporation of legumes in cropping system is to enhance the soil fertility (Meena et al. 2015b) and provide fodder for the animals and for the direct consumption as food by human. The lipids from grain legume also have the possibility to use as biodiesel (Jensen et al. 2012), one of the renewable sources of energy for clean environment.

The BNF ability of the grain legume makes them suitable to include in the cropping system as N is the most limiting nutrient for crops. It reduces the N demand and thereby decreases the production cost and environmental pollution since nitrogenous fertilizers are one of the prime causes of agricultural pollution. Moreover, the ability of the legumes to convert the unavailable form of phosphorus (P) to available form through releasing some organic acids by the roots also brings P sufficiency in a cropping system (Jensens 1996). In developing countries, with a crop livestock production, the nutrient deficiency is a common phenomenon in the cattle as they are mostly fed with cereal crop residues where the N content is below the threshold level. For an efficient digestion, about 1.0–1.2% of N content in livestock feed is necessary to support optimum growth of the microbes in the cattle rumen (Van Soest 1994). The N-rich legume residue can help to remediate the nutrient deficiency problem in livestock.

Besides the positive effects on soil fertility, grain legumes also reduce incidence of pests, diseases, and weeds. Therefore, with the developed agronomic practices like reduced tillage and organic farming, the production of grain legume is escalating (Meena et al. 2016). Crop rotation has a great influence on the yield performance of the crops in a cropping sequence, and helps to imorove the agro-economic and soil environmental sustainability (Reckling et al. 2014) (Fig. 16.1). For example, about 15–25% increase of cereal yield is reported by Kirkegaard et al. (2008), when grown in rotation with grain legume and thereby can reduce the need of agrochemicals. Hence, this is necessary to move toward the organic farming to achieve sustainability in agriculture (Verma et al. 2015a, b). Incorporation of legume crop and intercrop system is a good way of organic agriculture as diseases and pest attacks are disturbed without the application of chemicals. Another important issue of crop production in present day is escalating the costs of fertilizers. The cost of composite fertilizer is reported to increase by 113% between 2000 and 2007 (Huang 2007). Legumes have the ability to transfer fixed nitrogen to the coexisting crops; when legumes are grown with other crops, the weed competitions become less. For example, when they are cultivated with cereal, weeds are found in less number as cereals are a good competitor of weeds. The availability of P, K, Ca, and Mg is higher in`the intercropping systems than the monocultures (Vandermeer 1992; Li et al. 2007). In conservation agriculture, legumes are also used in rotation as a cover crop. When legumes are grown as intercrop, it not only increases the total productivity of the system but also plays an important role in efficient use of resources (Ghosh et al. 2007; Veronica et al. 2005; Varma et al. 2017). Results of legumes in intercropping systems are shown in Table 16.1.

