Technical Bulletin

Pulses in Cropping Systems

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Publication #	:	01 / 2009
Printed	:	January, 2009
Published by	:	Director Indian Institute of Pulses Research Kanpur – 208 024
Correct Citation	:	Singh, K.K., Ali, M. and Venkatesh, M.S. (2009). Pulses in Cropping Systems. Technical Bulletin, IIPR, Kanpur

Printed at : Army Printing Press, 33 Nehru Road, Cantt, Lucknow – 226002.

Foreword

In the post-green revolution period, the incessant rice-wheat crop rotation has undoubtedly made the country surplus in cereal production but has marginalized pulses. This has raised serious concern about sustainability of the production system. The area under pulses in North India reduced from 13.5 million ha to 7.5 million ha. Recognizing the importance of pulses for meeting dietary requirements of vast vegetarian population on one hand and their role in improving soil health and conserving natural resources on the other, the efforts were made to develop high yielding, short duration and disease resistant varieties of different pulse crops which can help in diversification and intensification of popular cropping systems. As a result, several new cropping systems have been designed, developed and advocated both for rainfed and irrigated areas by IIPR and AICRP centres. The value of pulses in enhancing productivity of the system and improving soil properties has been quantified.

The IIPR is commemorating its Silver Jubilee. On this occasion, publication of the compendium on 'Pulses in Cropping Systems' is very timely and comprehensive to cover all the aspects like new crop rotations and intercrops involving pulses, residual effect on N economy, effect on soil properties, crop productivity and their management. I congratulate Drs. K.K. Singh, Masood Ali and M.S.Venkatesh for their sincere efforts in bringing out this publication and putting all relevant information at one place in a very lucid manner. I trust and believe that this bulletin will be very useful to researchers and extension and development personnel in understanding the value of pulses in cropping system and promoting their cultivation under diverse agro-climate conditions.

(S. P. Tiwari)

January 3, 2009

Dy. Director General
(Education and Crop Science)
Indian Council of Agricultural Research

Preface

In India, pulses are grown on 22-24 million hectares area under diverse cropping systems in agro-ecological regions both as sole and mixed/intercrops. A major setback to pulses occurred during the Green Revolution period when rice-wheat rotation marginalized these crops in North India but an unprecedented expansion in central and southern regions compensated the loss in area. The 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.

Realizing the importance of pulses in nutritional security and sustainable crop production, systematic and comprehensive research programmes were initiated in late eighties at IIPR and cooperating centres of All India Coordinated Pulses Improvement Project (AICPIP) to design and develop new cropping systems involving pulses, quantify their contribution in improving productivity and soil quality, and efficient agronomic management. The outcome of these research programmes has been rewarding and very valuable information has been generated. An effort has been made to put together all relevant information on new cropping systems (sequential, inter / mixed crop, relay, catch crop, *etc.*) developed for rainfed and irrigated areas, effect of pulses in improving system productivity and soil properties and their role in crop diversification and intensification at one place. We are thankful to all the scientists of IIPR and centres of AICRP on Pulses involved in generation of valuable information in cropping systems which has been used in this bulletin. We believe that this compendium will be very useful to all those involved in pulse research and development and will serve as a base for further research. We are grateful to the encouragement and guidance received from Dr. Mangala Rai, Secretary, DARE and Director General, ICAR and Dr. S.P. Tiwari, Dy. Director General (Crop Science) for their guidance and support.

January 1, 2009

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1. Introduction

India has key place in global pulses production and contributes about 25% to the total pulse basket. During 2007-08, the total pulse production was 15.11 million tonnes from 23.81 million ha area. About a dozen of pulse crops, namely chickpea, pigeonpea, mungbean, urdbean, lentil, fieldpea, lathyrus, cowpea, common bean, mothbean, horsegram and ricebean are cultivated in different agro-ecological regions. The major pulse producing states in the country are Madhya Pradesh, Uttar Pradesh, Maharashtra, Rajasthan, Karnataka and Andhra Pradesh, which together contribute for 75% of the total pulses production in the country.

During 1991-2007, area under pulses ranged between 20.35 and 24.66 million ha while production and productivity varied from 11.15 to 15.11 million tonnes, and 533 to 635 kg / ha, respectively. At national level, area under all the pulses except chickpea and pigeonpea observed positive trends during the past 15 years. The area and production of minor pulses together, which have regional importance *viz*., horsegram, mothbean, lathyrus, cowpea and rajmash, showed negative growth rate. The area under chickpea has remained almost stagnant around 6.5 million ha during the period 1991-93 to 2006-08 but a significant shift has been witnessed from North to South. The area of chickpea has increased significantly in Andhra Pradesh, Karnataka, Madhya Pradesh and Maharashtra, whereas declined in the states of Bihar, Haryana and Rajasthan during 1972-74 to 2005-07.

On account of their values as nutritious food, feed and forage, pulses remained an integral component of subsistence cropping system since time immemorial. They are grown as a sole crop, intercrop, catch crop, relay crop, cover crop and green manure crop *etc*., under sequential / mono-cropping in different agro-ecological regions. In the cropping systems of dry areas pulses are predominant due to their low input requirements and capacity to withstand drought and consequently perform relatively better than other crops in the fragile and harsh climate prevailing of the regions. Intercropping is commonly practiced to obtain sustainable production even under adverse weather conditions. The development of short duration varieties of mungbean, urdbean and pigeonpea has paved way for crop diversification and intensification in North India. On slopes of hilly regions, urdbean, mungbean, cowpea, ricebean and frenchbean not only provide nutritious food and fodder but also act as an excellent cover crop. In these regions, pigeonpea, urdbean, mungbean soybean, *etc*., are also grown on rice bunds. In response to market opportunities and concern for systems sustainability, many new cropping systems involving pulses have replaced / modified the traditional crop rotations. Some glaring example are rice -wheat- mungbean, rice - chickpea / lentil, pigeonpea - wheat, rice-urdbean / mungbean, soybean+pigeonpea, groundnut + pigeonpea, potato + rajmash, *etc*. In humid regions of North-East India and drier regions of central and coastal regions of South India, some of the pulses like urdbean, mungbean, lentil and lathyrus are grown as para crop (relay) which facilitates double cropping and sustainable production of the systems.

The beneficial effect of pulse crops in improving soil health and sustaining productivity has long been realized. On account of biological nitrogen fixation, addition of considerable amount of organic matter through root biomass and leaf fall, deep root systems, mobilization of nutrients , protection of soil against erosion and improving microbial biomass, they keep soil productive and alive by bringing qualitative changes in physical, chemical and biological properties. As a result of this, the productivity of cereals following a preceding grain legume often increases and correspond to 40-60 kg N equivalent. Besides this, the cost of cultivation significantly decreases and returns per rupee investment increases. In the present scenario of degradation of natural resources, the value of pulses is far more important. It is, therefore, imperative that grain legumes are given a preference in cropping systems of both irrigated and dryland areas.

2. Present Status

Cropping system is a kind of sequence and arrangement of crops grown on a given area of land over a period of time. Cropping systems are the outcome of the technological innovations, household needs, reflection of government policies, availability of production inputs, market forces and socio-economic compulsion. An ideal cropping system should use natural resources efficiently, provide stable and high returns and do not damage the ecological balance. Cropping system is broadly grouped into sequential cropping and intercropping. It may be a regular rotation of different crops in which the crops follow a definite order of appearance on the land or it may consist of only one crop grown year after year on the same area. Other cropping systems may include different crops but lack definite or planned order in which crops follow one another or growing of two or several crops mixed together (Singh, 1972).

More than 250 double cropping systems of primary, secondary and tertiary importance in terms of their spread in the country have been listed. Out of which 30 are of primary importance (Yadav and Prasad, 1997). Among top ten popular cropping systems in the country, only two, *viz*., rice-chickpea and maize-chickpea contain a pulse crop with less than 6% of the total pulse area **(Table 1**) (Yadav 1996).

