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Increasing area under pulses and soil quality enhancement in pulse-based cropping systems – Retrospect and prospects

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ABSTRACT

India is the largest producer (25% of global production), consumer (27% of world consumption) and importer (14%) of pulses in the world (Anonymous 2016). Pulses accounted around 20% of the area under foodgrains and contribute around 7-10% of the total foodgrains production in the country. Productivity of pulses has improved by 65.07%, from 441 kg/ha in 1950-51 to 728 kg/ha in 2014-15. There is large scope to increase the area and production under pulses by utilizing existing rice fallows by growing chickpea, lentil, pea and khesari (lathyrus) after rice. But major hurdles in the successful cultivation of pulses in rice-fallows are the non-availability of quality seed, irrigation facilities, labour and other input availability. The production potential of pulses can be improved through introduction of short duration, nutrient responsive high yielding varieties and assured supply of quality seed, efficient nutrient management techniques and growth regulators, with supplemental irrigation. Declining factor productivity, depletion of soil fertility and over mining of native nutrient reserves, depletion of groundwater, increasing weed menace, and environmental pollution are major problems of rice-wheat cropping system. Introducing a legume (summer mungbean) in rice-wheat cropping system (RWCS) is one of the alternatives for overcoming some of these problems and provides additional economic returns and employment. Diversifying cropping systems with inclusion of pulse crops (mungbean or urdbean) can enhance soil water conservation, soil N availability, system productivity, soil physico-chemical properties such as aggregate stability, soil structure, bulk density and hydraulic conductivity, and soil biological activities. Moreover, levels of organic carbon, total N, available nitrogen, phosphorus, potassium and micronutrients increased significantly and substantially due to inclusion of mungbean in RWCS. Simultaneously the soil microbiological properties, viz. microbial biomass carbon, microbial biomass nitrogen and enzymatic (alkaline phosphatase, acid phosphatase, dehydrogenase, glucosidase, FDA hydrolysis, etc.) activities were also significantly higher in soils of rice-wheat-mungbean cropping system (RWMCS) than in RWCS. Therefore, this paper reviewed the inclusion of short duration pulses in different cropping systems in general and rice-fallows in particular which could help the farmers for getting the additional returns, besides improving soil physical, chemical and biological properties and help to sustain the agriculture productivity in the long-term.

Key words: Cropping system, Pulses, Rice fallow, Rice-wheat, Soil health

The 68th UN General Assembly declared 2016 the International Year of Pulses (IYP). The objective of this was to create public awareness regarding the nutritional benefits of pulses. This would be quite helpful to ensure food and nutritional securities. Pulses are an important ingredient in the diets of a vast majority of the Indian people, as they provide a perfect mix of vegetarian protein component of high biological value when supplemented with cereals. Pulses are also an excellent feed and fodder for livestock. Endowed with the unique ability of biological nitrogen fixation, carbon sequestration, soil amelioration, low water requirement and capacity to withstand harsh climate, pulses have remained an integral component of sustainable crop production systems since time immemorial, especially in the areas, receiving less rainfall or dry areas. They also offer good scope for crop diversification, since they grow profitably in relatively low-input management conditions, and intensification due to their short growing period.

Pulses are well known for their soil fertility restoration value. Deep-rooting, nitrogen-fixation, leaf-shedding ability and mobilization of insoluble soil nutrients, especially phosphorus, are some of the important characteristics of pulses. To arrest the declining trend in productivity of cereal-based cropping systems, legume inclusion is important alternative for improving physical, chemical and biological environment of soil. Even though production of foodgrains is increasing, it is on the expense of soil quality which is a consequence of intense use of chemical

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fertilizers in cereal-based cropping systems. According to an estimate 668000 tonnes of nitrogen can be incorporated in the soil through inclusion of legumes in cropping systems (Singh *et al.* 2009). The intrinsic nitrogen fixing capacity of pulse crops enables them to meet a large proportion of their nitrogen requirement and also helps in economizing nitrogen in succeeding non-legume crops due to the residual effect. Different legumes have different capacities to leave behind varying amounts of N for use by the succeeding crops. In sequential cropping involving pulses, the preceding pulse may contribute 18-70 kg N/ha to the soil and thereby considerable amount of nitrogen to succeeding crop (Ali and Mishra 2000). The beneficial effect of pulses was more pronounced in maize as compared to sorghum after chickpea and pigeonpea, whereas after lentil and peas the higher N equivalent benefit was observed after pearlmillet. Growing of short duration legumes such as greengram and cowpea in widely spaced crops and ploughing back the same in the soil after picking the grains resulted in an advantage of 30 kg N/ha on fertilizer basis in Alfisol of Hyderabad.

Area, production and productivity of pulses in India

India is the largest producer (25% of global production), consumer (27% of world consumption) and importer (14%) of pulses in the world. Pulses account for around 20% of the area under foodgrains and contribute around 7-10% of the total foodgrains production in the country (Anonymous 2016). Though pulses are grown in both *kharif* and *rabi* season, *rabi* pulses contribute more than 60% to the total pulses production in the country. The area under pulses has increased from 19 million ha in 1950-51 to 25 million ha in 2013-14 (Fig 1), indicating an increase of 31%, whereas the production of pulses during the same period has increased from 8.41 million tonnes to 19.27 million tonnes an increase of over 100%. Chickpea (*Cicer arietinum*) is the most dominant pulse having a share of around 40% in the total pulse production followed by pigeonpea (*Cajanus cajan*), blackgram (*Vigna mungo*) and greengram (*Vigna radiata*) contributing 15-20, 10 and 10% of the total pulses production in India, respectively. Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh and Karnataka are the top five pulses producing states. Productivity of pulses has improved by 46%, from 441 kg/ha in 1950-51 to 764 kg/ha in 2013-14. The compound annual growth rate (CAGR) in productivity for the same period however, shows a dismal picture at 0.64%.

