Research Review Article

Indian Journal of Agricultural Sciences **85** (6): 747–58, June 2015/Review Article

Improved crop management practices for sustainable pulse production: An Indian perspective

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Received: 18 May 2014; Accepted: 7 January 2015

ABSTRACT

Pulses are an integral part of Indian agricultural economy next to cereals and oilseeds in terms of acreage, production and economic value. Pulses are rich source of protein and energy, but in India, these are largely cultivated under energy starved conditions resulting in poor pulse productivity. This is mainly because of unavailability of quality seed at desired time, cultivation on marginal and sub-marginal lands, imbalanced use of fertilizers and non-adoption of crop improved management practices. India is the largest producer and consumer of pulses in the world, accounting for about 25% of global production, 27% of consumption and 34% of food use. To reduce the demand-supply gap, government of India launched various programmes in pulses. Still, prime attention is required to meet the food security challenges, especially in case of pulse sector. In order to enhance and sustain the pulse productivity at high levels, the development and promotion of low–cost pulse production technology need greater attention so that technology is widely adopted by the practizing farmers. The most potential technologies in pulse production include improved crop establishment and management practices, integrated soil fertility and pest management practices, etc. which enhance not only the productivity and profitability but also warrants environmental and social sustainability besides nutritional security. Various agronomic researches have shown that improved cultivation practices, such as seed replacement with improved varieties, raised bed planting method, use of biofertilizers, foliar application of fertilizers at critical stages in rainfed areas, application of secondary and micro-nutrients and adoption of appropriate modules for integrated weed and pest management, etc. have great potential in gearing–up pulses productivity. Thus, there is a great challenge for policy makers, farm scientists and farming community to enhance pulse productivity using improved farm technology to meet–out the national and local pulse requirements. Thus, this article presents a critical review on capacity of various improved crop management practices to scale–up pulses productivity on one hand and highlight future research priorities on the other with the prime objective of sustaining pulse production in India.

Key words: Crop management, Improved agronomic practices, Nutritional security, Pulse productivity, Sustainable production

India is one of the major pulse producing countries contributing about 25% to the global pulse production. Pulses are also an important component of Indian agricultural economy next to foodgrains and oilseeds in terms of acreage, production and economic value (Choudhary 2009). Pulses are an integral part of vegetarian diet of a large population in India. Besides being a rich source of proteins and essential amino acids; they also maintain soil fertility through biological nitrogen fixation in symbiotic association with *Rhizobium* bacteria present in their root nodules. Thus, pulses play a vital role as nitrogen fixing mini-factories, which help in sustaining crop productivity and soil health. Pulses are rich sources of protein and energy but in India, these are largely cultivated under energy starved conditions, mostly on marginal and sub-marginal land and more than three-fourth of the area under pulses is still rainfed resulting in poor crop productivity (Choudhary 2013). India is the largest producer of pulses in the world, with 25% share in the global production. The important pulse crops are chickpea, pigeonpea, mungbean, urdbean, lentil and fieldpea (Ali and Gupta 2012). In India, production of pulses is around 19.3 million tonnes (ESI 2015) with a very low average productivity of 764 kg/ha. Currently, total area under pulses is 26.3 million ha (Choudhary and Suri 2014b).

Pulse productivity in India is much lower than other pulse producing countries. This is mainly because of unavailability of quality seed at desired time, cultivation on marginal and sub-marginal lands, injudicious use of fertilizers and non-adoption of crop management practices and poor

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marketing infrastructure (Chandra 1994, Choudhary 2013). The country is importing pulses to the tune of 2.5-3.5 million tonnes every year for meeting the demand of the growing population; this led to decline in the availability of pulses in the country from 69 g/capita/day in 1961 to 33 g/capita/day in 2009-10 (Ali and Gupta 2012). To overcome the problem of protein energy malnutrition, a minimum of 50 g pulses/capita/day should be available in addition to other sources of protein. Thus, to make the nation pulse sufficient, average yield level has to increase substantially up to 1 200 kg/ha by 2020 (The Hindu 2005). To achieve this, more than 4.0% growth rate in pulse production is required. Pulses contain 20-25% proteins and essential amino acids required for proper growth and development of human body. These are comparatively cheaper than animal protein (milk and egg) for majority of vegetarian population in India and hence referred to as 'poor man's meat'. India is the largest producer and consumer of pulses in the world, accounting for 27% of consumption and 34% of food use (FAO). India is also the top importer with 11% share of global imports during 1995-2001 (Gregory 2003). To reduce the demand-supply gap, Government of India launched various programmes like integrated scheme of oilseed, pulses, oilpalm and maize (ISOPOM), national food security mission (NFSM) and front-line demonstrations (FLD) programme in pulses. Still, prime attention is required in pulse production to meet the challenges of increasing population. Thus, there is a great challenge for policy makers, scientists and farming community to enhance pulse productivity and diversify their cropping systems to meet out the national and local pulse requirements (Choudhary 2013). Thus, it is prime time to interospect on the status and capacity of various improved crop management practices to scale–up pulses productivity on one hand and highlight future research priorities on the other with the prime objective of sustaining pulse production in India.

IMPROVED CROP MANAGEMENT PRACTICES

Pulses have excellent source of high quality protein, essential amino acids, fatty acids, minerals and vitamins for millions of Indians. In order to enhance and sustain the pulse productivity at desired levels w.r.t. Indian perspective for better food and nutritional security, the development and refinement of low–cost pulse production technologies need greater emphasis so that these technologies are acceptable to resource-constrained Indian farmers. The most potential technologies in pulse production include improved crop establishment and management practices, integrated soil fertility and pest management practices, etc. which enhance not only the productivity and profitability but also warrants environmental and social sustainability besides nutritional security. It is desirable that agricultural practices should be economically viable, environmentally sustainable and socially acceptable inclusive of food safety and quality dimensions. A brief insight into status and production abilities of various improved crop management practices has been vividly presented below.