Table 1: Area under prevalent cropping systems and their contribution to the national food basket

Cropping system	Area (m ha)	Contribution (%)
Rice-wheat	9.77	25.00
Rice-rice	2.12	5.00
Cotton-wheat	1.39	2.36
Pearl millet- sorghum	1.35	1.68
Maize-wheat	1.29	2.25
Pearl millet- wheat	1.03	1.72
Sorghum-sorghum	0.74	1.65
Rice-chickpea	0.59	0.80
Sugarcane-wheat	0.54	0.86
Maize-chickpea	0.54	0.65

Yadav (1996)

In the pre-green revolution period, pulses found significant place in inter/ mixed cropping with major and minor cereals. Wheat was used to be generally grown with chickpea, lentil, mustard and other oilseed crops. Similarly, the coarse cereals were grown with short duration pulses like urdbean and mungbean in intercropping/mixed cropping systems. Cropping systems based approach of agricultural research, received little attention, except some considerations for utilizing the beneficial effects of growing crops of dissimilar nature in mixed/ intercropping (Aiyer, 1949) or sequential cropping and role of legumes in green manuring (Singh, 1972). After introduction of high yielding, short stature, photo and thermo-insensitive varieties of wheat and rice in sixties, the entire agricultural systems of country witnessed a change. The low productive, risk prone legumes and oil seed crops were diverted on marginal and fragile land of dry areas, whereas the cereal based multiple cropping systems covered irrigated areas in North. In Andhra Pradesh, Rajasthan, Gujarat, Karnataka, Maharashtra, Madhya Pradesh and Tamil Nadu states, area under pulses increased from 13.92 m ha in 1971-75 to 16.22 m ha in 2005-06, whereas Bihar, Haryana, Punjab, Uttar Pradesh, West Bengal and Orissa witnessed reverse trend, the area declining from 8.0 m ha to 4.6 m ha during the same period. The adverse effect of continued cereal based cropping system in northern India- the Green Revolution belt could be visualized only in the late nineties when compound production growth rate declined from 2.74% during 1981-90 to 1.66% during 1991-2000. Progressive decline in total factor productivity and deterioration in soil health necessitated crop diversification and inclusion of pulses in the system.

Availability of short duration varieties coupled with matching agro-technologies in eighties led to development of several remunerative and more productive cropping systems, which have either already shown their promise or have tremendous potential for expansion in new niches and diversification in the existing cropping systems (Ali, 1994). Considerable increase in area under mungbean, urdbean, pigeonpea and lentil was observed in mid nineties and many new cropping systems emerged **(Table 2)**.

Table 2: Possible new niches for pulses

Cropping systems	Possible niches	Expected area (m ha)	Suitable varieties of pulse crops
Pigeonpea-wheat	Haryana, Punjab, North-West U.P. and North Rajasthan	1.00	UPAS 120, Manak, Pusa 33, AL 15, AL 201
Maize-*rabi* pigeonpea	Central and Eastern U.P., North Bihar, West Bengal, Assam	0.30	Pusa 9, Sharad
Maize-potato/mustard+ mungbean/urdbean	Punjab, Haryana and West U.P.	1.00	**Mungbean:** Pant Mung 2, PDM 11, HUM 2, SML 668, Pusa Vishal **Urdbean**: PDU 1, Narendra Urd 1, Uttara
Spring sugarcane+ mungbean/ urdbean	East U.P., Bihar, West Bengal	0.15	**Mungbean:** Pant Mung 2, PDM 11, Narendra Mung 1 **Urdbean:** PDU 1, Pant Urd 19,
Rice-mungbean	Orissa, Part of Karnataka, Tamil Nadu, A.P.	0.35	TARM 1, Pusa 9072
Rice-urdbean	Coastal area of A.P., Karnataka, Tamil Nadu	0.35	LBG 17, LBG 402
Rice-wheat-mungbean	Western U.P., Haryana, Punjab	0.10	Pant Mung 2, Narendra Mung 1, PDM 139, HUM 2
Maize-*rajmash*-mungbean	Central and Western U.P., North Bihar	0.07	**Mungbean**: Pant Mung 2, PDM 11, HUM 2 ***Rajmash***: HUR 137, HUR 15, PDR 14, Amber
Rajmash+potato	Eastern and Central U.P.	0.03	PDR 14, Amber

3. Cropping Systems Involving Pulses

Pulses are grown in different cropping systems such as sequential cropping, mixed and intercropping, relay cropping, catch cropping and ratoon cropping.

3.1 Sequential cropping

It is a form of multiple cropping in which crops are grown in sequence on the same field, with the succeeding crop planted after harvest of the preceding crop. This system with relatively short growing season crops offers better total annual use of land than a single crop system. The prominent sequential cropping systems involving different pulses have been discussed crop wise.

Rice-Chickpea/ Lentil/ Fieldpea

With the development of wheat varieties amenable for late-planting upto late December and January, the area under rice-wheat system has increased at a faster rate in the last two decades. The adverse effect of this system on soil health is being widely recognized. In India, approximately 15 m ha area falls under rice fallow (Hegde, 1999). Studies on relative productivity of various pulse crops in rice fallows indicated that cowpea recorded highest productivity, followed by urdbean at Berhampur, but at Raipur, lathyrus, lentil and mungbean were more productive (Ali 2004). At Kanpur, Kumar and Ali (1998) evaluated various pulses and oilseed crops after rice and found that lentil, lathyrus and linseed were more productive and remunerative than chickpea, fieldpea, and *rajmash*.

In recent years, development of early maturing varieties of chickpea suitable for planting up to mid of December with yield potential of 15-20 q/ha has enabled farmers to adopt rice-chickpea system instead of cereal-cereal system especially in the tail end of command areas in eastern U.P. and Bihar. Similarly on the upland of Punjab, Haryana and western U.P., where cotton is grown as commercial crop, chickpea can be successfully introduced. Under resource constraint particularly irrigation water, chickpea is more remunerative than wheat. In low land areas of eastern region, lentil proved to be better one over chickpea. The major constraints in fast spread of this system are limited choice of improved varieties and incidence of pod borer, botrytis gray mold, Ascochyta blight besides poor soil tilth and nodulation.

Pigeonpea - Wheat

Pigeonpea is a major crop of Maharashtra, Uttar Pradesh, Madhya Pradesh, Karnataka and Gujarat. In the irrigated areas of the northern and central India, pigeonpea-wheat has emerged as a promising system. Availability of short duration varieties such as UPAS 120, Manak, ICPL 151, Pusa 992, which takes about 120-160 days to mature has enabled their introduction in rice-wheat systems in irrigated area of western U.P., Punjab and Haryana, Delhi and North-East Rajasthan. This has provided desired stability and sustainability to productivity of cereal based cropping system. But there are some issues, which need to be tackled for wider adoptability and profitability from this system. Presently, most of the short duration varieties of pigeonpea available for cultivation are affected by sterility mosaic, fusarium wilt and Phytophthora blight and have tendency to prolong maturity with the late monsoon. Therefore, development of varieties, which could mature by early November with 2 t yield / ha is required.

Pusa 992- a short duration variety of pigeonpea

In Bihar, eastern Uttar Pradesh, West Bengal, Orissa and Assam, pigeonpea is being grown as a pre-*rabi* after *kharif* maize, early rice, minor millets or jute but due to its sensitivity to temperature, it has promise only in the areas having mild winter.

