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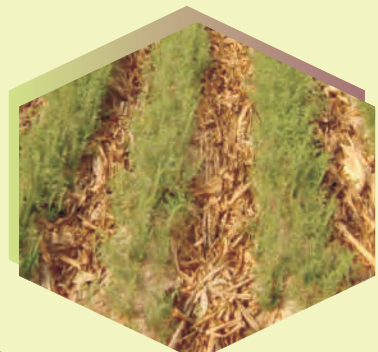
RESOURCE CONSERVATION TECHNOLOGY IN PULSE BASED CROPPING SYSTEMS



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Resource Conservation Technology in Pulse Based Cropping Systems

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FOREWORD

The conservation of natural resources becomes necessity to achieve sustainable and profitable pulse production system and subsequently to improve livelihoods of the farmers. The key challenge today is to adopt strategies that will address the twin concerns of maintaining and enhancing the integrity of natural resources and improved productivity. The improvement of natural resources forms the very basis for long-term sustained productivity. Over the past 2–3 decades globally, Resource Conservation Technology (RCT) has emerged as a way for transition to the sustainability of intensive production systems. RCT permits management of water and soil for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation like erosion, compaction, aggregate breakdown, *etc.*

Inclusion of pulses in cropping system needs to be viewed as long-term benefit for resource conservation because of their intrinsic virtues like nitrogen fixation ability, less dependence on external inputs like water, fertiliser and power, per day productivity and higher protein content and its role in ecological security. In recent years, research in agricultural science has undergone a change with more emphasis on sustainable high productivity under resource constraints. In this context, bringing out the publication on Resource Conservation Technology in Pulse Based Cropping Systems is very appropriate. I complement the authors for their sincere efforts in bringing out this publication and putting all relevant information at one place in a very lucid manner. I believe the results of various activities embodied in this technical bulletin will be very useful to researchers, extension and development personnel in understanding and implementing resource conservation practices in pulses and pulse based cropping systems.

(N. Nadarajan)
Director

PREFACE

Degradation of natural resources is a serious environmental problem that threatens ecosystem health and food security worldwide. The over exploitation of soil and water resources lead to reduction in use efficiency of inputs *e.g.*, fertilizer, irrigation *etc*. Enhancing the natural resource base is of paramount importance. It is relevant to study the stresses on these resources and assess the concerns related to their future use. The deteriorating production and sustainability of rice-wheat cropping system in country are evident from either stagnation or decline in the yield and factor productivity of rice and wheat.

Resource Conservation Technology (RCT) has shown to improve, conserve and use natural resources in a more efficient way through integrated management of available soil, water and biological resources. It is now widely recognised as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental and social terms. Pulses, endowed with unique ability of biological nitrogen fixation, deep root system, low water requirements and capacity to withstand drought, constitute an important component of crop diversification and resource conservation technology. The present bulletin is a compilation of the results of different resource conservation practices like crop diversification, conservation tillage, residue management, raised bed planting and mechanization for resource conservation carried out at IIPR. We are grateful to Dr. N. Nadarajan, Director, IIPR for his necessary guidance and constant support in compilation and publication of this technical bulletin. We wish to express our sincere thanks to all technical and supporting staff of the division for their help in compiling the manuscript. We hope that this bulletin, a compilation of results of different research programme carried out at IIPR will serve as a useful material for upgradation of the knowledge level of researchers and extension personnel.

Authors

PREFACE

Introduction

Indian agriculture is now at crossroads. We have come a long way. Over the past five decades our strategies, policies and actions were guided by goals of 'self-sufficiency' in foodgrain production with main focus on rice and wheat. Indian agriculture has been successful in achieving increased foodgrains production albeit at a low level of satisfaction. While the mission of increasing foodgrains production stands somehow achieved without major jump in pulses productivity and production in country, these were accompanied by widespread problems of resource degradation, which now pose a serious challenge to the continued ability to meet the demand of an increasing population and lifting our people above the poverty line.

Rice and wheat are the two major food crops of India. Therefore, primary food security concerns are focused on improving and sustaining their productivity. With the advent of the "Green Revolution", these two crops have come to occupy a significant area in the country. Of late, concerns have been expressed that the rice-wheat growing areas are developing a so-called "fatigue", due to continuous uninterrupted cultivation of this very exhaustive cereal-cereal (rice-wheat) cropping system, for nearly about five decades. There is no doubt that rice and wheat, which have similar adventitious rooting systems, are very heavy feeders of plant nutrients, and rice in particular requires large number of irrigations (20–25 in the irrigated rice-wheat areas of the IGP on light alluvial soils). Rice and wheat exploit the soil to a greater extent making it poorer year after year. The rice-wheat system accounts for annual removal of more than 650 kg/ha of N, P and K resulting in negative balance of these nutrients even with recommended fertilizer use which adversely affect the sustainability of production system (Abrol *et al.,* 1999).

Pulses are next to cereals in terms of their economic and nutritional importance as human food. The ability of pulses to fix atmospheric nitrogen in the soil-crop system is their unique and beneficial characteristics among all plant species. Thus, pulses can contribute significantly to achieve the twin objectives of increasing productivity and improving the sustainability of rice and wheat based cropping systems. The pulses grown together with or before a cereal crop can reduce and sometimes substitute the need of nitrogen application as well. The deleterious effect of spring fallow on soil physical and chemical properties, soil organic carbon content and soil fertility can be decreased by cultivating pulse crops during fallow period. On the other hand there is scope of increasing per capita availability of protein to rural poor population by the introduction of pulses in the rice fallows during dry season.

In spite of many beneficial effects, pulses are still considered as secondary crop with respect to management, more so with irrigation and hence have always been relegated to marginal land and cultivated with meager inputs. Pulses are grown on marginal and degraded land over the years with low or no inputs. Conservation practices have shown advantages over traditional practices by means of improving productivity and soil health in case of cereal crops in many parts of world.

Conservation Agriculture vs. Resource Conservation Technology

According to FAO, Conservation Agriculture (CA) is an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles, namely:

i. Continuous minimum mechanical soil disturbance,

ii. Permanent organic soil cover, and

iii. Diversification of crop species grown in sequences and/or associations.

However, the term resource conservation technology (RCT) refers to the practice that enhances resource- or input-use efficiency such as zero or reduced tillage, new varieties, laser land leveling, bed and furrow configuration for planting crops, *etc.*

Advantages of conservation agriculture

- Reduced soil erosion by wind and water
- Increased water infiltration and storage
- Reduced evaporation
- Prevention of overheating of the soil surface favours seed germination
- Build up of SOM
- Improved aggregate stability and soil structure
- Deepening of rooting horizon
- More abundant soil life - earth worms, *etc.*

- Less drought susceptibility
- Better quality of rural life, reduced drudgery
- Improved soil quality and fertilizer efficiency
- Reduction in poverty and labor demands for small framers.

Pulses: Component of RCT

Sequential Cropping

Sequential cropping is a kind of multiple cropping system in which two or more crops are grown in a sequence on same land within a crop year, one crop being sown after the harvest of the other. Pulses in the cereal/oilseed based cropping systems are introduced to break the monotony of crop rotation. Pulses being rainfed low input crop provide safeguard against crop failure due to poor rainfall and adverse weather conditions. Apart from enriching soil fertility, introduction of pulses in cropping system also improves nitrogen economy.

Early pigeonpea-wheat sequence was evaluated and found promising than traditional rice-wheat cropping system in irrigated areas of Punjab, Haryana, central and western Uttar Pradesh by advancing the pigeonpea sowing to May-June or earlier. Early pigeonpea genotypes UPAS 120, Pusa 992, Manak, AL 15, AL 201 and ICPL 88039 were found promising for this cropping system.

