3 Grain Legumes for Resource Conservation and Agricultural Sustainability in South Asia

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Contents

3.1 Introduction 79
3.2 Crop Diversification with Grain Legumes 82
3.3 Grain Legumes for Restoration of Soil Health 84
3.3.1 Biological Nitrogen Fixation 84
3.3.2 Nutrient Recycling 85
3.3.3 Soil Health Improvement 87
3.4 Grain Legumes for Water Economy 89
3.5 Weed Smothering Effects of Grain Legumes 90
3.5.1 Crop Rotation 90
3.5.2 Intercropping 91
3.5.3 Cover Crop 92
3.5.4 Pulse Crop Residues and Allelopathy 93
3.6 Grain Legumes in Conservation Agriculture 93
3.6.1 Reduced Tillage 93
3.6.2 Water Saving 94
3.6.3 Crop Residues 94
3.6.4 Crop Diversity 95
3.7 Higher Productivity and Sustainability 95
3.8 Grain Legumes in Rice Fallows 97
3.9 Grain Legumes for Ecosystem Services 98
3.10 Way Forward 100
References 102

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R. S. Meena et al. (eds.), *Legumes for Soil Health and Sustainable Management*,
https://doi.org/10.1007/978-981-13-0253-4_3

Abstract

Degradation of natural resources is a major environmental concern that threatens the agroecosystem health and food security in South Asian countries. About 1.8 billion people (24% of world population) are living in this region in an area of 5.03 km^2. The higher population pressure on agricultural land (7 person ha^{-1}) has further threatened the existing resources to a great extent. Thus, conserving natural resource base is essential to feed the burgeoning population. Continuous practice of cereal-cereal rotation including rice-wheat in Indo-Gangetic plains have emerged several soil- and environmental-related issues. Diversification of cereal-cereal cropping systems is warranted to mitigate those issues and to adapt to the changing climatic condition and to enhance the resource-use efficiency on a sustainable basis. Grain legumes are the suitable candidate crop for diversification because of its inherent capacity to build up soil health and in conserving natural resources. There exists a large scope to introduce pulses as the second crop in 22.2 million hectare areas of rice fallows in India, Bangladesh, and Nepal. System intensification with inclusion of mungbean in summer fallows of rice-wheat cropping system could add an additional pulse crops area of 1.0 m ha in Indo-Gangetic plains. Several alternative grain legume inclusive crop rotations have been identified for the different agro-zones that certainly could play an important role in popularizing the conservation of agriculture in cereal-dominated production systems of South Asia. Endowed with an inherent potential biological N-fixation (30–150 kg N ha^{-1}), of the deep root system, the root exudates mediated P-solubilization, and nutrient-rich residues of grain legumes improve the soil fertility and enhance the soil profile nutrient cycling. Crop diversification with grain legumes has additional benefits associated with improving water productivity, reducing input cost, and minimizing incidence of diseases and pests. Besides this, the low application rate of the N fertilizer to grain legumes has the advantage of reducing greenhouse gas emissions and groundwater pollution. Thus, grain legumes would play a crucial role in resource conservation, ecosystem balance, and in the sustainability of agricultural systems of South Asia.

Keywords

Conservation agriculture · Crop diversification · Nutrient cycling · Resource conservation · Rice fallow · South Asia · Sustainability

Abbreviations

@	At the rate of
AM	Arbuscular mycorrhiza
BNF	Biological nitrogen fixation
C	Carbon
CA	Conservation agriculture

CEY	Chickpea equivalent yield
cm	Centimeter
DNA	Deoxyribonucleic acid
DTPA	Diethylenetriaminepentaacetic acid
g	Gram
GHG	Greenhouse gas
IGP	Indo-Gangetic plains
ka	Hectare
kg	Kilogram
kj	Kilojoule
km	Kilometer
m	Million
mg	Milligram
mm	Millimeter
N	Nitrogen
NW	Northwest
P	Phosphorus
PEY	Pigeonpea equivalent yield
RCTs	Resource conservation technologies
SOC	Soil organic carbon
SOM	Soil organic matter
t	Tonne
Tg	Teragram
VAM	Vesicular-arbuscular mycorrhiza
w/w	Weight/weight

3.1 Introduction

Grain legumes are considered as the second most important group of food crops after cereals. Developing nations contribute about three-fourth to the global grain legume production, and the remaining one-fourth comes from developed nations. In 2014, the global grain legume production was 85.2 million tonnes from an area of 77.5 million hectares with an average yield of 909 kg ha^{-1}. India not only contributes maximum (around 25–28%) to the total global grain legume production but also largest consumer in the world. The total grain legume production in South Asia is 22.3 million tonnes from an area of 33.7 million hectares and with a yield of 660 kg ha^{-1}. India, Pakistan, Bangladesh, Nepal, and Afghanistan are the major grain legume-producing countries in South Asia with a relative share of 89.7%, 3.1%, 1.8%, 1.4%, and 0.3%, respectively (Table 3.1) (FAOSTAT 2014). The chickpea (*Cicer arietinum* L.) contributed the maximum (about 34.1%) to South Asia grain legume production followed by dry beans (30.6%), pigeonpea [*Cajanus cajan* (L.) Millsp.] (16.1%), lentil (*Lens culinaris* Medikus) (6.9%), and dry peas (3.7%) (Table 3.2).

Table 3.1 Area, production, and yield of grain legumes in South Asian countries and world (2014)

Countries	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
India	30309.0	19980.0	659
Pakistan	1358.6	682.2	502
Nepal	292.5	310.5	1062
Bangladesh	277.3	395.2	1425
Afghanistan	79.8	60.0	752
Sri Lanka	17.4	21.7	1251
Maldives	0.16	0.100	870
Total, South Asia	33708.4	22257.7	660
Total, world	85191.5	77473.1	909

Source: FAOSTAT 2014

Table 3.2 Area, production, and yield of major grain legumes in South Asia (2014)

Crop	Area (million hectare)	Production (million tonnes)	Yield (kg ha^{-1})
Chickpea	11.49	10.55	919
Beans, dry	10.3	4.56	442
Pigeonpea	5.62	3.31	589
Lentil	2.32	1.58	681
Peas, dry	1.26	0.84	667
Cowpeas, dry	0.011	0.015	1327
Total grain legumes	33.71	22.26	660

Source: FAOSTAT 2014

Grain legumes, belonging to the family Fabaceae, are a wonderful gift of nature to mankind. They provide not only nutritious food, feed, and fodder but also help in conserving the natural resources and maintain ecological balance. The cultivated legumes can be classified as grain legumes [chickpea, lentil, peas (*Pisum sativum* L.), grass pea (*Lathyrus sativus* L.), faba bean (*Vicia faba* L.), French bean (*Phaseolus vulgaris* L.), pigeonpea, urdbean (*Vigna mungo* (L.) Hepper), mungbean (*Vigna radiata* (L.) R. Wilczek), cowpea (*Vigna unguiculata* (L.) Walp.), moth bean (*Vigna aconitifolia* (Jacq.) Marechal), horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.), etc.], oilseed legumes [soybean (*Glycine max* (L.) Merr.) and groundnut (*Arachis hypogaea* L.)], vegetable legumes [peas, faba bean, cowpea, French bean, cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.), winged bean (*Psophocarpus tetragonolobus* (L.) D.C.), etc.], forage legumes [cowpea, berseem (*Trifolium alexandrinum* L.), lucerne (*Medicago sativa* L.), cluster bean, etc.], and range legumes [stylo (*Stylosanthes* spp.), siratro (*Macroptilium atropurpureum* (DC.) Urb.), etc.].