Rice - Urdbean/Mungbean/ Lathyrus

Cultivation of *rabi* urdbean and mungbean in coastal regions of South India is being practiced since long but it could get momentum only after development of powdery mildew resistant genotypes such as LBG 17, LBG 402, LBG 611 and LBG 22 having high yield potential. Development of these varieties in late eighties has revolutionized urdbean and mungbean cultivation in rice fallow especially in Andhra Pradesh. This system is highly productive and stable besides its benefits through improvement in soil health. This cropping system is now being practiced in other states like Orissa, Tamil Nadu and Karnataka.

Other systems

Mungbean / urdbean – mustard / barley is an important crop sequence in rainfed areas of north-western region of India like Punjab, Haryana, Western Uttar Pradesh, Rajasthan, Himachal Pradesh and Jammu & Kashmir whereas in irrigated areas, maize-potato-mustard-mungbean / urdbean and maize–wheat-mungbean / urdbean practices are followed. Similarly in the eastern Uttar Pradesh, Bihar, West Bengal, Orissa and Assam, maize-horsegram rotation is followed under rainfed conditions and maize-wheat-mungbean / urdbean under irrigated condition. In the central regions of India comprising Madhya Pradesh, Gujarat and Maharashtra, urdbean-wheat, mungbean-sorghum, cowpea / urdbean / mungbean-safflower and mungbean-niger are some of the important cropping sequences under rainfed conditions but under irrigated condition, maize-wheat-summer cowpea, maize-wheat-summer urdbean / mungbean are practiced. In the rainfed area of South India including Andhra Pradesh, Tamil Nadu, Karnataka and Kerala, cowpea-finger millets, mungbean-sorghum / safflower, rice-mungbean / urdbean / cowpea are followed while under irrigated conditions, rice-rice-mungbean / urdbean / cowpea are common. The cropping systems involving pulses in different cropping zones of the country are given in **Table 3**.

Table 3: Important pulse based cropping systems in different agro-climatic zones

Sl. No.	Agro Climatic Zones	States represented	Annual rainfall (mm)	Cropping systems
1	Western Himalayan Region	Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh	1650-2000	Rice-chickpea / lentil / fieldpea, maize-chickpea / fieldpea, ragi-chickpea / lentil / fieldpea,maize / urdbean / mungbean-wheat, pigeonpea-wheat, mungbean / urdbean- mustard,commonbean-potato
2	Eastern Himalayan Region	Assam, West Bengal, Manipur, Meghalaya, Nagaland, Arunachal Pradesh	1840-3530	Summer rice-urdbean / mungbean, rice-lathyrus, maize-maize-urdbean, maize-pigeonpea / horse gram, maize-chickpea / lentil / fieldpea, jute-urdbean-chickpea / lentil
3	Lower Gangetic Plains Region	West Bengal	1300-1600	Maize-chickpea / lentil / fieldpea, rice-chickpea / lentil / fieldpea, rice-chickpea+mustard / lentil
4	Middle Gangetic Plains Region	Uttar Pradesh and Bihar	1200-1470	Maize-wheat-summer mungbean / urdbean, rice-potato-summer mungbean / urdbean, rice-chickpea / lentil
5	Upper Gangetic Plains Region	Uttar Pradesh	720-980	Rice-wheat / potato-summer mungbean, maize-wheat / potato-summer mungbean, mungbean / urdbean-wheat, sorghum (fodder)-chickpea
6	Trans Gangetic Plains Region	Punjab, Haryana	360-890	Maize-potato-summer mungbean / urdbean, rice / maize-wheat-summer mungbean / urdbean, maize-early potato-late potato-summer mungbean / urdbean, rice-chickpea / lentil, maize-chickpea / lentil / fieldpea
7	Eastern Plateau and Hills Region	Madhya Pradesh, Maharashtra, Orissa, West Bengal	1270-1430	Early rice-urdbean, rice-rice-cowpea, jute-maize-cowpea, jute-urdbean

8	Central Plateau and Hill Region	Madhya Pradesh, Rajasthan, Uttar Pradesh	490-1570	Sorghum (grain / fodder)-chickpea, fallow-chickpea, sorghum+pigeonpea-fallow, pearlmillet+pigeonpea-fallow, rice / maize-chickpea / lentil / fieldpea, mothbean / mungbean / urdbean-wheat, pearlmillet-chickpea
9	Western Plateau and Hill Region	Maharashtra, Madhya Pradesh, Rajasthan	600-1040	Urdbean-*rabi* sorghum, sorghum-potato-mungbean, cotton+urdbean / mungbean-fallow, sorghum-wheat-cowpea / mungbean, cotton / sorghum-chickpea, mungbean / urdbean-safflower
10	Southern Plateau and Hill Region	Andhra Pradesh, Tamil Nadu, Karnataka	680-1000	Maize-sorghum+pigeonpea, sorghum-chickpea, pearlmillet-horsegram, mungbean / urdbean-safflower, rice-mungbean / urdbean / cowpea, mungbean-sorghum / safflower, mungbean-pigeonpea, rice+rice mungbean / urdbean / cowpea
11	East coast Plains and Hills Region	Orissa, Andhra Pradesh, Tamil Nadu, Pondicherry	780-1290	Rice-mungbean / urdbean, sorghum-mungbean / urdbean, tapoic+mungbean / urdbean, rice-rice mungbean / urdbean, rice-maize / cowpea, maize-horse gram / pigeonpea / chickpea
12	West Coast Plains and Hills Region	Tamil Nadu, Kerala, Goa, Karnataka, Maharashtra	2230-3640	Rice-urdbean / cowpea / chickpea, sugarcane+urdbean
13	Gujarat Plains and Hills Region	Gujarat	340-1790	Urdbean-safflower / niger, cowpea-safflower, mungbean-tobacco, pearl millet / sorghum+ pigeonpea-chickpea
14	Western Dry Region	Rajasthan	400	Rice / cotton-chickpea, pearl millet / sorghum-chickpea+mustard, mothbean / mungbean-wheat
15	Island Region	Andaman and Nicobar islands, Lakshwadeep islands	1500-3090	Rice-maize / rice-urdbean

Singh *et al* (2005)

3.2 Mixed/ Intercropping

Mixed cropping refers to growing of two or more crops simultaneously either by mixing seeds or sowing component crop separately without any definite row arrangements. In intercropping, the crops are arranged in definite rows. Sowing of both crops may be done simultaneously or in staggered manner. Similarly harvesting time may also differ. Intercropping is an improved system of mixed cropping which ensures desired plant stand, ease in cultural operation, spraying of chemicals and harvesting, and higher returns.

The major considerations for intercropping are the contrasting maturities, growth rhythm, height and rooting pattern and variable insect pest and disease associated with component crops so that these complement each other rather than compete for the resources and guard against weather adversities. Growing of crops in intercropping systems is found more productive particularly under rainfed conditions. More than 70% area of pulses in India is covered under intercropping systems. Pulses are intercropped with oilseeds, cereals, coarse grains and commercial crops. Pigeonpea is also inter / mixed cropped with short growing grain legumes.