Inclusion of pulses in rice-wheat system increased the system productivity besides improving the soil fertility. Inclusion of *rabi* pulses significantly increased the productivity of succeeding rice crop in comparison to wheat. In a three years study, the highest yield of rice (4,912 kg/ha) was obtained after preceding crop of rajmash which was at par with chickpea, lentil and fieldpea and significantly higher over wheat. Crop rotation involving *rabi* pulses particularly rajmash, chickpea and field pea economized N to the tune of 40 kg/ha over wheat and considerably increased total economic yield under irrigated condition. Similarly, the yield of wheat was improved significantly after *kharif* legumes especially mungbean, soybean and groundnut than maize. *Kharif* pulses particularly cowpea and pigeonpea + urdbean/mungbean contributed an equivalent of 40 kg N/ha to subsequent cereal crops (Table 1).

Table.1 Nitrogen economy due to inclusion of pulses in sequential cropping

Preceding pulse crop	Following cereal	Fertilizer N- equivalent (kg N/ha)
Chickpea	Maize	60
Chickpea	Rice	40
Pigeonpea	Wheat	40
Mungbean	Rice	40
Urdbean/mungbean	Wheat	30
Lentil	Maize	30
Fieldpea	maize	25
Rajmash	Rice	10
Cowpea	Rice	40
Cowpea	Wheat	43

(Source: Subbarao, 1988)

Inclusion of short duration catch crop in summer like mungbean not only provide a bonus yield of 700-1000 kg/ha, but also economises nitrogen in the subsequent rice crop to the tune of 34 kg/ha. Among the summer legumes, the highest improvement in system productivity was recorded with mungbean, followed by fodder cowpea and urdbean.

In low land areas of eastern UP, Bihar and parts of MP, where excess moisture after harvest of rice poses serious problem, rust resistant high yielding lentil varieties have been found suitable for rice-lentil sequence. Under this situation, two bold seeded lentil genotypes (K 75 and DPL 62) and two small seeded genotypes (Pant L 4076 and IPL 81) were found most suitable. However, in relay cropping system rice - lathyrus was found most remunerative, followed by rice-linseed.

Development of early maturing chickpea varieties suitable for planting upto mid-December with higher yield potential (1,500-2,000 kg/ha) has enabled the farmers to adopt rice-chickpea sequence instead of cereal-cereal systems especially in the tail end of command areas in eastern Uttar Pradesh and Bihar. After three years of research experiments, rice genotype NDR 359 and chickpea genotype BG 256 recorded significantly higher rice equivalent yield (10,633 kg/ha), net return and benefit cost ratio. Among the 10 AVT lines of chickpea along with two checks (DCP 92-3 and BG 372) for their suitability under rice-chickpea sequence, IPC 2005-61 recorded maximum yield (2,793 kg/ha), followed by DCP 92-3 (2, 790 kg/ha) and found most suitable for rice – chickpea sequential cropping.

Short duration high yielding varieties like Uday, Amber, HUR 15 and HUR 137 of rajmash have been successfully introduced in the central and eastern plain zone under irrigated condition. Cropping sequence like rajmash-mungbean and rajmash –urdbean were found most remunerative (gross return Rs. 38,963/ha). The yield of summer legumes after rajmash was higher than that after wheat and chickpea mainly due to timely planting. Among the six rice-pulses cropping system under lowland irrigated conditions, rice-rajmash-mungbean was found most productive (5,210 kg/ha) and remunerative (Rs. 37,515/ha), followed by rice-wheat-mungbean (4,644 kg/ha and Rs. 33,842 /ha) (Fig 1). However, B: C ratio of rice-lentil (2.64) and rice - field pea (2.38) was higher than other crop sequences probably due to low input cost as compared to other pulses. It was also observed that the yield of summer legumes after rajmash was higher than that after wheat and chickpea mainly due to timely planting.

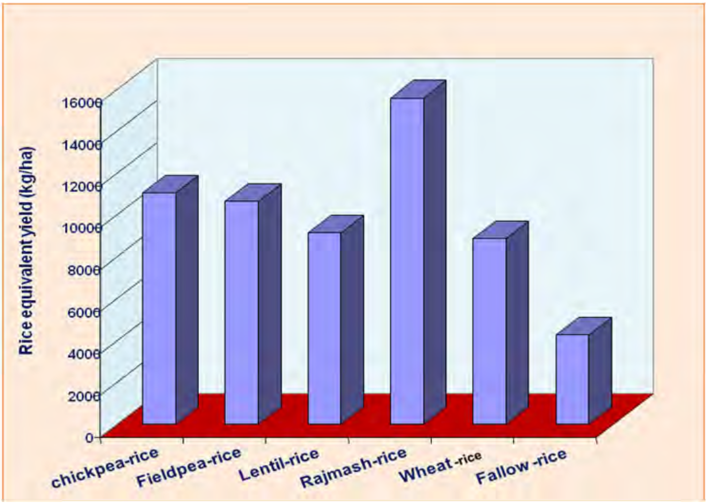


Fig.1 System productivity of different pulse based cropping systems
(Source: 25 Years of Pulses Research at IIPR, 2009)

In a long-term study, significantly highest system productivity in terms of chickpea equivalent yield (CEY) was recorded in case of rice-wheat-mungbean (10,050 kg/ha), followed by rice-chickpea (8264 kg/ha) and rice-chickpea-rice-wheat (7305 kg/ha) systems over rice-wheat (Fig 2). In maize based long-term experiment highest pigeonpea equivalent yield (PEY) was recorded in maize-wheat-mungbean (5244 kg/ha) as compared to maize-wheat system (3125 kg/ha) (Fig 3). Nitrogen economy due to preceding pigeonpea was 51 kg N equivalent/ha.

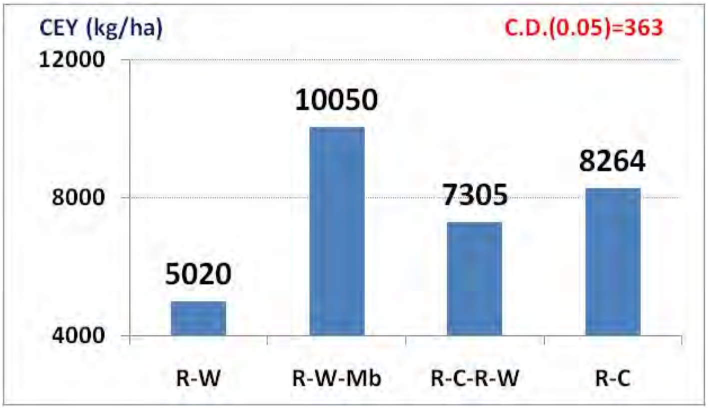


Fig.2 System productivity of rice-pulse system under long-term fertlility experiment. (R-W : Rice-Wheat; R-C : Rice-Chickpea; R-W-Mb : Rice-Wheat-Mungbean; R-C-R-W : Rice-Chickpea- Rice-Wheat) (Source: IIPR Annual Report 2010-11)

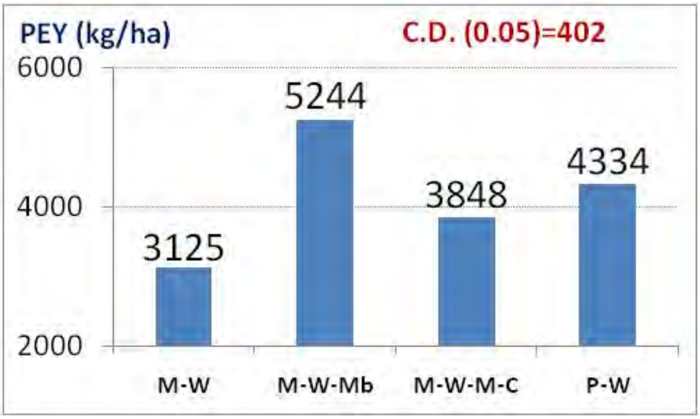


Fig.3 System productivity of maize-pulse system under long-term fertlility experiment (M-W : Maize-wheat; M-W-Mb : maize-wheat-mungbean, M-W-M-C : Maize-wheat-maize-chickpea; P-W, Pigeonpea-wheat) (Source: IIPR Annual Report 2010-11)

Intercropping

Intercropping is the practice of growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Pulses are generally intercropped with coarse cereals and oilseeds under rainfed condition in our country. The slow initial growth habit and deep tap root system makes these crops more suitable for intercropping with cereals and oilseed crops than any other crop. Apart from increasing profitability and resource use efficiency, pulses as intercrop act as safeguard under unprecedented moisture stress condition. Studies conducted at IIPR have also revealed that introduction of pulses as intercrop could reduce the disease and weed intensity. The major intercropping systems involving pulses are as follows:

***Kharif* pulses**

The early maturing cereals such as sorghum, maize and millets accumulate dry matter and utilized resources during the initial slow growth period of pigeonpea offer a good option for intercropping with long duration 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.