Grain legumes are the rich source of dietary protein. Other than proteins, these are an imperative source of the 15 essential minerals required by human beings. The sustenance estimations of seeds of grain legumes are high giving out 1040 to 1430 kJ calories per 100 g (Singh 2015). The protein content (20–28%) in grain legumes is twofold than that of most cereals and, however, is generally inadequate in sulfur-containing amino acids such as methionine and cystine. Proteins of cereal grains are poor in lysine but are higher in sulfur-containing amino acids. Therefore, the combination of grain legumes and cereals provides all essential amino acids (comparable with milk protein) in right proportionate required in a balanced human diet (Singh 2015; Meena et al. 2015a). The utilization of grain legumes minimizes the danger of assortment of chronic degenerative sicknesses, for example, cancer, obesity, diabetes, and cardiovascular diseases (Patterson et al. 2009). Grain legumes are likewise rich in dietary fiber, complex sugar, starch, and various vitamins and minerals, viz., folate, potassium, selenium, and zinc. In addition, a wide assortment of non-nutritive bioactive constituents, for example, catalyst inhibitors, phytic acid, lectins, phytosterols, phenols, and saponins, are available in grain legumes which have well-being defensive impacts (Champ 2002). The antioxidant and DNA protective properties of phytic acid (Phillippy 2003), antioxidant, and other vital physiological properties of phenolic compounds (Yeh and Yen 2003) and hypocholesterolemic impacts and anticancer action of saponins (Shi et al. 2004) are well documented.

Degradation of natural resources is an important environmental issue that debilitates the biological system well-being and in the sustenance of security around the world. The overexploitation of natural resources (soil and water) leads to a decrease in response to applied agricultural inputs, for example, tillage, fertilizer, water, inter-cultivation, and pesticides. Prior to the 1960s, different kinds of grain legumes were the important parts of crop rotations in the South Asia. The "green revolution" dating from the 1960s has increased the area and production of food grain crops, mainly rice and wheat which met the food demand of the ever-increasing population of South Asia. This has brought an imbalance in production between the different groups of crops, particularly the grain legumes which relegated from fertile areas to poor and marginal lands under rainfed farming. The maximum gain in area and production due to the green revolution in South Asia is recorded in wheat which increased from 25.9 million a hectare and 22.9 million tonnes during 1965 to 50.8 million a hectare and 140.9 million tonnes during 2014, respectively. However, the area and production of grain legumes during the 1960s to 2009 remained almost stagnant. The continuous practice of the exhaustive rice and the wheat production system over the last six decades has resulted in many problems which have restricted the ability of these resources to produce the level matching future food grain requirement of the country. The deteriorating production and sustainability of the cereal-based systems are evident from either stagnation or decline in the yield and factor productivity of rice and wheat due to an undesirable decline in soil physical environment and excessive mining of essential plant nutrients from soil (Yadav et al. 1998a; Timsina and Connor 2001). The overexploitation of groundwater for the irrigation of rice and wheat has crossed the natural ability to recharge itself in many parts of South Asia. In recent years, a growing deceleration in total factor productivity and deterioration of soil health under the cereal-based cropping system has necessitated for diversification of existing cropping systems (Yadav 1998; Buragohain et al. 2017). Thus, enhancing and sustaining the natural resource base is of paramount importance.

Endowed with a unique ability for biological N fixation (BNF), having a deep root system, low water requirements, and capacity to withstand drought, grain legumes constitute an important component of crop diversification and help to alleviate the detrimental effect of monoculture of cereal-based cropping systems. Thus, grain legumes can be an important source to reverse the detrimental effect of rice and wheat production systems and contribute to accomplishing the twin objectives of enhancing system productivity and sustainability of cereal-based cropping systems in South Asia (Yadav et al. 1998). Thus, the present chapter deals with the role of grain legumes in enhancing resource-use efficiency and sustainability of existing cereal-based cropping systems in South Asia (Tables 3.1 and 3.2).

3.2 Crop Diversification with Grain Legumes

The lack of crop diversity is one of the fundamental causes for several soil, environment, and pest problems, which are now increasingly being evident from different agro-regions of South Asia (Chauhan et al. 2012; Congreves et al. 2015). Indeed, with advancement in irrigation facilities and higher accessibility to the farm inputs, a large number of farmers have inclined toward cereals, which in turn aggravated the second-generation problems (Kerr et al. 2007). Therefore, in order to address the negative issues associated with continuous cereal-based systems, the diversification/intensification of conventional cropping systems could be a strategic option in achieving the production sustainability (Njeru 2016). Crop diversification is essentially an important component of profitable and sustainable agriculture (Hatfield and Karlen 1994). Inclusion of pulses/grain legumes in the cropping system is an age-old practice (Ghosh et al. 2007). Endowed with the inherent potential of a deep root system, BNF, and most importantly complementary with cereals and other non-legume crops, grain legumes could essentially serve in a key role in crop diversification/intensification in different production systems (Hazra et al. 2014; Meena et al. 2017). Presently, conservation agriculture (CA) is increasingly being advocated for cereal-based cropping systems of South Asia (Jat et al. 2014). Among the three major principles of CA, crop rotation particularly with grain legumes has been strongly recommended as a “missing ingredient” for restoration of soil health and resource conservation (Snapp et al. 2002). In general, grain legumes are thought to be less profitable than cereal crops. In view of this, von Richthofen et al. (2006) anticipated that grain legume inclusive rotations could fetch similar or higher economic returns when compared with non-legume-based rotations.

To date, several short-term as well as long-term effects of grain legume crop/s in different cropping systems have been documented, which are mostly optimistic in terms of productivity and soil fertility (Ganeshamurthy 2009). Long-term inclusion of grain legumes like mungbean, pigeonpea, and chickpea in the conventional maize-wheat system of subtropical Indo-Gangetic plains (IGP) can improve soil health, particularly the soil organic carbon (SOC) (Venkatesh et al. 2013). They also specified that grain legume crops can improve both the soil labile and non-labile fractions of soil organic C. Likewise, Ghosh et al. (2012) reported similar results from lowland ecosystem of Indo-Gangetic plains (IGP), where the intensification of the rice-wheat cropping system with cultivation of the mungbean during summer (April–May) has resulted in an improved SOC. A similar positive effect of growing summer mungbean in rice-wheat system on SOC was previously reported in *mollisols* and *inceptisols* of IGP (Saraf and Patil 1995; Ghosh and Sharma 1996). Likewise, every year and alternate year, substituting of wheat crop with chickpea in the rice-wheat system has been recommended to minimize the fertilizer input and irrigation requirement and at the same time maintain the total system productivity in subtropical IGP conditions (Hazra et al. 2014; Verma et al. 2015). In fact, the favorable effect of grain legumes in crop rotation is mainly associated with an improved soil health and higher accessibility of plant-available nutrients in the soil (Hazra et al. 2014; Ghosh et al. 2006). The effect of grain legumes was found to be more prominent where nutrient-rich grain legume residues are returned to the soil for an extensive period. Apart from the above ground crop residues, the progressive decomposition of leftover legume roots can enrich the soil N-pool equivalent to ~40 kg N ha^{-1} (Singh et al. 2005).

Besides this, inclusion of grain legumes in cropping systems is the need of the hour for several regional interests. For instance, in Northwestern India, the continuous practice of intensively irrigated rice-wheat cropping systems led to over-exhaustion of groundwater and developed secondary salinization and deteriorated the soil's physical conditions, which eventually made the system unsustainable and less productive over the years. To cope up with this situation, short-duration pigeonpea is now being advocated in the place of rice for this region to curtail the demand for irrigation water (Kumar et al. 2016). Presently, the demand for grain legumes is rising rapidly; and to meet the growing demand, more area should be dedicated for grain legume cultivation. The mungbean cultivation in summer fallows of irrigated cereal-based cropping system offers an immense scope to practice an "ecologically intensive" cropping system (Sharma et al. 2000b; Venkatesh et al. 2015; Dhakal et al. 2016). The short-duration heat-tolerant mungbean crop can be easily accommodated after the winter crop in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L), maize (*Zea mays* L.)-wheat, rice-potato (*Solanum tuberosum* L.), rice-chickpea, and rice-mustard (*Brassica* spp.) cropping systems of IGP, where assured that irrigation facilities were available. Likewise, in IGP conditions, chickpea is emerging as a potential alternative for wheat. Cropping systems such as rice-rajmash-summer mungbean, rice-lentil, rice-field pea, rice-wheat-mungbean in lowland, pigeonpea-wheat, and maize-wheat-mungbean in upland have been found promising under irrigated conditions (IIPR 2009). Nonetheless, the appropriate agro-techniques and short-duration varieties have to be developed for a higher adoption of grain legumes in these new niches. Apart from these, a large area of South Asia including India and Bangladesh is kept fallow after growing of the rainfed rice crop due to lack of irrigation facilities. In these rice fallows, grain legumes like lentil, chickpea, lathyrus, and mungbean (peninsular India) can be grown as secondary crop with appropriate soil moisture conservation practices and manipulating cultivation practice of both rice and pulse crops (Ghosh et al. 2016; Kumar et al. 2016a; Ali et al. 2014). This way, in the near future, certainly grain legumes would play a very important role toward utilizing untrapped niches and in improving sustainability of the cereal-dominated cropping systems.