Intercropping with oilseeds

Intercropping of winter pulses like chickpea and lentil with oilseeds is common in rainfed areas of India. Studies conducted under AICPIP during 1982- 2006 revealed that chickpea+mustard and lentil+mustard in northern plains, chickpea+ linseed in central plateau and chickpea+safflower in peninsular zone are the most profitable intercrops. In these systems, 100% plant population of pulses is kept and the oilseed crops are taken as bonus. Higher productivity and monetary returns from chickpea+mustard and lentil+linseed has been reported (Ali, 1992, Singh and Rathi, 2003). Chickpea and mustard intercropping systems have been tried in 1:1 to 1:8 row ratios by different

Chickpea+Mustard (6 : 2)

workers in the country. But, in most of the cases, it has been observed that 4:1 or 6:2 row ratios proved most productive and profitable. A study conducted at Kanpur showed that different chickpea varieties performed differentially in intercropping with mustard in 4:1 row ratio (Ali, 1992). However, differential preference of chickpea genotypes under sole and intercropping with mustard was observed. Semi erect *desi* genotype BG 256 proved better under sole cropping but erect tall type BG 261 proved better under intercropping with mustard var. Varuna. Out of five *desi* chickpea genotypes, KPG 59 (1,420 kg/ha) and Pant G 114 (1,256 kg/ha) were found most compatible for intercropping with mustard (cv. Vardan) under irrigated condition. The highest productivity (chickpea equivalent yield 2,609 kg/ha) and profitability (Rs.17,214/net return) were recorded with JG 315+Vardan intercropping. Among three *kabuli* chickpea genotypes (L 550, BG 1003 and KAK 2) and two mustard genotypes (Vardan and Varuna), KAK 2 + Vardan was found most compatible for intercropping system with higher CEY (1,751 kg/ha) and LER (1.38) (**Table 4**). In chickpea+mustard intercropping system, planting geometry of 6:2 row ratio was found ideal especially when Varuna variety of mustard was intercropped. Planting of chickpea+mustard in North-South direction proved advantageous resulting gain in yield of 147 kg/ha in chickpea and 235 kg/ha in total productivity over East-West planting. The effect of row orientation was associated with higher PAR penetration of the canopy in intercrops in North-South direction. Lentil and linseed make perfect combination for intercropping as compared to other *rabi* crops in rainfed conditions. Under lentil + linseed intercropping system, Lentil variety L 4076 under 6:2 row ratio was found more compatible than DPL 62 and recorded maximum productivity in terms of lentil equivalent yield (2, 171 kg/ha), net profitability (Rs.23, 060/ha) and land use efficiency (21% higher).

Table 4: Genotypic compatibility of chickpea intercropped with mustard

Genotype	Chickpea yield (kg / ha)		Mustard yield(kg/ha)	Reduction in intercrop over sole crop (%)
	Sole crop	Intercrop		
BG 256	2720	1580	1070	41.9
BG 261	2180	1470	1400	32.5
BG 267	2440	1380	1400	43.4
PDG 84-16	2530	1510	1380	40.3

Ali (1992)

Lentil+Linseed (2 : 1)

Development of short duration, photo- and thermo- insensitive varieties have made sunflower a promising crop for northern India. In sunflower/mungbean intercropping system, mungbean genotype PS 16 with sunflower cv. Modern was found most productive in terms of sunflower equivalent yield (1804 kg/ha) followed by PDM 84-139 (1669 kg/ha) in same ratio. Highest LER (1.19) was recorded with mungbean cv. PS 16 + sunflower intercropping. In spring planted sunflower + urdbean intercropping system, though SH 3322 variety in sunflower and PDU 88-31 variety in urdbean out yielded the other variety under sole cropping system, both the urdbean variety Pant U 19 and PDU 88-31 were found equally compatible genotypes with sunflower cv. SH 3322 under intercropping system and recorded higher sunflower equivalent yield and LER.

Intercropping with cereals

Traditionally chickpea was commonly grown with wheat and barley under rainfed conditions. Under limited availability of water, wheat + chickpea was more remunerative than wheat + mustard. But under irrigated conditions, wheat + mustard proved more profitable over wheat + chickpea. For optimum profit, proper row ratio is important besides selection of appropriate varieties. But with the increasing demands and advent of high yielding dwarf varieties of wheat and barley, the area under such cropping is decreasing progressively. But intercropping of pulses with wheat is not always profitable due to its closer spacing. Sharma *et al.* (1987) reported that intercropping of chickpea and lentil with wheat was not a sound practice. By adopting effective row proportion, one can minimize the adverse effect of companion crops. Studies on wheat + chickpea intercropping revealed that 2:2 row ratio allowed more light interception and transmission to the lower canopy and recorded significantly higher yield and LER than either of the sole crops.

Sowing of chickpea with barley and wheat in 2:1 row ratio was found better than mixing and broadcasting. Subedi (1998) from Nepal reported that barley + peas intercropping was advantageous in terms of overall grain yield, land equivalent ratio (LER), monetary advantage, economic return and dietary provision in the subsistence farming system. It also provided yield stability under adverse climatic conditions. Barley genotypes differed in their suitability for intercropping with peas. *Rabi* pigeonpea and rice under upland conditions of Bihar is also found efficient systems by way of maximizing the cropping intensity and minimizing the impact of weather vagaries.

Intercropping with commercial crops

Rajmash is a unique pulse crop, which requires input comparable to cereals. It is recently introduced in northern plain regions of the country. Development of several high yielding varieties suitable to northern plains enables it to be grown profitably as intercrop in winter season with potato under high input conditions. Experiment conducted at IIPR revealed that *Rajmash* + potato intercropping has been found quite profitable and efficient in irrigated areas of central Uttar Pradesh. On the basis of *rajmash* equivalent yield, intercropping of *rajmash* + potato was more productive and efficient under all planting geometry as compared to sole *rajmash* (**Table 5**). However, the highest productivity (3956 kg / ha) was obtained under 3:2 row ratio of Potato + *rajmash* intercropping system with 48% increase in land use efficiency. Among intercrops, *rajmash* + linseed in 1:1 row ratio at 45 cm spacing proved most efficient with LER of 1.79 and also recorded highest yield (1753 kg / ha). Considering the yield of component crops, *rajmash* + wheat under 5:1 row ratio proved more than sole *rajmash* and other intercrops (mustard,

PDR 14 - The first variety of *rajmash* for *rabi* cultivation

Potato+*Rajmash* (3 : 2)

pea, linseed). This system recorded higher rajmash equivalent yield (1731 kg/ha) than sole rajmash (1580 kg/ ha).

Growth of sugarcane is initially very slow which gives an opportunity to grow short duration pulses like chickpea/ fieldpea/ lentil / mungbean/ urdbean and cowpea in between two rows of sugarcane. Generally 1-2 rows of pulses are intercropped in between two rows of sugarcane. *Rabi* pulses are intercropped with autumn-planted sugarcane while urdbean and mungbean are grown in spring planted sugarcane. Spring planted sugarcane alone accounts for 65-70 % of the total area being adopted in the states of Punjab, Haryana, Uttar Pradesh and Bihar. Ratoon crop of sugarcane also provides good opportunities for intercropping of spring/summer pulses as the growth of the cane crop remains very slow in the early growth period of crop.

Table 5: Grain yield and LER under Potato + *rajmash* intercropping system

Cropping system	Yield (kg/ha)			LER*
	Potato	*Rajmash*	*Rajmash* equivalent	
Rajmash sole	-	2315	2315	-
Potato sole	24581	-	3090	-
Potato+*rajmash* (2:2)	14907	1778	3500	1.37
Potato+*rajmash* (3:2)	18150	1722	3956	1.48
Potato+*rajmash* (1:2)	9194	2463	3471	1.43
Potato+*rajmash* (2:1)	19861	1333	3643	1.38
LSD (p=0.05)			286	

*LER: Land Equivalent Ratio

Ali & Singh (1991-92)

Autumn Sugarcane + Lentil (1 : 2)

However, for achieving higher productivity, the choice of compatible crops, productive genotypes and adoption of management inputs such as planting time, population density, spatial arrangement, fertilizer, irrigation and weed management are an integral part of the production system. It has been observed that growing one row of mungbean gave about half tonne/ha additional yield of mungbean without affecting the sugarcane yield. Further, increase in mungbean rows to 2 -3 makes the systems non profitable. It has been also found that mungbean is more suitable than urdbean (Yadav *et al.* 1987 and Panwar *et al.* 1990). Studies conducted at Lucknow established that urdbean and mungbean had synergistic effects on cane yield in spring planted crop and provided 0.4-0.5 tons/ha additional yield of pulses grains. Among various pulses, mungbean has been found most profitable. Studies on intercropping pulses with ratoon crop of cane cultivar Co 1148 showed that urdbean was superior to mungbean, but in ratoon crop of Co 64 and Co 8228, mungbean was significantly superior to urdbean. In spring planted cane, PDM 11 of mungbean and PDU 88-31 of urdbean were more compatible than other genotypes (Lal *et al.*, 1999) (**Table 6**).