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) were recorded with 2:1 row ratio. In another set of study, highest pigeonpea yield (23.90 kg/ha) and PEY (27,40 kg/ha) were obtained with Pusa 9 (pigeonpea) + DPU 88-31 (urdbean) under 2:1 row ratio. However, pigeonpea cv. Pusa 9 and groundnut cv. Chitra in 5:2 row ratio was found more productive (4422 kg/ha

Table 2. Yield and land use efficiency as influenced by genotypes and planting geometry in pigeonpea + groundnut intercropping

Treatment		Yield (kg/ha)			LER
		Pigeonpea	Groundnut	Pigeonpea equivalent	
Sole cropping					
Pigeonpea cv. ICPL 151		626	-	626	1.0
Pigeonpea cv. UPAS 120		1150	-	1150	1.0
Groundnut cv. Chitra			1076	861	1.0
Intercropping (Pigeonpea + groundnut)					
ICPL 151 + Chitra					
Additive	2:1 RR	578	238	768	1.14
Replacement	2:2 RR	324	387	634	0.88
	2:4 RR	267	347	545	0.75
	1:2 RR	133	313	383	0.50
	1:4 RR	208	370	504	0.68
UPAS 120 + Chitra					
Additive	1:2 RR	1056	204	1219	1.11
Replacement	2:2 RR	857	476	1238	1.19
	2:4 RR	445	624	944	0.97
	1:2 RR	409	508	815	0.83
	1: 4 RR	350	509	757	0.78
LSD (p=0.05)				291	

RR: Row ratio (Source: IIPR Annual Report 1997-98) pigeonpea equivalent yield), followed by Bahar + Chitra in 1:1 row ratio. Similarly, ICPL 151 + Chitra with 2:1 (additive series) and UPAS 120 + Chitra in 2:2 (replacement series) were found most profitable (Table 2).

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 than 1:1 and mixed planting system.

Pigeonpea + sorghum intercropping (2:1)

Among pigeonpea based intercropping with 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.

Pigeonpea + urdbean intercropping

In paired row planting system, pigeonpea + sorghum recorded significantly higher system productivity in terms of pigeonpea equivalent yield (5792 kg/ha). Among different varieties/genotypes PDA 10 + sorghum gave highest yield, followed by Bahar + sorghum and PDA 10 + urdbean.

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.

Pigeonpea + groundnut intercropping

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%.

The companion crops *viz.,* urdbean, mungbean, cowpea, soybean and sorghum of pigeonpea appreciably suppressed the weed flora under both uniform and paired row planting. However, weed suppression under uniform row planting (1:1) was considerably higher (30.8%) than paired row planting (16.7%), mainly due to closer sowing. Among companion crops, cowpea was found to be the most effective with 43.4% weed suppression under uniform row planting and 22.6% under paired row system.

Pearl millet + urdbean and pearl millet + mungbean particularly under paired row system (2:1) were found to be highly productive and efficient (LER >2).

Rabi pulses

Chickpea, lentil and rajmash also offer suitable options for intercropping with cereals and oilseeds. *Kabuli* chickpea + barley in 3:1 row ratio recorded maximum productivity and higher LER (1.3) as compared to sole crops (Fig 4). Similarly, chickpea + linseed intercropping was found highly productive and profitable than their sole cropping.

Wheat + chickpea intercropping under 2:2 ratio was found more productive (4769 kg wheat equivalent yield/ha) and LER of 1.20 than two other row ratios. Application of recommended dose of fertilizer only to wheat was as efficient as applying the fertilizer to both crops.

Among three genotypes (BG 256, KPG 59 and KWR 108) and three spatial arrangements (2:1, 4:2 and 6:2), BG 256 with 6:2 row ratio of chickpea + linseed (Neelam) was found most productive (CEY 2,609 kg/ha), profitable (Rs.18, 531 / ha) and efficient (LER 1.48) as compared to others (Table 3). Similarly, *kabuli* chickpea cv. KAK 2 with mustard cv. Vardan was found most compatible for intercropping.

Table 3. Genotypic compatibility of chickpea intercropped with mustard

Genotype	Chickpea yield (kg/ha)		Mustard yield (kg/ha)	Decrease in intercrop over sole crop (%)
	Sole	Intercrop		
BG 256	2720	1580	1070	4190
BG 261	2180	1470	1400	3250
BG 267	2440	1380	1400	4340
PBG 84-16	2530	1580	1380	4030

Source: IIPR Annual Report 1993-95

Chickpea + mustard intercropping

Under late sown condition (first week of December), wheat + chickpea intercropping under 2:2 row ratio was found more productive (4769 kg/ha wheat equivalent yield) and LER (1.20) than the sole crop of either wheat or chickpea. In 3:1 and 2:1 row ratio, yield of chickpea was affected due to shading effect of wheat.

Lentil and linseed make perfect combination for intercropping as compared to other *rabi* crops in rainfed conditions. Under lentil + linseed intercropping system, lentil variety PL 4076 with 6:2 row ratio was found more compatible than DPL 62 and recorded maximum productivity in terms of lentil equivalent yield (2171 kg/ ha) and land use efficiency (21% higher) (Table 4).

Table 4. Yield, land equivalent ratio and net return in lentil + linseed intercropping system

Treatment	Yield (kg/ha)			LER	Net return (Rs/ha)	B: C ratio
	Lentil	Linseed	Lentil equivalent yield			
Sole cropping						
DPL 62	2118	-	2118	1.0	22025	2.88
PL 4076	1944	-	1944	1.0	19579	2.56
Neelam	-	1587	1444	1.0	15237	2.37
Intercropping						
DPL 62 + Neelam						
2:1	979	442	1429	0.74	13684	1.89
3:1	1344	570	1745	0.99	17096	2.33
4:2	1156	613	1714	0.93	16764	2.32
6:2	1427	599	1954	1.05	20022	2.77
PL4076 + Neelam						
2:1	1031	613	1589	0.92	15014	2.08
3:1	1513	559	2021	1.13	20960	2.85
4:2	1323	619	1886	1.07	19172	2.65
6:2	1625	600	2171	1.21	23060	3.14
LSD (p=0.05)		-	280	-		

(Source: 25 Years of Pulses Research at IIPR, 2009)

Lentil + linseed intercropping (2:1)

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*. 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 (Table 5). 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). Similarly, *rajmash* + wheat in 5:1 row ratio was found efficient.

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; (Source: 25 Years of Pulses Research at IIPR, 2009)

***Rajmash* + potato intercropping (3:2)**

The slow growth during winter season of autumn planted sugarcane is also ideal for intercropping with winter legumes like pea and lentil. Two lines of lentil or pea can be planted between sugarcane rows.

