Indian Journal of Agronomy **65** (3): 243–263 (September 2020)

Review Paper

Overview of agronomic research for greening rice (*Oryza sativa*)-fallows during winter in India

BASUDEV. BEHERA[1], S.S. NANDA[2], J.M.L. GULATI[3], B.K. SAHOO[4], A.K. BEHURA[5], A.K. MOHAPATRA[6] AND STUTI DEBAPRIYA BEHERA[7]

Institute of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed) University, Bhubaneswar 751 029, Odisha

Received: July 2020; Revised accepted: September 2020

ABSTRACT

An estimated area of 11.65 million hectare (m ha) accounting for 29% of rainy season (*kharif*) rice (*Oryza sativa* L.) area, remains fallow during the winter season in India. The climate of rice-fallow areas varies from sub-humid to per humid. Short-duration pulses and oilseeds are successfully grown by utilizing residual soil moisture and/or post-monsoon rainfall/ supplemental irrigation. The establishment methods included *utera*, zero-till, reduced-till and conventionally till cropping. An introspection to past research established the importance of system approach for choice of crops and cultivars and management of tillage, nutrient, water and weed. Seed priming of rice-fallow crops ensured better germination and stand establishment under harsh condition. Application of organic nutrient sources (green-manuring, farmyard manure), sulphur (S) and zinc (Zn) has positive direct effect on rice and residual effect on the succeeding crops. Application of nitrogen (N) and phosphorus (P) as diammonium phosphate (DAP) to preceding rice during terminal growth phase and foliar feeding of nutrients were found promising in *utera* cropping. Use of organic/ green-manure in rice, application of basal fertilizer and foliar feeding improved productivity in zero-minimum- and conventionally-till crops. One or two protective irrigations improved productivity of rice fallow pulses and oilseeds in eastern India and coastal peninsula. Quizalofop ethyl (50 g/ha) or imezethapyr (100 g/ha) as post-emergence spray provided satisfactory control of grassy weeds. Location-specific constraint analysis, strategic planning based on research findings and policy support would be helpful in greening more rice-fallow areas with pulses and oilseeds, enhancing domestic production, reducing import and saving foreign exchange. Important policy support needed for greening rice-fallows are discussed in the article.

Key words **:** Agro ecological subregion, Constraints, Crop establishment, Moisture, Nutrient, Policy measures, Seed priming, Weed

Rice-fallow areas (RIFAs) refer to medium and lowlands which remain uncropped during the winter *(rabi)* season due to lack of irrigation*,* cultivation of long-duration varieties of rice, early withdrawal of monsoon rains leading to soil-moisture stress at planting time of the winter crops, late withdrawal of monsoon resulting in waterlogging and excessive moisture in November/ December, lack of appropriate varieties of winter crops for late planting, and socio-economic problems like stray cattle, blue bulls, etc.

The major stumbling blocks for intensifying RIFAs are severe soil-moisture stress, lack of irrigation facility, unfavourable soil properties, lack of suitable variety, lack of mechanization, and poor socio-economic status of the farmers (Ghosh *et al*., 2016). In these lands, there is no scope for growing non-rice crops in the rainy season under standing water condition. Only rice, possessing aerenchymatous tissue, can utilize atmospheric oxygen and tolerate standing water. Such lands provide scope for growing a number of short-duration pulses and oilseeds in the winter after recession of standing water and harvesting of rice. These crops utilize the carry-over soil moisture and post-monsoon rainfall effectively. India is self-sufficient in cereals, but deficient in pulses and oilseeds. Pulses are grown in an area of 29.45 m ha, with production of 23.13 million tonnes (mt) and productivity of 786 kg/ha (GoI, 2019). The projected pulse requirement for the year 2030 is 32 million tonnes (Ali *et al*., 2014). Oilseed crops are grown in an area of 26.18 m ha, with production of 31.28 mt and productivity of 1,195 kg/ha (GoI, 2019). Growing