Spring Sugarcane + Mungbean (1:1)

Table 6: Effect of genotype compatibility in spring planted sugarcane

Cropping system	Yield (kg /ha)		Loss in cane yield (%)
	sugarcane	Intercrop	
Sugarcane sole (Co Lk 8102)	76200	-	-
Sugarcane+ mungbean			
PDM 11	71200	380	6.56
PDM 54	62000	496	18.63
Pant Mung 2	55400	503	27.29
PDM 84-143	69900	604	8.26
Pusa Bold	53100	412	30.31
Sugarcane +urdbean			
Pant U 19	61500	389	19.29
PDU 1	58300	469	23.49
Pant U 35	59200	373	22.30
PDU 88-31	70200	425	7.8
NDU 1	59200	467	22.30

Varshney *et al*. (2000-2001)

Intercropping with coarse grains

Maize is cultivated both in *kharif* and *rabi* season. Generally urdbean and mungbean is sown between the rows of maize crop. This system is practiced in North India and its adjoining hilly area. It has been seen that one row of maize sown after 2-4 rows of urdbean and mungbean has been found appropriate. The growth of maize in *kharif* is faster so, sowing of maize after 4 rows of mungbean/ urdbean gave higher equivalent yield than closer spacing. But in winter sown maize, the maize crop sown after every rows of vegetable pea gave high maize equivalent yield over maize + lentil or sole maize. Further, to minimize the shading effects of maize to legumes, North-South direction sowing was found to be best.

Common bean and maize intercropping is a successful proposition in North-eastern India. Sowing done in 2:1 row ratio of common bean and maize gave common bean yield equivalence of 1794, 998 and 2283 kg/ha in sole common bean, sole maize and common bean + maize (2:1), respectively (Ali and Singh 1997). This system also gave maximum LER (1.61) and proved profitable with the highest benefit-cost ratio (1.87). Pandita *et al* (2000) found that intercropping of maize and bean is economically sustainable under rainfed conditions of Kashmir valley.

Adhikary *et al.* (2008) examined the advantages of legume intercropping system with maize as main crops, on sandy upland loamy soils in Bihar plateau, India and reported maize-groundnut as the best system. Yield advantages were noticed between 22–44 % over sole maize cropping. Different production indices largely indicated the same pattern in ranking intercropping treatments. Of the other legumes used, mungbean also showed potential whereas cowpea and soyabean did not. Soil nitrogen enrichment through legume cultivation was also observed.

In Vertisols of central and peninsular India, intercropping of pulses with sorghum is very much productive and profitable and being adopted by the farmers. In central and peninsular India, sorghum + pigeonpea has been found to be the most productive system on Vertisols whereas on Alfisols and Entisols, pearl millet + pigeonpea proved to be the ideal system (Ali and Singh, 1997). Sowing of one row of sorghum followed by one row of pigeonpea gave additional yield of sorghum besides giving normal yield of pigeonpea. This system also reduced the wilt incidence in pigeonpea crop. The compact type varieties of pigeonpea are more suitable for intercropping systems than spreading varieties. For success of this system, choice of varieties having different plant growth habit, growth rhythm, maturity period and response to plant density is very important.

Pigeonpea + cereal intercropping systems are very common in central and western part of India. The short and early maturing cereals such as sorghum, maize and millets accumulated dry matter and utilized resources during the initial slow growth period of pigeonpea. As the reproductive growth of these intercrops does not coincide with pigeonpea, the yield of cereals is not affected adversely. After harvest of cereals, pigeonpea growth is compensated and additional pigeonpea yield is obtained. Experiment conducted at IIPR, Kanpur showed that in sorghum + pigeonpea intercropping system, the highest pigeonpea grain yield (2, 676 kg / ha), PEY (3, 146 kg / ha), net return (Rs. 43,303 kg / ha) and B: C ratio (3.6) was recorded with 2:1 row ratio on ridge and furrow planting system.

Appropriate spatial arrangement not only helps in maintaining the required plant density but also minimizes competitions among the component crops in intercropping systems resulting in higher total productivity. In pigeonpea + sorghum intercropping system spatial arrangement of 2:1 row ratio on ridge planting system recorded higher pigeonpea equivalent yield and B: C ratio as compared to 1:1 and mixed planting system. However, the spatial arrangement varied with the variation

Pigeonpea + Sorghum (1 : 1)

in plant types of base crop (pigeonpea).

Pearl millet and pulses intercropping practices are followed in rainfed areas of Rajasthan, Haryana and Gujarat. When 2 rows of mungbean / mothbean are intercropped in pearl millet sown at 70 cm row apart, the yield of pearl millet is not affected adversely by these pulses. On the other hand, 400-600 kg / ha additional yield of these pulses are met (Singh and Singh, 1980) besides two fold increase in the moisture use efficiency. Like other intercropping, selection of varieties of both the components is must. For higher profitability, selection of high yielding pulses varieties having drought resistance and shade tolerant characteristics should be chosen. Similarly, dwarf varieties of pearl millet are more suitable than tall varieties (Reddy *et al*. 1990).

Intercropping of short growing pulses with pigeonpea

Pigeonpea is a widely spaced crop, which offers short duration crops to be grown as intercrop. Being a deep-rooted crop, it extracts the nutrients and water deeper from the soil and thereby minimizes the competition for these inputs with cereals when grown in intercropping systems. In North and central India more than 90% pigeonpea is grown in association with short-duration pulses, cereals and oilseeds both under irrigated and rainfed conditions. Urdbean, mungbean and cowpea are quite compatible. These short duration pulses gave an additional yield of 400 – 500 kg / ha without affecting the yield of pigeonpea.

Pigeonpea intercropped with short duration pulses (mungbean, urdbean, and cowpea) is the most popular combinations in northern India. The special feature of

Pigeonpea + Mungbean (2 : 2)

this intercropping system is that productivity of the base crop of pigeonpea remains unaffected and an additional 400-500 kg / ha pulse grain is obtained without any additional inputs. Studies conducted at IIPR clearly revealed that pigeonpea intercrops with maize, urdbean and sesame under rainfed situation gave the highest pigeonpea yield (2390 kg / ha) and PEY (2740 kg / ha) with Pusa 9 (pigeonpea) + DPU 88-31 (urdbean) under 2:1 row ratio. Among different pigeonpea involving intercropping *viz*., maize, urdbean and sesame, Pigeonpea + urdbean was found best. Among the pigeonpea genotypes, Pusa 9, Bahar and urdbean genotype DPU 88-31 were found most compatible.

In early pigeonpea+groundnut intercropping system, 2:2 row ratio with row orientation in North–South direction was found most productive (1,238 kg pigeonpea equivalent yield / ha) and increased land use efficiency by 90% . For long duration pigeonpea + groundnut intercropping system, semi spreading type variety Pusa 9 was more productive under 5:2 row ratio but compact type variety Bahar recorded 67% yield advantage and 46% higher land use efficiency under 5:1 row ratio. Among the two spatial arrangements (2:1 and 2:2) for intercropping, pigeonpea +urdbean, 2:1 row ratio was found better.