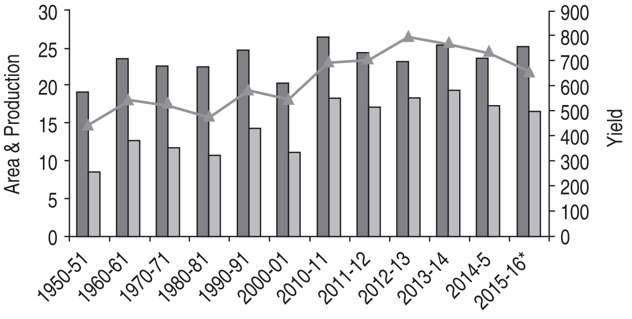

Fig 1 Area, production and yield of pulses in India (Agricultural Statistics at a glance 2016; *4th Advance Estimates)

Despite increase in production, India is the largest importer of pulses since the beginning of the present millennium. The import has increased to more than 20% of the domestic production during 2009-10 and 2012-13. In the earlier years was in the range of 15-20% of the domestic production, except during 2003-04 to 2005-06 where it varied in the range of 11 to 12% of the domestic production (Agricultural Statistics at a glance 2016).

Increasing area under pulses

Area under pulses can be increased by growing of pulses in the rice-fallows and their inclusion in rice-wheat cropping system (RWCS). Rice occupies an area of over 42 million ha. This area is not fully utilized for crop production in the subsequent *rabi* (post rainy) season; about 11.6 million ha remains fallow (Table 1). This unutilized area offers enormous opportunities to overcome the problem of food and nutritional insecurities. Out of this area, 2.5 million ha can be used for growing some pulses such as lentil, greengram and blackgram (Ali and Gupta 2012). Household food security remains the primary concern though at the national level India has piled up a huge stock of food grains, mainly rice and wheat. Food crops such as pulses and oilseeds are critical to nutritional security. According to FAO (2014) one in every five people in the developing world is chronically undernourished (a total of 777 million individuals) and fifty-five per cent of the 12 million child deaths each year are related to malnutrition.

The existing area under rice-fallows (11.65 million ha) is almost equivalent to the net sown area of Punjab, Haryana, and western Uttar Pradesh – the seat of Green Revolution in India. Rice-fallows are spread mainly in the states of Andhra Pradesh, Assam, Bihar, Chhattisgarh,

Table 1 Estimated area under rice fallows in different states of India (NAAS 2013)

State	*Kharif*-rice area (million ha)	*Rabi*-fallow (million ha)	Rice-fallow area as % of *kharif*-rice areas
MP + Chhattisgarh	5.60	4.38	78.21
Bihar + Jharkhand	5.97	2.20	36.85
West Bengal	4.62	1.72	37.23
Odisha	3.88	1.22	31.44
Maharashtra	1.76	0.63	35.80
Assam	2.23	0.54	24.22
Uttar Pradesh	6.62	0.35	5.29
Andhra Pradesh	2.66	0.31	11.65
Others	7.20	0.30	4.17
Total	40.18	11.65	29.00

Jharkhand, Madhya Pradesh, Odisha, West Bengal and Uttar Pradesh. The coastal regions of Andhra Pradesh, Karnataka and Tamil Nadu form an important rice-fallow ecology in peninsular India. Of the total area under rice-fallows, about 82% lies in Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, and West Bengal (Pande *et al.* 2012a). If this area is brought under cultivation, it may usher another 'Green Revolution' in the country benefiting millions of poor, deprived, and smallholder farmers. Promotion of cultivation of pulses in the existing rice-fallows would also improve sustainability of the rice production system besides enhancing production and augmenting income.

Causes for non-cultivation of rice-fallows

Abiotic constraints: Important abiotic constraints which affect pulses production in rainfed rice-fallow lands (RRFL) include water-logging during early stages of plant growth, poor plant stands, terminal drought, location specific micro/secondary nutrients deficiencies (Zn, S, B, Mo), soil acidity, soil salinity/alkalinity and low soil organic matter status (Pande *et al.* 2012b). Abiotic factors can be classified into two categories broadly: water related and soil related factors. Water related constraints include low available moisture content in the soil after rice harvest, fast decline in water table with advancement of *rabi* season and risk of drought towards flowering and harvest stages. A *rabi* crop in rice-fallow systems is grown on residual moisture after rice harvest, a good rainfall towards terminal period of rice crop provides sufficient moisture for germination and establishment of the next crop. But the rainfall is uncertain in quantity as well as in distribution. During *kharif* season water table is generally high but as the monsoon rains withdraw, the water table recedes fairly fast. This restricts investment in irrigation. Further, *rabi* rainfall is uncertain, and even if the crop has established well utilizing available soil moisture, lack of *rabi* rainfall towards harvesting stage creates drought conditions leading to crop failure. The success of *rabi* cropping is thus viewed uncertain by the farmers. Soil related constraints include soil cracks and a hard pan in sub-soil after the harvest of rice. Other soil problems include low organic matter content and salinity/alkalinity and nutrient deficiencies.

Crop management and suitable varieties: Chickpea, lentil (*Lens culinaris*) and lathyrus (*Lathyrus sativus*) have the potential for cultivation in almost all the states. Chickpea, however, is preferred everywhere. *Lathyrus* is important in Chhattisgarh, Jharkhand, Odisha, and West Bengal. Lentil is preferred by the farmers of Madhya Pradesh and in North Eastern States. Non-availability of short-duration varieties of the identified crops is the main limiting factor for their cultivation (Joshi *et al.* 2002). Short sowing period is the next important limiting factor, as the farmers have to sow the *rabi* crops on residual moisture, while at the same time farmers have to undertake threshing of the rice crop. The residual moisture disappears in due course, and delay in sowing reduces seed germination resulting in loss of seed. However, farmers feel that if the seed is sown soon after rice harvest, germination rate is high and plant stand is good. Further, as the crop advances in growth, the probability of crop failure increases if there is no rainfall. Long-duration varieties often suffer the most from terminal drought. Even if the crop is sown timely and establishes well, high incidence of insect-pests and diseases prevails in *rabi* crops. In chickpea, *Helicoverpa armigera* is reported to be a potentially severe problem in Chhattisgarh, Jharkhand, and Madhya Pradesh (NAAS 2013). Plant diseases are also viewed as a severe problem by a considerable number of respondents in these states. Insect pests and diseases are also viewed as serious problems in *lathyrus*, but not as severe as in chickpea. Similarly, these problems are less severe in lentil. This implies that before introduction of new crops in rice-fallows, the availability of seed of disease and pest resistant varieties of pulses need to be considered (Ali 2009).