Given the advantage of higher economic return, soil health maintenance, weed control, and less risk, intercropping is very popular in the areas of smallholding farmers (Ghosh et al. 2007). Grain legumes are the important candidate crop for intercropping, and several grain legumes inclusive of intercropping systems have been found highly productive and less competitive with the component crop. Some of the potential grain legume inclusive intercrop systems are pigeonpea + sorghum (*Sorghum bicolor* L.), pigeonpea + maize, soybean + pigeonpea (Ghosh et al. 2006), sugarcane (*Saccharum officinarum*) + lentil, potato + rajmash, chickpea + mustard, linseed (*Linum usitatissimum* L.) + lentil (IIPR 2009), etc. Intercropping of early pigeonpea with groundnut (5:2), chickpea + wheat/barley (2:1), and chickpea + mustard (6,2) is some of the potential grain legume-based intercropping system under irrigated conditions (Ali 1992; Ali 2004; Ali et al. 2012). Similarly, spring planted sunflower + mungbean/urdbean intercropping also became popular in some parts of Northern India (Ali et al. 1998). Mungbean (variety PDM 11 and PDM 84–143) and urdbean (variety DPU 88–31) intercropping with spring-planted sugarcane has been found promising under irrigated condition (Panwar et al. 1990). In the dry lands of subtropical India, pearl millet is grown extensively, and different grain legumes, viz., green gram, black gram, castor (*Ricinus communis* L.), cowpea, and groundnut, can be accommodated as intercrops (Ghosh et al. 2007; Ram and Meena 2014).

3.3 Grain Legumes for Restoration of Soil Health

3.3.1 Biological Nitrogen Fixation

Grain legumes have been utilized since time immemorial as an essential N source across the world. Mainly in South Asia, the winter grain legumes like lentil, chickpea, faba bean, and field pea are the major source of protein in human diets. Grain legumes are used in agribusiness since they improve the profitability and sustainability of agriculture. The most important being the ability to fix N by biological fixation. After carbon and water, N is the most imperative constraining elements for the development of plant and yield of crops (Vance 1997; Peoples et al. 1995). Young (1992) stated that the three groups of microorganisms are able to fix N_2 in beneficial interaction with plants: the nodule-forming organisms (*Rhizobium*, *Azorhizobium*, *Allorhizobium*, *Mesorhizobium*, *Sinorhizobium*, and *Bradyrhizobium*), the actinomycetes (Frankia), and the *Cyanobacteria* (*Nostoc*, *Anabaena*).

The contribution of N is the most ordinarily watched essential advantage of leguminous crops. Part of fixed N by leguminous crops is utilized by the succeeding crop; thereby the N fertilizer requirement decreases in the succeeding crop (Reeves 1994). Grain legumes are moderately high in protein content. This can be specifically credited to the capacity of grain legumes to supply the vast majority of its own N needs with the assistance of advantageous *Rhizobia* microbes living in their roots. Grain legumes fix 30–150 kg N/ha depending upon the rhizobial population, host crop, management level, and ecological conditions. The N fixation amount by legumes is quantified to a great extent by the hereditary capability of the crops and by plant accessible N rate in the soil. *Rhizobium* and *Bradyrhizobium* are responsible for symbiotic N fixation in grain legumes. The *Rhizobium* is quickly developing acid-releasing microbes, whereas the *Bradyrhizobium* is a slow grower that doesn't deliver acid to the soil (Brady and Weil 2002). Soil determinants, for example, temperature, moisture, and pH further decide the N fixation limit of grain legume crops. The amount of N released by the leguminous crops in the soil is adequate to make desired yield level of succeeding non-leguminous crops, while higher N requiring crop, for instance, the corn, by and large need supplemental N. Frye et al. (1988) suggested in such crops, N rates could be cut down evidently while keeping up the expected crop yields. Moreover, Peoples et al. (1995) reported that in agriculture systems about 90 to 140 Tg N $year^{-1}$ is supplied through biological N fixation (BNF). However, more checks on these values are necessary; most evidences proved that the BNF contributes more N than addition of synthetic N fertilizers for plant development. Usually, BNF provides 50–60% of the N uptake by grain legumes, 55–60% of the N in N-fixing trees, and 70–80% of the N uptake by leguminous pastures.

3.3.2 Nutrient Recycling

Grain legumes being hardy and having low input requirement offer a tremendous opportunity toward effective utilization of resources. Further, given the unique characteristics of the BNF, it has potential to establish itself with surface broadcast and soil fertility restoration property, and grain legumes can be best suited for resource savings. The N-sparing and synergistic effects of grain legumes are well recognized. The intrinsic N-fixing capacity of the grain legume crops enables them to meet the large proportion of their N requirement and also helps in economizing N in succeeding non-legume crops. In sequential crop involving grain legumes, the preceding grain legume crop may contribute 18–70 kg N ha^{-1} to soil, and thereby a considerable amount of N can be saved in succeeding crops. In rice-wheat rotation the growing of short-duration mungbean in summer may bring up N economy up to 40–60 kg N ha^{-1} in the succeeding rice crop. The N economy due to preceding pigeonpea over sorghum was found to be 51 kg N equivalent ha^{-1}. The effect of *rabi* (winter) grain legumes on yield and N economy in following rice revealed that chickpea, rajmash, and lentil exhibited a most favorable effect in economizing N to the extent of 40 kg ha^{-1} (IIPR 2009).

Grain legumes can recycle soil profile nutrients because of their deep root systems bringing about a more proficient utilization/recycling of applied nutrients and reduce the loss of soil nutrients especially nitrate underneath the root zone. The quantity of C and N provided by roots of grain legumes crop can be critical for enhancing the soil's organic matter (Sainju et al. 2005; Verma et al. 2015a) and thus