3.3 Relay cropping

The *utera* / paira, a type of cropping which is commonly practiced in Bihar, Eastern Uttar Pradesh, West Bengal Chattisgarh and Orissa is a kind of relay method of sowing in which lentil / lathyrus / urdbean / mungbean seeds are broadcast in the standing crop of rice about 2 week before its harvest. This practice enables to use better soil moisture available at the time of harvesting of rice crop, which could otherwise be lost quickly. Experimental evidences showed that paira cropping produced more yield of lentil than planting with tillage after harvesting of the rice crop. *Utera* system does not allow agronomic intervention such as tillage, weeding, irrigation and fertilizer application. However, rice variety decides the productivity of pulses in this system. There are certain issues which need to be resolved for better productivity and profitability. Available variety of rice are long duration and photosensitive, seedling mortality causes inadequate plant population, rare use of fertilizer, weed infestation due to lack of post emergence herbicides and moisture stress at the terminal stage. Most of the area of South eastern Uttar Pradesh in Vindhyan region is rainfed and chickpea is grown after rice. 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

Urdbean - A potential crop for rice fallows of coastal penninsula

Lentil - an ideal crop for relay cropping with rice in central India

(Tripathi, 1986).The development of zero till drill has now facilitated sowing of wheat/ chickpea /lentil immediately after harvesting of rice in moist soil.

3.4 Catch Cropping

Catch crop is a short duration crop that is grown between successive plantings of main crops or are also crops that are sown to prevent minerals being flushed away from the soil. It may be harvested or plowed under to improve the soil fertility.

Mungbean cv. Samrat maturing in 55-60 days

Development of extra-early varieties of mungbean (Samrat, Pusa Vishal, SML 668, Pant M 5, TMV 37) with synchronous maturity and resistance to MYMV has helped introduction and expansion in rice – wheat cropping system of Indo-Gangetic plain (IGP) as catch crop during spring/summer season. In the IGP, both area and production under mungbean experienced positive trend during the past three decades. While the area under mungbean in IGP has almost doubled from 1.63 lakh ha in 1970-71 to the present level of 3.19 lakh ha, the production has increased almost three-fold from 0.61 lakh tons to 1.68 lakh tonnes during the period.

3.5 Ratoon Cropping

The principles involved in ratoon cropping, a form of sequential cropping, are different from other types of multiple cropping because of such factors as the presence of a well developed root system, earlier maturity, and the perennial nature of the plant. Although the term may be applied to perennial pasture plants, it is considered more appropriately used with respect to field crops such as sugarcane, sorghum, banana (*Musa sapientum*, *M. cavendishii*), cotton, kodra millet (*Paspalum* *scrobiculatum*), pineapple (*Ananas comosa*), pigeonpea and rice. Ratoon cropping is a multiple-harvest system in which regenerating stubbles of the established crop in the field are managed for subsequent production. The development of short-duration genotypes of pigeonpea has generated interest in ratooning of pigeonpea. Instead of cutting, picking of pods is done for ratton crop and the plants are allowed to bear next flush of pods. Irrigation after the main harvesting of the crop increases the yield from the ratoon crop.The ratoon crop usually produces 50-65% of the sown-crop yield. The ratoon system is not viable if sequential cropping is possible. Pigeonpea ratoon crop may serve as a source of inoculum of sterility mosaic disease. Therefore, the cultivars for ratooning should be resistant to this disease.

Genotype ICPL 87 produced 4100 to 5200 kg / ha under irrigated conditions in three harvests during a growing period of 220 days. While under rainfed conditions of Alfisols, it yielded 2500 kg / ha in three harvest by picking pods (Chauhan *et al*. 1987, Rao and Sachan, 1988). However, performance of different varieties differs due to their variable growth and duration in different zones. In northern India where winter is very cold, ratoon cropping is not successful. For multiple harvesting of pigeonpea, minimum temperature should not go below 10^0C. Experiments conducted under AICPIP (All India Coordinated Pulses Improvement Project) to find out the suitable genotypes for different regions observed that under irrigated condition of South peninsular India, where winter are mild, ratoon management are promising. Variety ICPL 87 proved better than other varieties. But under rainfed conditions of Badnapur (Maharashtra) and Bangalore (Karnataka), the ratooning of medium duration local cultivars gave higher yield over ICPL 87 (Ali and Singh, 1997).

4. Effect of Pulses on System Productivity and N Economy

Pulses are known for their soil fertility restoration value. Deep rooting, nitrogen fixation, leaf shedding ability and mobilization of insoluble soil nutrients are some of the unique characteristics of pulses. By improving chemical, biological and physical environment in the soil, pulses can arrest the declining trend in productivity of cereal-cereal system. Inclusion of pulses in intensive cereal based system itself is a component of integrated plant nutrient supply system. Therefore, pulses have become viable alternative to improve the soil health and conserve the natural resources and agricultural sustainability.

4.1 N economy

It has been estimated that 668,000 tonnes of nitrogen can be incorporated in the soil through the inclusion of legumes in cropping systems. The intrinsic nitrogen fixing capacity of pulse crops enables them to meet 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 capacity 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 (**Table 7**). Growing of short duration legumes such as green gram 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. Rekhi and Meelu (1983) found that incorporation of crop residue of mungbean in rice-wheat system not only added 100 kg N / ha to the soil but also maintained high availability of N during various growth stages of rice.

In a three-year experiment on sandy loam soil of Kanpur, Kushwaha and Ali and Meena and Ali (1984-87) reported significant improvement in productivity and

Table 7 : Nitrogen economy due to inclusion of pulses in sequential cropping

Preceding legume	Following cereal	Fertlizer N-equivalent (kg N/ha)	Reference
Chickpea	Maize	60-70	Subbarao (1988); Lee and Wani (1989)
	Pearlmillet	40	
Pigeonpea	Wheat	40	
	Maize	20-49	
	pearlmillet	30	
Lentil	Pearlmillet	40	
	Maize	18-30	
Peas	Pearlmillet	40	
	Maize	20-32	
Greengram	Pearlmillet	30	
Lathyrus	Maize	36-48	
Cowpea	pearlmillet	60	
Pigeonpea	Sorghum	51	Ali (1984-87)
Chickpea	Rice	40	
Rajmash	Rice	40	
Fodder cowpea	Rice	40	
Mungbean	Rice	40	

N economy in wheat preceded by *kharif* legumes. Cowpea was most beneficial followed by pigeonpea and pigeonpea + mungbean. Soybean – wheat system was most productive followed by pigeonpea – mungbean – wheat among *kharif* pulse based cropping systems. The nitrogen economy due to preceding pigeonpea over sorghum was 51 kg N equivalent / ha. Influence of *rabi* pulses on productivity and N economy in succeeding rice revealed that chickpea and lentil exhibited most favourable effect in economizing nitrogen to the extent of 40 kg / ha. Among summer pulses, mungbean – rice was most productive (6620 kg / ha) followed by fodder cowpea – rice (**Fig. 1**), which was mainly attributed to the residual effect of nitrogen by the legumes. In Oxisols of Vamban, highest grain yield was recorded in cowpea – maize sequence followed by urdbean – maize. The superiority of cowpea as preceding summer pulse was attributed to its higher N fixation capacity and higher addition of plant residues in the soil, which enriched the soil fertility and promoted the growth of succeeding crop (Srinivasan *et al*. 1991). An overview of N economy of cereals and cropping systems in different agro-climatic zones under pulse based cropping system showed that N economy in different zones varied from 30-67 kg/ha (**Table 8**).