[1]**Corresponding author's Email**: basudevbehera@soa.ac.in
[3]Professor and Head, [1,2,5,6]Professor, Department of Agronomy, [4]Dean, Institute of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed) University, Bhubaneswar, Odisha 751 029; [7]Ph.D. Scholar, Department of Agronomy, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751 003

population, economic growth and rising disposable income will drive India's vegetable oil consumption growth, which is expected to grow by 3% annually to exceed 34 mt by 2030. Rice-fallows remain fallow in the subsequent *rabi* due to number of biotic, abiotic and socio-economic constraints. About 82% of rice-fallow areas is concentrated in eastern parts of the country comprising states like Chhattisgarh, Madhya Pradesh, Bihar, Jharkhand, West Bengal, Odisha, Assam and eastern Uttar Pradesh and the remaining 18% in the states

like Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and Gujarat. The existing rice-fallow area (11.7 m ha) is almost equivalent to the net sown area of Punjab, Haryana and western Uttar Pradesh the street of green revolution in India (Ali *et al.,* 2014). According to Singh *et al*. (2019), pulses and oilseeds can be grown in additional land of 3 and 1 m ha, respectively, by greening rice-fallows in the winter (*rabi*) season with alleviation of location-specific constraints. Rice-fallow agro-ecosystem is a special area of complex risk-prone and diverse rainfed agriculture belt of India. For successful raising of winter crops in this agro-ecosystem, there is a need for constraint analysis, location-specific recommendations and diagnosing policy issues. An attempt has been made in this paper to review and introspect past works on agronomy of crop raising in this harsh environment and chalk out strategic plan for turning fallows to green lands in winter.

Extent and spread of rice-fallow

India accounts for 79% of the total rice fallows of south Asia (15 m ha). Rice-fallow area in India is equal to 30% of the area under rice production during the rainy (*kharif*) season. As per revised estimate (Gumma *et al.,* 2016), approximately 11.695 m ha of land in India is left fallow during the *rabi* and summer after the *kharif* rice harvesting. This is mostly confined to rainfed rice-production areas. The state-wise rice-fallow area is given in Table 1. Chandana and Mondal (2020) identified about 2.2, 2.0 and 2.1 m ha of RIFAs in Odisha during 2015–16, 2016–17 and 2017–18, respectively, by using multi-temporal Landsat-8 OLI and Sentinel-1 Data. They identified about 1.34 m ha of permanent rice-fallows, whereas the remaining 0.6–0.8 m ha area was under the current-fallow category. About 50% of the total permanent rice-fallows were detected in the rainfed areas of Mayurbhanj, Bhadrak, Bolangir, Sundargarh, Keonjhar, Baleswar, Nawarangpur and Bargarh districts. They suggested using this approach for up-to-date estimation of RIFAs in South and South East Asia including India.

Constraints in rice-fallow areas

Joshi *et al*. (2002) classified constraints of RIFAs as abiotic (water and soil related), biotic, technological, socio-economic, resource based and gap in dissemination of information. Singh *et al*. (2017) have listed various abiotic, biotic crop production and socio-economic constraints that hinder pulse production in RIFAs. Many of the constraints (Table 2) affecting production of both pulses and oilseeds are common to all zones, while some are specific to a few zones.

Climate and soil

Singh *et al*. (2017) classified RIFAs into 3 sub-groups, viz. eastern and north-east region (eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal and north-eastern states), central India (Chhattisgarh, Madhya Pradesh and Maharastra) and coastal peninsula (coastal belt of Andhra Pradesh, Tamil Nadu and Karnataka). The climate varies

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

State	*Kharif*-rice Area (m ha)	*Rabi*-fallow (m ha)	*Rabi*-fallow area as % of *kharif* rice area	% of total *rabi*-fallow area
Andhra Pradesh	2.66	0.31	11.5	2.6
Assam	2.23	0.54	24.1	4.6
Bihar and Jharkhand	5.97	2.20	36.8	18.9
Gujarat	0.47	0.08	17.7	0.7
Karnataka	0.98	0.18	18.5	1.6
Madhya Pradesh and Chattisgarh	5.60	4.38	78.3	37.6
Maharashtra	1.76	0.63	35.7	5.4
Odisha	3.88	1.22	31.4	10.5
Rajasthan	0.21	0.03	11.7	0.2
Tamil Nadu	1.70	0.02	1.2	0.2
Uttar Pradesh	6.26	0.35	5.6	3.0
West Bengal	4.62	1.72	37.2	14.7
Total	40.18	11.65	29.0	100.0

Source: Ali *et al*. (2015), NAAS Policy Paper 64 from subtropical per humid in Assam and Meghalaya, subtropical humid in West Bengal, sub-tropical sub-humid in eastern Uttar Pradesh, tropical sub-humid in Chhattisgarh to tropical moist in Tamil Nadu. The ICAR-National Bureau of Soil Survey and Land-Use Planning (NBSS & LUP), Nagpur, Maharashtra has divided India into 20 agro-ecological regions (AERs) and 60 agro ecological subregions (AESRs) based on soil, crop, climate, physiography and length of growing period (LGP). The eastern India falls under 16 AESRs belonging to 8 AERs (Fig. 1 and Table 3).