Spring season

Spring sown sunflower + mungbean in 6:2 row ratio was found most efficient intercropping system. Intercropping of mungbean variety PS 16 was found most compatible with sunflowers cv. Modern for intercropping.

Spring planted sugarcane + mungbean intercropping (1:1)

Similarly, due to slow growth and wider row spacing of spring planted sugarcane provide a good opportunity to grow short duration low statured plants like mungbean and urdbean. Mungbean has shown advantage over urdbean and

Table 6. Genotypic compatibility of mungbean+urdbean for intercropping with spring planted sugarcane

Treatment	NMC (000/ha)	Yield	
		Sugarcane (t/ha)	Intercrop (kg/ha)
Sugarcane sole	**93.5**	**76.2**	**71.2**
Sugarcane + mungbean			
PDM 11	90.1	71.2	379.6
PDM 54	82.3	62.0	495.9
Pant mung 2	81.9	55.4	503.1
PDM 84-143	87.7	69.9	604.7
Pusa Bold	77.2	53.1	411.7
Sugarcane + urdbean			
Pant U 19	82.6	61.5	389.2
PDU 1	81.2	58.3	469.4
Pant U 35	77.2	59.2	372.8
DPU 88-31	91.9	70.2	424.5
NDU 1	76.8	59.2	467.1
LSD (p=0.05)	12.3	10.5	-

NMC-No. of Mileable cane (Source: 25 Years of Pulses Research at IIPR, 2009) mungbean varieties PDM 11 and PDM 84-143 were found compatible for intercropping with spring sugarcane (Table 6).

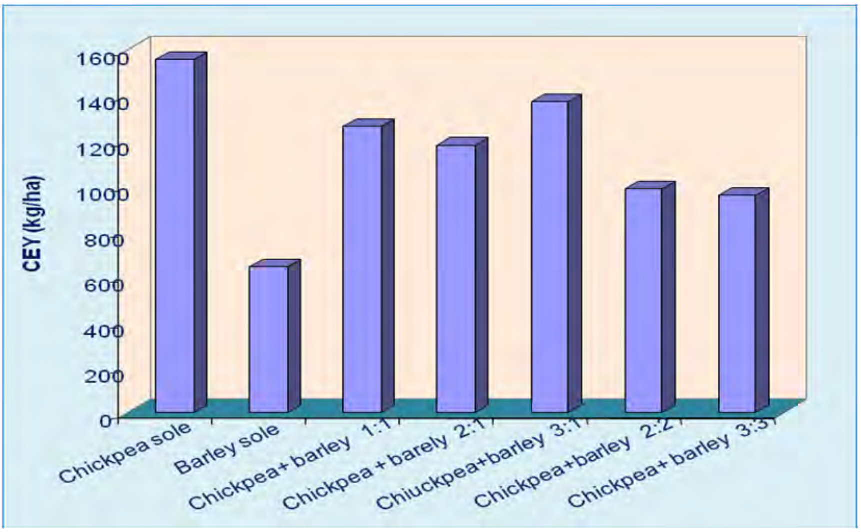


Fig 4. System productivity of chickpea + barley intercropping under different row ratio (Source: DPR Annual Report 1986-87) CEY : Chickpea equivalent yield

Improving soil health

In rice-wheat system, major concern for sustainability is decline in soil organic carbon (SOC). The process of decline in SOC can be reversed by inclusion of pulses in the cereal based system (Fig 5). The improvement in SOC was recorded under rice-lentil, pigeonpea-wheat and rice-wheat-mungbean/green manure. Similar observations were also recorded in a long-term trial at IIPR in which SOC improvement was recorded in rice-chickpea, rice-wheat-mungbean in lowland situation and maize-chickpea, pigeonpea-wheat and maize-wheat-mungbean system in comparison to rice-wheat and maize-wheat, respectively.

The inclusion of pulses in cropping system not only increases the availability of nutrients in the soil but also brings considerable changes in soil physical and biological properties, resulting in buildup of soil fertility. In a long-term maize based experiment, improvement in available P, K, S, Zn and B was recorded due to inclusion of pulses in the system (Table 7). Similar trend was also recorded in low land rice based cropping system.

Table 7. Effect of pulse based cropping systems on soil chemical properties in long-term experiment

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

(Source: IIPR Annual Report 2011-12)

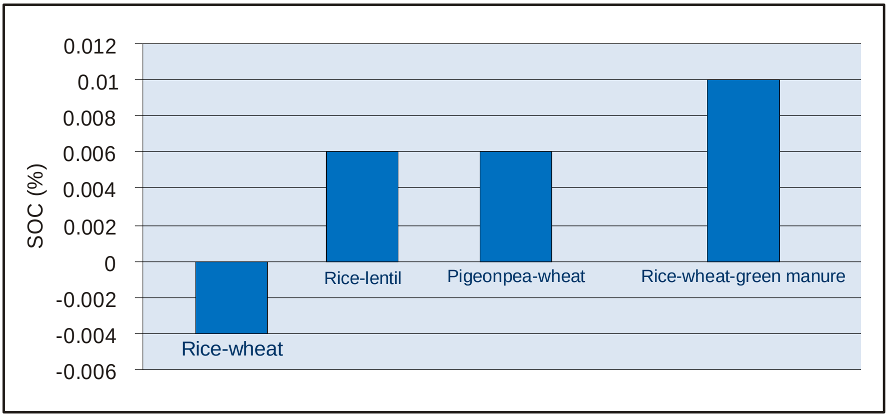


Fig.5 Changes in soil organic carbon (%) due to different pulse based cropping system
(Source: Singh *et al.*, 1996)

Pulses are known to improve microbial activities in the soil. Pulses release unused fixed nitrogen to soil which adds to microbial activities in soil. The increase in nitrogen also helps in improving microbial activities to breakdown carbon rich residue of non-leguminous crop. Improvement in soil microbial biomass carbon is also recorded in a long-term study (Table 8). Dehydrogenase activity, an index of soil microbial activity was also higher after the harvest of legumes in comparison to cereal. Thus, pulses contribute to an increase in diversity of soil flora and fauna which leads to greater stability of the total life of the soil.

Table 8. Microbial biomass carbon in maize and rice based cropping systems

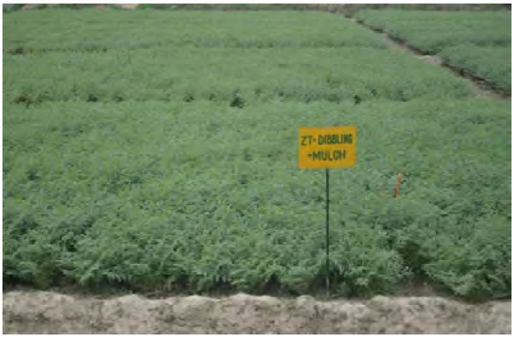
Cropping system	Microbial biomass carbon (g/g)			
	Control	Crop residue + biofertilizers + FYM @ 5 t/ha	Inorganic fertilizers (NPKSZnB)	Mean
Maize-wheat	247	298	291	279
Maize-wheat-mungbean	327	350	338	338
Maize-wheat-maize-chickpea	310	338	334	327
Pigeonpea-wheat	295	305	301	300
Rice-wheat	262	305	300	289
Rice-wheat – mungbean	367	376	361	368
Rice-chickpea-rice – wheat	305	342	358	335
Rice-chickpea	301	336	338	325

(Source: Ali and Venkatesh, 2009)

Conservation Tillage and Pulses

Excessive tillage of agricultural soils may result in short term increase in fertility, but degrade soils in the medium and long run. Structural degradation, loss of organic matter, erosion and falling biodiversity are all to be expected. Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation. This led to promote conservation tillage, and especially zero-tillage in many parts of the world. Over the last two decades the technologies have been improved and accepted by the farmers in our country, mostly in Indo-Gangetic plains. Conservation tillage involves the planting, growing and harvesting of crops with minimal disturbance to the soil surface. Conservation tillage (CT) is designed to reduce erosion and maintain or improve soil health and infiltration by reducing surface sealing and enhancing macropores connectivity and flow.