Selection of suitable varieties/cultivars

Varietal improvement programme in pulses was initiated in 1917 with selections from different parts of the country especially pigeonpea. Today, a large number of improved varieties have been released for improved yield, disease and pest resistance, short duration, synchronous maturity and short stature, etc. suitable to varied agro-climatic and soil conditions. Thus, in particular, development of short duration, disease resistant and high yielding varieties in the recent past made these crops a viable alternative to low yielding coarse cereals under rainfed conditions and also provided an opportunity for expansion in rice fallows and in double cropping systems. Breeding work is also underway to produce short duration varieties and hybrids for almost all pulse growing areas throughout country. A list of some promising pulse cultivars for different production zones in India (Table 1) as well as suitable pulses and their cultivars specifically for rainfed agro-ecosystems (Table 2) are furnished below.

Table 1 Promising pulse varieties in India and their salient features

Pulse crop	Features
Redgram (Cajanus cajan)	
UPAS 120	Extra early, suitable for double cropping, escapes drought
VL 1 Arhar	For hilly areas and intercropping in NW Himalayas
Azad	Resistant to sterility mosaic
Narendra Arhar 1	Resistant to sterility mosaic and tolerant to wilt, pod borer
ICPH 8	Hybrid, 30% more yield than UPAS 120
PPH 4	Short duration
Pusa 991, 992	Wilt and sterility mosaic resistant
Pusa 2001, 2002	*Phytophthora* blight tolerant
TJT 501	Sterility mosaic and wilt resistant
Durga	Short duration and determinate plant type
Surya	Medium duration
Greengram (Vigna radiata)	
Varsha	Synchronous and early maturity
PM 5	Bold seeded, extra early and resistant to yellow mosaic virus
HUM 16	Root-knot nematode resistant and yellow mosaic resistant
Pusa Vishal	Yellow mosaic resistant
Pusa 0672	*Cercospora* leaf spot resistant and yellow mosaic resistant
SML 668	Root-knot nematode tolerant and yellow mosaic resistant
RMG 492	Suitable for spring season and yellow mosaic resistant
TARM 1	Suitable for *rabi* season
Pusa 9531	Summer and yellow mosaic resistant
BM 2002-1	Powdery mildew resistant
Eksila (WGG 37)	*Rabi* and yellow mosaic resistant

Contd.

Table 1 (*Continued*)

Pulse crop	Features
Co 6 (COGG 902)	Suitable for all seasons and yellow mosaic resistant
VBN (GG 2)	Suitable for all seasons and yellow mosaic resistant
Blackgram (Phaseolus mungo)	
PDU 1	Suitable for spring season
Pant U 30	Resistant to yellow mosaic virus
NDU 99-3	Suitable for *kharif* and resistant to yellow mosaic virus
Shekhar 2	Yellow mosaic and *Cercospora* leaf spot resistant
WBU 109	Suitable for spring and yellow mosaic resistant
KU 96-3	Yellow mosaic resistant
VBN 5	Suitable for all seasons and yellow mosaic and powdery mildew resistant
Ujala (OBG 17)	Suitable for *rabi*, yellow mosaic and powdery mildew resistant
Cowpea (Vigna unguiculata)	
Swarna	High protein cultivar
Pusa Sampada	Free from common diseases
RCP 27	Yellow mosaic and *Macrophomina* blight resistant
Gujrat Cowpea 2	Drought tolerant
DFC 1	Fodder type
UPC 9202	Shattering tolerant
Co 6	Root-rot tolerant
Pusa Komal	Bacterial blight resistant
Pusa Sukomal	Suitable for *Kharif* and summer, resistant to golden yellow mosaic virus and leaf spot disease (*Pseudocercospora cruenta*).
UPC 628	Forage cowpea, resistance to yellow mosaic virus, anthracnose, collar/root rot, aphid, flea beetle and root-knot nematode
Horsegram (*Macrotyloma uniflorum*)	
VL Gahat 10	Yellow mosaic resistant
Birsa Kulthi 1	*Macrophomina* blight resistant
PHG 9	Powdery mildew and anthracnose resistant
GPM 6	Forage type
CRIDA Latha	Powdery mildew and yellow mosaic resistant
Mothbean (*Phaseolus aconitifolia*)	
Jawala	Suitable for western part of India
CAZRI Moth 1	Drought resistant
FMM 96	Resistant to yellow mosaic
JMM 259	Resistant to yellow mosaic
Chickpea (*Cicer arietinum)*	
Pusa 256	Resistant to wilt, tolerant to *Ascochyt*a blight, suitable for late planting
Uday	Late sowing and tolerant to wilt
Pusa 372	Late sowing and small seeded
Pant G 186	Resistant to wilt, blight and suitable for late planting
Anubhav	Suitable for rainfed condition
Karnal chana 1	Suitable for saline situation
BDG 72	Moderately resistant to wilt and root-rot
Co 3	Extra bold, resistant to wilt and collar rot
Phule G 95418	Resistant to wilt
Pusa 1088	Bold-seeded and tolerant to moisture stress
Pusa 1105	Moderately resistant to wilt and dry root-rot
WCG 10	Tolerant to wilt, erect and seed smooth
Gram 3	Resistant to wilt
Sweta (kabuli)	Wilt resistant and bold seeded
L 551 (kabuli)	Tolerant to wilt
BG 1053 (kabuli)	White bold seeded and tolerant to wilt
Pusa 1003 (kabuli)	White seeds
GPF 2	Plant grow erect with thick stems resistant to lodging
Field pea (Pisum sativum)	
IPF 99-25	Resistant to powdery mildew, tall type
Pant P 13 & 14	Resistant to powdery mildew, tolerant to rust, semi dwarf
Indra	Dwarf and resistant to powdery mildew
Pusa Prabhat	Extra early maturity
Sapna	Dwarf and resistant to powdery mildew
Alankar	Resistant to powdery mildew
TRCP 8	Resistant to powdery mildew
Lentil (Lens esculenta)	
VL Massor 103	Tolerant to rust
Pant L 5	Resistant to wilt, rust and blight, bold seeded
DPL 62	Bold seeded, resistant to rust
LLS 669	Tolerant to rust and blight
HUL 57	Small seed, tolerant to rust and wilt
Frenchbean (Phaseolus vulgaris)	
HPR 35	Red seed with purple streaks
IIPR 96-4	Resistant to bean common mosaic virus
PDR 14 (Udai)	Variegated red seeds
IPR 98-5 (Utkarsh)	Cold tolerance, attractive seed colour