Table 2. Constraints in rice-fallow areas (RIFAs) of India

Constraints	Remarks
Abiotic- water related	
Low soil moisture at sowing due to early withdrawal of monsoon	All RIFAs
High soil moisture at sowing due to late withdrawal of monsoon	All RIFAs
Low post monsoon rainfall	RIFAs with unimodal rainfall in *kharif*
Runoff loss in rainy season from rice field and inadequate on-farm water-harvesting structures	All RIFAs
Poor groundwater-resource development and management	All RIFAs
Short-sowing window due to rapid depletion of moisture from the top soil	All RIFAs without Vertisols
Terminal drought	All RIFAs
Abiotic-tmperature related	
Cold injury to warm-season pulses (greengram and blackgram)	All RIFAs
Global warming and high-temperature stress to cool-season pulses and oilseeds (chickpea, lentil, pea, lathyrus, rapeseed and mustard, linseed)	North and North-east India
Abiotic -soil related	
Deterioration of soil physical properties under puddle transplanted rice (PTR)	All RIFAs
Soil cracking	Vertisols
Low organic carbon and poor soil fertility	All RIFAs
Reduced *Rhizobium* activity due to continuous standing water in puddle transplanted rice (PTR)	All RIFAs
Improper land leveling affects germination of *utera* crops (seed rotting due to excess moisture, failure of germination inadequate soil moisture and poor seed soil contact)	All RIFAs
Poor germination in conventionally till crops due to formation of large clods	All RIFAs
Soil acidity	Eastern and North-east India
Soil salinity and alkalinity	Lower and Middle Gangetic Plains
Biotic	
Ratoon rice and escaped weeds in *utera* crops	All *utera* areas
Resurgence of insect pest due to ratoon rice	All RIFAs
Pod-borer (*Helicoverpa*) attack in chickpea	Chhattisgarh, Jharkhand and Madhya Pradesh
YMV in greengram and blackgram	Eastern India, Central India and Coastal peninsula
Wild animals (blue bull and monkey)	All RIFAs
Powdery mildew of greengram and blackgram	Coastal areas due to high humidity
Crop production-related constraints	
Growing of long-duration rice	All RIFAs except coastal peninsula
Non-availability of short-duration varieties of pulses and oilseeds	All RIFAs
Non-availability of varieties resistant to abiotic and biotic stresses	All RIFAs
Poor plant population due to surface seeding and trampling at harvesting	All *utera* areas
Low or no-fertilizer use	All RIFAs
No weed management in rice-fallow crops	All RIFAs
Socio-economic constraints	
Non-availability of labour for sowing and interculture in pulses due to coincidence of harvesting and threshing of rice	All RIFAs
Thin market for pulses and oilseeds, poor storage facility	All RIFAs
Lack of awareness on relevant technologies and poor adoption	All RIFAs
Fluctuating price in pulses and oilseeds	All RIFAs
Stray cattle menace	All RIFAs
Capital for seed, ferilizer and pesticides	All RIFAs
Poor draft power for sowing in limited available time	All RIFAs
Lack of water resources for protective irrigation	All RIFAs

RIFs, Rice-fallow areas

According to Bandyopadhyay *et al.* (2015), among the *rabi*-fallow areas, the maximum area is coming under Alfisols (43%), followed by Inceptisols (39%), Entisols (12%) and Vertisols (6%). Suitable rice-fallow pulses and oilseeds for different AESRs have been given in Table 3. The RIFAs offer ample opportunities for double cropping,

Table 3. Agro-ecological sub-regions (AESR) of eastern India with climate, soil and length of growing period (LGP) and suitable rice fallow crops