Resource and input constraints: Even if a crop has the technical potential to thrive good under rainfed conditions, non-availability of inputs and resources may not allow its cultivation. A majority of the farmers in these states lack capital to meet the operational costs of cultivation. Farmers feel that it is difficult to cultivate *rabi* crops without irrigation, and most of them indicate a lack of capital to invest in on-farm irrigation facilities. The farmers also experience scarcity of labour during the sowing period. Non-availability of good quality seed as the most binding constraint to *rabi* cropping. Besides, prices of quality seeds are often many times higher than the home produced seeds. Non-availability of pesticides at right time or availability at inadequate quantity is also an important hindrance in cultivation of crops.

Information technology constraints: Improving farmers' access to information related to crops and their cultivation practices is important in the process of utilization of fallow areas. In some villages, non-governmental organizations (NGOs) have been the main source of information on *rabi* crops. The next important source of information is the government extension system. Input dealers and mass media too provide information on *rabi* cropping in some states. However, more sincere efforts are needed by the government agencies in quick transfer of technology.

Marketing constraints: Lack of markets for the produce appears to be an important limitation in promotion of pulses in rice-fallow areas. Market infrastructures, such as good roads, transport, communication etc are lacking in the rice-fallow areas. Assured procurement of produce at a remunerative price is essential to promote new crops particularly in the backward areas such as rice-fallows.

Animal grazing: Whenever a considerable proportion of land remains fallow, domestic animals are often left to graze it freely. This is a common practice in the region and is likely to be a major threat to *rabi* crop production at least until a sizeable proportion of the fallow land is brought under cultivation. However, as more and more area is brought under cultivation, the threat would disappear. For example, a similar threat existed for soybean when it

Fig 2 Dominant rice pulses relay cropping system (IIPR 2013-14)

was first introduced in fallow systems of Madhya Pradesh (Joshi *et al.* 2002). However, when technical and economic feasibility of soybean production was proven, its cultivation spread on a wider area, and free animal grazing was stopped.

Crop production systems in rice-fallows

There are two production systems of pulses in rice-fallows, namely, 1) Rice-pulse relay cropping and 2) Rice-pulse sequential cropping. In rice-pulse relay cropping, pulses are sown by broadcasting seeds in the standing crop of rice. This system is also locally known as *paira* in Bihar and *utera* in Madhya Pradesh and Chhattisgarh. This system is widely practised in West Bengal, Madhya Pradesh, Bihar and Chhattisgarh (Fig 2). The development of zero till drill has now facilitated sowing of wheat/ chickpea/lentil immediately after harvesting of rice in moist soil. In rice-pulses sequential cropping system, pulses are sown after harvesting of rice crop. Before sowing, field is ploughed. In this operation generally the sowing of the next crop gets delayed, resulting in low soil moisture and terminal drought, leading to low yield. Sowing of chickpea is generally delayed by 10-15 days when sown after the harvest of the rice for soil to reach proper moisture after pre-sowing irrigation and for seedbed preparation. Due to this, delayed sowing of chickpea in the end of November may cause heavy reduction in chickpea yield. Sowing of chickpea by *utera* method in standing rice crop (about 10 days before rice harvest) gave 45% higher yield than the sowing after proper seed bed preparation (Singh *et al.* 2009).

Technological interventions for improving productivity of pulses in rice-fallows

Choice of appropriate crops and varieties: Selection of crops should be made based on existing winter temperature, soil texture and soil moisture (Table 2). In central zone, small seeded chickpea may be introduced although lentil has an edge over chickpea. Extra early chickpeas from ICRISAT, ICCV 96029 and ICCV 96030 may come handy in rice-fallow. *Lathyrus* is the most versatile and hardy crop being ideal both for north-east and central zone but due its β-N-oxalyl-diaminopropionic acid (ODAP) content, it is being replaced by lentil. In coastal region, powdery mildew is a deadly disease in blackgram and greengram, which restricted its spread until powdery mildew resistant varieties like LBG 17, 602, 623 etc. of blackgram, and Pusa 9072, NARM 1, NARM 2, and NARM 18 of greengram were developed (Table 3). LBG 17 is the first powdery mildew (PM) resistant variety with yield potential of 1.5 tonnes/ha revolutionized *rabi* blackgram cultivation in rice-fallows of coastal peninsula. Small seeded lentil varieties WBL 77, KLS 218, NM 1 and DPL 15 having resistance to rust are performing well in North-East region. The newly developed *lathyrus* varieties Ratan, Prateek and Mahatoera

Table 2 Potential crops for rice fallows in different states (NAAS 2013)

Crop	State
Lentil	Assam, West Bengal, Bihar, Odisha, Eastern Uttar Pradesh, Chhattisgarh and Jharkhand
Grass pea (lathyrus)	Tal area of Bihar, Chhattisgarh and West Bengal
Pea	Jharkhand, Chhattisgarh, Eastern Uttar Pradesh and northern Madhya Pradesh
Chickpea	Chhattisgarh, Bihar and Jharkhand
Mungbean	Odisha, Chhattisgarh, Jharkhand, Bihar, Andhra Pradesh, Tamil Nadu and Karnataka
Urdbean	Coastal Andhra Pradesh, Tamil Nadu, Karnataka and Odisha
Clusterbean	Andhra Pradesh, Tamil Nadu and Karnataka
Lablab bean	Andhra Pradesh, Tamil Nadu and Karnataka
Mustard	Eastern Uttar Pradesh, Bihar and Jharkhand
Groundnut	*Char* area of Bihar, Mahananda of Odisha, Brahmaputra valley of Assam and coastal Andhra Pradesh

Table 3 Choice of appropriate crops and varieties (ICARDA 2010)

Eastern region	
Lentil	DPL 15, WBP 77, KLS 218, PL 8, Moitree, NM 1
Chickpea	Pusa 372, PG 186, Udai
Central region	
Chickpea	Pusa 372, PG 186, Udai
Lathyrus	Ratan, Mahatoera, Prateek (low ODAP)
Coastal region	
Blackgram	LBG 17, LBG 602, LBG 623
Greengram	Pusa 9072, NARM 1, NARM 18

Table 4 Effect of seed priming on *lathyrus* under *utera* cropping at Beldanga (Gupta and Bhowmick 2005).