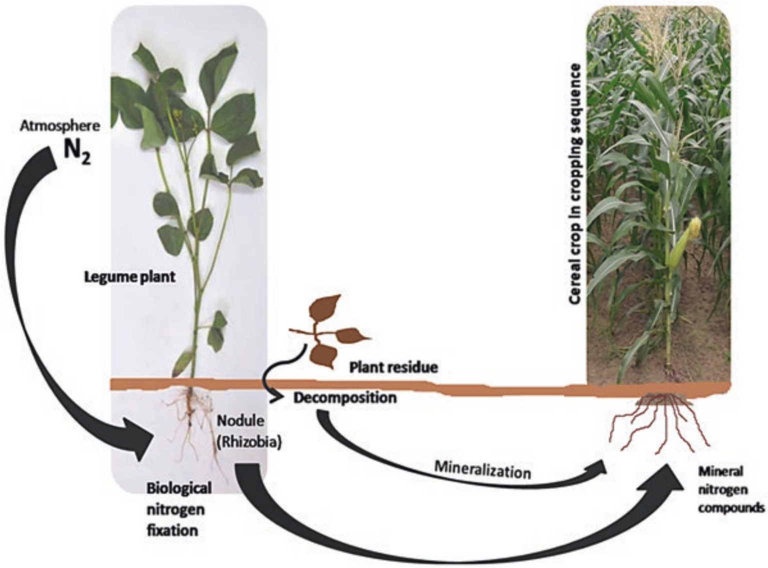

Fig. 3.1 Benefits of grain legumes inclusive cropping systems

improving nutrient recovery. The healthy and profuse root framework may have a predominant role in soil C and N cycles and may impact soil organic C and N levels than the above ground plant biomass. The legume crops have been accounted for to decrease the potential for NO_3 draining from farms (Staver and Brinsfield 1990). Meisinger et al. (1998) reported that grain legumes minimize the concentration of NO_3 by 20 to 80% in leachate over control of (non-leguminous crops). Grain legume crops store the inorganic soil N in between two principal crop seasons in an organic form, thereby reducing the NO_3 leaching. The N is along these lines discharged to the succeeding crop (Fig. 3.1). The association of grain legumes with vesicular-arbuscular mycorrhiza (VAM) helps in increasing the availability of nutrients and water to crop plants. Grain legumes add organic matter through leaf fall, root biomass, and easily degradable crop residues. Grain legumes also release organic acids into the soil (Fageria et al. 2002), in this manner mobilizing inaccessible soil nutrients. It is notable that acidification of the rhizosphere can solubilize a few low solvent macronutrients and micronutrients. For example, root instigated rhizosphere chemical changes have been accounted for to expand accessibility of P to pigeonpea (Ae et al. 1990). Roots of this plant discharge piscidic acid, which chelates Fe and in this manner free a portion of the firmly bound soil P. Henceforth, pigeonpea is effectively developed in P inadequate tropical soils. Grain legumes having a high biomass and more root exudates may contribute a noteworthy amount of C stock in the subsurface layer, along these lines increasing the C sequestration.

3.3.3 Soil Health Improvement

3.3.3.1 Soil Physical Properties

Grain legumes are true component crops in the cereal-dominating cropping systems of South Asia for enhancing soil physicochemical and biological properties. Wilhelm et al. (2004) revealed that the significance of soil organic matter (SOM) in enhancing soil productivity and sustainability is notable. Legume crops enhance SOM which balance out soil aggregates, make the soil easily cultivable, and increase air circulation, soil water holding, and buffering limits. Further, SOM breakdown delivers accessible nutrients to plants. SOM ties the primary soil particles in the aggregates, physically and chemically, and thus increases the stability of the soil aggregates and limits their breakdown amid the wetting procedure (Lado and Ben-Hui 2004). According to Tisdall and Oades (1982), roots and hyphae are the major binding agents for macroaggregates (>0.25 mm), while humic compounds promote microaggregate (<0.25 mm) formation. Frey et al. (1999) reported that the length of fungal hyphae ranged from 19 to 292 mg g^{-1} soil and was 1.9 to 2.5 times higher in grain legume system than over no legume system. Due to more rhizosphere activity and rhizo-deposition, macroaggregates are gradually bound together by temporary (i.e., fungal hyphae and roots) and transient binding agents (i.e., microbial and plant-derived polysaccharides). Crop rotations that included grain legumes are generally beneficial to aggregate stability and formation of a favorable soil structure. The fungi present in the grain legume crop rhizosphere produce a glycoprotein called "glomalin." The sticky part of glomalin entraps soil mineral, organic matter, and debris to form stable soil aggregates. Hence, the microbial activity of rhizosphere is directly responsible for the improved soil structure in crop rotations involving grain legumes. In a long-term rotational experiment, a higher percentage of soil aggregates exceeding 0.25 mm was recorded where the preceding crop was a legume (Sharma et al. 2000a; Meena et al. 2014). The narrow C/N ratios of grain legume residues fasten their decomposition and improve SOM, thereby impacting soil aggregations and lessen soil bulk density. Ganeshamurthy et al. (2006) reported that inclusion of mungbean in rice-wheat system resulted in lower bulk density and higher hydraulic conductivity. The improvement in overall soil physical parameters under grain legume inclusive cropping systems is also recorded in two sets of long-term study in sandy loam (*Typic Ustochrept*) soil of the Indo-Gangetic Plain (Kumar et al. 2012).

3.3.3.2 Soil Chemical Properties

Chemical properties impacted by grain legume crops are the soil pH, nutrient accessibility, exchange capacity, etc. Grain legume crops have the ability to reduce the pH of soil in the rhizosphere and make microenvironment favorable for nutrient availability. Since grain legumes acquire a greater part of their N requirement from the air as diatomic N rather than from the soil as NO_3, their net effect lowers the pH of

Table 3.3 Effect of cropping systems and nutrient management on soil fertility

Treatments	Soil organic C (%)	Avail. N (kg ha^{-1})	Avail. P_2O_5 (kg ha^{-1})	Avail. K_2O (kg ha^{-1})
R-W	0.35c	258.9c	18.1c	222.9c
R-C	0.38b	272.5b	20.7ab	237.9b
R-W-R-C	0.37bc	266.6b	19.2b	238.0b
R-W-M	0.42a	286.3a	21.1a	262.2a

R rice, *W* wheat, *C* chickpea, *M* mungbean

the soil. Among grain legumes, chickpea reduces the pH most followed by pea and pigeonpea (Singh et al. 2009). It was also reported by Singh et al. (2009) that significant amount of organic residues is added through grain legume crops to the soil in the form of root biomass and leaf litters. Roots and leaf litters being rich in N facilitate fast decomposition of crop residues in soil and increase microbial activity. The grain legume crop residues may change relatively unavailable nutrients P in organic forms to available P to succeeding crops. For example, lupine can retain more P than most other grain legume crops from soil testing low in phosphorus (Braum and Helmke 1995). On decay, natural P in the cover crop tissues could give a labile sort of P to succeeding crops. Soil biological and chemical properties are intimately related in controlling of soil tilth. Soil microorganisms assume a significant role in keeping up soil quality on account of their involvement in nutrient recycling through the breaking down of organic matter and nutrients stock. Inclusion of legume in cropping system not only economizes the N requirement of cropping system but also helps in the efficient utilization of native phosphorus due to secretion of certain acids that help in solubilization of various forms of phosphorus. This capacity of the legumes makes them efficient in native utilization of phosphorus present in different forms. Increased availability of P is a result of P acquisition from insoluble phosphates through root exudates. Chickpea has the ability to access P normally which is not available to other crops by mobilizing sparingly soluble Ca-P by acidification of rhizosphere through its citric acid root exudates in Vertisols, and pigeonpea have been characterized for dissolution of Fe-P in Alfisol (Ae et al. 1991). Long-term incorporation of grain legumes in rice-wheat and maize-wheat systems altogether enhances SOC and accessible N, P, K, S, and DTPA-extractable Zn and in this manner expanded the nutrient take-up by cereal component crops. Long-term cultivation of mungbean enriched the SOC by 12.0 and 12.5% in maize-wheat and rice-wheat rotation, respectively, proposing the significance of fallow management for SOC management in tropics (Table 3.3). Considering the relative efficiency in SOC management, the crop rotation was found in the order of maize-wheat-mungbean > pigeonpea-wheat > maize-wheat-maize-chickpea > maize-wheat (Venkatesh et al. 2013).

3.3.3.3 Soil Biological Properties

Living soil organisms contribute less than 0.5 percent (w/w) of the total soil mass, yet they play a significant role in agroecological sustainability by influencing several soil properties and processes that directly or indirectly affect crop yields. Many researchers have demonstrated that soil microbial activities are related to the soil physicochemical properties. Soil microbial community structure, size, and functions are highly dynamic and are greatly influenced by soil properties, crop management, and nature of crops grown. Grain legumes may give great natural conditions for the growth and development of soil microorganisms. The soil microbial biomass is the living portion of the soil that includes basically microorganisms and parasites, including soil microfauna and green growth (Kumar and Goh 2000). The enzymatic activity in the soil is generally a product of magnitude of microbial population in soil, being gotten from intracellular, from cell-related, or from free mixes. The symbiotic association of *Rhizobium* and arbuscular mycorrhizal (AM) with roots of grain legumes increases N and phosphorus availability in soil for plant use. This is attributed due to fixation of atmospheric N by root nodulating Rhizobium bacteria and through enzymatic activities of the AM fungi. The grain legume crops boost the dehydrogenase, urease, protease, phosphatase, and β-glucosidase reactions in the soil. Inclusion of grain legumes in rice-wheat and maize-wheat systems has shown altogether enhanced soil biological properties (soil microbial biomass C and dehydrogenase activity) in a long-term study (Venkatesh et al. 2013; Dhakal et al. 2015). Thus, realizing the significance of soil microorganisms in terms of agroecological sustainability and crop productivity, nowadays, and soil biological parameters are included as important indicators toward determining the soil health.

