12 Legume Green Manuring: An Option for Soil Sustainability

B. L. Meena, R. K. Fagodiya, K. Prajapat, M. L. Dotaniya, M. J. Kaledhonkar, P. C. Sharma, Ram Swaroop Meena, Tarik Mitran, and Sandeep Kumar

Contents

B. L. Meena (✉) · R. K. Fagodiya · K. Prajapat · M. J. Kaledhonkar · P. C. Sharma
ICAR – Central Soil Salinity Research Institute, Karnal, India
e-mail: bl.meena@icar.gov.in

M. L. Dotaniya
ICAR – Indian Institute of Soil Science, Bhopal, India

R. S. Meena
Department of Agronomy, Institute of Agricultural Sciences (BHU), Varanasi, UP, India

T. Mitran
Soil and Land Resources Assessment division, NRSC, ISRO, Hyderabad, Telangana, India

Carbon Management and Sequestration Centre, The Ohio State University, Columbus, OH, USA

S. Kumar
Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India

R. S. Meena et al. (eds.), *Legumes for Soil Health and Sustainable Management*,
https://doi.org/10.1007/978-981-13-0253-4_12

Abstract

Overuse of nitrogen (N) fertilizer to enhance agricultural production is threatening the environment. The concentrations of reactive forms (e.g., NOx, N_2O, NO_3^-, NH_3) of N have increased to around 120% in the atmosphere as a result of different industrial units and use of chemical fertilizers in agriculture. The scenario compels to rethink about the role of biological nitrogen fixation (BNF). Green manuring with inclusion of legumes appears to be the most feasible option. Intensive agriculture with repeated tillage, use of high-analysis fertilizers, burning of agricultural residue, and non-incorporation of biodegradable solid waste from domestic and industrial sectors into soil mass have resulted in the decline of soil organic carbon (SOC). This in turn impaired soil health, decreased soil biodiversity, and aggravated the demand for essential plant nutrients, leading to the agricultural land becoming less productive and sometimes unfit for economic cultivation. The uncontrolled use and improper management of synthetic fertilizers, especially, the nitrogenous fertilizers, emit nitrate (NO_3^-) causing water pollution and nitrous oxide (N_2O), speeding up climate change process and oxides of N (NO_x) causing air pollution. The OC and soil nitrogen have a positive correlation. It suggests that soil nitrogen level can be improved with improving levels of soil organic matter (SOM). It will also help in reducing environmental damage due to overuse of nitrogen fertilizers. Green manuring with legumes has added advantage as legumes fix atmospheric nitrogen and are easily decomposable. Legume green manuring (LGM) improves SOC, nutrient availability, physicochemical and biological properties of soil, and crop productivity. Several legumes which were used for green manuring showed high N accumulation rate, i.e., 80–100 kg ha^{-1} in duration of 45–60 days of crop growth. Legume crop cultivation, say seed legumes in symbiotic association with *Rhizobium*, contributes around 10 Tg N $year^{-1}$, while forage legumes (cover crops) contribute 12 Tg N $year^{-1}$. Application of LGM is an important option to optimize the BNF and to ensure soil sustainability. The LGM may have a realistic and applicable potential in the area where soil properties are marginal for crop production.

Keywords

Legume green manuring · Nitrogen fixation · Legume crops · Soil health

Abbreviations

BNF	Biological nitrogen fixation
C	Carbon
cm	Centimeter
CO_2	Carbon dioxide
FYM	Farm yard manure
GLM	Green leaf manuring
ha	Hectare

IRRI	International Rice Research Institute
K	Potassium
kg	Kilogram
LGM	Legume green manuring
Mg	Megagram
mm	Millimeter
MWD	Mean weight diameter
N	Nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NO_3^-	Nitrate
NOx	Oxides of nitrogen
NUE	Nitrogen use efficiency
OC	Organic carbon
OM	Organic matter
P	Phosphorous
pb	Bulk density
SOC	Soil organic carbon
SOM	Soil organic matter
Tg	Teragram
WHC	Water holding capacity
WUE	Water use efficiency

12.1 Introduction

The current world population is ~7.3 billion, and it will further increase to 8.5 and 9.7 billion during 2030 and 2050, respectively, and this is expected to be stabilized at ~11.2 billion by the end of the twenty-first century (UNDESA 2015). This additional three to four billion people will require extra food grain production, from shrinking land and water resources, to ensure food and nutritional security (Sulieman and Tran 2015). Increase in quality food grain production under intensive agricultural management practices would only be possible by doubling the use of energy and fertilizers consumption (Sulieman and Tran 2015). Food grain production increased manyfold at global level during the twentieth century, and a tremendous yield increase was observed due to the increase in the net cultivable area. Further, use of short-duration high-yielding varieties, synthetic fertilizers, and pesticides is inevitable (Sihag et al. 2015). This approach has resulted in gradual degradation of soil organic matter (SOM) because of the breakdown of stable soil aggregates and decomposition of organic matter (OM). Consequently, soil health is deteriorated in terms of reduction in water holding capacity (WHC) of soils, surface and groundwater pollution, and multiple nutrient deficiencies (Gill et al. 2008; Meena et al. 2013). Soluble nutrient is provided by synthetic fertilizers for crop production that are easily vulnerable to loss, if soils and irrigation water are not properly managed.

Moreover, higher application of synthetic fertilizers has led to an imbalance of the nutrient cycle, particularly N, illustrated by the growing accumulation of several reduced (NH_3) and oxidized (NOx, N_2O, NO_3^-) forms (Fagodiya et al. 2017), causing water pollution (NO_3^-), air pollution (NOx), and climate change (N_2O) (Galloway et al. 2003). There are severe concerns about sustainable soil productivity, and today most of the countries have moved into a post-green revolution phase and are facing the problem of stagnation or declining crop productivity. Hence, both farmers and researchers have opted for conservation agriculture practices, resources conservation, and use of green manuring into the farming system to enhance further food grain production while maintaining soil health (Meena and Majumdar 2016; Meena et al. 2016a, b, c).

It has been widely reported that leguminous green manure crops play an important role in soil health management (Whitbread et al. 2000) and recently received higher attention for improving soil fertility and agricultural sustainability (Ray and Gupta 2001; Fageria 2007). Green manuring is the practice of incorporation of undecomposed fresh/dry plant material into soils, both either in place or brought from a distance (Pieters 1927). In addition to this, green manure legume crops also fix atmospheric N biologically. Biological nitrogen fixation (BNF) is a microbiological process in which atmospheric N_2 is converted into a plant-usable form, which offers an economically attractive and ecologically sound option of reducing external inputs and improving internal resources (Sulieman and Tran 2014).

Legume green manuring (LGM) can enhance agriculture sustainability by improving nutrient retention (Dinnes et al. 2002), enhancing soil fertility (Fageria and Baligar 2005), by decreasing soil erosion (Smith et al. 1987), and reducing global warming (Robertson et al. 2000). LGM also has a major role to improve the SOC pool, thereby improving soil physicochemical and biological properties (Fageria and Baligar 2005; Fageria 2007). The incorporation of legume green manure crops into soil releases organic substances like organic acid, amino acids, sugars, vitamins, and mucilage (Shukla et al. 2011) during crop growth as well as after decomposition. These substances are capable to bind soil particles together and form better soil aggregation (MacRae and Mehuys 1985), resulting in increased hydraulic conductivity (MacRae and Mehuys 1985; Boparai et al. 1992), water holding capacity (WHC), water infiltration (Raimbault and Vyn 1991), and total pore space (Anderson et al. 1997) of the soil. Further, the green manure incorporation provides carbon (C) and energy to soil biota required for OM decomposition and nutrient recycling (Griffin and Garren 1976; Hu et al. 2006). In the process of LGM, soil pH is changed by addition of OM (Singh et al. 1992). The addition of organic amendments into soils, particularly green manure, has potential to control weeds and soil-borne diseases and to disrupt the life cycle of agriculture pest (Kumar et al. 2014; Varma et al. 2017). Green manure is important to small-scale farmers, for whom it is difficult to buy expensive mineral fertilizers (Meena et al. 2014). Therefore, legume green manure crops have great potential for sustainable food grain production. Keeping above facts in mind, the objective of this chapter is to provide information on the LGM for sustainable soil management and crop production.