Source: Prasad (2012), Bana *et al.* (2014)

Table 2 Pulse cultivars suitable for rainfed agro–ecosystems

Crop	Variety
Pigeonpea	Pusa Ageti, Sharda, ICPL 87, Pusa 991, T 21
Mothbean	Maru Moth 1, Jadia, Jwala, AKMO 33, AKMO 35, Moth 880, RMO 40, Maru Bahar
Clusterbean	Durgapura Safed, FS 277, Maru guar, HG 75, Navin, RGC-1017, RGC-936, RGC-1003
Chickpea	Ujjain 21, G 24, G 130, Phule G 5, K 850, Vijay, RSG 4, RSG 936, Pant G 114, Pusa 1053, Pusa 256, Pusa 372, Pusa 362

Source: Bana *et al*. (2014)

Tillage management

Tillage is necessary for manipulation of soil with farm tools and implements for obtaining ideal conditions for seed germination, seedling establishment and growth of crops (Das *et al.* 2014). Main aim of tillage is to produce good soil condition and tilth for crop establishment and initial root and shoot development. *Kharif* pulses require tillage for opening the soil through soil turning plough and two cross-harrowing followed by planking. In *rabi* pulses soil turning plough after *kharif* crops and two cross-harrowing or two-three cultivations by cultivator followed by heavy planking is needed. If necessary a pre-sowing irrigation should be given to ensure adequate moisture. Summer mungbean (*Vigna radiata*) residue recycling through soil turning plough in pulse as well as cereal based cropping systems lead to enhanced system productivity, profitability and soil health (Pooniya *et al.* 2014). In dryland areas, deep ploughing results in better moisture conservation, root proliferation and higher productivity over shallow cultivation (Vadi *et al.* 2006). The heavy soils require one pre-shower deep ploughing followed by 2-3 cultivations and harrowing after early shower. Tillage practices also depend upon climate and soil conditions. All the growth parameters were significantly improved when the seed bed prepared with only one ploughing due to better tilth (Tomar and Singh 1991). Conventional tillage is best for *tarai* region of India for higher productivity of lentil because in conventional tillage more aeration and proliferation of roots takes place which extracts more soil moisture and nutrients from per unit area of soil (Singh and Singh 2008). Tillage consumes maximum energy, hence efforts have been started world over since 1970s to reduce energy use on the farm by efficiently applying different inputs and reducing the number of tillage operations to bare minimum for seed bed preparation to harness higher or equivalent yields (Das *et al.* 2014). This led to development of zero-tillage and conservation tillage concepts. Zero tillage practices can have beneficial impacts on productivity as well as minimizing environmental degradation such as soil erosion in legume and cereal crop growing areas (Das *et al.* 2014).

Planting time and sowing depth

Time of sowing is the most important non-monetary input having significant effect on crop growth, phenological development, insect-pest and weed dynamics and crop productivity. The environmental conditions, viz. temperature, photo-period and moisture availability, etc. significantly changes with time of sowing. Delayed planting restricts vegetative growth and pod bearing branches, decreases biological-nitrogen fixation and also leads to forced maturity. At the same time, it also increases incidence of pests, especially pod borer (*Helicoverpa armigera*) in chickpea (Ali *et al.* 1998). Contrary to that sometimes off-season cultivation of green peas, beans, cowpea and other legume vegetables leads to enhanced profitability due to premium prices in the market though the yield levels are quite lower owing to less congenial climate (Rahi *et al.* 2013). *Rabi* greengram can be sown up to end of December and this is practiced in southern part of country, where the winters are not severe. Sowing of summer greengram in first fortnight of March recorded higher yield as compared to last week of March (Patel 2003). Suitable time for summer blackgram is March (Jaiswal 1995); and for spring season January is the best month to obtain higher productivity (Reddy *et al.* 2007). September first week is the suitable time for horsegram sowing during *rabi* season (Kalita *et al.* 2003). Optimum sowing depth depends on type of crop/cultivar, growing season, soil moisture, soil texture, and more importantly on seed size of the respective pulse crops (Dass *et al.* 1997).

Planting geometry

Optimum spacing requirement depends on type of crop and cultivar, growing season and planting system. Most of short duration pulse varieties need narrow spacing, while long duration varieties perform well under wider spacing. An appropriate planting density in field crops and vegetables lead to better harness of the solar radiation to translate into higher crop yields (Choudhary *et al.* 2014b). It is reported that sowing in first week of June recorded highest grain yield with both narrow and wider spacing in different varieties and sowing beyond that date reduced the pulse yield (Padhi 1995). Sowing of mungbean at 20 cm × 10 cm spacing was found more adequate (Kumar *et al*. 2006). In general, *kharif* sown crop requires wider spacing and less plant population compared to summer sowing due to fairly warm temperature, prolonged vegetative growth and profuse branching (Prasad 2012).