A study on *rabi* crops *viz.,* lentil, fieldpea, fababean, lathyrus and chickpea sown under zero as well as conventional tillage after rice harvest revealed that all pulses performed equally well under both tillage practices. Similarly in another set of study, performance of chickpea sown after rice in zero tillage (ZT) was at par with conventional tillage, however, retention of rice residue on surface had advantage over no-residue in zero tillage (Table 9).



Chickpea and lentil under mulching

Table 9. Chickpea productivity after rice under different tillage practices

Crop rotation	**Residue management**	**Tillage practice**	
		Zero	**Conventional**
Rice-chickpea	Residue	2020	2033
	No-residue	1972	1910
Rice chickpea-mungbean	Residue	2486	2498
	No-residue	2177	2288
Mean		**2164**	**2182**

In a another set of study, higher yield of chickpea was recorded in zero till drill and ZT dibbling sown chickpea crop when crop residue was retained as mulch after rice harvest under rainfed condition (Table 10). The increase in chickpea productivity was up to 28 per cent in comparison to conventional tillage. Leaf water content at flowering stage was also higher under zero tillage practices (Fig 6). Soil moisture dynamics was also worked out under the same set of study which revealed that initial depletion of soil moisture is higher under zero tillage, while at flowering and pod filling stages zero tillage + mulching retained higher soil moisture which lead to higher yield of chickpea under rainfed conditions (Fig 7).

Table 10. Effect of conservation tillage on chickpea productivity in rice-chickpea system

Treatment	Chickpea yield (kg/ha)	Increase over conventional tillage (%)
ZT dibbling + mulching	1660	28.2
No till drill + mulching	1589	22.7
Deep tillage	1314	1.5
Deep tillage + mulching	1482	14.4
Conventional	1295	-
CD (P=0.05)	115	-

(Source: IIPR Annual Report 2010-11)

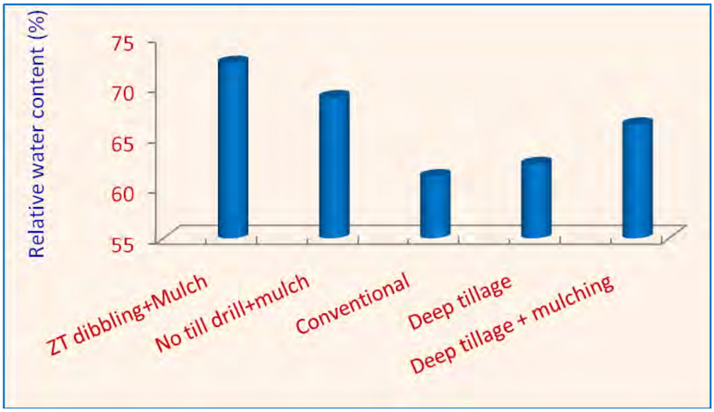
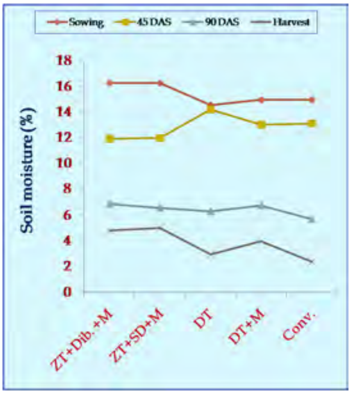


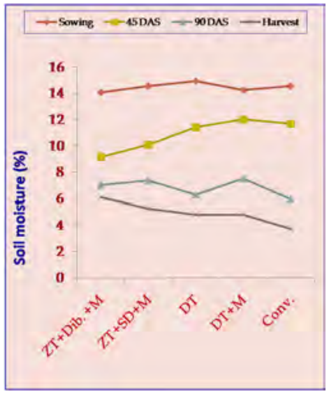
Fig. 6. Relative water content of chickpea leaf at flowering stage under rainfed condition
(Source: IIPR, Annual Report, 2010-11)

Residue Management and Pulses

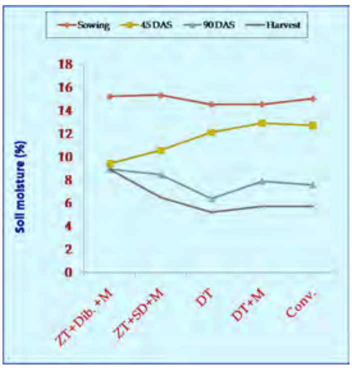
Crop residues are portions of plants remaining after seed harvest. Residues are important in nutrient distribution and plant growth and they affect the amount of soil nutrients available to crops. Plant residues influence N cycling in soils because they are primary sources and sinks for C and N. Residues allow N to be available to plants for longer period of time through initially immobilizing, and then gradually mineralizing N. However, in many parts of the tropics, crop residues are burnt in the field due to the ignorance of farmers about their value and lack of proper technology for in situ incorporation of residues (Samra et al., 2003). One tonne straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_4^{2-}. The heat from burning cereal straw can penetrate into soil up to 1 cm, elevating the temperature to as high as 42.2°C. About 32-76% of straw weight and 27-73% N are lost in burning. Bacterial and fungal populations are decreased immediately upon burning.



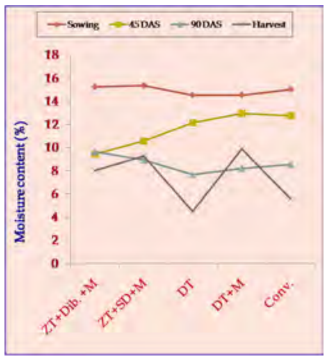
0-15 cm



15-30 cm



30-45 cm



45-60 cm

Fig 7. Soil moisture dynamics at different soil depth (0-15, 15-30, 30-45 and 45-60 cm) under conservation tillage (ZT: Zero tillage, Dib: Dibbling, M: Mulching, DT: Deep tillage, Conv.: Conventional tillage)

Pulses also contribute to soil organic matter by leaf litter. It was observed that long duration pigeonpea in northern India can add up to 2.8 t/ha leaf litter during whole crop season, whereas chickpea up to 1.7 t/ha. On an average, nutrients contribution by these leaf litters varies between 8-15 kg N, 2.5-5.0 kg P and 8-24 kg K per hectare.

Besides supplementing the fertilizers, incorporation of crop residues is also important for improvement of soil properties and thereby increasing productivity and fertilizer use efficiency. In rice-chickpea sequence, yield of chickpea was significantly influenced by rice-residue incorporation and highest seed yield was

Mungbean crop under residue incorporation

obtained with incorporation of chopped straw + irrigation + 20 kg N/ha, while lowest yield was obtained in rice residue removal treatment. Incorporation of chopped residue of mungbean + irrigation + 20 kg N/ha resulted in maximum wheat yield (4495 kg/ha) which was significantly higher (38%) than control (Fig 8).

