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Multiple agroecosystem services of forage legumes towards agriculture sustainability: An overview

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ABSTRACT

Forage legumes are contributing in sustainable crop production apart from nutritional security to the livestock. Forage legumes are crucial for the nutritional security for mankind as they are integral component for increased availability of animal protein and product which has higher biological value compared to plant proteins. The inclusion of forage legumes in crop production systems is more useful as these can not only provide food and feed to animals but also improves soil productivity and act as soil-conserving components of agricultural and agroforestry systems. Production system as a whole and tremendous deficit of forage nutritious resources demand in particular to give some importance to the forage crops especially leguminous forages. Therefore, critical assessment is necessary for determining the direction and magnitude of change in agricultural management practice with inclusions of forage legume. Forage legumes have good capacity as a feed to promote sufficient quantities and qualities required for different productive animals. Therefore, these crops can contribute to achieving the objectives of sustainable food/ fodder and environmental security. Hence, inclusion of legumes forages in cropping system is inevitable in advancing soil sustainability and food and nutritional security without compromising the long-term soil fertility base of the soil resources. Rational soil management practices must involve forage legume-based rotations and intercropping considerations for restoring soil health, and soil sustainability should be given due emphasis. Besides, forage legumes can also provide a wide range of benefits such as restoration of soil fertility, nitrogen fixation and fertilizer saving, enhancement of soil biology and biodiversity, improving soil carbon sequestration and by neutralizing negative impact of climate change. This review summarizes the potential role of forage legume in animal nutrition, soil fertility building, nitrogen fixation, soil biology and biodiversity, carbon sequestration, climate change and other ecological services provided.

Key words: Animal nutrition, Carbon sequestration, Climate Change, Forage legumes, Nitrogen fixation, Soil fertility

India has the largest livestock population in the world with more than 512 million heads (Anonymous 2012). It supports 56.7% of the world's buffaloes, 12.5% of the world's cattle and 20.4% of the world's small ruminants (Anonymous 2018). India is also the leading milk producing country in the world but milk productivity as compared to global is very low (Kumar *et al*. 2016a). India is having 5.4% of the cultivated area under fodder crops which has resulted in a severe deficit of green fodder (36%), dry crop residues (11%) and concentrate feed ingredients (44%) (Hindoriya *et al*. 2019). Lack of fodder/feeds with good quality is one of the major reasons for the low animal productivity (Godfray *et al*. 2010). The quality fodder production is also important in livestock because feed alone constitutes 60-70% of the milk production cost (Kumar *et al*. 2016b). The animals need proper feeding to meet their nutrient requirement to express their full genetic production potential. To feed the ever increasing animal population, the major issue is as how to raise the productivity of forage crops from the available land resources in a sustainable manner without deteriorating the natural resources base (Kumar and Agarwal 2013), maintaining the sustainability of production system and quality of soil and environment

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(Sachs *et al*. 2009). The above job further severely affected due to other challenges such as water insufficiency, land deprivation, biodiversity shortfall (bio-physical), fast human population growth, poor nutrition, poverty and health care, poor infrastructure and socio-economic circumstances (Thornton 2010). Hence, under this state of affairs, we require to give some significance to the forage crops especially legume forage crops as we are facing a tremendous deficit of forage resources (Christiansen *et al*. 2015). The adoption of improved package of practices has a great significance in improving the productivity of quality crop production (Kumar 2012, 2013, 2014a). Substantial attention has developed in current decades for these crops as they are known to improving crop and animal output in addition to sustaining soil quality (Louhaichi and Tastad 2010). The modification in management practices and inclusion of forage legume as well, can improve physical, chemical and biological soil quality parameters and for this reason considerably affect the agricultural system productivity (Fig 1).

There are 17000 species of legumes globally, out of them approximately 1500 species can be used as feed for domestic animals, however only about 60 species of forage legumes have been developed and widely used as cultivated forages (Schultze *et al*. 2018). Legume forage has a wide range of species from short-lived annuals to long-lived permanent trees and small herbaceous species to large woody species (Joshi *et al*. 2009) (Table 1). The forages legumes are used as a source of livestock forage in the form of cut and carry system and grazing as by the animals in pastures. In nutrition of dairy animals, inclusion of legumes in animal diet makes the feed balanced as well as digestible. Like other legumes forage legumes also have the potential to fix atmospheric nitrogen that distinguish them from other plants taking into consideration the soil quality improvement. In addition, forage legumes can also provide a wide variety of important soil quality remuneration, viz. increasing soil organic matter, improving soil porosity, recycle nutrients, improve soil structure, decreasing soil pH, diversifying the microscopic life in the soil, and breaking disease build-up and weed problems of grass-type crops (Mahanta *et al*. 2009). The majority of the forage legumes have hard-hitting tap roots that open deep pathways into the soil. Nitrogen-rich forage legume residues augment earthworms. Forage legumes can provide a large number of benefits to both the soil and other crops grown in mixture with them or following them in a rotation. Locally adapted forage legumes can be used in almost any conservation situation to improve soil quality. In this chapter an attention is given to highlight these forage legumes as feed animal sources, improvements in forage quality and indirect effects of forage legumes on soil quality, soil biology, soil fertility, carbon sequestration and agricultural sustainability (Ghosh *et al*. 2014).