12.2 Legumes as Green Manure

The green manuring practices are of two types: (a) in situ green manuring crops and (b) ex situ green leaf manuring (GLM) (Singh et al. 1991). In in situ green manuring, short-duration (~45 to 60 days) crops are grown and incorporated into soil at the same site. In ex situ green manuring, foliage and tender parts of green manuring crops collected from nearby forests, shrubs, and trees are incorporated into the soil at 15–30 days prior to the sowing of main crops (SSSA 1997).

There are many crops which can be used for green manuring; however the selection of the green manure crop depends upon several factors like the prevailing climatic conditions, cropping system practiced, availability of seed, and other factors including local habits and prejudices. The legume crops have an edge over nonlegume crops due to ability of fixing atmospheric N (Rao 2014). LGM is categorized under following categories:

(a) Grain legumes: pigeon pea (*Cajanus cajan*), green gram (*Vigna radiata*), soybean (*Glycine max*), or groundnut (*Arachis hypogaea*)
(b) Multipurpose perennial legume trees: subabul (*Leucaena leucocephala*), gliricidia (*Gliricidia sepium*), and kassod tree (*Cassia tora*)
(c) Non-grain legume crops: sunn hemp (*Crotalaria juncea*), dhaincha (*Sesbania rostrata*), centrosema (*Centrosema acutifolium*), stylo (*Stylosanthes guianensis*), and desmodium (*Desmodium ovalifolium*) (Palaniappan 1994)

The most commonly grown LGM crops are sunn hemp, dhaincha, berseem (*Trifolium alexandrinum*), and green gram. The leguminous crops, namely, cowpea (*Vigna unguiculata*), green gram, black gram (*Vigna mungo*), pigeon pea, chick pea (*Cicer arietinum*), black lentil (*Lens culinaris*), pea (*Pisum sativum*), lathyrus (*Lathyrus latifolius*), kidney beans (*Phaseolus vulgaris*), tephrosia (*Tephrosia purpurea*), groundnut, soybean, dhaincha, and sunn hemp; woody legumes, namely, subabul, gliricidia, karanj (*Pongamia glabra*), and delonix (*Delonix regia*), have the ability to fix the atmospheric N in their root nodules. Legume crops and tree species suitable for green manuring in different agroclimatic zones are mentioned in Table 12.1. Dry matter accumulation by these legume crops may vary from 1 to 10 Mg ha^{-1} $year^{-1}$ under ideal soil and environmental conditions, and the total N accumulation in the aboveground biomass ranges from 0.02 to 0.3 Mg ha^{-1} $year^{-1}$ (Lathwell 1990). Besides BNF, a green manure crop should have some desirable characteristics, viz., fast-growing habit, short duration, early onset of BNF, high N accumulation rate, high tolerance to biotic stresses (pest and disease), abiotic stresses (flood, drought, salinity, and adverse temperatures), wide range of ecological adaptability, timely release of nutrients, photoperiod insensitivity, high seed production, higher seed viability, and most importantly easiness in incorporation (Meena et al. 2015a).

Table 12.1 Leguminous green manure crops for different regions

(A) **In situ green manure crops**			
(a) **Tropical region**		(b) **Temperate region**	
Common name	**Scientific name**	**Common name**	**Scientific name**
Cluster bean	*Cyamopsis tetragonoloba*	Subterranean clover	*Trifolium subterraneum*
Cowpea	*Vigna unguiculata*	Ladino clover	*Trifolium repens*
Pueraria	*Pueraria phaseoloides*	Crimson clover	*Trifolium incarnatum*
Green gram	*Vigna radiata*	Faba bean	*Vicia faba*
Lablab	*Lablab purpureus*	Soybean	*Glycine max*
Dhaincha	*Sesbania aculeate*, *S. rostrata*	Red clover	*Trifolium pratense*
White lupin	*Lupinus albus*	Black lentil	*Lens culinaris*
Gray bean	*Mucuna cinerecum*	Alfalfa	*Medicago sativa*
Pigeon pea	*Cajanus cajan*	Barrel medic	*Medicago truncatula*
Sunn hemp	*Crotalaria breviflora*	Hairy vetch	*Vicia villosa*
Buffalo bean	*Mucuna aterrima*	Milk vetch	*Astragalus sinicus*
Jack bean	*Canavalia ensiformis*	Winter pea	*Pisum sativum*
Velvet bean	*Mucuna deeringiana*	Sweet clover	*Melilotus officinalis*
Stylo	*Stylosanthes guianensis*	Cura clover	*Trifolium ambiguum*
Desmodium	*Desmodium ovalifolium*	Purple vetch	*Vicia benghalensis*
Milk vetch	*Astragalus sinicus*	Common vetch	*Vicia sativa*
Zornia	*Zornia latifolia*	**(B) Ex situ green leaf manuring shrubs and trees**	
Jumby bean	*Leucaena leucocephala*	**Common name**	**Scientific name**
Kudzu	*Pueraria phaseoloides*	Subabul	*Leucaena leucocephala*
Adzuki bean	*Vigna angularis*	Gliricidia	*Gliricidia sepium*
Black gram	*Phaseolus mungo*, *P. trilobus*	Karanj	*Pongamia glabra*
Soybean	*Glycine max*	Milkweed	*Calotropis gigantea*
Alfalfa	*Medicago sativa*	Tephrosia	*Tephrosia purpurea*
Wild indigo	*Indigofera tinctoria*	Wild indigo	*Indigofera teysmannii*
Berseem	*Trifolium alexandrinum*	Sesbania	*Sesbania speciosa*, *S. rostrata*
Sunn hemp	*Crotalaria juncea*, *C. striata*	Kassod	*Cassia tora*

Modified from: Fageria and Baligar (2005) and Reddy (2016)

12.3 Biological Nitrogen Fixation in Legume Green Manuring

BNF is the process of conversion of atmospheric N_2 into ammonia (NH_3) or other molecules which are easily available to plants and other living organisms into the soil (Postgate 1998). The BNF and mineralization of leguminous green manure crop in soil are depicted in Fig. 12.1. Overall reaction of BNF is given below.

$$N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$$

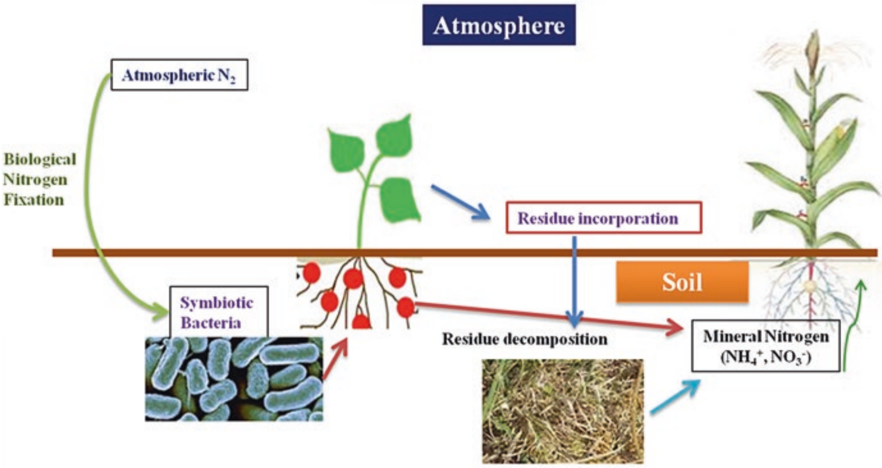

Fig. 12.1 N fixation and mineralization of leguminous green manure crop in soil

In many studies, it has been proven that the BNF is the most efficient process or way to supply the major amount of N required by legume crops or plant (Sulieman and Tran 2014) (Table 12.2). After sowing of the legume seed, soon after its germination, the inherent *Rhizobium* present in soil are externally added as seed inoculums and later on enters into the root hairs of legumes and moves through infection thread toward the main root. After invasion, these bacteria multiply rapidly in the root of legumes, which result into swelling of root cells to form nodules. The atmospheric N around the root hairs of legumes is "fixed" by binding it to other elements and converting it into a plant available ammonical form. The *Rhizobium* bacteria use carbohydrates as a source of hydrogen in the conversion of atmospheric N to ammonia (Fageria 2007), and this symbiotic association of legume with *Rhizobium* contributes 40% of world total N fixation (Ladha et al. 1992; Meena et al. 2015a). A detailed survey of the literature showed that on an average, grain legume crops could fulfill 50–80% of own N requirement through BNF. BNF through legume crop cultivation in agriculture adds 33 Tg N year^{-1}, of which symbiotic association of *Rhizobium* with seed legume crops, forage leguminous cover crops, non-*Rhizobium* N-fixing bacteria, cyanobacteria in rice, and endophytic N-fixing organisms in sugarcane contribute 10, 12, 4, 6, and 3 Tg N year^{-1}, respectively (Smil 1999).