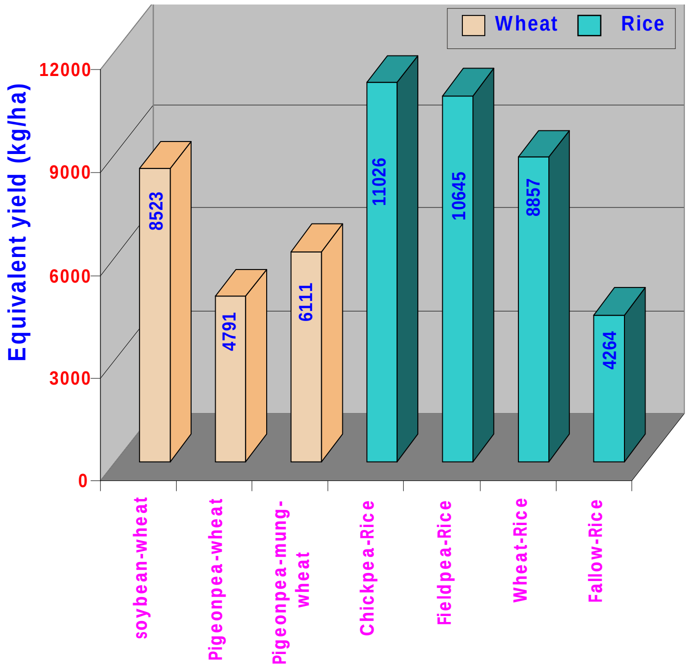

Fig. Effect of preceding legumes on productivity of succeeding cereals

Further, biofertilizers have profound effect on succeeding cereal crops. Yadav and Singh (1986) observed beneficial effect of urdbean inoculated with *Rhizobium* on succeeding wheat crop. Application of 10 kg N/ha to urdbean boosted the seed yield of wheat by 202 kg/ha over uninoculated *kharif* fallow. In sandy loam soils of Modipuram, Sharma *et al.* (1995) reported that inoculation of *Rhizobium* and PSB in chickpea produced 26.3 and 32.8 per cent more yields of succeeding maize and fodder sorghum respectively, showing a residual effect equivalent to 20 kg N/ha. The residual effect of *Rhizobium* inoculation along with P fertilizer was to the tune of 30 and 40 kg N/ha in maize and fodder sorghum, respectively. Higher yield of cereal crops after legumes in rotation has also been reported by Sinsinwar (1994), which is due to residual effect of biological N fixation together with addition of root biomass by legumes to succeeding wheat.

Table 8: Nitrogen economy in pulse based cropping systems in different agro-climatic zones of India

Agro-climatic zone	States represented	Soil type	Location of experiment	Cropping system	N – economy (kg/ha)	Reference
V	UP, Uttaranchal	Alluvial	Faizabad	Mung-wheat	30	Yadav (1990)
			Agra	Mung-wheat	37	Singh and Verma (1985) Singh and Singh (2006)
				Urd – wheat	41	
				Cowpea (F) - wheat	43	
			Kanpur	Cowpea (f) – rice	44	Ali (1992a) Baghel (2005)
				Mung – rice	35	
				Cowpea (f) - wheat	40	
VI	UP, Punjab, Rajasthan, Haryana	Red yellow, alluvial red loam	Faizabad	Urd - wheat	30	Yadav and Singh (1986)
			Ludhiana	Cowpea - wheat	40	Saxena and Tilak (1975)
				Pigeonpea-wheat	30	Gogoi and Sandhu (1984)
VII	Orissa, Bihar, WB	Alluvial	Ranchi	Chickpea - rice	30	Srivastava and Srivastava (1993)
				Lentil – rice	30	
				Fieldpea -rice	30	
VIII	MP, Rajasthan, UP	Alluvial, red brown, hill	Jhansi	Urdbean – wheat	30	Singh and Bajpai (1993)
				Cowpea - wheat	40	Sinsinwar (1994)
IX	Maharashtra	Vertisol	Rahuri	Sorghum - chickpea	50	Gawai and Pawar (2007)
X	Andhra Pradesh	Alfisol	Hyderabad	Mung-rice	36-67	De *et al* (1983)
				Cowpea – rice	10-37	Reddy and Surekha, 1999
				Urdbean - rice		
				Chickpea-rice		
	Assam	Alfisol	Jorhat	Urdbean-maize	60	De (2003)

4.2 Effect on soil properties

Physical properties

Aggregate stability is an important soil quality parameter, which can be used as an index to compare the long-term shift in soil quality. 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 produces a glycoprotein called "Glomalin". The sticky part of glomalin entraps soil mineral, 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). Bulk density is another soil quality parameter, which responds to change in management over a long period of time. In crop sequences which returns sizeable amount of residues to soil usually result in lower bulk density (Ganeshamurthy *et al.* 2006). Incorporation of mungbean stover in rice-wheat-mungbean sequence resulted in lower bulk density and hydraulic conductivity (**Fig. 2**). 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 deep into the soil. Results of AICPIP (All India Coordinated Pulses Improvement Project)

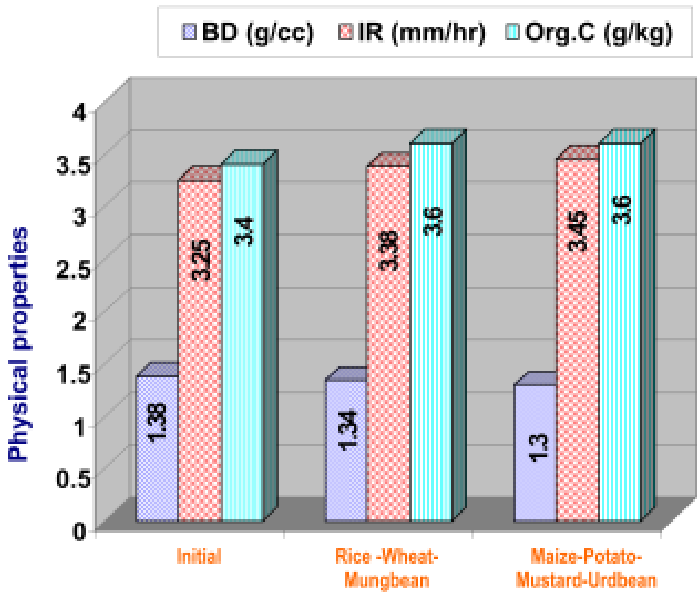

Fig. 2. Effect of pulse based cropping system on soil physical properties

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 pH : Pulse crops have the ability to reduce the pH of soil in the rhizosphere and make micro-environment favourable for nutrient availability. Since pulses acquire a greater part of their nitrogen requirement from the air as diatomic nitrogen rather than from the soil as $NO_{3,}$ their net effect is to lower the pH of soil. Some of the legumes like alfalfa and soybean can reduce the pH of soil by one complete unit. Among grain legumes, chickpea reduces the pH most followed by pea and pigeonpea. This reduction in pH of the soil helps to create favourable soil environment especially in neutral and alkaline soil environments and also to increase the nutrient availability and microbial activity. The reduction of pH becomes clearer with intense growth period.

Build up of Organic matter and nutrients : Pulses add significant amount of organic residues to the soil in the form of root biomass and leaf litter. Roots and leaf litter being rich in N facilitate decomposition of crop residues in soil and increases microbial activity. *Rabi* pulses contributed 7-14 kg N, 3-5 kg P and 8-20 kg K/ha. Pigeonpea added 8-16 kg N, 2.5-5.0 kg P and 13.5-24.0 kg K/ha through leaf drop in the entire crop growth cycle. In a study conducted over three years, mungbean green manuring or incorporation of mungbean stover after picking of pods in rice-wheat system considerably improved the available P status of soil, due to root exudates capable of mobilizing sparingly soluble P in soil (Saxena 1995). Study conducted at Pantnagar showed significant improvement in organic carbon and total N due to substitution of one cereal component with legumes **(Table 9**). Pulses

Table 9: Change in fertility status of soil under different cropping systems

Crop sequences	Organic carbon (%)	Total N (kg/ha)	Available P (kg/ ha)
Rice-wheat	-0.004	-8.0	1.4
Rice-lentil	0.006	10.0	4.8
Pigeonpea-wheat	0.006	9.0	8.8
Rice-wheat- green manure	0.010	15.0	13.8

Singh *et al.* (1996)

by virtue of their several characteristics have been found the best choice for diversifying the cereal based cropping systems to sustain the cropping systems. Availability of varieties having diverse characteristics and their role in soil amelioration has resulted into identifications of several remunerative and more productive cropping systems.