Nutritional profile of forage legumes

Chemical composition is an important indicator of nutritive value since the availability of nutrients from forages is variable. Nutritive value is an affair of the feed intake (FI) and the efficiency of drawing out of nutrients from the feed during digestion (digestibility). Feeds of high nutritive value encourage high levels of production (weight gain). Feed intake in livestock consuming fibrous forage is primarily

Table 1 List of important forage legumes alongwith their centre of origin and distribution

Genus	Species	Centre of origin	Distribution
Atylosia	*scarabaeoides*	India	Tropical and subtropical world
Centrosema	*pubescens*	South America	South east Asia and Africa
Clitoria	*ternatea*	Tropical America	Tropical and subtropical parts of the world
Desmanthus	*virgatus*	Argentina	Florida, throughout the India
Desmodium	*intortum*	Central and South America	Throughout Africa, Australia and new world
Macroptilium	*atropurpureum*	Central and South	Australia, South east Asia, Pacific Islands
Macroptilium	*lathyroides*	India	Tropical and subtropical world
Macrotyloma	spp.	Africaand Asia	Sri Lanka
Macrotyloma	*uniflorum*	India	Africa
Stylosanthes	*guianensis*	Brazil	West Indies, Africa and Pacific Islands
Stylosanthes	*hamate*	Islands of WestIndies	Coastal regions of north and south America
Stylosanthes	*humilis*	Brazil	Tropical parts of world
Stylosanthes	*scabra*	Tropical America	Kenya, Brazil and Queensland
Stylosanthes	*seabrana*	Brazil	Africa and PacificIslands
Lablab	*purpureus*	Asiaor Africa	India, subtropical areas of Africa, south Asia
Cyamopsis	*tetragonoloba*	Africa	India
Trifolium	*alexandrinum*	Syria	Egypt
Medicago	*sativa*	Asia Minor	Near East and centralAsia

Adopted from: Trivedi (2002)

determined by the level of rumen fill, which in sequence, is directly related to the rate of digestion and passage of fibrous particles from the rumen (Huhtanen *et al*. 2016). The palatability of a feed has been related to both physical characteristics and the presence of compounds which may affect taste and appetite for example proteins, fats and soluble carbohydrates. Modern concepts of feed evaluation require that quality be assessed in terms of the capacity of a feed to supply nutrients in proportions balanced to meet particular productive functions (Dumont *et al*. 2014). In most part of universe the nutrition of dairy animals is poor due to one or other reasons and feeding the livestock with such poor quality forages they may suffer from micro nutrient deficiency, which ultimately affects their reproductive and production efficiency. Legume forages if included in feeding schedule can provide solution to micronutrient deficiency. It is important because of differences in cation exchange capacity of cereals and legume crops, as the later have higher cation exchange capacity which leads to higher accumulation of multivalent micro nutrients in them. Further, better palatability and digestibility are important nutritive character and inclusion of forage legumes makes the forage more palatable and digestible. Productive livestock require protein and carbohydrates in balanced ratios and this combination is better produced from a mixture of cereals and legume forages (Kumar *et al*. 2016).

From a standpoint of animals, the prime benefit of the legume forages is that they provide greater nutrition compared with cereal forages/grasses at similar stage of crop growth resulting in better forage intake by livestock and improved animal performance (Table 2). The legume forage contains higher crude protein (CP) than cereals/ because of the higher supply of N to legumes by symbiosis between legume and Rhizobium. Besides higher concentrations of CP, leguminous forages also provide a better quality protein which may be more useful for non-ruminant livestock species like equines (Singh *et al*. 2018). Ginwal *et al.* (2019) reported that intercropping of leguminous fodder crops (cowpea and clusterbean) with fodder maize improved the fodder quality over sole maize.

Legume forages also have more digestible energy in comparison of grass/cereal forages. Indeed, the cell wall of legume plants contains rarer hemicelluloses and more pectin compared with cereals, consequently increasing their digestibility by livestock. As and when a cell matures, the overall availability of the structural carbohydrates in the digestive system is declined because of the cellulose and lignin (from secondary cell wall) is deposited on the interior of the primary cell wall. This sensation occurs only in vascular tissues of legume stems, whereas it occurs in all tissues types (i.e. leaves, stems, etc.) in cereal. Along with this, lignin of non-legumes/cereal forages is also more esterified to hemicelluloses and is more recalcitrant in composition (e.g. higher proportion of syringyl subunits) representing a more suppressed degradability as compared to legume species.