Ladha et al. (1988) reported an average accumulation of 2.6 kg N ha^{-1} day^{-1} under different legume green manure crops. Incorporation of such high N-fixing legume crops at 45–65 days of growth stage into soils results in rice yield equal to the application of N fertilizers at 50–100 kg N ha^{-1}. Similarly, Ladha et al. (1988) reported that 45–60 days old dhaincha species could fix N equal to 200 kg N ha^{-1}. Dhaincha legume crop age of 55 days fixed about 303 kg N ha^{-1} (at 5.5 kg N day^{-1}) and 383 kg N ha^{-1} (at 6.96 kg N day^{-1}) without and with inoculation of *Azorhizobium*

Table 12.2 N accumulation in major leguminous green manure crops

Crop species	Growth duration (days)	N accumulation (kg ha^{-1})	Reference
Glycine max	45	115	Meelu et al. (1985)
Crotalaria juncea	45	169	
Cajanus cajan	45	33	
Sesbania aculeata	45	225	
Vigna radiata	45	75	
Dolichos lablab	45	63	
Indigofera tinctoria	45	45	
Sesbania rostrata	56	176	Furoc et al. (1985)
Sesbania aculeata	56	144	
Vigna unguiculata	45	75	
Vigna radiata	45	75	Morris et al. (1986)
Sesbania rostrata	60	219	Ladha et al. (1988)
Sesbania cannabina	60	171	
Sesbania aegyptiaca	57	39	Ghai et al. (1985)
Sesbania grandiflora	57	24	
Cluster bean	49	91	Singh et al. (1991)
Common vetch	Flowering	105–210	
Sweet clover	Flowering	150–300	
Milk vetch	Flowering	65–131	Watanabe (1984)

bacteria, respectively (Ladha et al. 1988). The N supplied by hairy vetch (*Vicia villosa*) and crimson clover (*Trifolium incarnatum*) in cover crop experiments ranged from 72 to 149 kg N ha^{-1} (Hargrove 1986; Ladha et al. 1988; Holderbaun et al. 1990). Thus, it is clear that the amount of N fixed by different legume species varies, and it depends on the legume species, its variety, the number of effective root nodules, type of soil, agronomical and water management practices, and prevailing climatic conditions and their interactions with other factors (Buresh and De Datta 1991; Fageria and Baligar 2005). Sharma and Ghosh (2000) evaluated dhaincha as an intercrop with direct-seeded rice as well as incorporated pure dhaincha before transplanting of rice under flood-prone lowland conditions and found that dhaincha accumulated 80–86 kg N ha^{-1} in pure stand and 58–79 kg N ha^{-1} when intercropped with direct-seeded rice in alternate rows at 50 days of growth.

12.4 Nutrient Composition of Legume Green Manuring

LGM crops incorporation into the soil improves essential plant nutrients for succeeding crop (Bhuiyan and Zaman 1996). Legume green manuring crops, having low C/N ratio (high N), may behave like the chemical nitrogenous fertilizer application, when compared to the other crops used for BNF. However, the mineral composition and N content of legume may vary considerably depending upon the species (Singh and Bhattacharyya 1989; Verma et al. 2015a), crop growth duration, and

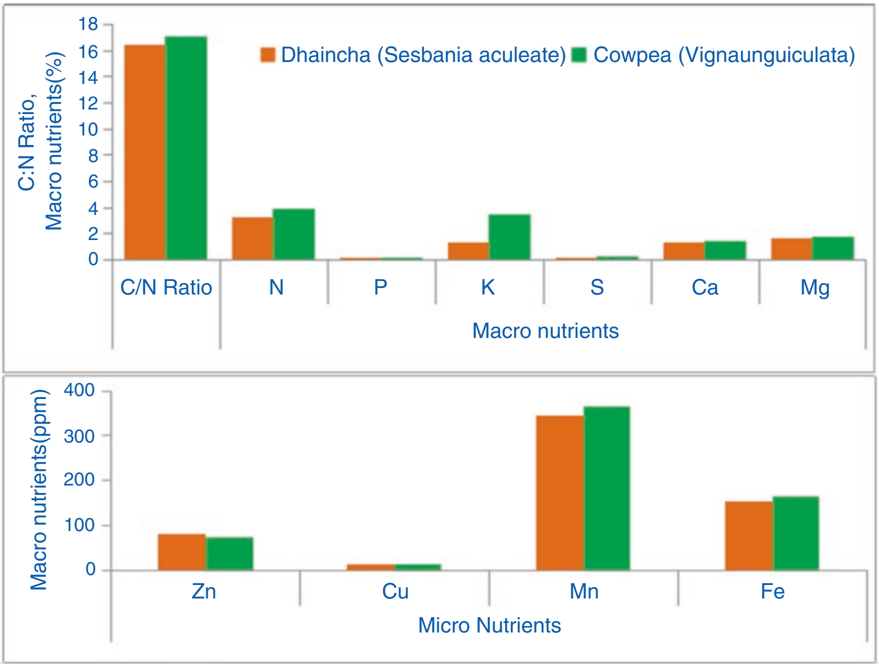

Fig. 12.2 Nutrient composition and supply of nutrient by 8-week-old green manuring crops. (Data source: Bhuiyan and Zaman 1996; Singh et al. 1992)

growth condition. With increased crop growth duration, carbonaceous content (carbohydrate and cellulose) increases and nitrogenous content (amino acid and protein) decreases leading to increase in C/N ratio of crops which results in slower decomposition of plant material (Ishikawa 1988). To overcome this problem, green manure crops should be incorporated at the flowering stage. The N and C content in roots, shoots, and leaves may also vary. In general, leaves contain lower C/N ratio as compared to stem and roots (Palm et al. 1988). In addition to N and C content, green manuring crops may also contain considerable amount of other nutrient and trace elements. A study conducted by Bhuiyan and Zaman (1996) under protected cultivation in greenhouse showed that cowpea has a higher mineral composition than dhaincha under wetland rice. The nutrient composition of dhaincha and cowpea is depicted in Fig. 12.2.

12.5 Decomposition and Mineralization

Incorporation of legume green manure into soil undergoes decomposition and mineralization process (Fageria 2007; Meena et al. 2018). Decomposition is a biological breakdown and transformation of complex organic compounds into simpler organic and inorganic molecules (Joffe 1955; Fox et al. 1990).

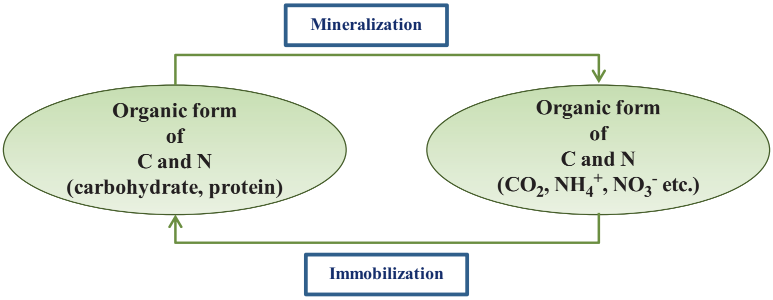

Fig. 12.3 Mobilization and immobilization of nutrient in soil

$$\text{Complex organic molecules} + O_2 = \text{Nutrients} + H_2O + CO_2 + \text{Energy}$$

There are mainly two processes, namely, mineralization and immobilization (Gil and Fick 2001; Dinnes et al. 2002) as shown in Fig. 12.3.

