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Technical Bulletin

Agro-technologies for Pulses in Rice Fallows

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FOREWORD

In India, about 11.695 m ha of the area under rainy season rice remains fallow in the subsequent winter season due to number of abiotic, biotic, socio-economic and production constraints. The fast decline of soil moisture with the advancement of winter season results in mid-season and terminal drought coinciding with flowering and pod filling stages, and is the major bottleneck in growing pulses under rice fallows. In addition, the inherited soil physical and biological constraints associated with rice fallow situation, such as disruption of soil structure, poor aeration and mechanical impedance in the seed zone, affect seed germination, seedling emergence and crop establishment following rice cultivation mainly under flooded condition. To exploit these areas of rice fallows for remunerative and sustainable pulses cultivation, location specific production technology needs to be developed and promoted.

In this context, bringing out this publication on *"Agro-technologies for Enhancing Pulses Production in Rice Fallows"* based on basic and strategic research outputs for rice fallows is very appropriate and timely. 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 research outcomes and appropriate site specific recommendations embodied in this technical bulletin will be very useful for researchers, extension personnel and policy makers in understanding and promoting pulses under rice fallow areas (RIFAs) in the country.

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PREFACE

In India, a considerable rice area remains fallow during winter season after rice harvest. A number of abiotic factors related to soil and water lead to low pulse production in rice fallows during past several years. Fast decline of available soil moisture after rice harvest, resulting in mid-and terminal-drought at flowering and pod filling stages, is the major limitation in growing pulses after rice in these regions. Due to lack of irrigation facilities cultivation of pulses mainly depends on the effective utilization of carry-over residual soil moisture. The inherited hostile soil environment creates potential threat to seed germination, seedling emergence and crop establishment due to disruption in soil structure, poor aeration and mechanical impedance at the seed zone. Soil microbial activity, nutrient availability, root growth and water and nutrients uptake also get adversely affected. Under such a situation following location specific improved agro-techniques in system mode can support successful cultivation of pulses by effective utilization of residual soil moisture. Thus, promotion of pulses under rice fallows with support of appropriate production technology may help to fulfill the self-sufficiency in pulses for the country. Therefore, utilization of this RIFAs (11.695 m ha) is crucial for meeting the Sustainable Development Goals (SDG) by enabling our country self-reliant.

The present bulletin is a compilation of findings of research carried out elsewhere and under a 5-years Project entitled 'Mitigating abiotic stresses and enhancing resource use efficiency in pulses in rice fallows through innovative resource conservation practices' funded by 'ICAR-National Agricultural Science Fund'. The project was implemented at 5 centres in different agro-ecological situations of rice fallow regions in the country. The interventions carried out at different centres included diversity in rice and pulse varieties, in-situ soil moisture conservation practices (conservation tillage), life saving irrigation, foliar nutrition, rice establishment methods, seed priming and seeding techniques which have shown their capabilities and advantages in enhancing pulses productivity under rainfed rice fallows.

In this context, we wish to acknowledge with our sincere thanks to 'ICAR-National Agricultural Science Fund' for funding a 5-years research project on rice fallows. We are grateful to Director, IIPR for his necessary guidance and constant support to carry out research activities and compilation of this bulletin. Thanks are due to all project team members, SRF, technical and supporting staff for their help in conducting field trials at different centres and in various capacities. We hope that this bulletin, a compilation of research recommendations made at different locations, will serve as a useful material for strengthening knowledge level of researchers, extension personnel and policy makers in the field of rice fallows.

S. S. Singh
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Contents

Chapter 1

Agro-technologies for Enhancing Pulses Production in Rice Fallows

Introduction

In India, rice is cultivated across the length and breadth of the country occupying 43.86 million hectares (DAC, 2016). The crop is grown in both irrigated and rainfed agro-ecosystems under diverse cropping systems. While rice-wheat, rice-rice, rice-sugarcane, rice-groundnut, rice-vegetables and rice-mustard are dominant in irrigated areas; rice-pulses, rice-sunflower, rice-sesame and rice-fallow are the major crop rotations under rainfed conditions. As per revised estimate (Gumma *et al.*, 2016), approximately 11.695 m ha of land in India is left fallow during rabi and summer after the kharif rice harvest (this is mostly confined to rainfed rice fallow). Besides socio-economic consideration, this is also attributed to a number of biotic and abiotic constraints. The above rice fallow areas (hitherto called, RIFAs) is mostly concentrated in eastern India (around 80%) covering the states of Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Chhattisgarh, Odisha, West Bengal and North Eastern Hill states (Singh *et al.*, 2016). The southern states of Tamil Nadu, Karnataka and Andhra Pradesh covers the remaining areas of RIFAs (Subbarao *et al*., 2001). The distribution of RIFAs in India under different states and districts are given in Table 1 and 2, respectively. Despite the fact that these RIFAs have tremendous potential for raising a crop profitably keeping in view the available modern agro-techniques and scientific crop husbandry using residual moisture following a rice crop (Huke, 1982), yet these rice fallow systems did not invite adequate interest during the past few decades (Fig 1 and Fig. 2). As a result, a significant level of production in terms of food, feed and fodder is lost over the years.

Fig 1. The typical RIFAs just after harvest of kharif rice

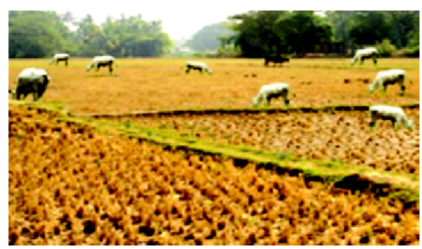


Fig 2. Unmanaged grazing by animals is a common sight in RIFAs

Defining these RIFAs, rice-fallow cropland areas are those areas where rice is grown during kharif growing season (June–October) which is commonly followed by a fallow during the *rabi* season (November–February). This is slightly altered in Southern India where the major rains occurred during rabi season as the rainfall pattern follows mostly a bimodal type. With the exception of few regions and hilly terrains, the key constraint for majority of these RIFAs is the unsuitability of growing rice again during *rabi* due to their high water requirements (not adequately replenished by winter rains). On the contrary, these RIFAs are suitable for short-season (3-4 months), low water-requiring (thriving best on residual moisture with adequate conservation measures) grain legumes such as chickpea (*Cicer arietinum* L.), urdbeans, mungbeans, and lentils. Traditionally, lathyrus and lentil are sown after rice as a relay crop in low land rice fields of Bihar, Jharkhand, West Bengal, eastern Uttar Pradesh and Chhattisgarh, and urdbean/mungbean in coastal peninsula (Tamil Nadu, Andhra Pradesh, Karnataka and Odisha). And now more advance crop management could enable profitable raising of a pulse (Praharaj *et al*., 2017) as a rotational crop after rice. Therefore, cropping system intensification involving two crops in this way further could improve smallholder farmer's income, human health *via* protein supplementation, and soil health through nitrogen-fixing legume crops as well as addressing food security challenges of burgeoning populations without having to expand croplands (Gumma *et al*., 2016). Hence, the focused target is towards sustainable intensification of these RIFAs with short-duration grain legumes.

Table 1. Area under rice fallow in different states of India

State	Kharif rice area (m ha)		Rice fallow (m ha)	Rice fallow as % of kharif area
	2001	2014-15	2001	
Andhra Pradesh	2.66	3.81	0.31	11.5
Assam	2.23	2.28	0.54	24.1
Bihar & Jharkhand	5.97	4.77	2.20	36.8
Gujarat	0.47	0.79	0.08	17.7
Karnataka	0.98	1.33	0.18	18.5
Madhya Pradesh & Chhattisgarh	5.60	5.96	4.38	78.3
Maharashtra	1.76	1.55	0.63	35.7
Odisha	3.88	4.17	1.22	31.4
Tamil Nadu	1.70	1.83	0.02	1.2
Uttar Pradesh	6.26	5.87	0.35	5.6
West Bengal	4.62	5.39	1.72	37.2
Total (All States)	**40.18**	**43.86**	**11.65**	**29.0**

Source: Subbarao *et al.* (2001)

Table 2. Major districts of different states under rice fallows in India

State	Major districts
Andhra Pradesh	Krishna, Guntur, East Godavari, West Godavari, Srikakullam, Nellore and Prakasham
Assam	Lakhimpur, Jorhat, Sibsagar, Dibrugarh, Golaghat, Karbi, Nagaon and Maringon
Bihar	Kishanganj, Gaya, Aurangabad, Katihar, Mokama, Bhagalpur and Nalanda
Chhattisgarh	Surguja, Jashpur, Raipur, Raigarh, Durg, Bilaspur and Bastar
Jharkhand	Ranchi, Bokaro, Purbi Singbhum, Pashchim Singbhum, Hazaribagh, Gumla, Sahibganj, Deogarh, Palamau, Dumka and Dhanbad
Maharashtra	Dhule, Amravati, Nagpur, Wardah, Bhandara, Chandrapur and Nanded
Madhya Pradesh	Shahdo, Seoni, Balaghat, Damoh, Mandla, Rewa, Jabalpur, Betul and Sidhi
Odisha	Koraput, Kalahandi, Sambalpur, Sundergarh, Bhadrak, Cuttak, Puri, Dhenkanal and Mayurbhanj
West Bengal	Purulia, Bankura, Birbhum, Bardhaman, Medinapur, Murshidabad, South 24-Parganas, Maldah, West Dinajpur, Jalpaiguri and Coochbihar
Uttar Pradesh	Gonda, Siddarthnagar, Lakhimpur, Kheri, Pilibhit, Etawah, Mirzapur, Sonbhadra and Chandauli
Karnataka	Shimoga and Belgaum
Tamil Nadu	Salem, Namakkal, Tiruchirappali, Cuddalore, Ramnathpuram, Madurai and Villupuram

Source: NAAS (2013)

Furthermore, pulses with their inherent properties like, low input requirements, short duration and ability to establish even with surface broadcast in standing rice fields besides soil fertility restoration through BNF, narrow C:N ratio enriched crop residues and leaf fall etc are the candidate crops for rice fallow rainfed agro-ecosystem, popularly called rice fallow areas or RIFAs. These are in fact soil building crops capable of transforming our dominant cereal based systems to an ideal and sustainable system in time to come (Praharaj and Blaise 2016, Praharaj *et al*., 2017). As an effective source of reversing the process of soil degradation, these pulses could have the potential in achieving the twin objectives of production system viz., enhancing crop(s) productivity and improving the sustainability of the cereal based cropping system.

It is reported that the existing RIFAs (11.659 mha) is almost equivalent to the net sown area of Punjab, Haryana and Western Uttar Pradesh - the sheet of green revolution in India (DAC, 2016). Cultivating this area could benefit millions of poor and small farmers solely dependent on agriculture for their livelihood or sustenance (Praharaj *et al*., 2015). In the process, besides ensuring nutritional security of poor section of the society, we would also save millions of foreign exchange incurred in importing pulses. Better utilization of rice fallows by cultivating pulses could also improve soil organic matter and fertility status of (poor and marginal) soils, thereby contributing to the long-term sustainability of rice based double cropping system (Ali *et al*., 2016).

During early 1960's rice fallow states were the major contributors as two-third of area and a half of production in respect of pulses goes to these states in India. But in early 2000s, with rapid progress in agro-technologies, their share on area and production declined drastically, although at the national level these witnessed a positive trend. Moreover, the increased yield have compensated the steeper fall in production of pulses in rice fallow. There is also shift in area. Amongst the *rabi* pulses, the area under chickpea declined in Madhya Pradesh, lentil and in West Bengal and lathyrus in all the rice fallow states. Consequently some of these traditional pulses areas in North have shifted to central and southern covering Maharashtra, Andhra Pradesh and Karnataka. Yet, about 0.5 million ha area of RIFAs are already under cultivation with pulses. There is ample scope for bringing an additional 2.0 to 3.0 million ha of these areas under cultivation of pulses by introducing short duration, disease resistant and improved varieties along with matching production technologies reinforced with *in-situ* conservation of residual soil moisture. Some of these areas in different states are also given below (Table 3).

To exploit these RIFAs amicably with pulses, location specific and economically viable technology of pulses are required to be assessed and refined for their better performances lbeit through a thorough understanding of the rice fallow ecology and constraints analysis. This effort should be amalgamated with a strong research back up capable of delivering appropriate varieties and befitting crop management technologies (Package Technologies) suitable to rice fallow cultivation. Besides ushering in another green revolution in India, promotion of pulses in RIFAs would also improve sustainability of the rice production system besides enhancing production and augmenting income. Popularizing the crop(s) suitable for RIFAs could be made through identifying and addressing abiotic, biotic and socio-economic constraints encountered during *rabi* cultivation through appropriate technological and policy interventions.

Table 3. Potential area in rice fallows for pulses production

Crop	States	Approx. additional area (Lakhs ha)
Chickpea	Eastern Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh	47.00
Urdbean/mungbean	Andhra Pradesh, Tamil Nadu, Odisha, Andhra Pradesh, Karnataka	23.30
Lathyrus	West Bengal, Jharkhand, Odisha, Chhattisgarh, Bihar, Madhya Pradesh, Maharashtra	3.16
Lentil	Eastern Uttar Pradesh, Bihar, Chhattisgarh, Madhya Pradesh, NE States	25.03

Source: IIPR (2013)

Chapter 2

Agro-ecological characteristics of rice fallow regions

On the basis of soil and agro-climatic conditions, rice fallow may be classified into three sub-groups i.e., *Eastern and Northeast region, Central India* and *Coastal Peninisula region. Eastern and Northeast region* includes Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal and north-eastern states where lentil and lathyrus are commonly grown following rice which is popularly known as relay cropping (*paira*). In case of Odisha, mungbean and urdbean are taken up as these pulses perform well under high humidity condition prevailed in coastal agroecosystem. *Central India* covers Chhattisgarh, Madhya Pradesh and Maharashtra where lathyrus and lentil are traditionally broadcasted as a *paira* crop. Similar to Odisha, C*oastal Peninisula region* comprising of coastal areas of Andhra Pradesh, Tamil Nadu and Karnataka is adapted to urdbean and mungbean grown under *paira*/relay cropping system after rice (Singh *et al.*, 2016). The soil and climatic condition of these RIFAs of the country are diverse and unique for the location or agro-climatic zone (Table 4). The soils vary from light (*Inseptisol* in West Bengal and Uttar Pradesh, and *Alfisol* in NEH region) to heavy or *Vertisol* (Tamil Nadu and Chhatisgarh). Similarly, the growing season changes at each location/zone and so is the extent of cold temperature and duration of winter months. The latter greatly influence soil moisture depletion pattern in RIFAs. Even the soil moisture declining pattern in the similar class differs. This declining trend in a *Vertisol* (black soil) of Tamil Nadu (TN) in southern India is much faster than a *vertisol* of Chhattisgarh in central India (Fig 3). Drying pattern of an *Alfisol* under upland condition in north-eastern states is similar to a *vertisol* of southern India although the ecologies of these two conditions are totally different (Fig 4). It is also evident that dynamics in development of water stress varies. For example, soil moisture decreasing pattern in case of a *Vertisol* (due to cracks) is much faster than that in an *Inceptisol*.