Optimum seed rate

Seed requirement varies with cropping system, growing season, test weight and germination percentage of the seed material. The seed rate also varies according to weather conditions and duration of crop growth. Primarily, plant population desired per unit of land area determines the seed/seedling rate (Prasad 2012). Spacing between rows, spacing of plants within row, plant size and seed germination, etc. affect the rate of planting required to reach a particular plant population (Poehlman 1991). In a study, it was revealed that optimum seed rate for higher yield of greengram is 37.5 kg/ha during summer and 30 kg/ha during rainy season in Punjab (Sekhon *et al*. 2006). In intercropping systems, the seed requirement depends on proportion of area available to each crop; and in case of drylands, slightly higher seed rate is required. In hill and mountain ecosystems, the seed rate for pulses are quite higher owing to less soil moisture availability in rainfed areas, erratic rainfall pattern and low temperature; adequate enough to better harness the solar radiation to translate into higher crop yields (Choudhary 2013).

Method of sowing

Sowing method is an important factor which has direct effect on seed requirement, plant establishment, and cultural operations and efficiency of production inputs. Sowing of pulses is mainly through broadcasting seeds in seed bed followed by planking; or drilling seeds in furrows opened by plough with or without attachment of seedling tube through tractor or bullock operated seed drills. In *kharif* pulses, raised/ridge-furrow planting technique has been found very successful in draining excess water from crop root zone and increase the yield by 25-30% over flat bed planting (Pramanik and Singh 2008, Das *et al*. 2014). Ali (1998) observed that in Ludhiana (Punjab), flat sowing recorded significantly higher pigeonpea yield over other treatments, but at Hisar and Pantnagar in North Indian conditions, raised bed with 2.7 m width recorded significantly higher yield over other sowing methods. It might be due to proper drainage of excess water from crop root zone and less incidence of insect-pest and diseases. Thus, application of appropriate sowing method also determines the success and productivity of crops in particular environmental, temporal and field variability regimes (Choudhary and Suri 2014a).

Nutrient management

Balanced supply of nutrients in adequate amount and available form holds the key to successful crop production. Fertilizer management encompasses on adding right amount of nutrients at right time through an appropriate method so as to minimize nutrient losses, thereby, making efficient nutrient-use for enhancing crop productivity and maintaining soil fertility (Dass *et al.* 2014). Pulses require less amount of nitrogen as they are capable of fixing atmospheric N biologically through *Rhizobium* bacteria but need adequate phosphorus and sulphur for their root proliferation and synthesis of sulphur containing amino acids (Choudhary 2009). Legume nitrogen fixation starts with formation of a nodule. A common soil bacterium, *Rhizobium*, invades the root and forms root nodules. Biological nitrogen fixation is the process that changes inert N_2 to biologically useful NH_3, thus, pulses require less fertilizer N though their P requirement is high. It is inevitable to add the fertilizer P in pulses through phosphatic fertilizers and microbial inoculants (Choudhary *et al.* 2014a, Bengia Bai *et al.* 2014). A breakthrough is essential in this matter to promote P fertilizer use in legumes by the farmers. It is observed that farmers use sub-optimal doses of P fertilizers in pulses (Choudhary and Suri 2014b). Pulses also require comparatively higher amount of some micronutrients like molybdenum and iron which are integral constituents of nitrogenase enzyme, essentially required for nitrogen fixation (Choudhary *et al.* 2014a). Application of sulphur significantly increases the grain (9.1%) and straw yield (9.6%) and protein content with application of 20 kg sulphur/ha. In a study, application of micronutrients alone or in combination did not influence yields significantly, but a combination of all three micronutrients (Zn+Mo+B) resulted in significant increase in grain yield (Anonymous 2009). Dass *et al.* (1997) have found 60 to 70 kg P_2O_5/ha to be an optimum dose for chickpea production in acid Alfisol of western Himalayas. Kushwaha (2007) reported that combined application of *Rhizobium* + phosphorus solubilizing bacteria (PSB) + nitrogen + phosphorous or inoculation of *Rhizobium* and PSB alone or in combination registered higher net returns over control due to lower cost of biofertilizers. Combined application of 40 kg sulphur/ha and 5 kg zinc/ha recorded significantly higher grain and pod yield of pea over 40 kg sulphur/ha and control. Application of S and Zn improved the root nodulation and amino acid content in pea seed (Kasturikrishna and Ahlawat 1999). Puste and Jana (1988) reported a positive and linear increase in pigeonpea yield due to application of $ZnSO_4$ from 0 to 20 kg/ha and concluded that application of 25 kg $ZnSO_4$/ha resulted in economically higher returns. Soil test crop response (STCR) based targeted precision nutrient management practices in legumes and other field crops can also be good alternative to enhance crop productivity with economic use of chemical fertilizers in Indian conditions (Suri *et al*. 2011a, 2011b, 2013; Suri and Choudhary 2012, 2013). Application of VAM fungi also play an important role in phosphorus transformations, P economy and enhanced productivity in green peas in acid Alfisol (Kumar *et al*. 2014, Yadav *et al.* 2015). Application of micronutrients, viz. zinc, boron and iron also influenced the performance of pulses (Table 3).