- Mineralization is the main process of conversion of organic carbon (OC) and N into the mineral form, i.e., CO_2 and NH_4^+ by microorganism. During this process, nutrients are released to soil solution and are made available to plants.
- Immobilization is the reverse process of mineralization in which the mineral form of C and N fixed into the organic form.

Decomposition and mineralization of green manures are affected by the type of soil, crops, crop growth stage at which it is incorporated, and prevailing climatic conditions (Fageria and Baligar 2005; Reddy 2016). Among these, the dominant factors are the quantity and quality of green manure crops. Soil factors, which affected the decomposition and mineralization of green manure, are the soil texture, structure, soil reaction, microbial activity, and the status of soil nutrients (Thonnissen et al. 2000; Dinnes et al. 2002; Dhakal et al. 2015). Decomposition and mineralization of OM mainly depend upon the availability of N in soil (Joffe 1955; Gil and Fick 2001). Due to low C/N ratio, lower lignin content, and high quantity of easily decomposable material, LGM generally leads to rapid and fast mineralization as compared to cereal residues (Janzen and Kucey 1988; Gil and Fick 2001). Decomposition rate of green manure legume was higher in sandy soils than the fine-textured soils (Verbene et al. 1990). Soybean residues incorporation into soils lost 68% of biomass within 1 month of incorporation (Broder and Wagner 1988). The incorporation of hairy vetch legume green manure rapidly released N within 15 days after incorporation (Varco et al. 1989). Legume residue incorporation into soils under field conditions led to that of the <30% of legume N recovered by a subsequent nonlegume cereal crop, and a major amount of it is retained in soil as organic forms of N (Ladd et al. 1983; Harris et al. 1994). Fractional C and N release was greater in dried and rewetted soil for green manuring legumes compared to continuously moist soil for all parts except for nodules (Franzluebbers et al. 1994). The

NH_4-N release and its accumulation increased significantly with a decrease in soil water; however there was a decrease in the release of NO_3-N (Brar and Sidhu 1995). Soil temperature also has an effect on the pattern of N release during decomposition of added green manure residue in the soil (Brar and Sidhu 1997). The suitable range of soil temperature and moisture are 20–30 °C and −0.01 to −0.05 MPa for faster decomposition of green manure into soil and subsequent release of nutrients (Cassman and Munns 1980; Sinha et al. 2009). Magid et al. (2001) reported higher N mineralization of both black medic and white sweet clover occurred at low temperature. Thonnissen et al. (2000) indicated that soybean and *Indigofera* decomposed rapidly and lost ~70% of the biomass in 1 month after incorporation.

12.6 Legume Green Manuring and Soil Properties

Modern agriculture, having intensive cropping system coupled with frequent tillage of the soil, higher doses of chemical fertilizers, and overlooking of the application of organic manures, led to the breakdown of soil aggregates and destruction of SOM. This further led to soil physicochemical and biological health degradation. Due to faulty management practices, the agricultural land is becoming less productive day by day. The adverse effects such as soil compaction, reduction in SOM, and reduced crop productivity have been recognized in many areas over several years (Unger and Kaspar 1994; Meena et al. 2016a). Green manuring with legumes also had a magnificent role of providing OM into the soil, thereby improving the physicochemical properties as well as biological properties of soil (Ebelhar et al. 1984; Fageria and Baligar 2005). The role of leguminous green manuring on soil physical, chemical, and biological properties is depicted in Fig. 12.4.

Besides the improvement of soil health, LGM helps in reducing insect-pest, disease incidence, and weed management (Kumar et al. 2014; Verma et al. 2015), acts as binding material in soil, and helps in improvement of soil structure (Schutter and Dick 2001). LGM between successive crop growth increased SOM (Pung et al. 2004) which stimulates the soil microbial activity and mineralization of plant nutrients (Eriksen 2005). Therefore, it enhances the soil quality and its fertility (Doran et al. 1988).

12.6.1 Soil Physical Properties

The continuous use of LGM results in buildup of OM in soil, which improves the soil physical properties (Table 12.3) and quantities of organic acid, amino acids, sugars, vitamins, and mucilage (Shukla et al. 2011). These organic substances are capable of binding the soil particles and better soil aggregation (MacRae and Mehuys 1985) which led to better hydraulic conductivity (Boparai et al. 1992) and improved drainage by increasing infiltration and percolation (Raimbault and Vyn 1991). The infiltration rates are mainly controlled by bulk density (*pb*) and aggregate stability; higher infiltration rate reduces soil erosion (Martens and Frankenberger

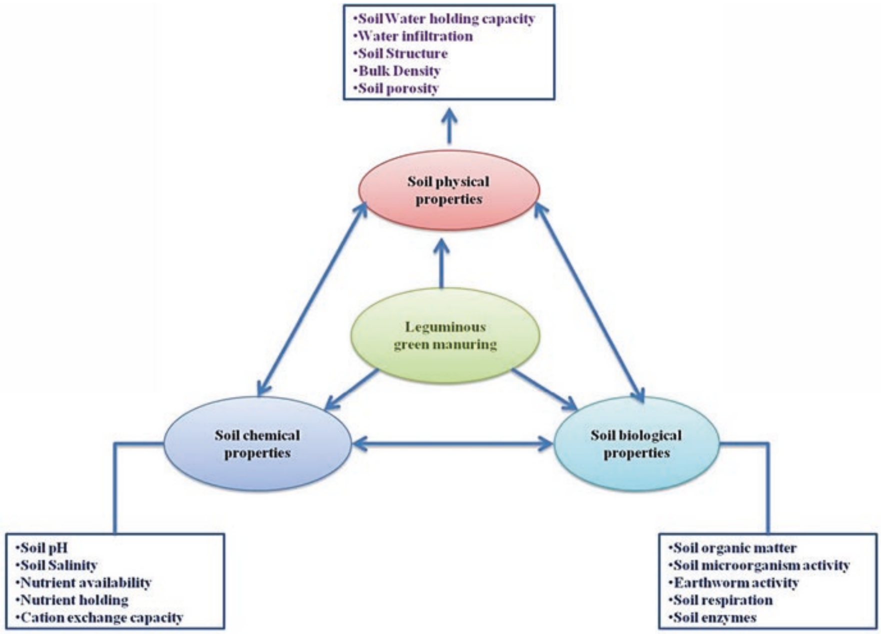

Fig. 12.4 Soil properties influenced by leguminous green manuring

Table 12.3 Physical properties of soil affected by LGM under rice-wheat system

Treatments	At rice harvest			At wheat harvest		
	Bulk density ($Mg\ m^{-3}$)	MWD[a] of soil aggregates (mm)	Hydraulic conductivity ($cm\ day^{-1}$)	Bulk density ($Mg\ m^{-3}$)	MWD of soil aggregates (mm)	Hydraulic conductivity ($cm\ day^{-1}$)
Fallow	1.52	0.519	3.65	1.55	0.531	3.74
S. rostrata	1.45	0.761	4.64	1.51	0.728	4.39
S. aculeata	1.46	0.713	4.55	1.51	0.699	4.28
Green gram	1.46	0.714	4.56	1.52	0.700	4.18

Data source: Mandal et al. (2003)
[a]Mean weight diameter

1992). The LGM improves total pore space by decreasing the soil *pb*, enhanced root development, soil water content, and nutrient use efficiency (Anderson et al. 1997).

The SOC is a more suitable index for crop production in arid and semiarid regions, as it has positive effects on the WHC (Dias-Zorita et al. 1999). The penetration of green manure roots, particularly dhaincha and sunn hemp in soil, holds it in place and prevents soil erosion (Schumann et al. 2000). Green gram and sesbania green manuring reduced the soil *pb* to the extent of 0.03–0.07 $Mg\ m^{-3}$ and enhanced the mean weight diameter of soil aggregates in the upper layer of soil when compared to fallow soils during the growth of rice and wheat (Mandal et al.

2003). In sandy soils, green manure helps to hold more water by reducing drainage rate through improvement in soil physical properties (Selvi and Kalpana 2009; Yadav et al. 2017).