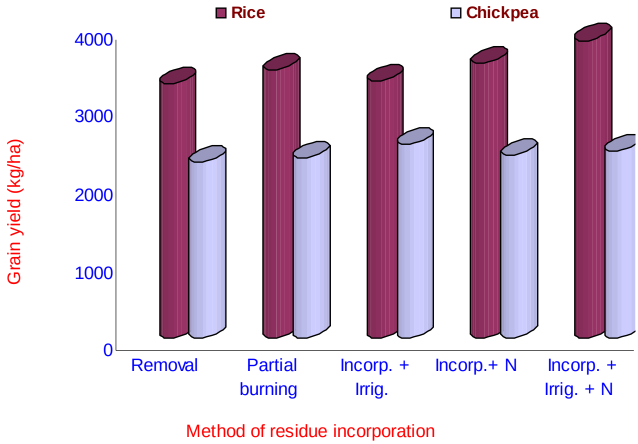


Fig. 8. Effect of residue incorporation on grain yield (kg/ha) of rice and chickpea in system
(Source: 25 Years of Pulses Research at IIPR, 2009)

Incorporation of urdbean and mungbean residue raised the organic carbon level by 35.48% over control. Residue incorporation also resulted in higher soil available N (24.6%), P (11.5%), and K (18.5%) over the initial fertility levels. Soil physical parameters measured *viz.*, bulk density, particle density, percent pore space and WHC also improved under residue incorporation plots over residue removal plots (Table 11). In same set of study, periodic changes in soil microbial biomass carbon (SMBC) were also recorded. The results revealed increase in SMBC up to 56 days after incorporation of urdbean and mungbean under chopping + incorporation + irrigation (Table 12). Similar trend was also observed after harvest of wheat crop. The ratio of microbial carbon to soil organic carbon was also higher under chopping + incorporation + irrigation.

Table 11. Effect of crop residue incorporation on soil physical properties

Treatments	Bulk Density (g/cc)	Particle Density (g/cc)	Pore space (%)	WHC (%)
Residue magement				
Mungbean 1	1.38	2.42	45.5	37.3
Urdbean 1	1.39	2.39	44.65	38.3
Mungbean 2	1.38	2.38	46.80	38.3
Urdbean 2	1.38	2.40	47.00	41.60
Mungbean 3	1.34	2.38	47.32	42.50
Urdbean 3	1.35	2.39	48.23	45.10
Mungbean 4	1.32	2.36	49.63	46.40
Urdbean 4	1.33	2.35	48.20	45.90
Control	1.44	2.50	38.15	33.40
CD (p=0.05)	0.05	0.10	3.51	3.8

Note: 1- Incorporation; 2- Incorporation + irrigation; 3- Chopping + incorporation; 4- Chopping + incorporation + irrigation (Source: Singh *et al.*, 2012)

Table 12. Effect of residue incorporation on periodic changes in microbial biomass carbon and organic carbon content in soil

Treatment	Periodic changes in soil microbial biomass carbon after residue incorporation (µg /100 g)				After wheat harvest	
	7	14	33	56	Microbial biomass carbon (µg /100 g)	Ratio of microbial carbon to soil organic carbon (%)
Residue management						
Mungbean[1]	335	347	345	351	262	6.71
Urdbean[1]	270	178	282	264	222	5.28
Mungbean[2]	345	351	358	367	322	8.25
Urdbean[2]	230	237	237	230	312	7.60
Mungbean[3]	348	369	363	378	327	9.08
Urdbean[3]	330	351	343	351	337	9.10
Mungbean[4]	355	395	377	391	320	9.14
Urdbean[4]	320	359	375	327	347	9.37
Control	240	242	268	248	132	4.25
CD (P=0.05)	4.78	4.81	5.16	4.96	39.8	NS

Note: 1- Incorporation; 2- Incorporation + irrigation; 3- Chopping + incorporation; 4- Chopping + incorporation + irrigation (Source: Singh *et al.*, 2012)

Pulses Under Raised Bed Planting System

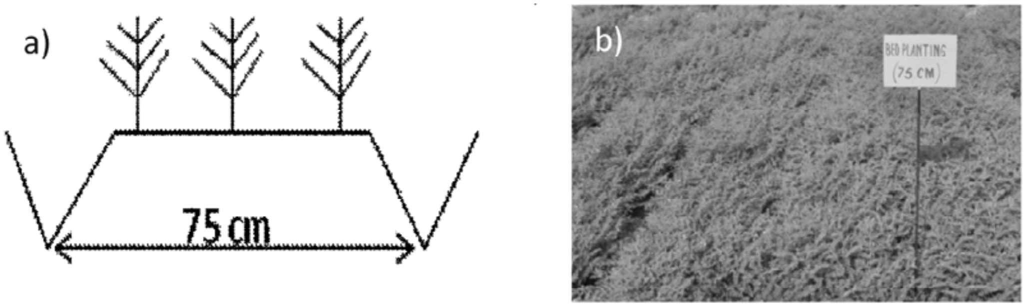
Technology of raising row crops on beds and furrows system is gaining popularity amongst the progressive farmers, mainly because the cost of crop production is considerably reduced as a result of minimum tillage, water saving, *etc.* Bed shapers/makers are used behind the tractors to form beds and furrows to sow row crops. Some of the advantages associated with furrow irrigated raised bed (FIRB) technology of crop production are:

- Savings of about 30-40 percent irrigation water.
- Reduce seed requirement and fertilizers (by 25-30%) as compared with flat system.
- Reduce chances of plant submergence due to excessive rain or over irrigation.
- Less crusting of soil around plants and, therefore, more suitable for saline and sodic soils.
- Adaptable for various crops without changing basic design/layout of farm.
- Enhance resource use efficiency due to local application and effective utilization by plants.
- Minimize the chances of lodging of crops, especially during rainy season.
- Reduce tillage under permanent beds reduces cost of labour and other inputs like fertilizers and seeds.
- Provide opportunities to take additional green leafy vegetables in furrows.

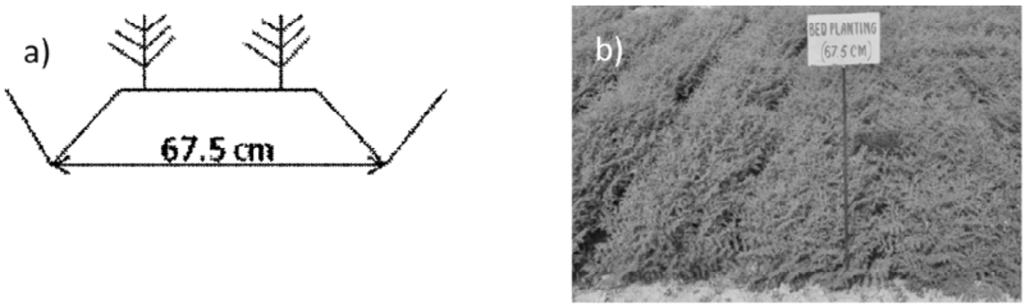
The study conducted at IIPR revealed that in rice-lentil system, raised bed enhanced the lentil yield by 16.5% over flat bed sowing. Increase in phosphorus from 25 kg/ha to 50 kg/ha did not show significant increase in lentil yield under raised bed as in case of flat bed system of planting. Similarly, lentil yield under 20 kg S/ha was at par with 40 kg S/ha in raised bed and significantly higher in flat bed. The nodulation in lentil was also higher under raised bed (Fig 9).

In another set of study raised bed size and number of lines per bed was evaluated. The study revealed that performance of chickpea and urdbean under 75 cm raised bed size was better than 67.5 cm and flat bed and the 2 lines per bed was at par with 3 lines per bed.