Treatment	Pods/ plant	Seeds/ pod	1000-seed weight (g)
No soaking	8.94	2.22	63.6
Soaking in water for 6 hr	9.48	2.54	66.6
Soaking in 2% KH_2PO_4 solution for 6 hr	10.70	2.76	70.4
Sowing of sprouted seeds	11.55	3.00	71.8
CD (P=0.05)	0.90	0.18	1.7

have low ODAP content and are suitable for rice-fallows. In Murshidabad district of West Bengal, lentil variety Moitree gave the highest yield (1.51 tonnes/ha) followed by Subrata (1.46 tonnes/ha) under rice-pulse double cropping (Fig 3) and these were selected by the farmers for cultivation and further promotion in the region.

Seed soaking/priming and optimum seed rate: Overnight soaking of seeds in water and shade-drying hastens seed germination and establishment under relay cropping. The term priming refers to soaking the seed in a nutrient/salt solution. Since all broadcast seeds do not establish good contact with soil and seed germination is low, a 20-25% higher seed rate ensures desired plant stand. Gupta and Bhowmick (2005) conducted an experiment at Pulses and Oilseed Research Station (PORS) Sub-Station at Beldanga to study the effect of pre-sowing seed soaking/priming on yield improvement in *lathyrus* and reported that sowing of sprouted seeds significantly increased the pods/plant, seeds/pod and 1000-seed weight in *lathyrus* (Table 4).

Foliar application of hormones and plant nutrients: Physiological problems like flower drop and premature shedding of reproductive structure diminish the number of potential sinks (or) accumulation of assimilates which seems to be associated with nutrient deficiency and hormonal imbalance and ultimately with the reduced translocation of dry matter to reproductive parts. The poor production potential of pulses is attributed to poor translocation of photosynthates to pods and seed setting, which may be improved through foliar application of macro and micronutrients and growth regulators. Consequently application of nutrients through foliar spray at appropriate stages of growth becomes important for their efficient utilization and better performance of the crop. The field experiments were conducted at Tamil Nadu by Ganapathy *et al.* (2008) during *rabi* season in Cauvery delta area tract under rice-fallow conditions. The results of the study (Table 5) indicated that the reproductive efficiency of blackgram, i.e. the number of flowers formed, number of flower shed, flower drop and fruit drop percentage were significantly influenced by various foliar spray treatments. The treatment with foliar application of di-ammonium phosphate (DAP) 2% + NAA 40 ppm + micronutrients significantly increased the total number of flowers formed per plant, decreased the number of flower shed and flower drop percentage compared to control and resulted in significant increase in number of pods formed, percentage of fruit set and grain yield, respectively. Gupta and Bhowmick (2005) reported that spraying of 2% urea solution at 10 days after rice harvest had the greatest beneficial effect on yield attributing characters and seed yield of *lathyrus* and it was followed by 2% solution of di-ammonium phosphate (Table 6).

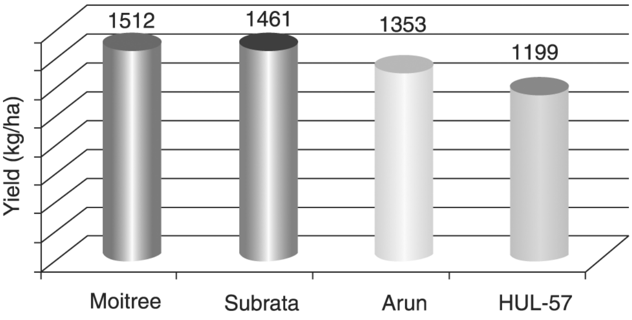

Fig 3 Performance of lentil varieties in participatory farmers' field under rice-fallow conditions (ICARDA 2010)

Supplemental irrigation: Supplemental irrigation (SI) can be defined as the addition of small amounts of water to

Table 5 Effect of foliar nutrition on reproductive efficiency and seed yield of blackgram under rice-fallow (Gupta and Bhowmick 2005)

Treatment	Flowers formed (Nos.)	Flower drop (%)	Seed yield (kg/ha)
Control	36.86	56.08	321
DAP 2%	43.36	41.83	460
KCl 1%	41.82	43.79	410
DAP 2% + KCl 1%	44.20	40.56	480
DAP 2% + NAA 40 ppm	44.78	39.26	540
KCl 1% + NAA 40 ppm	44.03	40.31	500
DAP 2% + NAA 40 ppm + $ZnSO_4.7H_2O$ 0.5% + $FeSO_4.7H_2O$ 1%	46.40	37.24	599
CD (P=0.05)	0.42	0.66	25

Table 6 Effect of foliar nutrition on lathyrus under rice-utera condition (Gupta and Bhowmick 2005)

Treatment	Pods/ plant	Seeds/ pod	1000-seed-weight (g)	Seed yield (kg/ha)
Water spray	9.62	2.54	67.7	798
Urea spray (2% solution)	11.25	2.87	69.5	963
DAP spray (2% solution)	10.84	2.69	68.7	912
KCl spray (2% solution)	9.95	2.63	68.1	878
CD (P=0.05)	1.01	0.20	1.9	58.7

essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. Kar *et al.* (2008) conducted an experiment in Brahmani river basin in Dhenkanal district, Odisha. Sufficient availability of soil moisture at the time of sowing resulted in better crop growth. With the depletion of soil water in the soil profile (50 cm depth), especially at reproductive stage from flowering to pod formation and supplementation of 60 mm of irrigation water resulted in significant increase in yield by 33% over no irrigation. Supplementing with one more irrigation resulted in marginal increase in yield indicating that one irrigation of 60 mm at pod formation was sufficient for optimum yield and water use efficiency (WUE) (Table 7).