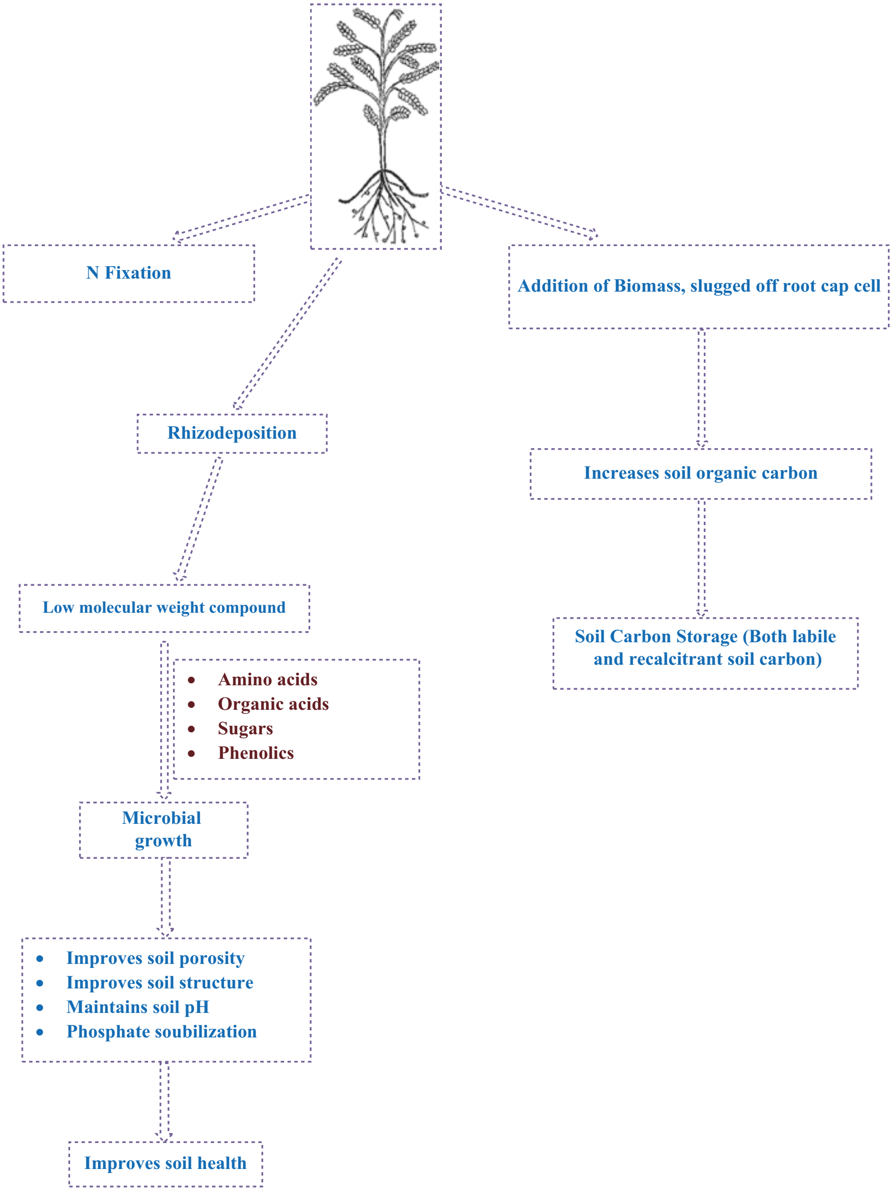

Fig. 16.1 Impact of legume on soil health

The reduced requirement of tillage in legume cultivation has positive influence in farm economic performance along with increased C sequestration due to the reduced disturbances in soil (Reckling et al. 2014). The decreased need of fertilizer application and agrochemicals helps in lowering the greenhouse gas emission and potential global warming. The emissions of greenhouse gasses and N deposition to terrestrial

Table 16.1 Various intercropping systems with legume in India

Intercropping system	Location	References
Sorghum intercropped with		
Green gram	Rajasthan	Laddha and Totawat (1997)
Soybean	Bhopal	Ghosh et al. (2005)
Pigeon pea	Hyderabad	Tobita et al. (1994)
Cowpea	New Delhi	
Black gram	New Delhi	
Groundnut	Junagarh, Gujarat	Ghosh (2004)
Maize intercropped with		
Groundnut	Junagarh, Gujarat	Ghosh (2004)
Black gram	Nainital	Singh (2000)
Soybean	West Bengal	Mandal et al. (2014)
Pearl millet intercropped with		
Pigeon pea	Hyderabad	Ghosh et al. (2008)
Groundnut intercropped with		
Pigeon pea	Hyderabad	Ghosh et al. (2008)

ecosystems are responsible for eutrophication and soil acidification (Clark et al. 2013). Agricultural emissions of both N and P compounds are a significant source of freshwater nutrients and are detrimental to biodiversity in aquatic ecosystems through eutrophication (Nemecek et al. 2008). The gaseous emissions of N compounds are dominated by ammonia, of which more than 93% comes from agriculture. According to findings of Pappa et al. 2011, the emission of nitrous oxide and leaching of nitrate from arable soils are high after the cultivation of grain legume and during the early stages of crop growth. But with the application of proper strategy, for example, using catch and cover crops (e.g., cereal-legume intercropping), it can be reduced substantially (Justus and Kopke 1995; Ram and Meena 2014). In temperate climate, when grain legumes are grown during summer with a fallow winter period, it also leads to nitrate leaching which can be minimized by growing cover crops. Thus, by recycling the nutrients on and between the farms, the cultivation of grain legume can potentially reduce the loss of nutrients and able to fulfill the basic requirements of modern agriculture in terms of resource utilization and effect on the environment and biodiversity.

Besides using as food and fodder, legumes can also be used in liquid form for producing milks, yogurt, and food formula for infant (Garcia et al. 1998). Legume can be milled to flour to make various chips and snacks. Other uses of legumes are production of biodegradable plastics (Paetau et al. 1994), oils, gums, dyes, and inks (Morris 1997).

16.4 Impact of Legume on Soil Biological Properties

The specially developed nodule structures of grain legumes support the atmospheric N fixation process with the help of the enzyme nitrogenase. In addition to the nitrogen storage in proteins, some legumes also have an extra layer of store of glycoprotein in their leaf cells (in between palisade and spongy mesophyll) (Klauer and Francesch 1997). After screening of the legume species for the presence of this paravenial layer, *Lansing* and Franceschi (2000) found that 39 legume species bear this potentially important structure of protein.

P is another essential element for plant growth to supply adequate energy within the cell. In the cell, the vacuole can store a substantial amount of phosphorus to provide the required energy transfer during later growth stages. In the soil solution, this important nutrient element usually makes complexes with calcium, iron, and aluminum and makes it unavailable for plant uptake, though the soil may have large amount of phosphorus (Sinclair and Vadez 2002; Meena et al. 2017a). In this regard, the cultivation of grain legume can improve the situation by following ways:

1. The release of available P is highly dependent on soil characteristics (Jones et al. 2003) such as pH. The organic acids (such as malate, citrate, oxalate, tartrate, and acetate) released by the roots of grain legume (Shen et al. 2002; Nwoke et al. 2008; Nuruzzaman et al. 2006) decrease the soil pH in the rhizosphere which helps in conversion of unavailable P to available form.
2. Grain legumes also release enzyme phosphatase into the soil which helps in breakdown of organic materials containing P (Gilbert et al. 1999; Helal 1990).