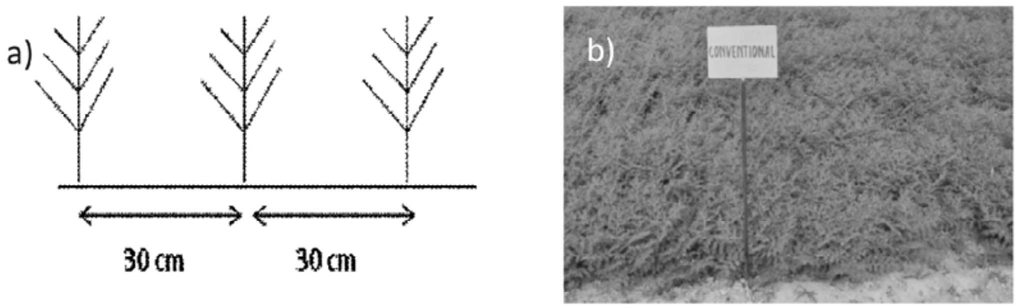
The increase in grain yield of chickpea in raised bed of size 75 cm was 20.2% and in 67.5 cm was 15.6% over flat bed planting. In case of urdbean, the yield increase was 32.9% and 29.7% under 75 and 67.5 cm raised bed planting over flat bed (Table 13). In the same set of study, yields of urdbean and chickpea at 75% of recommended



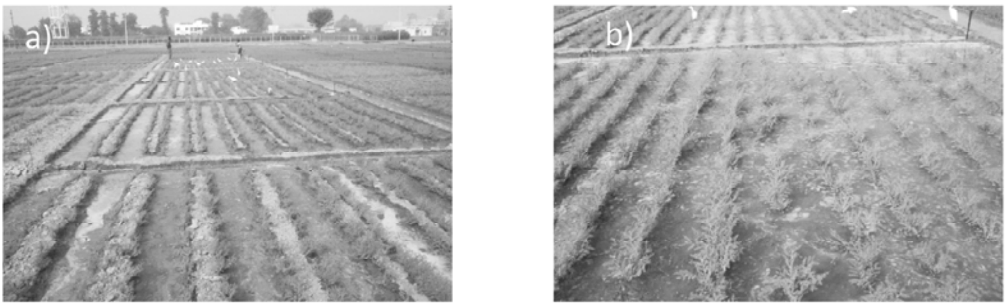
Three rows of chickpea in raised bed size 75 cm a) sketch diagram and b) field condition



Two rows of chickpea in raised bed size 67.5 cm a) sketch diagram and b) field condition



Conventional sowing on flat bed a) sketch diagram and b) field condition



Irrigation under raised bed (a) and flat bed

Intercropping of chickpea on raised bed and spinach in furrows

seed rate and fertilizer were at par with 100% under raised bed planting system. Therefore, 25% seed and fertilizer inputs cost can be saved following raised planting system. The better plant growth and relative leaf water content have attributed the higher yield under raised bed planting system (Fig 10). Total irrigation water requirement under raised bed chickpea was 40-45% less than flat bed system and hence the water productivity was higher under raised bed (Fig 11).

Table 13. Effect of planting methods on urdbean productivity

Planting methods	Chickpea		Urdbean	
	Grain yield (q/ha)	Per cent increase over conventional	Grain yield (q/ha)	Per cent increase over conventional
Bed planting (67.5 cm)	14.69	15.6	10.0	29.7
Bed planting (75 cm)	15.28	20.2	10.25	32.9
Conventional (flat bed)	12.71		7.71	
CD (P=0.05)	1.16		1.33	

Source: Annual report 2010-11

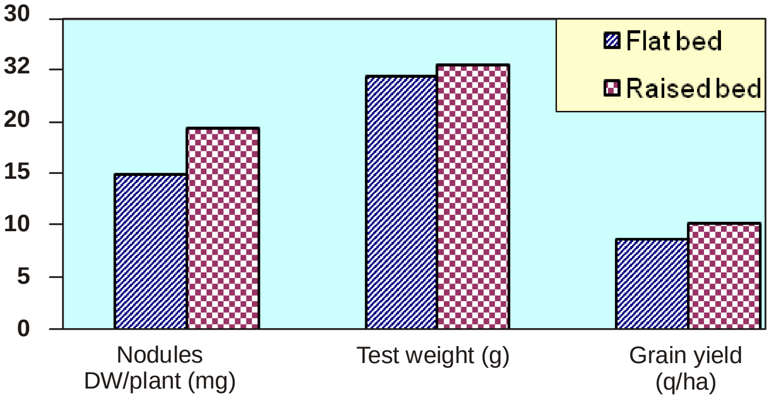


Fig. 9. Nodule dry weight, test weight and grain yield of lentil under raised bed system

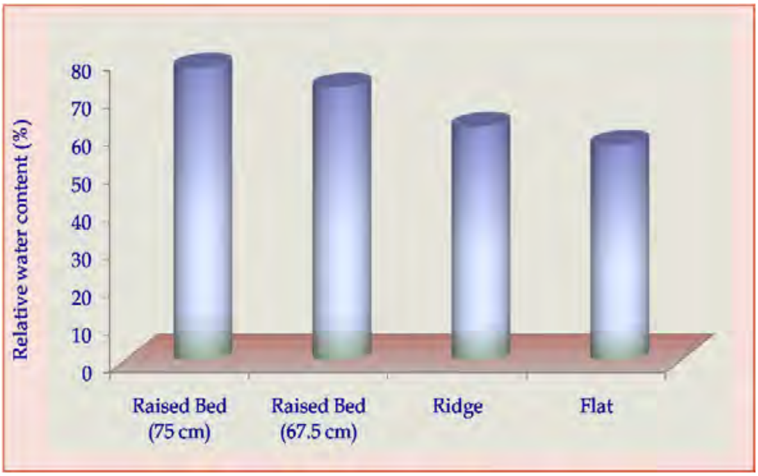


Fig. 10. Relative leaf water content of chickpea at flowering under different planting systems

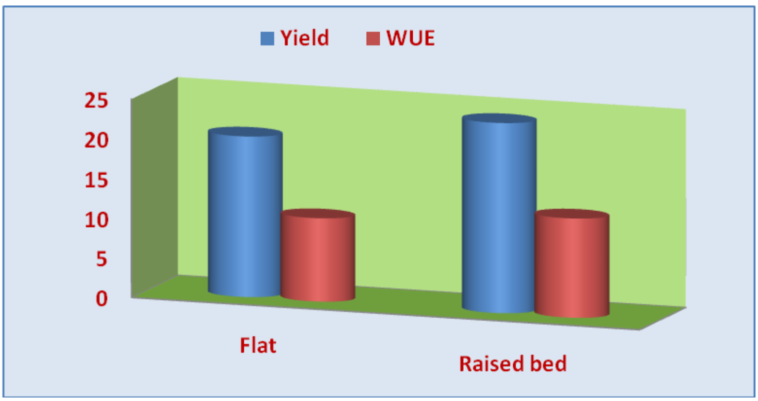


Fig. 11. Yield (q/ha) and WUE (kg/ha-mm) of chickpea under different planting system

Farm Mechanization and Pulses

Farm mechanization is the need of hour to improve the land and labour productivity. The rising wage rates and non-availability of manpower during peak hours further strengthen the case for mechanization. The factors that justify the strengthening of farm mechanization are numerous. The timeliness of operations and increasing precision in input application with minimum cost demand for more use of farm machinery. The various operations such as land preparation, leveling, sowing planting, irrigation, fertilizers application , plant protection, harvesting and threshing need a high degree of precision to increase the efficiency of the inputs and reduce the losses. For example, sowing of the required quantity of seed at proper depth and uniform application of given dose of fertilizer can only be possible with the use of proper mechanical devices. However, when such operations are performed through indigenous methods, their efficiency is reduced. The time taken to perform sequence of operations is a factor determining the cropping intensity. To ensure timeliness of various operations, it is quite inevitable to use such mechanical equipments which have higher output capacity and cut down the number of operations to be performed. This has helped in increasing area under cultivation and cropping intensity. The benefits of mechanization can be utilized not only by the farmers having large holdings, but even farmers with small holdings can utilize selected improved farm equipments through custom hiring to increase productivity and reduce cost of production.