AESR	Spread	Climate (rainfall, mm)	Soil	LGP (days)	Suitable crops	Remarks
9.2	Rohilkhand, Avadh and South Bihar Plains	Sub-humid, dry (1,000–1,200)	Alfisols, inceptisol, Entisol,	150–180	Lentil, *Lathyrus*, pea, greengram, blackgram, groundnut (*char* areas)	Singh *et al.* (2017)
11	Moderately to gently sloping Chhattisgarh, western part of Jharkhand	Sub humid, dry moist (1,200–1,600)	Alfisols, inceptisols, Entisols, vertisols	150–180	Chickpea	Kumar *et al.* (2018)
12.1	Garhjat Hills, Dandakaranya and Eastern Ghats	Sub-humid, moist (1,400–1,700)	Alfisols, inceptisols, Entisols, vertisols	180–210	*Lathyrus*, pea, gram, greengram, blackgram	Kar and Kumar (2009)
12.2	Eastern Ghats	Sub-humid, moist (1,200–1,900)	Alfisols, inceptisols, Entisols	180–210	Greengram	GoO (2020)
12.3	Chhotanagpur Plateau and Garhjat hills	Sub-humid, dry (1,200–1,500)	Alfisols, Inceptisols	150–180	Lentil	Kumar *et al.* (2018)
13.1	North Bihar and Avadh Plains	Sub-humid, dry moist (1,200–1,500)	Inceptisols, Entisols	180–210	Gram, lentil, rapeseed and Indian mustard	Kumar *et al.* (2017)
13.2	Foothills of Central Himalayas	Sub humid, moist (1,400–1,500)	Mollisols	180–210	Chickpea	Singh *et al.* (2017)
15.1	Bengal basin and North Bihar Plain	Sub-humid, moist (1,300–1,600)	Alfisols, Inceptisol, Entisols	210–240	Lentil, *Lathyrus*	Gupta and Bhowmick (2005)
15.2	Middle Brahmaputra plain	Humid (1,600–2,000)	Inceptisols	240–270	Greengram, blackgram, rapeseed and Indian mustard	AAU (2015)
15.3	Teesta, lower Brahmaputra plains and Barak Valley	Perhumid (2,000–3,200)	Inceptisols	270–300	Lentil, pea	Routaray (2008), Yadav *et al.* (2017)
15.4	Upper Brahmaputra plains	Perhumid (2,500–3,000)	Inceptisols	>300	Lentil, pea, *Lathyrus*, rapeseed and mustard	AAU (2015)
16.1	Foothills of Eastern Himalayas	Perhumid (2,600–3,000)	Inceptisols	270–300	Rapeseed and Indian mustard, horsegram, pea	Yumnam *et al.* (2011)
16.2	Darjeeling and Sikkim Himalayas	Perhumid (2,500+)	Inceptisols	>300	Lentil, greengram, blackgram	Singh *et al.* (2018)
17.1	Meghalaya Plateau and Nagaland Hills	Perhumid (2500+)	Alfisols	270–300+	Lentil	Singh *et al.* (2017)
18.4	Utkal plains and East Godavari delta	Sub-humid, dry (1,200–1,500)	Inceptisol, Entisols	180–210	Blackgram	GoO(2020)
18.5	Gangetic delta	Sub-humid moist (1,200–1,500)	Inceptisol, Entisols	240–270	Chickpea, lathyrus, lentil, green gram, groundnut, horse gram, *toria*	Singh (2012)

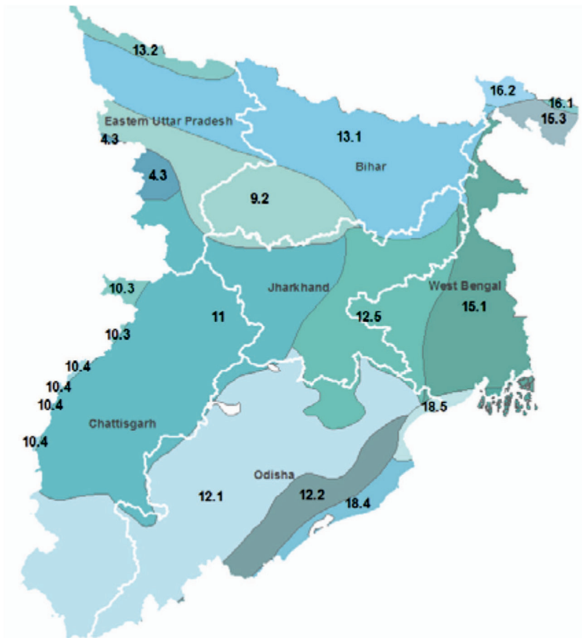

Fig. 1. Map depicting Agro-ecological sub-regions (AESRs) and states of eastern India with rice–fallow areas
Source: Bandyopadhyay *et al*., (2015)