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 fieldpea and lentil in contribution of residual NO_3 in the soil profile. Among the genotypes, chickpea cv. BG 1003, lentil cv. DPL 62 and fieldpea cv. Rachana were highest in increasing the nitrate content. *Kharif* pulses also increased the soil NO_3 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).

Phosphorus : 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 helps 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 rhizospere through its citric acid root exudates in Vertisols and pigeonpea have been characterized for dissolution of Fe-P in Alfisol (Ae *et al.*1991).

Biological properties : Pulses are known to improve the microbial environment in the soils. They are known to release a part of unused nitrate fixed through symbiotic nitrogen fixation to the soil. Also low molecular weight organic compounds are released to the soil as exudates. This serves as a substrate to soil microorganisms resulting in the build up of population of soil microbes. 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 highest soil microbial biomass carbon as compared to maize-wheat (**Table 10**). Dehydrogenase enzyme activity, an index

Table 10: Microbial biomass carbon in maize based cropping system

Cropping System	Microbial biomass carbon (µg/g)		
	Control	CRB + BF +FYM	NPKSZn B
Maize-Wheat	247	298	291
Maize-Wheat- mungbean	327	350	338
Maize –wheat –maize –chickpea	310	338	334
Pigeonpea-wheat	295	305	301

Kushwaha *et al.* (2007-08)

of soil microbial activity was also found to increase in soil after pulse crop. 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 over all system productivity increased. In rice-chickpea system, incorporation of residues + irrigation + N @ 20 kg/ha resulted in highest yield (**Table 11).**

Table 11: Effect of residue incorporation on grain yield (kg/ha) of rice and chickpea in sequential cropping system

Residue management	Yield (kg/ha)		
	Rice	Chickpea	Rice Equivalent
Removal	3273	2258	6848
Partial burning	3455	2323	7133
Incorporation + followed by irrigation	3313	2489	7253
Incorporation +20 kg N/ha	3535	2358	7286
Incorporation + Irrigation +20 kg N/ha	3828	2399	7626

Singh *et al.* (2007-08)

Chickpea @ Rs1900/ q and Rice Rs 1200/q

5. Economy in Fertilizer Use

5.1 Sequential cropping

There is a substantial residual effect of nutrients in cereal-pulse based cropping sequences. Application of phosphorus to chickpea was beneficial to succeeding rice giving a substitution effect of 20-30 kg P_2O_5/ha when compared with P applied to rice in rice-chickpea sequence. Rhizobium and application of 40 kg P_2O_5/ha in chickpea besides increasing chickpea yield also increased the yield of succeeding maize and fodder crops significantly. In urdbean – wheat sequence, a net saving of 25% of fertilizer could be made in wheat (Singh and Singh, 2006). Singh and Ahlawat (2007) reported that application of 17.2 kg P/ha to the preceding pigeonpea significantly increased the growth, yield attributes as well as yield of succeeding wheat over no P application. The direct application of P to wheat at 17.2 kg/ha was at par with that of 34.4 kg/ha, which showed that 50% of P requirement could be saved. Russel (1973) reported that pigeonpea made use of phosphate residues more effectively than wheat in this system. In chickpea-upland rice system in Alfisol of Hyderabad, direct effect of P was limited only up to 20 kg P in case of chickpea, the maximum residual response to kharif upland rice was significant upto 40 kg P/ha. From this, it appears that even chickpea feeds better on native P source leaving lot of residual P to succeeding crops.

Response to sulphur up to 20 kg/ha was also noticed in chickpea to sustain the yield of both the crops in rice-chickpea system. In case the sulphur is applied to pigeonpea, its application could be omitted to the succeeding wheat crop without any loss in the grain yield (Singh and Sekhon, 2007). Based on 2 year field studies in pigeonpea-wheat sequence, application of RDF + Zn+B+Mo to pigeonpea recorded significant residual effect on yield of wheat (5000 kg/ha) as compared to control (4000 kg/ha). Pigeonpea equivalent yield was also found highest (3148 kg/ha) in this treatment.

Inclusion of pulse crop in a cropping system itself acts as a component of integrated nutrient management and benefits arising out of this are very much comparable to the benefits obtained from any other organic manure. Application of

5 t FYM / ha significantly increased the seed yield of pigeonpea and residual effect of FYM resulted in significant increase in grain yield of wheat in pigeonpea – wheat system. Rice – chickpea system was found most productive and profitable system (Rs. 30,777/- net returns/ha) with 60 kg P_2O_5/ha applied to rice, 40 kg P_2O_5/ha applied to chickpea along with 5 t compost/ha applied to rice. Rice cv. NDR 359 and chickpea cv. BG- 256 were found to be the most productive genotypes in rice – chickpea system. In maize-chickpea system, seed yield of chickpea significantly increased with application of 30 kg S and 5 t FYM / ha. Residual effect of *kharif* applied S was not conspicuous where there was no direct application of S to chickpea.

Crop residue application increased the sorghum yield by 26% in sorghum + pigeonpea intercropping system. The residue management studies of *kharif* mungbean indicated a yield gain in *rabi* crop to the extent of 15.6%. Further, incorporation of mungbean residue substituted 50% NPK requirement of *rabi* sorghum. In sorghum-chickpea sequence, 75% RDF + FYM @ 5 t / ha + Biofertilizer (*Azospirillum* and PSB) to sorghum and 50% RDF to chickpea resulted in highest grain yield and benefit:cost ratio (Gawai and Pawar 2007).

5.2 Intercropping

The dilemma of nutrient management under intercropping system arises due to differences in nutrient requirement of intercrops and also due to biological nitrogen contribution from pulses. Biological efficiency is likely to improve when legumes are included in the cropping system as intercropping because they explore the same soil mass more thoroughly, compared to sole cropping and may be able to take up the nutrients from a place and a form which are inaccessible (Saraf and Patil 1995). Multi-locational trials on mode of fertilizer application in pigeonpea based intercropping system showed that recommended dose for the cereal component of the system is sufficient to achieve yield of component crops almost equivalent to those obtained with the recommended dose of nutrient applied to both the components. In general, application of 50% of recommended dose of N for cereal and full quantity of phosphorus and potash required for the system at the time of sowing and remaining dose of N a month after sowing would be optimum for pigeonpea + cereal intercropping system. The basal dose of N meets the initial demand of cereal and legume, afterwards, biologically fixed N will be available to both pigeonpea and intercrop component. In wheat + chickpea intercropping system, Ali (1993) reported that application of normal recommended dose of fertilizer to wheat only was as efficient as applying doses to both the crops indicating that fertilizer applied to wheat were adequate to meet the requirement of associated chickpea also. Singh *et al.* (1997) reported that chickpea in intercropping system was not influenced by N levels but was responsive to P applied upto 60 kg P_2O_5/ ha. In pigeonpea + urdbean intercropping, application of recommended dose of fertilizer to pigeonpea alone was significantly more effective and it met the initial requirement of fertilizer for urdbean (Singh and Singh, 1995). Benefit: Cost ratio was higher when blackgram supplied with no fertilizer or 50% of recommended fertilizer was intercropped with maize given with recommended fertilizer @ 120:26.4:33.2 kg NPK/ha (Kumar *et al.* 2002). Spatial arrangement and nutrient application in chickpea based intercropping systems across various centres of AICRP on Pulses revealed that intercropping of chickpea + mustard (6:1) along with 75% recommended dose of fertilizers recorded higher chickpea equivalent yield than sole crop of chickpea.

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