Table 4. Physiographic, climatic and soil characteristics of some representative RIFAs of India

SL. No.	Parameter	Kanpur (Uttar Pradesh)	Raipur (Chhattisgarh)	Umiam, Meghalaya (North-eastern hills)		Kalyani (West Bengal)	Aduthurai (Tamil Nadu)
				Upland	Lowland		
1	Soil texture	Sandy loam	Clay loam	Sandy clay loam	Sandy clay loam	Clay loam	Alluvial clay
2	Latitude	26^{o} $27^{/}$ N	$21^{0}13.906^{/}$ N	$25^{o}38^{/}$ N	25^{o} $38^{/}$ N	$22^{o}99^{/}$ N	$11^{o}00'$ N
3	Longitude	80^{o} $14^{/}$ E	$81^{0}41.976^{/}$ E	91^{o} $52^{/}$ E	91^{o} $52^{/}$ E	$88^{o}43^{/}$ E	79^{o} 28'E
4	Climate	Tropical sub-humid	Subtropical humid	Subtropical humid	Subtropical humid	Tropical sub-humid	Tropical humid
5	Annual rainfall (mm)	722	1582	2617.1	-	1470	1139
6	Mean annual Max. and Min. Temp.(^{o}C).	33.0 & 20.0	42.3 & 11.6	24.2 & 10.2	24.2 & 10.2	35 & 18	23 & 30
7	*p*H	8.22	7.7	5.12	6.0	7.1	7.81
8	Available N (kg/ha)	243	207	252	272	261	245
9	Available P (kg/ha)	17.5	9.8	15.4	33.0	58.6	81.0
10	Available K (kg/ha)	199.1	197.33	202.4	248.0	248	264
11	Bulk density (g/cc)	1.39	1.35	1.21	1.25	1.35	1.20
12	Soil organic carbon (% of dry soil)	0.25	0.60	1.43	2.19	0.52	0.69

Besides other factors, soil hardness and development of cracks in these soils are also dependant on soil texture and soil moisture content (SMC). As the soils become dry with time, the soils offered higher resistances to root penetration (observed through enhanced penetrologgger resistances) resulting in higher energy expenses for drawing water for crop growth and development. That is why the depletion of soil moisture is observed to be much faster in a *Vertisol* (due to development of more and wider cracks) resulting in higher soil resistances in these soil compared to an *Inceptisol* (Fig 3 and 4). As a result, the critical soil penetration resistance (SMR) differs from soils to soils. This SMR is observed to be 0.9 MPa for lentil root growth in an *Inceptisol* which corresponds to 12 per cent SMC (v/v). Higher SMR puts ample hindrances to root growth and so is the soil moisture extraction that results in reduced growth and biomass accumulation and its appropriate transformation.

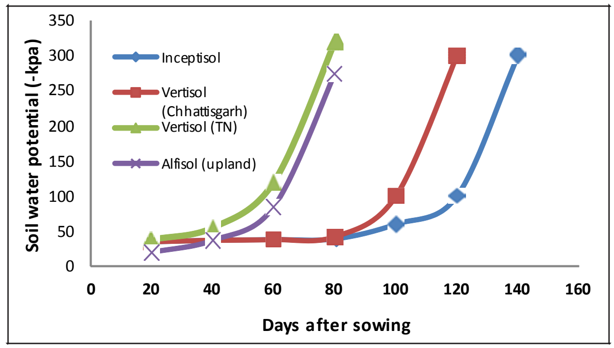
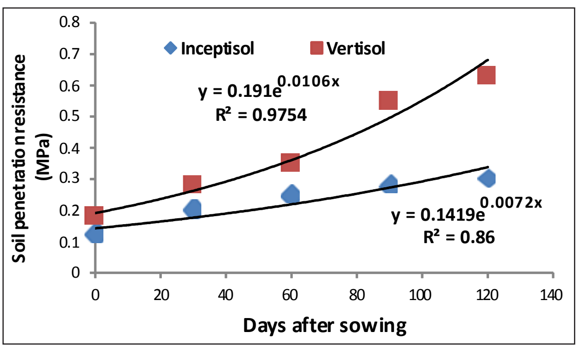


Fig 3. Drying pattern in different soil types in RIFAs



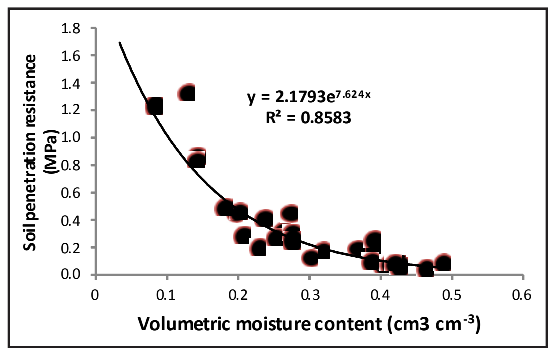


Fig 4. Temporal changes in soil resistances following depletion of soil moisture

i. Eastern and Northeast region

In Eastern and Northeastern region of India, a large tract of RIFAs remains fallow after the *kharif* rice. These soils have excessive SMC just after rice harvest. Since eastern region of the country covering states of eastern Uttar Pradesh, Bihar, Orissa, West Bengal and Assam comprises of mostly alluvial and calcareous soil, these are mostly deficit in soil organic carbon (SOC), phosphorus and zinc. On the contrary, the soils of north-eastern hilly regions are normally acidic in nature and are generally deficient in SOC, P, Zn and other cations. In high rainfall areas, more cations are leached down to lower layers in a profile resulting in higher acidity which necessitates for continuous reclamation/liming on a sustainable basis besides other management considerations.

In the alluvial soils in the states of Uttar Pradesh, Jharkhand and Bihar where drainage is not the major constraint, shorter duration and hardy pulses such as lathyrus *(khesari)* and lentils are popular occupying the major area during *rabi* after rice. However, with better soil moisture conservation and management and agro-technological interventions, relatively longer duration pulses such as chickpea and pea can also be profitably grown. In low land soils under north-eastern and NEH states, excessive soil moisture and consequently water logging condition during rice harvest in October/November renders difficulty in growing of pulses. Similarly, excess soil moisture accumulation, due to seepage from surrounding hillocks in some RIFAs under hilly terrains in NEH region, renders hardship in desired tillage and land preparation. However, appropriate land configuration coupled with improved soil and water management will provide suitability to grow lentils and peas in these RIFAs. Complementing this, severe winter and uncontrolled grazing by stray cattle (the age old practice of leaving cattle following harvest of rice for grazing) after harvest of rice are of serious concern for crop raising. However, with collective efforts of all the stake holders and through farmers' cooperatives, lentil and pea can be profitably grown resulting in increased cropping intensity and enhanced farm income.

The typical all-season rice belts in the eastern part of India, such as RIFAs of West Bengal bordering Bangladesh, where rice is cultivated in all the three seasons (summer, autumn and winter) is also undergoing rapid transformation. Here, lathyrus is used to be the major pulse grown. Due to high ODAP content in local land races of lathyrus and also with the advent of irrigation facilities, the farmers prefer to shift from relay cropping of lathyrus to more remunerative crops like, rapeseed, mustard, potato, other vegetables and even winter rice requiring more water. As a result, the area under lathyrus is diminishing drastically in these regions. Ironically, the state (of West Bengal) has to feed almost 70 million people from a mere 5.8 million hectares of cultivable land. And the pressure on land continues putting a question mark on intensification of unsustainable and high water requiring cropping systems in time to come.

It is reported that in high altitudes of north eastern India where prevailing low temperature puts a hold on crop growth whereas a high night temperature in lower altitudes and in eastern states especially during reproductive stage limits it, management of temperature as a production constraint is again a crucial issue. Further, late sowing of pulses in these RIFAs due to delayed transplanting of long duration rice and lack of short duration heat tolerant pulses genotypes are common constraints. Therefore, effective location specific strategy plays a crucial role for realizing productive potential from selective RIFAs coming under each agro-ecological zones/subzones.

ii. Central India

In the RIFAs of Central India covering Chhattisgarh, Madhya Pradesh and Maharashtra, clay soils predominate. Soils in these regions are generally deltaic alluvial, coastal alluvial, laterite, red loamy, medium black, red sandy, deep black, sandy red and black, mixed red and black with pockets of acidic and saline soils with *p*H 5.0 to 8.0. These soils are generally deficient in nitrogen, soil organic matter (SOM) and calcium. Laterite soils are usually low in nutrient status and organic matter with poor water holding capacity and strongly acidic.

The black soils also constitute the major part of Central India. Categorized under heavy soil, these are having a special characteristic of swelling and shrinkage following hydration and drying. Upon drying, these become very hard and develop deep cracks that facilitates in moisture depletion even from lower profile layers. This phenomenon often causes terminal moisture stress (coinciding with reproductive stages) for a growing crop including pulses. In addition, these soils are devoid of nutrient availability including that of micronutrients like, Mo and Zn.

Although these RIFAs receive a moderate rainfall of around 1,000 mm (of which >70% is received during July to September under SW monsoon) with the coefficient of variation in the range of 20-30 per cent, yet this region is often cited for erratic behavior of rainfall resulting in crop failure even during kharif season. Early withdrawal of rains further leads to soil moisture stress for timely planting of rabi crops posing a major concern for traditional practice of crop husbandry involving conventional tillage. Later in the growing season, terminal drought and heat stress further causes forced maturity with low yields of rabi crops which are normally grown under rainfed condition. Therefore, drought stress alone is responsible for >50 per cent yield loss in most of the *rabi* pulses. Hence, relay (*paira*) cropping of lentil/lathyrus is more common in this region so as to avoid soil moisture stress later in the life cycle of crops (Fig 5). Here, seeds of lathyus/lentil are broadcasted in standing rice field at around 1-2 weeks before harvesting of rice. Thus, this region offers a great scope for promoting chickpea in rice fallow. However, susceptibility of chickpea to root rot and wilt as well as to the pod borer, *Helicoverpa armigera* constitutes the major constraints in this region.

Fig 5. A typical soil moisture status for pulses sowing under Rice + Pulse relay cropping

iii. Coastal peninsula

The coastal India, comprising of costal RIFAs of Tamil Nadu, Karnataka, Andhra Pradesh, is typically known for its rice cultivation. During the harvest of rice, this area is often encountered with excessive soil moisture at the time of sowing of pulses. And later, it is accompanied with soil moisture stress following its rapid depletion with time coinciding with reproductive stages of pulses. The soils of these region are mostly deltaic alluvial, coastal alluvial, laterite and loamy with *p*H ranges of 5.0-8.0. However, the presence of deltaic alluvium makes these soils very fertile as these are endowed with potassium which is an essential major nutrient required by the plants. Mostly, Coastal areas of Andhra Pradesh, Tamil Nadu and Karnataka are covered under this region. Mild short winter is the main characteristics of the region favouring cultivation of short duration pulses like, urdbean and mungbean. The region receives bi-modal rains. Sowing of urdbean and mungbean, under rice fallow conditions, if delayed beyond end of January or so, there is drastic reduction in the productivity of these crops. Poor plant stand and terminal moisture stress are the two major constraints for pulses grown in these RIFA regions. The weather (warm with high relative humidity) experienced in this region is very conducive for development of viral diseases in pulses including mungbean yellow mosaic virus (MYMV). Urdbean and mungbean are also susceptible to powdery mildew, cercospora leaf spot and leaf curl virus.

Fig 6. Pulses seedling damage following rice harvest by combine harvester

The traditional practices of rice + pulse relay cropping system is prevalent in these RIFAs. Yet, the productivity of pulses (mungbean and urdbean) is very low because of insufficient plant population possibly due to many factors such as, poor seed-soil contact, higher soil moisture at the time of sowing causing seedling rot, emerging seedlings damage during rice harvest either manually or through combine harvester (Fig. 6), severe weed infestation and adverse soil physical properties. Popularization of medium duration rice coupled with availability of short duration disease resistant pulses' varieties could scale up the productivity potential of this region.

Chapter 3

Constraints in promoting pulses in rice fallows

RIFAs are endowed with many strengths and opportunities. These are again constrained with several weaknesses and threats that again hinders in scaling up of productivity potentials of these regions. Constraint analysis reveals the diverse nature of constraints or issues that need to be addressed amicably on a time bound manner. These may be categorized under common (biotic, abiotic or socio-economic) and production constraints which are discussed herein as under.

A. Common constraints

i. Abiotic constraints

Abiotic constraints are more or less related to physical stress that is most often associated with soil moisture stress, marginal soils with poor fertility status, problematic soils and unpredictable environmental conditions prevailing at the time of sowing. These are major abiotic constraints causing lower production in pulses in RIFAs during past several years. In addition, drought and heat stress at flowering and pod filling stages adversely affect the productivity of pulses which may reduce output up to 50% of potential yields. Under problematic soils, soil salinity and alkalinity restricts both root and shoot growth of pulses. While unfavourable low *p*H i.e., soil acidity is the major problem in eastern India, soil salinity and alkalinity on the other hand are of greatest concern in RIFAs of lower and middle Gangetic plains. Unfavorable and consistently deteriorated soil physico-chemical conditions following rice (mostly grown under puddled or flooded condition) cultivation restricts normal growth of the pulses (as these favours upland condition). The situation is further aggravated causing decline in growth and yield in pulses due to lesser availability of nutrients, poor microbial (*rhizobium*) activity and reduced root growth. Besides the inherent constraints associated with rice cultivation, this land also affects pulses seed germination and seedling emergence and establishment due to disruption in soil structure, soil water deficit, poor aeration and mechanical impedance at rhizospheric zone. Amongst these physical constraints, soil hardiness is the most limiting factor followed by low SOM content in the soil. Soil hardiness in the puddled rice fields also deteriorates soil hydraulic properties that adversely affect the soil moisture distribution and root growth of deep tap-rooted pulses. This hostile environment poses a potential menace to microbial activity, nutrient availability, root growth (mostly confined to top soil layer) and water and nutrients uptake. As a result, sub-soil resources in rice fallow areas remain under-utilized. Following relay (*paira*) cropping, plant population is often low because of low seed germination due to poor seed-soil contact, seed or seedling rotting (due to high soil moisture and anaerobic condition) as well as drying (due to undulated dry soil mostly seen in patches). If tillage is taken up after rice harvest in order to remove stubbles, sowing of *rabi* pulses gets delayed and germination will also be hampered due to formation of large size clods.

ii. Biotic constraints

Due to prevailing anaerobic conditions in rice cultivation, many of the organisms including rhizobia could not thrive well under such a situation. Even if the crop is sown timely and establishes well, it often experiences high incidence of insect pests and diseases. Although detailed studies on dynamics of disease pests in pulses under RIFAs have not been well taken up, yet these biotic agents thrive well under such a situation to cause perceptible damages afterwards. Evidences suggest that pulses are the most preferred host for insects. In chickpea, the pests (particularly, *Helicoverpa armigera* or pod borer) are reported to ring alarm as a potential threat in Chhattisgarh, Jharkhand and Madhya Pradesh (Table 5). Similar is the case for diseases such as, powdery mildew, mungbean yellow mosaic virus (MYMV) diseases and several dry/wet rots and wilts etc which are viewed as serious problems. Powdery mildew is yet another serious disease of *rabi* planted urdbean and mungbean in coastal belts due to higher relative humidity. Similarly, rust and *Fusarium* wilt are common in lentil. In peninsular RIFAs of India, urdbean and mungbean are susceptible to MYMV, powdery mildew, cercospora leaf spot and leaf curl virus. Among nematodes, root-knot nematodes are important in terms of its spread and damage to crop in rice fallow areas.