Role of forage legumes in agricultural sustainability

Soil sustainability refers to long term maintenance of soil fertility and productivity which enhances crop production over the period of time. Legumes (Grain/forage) releases nitrogen from decomposing leaf, roots and nodules which results to enhanced soil fertility and productivity, therefore they have immense potential to improve soil sustainability (Cherr *et al.* 2006). The important role of legumes include enhancement in soil organic carbon, soil restoration and fixation of nitrogen which positively affects the production of succeeding crop in rotation and soil sustainability (Dhakal *et al*. 2016). Forage legumes like *Stylosanthes, Crotalaria, Sesbania, Desmodium* etc. because of their soil covering growth habit can be used in mitigation of soil erosion problem (Singh *et al*. 2018) and forage legume such as *Stylosanthes hamata* can be used to ameliorate compacted soil (Lesturguez *et al*. 2004). Sustainable agriculture incorporates the principles of limited use of outside inputs and minimum soil disturbance; the cultivation of forage legumes also implies both of these principles. Production of legumes in a pasture involves minimum disturbance of top soil which results into lower rate of erosion and over a period of time build up the soil organic carbon and humus.

Table 2 Nutritional profile of some of the important forage legumes

Forage legumes	CP (%)	NDF(%)	ADF (%)	ADL (%)	EE (%)	Ash (%)
Atylosia scarabaeoide	17.21	64.10	44.36	6.44	7.80	2.00
Centrosema pubescens	18.90	55.40	39.50	8.50	7.60	2.50
Clitoria ternatea	21.30	53.30	37.50	9.10	9.90	3.00
Desmanthus virgatus	19.10	49.70	37.70	10.20	9.30	1.90
Dolicho sbiflorus	17.20	64.10	44.30	6.40	7.80	2.00
Lablab purpureus	18.40	44.60	32.00	7.20	11.10	2.60
Macroptilium atropurpureum	19.10	49.70	37.70	10.20	9.30	1.90
Stylosanthes hamate	15.90	51.60	40.10	9.10	8.10	2.60
Stylosanthes scabra	12.30	55.20	38.10	8.80	7.20	2.10
Stylosanthes seabrana	18.50	47.49	34.10	11.50	7.91	1.36

Adopted from: Trivedi (2002)

Further, forage legumes enhance the soil nitrogen status by fixing atmospheric nitrogen with the help of rhizobium bacteria which resides into the root nodules of these crops. Hence incorporation of forage legumes in a system makes the system more sustainable.

Forage legumes and agroecosystem

Forage legumes like red and white clover, alfalfa etc. found in a wide range of semiarid agroecosystem of the world (Corre-Hellou *et al.* 2006). Further, legumes contribute to reduce the emission of greenhouse gases, as they release 5–7 times less GHG per unit area compared with other crops; allow the sequestration of carbon in soils and induce a saving of fossil energy inputs in the system. Legumes could also be competitive crops and, due to their environmental and socioeconomic benefits, could be introduced in modern cropping systems to increase crop diversity and reduce use of external inputs in a particular agroecosystem (Stagnari *et al*. 2017).

Forage legumes and crop productivity

Intensive agriculture mainly relies on the use of chemical fertilizers and pesticides along with good irrigation practices. However, it is evident that over long term basis, application of fertilizers will not sustain the crop yield and soon after started of intensive agriculture, it manifest production systems with falls in productivity. Therefore, inclusion of legume crops in cropping system plays a key role in sustaining soil fertility and operates it at higher productivity level (Das and Ghosh 2012). Legumes are the potential source of nitrogen (Lascano and Peters 2007) and it becomes available after decomposition of residues which results into improved soil and crop productivity. Among the annual leguminous fodder, cowpea (Rathore *et al*. 2015, Mallikarjun *et al*. 2018), clusterbean (Pandey *et al*. 2018) and berseem are important fodder crops in India due to its short duration, quick growing habits, good in protein content and productivity along with higher palatability particularly to ruminants.