viz. good rainfall in *kharif*, high groundwater recharge for exploitation and the length of growing season spreading from 150–180 days in subhumid dry belt to as high as >300 days in per humid belt. As per the National Agricultural Research Project (NARP), India is divided into 131 agroclimatic zones (ACZs) basing on climatic and soil characteristics. There is a need of constraint analysis for ACZs located in RIFAs and identification of location-specific developmental strategy.

Suitable crops

Majority workers have recommended pulses and oilseeds as the most suitable crops for growing in RIFAs during winter. Kar *et al*. (2008) noted the opportunities for growing post-rainy season crops like groundnut (*Arachis hypogaea* L.), greengram [*Vigna radiate* (L.) R. Wilczek] and blackgram [*V. mungo* (L.) hepper] profitably in rainfed shallow lowland rice-fallow with utilization of residual soil moisture and soil upward flux in Dhenkanal district, located in mid-central table land agroclimatic zone (NARP) of Odisha. Reddy and Reddy (2010) found lentil [*Lens culinaris* Medikus]-based cropping systems as profitable for unexploited rice-fallows in different states under water-deficit conditions. Growing of *rabi* pulses in lowland rice-fallows of the north-eastern plain zone of India is promising to enhance pulse production without the risks of high-input agriculture (Biswas and Bhowmick, 2015). Ali *et al*. (2015) have listed pulses, viz. lentil, lathyrus (*Lathyrus* sp.), chickpea (*Cicer arietinum* L), pea (*Pisum sativum* L.), greeengram blackgram, clusterbean [*Cyamopsis tetragonoloba* (L.) Taubert] and lablab bean [*Lablab purpureus* (L.) Sweet] and oilseeds, viz. Indian mustard [*Brassica juncea* (L.) Czernj.] and groundnut, as potential crops for RIFAs in different states of India in Policy Paper 64 of NAAS. Ghosh *et al*. (2016) found low-input-demanding pulses as the most favoured alternative among the candidate crops, for intensification of rice–fallow production systems. Singh *et al*. (2016) suggested low input and low-water-requiring pulse crops, viz. lentil, chickpea, lathyrus, greengram and blackgram for rice-fallows. Singh *et al*. (2017) reported cultivation of pulses in an area of 0.5 m ha only in rice fallow belt of India as against the feasibility of growing such crops in additional area of 2–3 m ha. Yadav *et al.* (2017) recommended rice–garden pea, rice–field pea and rice–lentil systems for rice-fallow lands of eastern India due to low energy requirement, high energy and system productivity and low global warming potential (GWP). Rice–lentil system had the minimum GWP (7.97 CO_2 eMg/ha year) and GHG Intensity (0.93 kg CO_2 e/kg REY). Rice–maize (*Zea mays* L.) required the maximum energy input to cultivate among rice based systems. According to Reddy and Reddy (2017), 66.25% area is left fallow after harvesting of rice in Telengana having potential for cultivation of millets, pulses and forage crops. Kumar *et al.* (2019a) reported lower N_2O emission with rice–lathyrus, rice–lentil and rice–chickpea systems than rice–Indian mustard and rice–linseed (*Linum usistatissimum* L.) rotations. According to Kumar *et al.* (2019b), short-duration pulses, i.e. chickpea, lentil and lathyrus, and oilseeds, viz. safflower (*Carthamus tinctorius* L.), linseed and Indian mustard, can be grown successfully in rice-fallows with supplemental life-saving irrigation. Maji *et al*. (2019) suggested cool-season food legumes like lentil, chickpea, field pea, and grasspea as promising crops for enhancing productivity and imparting sustainability to rice-fallow systems of eastern India and central plateau. Kumar *et al*. (2020) reported higher productivity of pulses than oilseeds in rice-fallows in an order of chickpea>lentil >safflower >Indian mustard >linseed at Patna, Bihar.