Many a time in absence of resistance varieties and specific awareness as in parts of RIFAs especially in Odisha and West Bengal and parts of Bihar, Chhattisgarh and Jharkhand (where pulses area is small and scattered which may be attributed to lack of land consolidation), these biotic constraints puts a hold to potential productivity of these so called manageable fertile lands. Non-availability of pesticides in adequate quantity and at right time is also an important hindrance to profitable pulses cultivation. Similar to insect pests, weeds are also a menace for cultivation of pulses under rice fallows as these cause around 50% average crop loss if kept uncontrolled. Ratooning of rice after its harvest is yet another major problem in rice fallow relay cropping system in many parts of the country (causing pests' resurgence, uncontrolled weeds and deteriorated soil physic-chemical condition) which needs special attention so far its (rice ratoon) scientific management is concerned.

Table 5. Constraints in relay cropping and in rice fallow areas (RIFAs)

Crop	Stresses	
	Biotic	Abiotic
Chickpea	Fusarium wilt, root rot, chickpea stunt, Botrytis Gray Mould and pod-borer	Low and high temperature and terminal drought
Mungbean	MYMV, root and stem rot, sucking insect pests and Pre-harvest sprouting	High temperature, terminal drought and excessive soil moisture at sowing
Urdbean	MYMV, root and stem rot, stem and Pre-harvest sprouting	Temperature stress, terminal drought and excessive Soil moisture at sowing
Lentil	Fusarium wilt, root rot and rust	Soil moisture and high temperature (under late sown)

iii. Socio-economic constraints

Performance of public extension programmes for effectively delivering the technology, awareness about inputs and latest information to the farmers is crucial for out-scaling production potential of pulses in RIFAs. Lack of scientific knowledge, non availability of seeds of improved varieties and poor technical expertise are some of the socio-economic institutional constraints while, unavailability of seed storage and life saving/supplementary irrigation and poor marketing support were socio-economic infrastructural constraints in pulses production (Praharaj *et al.*, 2016 & 2017). In most part of the country, improving farmer's access to information related to crops and their cultivation practices is of prime importance in the process of successful utilization of RIFAs. It is inferred that in absence of irrigation infrastructure, most of the RIFAs of eastern India are inhabited by farmers belonging to low social strata where socio-economic considerations for their welfare plays a crucial role for tangible advances in crop husbandry. Scarcity and diversion of labour is the biggest bottleneck during the sowing and intercultural operations of pulses following rice harvest when priority shifts towards timely harvesting and threshing of rice (rather than sowing of a fresh crop of pulses which requires additional investment). As the availability of soil moisture goes on fast depleting, there is little time lag for sowing of next crop in rotation or through paira cropping.

More often it is observed that, farmers lack information on different soil and water conservation technologies and sowing techniques that help to germinate the seed even in low moisture regimes. Poor and marginal farmers also lack sufficient capital to purchase critical inputs such as seed, fertilizer and pesticides. Non-availability of these inputs particularly in respect of quality seeds pose further problem in growing a rabi crops in rice fallows. Low volume of produce and lack of proper markets may deprive the small and marginal producer to get the support price also. Non-availability of high yielding, early maturing and disease resistant varieties at village level and improved post-harvest technologies (and value addition) to reduce post harvest losses also hinder cultivation of pulse crops in rice fallow areas.

Besides this, other issues (like, grazing problem and risk involved as the crop will not be grown under assured irrigation) sometimes discourage farmers to go for sowing of another crop (pulses) in quick succession. Many farmers don't possess draft power for which they also need credit to acquire energy support (in terms of bullocks or tractor) to ensure timeliness in sowing. Following non-utilization of this vital resources (towards realization of profitable production from RIFAS for a greater part of the year), the net result is agricultural backwardness, low levels of farm income, unemployment of rural mass, abject poverty and malnutrition (Joshi *et al*., 2002).

B. Production constraints

Poor plant population under surface seeding is the major production constraint in RIFAs. Less or no use of fertilizers is another reason due to which pulses face nutrient stress. The physical condition of soil and *rhizobium* population is poor due to anaerobic condition under transplanted rice and consequently nutrient mobilization is reduced. The sowing of pulses in rice fallows depends on duration of rice cultivars, withdrawal of monsoonal rains and soil moisture status which are highly dynamic and diverse. Thus, sowing of pulses often gets delayed. Lack of pulses varieties suitable for rice fallows (such as unavailability of early maturing and early high biomass accumulating genotypes) further limits adoption of pulses in rice fallows. Unavailability of quality seeds of pulses suitable for rice fallows in desired quantity at appropriate time and reasonable cost is also a big hurdle. In addition, pulses productivity in rice fallows is severely affected due to high incidence of insect-pest and diseases and low or no use of inputs like, pesticides and herbicides by resource poor rice farmers. In addition, situation specific improved production technology dealing with soil moisture conservation, adequacy in timely plant population management, mitigation or termination drought and heat stresses, optimum seed rate, improved seeding techniques (e.g. with zero till drill) and improvement in soil physical condition could be a boon to such a situation (Fig 7).

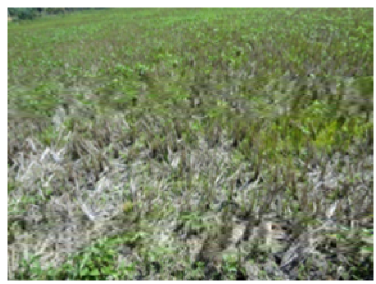


Fig 7. Poor plant population of urdbean under rice fallow

Chapter 4

Site specific technological interventions

Site specific technological interventions are critical as it facilitates both up-scaling and out-scaling such interventions over time and scale. In this context, continuous and consistent efforts have been made at National Level to have the desired breakthrough in bringing additional areas under RIFAs for pulses cultivation. In this endeavour, an ICAR-National Agricultural Science Funded (NASF, previously called NFBSFARA) project entitled '*Mitigating abiotic stresses and enhancing resource-use efficiency in pulses in rice fallows through innovative resource conservation practices*' have been operational from June 2011 to May 2016. It is basically aimed at assessing and refining agro-technologies suiting rice fallows through a thorough study on its both basics (that includes agro-ecology and other related studies) and practicability so as to amicably address the issues related to RIFAs in the country. Two objectives have been well fulfilled during 5-years period of the project operation which are included as under.

1) To understand the **rice - pulse relay cropping** as a conservation agriculture system and mitigate moisture stress faced by the pulse crop in the system, and

2) To evaluate the role of use of rice stubbles and zero-tillage in the **rice - pulse system** for conserving soil moisture and enhance soil physico-chemical characteristics

The project was implemented for the above 5 consecutive years at 5 strategic centres throughout the country. The location included ICAR-Indian Institute of Pulses Research, Kanpur (Uttar Pradesh) as lead centre, while Indira Gandhi Krishi Viswavidyalaya, Raipur (Chhattisgarh), Bidhan Chandra Krishi Viswavidyalaya, Kalyani (West Bengal), Tamil Nadu Rice Research Institute, Aduthurai (Tamil Nadu), and ICAR Research Complex for North Eastern Hill Region (ICAR RC NEH), Umiam (Meghalaya) were sub-centres. These centers are selected based on diverse agro-ecological regions of rice fallows in the country. The novelty of the project is that it had assessed/refined suitability of many and diverse technological interventions for the location/zone/state of the country which can have wider applicability with fine tuning. These interventions along with the universally accepted technological interventions are given herein as under the following heads.

A. Rice + pulse relay cropping

i. Southern India (rice + urdbean)

Here, the relay cropping system involving rice, mungbean and urdbean is popular. Urdbean is mostly grown in Tamil Nadu while, both mungbean and urdbean are cultivated in Andhra Pradesh and Karnataka. These crops are grown under paira/relay cropping system in which mungbean and urdbean seeds are broadcasted 1-2 weeks before harvest of rice crop in the month of December and January. Here, the soil moisture at the time of broadcasting of pulses is usually high (varies from 37-45 %) causing wide-scale mortality in emerging seeds/young seedling. Hence, the interventions are assessed and modified with the help from TRRI, Aduthurai (Tamil Nadu) for growing a successful mungbean/urdbean crop in RIFAs of Southern India. The interventions include the followings.

Improved rice/urdbean varieties and retention of rice stubble

The superiority of long duration and high tillering rice variety 'CR1009' (over medium duration 'ADT 49'), retention of 30 cm rice stubble (over 15 cm) and 'ADT 3' urdbean (due to more branching and foliage development covering the ground early in the season over 'VBN 4') were well established through diverse soil/plant (growth and yield) attributes along with other related parameters evaluated at the location. Enhanced relative leaf water content (RLWC), a determinant for soil moisture stress indicator, along with higher per plant nodules and nodules dry weight in urdbean due to extended conservation of soil moisture, were associated with the above factors of superiority under rice fallow condition. Similar trend was also observed in case of other growth and yield attributes observed in case of urdbean (Table 6). However, the beneficial effect of rice variety 'CR 1009' could very well be ascertained only when the re-growth of rice stubbles was contained by application of early post-emergence herbicide following rice harvest.

Table 6. RLWC, nodulation (45 DAS) and yield of urdbean as influenced by cultivars and stubble height

Rice Variety	Stubble height (cm)*	Urdbean cultivar	RLWC (%)			Nodules/ Plant	Nodules dry weight/ plant (g)	Yield (kg/ha)
			30 DAS	45 DAS	60 DAS			
CR1009	15	ADT3	68.5	82.5	71.4	8.2	0.016	880
		VBN4	64.8	78.0	67.5	6.7	0.014	680
	30	ADT3	74.5	89.7	77.7	10.5	0.021	960
		VBN4	70.6	85.0	73.6	9.1	0.020	745
ADT 49	15	ADT3	67.6	81.4	70.5	7.8	0.018	840
		VBN4	61.2	73.7	63.8	6.5	0.015	650
	30	ADT3	71.5	86.1	74.5	9.8	0.021	915
		VBN4	70.2	84.5	73.2	8.6	0.019	700
Mean	CR 1009		69.6	83.8	72.5	8.6	0.018	816
	ADT 49		67.6	81.4	70.5	8.2	0.018	776
	15 cm stubble		65.5	78.9	68.3	7.3	0.016	763
	30 cm stubble		71.7	86.4	74.7	9.9	0.021	830
	ADT 3		70.5	84.9	73.5	9.1	0.019	899
	VBN 4		80.3	69.5	43.9	7.7	0.017	694

*Relative leaf water content (RLWC)

Rice establishment method

Destruction of soil structure and increase in soil hardiness due to common practice of puddling before transplanting of rice restricts seed germination and root growth of pulses under rice fallows. Under such a situation, the practice of unpuddled transplanting of rice (or even direct seeding) could be an improved option in black soils of southern India. In case of unpuddled situation, when rice is transplanted after land preparation following irrigation without puddling, a lot of water (and money/energy) is saved. Thereafter, saturated condition of soil could be maintained in field through irrigation after 2-3 days of disappearance of ponded water.

On the contrary, the study indicated the higher suitability of puddled transplanting condition (PTR) as it maintained higher SMC for succeeding urdbean as compared to unpuddled transplanted rice (UPTR). As a result, deeper soil cracks (3.83 cm width and 11.55 cm depth) were observed in UPTR as compared to PTR (3.3 cm width and 10.8 cm depth) in urdbean following drying of soil with time. Similar was the case for higher soil penetration resistance (7-10%) observed under UPTR recorded at 30 DAS. Moreover, better plant growth (measured through higher number of nodules, nodule dry weight/plant at 30 and 45 DAS and even higher plant population/m^2, plant height, pods/ plant and seeds/ pod and 100-seed weight, and other physiological attributes *viz*., RLWC, specific leaf weight (SLW) and chlorophyll content index (CCI) at 30 and 45 DAS) following puddled condition (as a result of higher SMC) tended to be higher. As a consequences of all these, enhanced urdbean grain yield was realized with PTR (594 kg/ha, over UPTR with 558 kg/ha). Therefore, under black soil of southern India following rice + urdbean relay cropping system, site specific puddled transplanting has shown higher advantage over unpuddled situation.

Seeding techniques in pulses

Broadcasting of pulses seed at 1-2 weeks before harvesting of rice is a common traditional practice of sowing pulses in rice + pulse relay cropping system in RIFAs of Sothern India. However, following harvesting of rice either manually or through combines, extensive damage to young seedlings is most common that results in poor plant stand. Hence, there is a need for seed drills which can be taken up just after harvest of rice. Alternatively, seed can also be broadcasted 4-6 days before rice harvest. This practice has the reduced level of soil penetration resistance in surface soil (0-15 cm) under urdbean. The crop can later get a life saving irrigation using a micro-irrigation system (sprinkler), if required at 30 DAS. Confirming this, it is established that this practice (sowing urdbean by broadcasting 4-6 days prior to rice harvest along with life saving irrigation) has resulted in higher RLWC (84.1%), SLW (6.89 g/cm^2), CCI (43.65) at 45 DAS and growth and yield attributes (plant stand, plant height, pods/plant, seeds/pod, 100-seed weight, nodules number and its dry weight at 30 and 45 DAS) compared to sowing with a Zero Tilled Drill (ZTD, where higher root length and root

Fig 8. A field view of crop establishment under urdbean 'ADT-3' following sowing by IIPR seed drill

Table 7. Seeding techniques in urdbean has a bearing on soil cracking and crop productivity

Treatments	Soil cracking at critical stage		Soil resistance x at 30 DAS			Yield (kg/ha)
	Width (cm)	Depth (cm)	0-5cm	5-10cm	10-15cm	
T_1 –Broadcasting 7-10 days before rice harvest	3.33	10.07	580	500	420	542
T_2 - Sowing by NTD on the rice harvest day	4.10	14.13	600	520	480	452
T_3 - Broadcasting 4-6 days before rice harvest (CH)	2.93	7.27	480	450	400	607
T4 -T_1 + LSI	3.57	10.50	560	450	460	612
T5 -T_2 + LSI	3.85	13.80	580	480	440	566
T6 -T_3 + LSI	2.87	6.53	460	400	370	738

NTD: No till seed drill; CH: Combine harvestor; LSI: Life Saving Irrigation with mobile sprinkler once at critical stage dry weight were observed, Fig 8). All these beneficial effects had a bearing on realization of higher urdbean yield (738 kg/ha) following its bradcasting 4-6 days before harvest. However, machines have their own advantages and short-comings, and needs fine tuning to work efficiently under such a harsh situation (Table 7).