Inclusion of pulses under rice-wheat cropping system (RWCS)

The RWCS occupies about 10.5 m ha area in India, which contributes about 40% in total food grain basket of the country (Singh and Kaur 2014). Rice and wheat crops have been grown in South Asia (India, Pakistan, Nepal, Bangladesh and Bhutan) and China for more than 1000 years. This cropping system is one of the world's largest agricultural production systems, covering an area of 26 million ha spread over the Indo-Gangetic Plains (IGP) in South Asia and China (Prasad 2005). It accounts for about one-third of the area of both rice and wheat in South Asia and produces staple food for more than 20% of the world population. The RWCS now comprises about 13 m ha in area in the IGP, of which the Indian part of the IGP comprises about 10.5 million ha. In India, the IGP cover about 20% of the total geographical area (329 million ha) and about 27% of the net cultivated area and produce about 50% of the total food consumed in the country (Dhillon *et al.* 2010). Prasad (2011) stated that even if half of such area, which is estimated 10 million ha, can be brought under summer mungbean cultivation, a production of 2.5-3.0 million tonnes of pulses is easily achievable, which will nearly offset the import of 2-3 million tonnes of pulses. The major problems with the rice-wheat cropping system include declining factor productivity, depletion of soil fertility including SOM and over mining of native nutrient reserve, emergence of secondary and micronutrient deficiency, depletion of groundwater, increasing menace of weeds, declining factor productivity of fertilizer and environmental pollution (Prasad 2005, Katyal and Reddy 2005). Introducing a legume in RWCS is one way of overcoming some of these problems. A summer legume (pulse) variety maturing in 60-70 days provides additional economic return. Incorporation of legume residues after harvesting the grain benefits the succeeding rice crop as it reduces fertilizer N requirement.

Table 7 Grain yield, water use efficiency and net returns of chickpea under rice-fallow system (Kar *et al.* 2008)

Irrigation	Grain yield (kg/ha)	WUE (kg/ha-mm)	Net returns (₹/ha)
No irrigation	510	1.42	3650
One irrigation	725	1.77	6375
Two irrigations	750	1.69	6250
CD (P=0.05)	26.63	0.24	

Many short duration varieties of summer mungbean, including SML 668, SML 832, Samrat, Pusa 9531 and Pusa Vishal, have been developed, which can easily fit well in the window period between wheat harvest and transplanting of rice. For obtaining high grain yields of summer mungbean, technologies have been developed with respect to planting methods (Singh and Singh 2010), sowing time (Sekhon and Singh 2005b, Singh and Singh 2009), plant density (Singh *et al.* 2007, Singh *et al.* 2011b), nutrient management (Singh *et al.* 2008, Singh *et al.* 2011a) and weed management (Kaur *et al.* 2010, 2015). Furthermore, at crop maturity, paraquat can be sprayed for drying of foliage for facilitating combine harvesting of mungbean (Sekhon and Singh 2005a, Singh *et al.* 2012).

Sekhon *et al.* (2006) studied the economics of cropping system with and without summer mungbean and concluded that there was an advantage of 1.16 tonnes/ha and ₹ 10200 in total productivity and net return in rice-wheat-summer mungbean system over RWCS (Table 8).

Gan *et al.* 2015 showed that diversifying cropping systems with pulse crops can enhance soil water conservation, improve soil N availability, and increase system productivity. A 3-year cropping sequence study, repeated for five cycles in Saskatchewan from 2005 to 2011, showed that both pulse- and summer fallow-based

Table 8 Economics of cropping system with and without summer mungbean (Sekhon *et al.* 2006)

Cropping system	Yield (tonnes/ha)			Total productivity (tonnes/ha)	Net returns over variable costs (₹/ha)
	Rice	Wheat/ Potato	Summer mungbean		
Rice-wheat	7.0	4.8		11.8	38116
Rice-wheat-summer mungbean	7.0	4.8	1.16	12.96	48316
Rice-potato-summer mungbean	7.0	24.0	1.75	32.75	53150

systems enhances soil N availability, but the pulse system employs biological fixation of atmospheric N_2, whereas the summer fallow-system relies on 'mining' soil N with depleting soil organic matter. In a 3-year cropping cycle, the pulse system increased total grain production by 35.5%, improved protein yield by 50.9%, and enhanced fertilizer-N use efficiency by 33.0% over the summer fallow system. Diversifying cropping systems with pulses can serve as an effective alternative to summer fallowing.

Singh *et al.* (2011b) studied the productivity of different crop sequences at Varanasi on sandy loam soils (Table 9) and found that the inclusion of mungbean in RWCS increased the net returns and total productivity of the system. Four rice-based cropping systems, viz. rice-wheat (RW), rice-chickpea (RC), rice-wheat-mungbean (RWMb) and rice-wheat-rice-chickpea (RWRC) were evaluated. The RWMb system had higher system productivity (rice equivalent yield (REY) of 14595 kg/ha). Inclusion of summer mungbean in R-W system increased rice yield by 10% under recommended inorganic fertilizations (NPKSZnB), while inclusion of chickpea in alternate and every year had relatively marginal effect on rice productivity. After 10 years of continuous cropping, RWMb system with higher annual nutrient input resulted in higher soil available nutrients. Effect of crop rotation on system productivity found that the inclusion of mungbean in RWCS gave the highest rice equivalent yield (REY) over the rice-wheat alone. Thus inclusion of pulses under RWCS is the best option to increase net returns to the farmer (Fig 4).