Varietal suitability

The second crop in RIFAs grows in receding soil-moisture conditions. Short-duration varieties should be selected so that they could complete life-cycle successfully by utilizing the available resources. The varieties should have strong, deep and penetrating root-system to tap-water and nutrients under the harsh conditions. They should be resistant/ tolerant to biotic (weed, disease, insect-pest) and abiotic stresses (mostly water scarcity). *Lathyrus* is a promising pulse for RIFAs of West Bengal. Its use is limited due to presence of endogenous neurotoxic nonprotein amino acid β-N-oxalyl-L-α,β-diamino propionic acid or β–ODAP (Xu *et al*., 2017). Gupta and Bhowmick (2005) identified low toxic (< 0.2% neurotoxin) varieties like 'BioL 2012' and 'BioR 202' yielding more than 'LSD 3', 'P 24', 'P 505' and 'Nirmal' for coastal zone of West Bengal. Early flowering, short duration, faster biomass accumulation, deep root-system, high water-use efficiency (WUE) and high root proliferation before onset of terminal drought and heat have been found to be the desired traits in pulses to escape the abiotic stresses (Basu *et al*., 2016). Promising varieties of pulses like greengram, blackgram, lentil, chickpea and pea and oilseeds like groundnut and Indian mustard for RIFAs of India are listed in Table 4.

Crop establishment

Rice-fallow pulses and oilseeds are grown under *utera* cropping system without any tillage operations or sequence cropping by zero-minimum or conventional-tillage. The winter crop depends on residual soil moisture and fertility for growth and development. Singh *et al*. (2016) and Singh *et al*. (2017) have described various cropping systems (*paira,* relay and sequence) for RIFAs. Many workers have reported positive direct effects of green-manure, FYM, chemical nutrients (macro and micro nutrients) applied to rice on rice and residual effects on the succeeding crops in rice-fallow lands. Acid soils should be reclaimed with low-cost liming materials before establishment of rice. Singh *et al.* (2013) reported the maximum grain yield of both rice and the succeeding lentil and extra net return from the system with the application of 30 kg S and 6 kg zn/ha to rice. Kumar *et al*. (2019a) reported the trend in energy-use efficiency as *utera* system > zero-tillage > zero-tillage + mulch.

Utera *cropping*

Crop establishment by sowing seeds before harvesting of rice without any tillage operations is known as *paira* or *utera* cropping. Some promising *utera* cropping systems popular in RIFAs along with constraints and interventions to improve performance are given in Table 5.

*Management of pre-*utera *rice*

There is 10–15 days coincidence in life-cycle of pre-*paira* rice and *paira* pulse. Success of both crops depends on adoption of system approach in management. It includes use of medium duration 130–145 days rice varieties

Table 4. Agro-ecosystem and statewise suitable crops and varieties of pulses and oilseeds for rice-fallow areas (RIFAs)

RIFA Sub group	State	Suitable rice-fallow crops(varieties)	Reference
Eastern and North-east India	Eastern Uttar Pradesh	Mustard ('Parasmani-8')	Singh *et al.* (2014)
	Bihar	Lentil ('Pusa Vaibhav', 'Mallika')	Singh *et al.* (2015)
		Lentil ('L 4076')	Singh *et al.* (2018)
	Jharkhand	Lentil ('HUL 57', 'KLS 218', 'Arun', 'DPL 62', 'Vaibhav')	Kumar *et al*. (2018)
	Odisha	Greengram ('K 851'), blackgram ('T 9'), groundnut ('TMV 2')	Kar *et al*. (2008)
	West Bengal	Lentil ('L 6-23', 'B 256' or 'Ranjan'), Lathyrus ('Kh 03')	Gupta and Bhowmick, (2005), Bhowmick *et al.* (2010)
	North Eastern states	Pole type pea ('Arkel', 'VL 42' and 'MUD P 15'), dwarf pea ('IPFD 4-6', and 'IPFD 99-13')	Das *et al.* (2017)
		Lentil ('RL-12-171', 'L 112-7', 'ILL 10951')	Yadav *et al.* (2015)
		Lentil ('DPL 81', 'IPL 406' and 'DPL 62')	Layek *et al.* (2014)
Central India	Chhattisgarh	Chickpea ('GCP 105', 'Pusa 372', 'JG 11', 'JG 14', 'JG 11', 'Pant G 186', 'Rajas','Pusa 547', 'Pusa 256', and 'Vaibhav')	Kumar *et al*. (2018)
Coastal peninsula	Andhra Pradesh	Greengram ('LGG 460', 'TM 96-2', 'LGG 410', 'LGG 407')	Rao *et al*. (2015)
	Telangana	Blackgram ('LBG 17', 'LBG 602', 'LBG 623', 'LBG-402', 'LBG-611','LBG-22', 'LBG-648', 'LBG-685','LBG-645', 'LBG-709' and 'LBG-752'); Greengram ('Pusa 9072', 'NARM-1','NARM -2','NARM -18', 'LGG-460', 'LGG-410', 'LGG-450','LGG-407' and 'IM 96-3'); Groundnut ('Kadiri 4', 'Kadiri 6','TAG 24', 'Greshma', 'Rohini', 'Tripura 4' and 'Narayani')	Reddy and Reddy (2017)
	Tamil Nadu	Blackgram ('ADT 3')	Ramesh and Rathika (2015)
		Horsegram ('CRIDA 18R')	Vijayakumar and Jalaluddin (2016), Hanif *et al.* (2017)
	Karnataka	Blackgram ('TAU 1')	Shashikumar *et al.* (2013)