Seed priming and rhizobium inoculation

Poor nodulation and BNF has always been the key issue for N management in RIFAs. This is due to soil impediments like, poor soil structure and anaerobic conditions following rice cultivation under flooded condition. Thus, there is a need for seed inoculation with proper cross inoculation group of rhizobia. When combined with priming of seeds (4-6 hours seed soaking in water), the inoculation had benefitted nodulation (through enhancing nodules/plant by 25.2% and nodules dry weight/plant by 42.2%), growth and yield attributes (36.4 and 8% higher in pods/plant and 100-seed weight, respectively) and seed yield of urdbean (25% more) by decreasing soil resistances to root penetration (Fig 9). Seed priming alone was also known to increase grain yield by 10.5%.

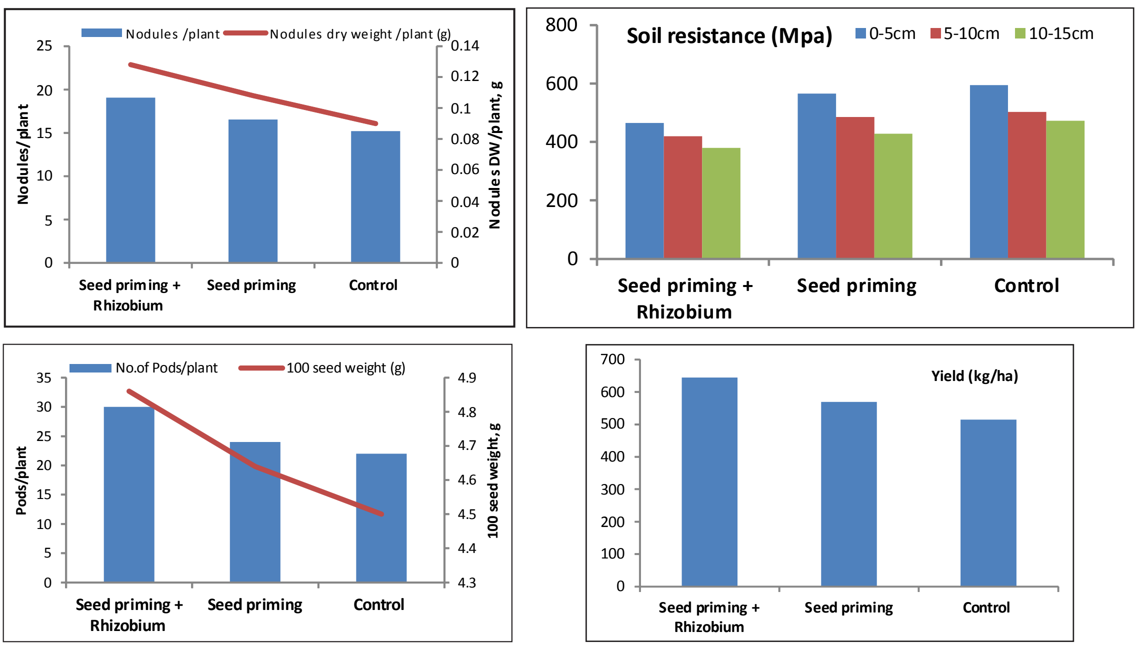


Fig 9. Synergy in seed priming & rhizobium inoculation on root characters and yield attributes in urdbean

ii. Eastern India (rice + lentil)

In relay cropping system under eastern India, lentil plays a dominant role especially in RIFAs of West Bengal. An early and disease resistant variety of lentil is becoming popular owing to ease of sowing, good yields and local food habits. The technological interventions were assessed and refined with the help from BCKV, Kalyani (West Bengal) which include adoption suitable rice establishment method, popularization of appropriate varieties of both rice and lentil, and retaining rice stubbles. These are discussed herein as under:

Improved rice/lentil varieties and rice stubble retention

Although the usual practice is broadcasting lentil at 15 days before rice harvest under very high SMC (35-38%) yet, the soil moisture depletion across whole of the soil profile is relatively slower when it is preceded by a short duration and dwarf rice 'IET 4786' (over the long duration and tall rice 'IET 5656'). The study showed that in contrast to tall habit group, the soil moisture storage in lentil root zone (up to 40cm soil depth) under dwarf rice also remained high till reproductive stages and the (soil moisture storage) values (>10cm) were still above the PWP (7.0 cm) of the soil while, root penetration resistance up to 40 cm soil depth fell below the critical value of 0.85 MPa under tall habit group as the crop traversed from vegetative to pod formation stage. Similar favorable conditions such as higher microbial activities like, SMBC, Rhizobium & PSB were prevailed under short duration rice variety 'IET 4786'. Similarly, retention of 20 cm of rice stubble height was optimum under the rice fallow situation because of conservation of more soil moisture at 0-30 cm soil depth at all growth stages of lentil resulting in lowest penetration resistance at 30cm depth (<0.8Mpa). As a result of reduced soil compaction and aeration, higher microbial activities were observed under it. Further, medium duration lentil variety 'Subrata (WBL 58)' depleted more moisture (11%) than Asha (B 77) under both rice cultivars and stubble height (Fig 10, 11 and 12) although both lentil varieties yielded similar.

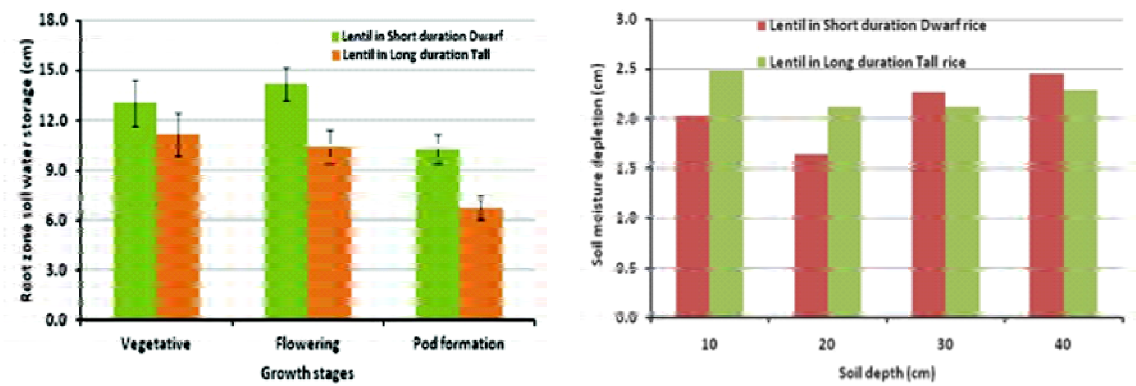


Fig. 10. Root zone (0-40cm) soil moisture storage and its depletion in lentil under different rice habits (T: Tall, D:Dwarf, CH for stubble or cutting height)

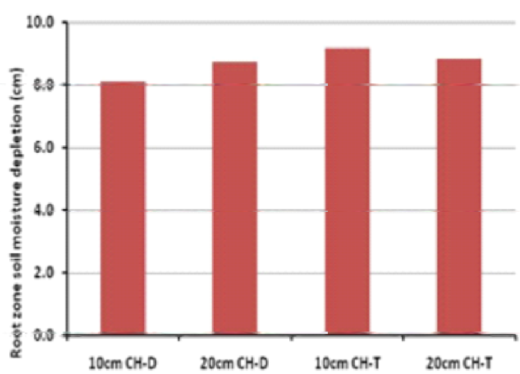


Fig 11. Soil moisture depletion at different soil depths under different rice habit groups

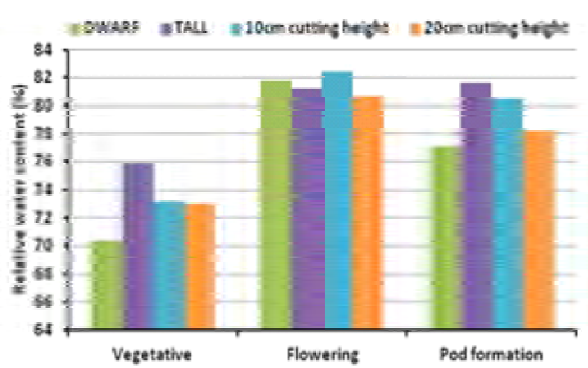


Fig 12. RLWC under different rice habit groups and cutting height of stubbles

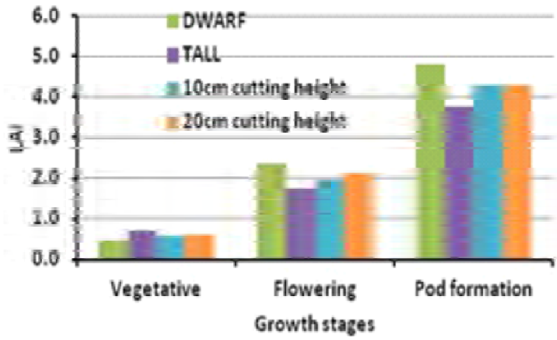


Fig 13. LAI in lentil at growth stages following different rice habit groups and residue retention

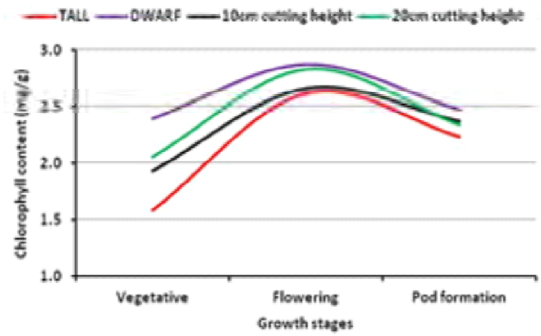


Fig 14. Chlorophyll content at lentil growth stages following different rice habit group and residue retention

The combination of dwarf rice variety and 20 cm rice stubble retention had also resulted in higher soil moisture storage for an extended period of crop growth that further enhanced nodulation, BNF, plant physiological parameters in lentil (RLWC, LAI and chlorophyll content) and grain yield (22% higher under dwarf rice while, 11 % more under 20 cm residue retention over tall rice and 10 cm residues, respectively) (Fig 13 and 14).

Rice establishment method

Rice transplanting under unpuddled condition has an edge over puddled condition due to higher soil moisture storage (and with 11% more depletion under puddled condition). Consequently, enhanced soil crack volumes, greater soil penetration resistance, decreased nodule number and its weights were somewhat the detrimental characteristic features in puddled condition (Fig 15 and 16) although average yield of lentil (and water use efficiency) were not influenced by rice establishment method (PTR *vs.* UPTR).

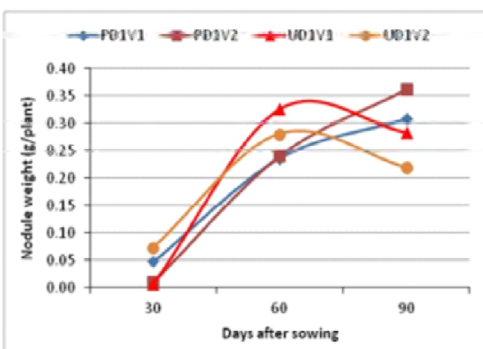


Fig 15. Nodule dry weight in lentil in diverse situations (P-PTR; U-UPTR,D1: Normal sowing, V1-B 77, V2-PL 6)

Fig 16. Performance of lentil varieties under unpuddled and puddled conditions

iii. Central India (rice + lathyrus)

In relay cropping system under Chhattisgarh in Central India, lathyrus (*khesari*) is most popular due to many reason right from local preference to hardy and drought tolerant nature of the pulse crop. Higher average of yield of crops, even under harsh climate commonly accompanied with moisture stress agro-ecology, facilitates its popularity among native people (Basu *et al*., 2016). Yet, improved varieties with low BOAA content warrant its improvement both genetically and agronomically (*Lathyrus* grain containing high concentrations of the glutamate analogue neurotoxin b-oxalyl-L-a, b-diaminopropionic acid called ODAP, is also known as b-*N*-oxalyl-amino-L-alanine, or BOAA causes paralysis). Hence, the need arises for technological interventions suiting these RIFAs. With the assistance from IGKV, Raipur (Chhattisgarh), newer and improved production practices (including adoption of suitable rice/lathyrus varieties with retention of proper rice stubble height) have been developed and assessed/refined. These are discussed herein as under:

Rice/lathyrus varieties and rice stubble retention

Short duration rice 'Swarna' (110 days) when preceded with early high biomass accumulating lathyrus 'Ratan' resulted in decreasing soil moisture depletion rate during its growth cycle (compared with long duration rice 'Mahsuri' that takes a month more, and medium high biomass accumulating lathyrus 'Prateek' requiring a week extra for maturity). In addition, when these were combined with retention of rice residues measuring 30 cm height, the rate of depletion of soil moisture again went slower compared to retention of shorter residues of 15 cm (that led to moisture storage below the available water content of 0.57 cm) at pod development stage of lathyrus. Consequently higher SMC favours microbial activities in soil and the maximum rhizobium population (8.13-10^4 CFU/g of soil) was analysed under the plot that involved improved practices (rice 'Swarna', lathyrus 'Ratan' and 30cm rice stubble). Similar was the case for other microbial activities (PSB & diazotrophs population), dehydrogenase activities, RLWC, root volume, growth and grain yield (Table 8) of lathyrus (although almost similar yields were recorded due to rice varieties and stubble height because of often prevalence of winter rains).