3.4 Grain Legumes for Water Economy

Presently, the increasing water scarcity is a potential threat for crop production. Given the higher water use efficiency, grain legumes are always a preferred choice under water-limited conditions (Siddique et al. 2008). Water requirement of grain legumes is lower than cereals (Table 3.4). Global water consumption by cereals is reported to be about 60% as against 4% in grain legumes. Grain legumes have the ability to use water more efficiently than other crops due to their morphological and physiological features. Due to their deep root system, grain legumes are able to extract moisture from a deeper layer of soil profile thereby having the ability to thrive well under rainfed situations. Thus, including grain legumes in the cropping system could substantially reduce the irrigation water requirement and thereby

Table 3.4 Water requirement of grain legumes and cereal crops

Kharif/summer crop	Water requirement (cm)	Rabi crops	Water requirement (cm)
Urdbean (summer)	22–30	Chickpea	12–21
Mungbean (summer)	20–35	Lentil	10–12
Urdbean (kharif)	6–12	Field pea	12–14
Mungbean (kharif)	12–15	Rajmash	20–25
Pigeonpea	16–23	Wheat	30–45
Rice	100–220		
Maize	25–40		

curtails the production cost. A higher emphasis should be directed to design the climate resilient and low-input sustainable cropping systems involving grain legumes as a key component. In parallel, identification of stress-tolerant genotypes can further improve the water productivity. Pala et al. (2007) have compared wheat-wheat, wheat-chickpea, and wheat-lentil production systems in Mediterranean water-limited condition. They found that wheat-lentil production system had higher water productivity followed by wheat-chickpea and was least in case of wheat-wheat system. On the same line, Timsina and Connor (2001) suggested that grain legumes can be included in rice-wheat cropping system of IGP for upscaling water and nutrient use efficiency of the rotation. Besides this, it was found that adoption of the drip irrigation in pigeonpea and pigeonpea-based intercropping system improves the water productivity (Verma et al. 2015b; Praharaj et al. 2017). In general under subtropical climates like in IGP, *rabi* grain legumes like chickpea and lentil need only one irrigation, whereas wheat crop required five to six irrigations. Therefore, the problem of groundwater depletion commonly observed in rice-wheat regions of Indo-Gangetic plains could be reversed by replacing one of the cereal crops by pulse crop. Crop management strategies like laser land leveling and ridge furrow planting enable the crop to efficiently utilize the rainfall water and thus further improve the water use efficiency in dryland areas.

3.5 Weed Smothering Effects of Grain Legumes

Weeds are always a major constraint in the agricultural production system. It is perceived that existence of some weeds in fields can be helpful to the crop as it gives sustenance and living space to a wide range of agriculturally important organisms. However, weed population above critical threshold limits can adversely affect the crop productivity and quality of produce. Therefore, weed control has become imperative in arable crop production. The major emphasis of weed management strategies is to maintain weed populations below threshold level through a scope of cultivation methodologies all through the turn, which implies that immediate control activities inside the individual product have a more noteworthy guarantee to get success. It is critical to contemplate weeds as a component of the biodiversity of the agroecosystem, so weed control strategies should include their management rather than eradication. There is an extensive variety of weed control techniques, and consideration of grain legumes in crop rotation is a wise option to maintain weed population below the threshold level. Grain legumes manage the weeds in a particular situation as (i) crop rotation/diversification, (ii) cover crops, (iii) intercrop, and (iv) crop residues and through allelopathy.

3.5.1 Crop Rotation

Grain legumes in a crop rotation are key determinants for the levels of weeds in a system and affect the relative dominance of various weed species. The advantages of crop rotation rely upon the determination of crops and their order in a rotation.

Constant development of a solitary crop or crops having same cultivation practices permits certain weed species to end up plainly predominant in the framework, and, after some time, these weed species turn out to be difficult to control. For example, *Phalaris minor* Retz. has become a menace in the cereal-dominating cropping systems of South Asia (Brar 2002). Likewise, Chauhan and Johnson (2010) reported that weedy rice *(Oryza sativa* L.) is turning into a major weed issue in rice monoculture in Southeast and South Asia. Hence, crop rotation is critical with crop having an alternate developmental behavior. The fallow period between two main crops can be utilized by grain legumes to smother weeds. Replacing one rice crop in rice-rice-rice or rice-rice system with a grain legume in the dry season may altogether help in diminishing the seed bank of weedy rice in the soil. Extremely reassuring outcomes have been found in decreasing the weedy rice seed bank in a rice-rice-rice systems in Vietnam (Chauhan et al. 2010) when rice in dry season was supplanted by mungbean. In India, from a long-term experiments reported that (Kumar and Singh 2009; Hazra et al. 2012) incorporation of grain legume can minimize the pervasion of *Phalaris minor* and *Avena fatua* (wild oat) in winter crops. A crop like mungbean and urdbean which develop quickly and can contend with the weeds ought to be incorporated into the crop rotation either as sole crop or intercropping (Kumar et al. 2013; Meena et al. 2015b).

3.5.2 Intercropping

At present, intercropping is experienced where growers look for the highest consolidated yield of at least two crops for each unit of land or hazard not meeting the farmer's income. Intercropping infers growing of at least two crops of various development propensities at the same time on a similar land, which provides early cover of canopy and seedbed utilize bringing about decreased weed development by rivalry for various natural resources among crops component. Intercrops can be more powerful than sole crops in utilizing resources and stifling of the weed development due to existence of a complementary relationship in resource utilization (nutrients, water, and light) and facilitative interaction between intercrop plants (Liebman et al. 2001). Intercropping provides the sustainability of agricultural production systems especially under rainfed situations. Intercropping of short growth length, speedy developing, and early developing grain legume crop with longer growth habit and wide-spaced crops resulted in early land cover and smothering rising weeds adequately. The intercropping of corn with legumes prompted a higher soil cover and diminished light accessibility for weeds, which brought about a decrease in weed populations and dry matter contrasted with sole crops (Kumar et al. 2010b; Meena 2013). Reduction in development of weeds by grain legume crops is more prominent at a low-efficiency site than at a high-profitability site. In contrast to sole cropping, a grain legume-added intercropping system diminishes relative cover of weeds by 41% and lessened the population of *Senecio vulgaris* L. by 58% and enhances crop yield by 10% (Baumann et al. 2000). In pigeonpea-based intercropping (Table 3.5), fast-growing early-maturing grain legumes (cowpea and mungbean) decreases weed population by 30 to 40% compared to 22% by sorghum

Table 3.5 Weed smothering efficiency of important cropping system

Intercropping systems	Weed smothering efficiency (%)
Pigeonpea + urdbean	32.82
Pigeonpea + mungbean	31.01
Pigeonpea + cowpea	39.06
Pigeonpea + sesame	36.6
Pigeonpea + pearl millet	50.8
Maize + urdbean	17.3
Maize + pigeonpea	16.4

Source: Ali (1988)

(Ali 1988). In central and peninsular India, pigeonpea + sorghum has been found to be the most productive system on Vertisols, whereas on alfisols and entisols, pigeonpea + pearl millet proved to be the ideal system. It was found that weeds caused 79.93% reduction in pigeonpea grain yield if weeds were allowed to grow till harvest; however, grain yield losses were only 38.19% in pigeonpea + soybean intercropping system (Ali and Singh 1997). A similar effect was also reported in chickpea +wheat (Banik et al. 2006) and chickpea + mustard (Kaur et al. 2014) intercropping systems. Improvement in yield and weed suppression has also been demonstrated in many environments for cereal-grain legume intercrops.