Table 3 Response of pulses to micronutrients

Micronutrient	Crop	Response (kg grain/ha)	
		Range	Average
Zinc	Pigeonpea		160
	Blackgram	110–1 120	240
	Greengram	60–300	170
	Cowpea		210
Boron	Pigeonpea	30–320	100
	Blackgram	40–350	170
Iron	Blackgram	160–500	340

Source: Singh (2001)

Application of 40 kg P_2O_5/ha as rock phosphate combined with phospho bacteria and VAM increased grain and straw yield of horsegram (Prabakaran *et al.* 1999). A significant response of chickpea to application of 15 kg K_2O/ha in both medium and high K soils and maximum response in medium soils was recorded by Thyagarajan *et al.* (2003). Sulphur is also essential for pulse crops like NPK and its deficiency is common under intensive pulse-cropping systems (Thyagarajan *et al.* 2003). Long duration crops like pigeonpea responded up to 40 kg S/ha, whereas short duration pulses like chickpea, lentil and urdbean showed significant response up to 20 kg S/ha (Table 4).

Table 4 Response of pulses to sulphur application

Pulse crop	Seed yield (tonnes/ha)	
	20 kg S/ha	40 kg S/ha
Chickpea	0.19	0.19
Lentil	0.15	0.15
Pigeonpea	0.14	0.15
Urdbean	0.10	0.10
Mungbean	0.12	0.17

Source: Adapted from Ali and Singh (1995), Thiyagrajan *et al.* (2003)

Green manuring of pulses for long-term productivity of soils

Green manuring of pulses usually perform multiple functions that include soil improvement w.r.t. physico-chemical and biological properties as well as enhancement of soil microbial biomass and enzymatic activity. In a study, regular incorporation of *Sesbania aculeata*, cowpea and mungbean green manuring improve availability of micronutrients to crop plant, i.e. zinc, iron, manganese, and copper in soil compared to summer fallow (Pooniya and Shivay 2013). Incorporation of *Sesbania aculeata* residue also enhanced soil microbial activities, which are vital for the nutrient turnover and long-term productivity of soils, leading to enhanced productivity of field crops (Pooniya *et al*. 2012). *Sesbania* green leaf manuring and cowpea intercropping also enhances the soil fertility and consequently crop productivity (Bana and Gautam 2009, Bana *et al*. 2012).

Water management

In general, all the *kharif* pulses are grown under rainfed conditions without irrigation in India. On the contrary, pulse crops need proper drainage as they are very sensitive to waterlogging (Sharma *et al*. 2005). Pulses grown during spring/summer and winter months require irrigation when the soil moisture becomes limiting factor. At critical growth stages of flowering and pod formation, *kharif* pulses also responded to irrigation when there is dry-spell (Prasad 2012). Experimental results showed that first irrigation should be given 20 days after sowing and subsequent irrigations at 10 days interval. Delay in application of first irrigation (30 DAS) could not reverse the growth and yield even if subsequent irrigations were given at short intervals (Anonymous 2009). The results reveal that use of furrow irrigation with raised-bed systems improve the irrigation water-use efficiency under permanent raised-bed seeding where tillage is done on top of the beds. Furrow irrigated seeding system in north-west India (Table 5), resulted in both higher yield and significant water savings (16-20%) for a wide spectrum of legumes compared to traditional farmers' practice (Lumpkin and Sayre 2009). In a study on application of anti-transpirants in soybean, it was revealed that $MgCO_3$ (5%) and KNO_3 (1%) enhance soybean productivity significantly over control (Dass *et al*. 2013). Thus, this can be a new area of research to be explored in other legumes, i.e. pulse crops to enhance their production under rainfed areas. Application of VAM fungi also holds great promises in tolerance to water stress besides phosphorus nutrition management in rainfed peas (Kumar *et al*. 2014).

Table 5 Comparision of irrigation water use under different crop management systems

Pulse crop	Irrigation water use (cm)		% saving of water by furrow irrigation
	Raised bed seeding with furrow irrigation	Conventional seeding with flood irrigation	
Pigeonpea	13	15	16
Soybean	17	20	16
Greengram	17	21	16
Vegetable pea	8	10	18

Source: Lumpkin and Sayre 2009

Weed management

Critical period of crop weed competition varies among different pulses. Several studies showed that critical period was 40-60 days after sowing (DAS) in dwarf pea while in pigeonpea + sorghum intercropping in rainfed condition, it is up to 60 DAS. Unchecked weeds cause 20-90% yield losses in different pulse crops. The major weed flora associated with pulses are presented in Table 6.

Integrated weed management (IWM) is basically integration of effective, dependable and workable weed management practices such as cultural, mechanical, chemical and biological that can be used economically by the farmers. Mishra and Bhan (1997) obtained higher grain yield due to better weed control with application of fluchloralin (ppi) and pre-emergence pendimethalin 1.0 a.i. kg/ha + one hand weeding at 30 DAS in pea at Jabalpur (Madhya Pradesh). Choudhary (2013) again obtained higher grain yield with the pre-emergence application of pendimethalin 1.0 kg a.i./ha in blackgram, pigeonpea, kidneybean, cowpea, chickpea and lentil in Himachal Pradesh. Similarly, grain yield and net returns of chickpea were significantly higher with pendimethalin 30 EC @ 0.5 kg a.i./ha + one hand weeding at 30 DAS as compared to other treatments like pendimethalin 1.0 kg a.i./ha and control (Rathi *et al*. 2004). In a study, the cultural method (hand weeding) was found most efficient in chickpea which recorded highest seed and straw yields by 19.6 and 18.6% higher yield than un-weeded control (Jayapaul and Devasagayam 1998). Highest seed yield of chickpea was recorded at row spacing of 30 cm, while among weed control measures, hand weeding gave significantly higher seed yield over other treatments and it remained at par with chickpea + paddy straw mulching (Pooniya *et al*. 2009). Gajera *et al.* (1998) reported that mulching with sugarcane trash @ 8 tonnes/ha is effective for control of weeds and equally important in increasing yield, conservation of soil moisture, moderation of soil temperature and suppression of weed growth in pigeonpea (Table 7).