Forage legumes and crop rotations

Forage legumes offer an alternative way to meet the nutritional requirements of crops in rotation. Hence, these crops are helpful in reducing the second generation problems in India which caused due to long term use of single cropping system/crop rotation with cereal-cereal (Rice-wheat) in a particular region. Leguminous forage crop such as berseem can fix the atmospheric nitrogen and converts it to useable parts of plant. This fixed nitrogen not solely used by the berseem crop but it also enhanced the production of sequent crops in rotation. Singh *et al.* (1997) and Prasad *et al.* (2011) reported that yield of rice and other succeeding crops increased significantly after leguminous crops as compared to other crops. Kumar (2014b) reported the enhanced yield of mustard grown in succeeding years after the cultivation chickpea crop for 5 consecutive years. Zia *et al.* (1997) reported that rice-wheat cropping system is highly nutrient exhausting system and over long term basis it causes the deficiency of both macro and micro nutrients which leads to poor soil fertility. As per the principles of crop rotation a restorative crop must be included in an exhaustive system so that the fertility level of soil maintained (Sher *et al*. 2016). Hence, inclusion of leguminous forage like berseem in rice-wheat cropping system fulfills the fodder requirement and increase in yield of succeeding crops beside this, it also improves soil fertility, reduces nitrogenous fertilizer demand, enhances water holding capacity and reduces the weed problems (Singh *et al*. 1997). The yield of rice crop was increased by 10.53% when sown after berseem compared to the rice sown after wheat, whereas, yield of wheat increased by 7.92% when sown after berseem as compared to wheat sown after rice (Sher *et al*. 2016). Stylosynthes helped in building up of soil fertility, which was reflected by better plant growth and enhanced yield when sorghum was taken after stylosanthes (Gosh *et al*. 2008).

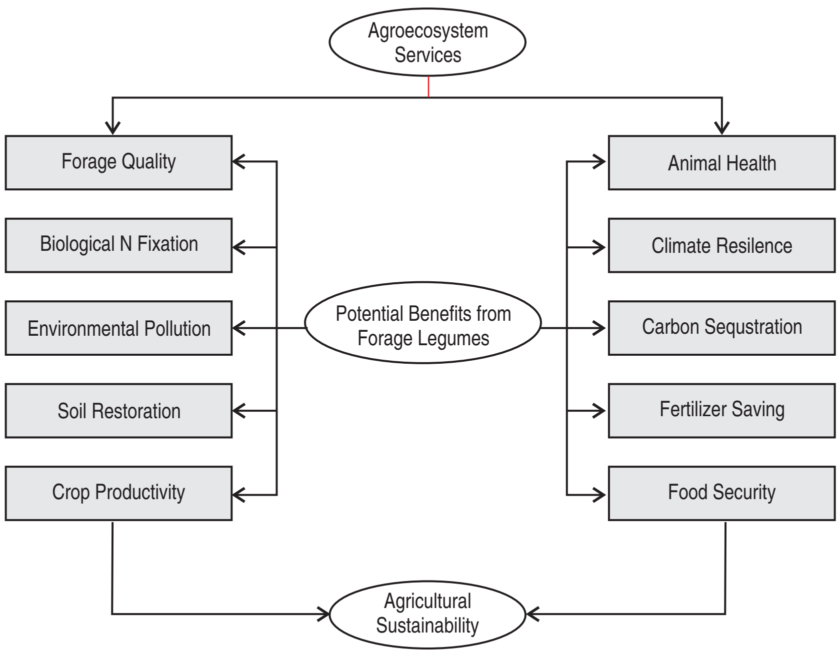

Fig 1 Flow diagram showing multiple agro-ecosystem services of forage legumes to agricultural production system.

Forage legumes and soil conservation

Forage legumes play a key role in maintaining natural resource base through soil stabilization, reduced soil degradation and by preventing soil erosion particularly in small and marginal areas. Leguminous forages generally used as live mulches due to their ability to fix nitrogen through rhizobia and restorative and protective value of these organic mulches are very well known (Lal 1984). Leguminous crops like stylosanthes showed improved soil physicochemical and biological properties. Leguminous forage acts as a cover crop and improved soil bulk density and soil moisture retention which gave better protection against erosion (Lal *et al*. 1978 and Wilson *et al.* 1982). Annual and perennial legumes reduce soil erosion by enhancing infiltration rate and by reducing surface runoff. Further, living parts and residues of legume protect the soil surface from the impact of falling raindrops, reduces pore blockage and reduces the velocity of runoff (Hargrove and Frye 1987). Roots and shoots residues after decomposition increase organic carbon, water stable aggregates and macroporosity hence it enhances water infiltration and soil water retention (Rasse *et al.* 2000).