12.6.2 Soil Chemical Properties

Green manuring have effects on soil chemical properties, and particularly soil pH is reduced, (a) by addition of organic acids and generation of CO_2 during OM decomposition, resulting in reduced soil pH of furnishing proton by organic manure; (b) simultaneously soil pH is increased by reduction of H^+ by organic anions to H_2O and CO_2 during mineralization of organic manure (Singh et al. 1992; Buragohain et al. 2017). Reduction of organic substances may reduce Fe and Mn oxides causing soil pH to rise (Meena et al. 2017), because of oxidation of Fe and Mn consumed proton generated during decomposition of OM. The 12 year long-term experiments conducted by Yadav and Singh (1986) indicated that soil pH reduced with the time under green manuring. Soil pH after 12 years of uninterrupted sugarcane crop cultivation was 8.0 under green manuring and 8.5 under control treatments, respectively. Green manures also prevent nutrients from being washed out from the soil. The nutrients are drawn up by the green manure crop from deep soil layers and held inside the plant and recycled back to soil upon decomposition. Organic materials, acting as a slow-release source of N, are expected to more closely match N supply and N demand of crops, and this could reduce N losses (Becker et al. 1994). In flooded soils condition, the average N loss from applied green manure and split-applied urea were 14% and 35%, respectively (Becker et al. 1995). Thus, N from green manure crops contributes significantly lower to air and water pollution compared to urea application.

Green manure added around 50–60 kg N ha^{-1} to the soil for the succeeding crop of rice (Singh and Bhattacharyya 1989). The leaching losses of green manure N are normally expected to be smaller than inorganic fertilizers, because it must be mineralized before it can be lost via leaching (Singh et al. 1992), and make it available to succeeding main crop, thereby reducing needs of N fertilizer (Stute and Posner 1993). The NO_3^- leaching from nonlegume manuring ranged 29–94%; while, from legume manuring, it was 6–48%, showing that green manuring with legume crop of hairy vetch had more potential of reduction of NO_3^- leaching than nonlegume crops (rye, *Secale cereale*) (Sainju and Singh (1997). Green manuring enhanced the availability of phosphorus (P) from added rock phosphate in rice crop (Cavigelli and Thien 2003). Hundal et al. (1992)and Bah et al. (2006) evaluated the contributions of different green manures to P nutrition in rice crop in soils of arid tropical climate and found that the utilization of phosphorous fertilizers had markedly enhanced it from 3% to 39% in treatments having green manure.

The integrated effect of legume green manure crops with mineral fertilizers improved SOC, nutrient availability, intake of nutrients by crops, and yield of rice-wheat system (Kumar and Prasad 2008). The incorporation of dhaincha at flowering stage adds about 60–90 kg ha^{-1} N into soil (Pandey et al. 2008), and it also helps improve the soil chemical properties. Legume green manure crops prevent nutrient leaching, decrease weed growth, and reduce the harmful effect of agrochemicals and soil-borne phytopathogens (Kumar et al. 2010; Dhakal et al. 2016).

12.6.3 Soil Biological Properties

The decomposition of green manures serves major functions for microflora providing both C and energy for growth and formation of new cell material, which further multiplies its colony saprophytically on the decomposing OM (Ye et al. 2014). A large number of soil microorganisms exist in the soil as long as there is a C source for energy (Kumar et al. 2014). Soil-inhabiting microorganisms are very critical for decomposing organic residues and recycling soil nutrients (Akpor et al. 2006). The process of decomposition is of great significance because unless the energy and nutrients are released through microbial activity, the primary product cannot exist for a long time (Kumar et al. 2014).

The LGM has two main positive points from the microbiological point of view: (a) primarily it provides nutrient-rich OM for the microbial community which easily converts organically bound nutrients in plant residues to easily available nutrient form to the crops; (b) secondly it enhances the biodiversity of soil microorganisms. This microbial diversity can be increased by incorporating different legume green manure in crop rotation and cropping system programs (Schutter and Dick 2001; Eriksen 2005; Kumar et al. 2016). Since the begining of agriculture, it has been found that legume green manures and other organic amendments improve the soil tilth ability and fertility (MacRae and Mehuys 1985). The increase in beneficial microbial community and its activity is most often directly related to an overall increase in soil organic matter. Sikora and Stott (1996) and Griffin and Garren (1976) studied the colonization of *Aspergillus flavus* and *Aspergillus niger* fungi in different soil textures in deep-plowed, decomposing rye, a green manuring crop in the soils of groundnut field. The greater colonization of *A. flavus was reported,* in heavy textured soil adjacent to rye (*Secale cereal*) and groundnut crops i and *A. flavus* population was as high as 165 propagules g^{-1} soil adjacent to rye.

12.7 Effect of Legume Green Manuring on Crop Yield

The positive impact of legume green manuring on SOM and other soil properties associated with increase in nutrition to growing crop is well reflected on grain yield. It was found that the average yield of rice grain increased by 1.7 Mg ha^{-1} in green manuring treatments, over controlled plots. The increase in rice yield ranged from 0.5 to 3.3 Mg ha^{-1}. The average application of N @ 80 kg N ha^{-1}, green manure N shows an agronomic N use efficiency (NUE) of 20 kg rice grain increased kg^{-1} N applied (IRRI 1990). Besides this, green manures supply N constantly, and due to slow release of N from the green manure incorporation in soils, this would match with the requirement of N by plants resulting in improved crop performance

(Westcott and Mikkelson 1987). The yield response of high-yielding varieties of rice crop to different green manuring crops in India ranged from 0.65 to 3.1 Mg ha^{-1} (Singh et al. 1991). Ali and Narciso (1993) compared NUE in long-term fertilizer experiments conducted in India, Indonesia, and the Philippines by the International Network on Soil Fertility and Fertilizer Evaluation (INSURF). The NUE of lowland rice is higher in the case of green manuring when compared to mineral fertilizer N (Peoples et al. 1995). In general, the linear relationship of NUE and N application rate does not differ significantly among different N sources, but it tends to decrease more and more with a higher application rate of green manuring (Becker et al. 1995). The highest rice production was recorded in dhaincha green manuring and it was at on par with 20 Mg ha^{-1} of FYM (Misra et al. 1996). To find out the relationship between the rate of application of dhaincha green manure and rice yield, a fie1d experiment was conducted at Bangladesh Rice Research Institute, Regional Station, Barisal. The rice grain yield showed a quadratic relation to the added dhaincha green manure, and maximum rice yield was obtained at ~6 Mg ha^{-1}.

The effect of dhaincha green manuring on crop growth and yield of direct seeded rice and transplanted rice under intermediate water stagnation condition was studied by Sharma and Das (1994) and Meena et al. (2016b). They found that the highest yield of the rice crop was observed when rice and dhaincha were grown at a 2:1 ratio as 20 cm row-to-row spacing. The increase in rice yield under dhaincha green manuring was attributed to greater panicle weight, which was probably due to a continued supply of N following decomposition of added dhaincha OM. The dhaincha green manuring intercropped with direct seeded rice and the conventional practice of before transplanting incorporation of dhaincha green manuring was compared under lowland flood-prone conditions. It was found that the grain yield of direct seeded rice was significantly higher when 20 kg N ha^{-1} was applied at sowing and dhaincha was incorporated at 50 days of growth (Sharma and Ghosh 2000).

Bokhtiar et al. (2003) found that dhaincha and sunn hemp green manuring and supplemented urea increased yield of subsequent sugarcane by up to 57%. Besides this, there was a significant increase in SOM, total N, available P, and S of the soil. Comparison of the relative efficiency of green manures with inorganic N sources by Selvi and Kalpana (2009) revealed that the cowpea green manuring application at 0.17% (3.4 Mg ha^{-1}) and dhaincha green manuring at 0.36% (7.2 Mg ha^{-1}) on a dry matter basis would be more than enough to produce a yield of rice crop equal to that obtained with the application of the recommended dose of fertilizers, i.e., at 80-25-35 kg/ha N-P-K. Further, demonstration of rice grain yield response showed that the cowpea was a better green manure crop than dhaincha mainly for wetland rice. In addition, substantial residual effects of cowpea and dhaincha green crops were also observed and in some cases even up to two to three successive rice crops (Bhuiyan and Zaman 1996; Selvi and Kalpana 2009; Meena 2013).