Table 6 Major weed flora associated with pulses

Kharif pulses	*Rabi* pulses
Cyperus rotundus	*Chenopodium album*
Amaranthus viridis	*Fumaria parviflora*
Commelina benghalensis	*Lathyrus* spp.
Euphorbia hirta	*Melilotus* alba
Portulaca oleracea	*Vicia sativa*
Eragrostis spp.	*Phlaris minor*
Digera arvensis	*Argemone mexicana*

Source: Prasad (2012)

Table 7 Effect of mulching on yield of winter pigeonpea

Treatment	Grain yield (tonnes/ha)	Stalk yield (tonnes/ha)
No mulch	1.40	3.31
Soil mulch	1.69	3.99
Sugarcane trash mulch @ 8 tonnes/ha	2.07	5.08
CD (*P*=0.05)	0.06	0.22

Source: Gajera (1998)

Plant protection

Pulses are susceptible to many insect-pests and diseases. The losses in yield due to lack of plant protection measures vary from 46-96% depending on the crop and varieties. Major pests and diseases of pulses are mentioned in Tables 8 and 9.

Integrated pest management (IPM) in pulses refers to application of an inter-connected set of principle and methods to minimize problems caused by insects, diseases, weeds and other agricultural pests. IPM includes use of resistant or tolerant varieties, crop rotation with non-host crops etc. Intercropping of gram + linseed/mustard or gram + coriander encourages natural enemies of pod borers. Use of bio-insecticide NPV @ 250-500 LE/ha controls pod borers. Use of neem seed kernel extract (5%) is also helpful for control of pod borers. Use of sex pheromone trap is also helpful in controlling pod borers. Ahmad *et al.* (1999) reported that appropriate IPM module for control of gram pod borer NPV @ 250 LE/ha followed by cypermethrin 0.02% at 10 days interval was effective and recorded higher grain yield compared to NPV @ 250 LE/ha alone. Pheromone based fruit fly management is another viable option for fruit fly management in beans and other vegetables (Sood *et al.* 2013).

Integrated disease management (IDM) is a approach that uses all available management strategies to maintain disease pressures below an economic injury threshold. It does not advocate a routine chemical application program to prevent disease, but promotes the integration of cultural, physical, biological and chemical control strategies. The basic objectives are to reduce the possibility of introducing diseases into the crop and avoid creating conditions suitable for disease establishment and spread. IDM includes deep summer ploughing and field sanitation, growing resistant varieties, seed treatment with fungicides, crop rotations with sorghum and tobacco, soil solarization and soil treatment with formaldehyde, captan and vapam etc., application of neem cake @ 150 kg/ha basically to reduce root-rot. AM fungi also induce disease tolerance in legume crops (Kumar *et al*. 2014). Various fungicides and bio-agents are tried as seed treatment to control pulse diseases. Application of carbendazim + thiram and bio-agent (*Trichoderma viride*) in combination with vitavax are best for reducing wilt incidence in pulses.

Table 8 Major pests of pulses

Kharif pulses	*Rabi* pulses
Gram pod fly (*Melanagromyza obtusa*)	Gram pod borer (*Helicoverpa armigera*)
Hairy caterpillers (*Spilosoma cajetani*)	Cut warms (*Agrotis ipsilon*)
White fly (*Bemisia tabaci*)	Aphids (*Aphis craccivora*)
Bristle beetle (*Mylabris spp.*)	Gram semilooper (*Autographa nigrisigna*)
Termites (*Odontotermes obesus*)	Pea leaf minor (*Liriomyza huidobrensis*)

Table 9 Major diseases of pulses

Disease	Causal organisms/vector
Sterility mosaic	Eriophyid mite *(Aceria cajani)*
Wilt	*Fusarium oxysporum*
Yellow mosaic virus	Transmitted by vector
Downy mildew	*Peronospora pisi*
Damping-off	*Pythium* spp., *Fusarium* spp. and *Rhizoctonia* spp.
Collar rot	*Sclerotium rolfsii*
Ascochyta blight	*Ascochyta rabiei*
Botrytis gray mould	*Botrytis cinerea*
Rust	*Uromyces fabae*
Powdery mildew	*Erysiphe polygoni*

LEGUME–BASED CROPPING SYSTEMS: NEED OF THE HOUR

During post green revolution era, the major emphasis was given on promotion of cereal–based/dominated cropping systems, in order to feed fast growing Indian population and to achieve national food security. We were successful in achieving the aforesaid targets, but cereal–based cropping system had also led to several production vulnerabilities besides receding resource base and poor soil health. Now, its high time to diversify the cereal–based cropping systems especially with legumes to restore the soil fertility in holistic manner (Choudhary *et al*. 2013, Choudhary and Suri 2014b). Moreover, escalating chemical fertilizers prices as well as poor socio–economic conditions of Indian farmers with dominance of small and marginal farmers also urge for inclusion of legumes in the cereal–based systems to supplement N–requirements due to their nitrogen–fixing ability (Kumar *et al.* 2014).