Table 8. Effect of genotypic differences and rice stubble height on soil micro-biological properties

Treatment	Rhizobium (10^4 CFU/ g of soil)	PSB (10^4 CFU/g of soil)	Diazotrophs (10^5 CFU/g of soil)	Dehydrogenase activity (µg TPF/g soil)	Nodule dry weight (mg/plant)	Root volume (ml/cm³)	Yield (kg/ha)
Rice varieties							
Swarna	7.5	4.88	3.13	91.63	7.9	1.25	719
Mansuri	7.8	4.96	2.85	76.45	11.03	1.15	711
Lathyrus varieties							
Ratan	7.7	4.77	3.11	86.04	9.7	1.20	595
Prateek	7.6	5.07	286	82.05	9.3	1.20	850
Rice stubble height							
15 cm	7.5	4.68	2.65	81.03	8.3	1.15	742
30 cm	7.9	5.15	3.34	85.95	10.7	1.25	704

Rice establishment method

Among three prevailing practices of rice establishment methods such as puddled transplanted rice (PTR), unpuddle transplanted rice (UPTR) and direct seeded rice (DSR) evaluated under rice + lathyrus relay cropping system in clay loam soils under RIFAs in central India, PTR had higher SMC throughout crop cycle of lathyrus although initial SMC at sowing of pulses was similar (40-44%) in these establishment methods. However, other physical parameters varied as higher values of BD (1.38 Mg/m³) in the surface soil (along with higher soil resistances) was recorded in UPTR while infiltration rate was higher in DSR (30 mm/h). On the contrary, SMC and soil crack volume were higher under PTR (Fig 17, Table 9 and 10). As a result, maximum population of diazotrophs (2.49 x10^5 CFU/g of soil), rhizobium (7.54 x10^4 CFU/g of soil), PSB (4.96 x10^5 CFU/g of soil), and dehydrogenase activity (72.10 µg TPF/soil/day) were recorded at rice harvest under PTR. So was the status of these at flowering of lathyrus. All these resulted in higher root nodule/plant and its dry weight, RLWC, SLW, pods/plant and grain yield (1592 kg/ha) and its attributes under PTR (Table 9 and 10).

Table 9. Effect of rice establishment methods on soil physical properties under lathyrus

Treatment	B.D. (Mg/m^3)		Infiltration rate (mm/hr)	Cumulative Infiltration (mm/hr)	WUE (kg/ha/mm)	Crack volume (ml/m^2)		Soil strength (kN)	
	10cm	20cm				At flowering	At harvest	10 cm	30cm
PTR	1.37	1.41	23	140	4.00	506	1465	0.11	0.11
UPR	1.37	1.42	21	135	3.94	391	1375	0.15	0.15
DSR	1.34	1.38	30	240	3.48	132	1169	0.07	0.09
C.D. (0.05)	0.01	0.015	0.114	9.829	NS	114	45.5	0.012	0.015

Table 10. Effect of rice establishment methods on soil microbiological properties under lathyrus

Treatment	Rhizobium (10^4 (CFU/g soil) (At flowering)	Nodule (75 DAS)		PSB (10^5 CFU/g of soil)	Dehydrogenase activity (µg TPF/g soil)
		No.	Drywt.(mg/plant)	(Flowering)	
PTR	7.79	16	37.7	5.21	74.52
UPR	7.60	14	32.2	5.08	72.90
DSR	7.38	14	30.9	4.98	70.10
C.D. (0.05)	0.172	1.32	2.98	0.236	0.36


Puddled transplanted rice

Unpuddled transplanted rice


Direct seeded rice

Fig 17. Soil structural cracking pattern at harvest of lathyrus

B. Rice - pulse sequential cropping

i. Eastern India (rice - chickpea)

In sequential cropping involving RIFAs under eastern India, chickpea (in rice-chickpea system) is becoming popular especially under rainfed condition in Uttar Pradesh. Here comes the role of short duration and disease (like, *Fusarium* and *Ascochyta* blight) resistant variety of chickpea. The technological interventions were assessed and refined with the help from ICAR-IIPR, Kanpur (Uttar Pradesh) that include adoption of suitable rice establishment method, popularization of appropriate varieties of both rice and chickpea and retention of rice stubble after the harvest of rice crop. These are discussed herein as under:

Rice/chickpea varieties and residue management

The superiority of medium duration rice variety 'Pant Dhan 12' (maturing in 90-100 days over local cultivar with tall habit and longer duration), retention of 30 cm rice stubble (against a short 15 cm stubble) and early high biomass accumulating chickpea 'Jaki 92-18' (over 'DCP 92-3') were well established through diverse soil/plant (growth and yield) attributes along with other related parameters assessed and refined at the location.

Basic soil parameters studied at the location indicated that even cumulative infiltration after chickpea harvest was significantly more (21.1%) under 'Pant Dhan-12' and mulch/stubble (Fig 18 and 19) retained plots (with higher basic infiltration rate in stubble retained followed by mulch and no-residues retained plots). Similar was the trend for soil dehydrogenase activity and SMBC in case of 'Pant Dhan-12' (6.19 µg of TPF/g and 814.8 g/kg of soil, respectively) and mulch (with 6.25 µg of TPF/g and 816.0 g/kg of soil, respectively). After 15 days of sowing of chickpea made by a ZTD, soil moisture depleted faster under local rice habit group in comparison to 'Pant Dhan-12' although chickpea varieties (early high biomass 'Jaki 92-18' *versus* medium high biomass 'DCP 92-3') could not influence the above rate. Enhanced RLWC and SLW, higher nodulation (and BNF) and more chlorophyll content in chickpea leaves, due to extended conservation of soil moisture and temperature, were associated with the above improved practices (factors of superiority) under rice fallow condition (Fig. 20, 21, 22, 23 and 24). Similar trend was also observed in case of suppression of weed growth, improved crop growth, enhanced yield attributes and chickpea yield.

Table 11. Effect of rice cultivar & residue management practices on microbial activity of chickpea

Treatment	SDA (µg of TPF/g)*	SMBC (g/kg)	Treatment	SDA (µg of TPF/g)	SMBC (g/kg)	Treatment	SDA (µg of TPF/g)	SMBC (g/kg)
Rice varieties			***Residue retention***			***Chickpea varieties***		
local (tall)	5.32	791.8	Residue removal	4.89	778.0	Jaki 92-18	6.28	785.7
Pant Dhan12	6.19	814.8	Mulch	6.25	816.0	DCP 92-3	5.24	821.0
			Stubble	6.13	816.0			

*Soil dehydrogenase activity (SDA)

Although variable performance in terms of grain yields were observed in chickpea due to uneven occurrence of winter rains during all three years of study, yet the yields were invariably higher under 'Pant Dhan 12', mulch/residue retention and early high biomass accumulating chickpea 'Jaki 92-18' following rice-chickpea rotation under conservation tillage (zero tillage).

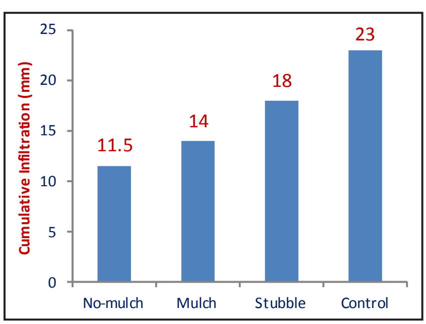


Fig 18. Cumulative infiltration under mulching practices

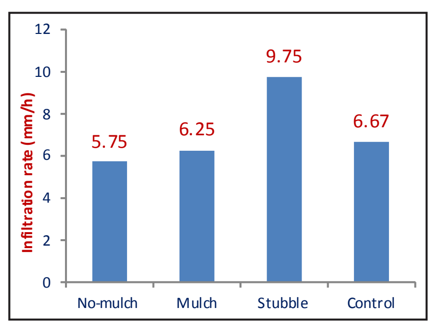


Fig 19. Basic infiltration rate under mulching practices

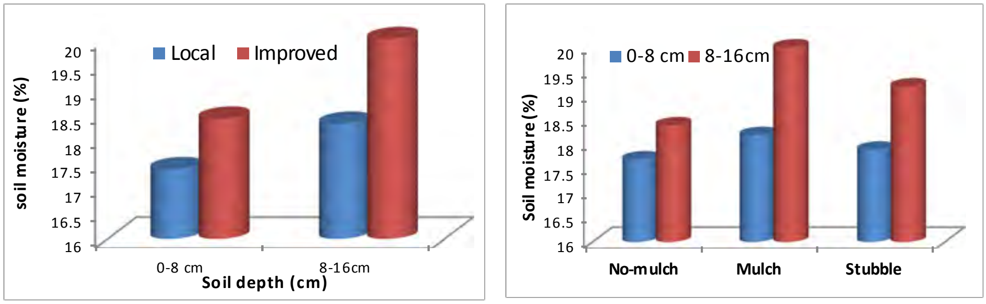


Fig 20. Effect of rice cultivar and residue management practices on initial soil moisture (after 15 DAS of chickpea sowing)

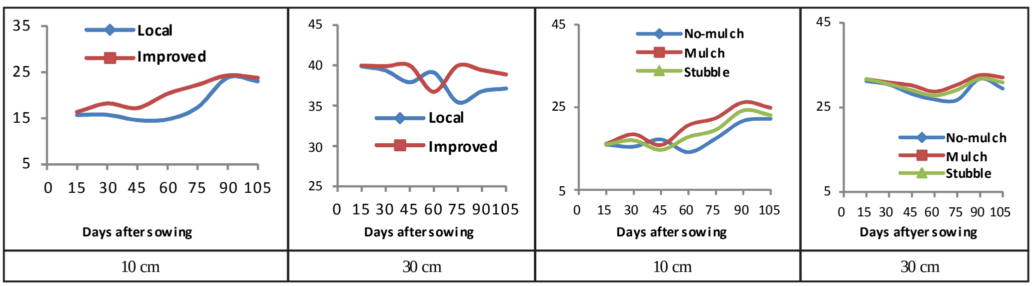


Fig 21. Soil moisture dynamics following application of crop residues in chickpea

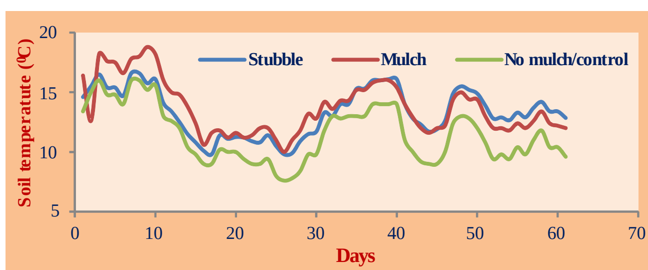


Fig 22. Surface soil temperature under residue management practices (morning 8.0 h) between beginning December to end January

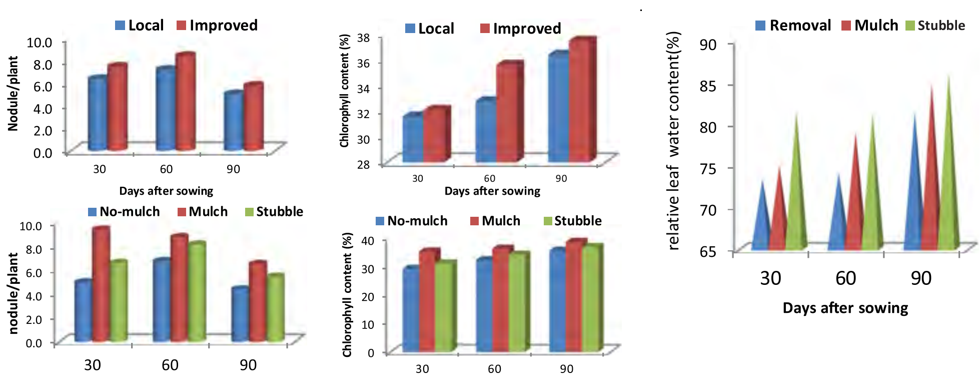


Fig 23. Effect of rice cultivar and residue management practices on nodulation, chlorophyll content and RLWC in chickpea

Residue removal Stubble Mulch Comparison among these

Fig 24. Performance of chickpea under diverse residue management

Rice establishment method

Among three prevailing practices of rice establishment methods such as puddled (PTR) & unpuddled transplanted rice (UPTR or UPR) and direct seeded rice (DSR) under rice - chickpea system in sandy loam soils under RIFAs in Eastern India, UPTR had higher SMC (19.7% v/v at 10 cm depth to 10.7 % at 30 cm) throughout growth cycle of pulse crop although initial SMC at sowing of pulses was similar (18.4-20.0%) for all these rice establishment methods. The trend of SMC throughout chickpea growth season was UPTR>DSR>PTR. On the contrary, at flowering stage, higher soil dehydrogenase activity (3.38 µg of TPF/g), SMBC (883.3 g/kg of soil, respectively), RLWC, nodule number, its dry weight, and ratio of chlorophyll 'a' to 'b' pigments were with UPTR (and is contrary to analysis of carotenoid pigment as it was higher under PTR) (Fig 25 and 26; Table 12 and 13).

Following favorable soil physical condition, higher shoot dry weight was in UPTR at both flowering and pod development stages (46.9 and 63.6%), respectively. Similar was the trend for maximum root length, its dry weight and grain yield.