Pooniya et al. (2012) conducted a field experiments with summer green manuring crops, namely, green gram, cowpea, and dhaincha, it was found that that the highest crop residue was added by dhaincha, i.e., 38.56 Mg ha^{-1}, which in turn led to the recycle of 180.5, 22.6, and 267.8 kg N, P, K ha^{-1}, respectively. Further dhaincha incorporation also led to a significantly higher yield of succeeding basmati rice crop, and it was 2.38%, 4.14%, and 10.82% higher over cowpea, green gram, and summer fallow, respectively.

12.8 Limitations of Legume Green Manuring

In spite of the wide range of literature which reveals associated benefits of legume LGM, its applicability still remains in the research farms. Their adaptation by farmers is still not a common practice due to lack of awareness and some limitations at farm levels. There are few cases to cite. Haryana Government promotes LGM in rice-wheat areas of state. Becker et al. (1995) reviewed several available literatures (Ladha et al. 1992; Ali and Narciso 1993; Garrity and Flinn 1988; Ashoka et al. 2017) and identified the following limitations of green manuring and the possible reasons behind it. They are listed below:

(a) Establishment and incorporation of green manuring crops are relatively costly.
(b) Narrow window period between the two crops for growing and incorporating green manure crops during most of the cropping season.
(c) Green manure crop, if not incorporated at proper growth stage and time, may lead to immobilization of N on a temporary basis.
(d) Being a high water requiring crop, it may not be suitable for dryland agriculture.
(e) Problems of decomposition of green manuring in the sowing of the following crop if proper moisture is not available, particularly in semiarid regions (Aase et al. 1996).
(f) No visible economic benefits are seen during initial few seasons of green legume manuring.
(g) Easy availability of fertilizers and their ease of application in comparison to green manuring.
(h) Prices of mineral fertilizers are relatively low when compared to the high price of land and labor.

12.9 Conclusion

The ever increasing human population poses a burden on soils to produce more food. The intensive use of agrochemicals is threatening the soil sustainability. Use of chemical fertilizers in intensive cropping systems may lead to degradation of natural resources, particularly soils. These degraded soils will not be fit for profitable agriculture. Therefore, incorporation of legume green manure crops into the soil is emphasized for crop production. In ancient times, also legumes were recognized as suitable crops for green manuring to improve soil health and crop productivity. In addition to fixing of atmospheric N, it helps in conservation of soil water and reduction of soil erosion. LGM is to be considered superior over the nonlegume crops due to a higher N content and lower C/N ratio, helping in easy decomposition of OM and mineralization for nutrient release at a faster rate. Besides this, it also reduced the N immobilization risk for succeeding crops. Therefore, practices of LGM have a large scope for inclusion, to make the farming system more sustainable.

12.10 Future Perspectives

Future research for legume green manures is needed on following topics:

(a) The studies across the globe have established the benefits of green manures on soil physicochemical and biological health. However, their application to the farm level is still at a limited stage because of lack of awareness and suitability under particular environments and cropping system.
(b) There is need to develop a location-specific cropping system with compatible legume green manure crop either partly or in the window period between two crops.
(c) Benefits of green legume manure need to be quantified regarding fertilizer saving, water saving, increase in crop productivity, and more importantly soil health improvement, so that the extra cost involved in raising the green manure crop may be justified to the ultimate adapter, the farmers.
(d) Efforts are to be directed to find out alternative techniques like brown manuring of legume crops by growing them as intercropped, which can save time as well as need of incorporation. Such easily acceptable techniques are to be devised.

References

Aase JK, Pikul JP, Prueger JP, Hatfield JR (1996) Lentil water use and fallow water loss in a semi-arid climate. Agron J 88:723–728

Akpor OB, Okoh AI, Babalola GO (2006) Culturable microbial population dynamics during decomposition of *Theobroma cacao* leaf litters in a tropical soil setting. J Biol Sci 6(4):768–774

Ali M, Narciso JH (1993) The perception and reality of GM use in rice: an economic evaluation, IRRI Social Science Division Paper Series. The International Rice Research Institute, Los Bafios, p 42

Anderson IC, Buxton DR, Karlen DL, Cambardella C (1997) Cropping system effects on nitrogen removal, soil nitrogen, aggregate stability, and subsequent corn grain yield. Agron J 89:881–886

Ashoka P, Meena RS, Kumar S, Yadav GS, Layek J (2017) Green nanotechnology is a key for eco-friendly agriculture. J Clean Prod 142:4440–4441

Bah AR, Zaharah AR, Hussin A (2006) Phosphorus uptake from green manures and phosphate fertilizers applied in an acid tropical soil. Commun Soil Sci Plant Anal 37:2077–2093

Becker M, Ladha JK, Simpson IC, Ottow JCG (1994) Parameters affecting residue N mineralization in flooded soils. Soil Sci Soc Am J 58:1666–1671

Becker M, Ladha JK, Ali M (1995) Green manure technology: potential, usage, and limitations. A case study for lowland rice. Plant Soil 174:181–194

Bhuiyan NI, Zaman SK (1996) In: Rahmaned et al (eds) Biological nitrogen fixation associated with rice production. Kluwer Academic Publishers., The Netherlands, Dordrecht, pp 51–64

Bokhtiar SM, Gafur MA, Rahman ABMM (2003) Effects of *Crotalaria* and *Sesbania aculeata* green manures and N fertilizer on soil fertility and the productivity of sugarcane. J Agric Sci 140:305–309

Boparai BS, Singh Y, Sharma BD (1992) Effect of green manure (*Sesbania aculeata*) on physical properties of soil and growth of rice-wheat and maize-wheat cropping system. Int Agrophys 6:95–101

Brar DS, Sidhu AS (1995) Effect of soil water on patterns of nitrogen release during decomposition of added green manure residue. J Indian Soc Soil Sci 43(1):14–17

Brar DS, Sidhu AS (1997) Effect of temperature on pattern of nitrogen release during decomposition of added green manure residue in soil. J Res 34(3):275–278

Broder MW, Wagner GH (1988) Microbial colonization and decomposition of corn, wheat and soybean residue. Soil Sci Soc Am J 52:112–117

Buragohain S, Sharma B, Nath JD, Gogaoi N, Meena RS, Lal R (2017) Impact of ten years of biofertilizer use on soil quality and rice yield on an inceptisol in Assam, India. Soil Res. https://doi.org/10.1071/SR17001

Buresh RJ, De Datta SK (1991) Nitrogen dynamics and management of rice-legume cropping systems. Adv Agron 45:1–59

Cassman KG, Munns DN (1980) Nitrogen mineralization as affected by soil moisture, temperature and depth. Soil Sci Soc Am J 44:1233–1237

Cavigelli MA, Thien SJ (2003) Phosphorus bioavailability following incorporation of green manure crops. Soil Sci Soc Am J 67:1186–1194

Dhakal Y, Meena RS, De N, Verma SK, Singh A (2015) Growth, yield and nutrient content of mungbean (*Vigna radiata* L.) in response to INM in eastern Uttar Pradesh, India. Bangladesh J Bot 44(3):479–482

Dhakal Y, Meena RS, Kumar S (2016) Effect of INM on nodulation, yield, quality and available nutrient status in soil after harvest of green gram. Legum Res 39(4):590–594

Dias-Zorita M, Buschiazzo DE, Peinemann N (1999) Soil organic matter and wheat productivity in the semiarid Argentine Pampas. Agron J 91:276–279

Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA (2002) Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron J 94:153–171

Doran JW, Fraser DG, Culik MN, Liebhardt WC (1988) Influence of alternative and conventional agricultural management on soil microbial process and nitrogen availability. Am J Alt Agric 2:99–106

Ebelhar SA, Giddens JE, Beaty ER (1984) Nitrogen from legume cover crops for no-till corn. Agron J 76:51–55

Eriksen J (2005) Gross sulphur mineralization-immobilization turnover in soil amended with plant residues. Soil Biol Biochem 37:2216–2224

Fageria NK (2007) Green manuring in crop production. J Plant Nutr 30(5):691–719

Fageria NK, Baligar VC (2005) Role of cover crops in improving soil and row crop productivity. Commun Soil Sci Plant Anal 36:2733–2757

Fagodiya RK, Pathak H, Kumar A, Bhatia A, Jain N (2017) Global temperature change potential of nitrogen use in agriculture: a 50-year assessment. Sci Report 7:44928