Soil biological properties such as soil microbial biomass (SMB) are generally used as an early indicator of changes in soil physicochemical properties because of soil management in agricultural ecosystems (Brookes 1995; Trasar-Cepeda et al. 1998; Suman et al. 2006) (Fig. 16.2). During the process of BNF, hydrogen gas is produced which in turn encourages the bacterial growth in the legume rhizosphere leading to higher microbial biomass C in the soil. The soil microbial C (C_{mic}) and N (N_{mic}) contribute 1–7% of total soil C (C_{org}) and up to 5% of total soil N (N_{tot}), respectively (McGill et al. 1986; Sørensen 1987; Anderson and Domsch 1989; Insam et al. 1989; Sparling 1992), which is among the most labile C and N pools in soils (Jenkinson and Ladd 1981). Consequently, size and activity of the SMB can influence nutrient availability and yield of the agroecosystems. The nodule-rhizosphere interaction of the leguminous plants results in enhanced microbial activity in the soils of legume crops. Alvey et al. (2003) reported that the introduction of legume crop rotations had a significant influence on the microbial community structure and increased microbial diversity. Similar results have been achieved in intercropping experiments in which bacterial biomass and activity varied from those in monocropping systems (Latati et al. 2014; Li et al. 2009; Qiang et al. 2004; Song et al. 2006; Tang et al. 2014; Wang et al. 2007). The ability of the leguminous rhizospheric fauna to capture atmospheric N and enhanced root exudation results in higher C:N ratio, and it has been found by Liang et al. (2014) that legume species,