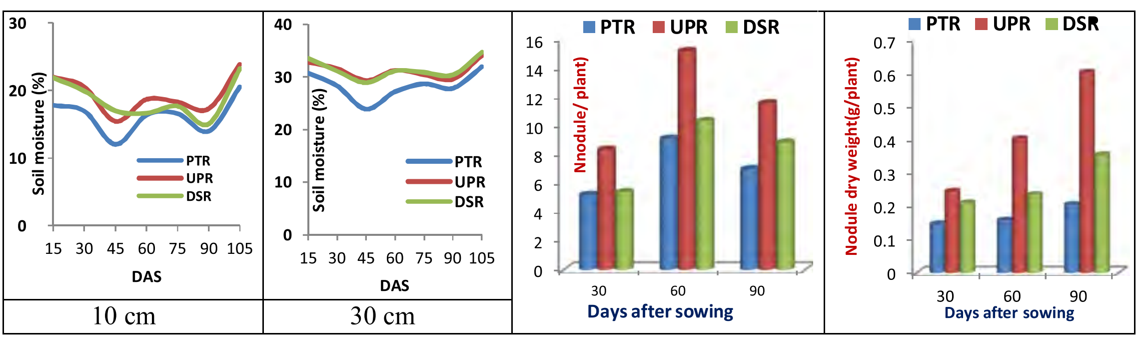


Fig 25. Soil moisture dynamics along with nodule attributes (number and dry weight) under different rice establishment methods

Table 12. Effect of rice cultivation method on soil microbial activity and weed dynamics

Treatments	Soil dehydrogenase activity (µg of TPF/g)	SMBC (g/kg)	Weed density (no./m^2)	Weed dry biomass (g/m^2)
PTR	2.31	853.7	106	13.1
UPTR	3.38	883.3	150	41.6
DSR	3.01	879.3	166	58.4

Table 13. Effect of rice cultivation method on chlorophyll pigments, RLWC and yield of chickpea

Treatments	Chlorophyll a/b content (mg/g FW)	Carotinoids content (mg/g FW)	RLWC (%)			Yield (kg/ha)
			Vegetative	Flowering	Pod development	
PTR	1.678	2.671	73.5	73.6	73.4	1290
UPTR	2.414	1.572	79.4	82.7	81.9	1590
DSR	2.150	1.958	75.9	76.32	79.4	1500
CD (P=0.05)	0.321	0.739	NS	1.9	1.8	90

Direct seeded rice — Unpuddled transplanting — Puddled transplanting

Fig 26. Weed infestation under different rice cultivation methods under rice fallows

INM for soil health improvement

Puddling under flooded condition for rice transplanting has detrimental effect on soil physico-chemical properties. Deterioration in soil structure due to puddling may lead to development of soil hardiness following drying which may sustain over seasons hindering proper root and shoot growth of upland crops like, pulses. For improvement in soil physical properties and overall health, soil conditioner like, FYM or other manures, if available could be immensely useful. Since pulses under RIFAs are mostly sown under zero tillage for which these may not be possible to apply to a rabi crop. Instead, these are needed to be applied to the Kharif crop of rice. The role of manure in combination with nutrients (INM) has also been scientifically established and is well known through improvement in both soil physical and chemical properties. This has been confirmed from lower soil resistances (Fig 27) offered by soil to penetration of roots. NPK at recommended dose + FYM at 5 t/ha also conserved more soil moisture (Fig 28), reduced weed count/density, improved soil microbial activity like, soil dehydrogenase activity (to 8.97µg of TPF/g) and SMBC (to 899.3 g/kg of soil), accelerates crop growth, RLWC, chlorophyll pigment a & b, nodulation and BNF, yield attributes and above all, grain yield

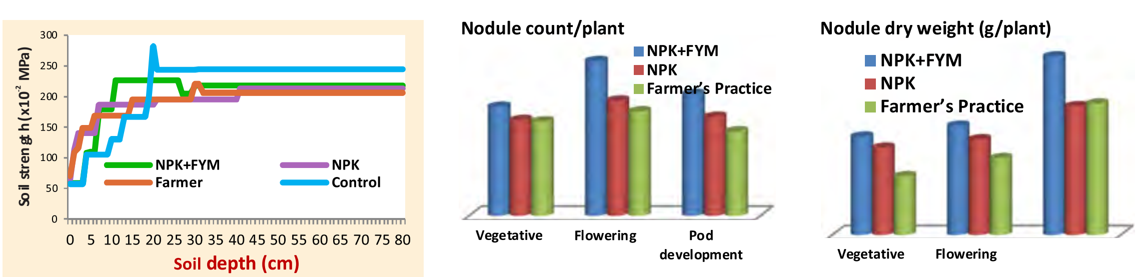
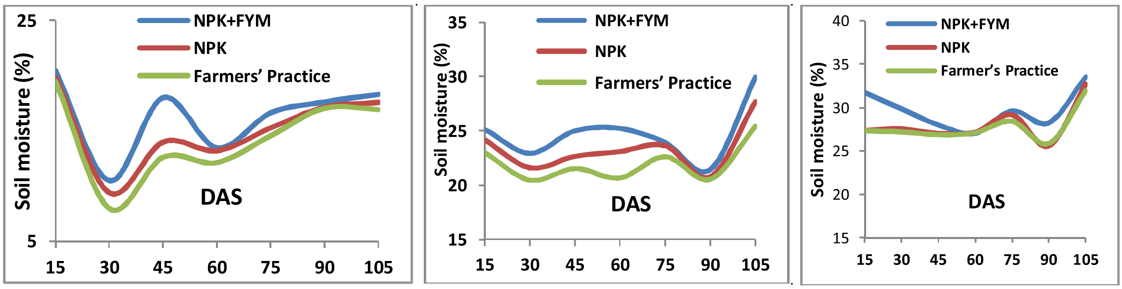


Fig 27. Effect of nutrient management practices on soil strength, nodule count and nodule wt.

over farmer's practice (50% NPK, Table 14 and 15). The improvement in soil properties following INM in RIFAs has also been shown to improve chickpea grain yield (by 57.4%, followed by NPK, 27.4% and farmer's practice). Hence, to counter the negative effect of puddling on soil health, INM could be handy.



10 cm 20 cm 30 cm

Fig 28. Effect of nutrient management practices on soil moisture dynamics in chickpea at 10, 20 and 30 cm soil depth

Table 14. Effect of nutrient management practices on soil dehydrogenase activity and SMBC

Treatment	SDA (µg of TPF/g)		SMBC (µg/g)	
	Pre-sowing	Mid-season	Pre- sowing	Mid- season
NPK+FYM	8.97	7.07	899.3	866.3
NPK	8.16	2.84	871.5	871.8
Farmer's Practice	7.07	2.52	873.3	862.5

Table 15. Effect of nutrient management practices on weed dynamics, RLWC and chickpea yield

Treatments	Weeds density (No./m^2)	Weed DW (g/m^2)	RLWC (%)			Grain Yield (kg/ha)
			15 DAS	30 DAS	45 DAS	
NPK+FYM	29.5	8.75	81.1	83.0	80.2	1450
NPK	37.2	10.32	79.1	80.6	76.0	1174
Farmer's practice	43.1	11.52	75.1	78.7	73.2	921
CD (P=0.05)	-	-	1.0	1.2	3.9	92

ii. Central India (rice - chickpea)

Chickpea is an important rabi crop grown in sequential cropping with kharif rice under RIFAs of Chhattisgarh in Central India. Chickpea is becoming very popular in Central and Southern India replacing many traditional areas in North. Yet, its productivity is low in relation to his potential which calls for application of suitable technological interventions. With the assistance from IGKV, Raipur (Chhattisgarh), newer and improved production practices (including adoption of suitable rice/chickpea varieties with retention of rice stubbles) have been evaluated/assessed for its promotion. These are discussed herein as under:

Rice/chickpea varieties and residue management

Under rice-chickpea rotational system, again medium duration rice 'Swarna' (over long duration and tall rice 'Mahsuri'), early high biomass accumulating chickpea 'JG 130' (against medium high biomass developing 'JG 226') and residue management with mulching (compared to both 30 cm stubble retention and residue removal) showed its superiority over other comparable practices. This was more evident as higher soil moisture was conserved (due to slow down in moisture depletion rate) following above improved technologies (viz., improved variety of both the crops and mulching). Beyond the rooting depth (say, at 40 cm), similar rate of soil moisture depletion was observed between two contrasting plots/treatments. However, after pick winter (towards mid January), the soil moisture depletion rate was again increased abruptly reaching at its maximum under slow growing chickpea 'JG 226' followed after rice 'Mahsuri' especially under residue removal plots. Similar was the trend for cumulative infiltration and total soil moisture storage in one meter soil profile depth (Fig 29).

As a result, maximum population of rhizobium ($8.73 x 10^4$ CFU/g of soil) was counted under chickpea 'JG 130', rice 'Swarna' and mulched plots. Similar trend was also recorded in other microbial parameters, crop physiological attributes (RLWC), SLW, nodule count and its dry weight. Contrarily, weed density was more under rice 'Mahsuri', residue removal and chickpea 'JG 226' (Table 16 & 17). All this favourable factors caused significant influence on yield attributes resulting in highest yield of chickpea (1793 kg/ha) in 'JG 130' with mulch that followed after rice 'Swarna'. Therefore, under RIFAs of central India, short duration rice variety could be a boon in the popular rice-chickpea system. When it is integrated with soil moisture conservation practices like, application of rice residues mulch or retaining 30 cm rice stubbles, chickpea performed the best.

Table 16. Effect of rice and chickpea varieties, and residue management on microbial activity of chickpea

Treatments	*Rhizobium* (10^4 CFU/g of soil)	PSB (10^5 CFU/g of soil)	Dizotrophs (10^5 CFU/g of soil)	Dehydrogenage activity (µg TPF/soil/day)
Rice varieties				
Mahsuri	7.93	4.49	2.52	75.14
Swarna	8.04	4.56	2.55	75.69
Residue management				
Stubble	7.9	4.5	2.47	75.15
Mulch	8.3	4.52	2.63	77.07
Residue removal	7.84	4.45	2.50	74.01
Chickpea varieties				
JG 130	8.07	4.59	2.59	75.88
JG 226	7.90	4.47	2.48	74.96

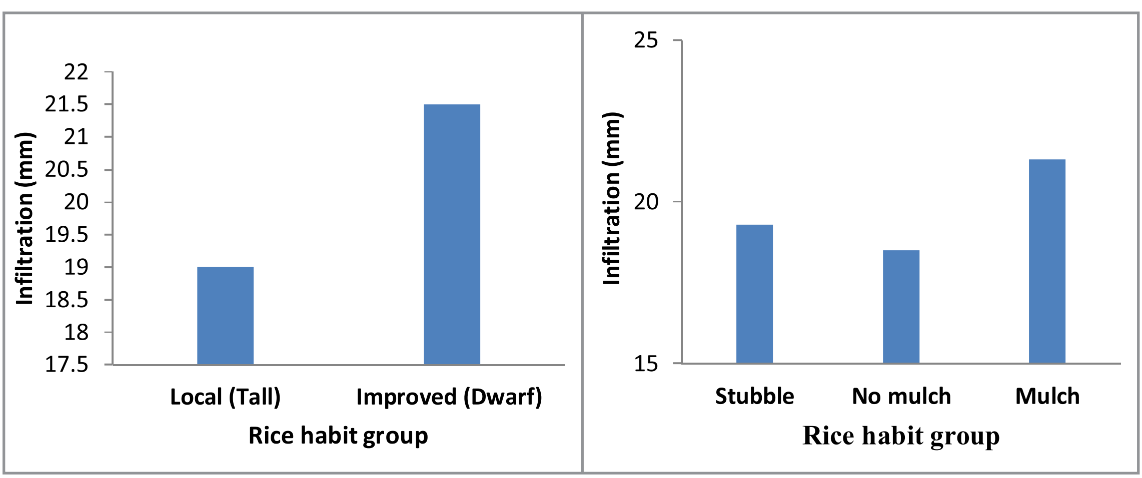


Fig 29. Effect of rice varieties and residue management on cumulative infiltration (mm) in chickpea

Table 17. Effect of rice and chickpea varieties and residue management on chickpea nodulation and RLWC

Treatments	Plant density (No./m^2)	Nodule/ plant	Dry weight of nodule (mg/plant)	RLWC (%)		
				30DAS	60DAS	90DAS
Rice varieties						
Mahsuri	33	26	0.05	69.50	68.51	67.50
Swarna	34	27	0.05	68.63	68.06	67.00
Residue management varieties						
Stubble	35	26	0.045	67.94	67.42	67.47
Mulch	37	29	0.06	71.63	70.89	69.88
Residue removal	33	25	0.045	67.62	66.53	65.30
Chickpea varieties						
JG 130	35	27	0.048	69.14	68.33	67.29
JG 226	34	27	0.051	69.00	68.24	67.20

Table 18. Effect of rice cultivar and residue management practices on root study and weed control treatment

Treatments	Root volume (cm^{3}x10^{-3})	Root: shoot ratio	Weed density (No./m^2)	Weed DW (g/m^2)	Pod per plant	Yield (kg/ha)
Mahsuri	9.84	0.56	28.5	12.74	50	1302
Swarna	10.09	0.59	24.8	10.12	51	1283
Stubble	9.82	0.56	25	11.02	51	1308
Mulch	10.23	0.58	24	9.85	60	1470
Residue removal	9.84	0.59	30	13.2	41	1100
JG 130	10.04	0.57	26.5	11.58	54	1389
JG 226	9.9	0.57	26.8	11.82	47	1197

Rice establishment method

Following common intervention of zero tillage and 30 cm rice stubble retention in a rice 'Swarna' - chickpea 'JG 130' sequential cropping, puddled transplanted rice (PTR) showed its superiority. This has been confirmed among diverse rice establishment methods (viz., puddled transplanted rice, PTR, unpuddled transplanted rice, UPTR and direct seeded rice, DSR) tested at the location under RIFAs. PTR established its edge by maintaining higher SMC (over other methods, Fig 30) and WUE (5.1 kg/ha/mm) throughout crop season of chickpea, nodulation (and soil microbial population especially rhizobium and dehydrogenase activities), RLWC, SLW and chlorophyll content despite higher crack volume (56.03 m^3/m^2 x10^{-4}). This also resulted in significantly higher plant growth and development inclusive of yield attributes under the treatments or plots. Consequently, highest grain yield of chickpea was under PTR (1891 kg/ha, followed by UPTR and DSR).

On the contrary, the maximum soil strength measured by a penetrologger at different soil depth along with highest bulk density (1.34Mg/ m^3) and a minimum infiltration rate were observed under UPTR (followed by PTR and DSR). Obviously, because of higher infiltration rate with lower bulk density, significantly higher root length (38.5cm), root volume (10.4cm^{3}x10^{-3}), root shoot ratio (0.58) and dry root weight (2.4 gm) was observed under DSR (followed by PTR and UPTR) (Table 19). This also resulted in higher weed population (26 m^2) and weed dry weight (6.97 g/m2) under it (DSR followed by UPR and PTR). Therefore, puddled transplanted rice could be advantageous in case of *Vertisol* in RIFAs of central India where rice-chickpea is the dominant cropping system (Table 19, 20 and 21).