Fox RH, Myers RJ, Vallis I (1990) The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin, and nitrogen contents. Plant Soil 129:251–259

Franzluebbers K, Weaver RW, Juo ASR, Franzluebbers AJ (1994) Carbon and nitrogen mineralization from cowpea plants part decomposing in moist and in repeatedly dried and wetted soil. Soil Biol Biochem 26(10):1379–1387

Furoc RE, Dizon MA, Morris RA, Marqueses EP (1985) Effects of flooding regime and planting dates to N accumulation of three Sesbania species and consequently to transplanted rice. Paper presented at the 16th annual scientific convention of the crop science Society of Philippines, 8–10 May 1985, Central Luzon State University Munoz, Nueva Ecija, Philippines, 1985

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB, Cosby BJ (2003) The nitrogen cascade. Biol Sci 53:341–356

Garrity DP, Flinn JC (1988) Farm-level management systems for green manure crops in Asian rice environments. In: Sustainable agriculture: green manure in rice fanning. The International Rice Research Institute, Los Baiios, pp 111–129. IRRI, Philippines

Ghai K, Rao DLN, Batra L (1985) Comparative study of the potential of sesbania for green manuring. Trop Agric 62:52–56

Gil JL, Fick WH (2001) Soil nitrogen mineralization in mixtures of eastern gamagrass with alfalfa and red clover. Agron J 93:902–910

Gill MS, Pal SS, Ahlawat IPS (2008) Approaches for sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system in Indo-Gangetic plains of India-a review. Indian J Agron 53(2):81–96

Griffin GJ, Garren KH (1976) Colonization of rye green manure and peanut fruit debris by *Aspergillus flavus* and *Aspergillus niger* group in field soils. Appl Environ Microbiol 32(1):28–32

Hargrove WL (1986) Winter legumes as nitrogen sorghum. Agron J 78:70–74

Harris GH, Hesterman OB, Paul EA, Peters SE, Janke RR (1994) Fate of legume and fertilizer nitrogen-15 in a long-term cropping systems experiment. Agron J 86:910–915

Holderbaun JF, Decker AM, Meisinger JJ, Mulford FR, Vough LR (1990) Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron J 82:117–127

Hu C, Cao ZP, Ye ZN, Wu WL (2006) Impact of soil fertility maintaining practice on soil microbial biomass carbon in low production agro-ecosystem in northern China. Acta Ecol Sin 26:808–814

Hundal HS, Dhillon NS, Dev G (1992) Contribution of different green manures to P nutrition of rice. Indian J Soil Sci Soc 40:76–81

IRRI (1990) World rice statistics. The International Rice Research Institute, Los Bafios, Philippines. 320p

Ishikawa M (1988) Green manure in rice: the Japanese experience. In: Green manure in rice farming. International Rice Research Institute, Los Banos, pp 45–61

Janzen HH, Kucey RMN (1988) Carbon, nitrogen, and sulfur mineralization of crop residues as influenced by crop species and nutrient regime. Plant Soil 106:35–41

Joffe JS (1955) Green manuring viewed by a pedologist. Adv Agron 7:14–187

Kumar V, Prasad RK (2008) Integrated effect of mineral fertilizers and green manure on crop yield and nutrient availability under rice-wheat cropping system in Calciorthents. J Indian Soc Soil Sci 56(2):209–214

Kumar R, Srivastava S, Srivastava M, Sinha A (2010) Effects of organic amendments on soil mycoflora. Asian J Plant Path 4(2):73–81

Kumar R, Mahajan G, Srivastava S, Sinha A (2014) Green manuring: a boon for sustainable agriculture and pest management – a review. Agric Rev 35(3):196–206

Kumar S, Sheoran S, Kumar SK, Kumar P, Meena RS (2016) Drought: a challenge for Indian farmers in context to climate change and variability. Prog Res An Int J 11:6243–6246

Ladd JN, Amato M, Jackson RB, Butler JH (1983) Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biol Biochem 15:231–238

Ladha JK, Watanabe I, Saono S (1988) Nitrogen fixation by leguminous green manure and practices for its enhancement in tropical lowland rice. In: The International Rice Research Institute (ed) Sustainable agriculture: green manure in rice farming. IRRI, Los Banos, pp 165–183

Ladha JK, Pareek RP, Becker M (1992) Stem-nodulating legume-rhizobium symbiosis and its agronomic use in lowland rice. Adv Soil Sci 20:147–192

Lathwell DJ (1990) Legume green manures, Trop Soils Bulletin Number 90-01. Soil Management Collaborative Research Support Program, North Carolina State University, Raleigh

MacRae RJ, Mehuys RG (1985) The effect of green manuring on the physical properties of temperate area soils. Adv Soil Sci 3:71–94

Magid J, Henriksen O, Thorup-Kristensen K, Mueller T (2001) Disproportionately high N mineralisation rates from green manures at low temperatures – implications for modelling and management in cool temperate agroecosystems. Plant Soil 228:73–82

Mandal UK, Singh G, Victor US, Sharma KL (2003) Green manuring: its effect on soil properties and crop growth under rice-wheat cropping system. Eur J Agron 19:225–237

Martens DA, Frankenberger J (1992) Modification of infiltration rates in an organic amended irrigated soil. Agron J 84:707–717

Meelu OP, Furoc RE, Dizon MA, Morris RA, Marqueses FP (1985) Evaluation of different green manures on rice yield and soil fertility. Paper presented at the 16th annual scientific convention of the Crop Society of Philippines, 8–10 May, 1985, Central Luzon State University, Munoz, Nueva Ecija, Philippines

Meena RS (2013) Response to different nutrient sources on green gram (*Vigna radiata* L.) productivity. Indian J Ecol 40(2):353–355

Meena BL, Majumdar SP (2016) Improving yield of barley grown on coarse textured soil by compaction and sulphur fertilization. Ecol Env Cons 22:151–156

Meena BL, Rattan RK, Datta SP (2013) Efficacy of seed treatment in ameliorating iron deficiency in aerobic rice on a calcareous soil. J Indian Soc Soil Sci 61:147–152

Meena BL, Meena RL, Ambast SK, Pandey M (2014) Impact assessment of agriculture technological interventions in tsunami affected South Andaman- a case study. Bharatiya Krishi Anushandhan Patrika 28(3):141–148

Meena RS, Yadav RS, Meena H, Kumar S, Meena YK, Singh A (2015a) Towards the current need to enhance legume productivity and soil sustainability worldwide: a book review. J Clean Prod 104:513–515

Meena VS, Maurya BR, Meena RS (2015b) Residual impact of well-grow formulation and NPK on growth and yield of wheat (*Triticum aestivum* L.). Bangladesh J Bot 44(1):143–146

Meena BL, Majumdar SP, Meena VK, Dotaniya ML (2016a) Response of compaction with sulphur fertilization to nutrient content, uptake and economics of barley on highly permeable soil. Int J Agric Sci 34:1719–1722

Meena BL, Rattan RK, Datta SP, Meena MC (2016b) Effect of iron application on iron nutrition of aerobic rice grown in different soils. J Environ Biol 37:1377–1383

Meena RS, Bohra JS, Singh SP, Meena VS, Verma JP, Verma SK, Shiiag SK (2016c) Towards the prime response of manure to enhance nutrient use efficiency and soil sustainability a current need: a book review. J Clean Prod 112:1258–1260

Meena BL, Rattan RK, Datta SP (2017) Solubility relationships of iron and evaluation of its fertility status in degraded soils. Commun Soil Sci Plant Anal 48:1059–1067

Meena RS, Kumar V, Yadav GS, Mitran T (2018) Response and interaction of *Bradyrhizobium japonicum* and *Arbuscular mycorrhizal* fungi in the soybean rhizosphere: a review. Plant Growth Regul 84:207–223

Misra RD, Gupta VK, Pandey DS (1996) Management crop residues in rice. Int Rice Res Notes 21:71–72

Morris RA, Furoc RF, Dizon MA (1986) Rice response to a short duration green manure. II. Nitrogen recovery and utilization. Agron J 78:413–416