Legume crops are also popular for their suitability in different cropping systems, owing to their short–life cycle. Development of large number of high yielding cultivars of pulse crops with varying maturity duration and resistance to biotic and abiotic stresses, have made it possible to include them in irrigated crop sequence as well. Thus, legume–based cropping systems can transform the rural livelihoods by overcoming the production constraints largely experienced over the decades due to cereal–based production systems (Dass *et al.* 2014). The popular and promising legume–based cropping systems are pigeonpea–wheat in Madhya Pradesh, Uttar Pradesh and Bihar, groundnut–wheat in Gujarat, Maharashtra and Madhya Pradesh, groundnut–sorghum in Andhra Pradesh and Karnataka, urdbean–wheat, kidney bean + maize–wheat in north–western Himalayan states like Himachal Pradesh, Uttarakhand and Jammu and Kashmiri, clusterbean, mungbean and mothbean based cropping systems of semi–arid and arid areas of Rajasthan and summer mungbean based cropping system in IGPR (Bana *et al.* 2014). The major issues in legume based cropping systems, which still need to be addressed are:

- Most of pulse growing soils areas are phosphorous–deficient, hence P needs critical attention in pulse production systems (Kumar *et al*. 2014).
- Nutrient needs on cropping system basis by taking biological N–fixation capacity of legume crops into account (Bengia Bai *et al.* 2014).
- Slow growth habit at initial vegetative growth stages leads to higher weed infestation (Das *et al*. 2014).
- No technological breakthrough has been achieved so far w.r.t. yield barriers in pulses (Choudhary 2013).
- Susceptibility of the pulses to aberrant weather conditions, especially waterlogging and adverse soils making them highly unstable in performance (Bana *et al*. 2014).
- High susceptibility to diseases and pests (Sood *et al.* 2011).
- Physiological and genetic attributes like low harvest index, flower drop, indeterminate growth habit and very poor response to fertilizers and water in most of the grain legumes (Bana *et al*. 2014).

Technological interventions to overcome production vulnerabilities in legume–based cropping systems

Promotion and adoption of short duration, disease and insect pest resistant high yielding legume cultivars with added ability to adjust in the intensive cropping system; is need of the hour. Bed planting, planting on ridges and use of mulches are helpful for water stress management in addition to their other added advantages (Bana *et al*. 2014). Adoption of integrated crop management practices w.r.t. weed, insect, disease and nutrient management is urgently needed. Government and policy support particularly for marketing and institutional credit also need dire attention for the resource–poor small and marginal farmers India.

TECHNOLOGICAL AND EXTENSION YIELD GAPS IN PULSES PRODUCTION

The successful development, dissemination and adoption of improved technologies for small-holders depend on more than careful planning of research and the use of appropriate methodologies in extension (Biggs and Smith 1998, Cramb 2003, Choudhary *et al*. 2013). In order to boost pulse production in India, farm scientists have generated state of art technologies right from varietal development to crop and resource management technologies. Now, main emphasis should be on technology transfer mechanism for adoption of pulse production technologies in India (Badiyala *et al*. 2012). This sector is being given more and more attention by the Government of India. But, still there are many gaps in the technology generated by the research institutions and what has actually reached on farmers fields (Choudhary *et al*. 2009, Paul *et al*. 2011). A study on technological and extension yield gaps in pulses was conducted in wet temperate region of NW Himalayas in India for three years from *kharif* 2008 to *rabi* 2010-11 (Choudhary 2013). In this study, it was revealed that there was a wide yield variation between demonstration plot yields and farmers plot yields mainly due to technology and extension gaps (Table 10). Extension yield gaps varied to the extent of 368-492 kg/ha in blackgram (*Vigna mungo*), 220-417 kg/ha in kidneybean (*Phaseolus vulgaris*), 477-563 kg/ha in pigeonpea (*Cajanus cajan*), 372-494 kg/ha in cowpea (*Vigna sinensis*), 225-601 kg/ha in chickpea (*Cicer arietinum*) and 253-510 kg/ha in lentil (*Lens culinaris*) during study period. Improved technology package has also enhanced the profitability of pulses in terms of gross and net returns. Technology index in blackgram (35.7-40.3%), kidneybean (31.3-71.0%), pigeonpea (44.9-48.9%), cowpea (62.3-71.1%), chickpea (54.7-65.8%) and lentil (56.4-60.5%); has revealed that there is urgent need to make aware and educate the farmers to adopt the technologically feasible and economically viable farm technology for enhancing yields and profitability. Overall, improved farm technology has great potential in enhancing the pulse productivity in NW Himalayas and collateral farming situations as well. Thus, introduction of HYVs' embedded

Table 10 Technology gap, extension gap and technology index in pulses in north-western Himalayas, India

Crop/Variety	Varieties	Yield (kg/ha)		%	Technology	Extension	Technology
		DP*	FP*	YIOFP*	gap (kg/ha)	gap (kg/ha)	index (%)
Blackgram	UG-218; Himachal Mash-1; Palam-93	895-1017	505-540	68.2- 97.4	535-620	368-492	35.7-40.3
Kidneybean	Kanchan (HPR-35); Triloki; Baspa	870-1067	645-650	33.6-64.2	470-2130	220-417	31.3-71.0
Pigeonpea	Sarita (ICPL-85010)	1022-1102	510-625	76.3-110.4	898-978	477-563	44.9-48.9
Cowpea	C-475 (HL-1)	867-1131	495-637	75.2-83.2	1869-2133	372-494	62.3-71.1
Chickpea	Himachal Chana-1; Himachal Chana-2; HPG-17; GPF-2	850-1021	415-625	36.0-143.1	1203-1644	225-601	54.7-65.8
Lentil	EC-1; HPL-5	678-908	355-425	72.1-128.1	922-1392	253-510	56.4-60.5

*DP – Demonstration plot, FP – Farmers' plot, YIOFP – Yield increase over farmers' practice. Source: Choudhary (2013).

with proven location specific farm technology and its proper demonstration followed by intensive awareness campaign besides creation of better irrigation infrastructure eventually may also lead to higher technology adoption in pulses among Indian farmers.