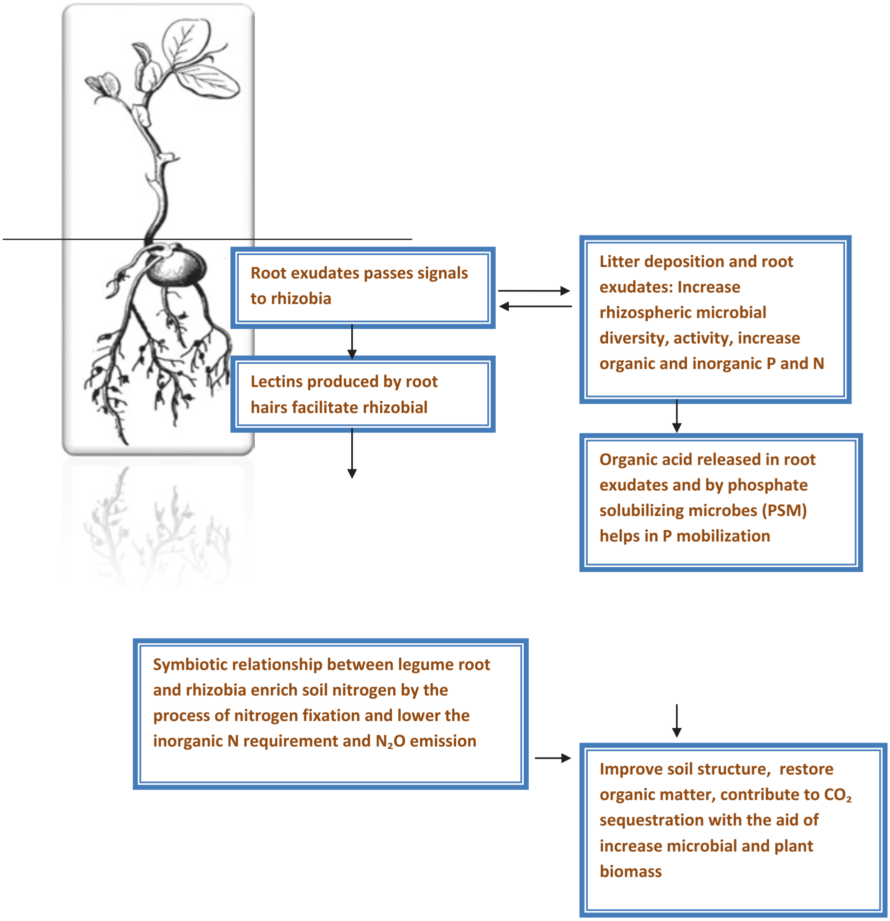

Fig. 16.2 Impact of legume on soil biological property

even with small variations in C:N ratio and lignin and cellulose contents, triggered ample divergence in soil microbial properties (Meena et al. 2014). The production and exudation of lectins by legumes have shown to be capable of influencing the mobility of plant growth-promoting rhizobacteria (PGPR) and improving root colonization and the phyto-beneficial activity of these PGPR (Schelud'ko et al. 2009). Legumes are known for their tripartite symbiosis (mycorrhiza-legume-*Rhizobium*) (Hay- man 1986) and have been shown to be responsible for colonization of specific arbuscular mycorrhizal (AM) fungi, mainly due to their special nutritional requirements associated with their root nodule activity (Scheublin et al. 2004; Vandenkoornhuyse et al. 2002; Meena et al. 2017b). The dual symbiosis of AM fungi and *Rhizobium* bacteria on legume plants enhances plant growth and yield under several environmental conditions. It is due to the higher dependency of the legume plants on mycorrhiza to achieve their maximum growth. The hyphae of the mycorrhiza have the ability to access a greater volume of soil and can absorb and transport fairly large amounts of low-diffusing nutrients like P to their host plant and help in nodule formation (Zahran 1999). Though the AM fungi don't possess specificity in symbiotic relationship, they differ in their ability to enhance nutrient uptake by the host plant. Therefore, the combination of different AM fungal strains or species is important since the compatibility of such interactions may be relevant to N fixation and to nutrient and water uptake by the legume plants (Vinicius Ide 2013). Legumes also appear to promote AM colonization in low-input systems. Previous studies largely showed that AM results in an increased flow of nutrients, plant productivity, and ecosystem sustainability (Gianinazzi and Wipf 2010). Legumes are also used extensively as a cover crops to reduce soil N loss and erosion in agricultural fields. Short-term management (e.g., 1 year) of legumes has shown the influence on microbial population of the cultivated soils. However, all soil properties and processes are not sensitive to short-term management with legume cover crops (Liang et al. 2014; Meena et al. 2014), while soil enzyme activities, microbial biomass, and respiration are sensitive toward the termination strategies of cover crops.

16.5 Soil Processes

The residual N supply obtained from introduction of legumes in crop rotation through symbiotically fixed N depends on climate, crop management practices, and the species of the legume grown (Heichel and Barnes 1984; Meena et al. 2015a, b, c, d). A cropping system with leguminous crops and sufficient N fertilizer also enhances SOC concentration (Varvel 1994). A study on *Mucuna* with maize resulted in a decline in runoff and erosion, an upsurge in soil organic matter content and in the production of maize grains, and an improvement of soil water regime (Blanchart et al. 2006). In a legume-nonlegume crop sequence, the amount of N returned to the soil for nonlegume succeeding crop depends on the following factors:

1. The quantity of legume residue returned to the soil
2. The content of the symbiotically fixed N in the residues
3. The availability of the legume residue N to the subsequent crop (Heichel 1987)

Drinkwater et al. (1998) documented a significant increase in C and N retention under legume-based cropping systems and suggested the contribution of narrow C:N organic residues combined with the relatively higher temporal diversity on the same. It was also reported that crop rotations, which include legumes, are able to maintain higher organic matter levels than continuous cropping systems with non-leguminous row crops (Campbell et al. 1991; Campbell and Zentner 1993; Stevenson 1982). Inclusion of legumes into crop rotations is justified by their natural capability to exploit atmospheric N, and this additional source of N is likely to avoid interspecific struggle between crops and legumes for N acquirement (Carof 2006; Hauggaard-Nielsen et al. 2008) and to make ample N contents available for the following crop through increased soil N content after destruction of the legume cover crop.

The N-rich legume residue also encourages the activities of earthworm in the soil, and thus, it improves the soil porosity promoting higher water and air movement (Meena et al. 2015). For example, growing legume has a positive effect on soil structure due to its continuous network of residual root channels and macropores which leads to improve soil water-holding capacity (Jensen et al. 2012). The higher protein content in the legume facilitates the decomposition of crop residue by encouraging the microbial growth in the soil (Dhakal et al. 2016) and their conversion into soil building organic matter because most of the crop residues are rich in C. Improvements in both soil humus and organic C content are reported after legume cultivation as they supply biomass and organic C and N in the soil (Lemke et al. 2007). Additionally, the reduced tillage used during cultivation of legume crops helps in buildup of organic C (Alpmann et al. 2013). The quantity of organic C buildup depends on the soil, climatic condition, and species of grain legume. Higher organic carbon sequestration has been documented in a mixture of grasses and legumes than the monocultivation of the same (Lopez-Bellido et al. 2009; Yadav et al. 2017).

Through the process of BNF, the grain legume can save some 150–200 kg ha^{-1} of N per year compared to other cereal or rapeseed crops (Peyraud et al. 2009). When inoculated with proper strains of *Rhizobium* bacteria, legume can supply up to 90% of their own N. Shortly after the germination of the seed, the bacteria penetrate the root to form the nodule where the N present in the soil air is bound and supply it to the aboveground plant during photosynthesis. The bacteria produce ammonia with the help of hydrogen acquired from the plant carbohydrate synthesized during photosynthesis. Though variable results were obtained regarding the savings of N fertilizer from different sites, Bues et al. (2013) had reported that an average of 21 kg ha^{-1} of nitrogen fertilizers can be saved in 3–6 years of rotations with grain legume. Some of the N fixed by legume is recycled – mostly during decomposition of aboveground and belowground crop residues (Meena et al. 2015). N cycling is mediated by soil organisms, and the rate and the pattern of nitrogen released from crop residues are regulated by soil microbial activity, residue quality (rhizodeposition), and soil environment. For example, in alkaline soil, legume can help in maintenance of plant soil microbial activity by reducing soil pH where the organic acid released from legume facilitates the process. The highest maize yield was reported by Ghosh and Singh (1994), while growing after cowpea (fodder) compared to the maize grown after maize (fodder). This enhancement in yield is primarily because of enrichment of soil N by leguminous cowpea (Tables 16.2 and 16.3).