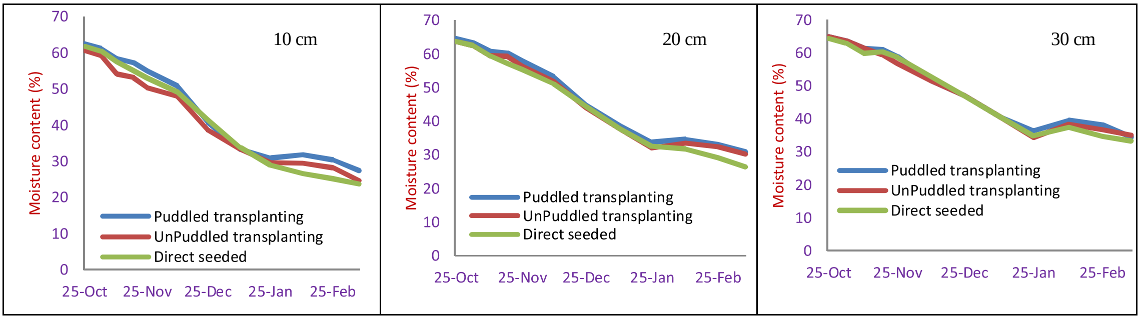


Fig 30. Soil Moisture depletion pattern in different rice establishment methods at 10, 20 and 30 cm depth

Table 19. Soil Strength (kN) at rice harvesting under different rice establishment methods

Treatment	Soil Strength (kN)		Bulk density (Mg/m^3)		Infiltration rate (mm/hr)	Cumulative infiltration (mm)	WUE (kg/ha/mm)	RLWC (%)
	10cm	30 cm	10 cm	20 cm				60 DAS
PTR	0.12	0.11	1.34	1.39	26	206	5.1	69.7
UPTR	0.15	0.15	1.34	1.40	23	186	4.6	67.5
DSR	0.08	0.09	1.31	1.37	32	259	4.2	67.2
CD(P=0.05)	0.011	0.016	0.01	0.02	1.294	10.33	0.26	1.47

Table 20. Physiological parameters under different rice establishment methods

Treatment	SLW (g/cm^2)		Root volume (cm^{3}x10^{-3})	Chlorophyll content (mg/g FW)	Nodules/ plant	Nodule dry wt./ plant (mg)	Yield (kg/ha)
	30 DAS	60 DAS			45 DAS		
PTR	0.057	0.074	10.0	1.66	16	7.38	1891
UPTR	0.050	0.061	9.8	1.46	14	6.74	1800
DSR	0.047	0.065	10.4	1.43	14	6.65	1740
CD (P=0.05)	0.006	0.006	0.307	0.15	NS	NS	NS

FW: Fresh weight

Table 21. Rhizobium population under rice establishment methods and different management practices

Treatment	Rhizobium (10^4 CFU/g of soil)		Dehydrogenase activity (µg TPF/soil)	
	At sowing	At flowering	At sowing	At flowering
PTR	7.54	7.79	72.15	74.52
UPTR	7.33	7.58	69.42	71.79
DSR	7.13	7.38	67.73	70.10
CD (P=0.05)	0.171	0.172	0.07	0.040

iii. Eastern India (rice - lentil)

Rice residue management

Whether it is grown as a component of rice based relay cropping system or sequential cropping system, lentil dominates in RIFAs of West Bengal. Raising a successful crop in the later case under rice fallows is a challenge as the residual availability of moisture further diminishes in comparison to the former. However, it is manageable through *in-situ* conservation of residual soil moisture following conservation agriculture (CA, Resource conservation through zero tillage with residue retention). In fact, all the three principles of CA are used here. The rice residues can be kept on soil surface as mulch or can be cut at 20 cm height to retain the standing stubbles *in situ*. Lentil sowing is thus, possible by a Zero Till Drill in these rice fallows where mulch/stubble already exists. Here is the need for improved production technologies matching this agro-ecosystem. The technological interventions concerning this rice-lentil sequential system were assessed and refined with the support from BCKV, Kalyani (West Bengal) which could lead to further popularization of above cropping system. These are discussed herein as under:

As in case of refined agro-technologies (through suitable rice establishment method, retention of rice residues and adoption of improved variety of rice/pulses) mentioned in case of relay system, here also the importance of these especially that of soil cover has been established. Thus, SMC under mulch and stubble plots were greater than that in residue removal plots at all the crop growth stages in lentil. The study showed that rice residue mulch conserved around 8.5 % higher soil moisture compared to residue removal at surface depth. Conservation tillage therefore, plays a key role in altering soil moisture and the order of decreasing soil moisture storage was in order as: mulch>stubble>residue removal (Fig 31). Even during flower initiation, the rate of soil moisture depletion was more with residue removal and less in mulch. Similarly, penetration resistance measured through a penetrologger to simulate the degree of resistance offered by soil to the root growth underneath increased with crop age and reached a maximum of <0.85 MPa during pod formation stage which occurred at around 100 DAS, and was invariably of lower order following straw mulch. A combination of zero tillage with straw mulch also showed complementing effect in altering soil temperature which facilitated in maintaining a minimal diurnal variation that helps in root proliferation and nutrient uptake effectively leading to increased crop yield. Soil temperature stability was in increasing order as: residue removal>stubble>mulch.

The RLWC and chlorophyll content also increased up to pod formation stage which followed the decreasing trend as: mulch>stubble>residue removal. Similar trend was also observed in shoot dry biomass of lentil at all stages of crop growth (Fig 32). As a result, mulch and stubble produced 14 and 10% more grain yield; and 23 and 19 per cent more WUE over those in residue removal, respectively. Thus, mulch and stubble (20 cm) have shown advantages over residue removal in conserving residual soil moisture after rice harvest for adequate growth and development in pulses under RIFAs.

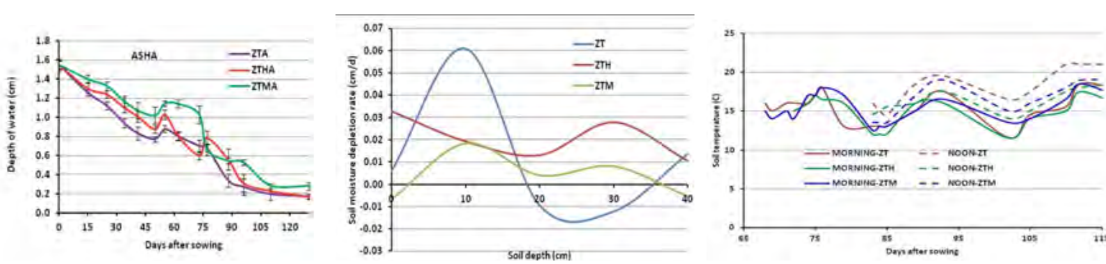


Fig 31. Temporal variation in soil water at soil surface and root zone soil moisture depletion rate during flowering initiation & diurnal soil temperature (ZTA:zero tillage without residue; ZTHA: zero tillage with stubble and ZTMA: Zero tillage with mulch)

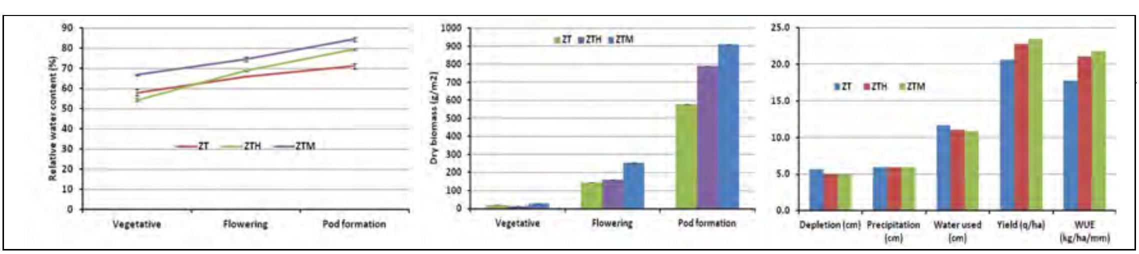


Fig 32. RLWC, shoot dry mass, grain yield and WUE in lentil under diverse residue management

Rice establishment method

While establishing relative efficacy of different rice establishment systems in crop production and its water use under rice-lentil rotation, it was observed that spatial and temporal distribution of soil moisture decreased with increasing depth and time for both DSR and PTR although both have the same SMC (29 - 33%) in surface soil (0-15cm). The rate of soil moisture depletion got faster around 45 DAS to maturity under both rice establishment methods (DSR and PTR); and the temporal SMC decreased from 33% to <10% (at maturity). Yet, transplanted puddled rice (PTR) plots had higher SWC as compared to DSR (Fig 33). At the time of lentil sowing, lower bulk density (0-15 cm) and more soil pore space were also observed under PTR. Thus, Plant physiological parameters like, RLWC, chlorophyll content and leaf area index (LAI), higher grain yield of lentil was realized under PTR (by 14 per cent over DSR) although higher soil penetration resistance and more crack volumes were apparent with PTR plots (compared to DSR plots).

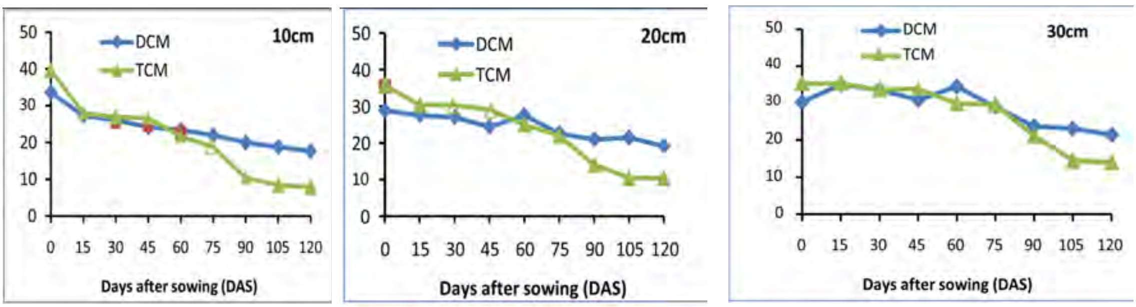


Fig 33. Temporal changes in soil moisture distribution (% v/v) up to 30cm depth in lentil plots; DCM: Direct seeded rice, TCM: Puddled transplanted rice.

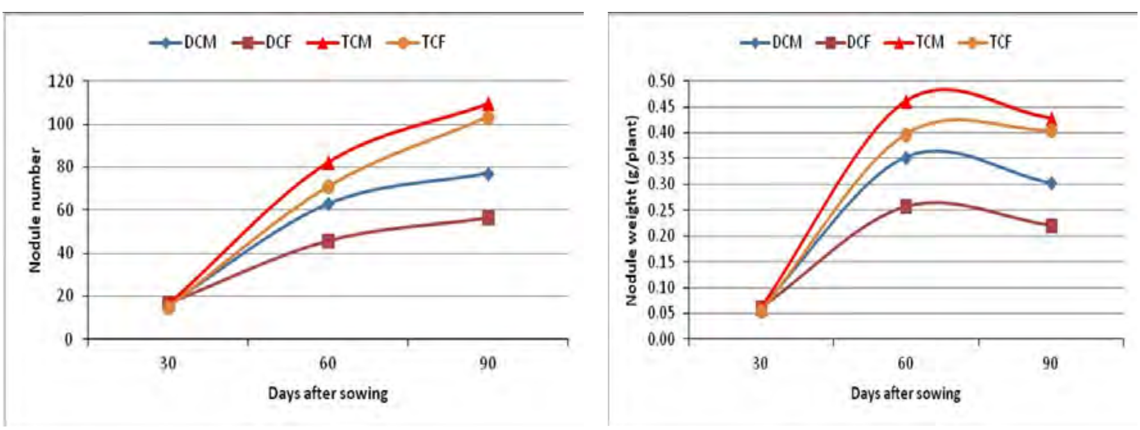


Fig 34. Nodules number and dry weight under rice cultivation method, DCM: Direct seeded rice, TCM: Puddled transplanted rice; DCF: Direct seeded rice (Farmers' practice), TCF: Puddled transplanted rice (Farmers' practice)

Due to higher SMC, soil microbial population, SMBC and dehydrogenase activity were increased from initial in both PTR and DSR (Table 22). However, these values were higher in DSR over that in PTR. On the whole, lentil under zero tillage followed after puddled transplanted rice (rice - lentil sequential system) could be the viable option in RIFAs of West Bengal.

Table 22. Microbial population, SMBC and dehydrogenase activities following different mode of rice establishment method at lentil harvest

Microbial parameter	Initial values at lentil sowing	Rice establishment method	
		Puddle transplanted	Direct seeded rice
Diazotrophs (×10^3 cfu)	1.0	3.8	32
Rhizobium (×10^3 cfu)	21	550	920
PSB (×10^3 cfu)	0.9	11	33
MBC (μg g^{-1})	136	255	233
Dehydrogenase activity (μg TPF/g/d)	93	267	254

iv. Northeast Region (rice - lentil)

Two contrasting situations were prevalent at NEH region especially under rice fallow region *viz.*, upland and lowland condition. Both have different agro-ecologies and other unique characteristic features that affect growth and development of crop, and completion of their life cycle. Accordingly, applicable agro-technologies differ. These have been evaluated and refined for optimum crop production and sustainability of the system with the help of ICAR RC NEH, Umiam (Meghalaya). These are discussed as under:

Upland situation

Under upland situation, mulch and stubble play a dominant role in conserving soil moisture and improving productivity of lentil in the upland environment of NE hilly region of India (Fig 35, 36 and 37). Lentil 'DPL 62' also performed well under the location. This was due to suitability of the variety for the location, its physiological attributes (RLWC and chlorophyll content), plant growth parameters, yield and its attributes (pods/plant, grain and straw yield). Similar trend was obtained with mulch (Table 23). An important feature in the upland situation in NEH region was the superior performance of lentil after long duration local rice 'Kbalum' (compared to short duration high yielding 'IURON 514').