OTHER VIABLE OPTIONS TO ENHANCE PULSE PRODUCTION IN INDIA

Pulse area expansion in non-traditional areas and rice fallow areas

During last few decades, growth in pulses production has increased significantly. India achieved a record output in pulses production at 18.9 million tonnes in 2010-11 with an all-time high production achieved in chickpea (8.25 million tonnes), mungbean (1.82 million tonnes) and blackgram (1.74 million tonnes). Although, sustaining this growth rate is a big challenge for researchers, extension agencies and policy makers. The major factor for achieving this record production is introduction in new areas and non-traditional production belts. We have to bring pulse crops to non-traditional areas of rice fallows in central and eastern parts of the country – Bihar, Madhya Pradesh, Chhatisgarh, Odisha, eastern Uttar Pradesh and West Bengal. Chickpea production in Andhra Pradesh is an example. Introduction of chickpea crop into non-traditional areas like south Indian states is an example of technological and institutional breakthroughs. Introduction of chickpea into black cotton soils, utilization of *rabi* fallow lands, adoption of short duration HYVs' (i.e. KAK 2 and JG 11), and large scale mechanization to cope-up labour shortage are some of the contributors for area expansion in chickpea in south Indian states (Reddy *et al.* (2013).

Thus, Indian government needs to provide adequate policy and institutional support to production of pulses in rice fallow areas to complement efforts of scientists in raising productivity levels of these crops and bring larger rice fallows under pulses production. In this context, government should extend more facilities to pulses growers in rice fallow areas.

Intercropping and new cropping systems

Increased efforts to produce more food have resulted in tremendous shift in cropping systems towards cereal-cereal based cropping systems. India is the largest producer and consumer of pulses with about 25-28% of global share. It is paradoxical that India being one of the major pulse growing countries at global level accounts for about 11% share of world pulse imports. Similarly, edible oil imports are also high. Thus, intercropping and growing short-duration varieties between *kharif* and *rabi* seasons, by relay cropping, intercropping of pulses can ensure further utilization of existing arable lands. Replacement of upland paddy with pulses is another viable option having potential to give better net returns to farmers. Fallow substitution in irrigated lands has resulted in increased production in several countries. Thus, Department of Agriculture and Cooperation (DAC), GOI, New Delhi has also proposed a strategy for increasing production and productivity of pulses that involves a thrust on non-conventional cropping systems (Table 11).

Agriculture plays a key role in overall economic scenario and rural livelihoods of India. The growing climate change threats besides *El Nino* events in current scenario are now supposed to have significant impact on the yields of certain major food crops which would definitely affect the world food security in general and its regional impacts in particular as per the world scientific community. This means, agriculture production in rainfed regions, which constitute about 65% of the area under cultivation and account for

Table 11 New options in pulse based intercropping and cropping systems in India

Intervention	New options in pulse based intercropping and cropping systems in India
Short duration pulse cultivation	• Introduction of short duration pigeonpea varieties into irrigated cropping system in northern and central India in sequence with wheat; • Introduction of *rabi* pigeonpea in Bihar, West Bengal, Odisha, eastern Uttar Pradesh, Gujarat, Andhra Pradesh. • Introduction of *rabi* kidneybean in Uttar Pradesh, Bihar, Odisha, Madhya Pradesh, Maharashtra and West Bengal.
Pulses as summer crops	• Introduction of summer pulses (blackgram, greengram, cowpea) in irrigated areas after the harvest of *rabi* crops. • Introduction of greengram and blackgram in fields vacated by potato, mustard, sugarcane and wheat in Andhra Pradesh, Bihar, Haryana, Madhya Pradesh, Odisha, Punjab, Rajasthan and Uttar Pradesh.
Shift to pulses from other crops	• Replacement of high water duty crops by low water intensive crops like pulses in command areas in order to make irrigation water available at critical stages of crop growth through effective water scheduling. • Substitution of upland crops like rice, sorghum, maize, pearl-millet and diverting these areas to short duration pulses in eastern and southern states.
Intercropping	• Intercropping of pigeonpea, greengram and blackgram with sorghum, pearlmillet, maize, cotton, groundnut, soybean, etc.

about 40-45% of the total production in India, is expected to suffer severe water crisis due to delayed monsoon, uneven rains distribution as a result of above climate change threats. But, pulses are one of the important segments of Indian agriculture after cereals with 25% share in the global pulse production and covering an area of about 263 m ha, majority of which falling under rainfed condition where irrigation facilities are inadequate or not available. Pulses are predominantly grown under resource poor and harsh environments frequently prone to drought and other biotic and abiotic stresses. The pulses have great potential to bear the vagaries of the changing climate, provided other crop management practices are strictly followed to harness good yields.

In addition, pulses also play an important role in improving soil health, long term fertility and sustainability of the cropping systems. It meets up to 80% of its nitrogen fixation from air and leaves behind substantial amount of residual nitrogen and organic matter for subsequent crops. Pulses are being neglected since green revolution. As a result, the productivity of the pulses in India is quite low. Besides, to meet the demand of pulses, India imports huge amount of pulses every year. Thus, there is a great challenge to enhance pulse productivity to meet out the national and local pulse requirements. In this paper, an attempt has been made to discuss improved pulse production practices which can play a vital role in sustainable pulse production in India. Besides this, area expansion through their introduction in non-traditional area would also add to national pulse production. The improved production practices and strategies with context to pulses crop in Indian perspective discussed in this paper would definitely enlighten the agricultural professionals and policy makers to enhance their capabilities for sustainable pulse production in India inspite of various production vulnerabilities.

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