Table 16.2 Grain yield of maize crop and total nitrogen content in soil as influenced by preceding summer crops and nitrogen applied to maize crop (Adopted from Ghosh and Singh 1994; Bues et al. 2013)

Treatment	Grain yield (kg ha^{-1})	Total N (%)	
		After summer crop	After maize harvest
Summer crop			
Black gram	3920	0.069	0.068
Green gram	4208	0.071	0.069
Cowpea (fodder)	4404	0.075	0.070
Cowpea (grain)	3594	0.071	0.070
Maize (fodder)	3477	0.065	0.066
Fallow	3946	0.068	0.068
$LSD_{(0.05)}$	506		0.0008
N to maize (kg ha^{-1})			
0	2790	–	0.063
30	3775	–	0.066
60	4451	–	0.067
90	4684	–	0.070
$LSD_{(0.05)}$	279	–	0.0008

Table 16.3 Yield potentiality of legumes

Grain legume	Yield (kg/ha)	References
Soybean (*Glycine max*)	1000	Masuda and Goldsmith (2009)
Pea (*Pisum sativum*)	182	Cousin (1997)
Pigeon pea (*Cajanus cajan*)	657	Singh (2013)
Lentil (*Lens culinaris*)	667	Singh (2013)
Rice bean (*Vigna umbellata*)	907–1089	Khadka and Acharya (2009)
Cowpea (*Vigna unguiculata*)	300	Ehlers and Hall (1997)
Faba bean (*Vicia faba*)	5112–5737	Song et al. (2006)
Common bean (*Phaseolus vulgaris*)	729	El-Al et al. (2011)
Groundnut (*Arachis hypogaea*)	310	Ramana et al. (2002)
Chickpea (*Cicer arietinum*)	792	Singh (2013)
Mung bean (*Vigna radiata*)	346	Singh (2013)
Black gram (*Vigna mungo*)	733–900	*agritech.tnau.ac.in*

16.6 Greenhouse Gas Emission

The enhanced N_2O emissions from agricultural and natural ecosystems are believed to be caused by increasing soil N availability due to increased use of fertilizer, BNF, and N deposition (IPCC 2013). The potentiality of N_2O emission from arable soil under agriculture is drastically reduced due to legume cultivation through the savings in fertilizers (N and P) as the estimated CO_2 emission from fertilizer production is about 300 Tg per year (Jensen et al. 2012). N_2O production in soil occurs mainly by two microbial processes:

(i) Nitrification in aerobic conditions
(ii) Denitrification in anaerobic conditions

Both the incidence and intensity of these processes are strongly affected by soil mineral N and the availability of soluble C, water and oxygen contents, temperature, pH, and soil texture (Conen et al. 2000; Gu et al. 2013; Smith et al. 1998). In agricultural fields, cover crops are frequently used as catch crops to mitigate nitrate leaching and erosion during the autumn and winter fallow periods (Thorup-Kristensen et al. 2003). When legume cover crops are used either alone or in mixture, they provide an additional N green manure effect for the subsequent crop (Tribouillois et al. 2015; Dhakal et al. 2016) and are responsible for the modification of mineral N availability in the soil, either reducing it during plant growth or increasing it after incorporation into the soil. They can also affect soil water content through increased transpiration compared to bare soil. Studying alternative crop emissions, Jeuffroy et al. (2013) observed that legume crops emit about five to seven times less GHG per unit area compared to other crops. Results of N_2O fluxes from different crops demonstrated that pea emitted 69 kg N_2Oha^{-1}, far less emissions than winter wheat (368 kg N_2Oha^{-1}) and rape (534.3 kg N_2Oha^{-1}). The company of legumes in the cereal-based crop rotation instead reduces the amount of synthetic N required by the following cereal crop and consequently decreases the N_2O emissions associated with synthetic N fertilizers (Jensen and Hauggaard-Nielsen 2003; De AntoniMigliorati et al. 2015). Tillage is another factor associated with N_2O emission from agricultural fields. There is a general tendency to observe higher emissions under conventional tillage (Plaza-Bonilla et al. 2014; Yadav et al. 2017) which can be minimized with the inclusion of legume as legume needs very low tillage compared to the conventional tillage used for cereal crops and is reported to increase carbon sequestration in the soil.