Table 5. *Utera* cropping systems for rice-fallow areas in India

Situation and cropping system	Constraints	Interventions
West Bengal (Eastern India) Rice + lentil	Higher soil-crack volume under puddled transplanted rice (PTR), moisture deficit to lentil due to tall and long-duration rice + medium duration lentil ('Subrata')	Non-puddled transplanted rice (NPTR), dwarf, medium-duration rice ('IET 4686')-early lentil cv. 'Asha', rice stubble (20 cm) retention
Chhattisgarh (Central India): Rice + lathyrus	Moisture deficit to lathyrus due to late rice cv. 'Mahsuri', BOAA- rich lathyrus	Medium rice 'Swarna', PTR, BOAA-free lathyrus cv. 'Ratan'
Tamil Nadu (Coastal Peninsula) Rice + blackgram	Seedling mortality due to high soil moisture (37–45%) at sowing of black gram	Long duration rice + blackgram cv. 'ADT 3', 30 cm rice stubble retention, PTR for moisture retention, switch over to zero till drilling of the 2nd crop or *utera* sowing 4–6 days before rice harvest, seed soaking for 4–6 hours before sowing
Andhra Pradesh, Karnataka (Coastal Peninsula) Rice + greengram/blackgram	Seedling mortality due to high soil moisture (37–45%) at sowing of blackgram	Long duration rice + blackgram cv. 'ADT 3', 30 cm rice stubble retention, PTR for moisture retention, switch over to zero till drilling of the 2nd crop or *utera* sowing 4–6 days before rice harvest, seed soaking for 4–6 hours before sowing

Source: (Singh *et al*., 2017)
PTR, Puddled transplanted rice
BOAA, β-N-oxalylamino-L-olamin

with short stature (1.0–1.2 m), upright leaves, strong and stiff straw, so as to avoid lodging at harvesting, timely sowing/ planting to enable harvest before mid-November, use of varieties with non-sprouting or low-sprouting stubbles, perfect land leveling before planting or sowing, provision of drainage channel for draining excess water, proper weed management to avoid weed menace to *paira* crop, use of weeder at 2nd top-dressing at panicle-initiation (PI) stage to loosen the soil and drainage of excess water at 15 days before harvesting. Singh *et al.* (2017) reported success of rice–lentil *utera* cropping with use of dwarf, medium-duration rice (IET 4686).