Table 9 Productivity of different crop sequences at Varanasi on sandy loam soils (Singh *et al.* 2011b)

Treatment	Grain yield of rice (tonnes/ha)	REY[1] of winter crop (tonnes/ha)	REY of summer crop (tonnes/ ha)	System REY (tonnes/ ha)
Rice-wheat	4.0	5.9		10
Rice-wheat-greengram	4.5	6.4	3.1	13.9
Rice-wheat-*Sesbania*	4.6	6.5		11.1
Rice-lentil + mustard (3:1)-cowpea fodder	4.6	5.3	3.1	12.9
CD (P= 0.05)	0.38	1.13	0.53	1.23

[1] REY, Rice equivalent yield

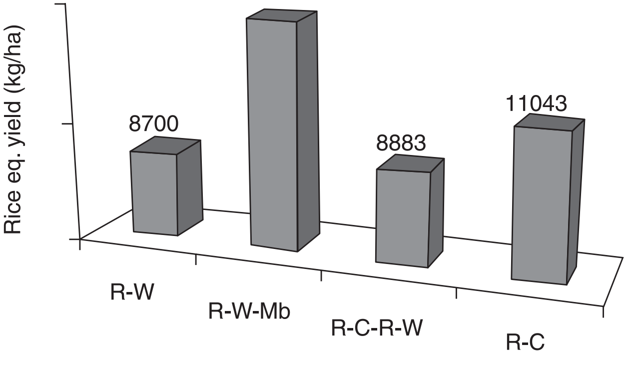

Fig 4 Effect of crop rotation on system productivity after 10 years cropping cycles (Singh *et al.* 2011b)

Effects of pulses on crop yield and soil health

Grain and seed yield: Kumar (2014) reported that averaged across seven years, rice-wheat-mungbean cropping system (RWMCS) produced 12.5 and 8.0% higher grain yields of basmati rice and wheat crops, respectively over RWCS. Furthermore, RWMCS also gave 0.88 tonne/ha additional seed yield of mungbean besides a significant improvement in soil fertility over RWCS. With respect to profitability, the basmati RWMCS was more profitable over the traditional RWCS. The increase was the most when biofertilizers and crop residues were combined either with farmyard manure (FYM) or vermicompost (VC). The yield increase in grain and seed yield resulted in increased net returns.

Soil health

Physical properties: Crop rotations that included pulses are generally beneficial to aggregate stability and formation of favourable soil structure. The fungi present in the pulse crop rhizosphere produce a glycoprotein called "Glomalin". The sticky part of glomalin entraps soil minerals, organic matter and debris to form stable soil aggregates. Hence, microbial activity of rhizosphere is directly responsible for the improved soil structure in crop rotations involving pulses. In a long-term rotational experiment, higher percentage of soil aggregates exceeding 0.25 mm were recorded where preceding crop was a legume (Sharma *et al.* 2000). Crop sequences that return sizeable amount of residues to soil usually result in improved (lower) bulk density (Ganeshamurthy *et al.* 2006). Incorporation of mungbean stover in rice-wheat mungbean sequence resulted in lower bulk density and increased hydraulic conductivity. Legume roots being rich in nitrogen content and having ability of deep penetration in the soil also encourage earthworm activity. The root channels and earthworm burrows increase soil porosity promoting air movements and water percolation

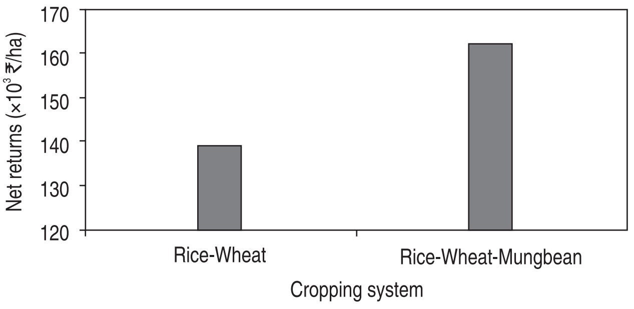

Fig 5 Net returns (₹×10^3/ha) as affected by cropping systems and nutrient management during 2011-12 (Kumar 2014)

Table 10 Yield of basmati rice, wheat and mungbean crops in organic rice-wheat and rice-wheat-mungbean cropping systems (Kumar 2014)

Year	Yield of rice-wheat (tonnes/ha)			Yield of rice-wheat-mungbean (tonnes/ha)			
	Rice	Wheat	Mean	Rice	Wheat	Mean	Mungbean
2009-10	3.94	3.81	3.88	5.10	4.04	4.57	0.81
2010-11	4.49	3.38	3.94	5.18	3.78	4.48	0.95
2011-12	3.71	3.52	3.62	4.08	3.97	4.03	0.83
2012-13	3.88	3.61	3.75	4.33	3.87	4.10	0.87

deep into the soil. Results of All India Coordinated Pulses Improvement Project (AICPIP) revealed that soil physico-chemical properties at the end of 7th crop cycle improved significantly in the crop sequences wherever mungbean or urdbean were involved in the sequence.

Chemical properties

Soil organic carbon: In a long-term trial at Indian Institute of Pulses Research in which soil organic carbon (SOC) improvement was recorded in rice-chickpea, rice-wheat-mungbean in lowland situation and maize-chickpea, pigeonpea-wheat and maize-wheat-mungbean system in comparison to rice-wheat and maize-wheat, respectively. Singh *et al.* (2009) reported increased SOC, total N due to inclusion of legumes in cropping systems (Table 11). Sharma *et al.* (2004) also reported an increase in SOC and available N due to summer mungbean.

Ghosh *et al.* (2012) reported that compared with the conventional rice–wheat system, rice–wheat–mungbean system resulted in 6% increase in soil organic carbon (SOC) and 85% increase in soil microbial biomass carbon. Relatively greater amount of carbon fractions and carbon management index (CMI) were obtained where crop residues, farmyard manure (5 tonnes/ha) and biofertilisers were applied over control and the recommended inorganic (NPKSZnB) treatment in the soil surface, specifically with inclusion of pulses in the system. In rice–wheat–rice–chickpea system the relative proportion of active carbon pool in surface layer (0–20 cm) to subsurface layer (20–40 cm) was highest (1.14:1) followed by rice–wheat–mungbean (1.07:1) and lowest in the rice–wheat system (0.69:1). A positive impact on SOC restoration and CMI was reported by replacing wheat with chickpea either completely or during alternate year in the conventional rice–wheat system.