16.7 Crop-Legume Intercropping

Intercropping is a mixed cropping system of cultivating two or more crops in the same space at the same time (Andrews and Kassam 1976; Sanchez 1976) in a definite row arrangement. Four different types of intercropping, namely, mixed intercropping, row intercropping, strip intercropping, and relay intercropping, are in use. Due to higher density of crops under intercropping, particularly with the inclusion of legumes, microbial diversity of the soil increases which brings stability to the agroecosystem (Ram and Meena 2014). Crop-legume intercropping plays an important role in improving soil fertility, water and radiation use efficiency, weed, pest and disease control, and profit maximization for farmers. Success stories of pulse as an intercrop have already been documented by many researchers. For example, intercropping soybean with corn gives higher economic return with more crude protein compared to the pure stand. Rhizobia and legume are found in a symbiotic association, where both of them are benefited. Rhizobia receive food and shelter from the legume, and in return legume gets fixed N ammonia and is utilized in biosynthesis of amino acid and nucleotides. Crop plant when grown with legume in nutrient poor soil better yield is achieved compared to the plant grown alone. Cereal legume intercropping has higher capacity to restore soil mineral N through its ability to biologically fix atmospheric nitrogen (Fujita et al. 1992; Giller 2001; Meena et al. 2017b). Intercropping falls under organic farming, as here disease and pest are controlled biologically, while soil fertility is maintained organically. The use of biochar as organic amendment in intercropping was found to enhance legume N fixation and increased yield compared to single crop and facilitate N transfer from legume to coexisting crops (Ling Liu et al. 2017).

According to some researchers, legume plants are weak suppressors of weed as they grow slow at early development or lose leaves in the ripening stage (Hauggaard-Nielsen 2001; Jensen et al. 2005). But when cereal crops and legumes are grown together, the weed suppression ability increases. Disease risk minimization is another benefit obtained from crop-legume intercropping. Common bacterial blight and fungal rust can be controlled by intercropping (Boudreau and Mundt 1992; Fininsa 1996) with legume. Viral diseases such as cassava mosaic disease of cassava plant and whitefly attack can be reduced by intercropping cassava with green gram.

Cultivating crop repeatedly in the same piece of land reduces soil fertility, and the addition of chemical fertilizer is not the solution as it increases the price of the produce along with its effects on the ecosystem. In this situation, crop rotation is one of the adaptation options through which the soil fertility can be maintained. Intercropping cereals with legume is a main component of integrated soil fertility management practices (ISFM) (Sanginga and Woomer 2009; Mucheru-Muna et al. 2010; Meena et al. 2015b). Cereal legume intercropping is being practiced in agriculture for last decades. In this regard, right choice of both cereal and gain legume crop is very important; otherwise profit may shift to loss as maximum utilization of soil nutrient will be hampered. For example, combination of two crops having different ripening period reduces crop yield rather than increases yield. So cereal legume intercropping does not automatically improve crop yield, but the correct combination of crop is important. In rotation cropping system, legumes are mainly used as green manure. Though some other crops can also be grown as green manure, but due to N-fixing ability (Table 16.4), the legume crops are preferred the most. Green manuring in maize field with *Sesbania rostrata* + 30 kg N ha^{-1} gives same yield as application of 90 kg N ha^{-1}, indicating 60 kg of N is saved through green manuring (Tiwari et al. 2004). Sometimes, legume green manure crop can supply entire N need for the next crop. Legume litters contain K, P, and other nutrients which are recycled to the soil. In intercropping system, N is transferred to the coexisting crop. Intercropping of peanut with rice crop which transfers N from peanut to rice is prominent especially in N-poor soil (Chu et al. 2004; Meena et al. 2015). In maize and cowpea, when intercropping has been done at low N level, the N content of intercropped maize was found to be higher than sole maize crop, which shows the

Table 16.4 Nitrogen-fixing ability of legumes

Grain legume	N-fixing ability (kg ha^{-1})	Reference
Soybean (*Glycine max*)	71–108	
Pea (*Pisum sativum*)	90–128	Jensen (1996)
Pigeon pea (*Cajanus cajan*)	120–170	Adu-Gyamfi et al. (1997)
Lentil (*Lens culinaris*)	8–14	Cowell et al. (1989)
Rice bean (*Vigna umbellata*)	13–30	
Cowpea (*Vigna unguiculata*)	14–35	Okereke and Ayama (1992)
Faba bean (*Vicia faba*)	23–79	Danso et al. (1987)
Common bean (*Phaseolus vulgaris*)	20–60	Silva et al. (1993)
Groundnut (*Arachis hypogaea*)	150–200	Toomsan et al. (1995)
Chickpea (*Cicer arietinum*)	64–103	Fatima et al. (2008)
Mung bean (*Vigna radiata*)	19–54	Hayat et al. (2008)
Black gram (*Vigna mungo*)	16–79	Hayat et al. (2008)

transfer of fixed N from cowpea to maize (Francis 1986). Thus, with intercropping, food quality can be enhanced by increasing protein content of cereal and other crops, and the food security can be fulfilled to some extent. Intercropping in upland rice with soybean at the ratio of 4:2 was found beneficial to increased productivity along with soil fertility improvement (Hazarika et al. 2006). The cereal crops such as rice, wheat, and maize are cultivated extensively, these crops alone cannot contribute to all nutritional needs of the animals. Therefore, the diversification of crops by growing various valuable crops is necessary, which will provide all the dietary requirements of the human population including other animals. Thus, crop diversification with legume has advantage of N nutrition to the plant, along with breakage effect on disease cycle and pest (Voisin et al. 2014).