3.5.3 Cover Crop

Grain legumes for cover crops have turned into a suitable alternative for sustainable farming in the light of its importance in soil health and crop yield improvement besides controlling weeds. Cover crops smother weeds by giving a physical obstacle; however, cover crops likewise trap light and regulate soil temperature, both of which act as a germination barrier for some small seeded seasonal weed species. Various grain legumes (urdbean, cowpeas, mungbean, and horse gram) have been found to stifle and reduce the population of different weeds due to competition for resources or allelopathic effect. Constant soil cover with grain legumes decreases light absorption by weed seeds and rivals the weeds for space and other resources. Norris and Kogan (2000) reported that the utilization of the cowpeas as cover crop advances the parasitic, bacterial, and mycorrhizal groups that might be unfavorable for weed growth and development but favorable for crop plants. Hence, cover crops control weeds and thus minimize the use of herbicides in agriculture. Weed control is generally the best under thick cover crops like cowpea, horse gram, and peas and, further, when cover crops are maintained for the longest manageable time. Cover crops may also influence weed diversity and dominance through modification of nutrient cycling, especially N cycling.

3.5.4 Pulse Crop Residues and Allelopathy

Surface crop residues can influence seed germination by means of physical and biochemical changes in the seed zone of soil layer. The two fundamental physical impacts of soil surface crop residue are decreasing light and shielding of the soil surface. Shielding of the soil surface has impacts on both soil temperature and moisture (Varma et al. 2017). Grain legumes may likewise add to weed control by delaying weed seed germination and decreasing weed population and weed growth and, thereby, minimize the crop yield loss due to weeds. Additionally, the surface cover in combination with grain legume crops changes the chemical environment of the soil zone around weed seed by means of allelopathy. According to Liebman and Davis (2000), the allelopathic reaction of crop residue decomposition has seen more articulated consequences in germination of small weed seeds. Various grain legume crops (lentil, cowpeas, and lupins) have been found to stifle and decrease the many weeds due to crop-weeds competition or allelopathic properties. Soybean crop residues have an ability to smother weeds and help improve the performance of summer squash (*Cucurbita pepo* L.) and tomato (*Solanum lycopersicum* L.) (Barker and Bhowmik 2001). Also, water-soluble extracts from lentil crop residues are lethal to stinkweed (*Thlaspi arvense* L.), downy brome (*Bromus tectorum* L.), and flixweed (*Descurainia sophia* [L.] Webb.) rather than wheat and confirmed that residues of these crops might be utilized for the specific control of weeds in wheat and to minimize the dependence on herbicides (Moyer and Huang 1997).

3.6 Grain Legumes in Conservation Agriculture

The basic principles of conservation agriculture (CA) such as least disturbance of soil, rational retention of adequate crop residue on the soil surface, and sensible crop rotation for improving livelihood and ecological security are well met while bringing grain legumes in production systems. Grain legume crops are considered as hardy crops which can thrive better than many other crops under adverse conditions and thus have immense value in CA. Inclusion of grain legumes in cereal-based crop rotations enhances input-use efficiencies and hence is considered as one of the best in resource conservation technology. Some of the CA-related values of grain legumes are as follows:

3.6.1 Reduced Tillage

Unlike cereals, grain legumes need rough and well-aerated seedbed. Grain legumes like lentil, lathyrus, urdbean, and mungbean are amenable for surface seeding in rice fallows under relay (*paira*) cropping. Chickpea and lentil also perform well under no-till (Table 3.6). The deep and strong roots of pigeonpea are capable of breaking hard pan in subsoil.

Table 3.6 Effect of tillage practices on chickpea yield

Treatment	Grain yield (kg ha^{-1})	Increase over conventional tillage (%)
No-till dibbling +mulching	1660	28.2
No-till drill + mulching	1589	22.7
Conventional tillage	1295	
CD (P = 0.05)	115	

Table 3.7 Grain yield of rice and wheat as influenced by residue management in rice-wheat-mungbean system

	Yield (Kg ha^{-1})		
Residue incorporation	Rice	Wheat	Sustainability Yield index
Rice-wheat-mungbean	3507	5082	0.79
Rice-wheat	3327	4902	0.74
Rice	3089	4855	0.74
No residue	2839	4434	0.67

3.6.2 Water Saving

Water requirements of grain legumes are much less than cereals and commercial crops; hence, they have a comparative advantage in rainfed/dryland areas. The water requirement of rice crop is 900–2500 mm, wheat 400–450 mm, and sugarcane 1400–2500 mm; however, grain legumes need only 250–300 mm of water. On account of their unique morphological and physiological features, they are capable of utilizing water more efficiently. Further, their deep root system enables them to draw soil moisture from deeper layers of the soil profile. In general under subtropical climate like in Indo-Gangetic plains, *rabi* grain legumes like chickpea and lentil need only one irrigation that too many times meet through winter rains. With 1 ha-mm of water, 12.5 kg chickpea could be produced as against 7.0 kg wheat and 2.5 kg rice.

3.6.3 Crop Residues

Grain legumes not only provide an excellent cover to soil surface due to their dense canopy but also leave substantial amount of easily decomposable crop residues. Incorporation of the mungbean residue further improved yield of rice and wheat as well as the sustainability index over and above rice + wheat residues (Table 3.7; Fig. 3.2). The low harvest index in grain legumes eventually provides large amount of crop residues. A good crop of chickpea may provide 8–10 tonnes of straw (crop residue). Winter grain legumes and pigeonpea shed a large number of their leaves at maturity (2–3 t ha^{-1} dry leaves) which provides a thin soil cover (Table 3.8).

Fig. 3.2 Pigeonpea leaf litters at podding and after harvest

Table 3.8 Leaf litter fall and nutrient contribution through leaf litter

Crop	Leaf litters (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Chickpea	1.1–1.7	7–14	3–5.5	8–20
Lentil	1.3–1.6	8–10	3.5–4.5	12.5–19
Pigeonpea	1.3–2.8	8–16	2.5–5	13.5–24

3.6.4 Crop Diversity

Crop diversity in cropping system is one of the important principles of CA. Grain legumes on account of their numerous virtues like short duration, low input requirements, biological N_2 fixation, nutrient recycling due to deep root system, and reversing the adverse effect of continued cereal-based production system are considered ideal for crop diversification. Grain legumes may find a place in the existing crop rotation as an intercrop, catch crop, substitute of low yielding cereals/millets, green manure crop, and alley crop. A sizeable shift of chickpea from the Indo-Gangetic plains to central and southern regions and cultivation of spring/ summer urdbean and mungbean as well as short-duration pigeonpea in the irrigated belt of north India is a glaring example of crop diversification. Some of the prominent crop rotations are rice-wheat-mungbean, rice/maize/bajra-chickpea/lentil/grass pea, pigeonpea (short duration, 140–155 days)-wheat, and rice-rice-urdbean/mungbean.

Thus, the inclusion of grain legumes in cereal-based crop rotations under CA may be considered as one of the RCTs which will reverse the negative effect of cereal-cereal rotation systems in this region.

3.7 Higher Productivity and Sustainability

Declining yield and factor productivity of major cereal-based cropping systems are a major concern since the last two decades in South Asia especially in IGP. This has forced the researchers and farmers to look for an alternative crop which can solve dual problems of declining factor productivity and system sustainability. Grain

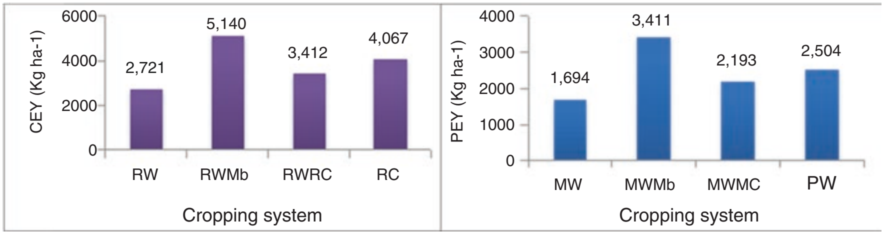

Fig. 3.3 Long-term effect of rice- and maize-based cropping system on system productivity; R, rice; W, wheat; Mb, mungbean; C, chickpea; M, maize; P, pigeonpea. (Source: IIPR 2012–2013)

legumes due to the intrinsic nature of fixation of atmospheric N and improving soil health can be fitted well under such situations in cereal-based systems. The lower cost of cultivation and higher market price resulted in higher system productivity and profitability from the grain legume-based cropping system in comparison to the cereal-based system.