Forage legumes and intercropping

Intercropping is mainly practised by the small and marginal farmers because it provides maximum profit with minimum risk. Intercropping has also several advantages, viz. flexibility in planting and sowing time, maintenance of soil fertility, soil conservation, nutritional benefit and weed control. Intercropping of cereals with legumes is generally practised in dry land tracts of India (Singh *et al.* 1990). Forage legume in intercropping enhanced the total productivity of the soil as well as crop through the process of biological nitrogen fixation. Intercropping of perennial legumes is generally considered as an effective way for forage production because it offers higher yield and yield stability, reduces weed problem and enhanced the protein content within a mixed diet with higher land use efficiency (Anil *et al.* 1998). Tamta *et al.* (2019a) reported that intercropping of fodder cowpea with maize improved the growth, dry matter yield as well as farm profitability over fodder maize alone. The maximum crude protein, ether extract, ash content and lowest NDF, ADF and ADL of maize and cowpea, respectively were achieved from maize + cowpea (1:2) (Tamta *et al*. 2019b).

Lithourgidis *et al*. (2011) observed that in maize-alfalfa intercropping system incidence of soil-borne take all disease pathogen was reduced. Zougmore *et al*. (2000) reported that runoff losses of soil reduced significantly in sorghum-cowpea intercropping system. Study of maize and cowpea intercropping revealed that at low nitrogen level, the content of nitrogen was higher in intercropped maize as compared to sole maize (Francis 1986).

Forage legumes and soil health

Legumes acts as soil amendments and have positive effect on soil health (Hauggaard-Nielsen *et al.* 2007). Forage legumes have potential to bind the soil aggregates with organic matter after decomposition of their residues hence these recognized as the soil building crops. Incorporation of legume residues in the soil enhanced the soil pH it might be due to decomposition and mineralization of organic residues by micro-organisms which resulted into increased soil pH (Macharia *et al*. 2011). As a result of higher soil pH or less acidic condition nutrients such as carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur etc. became available for plant use (Miles and Manson 2000) and it provides a favourable soil environment for plant growth.

Soil physical properties

Forage legumes are much more effective in improving soil physical properties because of their large and deep root system, longer growth period and greater capacity for nitrogen fixation, improve the soil structure by binding soil particles into aggregates and form more pore space. Hence, as a result of this soil become more friable, less erosive and hold more water. Forage legume (Alfalfa) drains excess water from the soil due to deeper penetration of their roots and thus it also reduces the salinity problems. Lesturguez *et al*. (2004) reported that due to deep root system of *Stylosanthes hamata* it could be used to ameliorate compacted soil. Inclusion of forage legume in the cropping system as a green manure increases the organic matter in the soil which increases the stability and distribution of the soil aggregates and decreases the bulk density (McRae and Mehuys 1988). Above and below ground plant materials of alfalfa improved the soil physical properties (Angers and Caron 1998). Rasse *et al.* (2000) showed that alfalfa root and shoot mulch modify the soil physical properties and water movement in the soil through increased saturated hydraulic conductivity, total porosity and macro porosity of the soil.

Soil chemical properties

Decomposition and mineralization of organic residues from forage legumes affect the favourable soil pH and nutrient balance which definitely influence the chemical properties of soil. Legumes added atmospheric nitrogen and high quality organic matter into the soil which favorably affect C/N ratio. Deep rooted legumes facilitate the nutrient solubilization by root exudates and enhance their uptake as well as water infiltration into the soil (Stagnari *et al*. 2017). Incorporation and decomposition of legumes as a green manure has a solubilizing effect on both macro (N, P and K) and micro (Zn, Fe, Mn and Cu) nutrients in the soil (Saraf and Patil 1995). Soil analysis at beginning and end of introduced forage legume experiment revealed that soil pH, carbon, nitrogen and potassium increased while calcium decreased significantly from the soil by end of the experiment. In this experiment the higher soil pH was probably due to addition of leaf litters and decay of roots and nodules by legumes (Macharia *et al.* 2011). Decomposition and mineralization process released the nutrients from the organic residues and it enhanced due to increased microbial activities which accelerated by favourable soil condition and carbon availability (Landon 1984, Muriuki and Qureshi 2001).

Soil biological properties

The biomass and diversity of microorganism in the soil are good indicators of soil quality. Legumes contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Legumes also foster production of a greater total biomass in the soil by providing additional N (NRCS-USDA 1998). The diversity and activity of microorganism in the soil largely depends on soil-plant-management factors (Wei *et al*. 2008, Ngosong *et al*. 2010). Inclusion of legume in cropping system favours the microbial activities in the soil because rhizo deposits of legumes are higher in substrate quality with low carbon/ nitrogen ratio (Nair and Ngouajio 2012). Increased microbial population and activity in the soils containing alfalfa might be due to release of better quality substrate from alfalfa roots as compared to grasses (Dhakal and Islam 2018). Alfalfa roots secrete the good quality substrate with low carbon/ nitrogen ratio which increases the total microbial, bacterial and actinomycetes activities in the soil (Chen *et al*. 2008).