Legume can reduce disease and pest attack, increase production of coexisting crop with higher protein availability, and thus help in food security. In rotation, legume brings diversification in the cropping sequence which affects the associated diversity of wild flora, fauna, and soil microbes (Collette et al. 2011; Meena et al. 2014) with the potentiality of a dynamic and more sustainable agriculture (Peoples et al. 2009). By providing nectar and pollen, the mass flowering of grain and forage legumes contributes in the maintenance of wild and domesticated bees (Kopke and Nemeck 2010). Though there are controversial reports on the effects of legume on honey bees' population where it is argued that because of the regular disturbances in soil, use of biocides, and dense covering on the soil, the crop fields are not the foraging place for honey bees (Power and Stout 2011; Jeanneret et al. 2006). The diversification of cereal-dominated cropping systems with legumes enables pesticide savings, especially of specific fungicides in rotations (Von Richthofen et al. 2006; Kirkegaard et al. 2008).

16.8 Soil Erosion and Legume

The physical removal of soil by agents which provide the kinetic energy to move soil from one location to another is called soil erosion. Topsoil is the layer of soil where plants grow as it has the highest fertility than the other soil layers due to the presence of organic matter content, soil microorganism, and mineral nutrients. The primary causes of soil erosion are wind, water, grazing animals, and anthropogenic activity. Natural soil erosion is a slow process, and it is not a major problem as natural soil-forming processes can replenish it. Soil erosion is becoming a matter of concern as it is accelerated by anthropogenic activity. The use of land in different purposes indicates soil loss, so revegetation can help to reduce soil loss. Legumes are known to use as cover crop to control soil erosion. For example, legume shrubs (*Colutea arborescens*, *Dorycnium pentaphyllum*, and *Medicago strasseri*) grown as cover crops were found to reduce runoff and soil loss (Garcia-Estringana et al. 2013). Hedgerow with leguminous species is planted for erosion control which also adds N to the soil. Bhatt and Bujarbaruah (2006) reported that on an average, pruning of the leguminous hedgerow species can add 20–80, 3–14, and 8–38 kg of N, P, and potassium (K) per hectare per year, respectively.

Organic matters are the integral component of topsoil and function as a main indicator of soil quality and fertility (Franzluebbers 2002; Verma et al. 2017). It has direct impact on plant growth and productivity. Cover crops are planted for soil erosion control, soil fertility, and quality management as subsequent cropping in the same land reduces the soil quality by removing soil organic matter. In conventionally tilled legume-based rotation, use of cover crop was found to be effective to mitigate SOC and soil organic nitrogen (SON) losses, increasing N use efficiency of the crop system while maintaining optimum productivity (Daniel Plaza-Bonilla et al. 2016). Soil erosion can be significantly reduced by crop and soil management practices, such as minimal tillage, contour ridging, mulching, fertilizer, intercropping, narrow plant spacing, and planting cover crop of grasses or legume (Howeler 1987 and 1994; Ruppenthal et al. 1997; Yadav et al. 2017). Annual legumes when grown as cover crop have the advantage of providing adequate cover within short duration of 6 weeks from planting and can be effectively used to control soil erosion faster.