In a long-term study at IGP, this revealed higher system productivity and sustainability in pulse inclusive of diversified cropping system over cereal-cereal system. The increase in system productivity is attributed due to increase in yield of component crops. Among different cropping systems, rice-wheat-mungbean gave a maximum production of 5, 140 kg ha^{-1} chickpea equivalent yield (CEY). This was followed by rice-chickpea and lowest under rice-wheat. In another set of a long-term study in which maize-wheat system performance was compared with pigeonpea- wheat, maize-chickpea, and maize-wheat-mungbean. Among these systems, maximum productivity of 3,411 kg ha^{-1} pigeonpea equivalent yield (PEY) was recorded in maize-wheat-mungbean followed by pigeonpea-wheat and least under maize-wheat (Fig. 3.3). However, results of another field trial on resource conservation revealed that rice-chickpea-mungbean and rice-chickpea performed better than the rice-wheat system in terms of system productivity, economics, and sustainability (IIPR 2012–2013). Similar results were also reported by Ali and Kumar (2006) and Ghosh et al. (2012).

Growing grain legumes as intercrop also a way to increase total productivity per unit are notable in time. Intercropping of short-duration (60–75 days) grain legumes (mungbean and urdbean) is most popular among farmers in IGP of South Asia. The special feature of this system is that the productivity of the base crop, i.e., pigeonpea, remains unaffected and an additional 400–500 kg ha^{-1} of mungbean or urdbean or 600–800 kg ha^{-1} of sorghum can be obtained without any additional inputs. Intercropping of winter grain legumes like chickpea and lentil with oilseeds is common in rainfed areas. Literatures reveal that high productivity and monetary returns can be obtained from chickpea + mustard, lentil + linseed, and wheat + lentil intercropping systems (Ali and Mishra 1996; Singh and Rathi 2003). Similarly, the horse gram can be also intercropped with early pigeonpea and maize in mid hills of Himalaya (Kumar et al. 2010a). Further, under rainfed wheat+ chickpea was found more remunerative than wheat + mustard, but in irrigated conditions, wheat+ mustard proved more profitable over wheat + chickpea. Lentil and linseed make a perfect combination for intercropping as compared to other *rabi* crops in rainfed conditions. Many other intercropping systems were also reported by several workers Ahlawat et al. (2005), Kumar et al. (2006, 2008, and 2010a, b). It has also been observed that growing one row of mungbean gives about half tonne/ha additional yield of mungbean without affecting the sugarcane yield. A further increase in mungbean rows 2–3 makes the systems nonprofitable. It has been also found that mungbean is more suitable than urdbean (Yadav et al. 1987 and Panwar et al. 1990). Another study has proved synergistic effects of urdbean and mungbean on cane yield in spring-planted crop with additional yield of 0.4–0.5 tonnes per hectare of these legumes (Lal et al. 1999; Varma and Meena 2016). Similarly, lentil is suitable for intercropping with autumn-planted sugarcane.

3.8 Grain Legumes in Rice Fallows

Growing rice is the predominant activity for farmers during the *kharif* season in most parts of South Asian countries. It is grown in both irrigated and rainfed conditions under various cropping systems. About 22.2 million hectares of land in South Asia remains fallow after rice harvest during rabi/winter season (Gumma et al. 2016) due to number of biotic, abiotic, and socioeconomic constraints. Out of total rice fallow area, 88% lies in India followed by 8.6% cent in Bangladesh. Despite ample opportunities, rice fallow systems did not get enough attention in the past. A number of abiotic factors related to soil and water lead to low productivity of grain legumes in rice fallows during the past several years. Low moisture content in soil after rice harvest followed by a fast decline in soil moisture with the advancement of *rabi* season results in mid- and terminal drought at flowering and pod-filling stages which adversely affect the productivity of grain legumes. Due to anaerobic conditions in rice cultivation, many of the organisms including rhizobia would not be able to survive. Besides the inherent constraints, rice fallows also affect seed germination, seedling emergence, and crop establishment due to disruption of the soil structure, soil water deficit, poor aeration, and mechanical impedance of the seed zone. This hostile environment creates a potential threat to microbial activity, nutrient availability, root growth (root is mostly confined to the top soil layer), and water and nutrients uptake; thus, subsoil resources in rice fallows remain unutilized.

Pulses with properties like low input requirements, short duration, ability to establish even with surface broadcast in standing rice fields (para/utera cropping), and soil fertility restoration are ideal crops for the rice fallow agroecosystem. They have the ability to fix atmospheric N and thus improve/restore soil fertility of sick soils which developed due to continuous cultivation of the rice crop. If this area is brought under cultivation, it may benefit millions of poor and small farmers solely dependent on agriculture for their livelihood. Productivity and profitability from grain legumes in rice fallows can be improved with suitable crop management technique and even by utilizing residual soil moisture. By adopting improved technologies like resource conservation, short duration, disease resistance, improved varieties, timely sowing, plant population, biofertilizers inoculation, fertilizer application, timely weed management practices, need-based plant protection measures coupled with proper irrigation schedule (lifesaving) would definitely increase the yield of grain legumes in rice fallow agroecological situation (Kumar et al. 2016a, b). Further, resource conservation technologies which deal with soil moisture conservation, organic matter buildup, improvement in soil structure, and microbial population could be an appropriate approach to address these problems in rice fallow. Therefore, if crop residues are retained on the soil surface in combination with suitable planting techniques (no-till planting or paira cropping), it may alleviate terminal drought/heat stress in pulses by conserving and regulating the soil moisture (Kumar et al. 2013a; 2016c). A minimum soil traffic by adoption of a suitable technology involving no-till and minimum soil disturbance and management of crop residues (conservation tillage) could lead to favorable effect on soil properties that further conserve the soil moisture to a longer period for plant use (Kumar et al. 2014; Meena et al. 2015c).

Conservation tillage with proper crop residue management is reported to reduce soil water evaporation, soil sealing, and crusting (Kumar et al. 2016a). It is also evident that hydraulic conductivity under straw retained in no-till drill is many times higher than that of a conventional tillage. In fact higher yield of lentil after wet season (rainy season) rice and with conservation tillage was also reported by Bandyopadhyay et al. (2016) under rainfed areas of eastern India. This will also reduce cost of cultivation through savings in labor, time, and farm power and improve input-use efficiency. Traditionally, seeds of pulses (lentil, lathyrus, mungbean, and urdbean) are broadcasted in the standing rice (para/utera cropping) field without any tillage. Under such situation, 20–30 cm rice stubble needs to be maintained in the field to get an advantage similar to that of conservation tillage. In areas where grain legumes are sown after a harvest of rice with land preparation, zero-till seeding may be advocated as it facilitates advance planting by 7 to 10 days and saves energy and labor. Rice ratoons are also a major problem in growing grain legumes under rice fallows. It is observed that a large quantity of residual soil moisture is lost by nonproductive rice ratoons. Besides, the farm pond concept need to be advocated for the harvesting of excess rainfall and to use during the critical growth period of grain legumes for life saving irrigation through micro-irrigation system. To contain the growth of rice ratoons, postemergence herbicides like quizalofop-ethyl @ 100 g ha^{-1} can be used at 3–4 leave stage (Kumar et al. 2013b). Under soil moisture stress, movement of plant nutrients from soil is a limiting factor for plant growth and yield. Under such situations, foliar nutrition of 2 percent urea and micronutrients may be used to mitigate the effect of soil moisture stress to certain extent (Kumar et al. 2014a).