Leguminous forage option for carbon sequestration

Carbon plays a widespread role in many chemical processes and considered as one of the fundamental building block of life on the planet. Inclusion of legumes forages in cropping systems depending upon the agro-climatic conditions in order to create a positive soil carbon budget in the soil is an important strategy for SOC/terrestrial sequestration (Wright *et al*. 2004). The mixture of legume species with pasture increases the production of below and aboveground biomass which in turn serve the purpose of soil carbon sequestration by ensuring a higher soil C pool (Lynch *et al*. 2005, Chan *et al*. 2011). The C balance should be favorably changed by enhancing the chemical complexity, quantity, and quality of carbonic substance being added in soil to compensate the C losses from microbial attack or decomposition (Kumar *et al*. 2018). Moreover, inclusion of forage legumes in pastures or rotating with crops results in net C sequestration helps maintains SOC stocks, or simply slows the rate of loss of SOC compared to continuously cropped soils will be influenced by the prevailing climatic condition effects on C inputs and C loss processes, and the frequency or duration of the pasture phase (Chan *et al*. 2011). The effects of forage legumes on SOC are associated with the lower losses of C from their organic residues than from annual legumes as a result of a lower soil water content maintained under perennials reducing microbial activity and respiratory losses of the organic C (Sarkar *et al*. 2018), and higher potential inputs of C due to the capacity of perennials to respond to rainfall and grow outside an annual's normal growing season (Coonan *et al*. 2019).

Legume forage for mitigating the climate change

Agriculture is highly sensitive to climate change, i.e. the changes in temperatures and precipitation patterns, increased frequency of extreme weather events, and water availability (Altieri *et al*. 2015). Climate change has profoundly affected human societies and natural environment global warming by changing the atmospheric concentration of greenhouse gases (GHGs) like methane, carbon dioxide, and nitrous oxide (IPCC 2007). It is well known fact that production of each kg of ammonium nitrate using Haber–Bosch process needed a significant quantity of energy (58 MJ) and also emits a large quantity greenhouse gases in the form of N_2O (8.6 kg CO_2 equivalents) (Boulamanti and Moya 2017). Moreover, application of every 100 kg of nitrogenous fertilizers known to emitted 1.0 kg N_2O, a greenhouse gas having 300 times more global warming potential than CO_2 (Campbell *et al*. 2017). Inclusion of forage legumes in grasslands and cultivated forages reduces N_2O emissions (Fig 2) due to i) symbiotically fixed N within the nodules of legumes is not freely available in the soil in a reactive form, ii) in grass–forage legume based mixtures, the grass components take up nitrogen derived from legume and from mineralization of soil organic matter. Jensen *et al*. (2012) suggested that annual N_2O emissions were largest (449 kg N_2O ha^{-1}) in N-fertilized grass swards compared to mixed grass–forage clover swards (54 kg N_2O ha^{-1}). These authors concluded that the N_2O emissions induced by the growth of legume crops/forages may be estimated solely as a function of the above-ground and below-ground N inputs from crop/ forage residue during pasture renewal. Emissions of N_2O from legumes do occur as a result of the decomposition of residues from leguminous plants, but the magnitude of such emissions remains uncertain (Volpi *et al*. 2016).

Carbon dioxide based industrial production of each kg of inorganic N resulted in emission of 225 kg of CO_2. Legumes offer a big advantage because the entire C needed for symbiotic N_2 fixation comes directly from the atmosphere via. photosynthesis and, thus, they are considered to be 'greenhouse gas neutralizers'. A further option to mitigate CO_2 emission by C sequestration into the soil. Fresh C can only be introduced into the soil via photosynthesis by plants, and the C:N ratio of soil organic matter is fairly constant in almost all soils (Jensen *et al*. 2012). Consequently, C sequestration into soil organic matter ultimately means sequestration of N into soil organic matter (80 kg N t^{-1} of C). Current evidence suggests that humus formation is particularly limited by the availability of N (Christopher and Lal 2007). This again points to the importance of legumes (forage/grain) and their symbiotic N_2 fixation for coupling C and N cycles and for delivering the N needed to sequester C into soil organic matter. Data from a large survey of soil organic matter (Arrouays *et al*. 2001), and models (Soussana *et al*. 2004), show that the conversion of short-term N-fertilized grass leys into grass–forage legume mixtures could sequester C into soil organic matter. Indeed, several studies found higher soil organic matter contents under grass–forage legume mixed swards than under pure grass swards (Mortensen *et al*. 2004).