Palaniappan SP (1994) Green manuring: nutrient potential and management. In: HLS T (ed) Fertilizers, organic manure, recyclable waste and biofertilizers. Fertilizer development and Consultation Organization, New Delhi

Palm O, Weerakoon WL, DeSilva MAP, Thomas R (1988) Nitrogen mineralization of *Sesbania sesban* used as green manure for lowland rice in Sri Lanka. Plant Soil 108:210–209

Pandey DK, Pandey R, Mishra RP, Kumar S, Kumar N (2008) Collection of Dhaincha (*Sesbania* spp.) variability in Uttar Pradesh, biodiversity and agriculture (souvenir). Uttar Pradesh Biodiversity Board, Lucknow, pp 48–51

Peoples MB, Herridge DF, Ladha JK (1995) Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production. Plant Soil 174:3–28

Pieters JA (1927) Green manuring, principles and practice. Wiley, New York, p 365

Pooniya V, Shivaya YS, Rana A, Lata N, Radha P (2012) Enhancing soil nutrient dynamics and productivity of Basmati rice through residue incorporation and zinc fertilization. Eur J Agron 41:28–37

Postgate J (1998) Nitrogen fixation, 3rd edn. Cambridge University Press, Cambridge. Proc Indian Natn Sci Acad 80(2):359–378

Pung H, Aird PL, Cross S (2004) The use of Brassica green manure crops for soil improvement and soil borne disease management. 3rd Australian Soil borne diseases Symposium 8–11 February 2004. pp 1–2

Raimbault BA, Vyn TJ (1991) Crop rotation and tillage effects on corn growth and soil structural stability. Agron J 83:979–985

Rao DLN (2014) Recent advances in biological nitrogen fixation in agricultural systems. Proc Indian Natn Sci Acad 80:359–378

Ray SS, Gupta RP (2001) Effect of green manuring and tillage practices on physical properties of puddled loam soil under rice-wheat cropping system. J Indian Soc Soil Sci 49(4):670–678

Reddy PP (2016) Sustainable intensification of crop production. doi:https://doi.org/10.1007/978-981-10-2702-4

Robertson GP, Paul EA, Harwood RR (2000) Greenhouse gases in intensive agriculture: contributions of individual gases to the radioactive forcing of the atmosphere. Science 289:1922–1925

Sainju UM, Singh BP (1997) Winter cover crops for sustainable agricultural systems: influence on soil properties, water quality and crop yields. Hortic Sci 2:21–28

Schumann RA, Meyer JH, Van Antwerpen R (2000) A review of green manuring practices in sugarcane production. Proc S Afr Sugar Technol Assess 74:93–100

Schutter M, Dick R (2001) Shifts in substrate utilization potential and structure of soil microbial communities in response to carbon substrates. Soil Biol Biochem 33(11):1481–1491

Selvi RV, Kalpana R (2009) Potentials of green manure in integrated nutrient management for rice – a review. Agric Rev 30(1):40–47

Sharma AR, Das KC (1994) Effect of green manuring with dhaincha (*Sesbania aculeata*) on growth and yield of direct-sown and transplanted rice under intermediate deepwater conditions. J Agric Sci 122(3):359–364

Sharma AR, Ghosh A (2000) Effect of green manuring with *Sesbania aculeate* and nitrogen fertilization on the performance of direct-seeded flood-prone lowland rice. Nutr Cycl Agroecosyst 57:141–153

Shukla KP, Sharma S, Singh NK, Singh V, Tiwari K, Singh S (2011) Nature and role of root exudates: efficacy in bioremediation. Afr J Biotechnol 10(48):9717–9724

Sihag SK, Singh MK, Meena RS, Naga S, Bahadur SR, Gaurav, Yadav RS (2015) Influences of spacing on growth and yield potential of dry direct seeded rice (*Oryza sativa* L.) cultivars. Ecoscan 9(1–2):517–519

Sikora LJ, Stott DE (1996) Soil organic carbon and nitrogen. In: Methods for assessing soil quality. SSSA Special Publication 49. Soil Science Society of America, Madison, pp 157–167

Singh KN, Bhattacharyya HC (1989) Direct-seeded rice. Published by Mohan Primlani for Oxford and IBH publishing Co. Pvt. Ltd. New Delhi, pp 135–142

Singh Y, Khind CS, Singh B (1991) Efficient management of leguminous green manures in wetland rice. Adv Agron 45:135–189

Singh Y, Singh B, Khind CS (1992) Nutrient transformations in soils amended with green manures. Adv Soil Sci 20:237–309

Sinha A, Kumar R, Kamil D, Kapur P (2009) Release of nitrogen, phosphorus and potassium from decomposing *Crotalaria juncea* L. in relation to different climatic factors. Environ Ecol 27(4B):2077–2081

Smil V (1999) Nitrogen in crop production: an account of global flows. Glob Biogeochem Cycles 13:647–662

Smith MS, Frye WW, Varco JJ (1987) Legume winter cover crops. Adv Soil Sci 7:95–139

SSSA (1997) Glossary of soil science terms. Soil Science Society of America, Madison

Stute JK, Posner JL (1993) Legume cover option for grain rotations in Wisconsin. Agron J 85:1128–1132

Sulieman S, Tran L-SP (2014) Symbiotic nitrogen fixation in legume nodules: metabolism and regulatory mechanisms. Int J Mol Sci 15:19389–19393

Sulieman S, Tran L-SP (2015) Legume nitrogen fixation in a changing environment. Springer International Publishing, Cham, p 35. https://doi.org/10.1007/978-3-319-06212-9_3

Thonnissen C, Midmore DJ, Ladha JK, Olk DC, Schmidhalter U (2000) Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. Agron J 92:253–260

UN DESA (2015) United Nations, Department of Economic and Social Affairs, Population Division (UN DESA), world population prospects: the 2015 revision, key findings and advance tables. Working Paper No. ESA/P/WP.241, United Nations, Department of Economics and Social Affairs, New York

Unger PW, Kaspar TC (1994) Soil compaction and root growth: a review. Agron J 86:759–766

Varco JJ, Frye WW, Smith MS, Mackown CT (1989) Tillage effects on nitrogen recovery by corn from a nitrogen-15 labeled legume cover crop. Soil Sci Soc Am J 53:822–827

Varma D, Meena RS, Kumar S (2017) Response of mungbean to fertility and lime levels under soil acidity in an alley cropping system of Vindhyan Region, India. Int J Chem Stu 5(2):384–389

Verbene EL, Hassink J, Willingen P, Goot JJ, Van Veen JA (1990) Modeling organic matter dynamics in different soils. Neth J Agric Sci 38:221–238

Verma JP, Meena VS, Kumar A, Meena RS (2015a) Issues and challenges about sustainable agriculture production for management of natural resources to sustain soil fertility and health: a book review. J Clean Prod 107:793–794

Verma SK, Singh SB, Prasad SK, Meena RN, Meena RS (2015b) Influence of irrigation regimes and weed management practices on water use and nutrient uptake in wheat (*Triticum aestivum* L. Emend. Fiori and Paol.). Bangladesh J Bot 44(3):437–442

Watanabe I (1984) Use of green manure in northeast Asia. In: International Rice Research Institute (ed) Organic matter and rice. IRRI, Los Banos, pp 229–234

Westcott MP, Mikkelson DS (1987) Comparison of organic and inorganic nitrogen sources for rice. Agron J 79:937–943

Whitbread AM, Blair GJ, Lefroy RDB (2000) Managing legume leys, residues and fertilisers to enhance the sustainability of wheat cropping systems in Australia 1. The effects on wheat yields and nutrient balances. Soil Tillage Res 54(1/2):63–75

Yadav RL, Singh K (1986) Long term experiments with sugarcane under intensive cropping system and variation in soil fertility. Indian J Agron 31:322–325

Yadav GS, Lal R, Meena RS, Babu S, Das A, Bhomik SN, Datta M, Layak J, Saha P (2017) Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping of rice in North Eastern Region of India. Ecol India. http://www.sciencedirect.com/science/article/pii/S1470160X17305617

Ye X, Liu H, Li Z, Wang Y, Wang Y, Wang H, Liu G (2014) Effects of green manure continuous application on soil microbial biomass and enzyme activity. J Plant Nutr 37(4):498–508