3.9 Grain Legumes for Ecosystem Services

Agriculture is one of the major sources of the greenhouse gas (GHG) emission and soil water pollution and also the major consumer of fossil energy. The projected environmental change will certainly impact on productivity and sustainability of

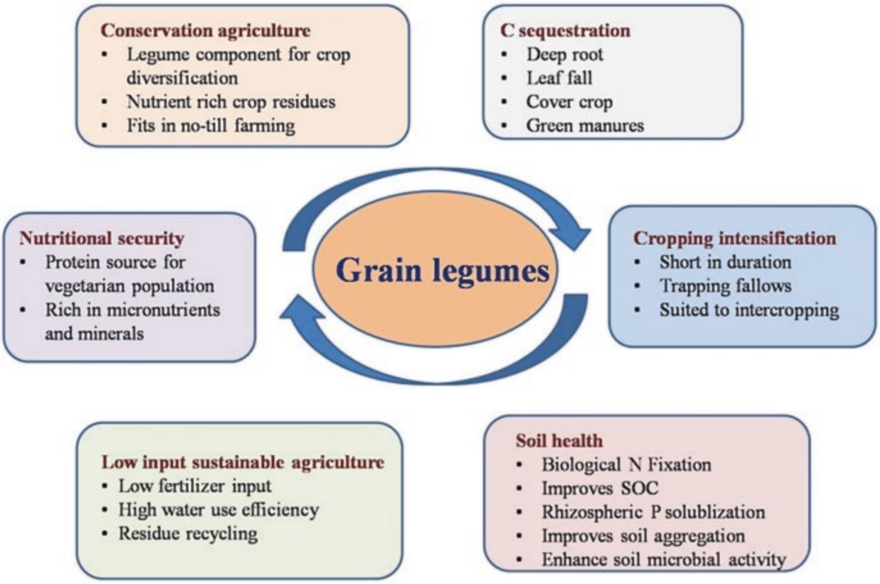

Fig. 3.4 The multipronged benefits of grain legumes in soil-plant systems and human nutrition

agricultural production systems (Keatinge et al. 2014) in the near future. A higher reliance on cereal-based rotations may lead to higher agronomic and ecological risks in the background of global climate change (Ebert 2014). According to the Newton et al. (2011), to improve the crop resilience to biotic and abiotic stress, there is a need to increase the heterogeneity (both temporal and special) into the cropping system. Grain legumes in the cropping system can play a vital role in ecosystem services (Fig. 3.4). Inclusion of grain legumes in intensive cereal-based crop rotations curtails the rate of N fertilizers, subsequently reduces the energy use, and GHG emission per unit cropping area (Nemecek et al. 2008). Likewise, Fuhrer (2006) (Meena and Yadav 2015) specified that grain legumes can minimize the use of fossil energy as well as reduce the N losses. Based on a comparative assessment of N fixation by legume and industrial fertilizer manufacturing, Crews and Peoples (2004) concluded that the ecological impact of grain legume N fixation is positive. The low C:N ratio of legume residues increases the retention of soil C and N and improves environmental quality (Drinkwater et al. 1998). However, legumes cultivation sometimes favors higher N_2O emissions. The main processes involved in the N_2O emission in legumes are rhizobial denitrification within the nodule, nitrification/denitrification of biologically fixed N, and decomposition of N-rich legume residue. Added to this, the altered N dynamics with the symbiotic N fixation may cause N losses like NO_3^- leaching. Intercropping of grain legumes in cereals can reduce nitrate leaching (Yadav 1981). Sugarcane + urdbean and pigeonpea + maize resulted in a low nitrate N leaching as compared to the sole cropping of sugarcane and maize (Yadav 1982). In addition, the inclusion of short-duration summer grain legumes reduces the fallow period between two crops (rice-wheat) and thus reduces C loss during hot summer and enhances C sequestration of a system.

3.10 Way Forward

The research emphasis on following aspects needs to be focused:

- The quantification of intensification effects due to inclusion of different grain legumes in existing cropping systems on the system productivity, profitability, sustainability, soil health, and insect-pest dynamics in system mode needs to be attempted under different agroecological regions.
- There is also a need to quantify the beneficial effect of grain legumes on soil microbial diversity and their dynamics, soil nutrients availability, soil productivity, and agroecological sustainability.
- Intensification approaches are highly location specific which depend upon the existing resources and socioeconomic and climatic conditions. Therefore, location-specific strategies need to be developed for obtaining beneficial advantages of inclusion of grain legumes as a component of crop diversification using short-duration and disease resistance varieties against different driving forces.
- Concerted research efforts are required for identification of a climate-resilient grain legume-based production system (cropping sequence or intercropping) for different agroecosystems. Further, possibilities need to be explored to identify water-saving technology such as micro-irrigation, resource conservation technology, and conservation tillage. In situ soil, the moisture conservation strategy needs to be strengthened for mitigation of mid-season and terminal drought in *rabi* season grain legumes especially under rice fallows. Farm pond water harvesting can be promoted to harvest excessive runoff water during rainy season for use in rabi season grain legumes as lifesaving irrigation through the micro-irrigation system.
- Conservation agriculture is increasingly being practiced in many parts of South Asia. Diversification or intensification of the rice-wheat system under CA in the Indo-Gangetic Plain through popularization of short-duration varieties of pigeonpea, chickpea, lentils, and summer mungbean needs to be promoted as the key to sustainability.
- Widespread micronutrient deficiency is observed in South Asia which adversely affects the yields of grain legumes in this region. Thus, to minimize the micronutrient deficiency in grain legumes, emphasis should be given for evaluation and development of micronutrient fortified customized fertilizers for different agro-climatic zones. Further, to improve grain quality, agronomic bio-fortification strategies need be promoted to ensure nutritional security in this region.
- Suitable resource conservation technologies need to be developed for grain legumes to mitigate the ill effect of increasing ambient temperature and CO_2 concentration and soil temperature.
- Yield loss in grain legumes due to weeds is more than in cereal crops. Mostly, application of preemergence herbicides followed by manual weeding is used in

grain legumes to control weeds in all seasons. But due to high cost and unavailability of labor on time, later flush of diversified weeds must be controlled through postemergence herbicides to realize higher yield of grain legumes as it is possible in cereal crops. Unfortunately, none of the postemergence herbicides available in the market are effective for controlling weeds in grain legumes especially during the rabi season. Thus, a new generation highly effective postemergence herbicides need to be identified for effective weed control in grain legumes. Further, development of genotypes tolerant to postemergence herbicide (imazethapyr, metribuzin, and glyphosate) is the need of the hour.

- In the last few decades, research evidences have shown that some of the grain legumes can be grown during nonconventional seasons. Thus, research should be initiated for strengthening of agro-techniques for popularization of the *rabi* rajmash in northern plains, spring rajmash in NW Himalaya, and pre-*rabi* pigeonpea in flooded areas under irrigated conditions.
- Grain legumes are mostly grown under rainfed conditions. Many biotic and abiotic stresses are affecting the yields of grain legumes in this region. Therefore, research efforts can be thrust on developing abiotic stresses (water logging, heat, and salinity), tolerant pulse genotypes, and their improved management for minimizing the ill effects of climatic variability. Further, transplanting of long duration pigeonpea can be popularized as a contingent crop measure to assure optimum plant population.
- Grain legume production systems are poorly mechanized. Sowing is commonly done through broadcasting of seeds and harvesting through manual labors. Thus, for increasing profitability and for enhancing the yield, farm machineries should be developed for grain legume production systems. Popularizing the machine harvestable varieties further can facilitate large-scale cultivation of grain legumes. The varieties having higher podding height above the ground and effect plant type even at maturity will be an obvious choice for mechanical harvesting. Therefore, genotypes suitable for mechanical harvesting need to be developed in different grain legume crops.
- Grain legumes can be best fitted under organic farming in comparison to cereal crops due to its low requirement of inputs like nutrients and water. The profuse development of roots and nodules is observed in grain legumes under application of organic manure. Thus, suitable agro-techniques and cropping systems should be developed for grain legumes for organic farming.
- New niches (intensification or diversification) should be identified for inclusion of grain legumes particularly in irrigated cereal-based agroecosystems for increasing pulses acreage and production in South Asia.
- For making grain legume cultivation profitable, the development of a market regulation mechanism for fluctuating prices and supportive policy is to be developed to make grain legume cultivation a profitable enterprise.

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