Table 11 Changes in fertility status of soil under different cropping systems (Singh *et al.* 2009)

Crop sequence	Organic carbon (%)	Total N (kg/ha)	Available P (kg/ha)
Rice-wheat	-0.004	-8.0	1.4
Rice-lentil	0.006	10	4.8
Pigeonpea-wheat	0.006	9.0	8.8
Rice-wheat-mungbean	0.010	15.0	13.8

Nitrogen: It is well documented that pulses leave behind substantial amount of N in soil after their harvest. An improvement in the N budget of soil measured by improved mineralizable organic N and microbial biomass C and N has been reported by many workers. Nitrate nitrogen left after harvest of *rabi* pulses were estimated and chickpea ranked first (20.4 kg/ha) followed by field pea and lentil in contribution of residual NO_3 in the soil profile. Among the genotypes, chickpea cv. BG 1003, lentil cv. DPL 62 and field pea (*Pisum sativum*) cv. Rachana were highest in increasing the nitrate content. *Kharif* pulses also increased the soil NO_3-N by 4-8 kg/ha. Reduced use of soil nitrate is the reason for this extra nitrate during the growth of pulses (nitrate sparing effect) (IIPR 2011-2012).

Available P, K, S, Zn and B: Inclusion of legume in cropping system not only economizes nitrogen requirement of cropping system but also helps in efficient utilization of native phosphorus due to secretion of certain acids that help in solubilization of various forms of phosphorus. This capacity of legumes makes them efficient in native utilization of phosphorus present in different forms. Increased available P is a result of P acquisition from insoluble phosphates through root exudates. Chickpea has the ability to access P normally not available to other crops by mobilizing sparingly soluble Ca-P by acidification of rhizosphere through its citric acid root exudates in Vertisols , pigeonpea has the ability for dissolution of Fe-P in Alfisol (Ae *et al.* 1991). In a study conducted over three years, mungbean green manuring or incorporation of mungbean stover after picking of pods in rice-wheat-summer mungbean system considerably improved the available P status of soil, due to root exudates capable of mobilizing sparingly soluble P in soil (Saxena 1995). Inclusion of legumes also increases available P, K, S, Zn and B in soils (Table 12). Singh *et al.* (2009) also reported an increase in available P due to inclusion of mungbean.

Table 12 Effect of pulse based cropping system on soil available P, K, S, Zn and B (IIPR 2011-12)

Cropping system	Available P (kg/ ha)	Available K (kg/ ha)	Available S (kg/ ha)	DTPA–Zn (kg/ ha)	B (kg/ ha)
Maize-wheat	16.0	173.0	17.3	0.6	0.9
Maize-wheat-mungbean	17.2	186.0	19.4	1.1	0.9
Maize-wheat-maize-chickpea	18.0	185.9	18.5	0.8	1.0
Pigeonpea-wheat	16.8	183.2	19.1	0.8	1.0
Rice-wheat	18.55	234.2	14.10	1.68	0.86
Rice-wheat-mungbean	18.37	271.6	16.71	1.60	0.89
Rice-wheat-rice-chickpea	21.20	247.9	17.54	1.69	0.92
Rice-chickpea	21.55	243.4	17.15	1.82	0.93

Biological properties: Experimental results have revealed the higher microbial population in rice-wheat system due to inclusion of mungbean in the system when compared to fallow. Similarly in maize-based system, maize-wheat-mungbean recorded the highest soil microbial biomass carbon as compared to maize-wheat. Dehydrogenase enzyme activity, an index of soil microbial activity was also found to increase in soil after pulse crop (Kumar 2014). These increases in microbial activity in turn influence mineralization and immobilization of nutrients like N, P and S depending upon the environment. These results indicate that inclusion of pulses in crop rotation improves soil microbial biomass and their activity that could be vital for long-term soil health and productivity. Similarly, when legume residues were incorporated into the soil, microbial activity and overall system productivity increased. Tilak (2004) reported higher counts of bacteria, actinomyctes, fungi, *Azotobacter* and PSB due to growing of mungbean in fallow after rice (Table 13). Similarly, Venkatesh *et al.* (2013) reported 10 and 15% increase in soil microbial biomass carbon, 11 and 10% increase in total organic carbon under maize-wheat-mungbean and pigeonpea-wheat cropping system compared to wheat-maize cropping.

Kumar (2014) revealed that inclusion of mungbean in rice-wheat cropping system (RWCS) was quite advantageous. Levels of organic carbon, total N, available nitrogen, phosphorus, potassium and micronutrients increased significantly and substantially due to inclusion of mungbean in RWCS. Simultaneously the soil microbiological properties, viz. microbial biomass carbon, microbial biomass nitrogen and enzymatic (alkaline phosphatase, acid phosphatase, dehydrogenase, glucosidase, FDA hydrolysis, etc.) activities were also significantly higher in soils of rice-wheat-mungbean cropping system (RWMCS) than in RWCS. Application of FYM, crop residues, vermicompost, biofertilizers and growing of mungbean have a positive interaction in improving indices of soil biological activities, such as, glucosidase and alkaline and acid phosphatases (Table 14).

New recommendations and initiatives taken by Government of India

First of all, there is need to identify major research gaps for each intervention through appropriate research projects like information on appropriate crops and varieties, soil health, water management, agro-techniques, pest management, mechanization etc. which will help in refining the need-based technologies for different ecosystems. Already published satellite data on rice fallows provide some preliminary information but are inadequate for sound planning for agricultural development in these regions. So mapping of rice fallows with respect to health of our

Table 13 Soil microbial population as affected by legumes (Tilak 2004)

Treatments	Microbial population (per g soil)					Soil depth (cm)	
	Bacteria 10^5	Actinomycetes 10^4	Fungi 10^4	*Azotobacter* 10^2	PSB 10^2	0-15	15-30
Rice-fallow	42	0.3	0.1	22	0.4	192.1	156.5
Rice-MB (SR)	105	1.2	0.8	87	3.5	200.5	155.5
Rice-MB (SI)	167	5.5	1.3	202	6.0	244.0	195.7
C D (P= 0.05)	40.5	1.25	0.72	25.8	0.9	35.58	21.24