16.9 Agronomic Use Efficiency

In natural ecosystem, plant follows ecological succession, and better adapted plant replaces the pre-existing one. But in managed ecosystem (like the agricultural land), cultivation of crops can be done according to the necessity of human being. For a sustainable production of crop, the management of soil is very important (Meena et al. 2015c). Soil fertility is generally maintained by application of chemical fertilizers. NPK are the main nutrients applied in field during crop cultivation. Testing of soil is essential before application of fertilizer to find out which element is less in soil for crop production. It was found that in most intensive crop production systems, 50–75% of N applied to field is not used by crops and N is lost by leaching into the soil causing environmental pollution, such as surface and groundwater pollution (Hodge 2000; Asghari and Cavagnaro 2011). Contaminated water with nitrate is not potable, and at higher concentration, it can cause serious health problems (Umar and Iqbal 2007). Well-grown grain legumes are self-sufficient in their N requirement and even can contribute to N economy of the entire cropping system by adding fixed N to the soil pool, using little or none from the soil reserves of N (Walley et al. 2007). Studies are in progress on whether increasing water use efficiency (WUE) and nutrient use efficiency (NUE) in food legumes is possible through agronomic means. Grain yield per unit of water use, evapotranspiration, or growing-season rainfall is termed as crop WUE of plant. Increasing WUE is associated with increasing grain yield and water use after flowering (Loss et al. 1997; Siddique et al. 2001). For example, late planting reduces the WUE with decreasing grain yield. Early planting is preferred to give better yield and higher WUE. Exceptions are there in field pea, where too early plantation leads to the development of black spot disease (Siddique et al. 1998). Use of herbicides or manual weeding increases the water use efficiency and crop yield by increasing NUE and the economic yield per unit of nutrient applied (Verma et al. 2017). NUE is declining gradually with time, and the nutrients lost from the agricultural system have detrimental effects on adjacent ecosystems (Cloern et al. 2007). Therefore, it is necessary to increase fertilizer use efficiency and apply minimum fertilizer as possible. During the process of domestication and breeding, the genetic diversity of some important crops has been reduced (Warschefsky et al. 2014). Genes from the crop with higher nutrient utilization ability can be used in genetic engineering for improving NUE of other crops. Performing organic farming can minimize the detrimental effects on environment and reduce the environmental risk. Legume can be utilized for better NUE. For example, legumes such as lupin have the capacity to utilize P from partially available sources than other crop species (Braum and Helmke 1995). Depending on the environmental conditions, the legume can add maximum possible N to the system leading to high crop yield. For example, legumes are reported to be sensitive to stress and stop fixing N on exposure to drought (Sinclair et al. 1987).

Low-Input Sustainable Agriculture (LISA) was replaced by Sustainable Agriculture Research and Education (SARE) program through an act passed in the US Congress during 1985. The main focus of this program was to maintain high land productivity to using the techniques that minimize the use of pesticides, fertilizers, and off-farm purchases through appropriate rotations; biological weed, pest, and disease control; integration of livestock with crops; and minimum tillage systems. Lower-input in sustainable systems do not mean practicing of only organic system; rather, it requires a farmer to understand more about the biological effects of a crop or management systems and how to use this information cheaply and effectively in farm programs (Meena et al. 2015b), e.g., integrated pest management.

For the healthy growth of food legumes, formation of adequate nodule is necessary (Dhakal et al. 2016) even in cool and dry conditions where rhizobia are not available in soil. Under that situation, the inoculation of rhizobia is essential. Cultivated legumes are mostly slow grower at early stage and prone to weed competition. Pandey et al. (1998) reported that weed can reduce the legume yields by 25–40%. Weed control in legume crop can minimize the loss of grain yield. Herbicides are becoming noneffective due to the development of herbicide-resistant weed variety. Manual weeding is also becoming increasingly expensive due to shortage of labor. Paolini et al. (2003) and McDonald et al. (2007) found an increased weed infestation with the increasing density and competitive ability of lentil, which enhances the cost for weed suppression relative to mechanical and chemical pest control mechanism.

16.10 Future Perspectives

Among the diverse species of legumes, only very few have received the attention of the researchers. Therefore, this is necessary to explore the other legume species (both wild and cultivated) for their multiple benefits. The explored valuable qualities of grain legumes should cross into the germplasm to produce higher nutritious food for human and livestock. To obtain it, research objective aiming on this area is required. Research emphasis focusing on the use of legume and their rhizobia for value-added future exploitation including the opportunities such as use as a source of pharmaceutical drugs against various diseases is very much essential. In this regard, to practically realize the benefits of rhizobia to its fullest, in-depth studies on the rhizobial manipulation are a must involving the agricultural biotechnologist (Meena et al. 2017b). There is also an urgent need to assess the overall socioeconomic and environmental significances which may arise from the widespread adaptation of legume-based agriculture so that it helps the farmers in decision-making. With the escalating rate of climate change, this is also important to breed legume cultivars for various abiotic stress resistances.

16.11 Conclusion

This chapter gives an overview of different aspects of legume growth, productivity, and their impact on soil health. Legumes are an important ingredient of human diet especially for the large vegetarian population of the world. In the era of green revolution with major focus on staple foods like rice, wheat, and potato, cultivation of legumes was relegated to the marginal land with least of inputs. This, coupled with the increasing population, resulted in reducing per capita availability of legumes to the common people. Cutting-edge technologies on legume culture need to be developed in order to face the challenges of climate change. Genomics, transgenics, molecular breeding, quality improvement, and biotic and abiotic stress management of different legume crops need more attention. Legumes can be considered as smart food for high nutritional value having low water footprint, low carbon footprint, and ability to sustain soil health. Agribusiness opportunities of legume crops are an emerging area which can help the small landholders of countries like India. These crops can be a good source of study for soil N dynamics and soil N_2O production and emission. The leguminous intercrop can increase soil available N for the subsequent crop. Legume as intercrop may reduce the N loss and can improve soil N availability for the subsequent crop. Legumes grown in an ecosystem can also be a good source of carbon sink in the form of biomass and in soil as well. Well-designed studies on legume crops and their impacts on soil C dynamics and carbon storage are needed for climate resilient agriculture.

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