The development, standardization and adoption of suitable farm machinery for conservation agriculture including seeding with minimum soil disturbance keeping residue maintained on the soil surface and developing harvesting equipment are of major concern. To fetch the benefit of CA, the machinery suitable to CA must be adapted to small landholder farmers and to different ecological conditions. The main criteria which should be considered during the development are that the machines should be suitable for use in small farms, easily repairable and maintainable, inexpensive, and environmental friendly. The role of farm mechanization in CA especially in rainfed regions would need to be very specific and could include:

- Suitable equipments able to plant into unploughed soil.
- Direct seeders need to be designed to seed in the surface mulch in untilled soils.
- Equipments for small farmers for sowing specific crops under CA need to be made available.

Raised bed planter

The ridge/ raised bed planting of crops not only ensure desired plant stand of the crop but also minimize the incidence of phytophthora stem blight as through proper drainage. It avoids the negative effects of ponding and associated water logging. This method increases water use efficiency by saving irrigation water as it is applied only in the furrows requiring less volume of water, which works out to be 20-30% water saving as compared to flat method. The other advantages of raise bed technology include:

- Saving of seed and fertilizer Zby over 25%
- Less problem of *Phalaris minor*
- Mechanical weed control between rows by adjustment of drill
- Less lodging of crops
- Promotion of para-cropping *i.e.,* moong/green manure crops in furrow before wheat harvest
- Diversified application for legume crops *etc.*

Happy Seeder

Happy Seeder was developed by PAU, Ludhiana, in collaboration with Australian Centre for International Agricultural Research was developed for residue covered fields. This handles high rates of residue and seeds either on beds or on the flat. A combination of two machines, a forage harvester and a zero tillage drill using inverted T winged openers. The chopped material is blown directly behind the drill and floats down as mulch. The ***'Turbo Happy Seeder'*** is a modified, advanced and light weight version of the 'Happy Seeder' to plant in presence of loose and or anchored residues. Turbo seeder differs from Happy Seeder in type of the cutting blades, provision for adjustment of the rows, seed metering system and is lighter in weight. This machine works satisfactorily in combine harvested fields.

Star wheels drill

Direct drilling in combine harvested rice field requires drill capable of cutting through large quantities of crop residue, penetrating untilled soil and dropping seed 25 to 50 mm deep. Disc openers meant for trashy conditions, fail to cut through the crop residue resulting in the seed being placed either in the residue or on the soil surface. In softer soil the trash is pushed into the bottom of the furrow without being cut. With fixed type furrow openers drill, crop residue tends to collect in front of the Tyne and block the machine operation. Therefore, there is need to develop a device which may cut residue and help the openers to penetrate up to desired depth for seeding. The star wheels drills are designed to plant into high density of crop residues in high-yielding irrigated conditions but the main limitations is proper planting depth. However, this limitation can be managed by using proper management of irrigation at seeding.

Laser land leveler

Land leveling is necessary for good agronomic, soil and crop management practices. It saves irrigation water, facilitates field operations and increases yield and quality of the produce. Leveled land also helps in smooth operations of various farm machineries during field operations. The main components of laser guided land leveler are Laser transmitter, Laser receiver mounted on electric manual mast and one receiver is used for mapping, control box, electric/ manual mast fitted on the leveler, external hydraulic system of leveler and drag scraper. The major advantages of laser land leveler are:

Laser Land Leveler

- Precise leveling and smooth surface
- Reduction in time and water required to irrigate the field
- Uniform distribution of water
- Increased crop yields (10-20%)
- Control over soil salinity and water logging
- Increase in fertilizer uptake efficiency
- Increase of machinery use efficiency by up to 30%
- Increase in cultivable land area by 2-5%.

Direct drilling (No-Till Drilling)

It is a practical tool to use crop residues and explore its advantages. *Rabi* pulses after rice are generally delayed due to late harvesting of rice, soil wetness, poor rice residue management and multiplicity of tillage operations, scarcity of power source and appropriate farm equipment during peak hours and some time even arrivals of rain in the month of November. The major advantages of Zero-till drill through various field experiences include:

Zero Till-cum-Fertilizer Drill

- Savings in cost of seed bed preparation of approximately by Rs. 2,500 to 3,000 per ha
- Savings in fuel from 37.3 to 70 liters of diesel/ha dependent on soil condition
- Saving in time through seed bed preparation and sowing
- Advancement in sowing time over conventional system by 2 weeks depending upon soil conditions
- Saving in water up to 30%

Rice Fallow and No-till Drill

The timely sowing of pulses is crucial in view of the moisture deficit during critical periods in the rice fallow conditions. The farmers usually broadcast the seeds to take advantage of residual moisture in rice fallow. The mechanization in such conditions needs development, standardization and adoption of farm machinery for direct seeding under residue retained on the soil surface.

The small landholder farmers, apart from broadcasting, also sow the seeds in the furrow opened with the help of hand plough. The hand plough generally opens wide and shallow furrow (trapezoidal shape), in which poor germination as well as plant stand establishment is observed. This practice is also inconvenient, labour intensive and not suitable for rice fallow.

Keeping in view of this situation, a low-cost manually operated No-Till Drill for small farmers, having low purchasing power, was developed for line sowing in rice fallow. This helps more moisture retention as least soil disturbance occurs. By use of this no-till drill, the seeding is done timely at a reduced cost. It has field capacity of 0.05 ha/h with two manpower against four manpower needed for hand plough and is expected to be used for working on 20 ha per year. The cost of operating manual zero-till drill is Rs.845/ha as against Rs.1690/ha incurred in hand plough (Table 14 & 15).

Table 14. Comparative economics of manual operated No-till drill

Particulars	Manually Operated No-Till Drill	Sowing with Hand Plough
Labour Requirement, Man-h/ha	40	80-100
Field Capacity, ha/h	0.05	0.04-0.05
Cost of operation, Rs/ha	845	1690
Energy Consumption, MJ ha^{-1}	78.4	149-186.25

Table 15. Details of manually operated No-till drill

Particulars	Specification	Field performance
Overall dimensions (LxBxH), mm	970x520x1070	Operating speed, km/h = 2.0-3.0
Source of power	Manual	Field capacity, ha/h = 0.05
Type/no. of furrow openers	Inverted 'T' type/01	Labour requirement, Man-h/ha = 40
Metering mechanism	Fluted roller	Cost of operation, Rs/ha = 845
Drive wheel	Circular ring - front mounted	
Seed placement depth (mm)	30-50mm, adjustable	

Sowing with the help of Hand Plough with four manpower

Sowing with the help of No-Till Drill with two manpower

Critical Gaps and Researchable Issues

- The success of conservation agriculture in rainfed areas depends on two critical elements, *viz.,* residue retention on surface and weed control. Since residues are generally used as fodder in drylands, there is a need to determine the minimum residue that can be retained without affecting the crop-livestock system. Initially, emphasis may be given for crops whose residues are not used as fodder.
- More research is needed on weed management under minimum tillage in a cropping system perspective.
- Identification of alternative sources of fodder for livestock to spare crop residue for conservation farming.
- Identification of critical thresholds of tillage for various rainfall, soil and cropping systems, so that the main objectives of rainwater conservation are not compromised. This will balance the need for conserving soil and capture rainwater in the profile.
- Farm implements needed for seed and fertilizer placement simultaneously for ensuring optimum plant stand, early seedling vigour in rainfed crops under minimum tillage.
- Control of termites in order to enhance the value of residue left on surface during long interval period between two crops.
- Scarce crop residue leads to strong competition between soil and animals.
- In prolonged dry seasons the demand for residue is the greater, no farmer will sacrifice residue in dry land areas.
- In irrigated region (Indo-Gangetic plains) production leads to high/ more crops/year therefore residue competition is less.
- Managing feed supplies over the transition period from conventional agriculture to CA system is a problem.

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