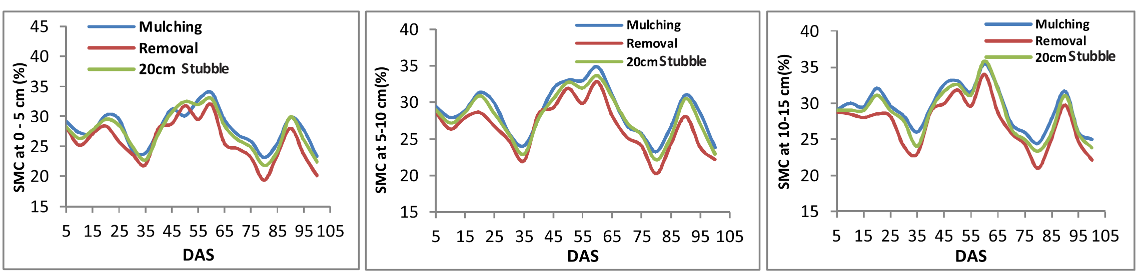


Fig 35. Soil moisture content under rice residue management in upland condition

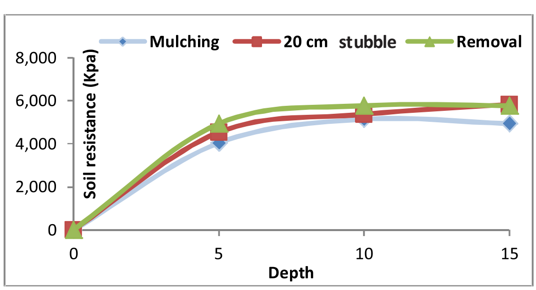


Fig 36. Soil resistance at flowering stage under rice residue management in upland condition

Residue removal Stubble (20 cm) Mulch

Fig 37. Performance of lentil under different residue management practices under upland situation

Table 23. Effect of different crop variety and rice residue management practices on RLWC in lentil

Treatment	RLWC (%)			Pods/ plant	Seeds/ pod	Grain yield (t/ha)	Stover yield (t/ha)
	30 DAS	60 DAS	90 DAS				
Rice variety							
IURON 514	71.2	66.7	59.9	16.18	1.32	0.50	0.77
Kbalum	72.2	65.2	63.0	20.35	1.33	0.64	1.05
CD (P=0.05)	NS	NS	2.9	3.92	NS	0.10	0.13
Lentil variety							
DPL 62	73.1	66.7	62.2	20.42	1.30	0.65	0.97
DPL 15	70.3	65.2	60.8	16.11	1.35	0.49	0.85
CD (P=0.05)	1.5	1.9	NS	3.92	NS	0.10	NS
Residue management practice							
Mulch	76.7	72.0	67.1	26.31	1.54	0.79	1.15
Stubble (20cm)	73.4	66.7	63.5	20.45	1.46	0.64	0.99
Residue removal	72.3	64.2	61.5	15.80	1.30	0.50	0.88
CD (P=0.05)	2.2	2.8	4.2	5.55	0.25	0.14	0.18

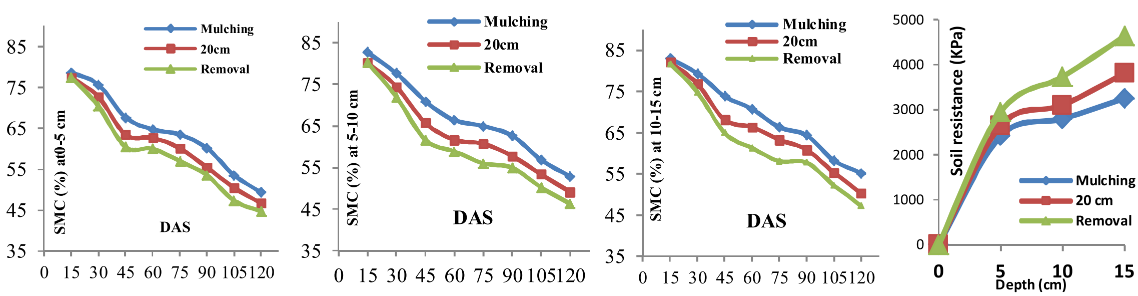


Fig 38. SMC and soil resistance in lowland lentil under rice residue management

Fig 39. A field view of the experiment with tall & short varieties under lowland condition (90DAS)

Lowland situation

Under lowland situation in RIFAs of Northeast Region, early high biomass lentil DPL 81' (compared to medium high biomass 'IPL 406') and mulch of rice residue or 20 cm stubble retention had performed consistently well over the years. This was confirmed from availability of soil moisture in the profile (slow *versus* rapid depletion rate) under the above agro-techniques (Fig 38 and 39). As a result, soil resistance was minimum in case of mulch followed by stubble and residue removal. Higher yield of lentils following 'medium duaration rice 'Shahsarang 1' (over long duration local variety 'Mendri') resulted in higher grain yield and yield attributes in lentil (Fig 40 and Table 24).

Residue removal — Stubble (20 cm) — Mulch

Fig 40. Performance of lentil under different residue management practices under lowland situation

Table 24. Yield and its attributes in lentil under crop varieties and residue management in lowland condition

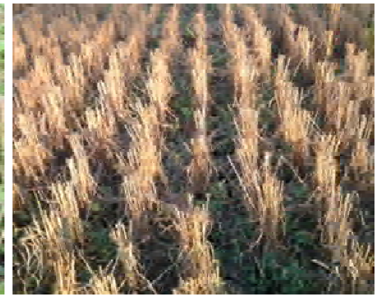
Treatments	Pods/ plant	Seeds/ pod	1000-seeds weight (g)	Seed yield (t/ha)	Stover yield (t/ha)
Rice variety					
Shahsarang 1	53.96	1.50	25.77	1.52	3.10
Mendri	46.63	1.43	26.35	1.39	2.97
CD (P=0.05)	4.85	NS	NS	0.09	0.13
Lentil variety					
DPL 81	52.80	1.61	21.03	1.50	3.07
IPL 406	47.78	1.32	31.09	1.41	3.00
CD (P=0.05)	4.85	0.18	0.87	0.09	NS
Residue management practice					
Mulch	60.53	1.58	26.78	1.59	3.18
Stubble (20cm)	50.92	1.43	25.92	1.46	3.07
Residue removal	39.43	1.38	25.47	1.32	2.85
CD (P=0.05)	5.94	NS	NS	0.11	0.16

C. Common interventions

Rice ratoon management

Ratooning of rice is a major problem in almost all rice fallow regions. Re-growth of rice stubble starts just after harvest of rice and within a week, new narrow leaves emerge out from the apparently dry rice stubbles. It is due to higher soil moisture availability at the soil surface that also contributes loss of soil moisture through transpiration by ratoons resulting in faster rate of soil moisture depletion. This may cause up to 25% loss in total water from the rice fallow system. Under relay cropping of rice + urdbean, however, preemergence herbicide application may not be feasible. Therefore, post-emergence herbicide 'Quizalofop-ethyl' at 100g/ha - a grass killer- could be a viable option for early season control of rice rations (Fig. 41). Other non-selective herbicide *viz.*, glyphosate 1.0 kg/ha applied either before or after sowing of pulses under zero tillage through seed drill could be another option under rice-pulse sequential cropping. Besides this, some of the rice varieties like, 'IET 4786' with no or minimal ratooning habit could also be helpful in containing rationing in rice under RIFAs (Fig. 41).

Quizolofop ethyl 100 g/ha



'IET 4786' with least ratoon

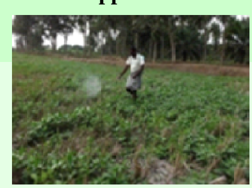
Fig 41. Management of rice ratoons in rice fallows

Foliar nutrition

Deficit in soil moisture at flowering and pod development stages is most commonly observed in pulses under rice fallows that limits the flow of nutrients and water from soil to leaves and foods from source to sink. Under such a stress situation, foliar nutrition with 2% urea/DAP and micronutrients (Fe, Zn, Mo and B) may alleviate the soil moisture stress up to some extent.

In urdbean, foliar application of micronutrients and urea (2%) could be beneficial in term of nodulation and BNF (Table 25). Higher values of RLWC and SLW and chlorophyll content at flowering and pod development stages were also observed following foliar nutrition of 2% urea. Further studies, on foliar application of 2% urea combined with micronutrients at flowering and early pod development stage, had shown great promise. These nutrients have also shown to enhance micronutrient content seed (bio-fertification).

Table 25. Effect of foliar nutrition in urdbean on grain yield and its yield attributes

Treatment	Plant population/m^2	Plant height(cm)	Pods/ plant	Seeds / pod	100-seed weight (g)	Yield (kg/ha)	Foliar supplementation
Control	24.0	26.08	24	6.06	4.62	519	
Foliar nutrition	27.0	27.70	27	6.42	4.71	634	
CD(P=0.05)	0.31	0.17	0.17	0.04	0.11	55	

Life saving irrigation

Soil moisture deficit and the stress associated with it is solely responsible for instability in yield performances in many post-rice crops (including pulses) as it happens to be usually observed at different crop stages in variable intensities in RIFAs. Sometimes severe soil moisture stress leads to complete failure of pulse crop under rainfed rice fallows. Under such a situation, life saving irrigation once during a critical stage could not only save the crop but also enable farmers to harvest some yield following completion of life cycle of the crop. Here comes the role of on-farm water harvesting through community ponds or village ponds so as to facilitate in life-saving/supplementary irrigation to crops (through a mobile irrigation system). Thus, the water economy can further be scaled up through micro-irrigation (sprinkler/drip). Improvement in plant growth parameters and yield of pulse crops (20-35%) was recorded with single application of life saving irrigation given at flowering or pod development stage under both rice + pulse relay cropping and rice – pulse sequential cropping system in RIFAs (Fig. 42).

Fig. 42 Onfarm water harvesting pond for life saving irrigation

Chapter 5

Conclusion and recommendations

The projected pulse requirement for the year 2030 is 32.0 million tonnes with an anticipated growth rate of 4.2 per cent. On a short-term, we need around 22 million tonnes for 2020. To meet out the growing demand of pulses in the country, at least 50% of the RIFAs needs to be cultivated for pulses. However, realization of potential productivity in pulses especially under rainfed RIFAs is a major concern which may be attributed to many intricate factors right from seed availability of improved variety to traditional method of cultivation (surface seeding and without any input) without matching agro- technologies. The research evidences suggest that pulses productivity in RIFAs can be accelerated through use of improved technologies holistically, be it related to production, protection or post-harvest. The adoption of viable agro-technologies like, seed priming, seeding techniques, foliar nutrition, rice cultivation methods and nutrient management practices discussed in the previous sections have shown their advantages in enhancing pulses productivity in RIFAs of different agroecologies. For example, a simple modification in seed broadcasting at 4-6 days in lieu of 10-15 days prior to harvest helps in reducing the damage to growing embryos by combine harvesters. Similarly, soil moisture conservation through rice residue mulch and stubble (20-30 cm) helps in conserving residual soil moisture for longer period. Thus, conservation tillage involving zero tillage + residue on soil surface may be a better option for growing pulses under rice fallows. Delayed sowing of pulses under rice fallows is another major constraint. Therefore, cultivation of medium duration rice needs to be promoted in the rice fallows for timely planting of pulses after rice harvest for maximizing the use of residual soil moisture. Integrated nutrient management and alteration in rice establishment method from puddled transplanting to unpuddled translating or direct seeding are very pertinent to have their impact on improving soil physical properties (with water and farm economy) for better development of roots and nodulation in pulse crops under hostile environment of rice fallow. *Thus, by increasing area and productivity of pulses in rice fallows with situation specific appropriate package technology may usher in another green revolution in the backward, poverty-ridden and deprived region of the country.*

Recommendations

There are two specific situations exist in RIFAs in which pulses can be accommodated. This includes rice + pulse relay cropping and rice - pulse sequential cropping. Based on research carried out in our five years of multilocations research, the following agro-technological recommendations have been emerged keeping in view different agro-ecological situations in RIFAs of the country.

i. Rice + Pulse relay cropping

- Planting pulses 4-6 days before harvest of rice to minimize the seedling damage during rice harvest.
- Seed priming (soaking seeds in water or micro-nutrients solution for 4-6 hrs) to enhance initial plant vigour and development.
- Seed treatment with appropriate stains of *Rhizobium* and PSB to enhance nodulation and mobilization of nutrients in soil.
- Harvesting of rice 20-30 cm above ground to maintain stubble in the field to minimize the soil moisture loss through evaporation and improve soil physical and microbial properties.

- Application of quizalofop-ethyl at 100 g/ha as early post-emergence to control rice ratoons and grassy weeds in rice fallow pulses. Minimum or non-ratooning rice variety like 'IET 4786' can also be preferred.
- Foliar application of 2% urea or DAP and micronutrients, 1st at 50 per cent flowering and 2nd at 10-15 days thereafter to mitigate the effect of soil moisture stress at reproductive stage.
- Based on soil type and climatic condition, rice cultivation such as unpuddled transplanting and direct seeded rice can be encouraged and adopted as per specific situation.
- Flooding in any case is to be avoided so as to have enhanced water and farm economy.

ii. Rice-Pulse cropping sequential

- Pulses after rice harvest should be sown in appropriate soil moisture by zero tillage (ZTD or other suitable equipments) to conserve residual soil moisture.
- Suitable mid-duration rice varieties (130 $\pm$ 5 days) should be grown so that pulses can be sown timely under rainfed rice fallows for better utilization of residual soil moisture. Early vigour short duration and disease resistant varieties of pulses should be used under rice fallows.
- Paired row planting of pulses can be followed for better utilization of available resources, irrigation economy (in case of micro-irrigation) and higher yield (5-10%).
- Pulses seeds should be treated with appropriate *Rhizobium* belonging to specific cross inoculation group and PSB to enhance nodulation and mobilization of nutrients in soil.
- Soil surface should also be covered either with rice residue mulch or stubble (20-30 cm) to conserve soil moisture and enhance soil microbial activities by maintaining soil temperature.
- In addition to scientific method of rice-ratoon management, non-selective herbicide like, glyphosate 1.0 kg/ha (or suitable varietal interventions) can be used either before or after sowing of pulses.
- Foliar application of 2% urea or DAP, 1st at 50 per cent flowering and 2nd 10-15 days after to mitigate the effect of soil moisture stress at reproductive stage.
- For improvement of soil physical conditions and increasing water economy, rice cultivation methods like unpuddled transplanting and direct seeded rice can be practiced and promoted under rice fallows. *Flooding in any case is to be avoided*.
- Recommended fertilizers along with FYM at 5 t/ha (INM) can be applied to rice crop for improvement of soil physical-chemical properties which can help proper root development and nodulation in pulses under rice fallows.

Potential varieties of pulses suitable for rice fallows

Crop	State	Variety
Chickpea	Uttar Pradesh, Bihar, West Bengal	GCP 105, Pusa 372, JG 14, Rajas, Pant G 186, Pusa 547
	Chhattisgarh and Madhya Pradesh	Rajas, JG 14, JG 130
Urdbean	Odisha, Tamil Nadu, Andhra Pradesh, Karnataka	LBG 752, Pant U 31, LBG 402, LBG 709
Lentil	West Bengal, Assam, Bihar, Uttar Pradesh, Jharkhand	HUL 57, KLS 218, Narandra Masoor 1, WBL 58
	Chhattisgarh, Madhya Pradesh	JL 3, IPL 81
Lathyrus	Chhattisgarh, Madhya Pradesh, Bihar	Ratan, Prateek, Mahateora

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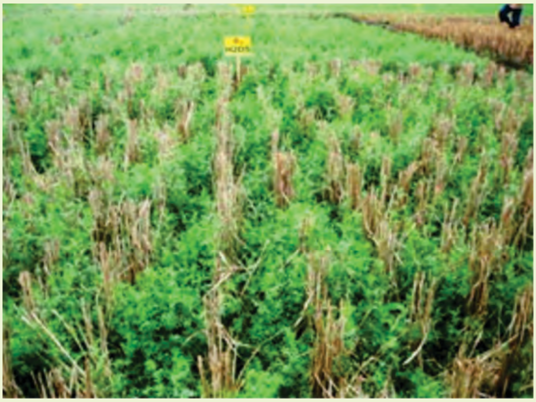
Rice - Chickpea



Rice + Lentil

Rice + Urdbean

Rice + Lathyrus

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