Forage legumes and fodder quality

Legumes improve nutritive value and voluntary intake which consequently influence the livestock production. In comparison of the perennial ryegrass (*Lolium perenne* L.), lucerne and clover (white and red clover) contains higher CP and minerals such as calcium, but are relatively poor in of water-soluble carbohydrates. INRA (2007) reported that white clover has more organic matter (OM) digestibility, net energy concentration and supply of metabolizable protein

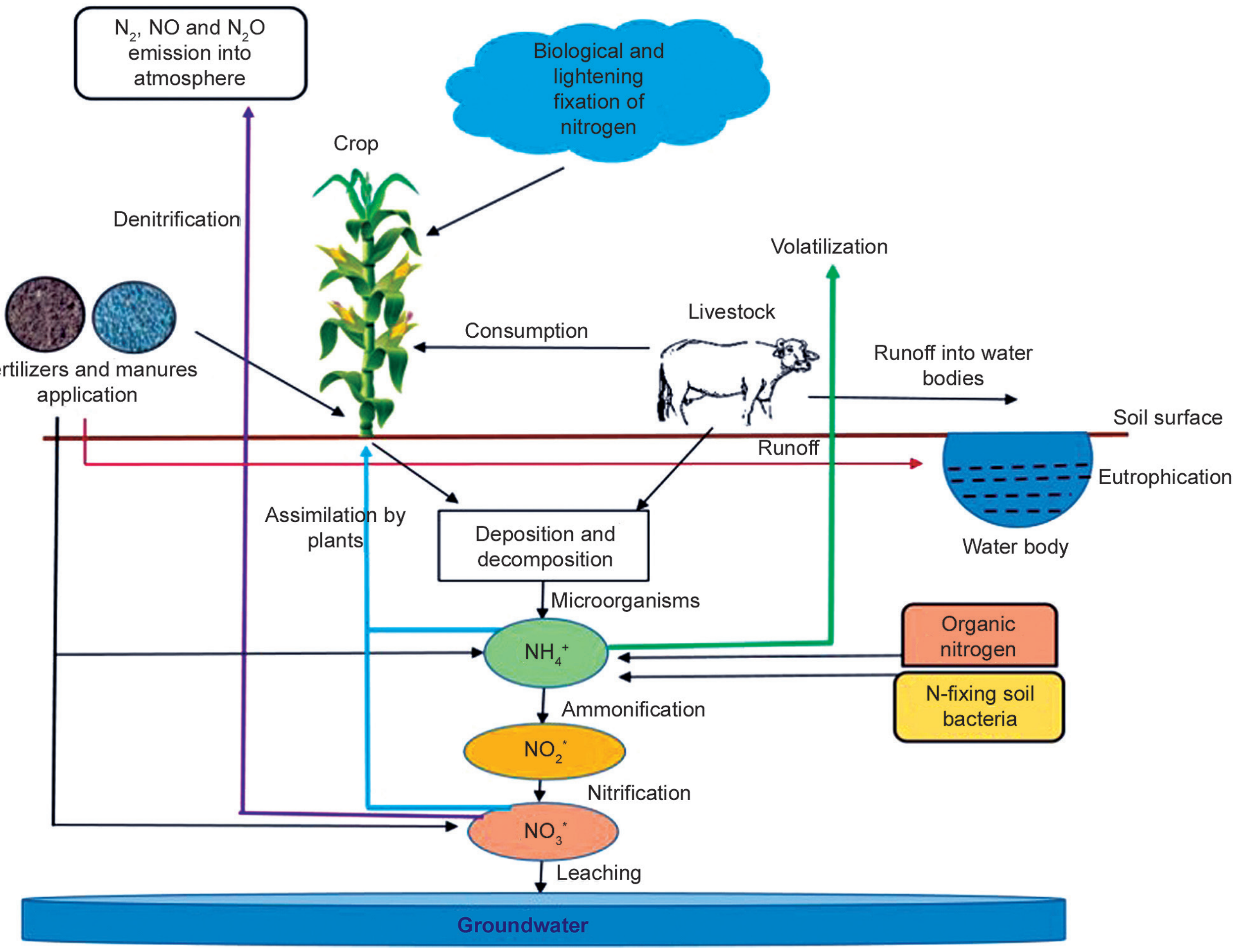

Fig 2 Global nitrogen cycle in relation to the crop production system (modified from Luce *et al*. 2011).

Please check legends

than grasses. INRA (2007) revealed a comparison among legume forages that white clover again has more net energy concentration (7.17 MJ kg^{-1} DM) than red clover (6.10 MJ kg^{-1} DM) and alfalfa (5.54 MJ kg^{-1} DM). The feeding of fresh legume forages is always better in terms of net energy concentration and metabolizable protein content. These values are further reduced in silage and hay. However, metabolizable protein could be maintained in hay making but is reduced during silage formation.