Table 14 Interactive effect of cropping system and nutrient management practices on glucosidase, alkaline phosphatiase and acid phosphatase activities in soil (Singh *et al.* 2015)

Cropping system/Nutrient management	Glucosidase (µg pNPG/g soil/h)		Alkaline phosphatase (µg pNPP/g soil/h)		Acid phosphatase (µg pNPP/g soil/h)	
	Rice–wheat	Rice-wheat-mungbean	Rice-wheat	Rice-wheat-mungbean	Rice-wheat	Rice-wheat-mungbean
Control	13.7	16.7	530	523	120	97
FYM	14.6	20.3	359	296	111	108
Vermicompost (VC)	14.9	27.3	297	411	147	136
FYM + Crop residue (CR)	19.7	24.0	200	386	112	127
VC + CR	20.6	27.8	374	322	139	104
FYM + CR + BFs	21.0	22.1	253	383	158	123
VC + CR + BFs	21.3	23.8	536	289	156	165
Mean	18.0	23.2	364	373	135	123
LSD (*P* = 0.05)	Cropping system (CS): NS Nutrient management (NM): 5.0 CS × NM: 3.2		Cropping system (CS): NS Nutrient management (NM): 69 CS × NM: 50		Cropping system (CS): NS Nutrient management (NM):14.8 CS × NM: 29.3	

Values are mean of the data (n = 3) and are statistically significant at $p < 0.05$. Data analysed by Two-way ANOVA at LSD < 0.05

soils and pattern of rainfall; existing cropping system, crop productivity, stability and production problems; socio-economic indicators like family income, poverty, education, stray cattle menace and livelihood security; existing infrastructures and marketing should be done so that location specific programmes could be developed. There is a need to critically examine the developments, drawbacks and suggestions made for improvement in promotion of research and development (R & D) efforts in other areas.

In order to monitor impact of R&D efforts on area expansion in rice fallows under different crops, cropping systems and soil health, periodic monitoring through GIS is required. Despite heavy rains during *kharif* season, soil moisture becomes the most critical limiting factor for raising second crop during winter as most of the runoff is wasted. It is, therefore, necessary to create farm pond and community water reservoirs in the area well supported by government. This will serve as important source for life-saving and supplemental irrigation. Further, the loss of soil and plant nutrients from productive lands will be reduced. Community-based seed production programmes need to be launched with appropriate processing and storage facilities. The national and state seed corporations should strengthen their activities in these areas. Poor socio-economic conditions and purchasing power compel farmers either to skip second crop after rice or resort to no input use. Therefore, subsidies on farm inputs, credit and crop insurance schemes should be implemented. Marketing plays a key role in enthusing farmers for crop production. Well organized marketing and processing of farm produce need attention. A scheme has been launched in *rabi* 2016-17 for targeting 30 lakh ha of rice-fallow under pulses by next three years.

Targeting rice-fallow areas in eastern India

Department of Agriculture Cooperation & Farmers Welfare is implementing a sub-scheme under Rashtriya Krishi Vigyan Yojana (RKVY) – “Targeting Rice-Fallow Areas” in Eastern India since *rabi* season 2016-17. The implementing states for this programme are:

- Assam, Bihar, Chhattisgarh, Jharkhand, Odisha and West Bengal with a total allocation of fund of ₹ 75.00 crore. Potential area: More than 57.00 lakh ha
- Target area: 30.00 lakh ha in 3 years.
- An area of 19.00 lakh ha has been covered during *rabi*/ summer in these states

Mapping rice-fallow areas in India

- In India efforts on mapping of rice-fallow areas in some Eastern States using remote sensing technique has been attempted through Mahalanobis Crop Forecasting Centre, New Delhi.
- The centre has applied remote sensing data with ground validation survey to identify rice-fallow areas in Odisha, Chhattisgarh and other states.

Conclusion

Rice-based systems are the predominant cropping systems in India. These systems have led to a number of problems including, depletion in soil fertility, weed infestation, water table depletion and decrease in the area under pulses and consequent lowered pulse production. Legumes can play an important role in reversing the process of degradation of soil and water resources, and improving the production potential of the total cropping system. Legumes can be included in the rice-wheat based cropping system either as catch crops, or can be grown as a spring crop. The scope of extra-short- and short-duration pulses is enormous provided biotic constraints, mainly insect pests are minimized. In the eastern IGP, there is large scope of utilizing existing rice-fallows by growing chickpea, lentil, and *khesari* (*lathyrus*) after rice. Residual soil moisture in surface layer at the time of planting *rabi* crops is the major constraint in rice fallows. Relay cropping in standing rice is often practiced, the option is now shifting for direct seeding using zero-till drill or turbo type Happy Seed drill which need to be designed for different situations. Tillage and plant population management, application of nutrients and weed management in *rabi* crops also pose serious challenges in rice fallows. Therefore, early-maturing crop varieties, relay cropping, using higher seed rate, seed priming, seed inoculation with microbial culture, mulching, foliar spray of nutrients etc. are recommended practices which need to be further evaluated and standardized for different ecosystems. More research efforts are needed to better understand the IGP ecosystem in the context of production of pulses, and their positive effects on sustainability of the natural resource base. Other constraints are unassured prices and poor market infra-structure. Although the Government of India announces procurement prices for legumes at higher levels than for cereals, their effective implementation is lacking. In the changing climate scenario adoption of environmental friendly technologies is important to mitigate the adverse effect of climate drivers like CO_2, N cycle, increasing temperature and unpredictable precipitation. Around 12.7 = 38% increase in wheat yield was observed when legume residue was incorporated in cereal-based cropping system (Singh *et al.* 2011c). Inclusion of legume can improve soil quality by virtue of increasing soil fertility 11, 28, 25 and 20% of SOC, N, P and K, respectively. Inclusion of pulses also improves soil physical and biological properties of soils. Therefore, creation of awareness of these findings to the farmers is of utmost importance to achieve the goal of “International Year of Pulses – 2016”.

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