Voluntary intake is expressed as g DM kg^{-1} of metabolic weight. Voluntary intake of legume forage is 10-15% greater than that of grasses (INRA 2007) owing to the lower resistance of legumes to chewing, a faster rate of digestion and particle breakdown and clearance from the rumen (Waghorn *et al*. 1989, Jamot and Grenet 1991, Steg *et al*. 1994, Dewhurst *et al*. 2009), which in turn reduce rumen fill. Compared to the perennial rye grass, DM intake of silage made up of white/red clover by cow is two to three times higher (Dewhurst *et al*. 2003). White clover is usually mixed with perennial ryegrass; the optimal proportion of white clover in the forages for housed dairy cow was 60% for maximum DM intake as reported by Harris *et al*. (1998). Herbage intake by grazing livestock generally depends on nature of pasture. Alder and Minson (1963) reported that herbage intake was 15-20% higher with sole lucerne compared with sole cocksfoot.

Ribeiro-Filho *et al*. (2003) have reported a higher rate of intake of mixed white clover-perennial ryegrass compared with sole perennial ryegrass pastures. Ulyatt (1970) studied many years and reported that rate of decline in nutritive value for white clover throughout the plant-ageing process is much lower than for grasses. Ribeiro-Filho *et al*. (2003) reported higher reduction of DM intake of grass sward herbage (20 kg d^{-1}) compared with mixed grass–clover swards (08 kg d^{-1}). Goyal and Tiwana (2016) reported that the addition of cowpea in corn and alfalfa in oats considerably increased the CP, ash content, pH value, NH_3-N and total digestible nutrients of silage mixtures over sole corn and oats and the fermentation characteristics of silage also improved with corn+cowpea (75:25) and oats+alfalfa mixture (75:25) compared with the other combination. Undersander *et al*. (2009) reported that decline in nutritive value which occurs with advancement in maturity could be minimized with low-lignin lucerne cultivars.

Forage legumes and animal performance

It was reported that dairy cow fed with pea + barley produced higher milk as compared to fed with barley alone

(Skovborgand Kristensen 1988). Dalgliesh *et al*. (2010) also showed the importance of legumes fodder in performance of animals and reported that animals fed with forage legumes gained live weight at a rate of 230 g/day compared with 290 g/day when fed leucaena.

Since legumes are difficult to conserve, therefore, special care must be taken to ensure better silage quality and to reduce leaf losses while hay making (Arnaud *et al*. 1993). Increasing the total non-structural carbohydrates (TNC) concentration in legumes that can be attained by cutting legumes during afternoon when sugar content is at its maximum level, will absolutely aid in the production of high-quality silages and improve the animal performance (Pelletier *et al*. 2010, Morin *et al*. 2011). Results based on the experiments carried out by Ribeiro-Filho *et al*. (2003) revealed that milk yield of cow was increased by 1-3 kg day^{-1} when dairy cows are allowed to graze on a pasture sward containing higher content of white clover. On the other hand, Gately (1981) reported that milk yield is reduced when the proportion of clover is low (<20%). The growth rates of growing cattle are relatively similar when grazing these types of pasture; however, a slightly better growth rate of lambs was recorded when they allowed to graze on mixed grass–legume swards supported compared with fertilized grass swards (Speijers *et al*. 2004). Since very low inputs are required to manage the white clover + grass mixed pasture, therefore, their biomass production might also be lower as compared to heavy fertilized grass pastures. Humphreys *et al*. (2009) also reported the lower milk yields and live-weight gains per hectare from mixed pastures in comparison of sole perennial ryegrass pastures. Guckert and Hay (2001) revealed the probable reasons behind the preference of sole grass swards by many farmers was the troubles in maintaining well-balanced grass + legume mixtures and their affinity to lose key species.

Conclusion

Forage legumes have tremendous use as feed of human and animal, as wood, and as soil improving constituents of agriculture system and agro forestry. Legume forage has the ability to fix atmospheric nitrogen (N) useful in soil quality improvement. Nevertheless forage legume are significant in enhanceing the soil organic matter their prominence for soil fertility for their N fixation. A major role of forage legume is enhanced biodiversity and enrichment of soil carbon. Enhancing C sequestration in the soil is linked to increased biomass and hence to soil fertility. Moreover, forage legumes are also most promising crops for providing a wide range of soil improvement by improving biological, chemical, and physical properties, processes, and their interactions. These improvements in soil health through inclusion of forage legumes also advance food and nutritional security while improving the environment. Forage legume-based agronomic practices advance environmentally sustainable and economically viable crop yields in rotations. However, long-term and multi-disciplinary research efforts are required to assess the effects of these forage legumes on different soils under diverse and changing climatic conditions on soil quality, agronomic productivity, and environment quality.

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