Establishment of *utera* crop

Gupta and Bhowmick (2005) reported higher seed yield of *utera lathyrus* sown 20 days before rice harvesting compared that sown 10 and 30 days before harvesting. This helped in effective utilization of moisture in rice field. Bhowmick (2010) reported the maximum seed yield of lentil sown 15 days before rice harvesting in rice–lentil *utera* cropping system at Murshidabad, West Bengal. Seeds are broadcast in the standing crop of rice in presence of adequate soil moisture. Pulses have the ability to establish with surface seeding in standing rice crop (Choudhary *et al*., 2014). Seeds of pulses absorb moisture quickly and efficiently due to high protein content and germinate readily. Seeds of cereals with high carbohydrate content and oilseeds with high fat content cannot absorb moisture as efficiently as pulses. Thus pulses like greengram, blackgram, pea, gram, lentil, lathyrus and cowpea [*Vigna unguiculata* (L.) Walp.] are cultivated as *paira/uttera/amuhan* crop. Kumar *et al.* (2019a) recommended lathyrus and lentil in *utera* for sustainable cropping intensification and improving the farmers' income in eastern India. This type of cropping is possible in rainfed lowland with high-water retentive soils. The cropping system comprises green manure–rice–pulse. Sowing of green-manuring crop *dhaincha* [*Sesbania bispinosa* (Jacq.) W. Weght] is done in May before onset of monsoon. The green-manure crop is incorporated at 6-week stage before transplanting in mid-July. Singh *et al.* (2004) reported significant residual effect of organic sources of nutrients, viz. FYM, *dhaincha* green-manuring, green gram green manuring after 1 picking and carpet waste applied to rice on yield, nutrient uptake and net returns of succeeding lentil. Seeds of pulse crops are broadcast in the standing crop after milking stage of rice in November. Gupta and Bhowmick (2005) reported higher seed yield of *utera* lentil sown on 21 November than that sown on 14 November. Normally, 1.5 times of the normal seed rate is used to make up the stand loss due trampling at harvesting of rice. Gupta and Bhowmick (2005) reported higher seed yield of *utera* lentil at seed rate of 80 kg/ha compared to 60 kg/ha. Varietal choice has positive effect on yield of *utera* crops. Layek *et al.* (2014) recommended the lentil cultivars, viz. 'DPL 81', 'IPL 406' and 'DPL 62', for lowland rice-fallow under no-till system. Maruthupandi *et al*. (2016) reported the maximum grain yield of rice-fallow blackgram by line dibbling at 10 days before rice harvesting at Madurai, Tamil Nadu. Fertilizer dose of *utera* pulses are applied as diammonium phosphate 15 days before harvesting of rice after draining the standing water. Geetha and Velayutham (2009) and Ramesh *et al*. (2016) reported higher yield of *utera* blackgram by application of N and P as DAP 7–10 days before harvesting of rice.

Advantages include utilization of soil moisture after harvesting of rice, saving of fuel, money, energy and time, advancement in crop growth by 10–14 days compared to conventional tillage, coverage of more area in less time, reduction in cost of cultivation and avoidance of adverse effects of excess tillage (loss of carbon, soil moisture). Kumar *et al*. (2019a) reported less emission of greenhouse gas (GHG) and low global warming potential (GWP) with winter crops grown under *utera* as compared to zero-tillage and zero-tillage + mulch. This system has disadvantages, viz. higher seed rate requirement than conventional sowing, non-uniform plant stand (in uneven land), inadequate opportunities for fertilizer and weed management, seedling damage due to trampling during harvesting, bundling and transportation of rice bundles, diseases and insect-pests susceptibility due to poor growth of seedlings, less yield due to low level of management and non-adoptible in light-textured soil (upland and medium land). Veeramani *et al*. (2018) developed a rice-fallow pulse planter costing ₹125,000 for achieving uniform plant stand, and evaluated it for planting blackgram at spacing of 25 cm × 10 cm and depth of 3–4 cm in line-sown standing rice crop fields 10 days before harvesting in wetland rice ecosystem. The machine planting incurred extra cost of ₹1,250/ha compared to conventional broadcasting and gave grain yield of 839 kg/ha, registering 21 and 56% higher value than manual dibbling and broadcasting respectively. Routaray (2008) found rice–lentil (*utera*) as the most efficient with the maximum production efficiency of 30.5 kg/ha/day and net return of ₹32,935/ha in lower Assam among 6 systems, comprising rice as base crop and lathyrus, lentil, pea, chickpea, lentil and *toria* (*Brassica rapa* L.) as *utera* crop.

Zero till seeding (after harvesting of rice)

Rahmianna *et al*. (2000) recommended sowing of pulses immediately after harvesting of lowland rice to minimize loss of soil moisture. He found the farmer's practice of dibbling with depth of planting ranging from 4–7 cm without covering of seeds is promising for stand establishment of greengram or mungbean after lowland rice. The seed cover improved plant stand to some extent. Behera *et al*. (2014) reported 45% increase in grain yield of greengram with conservation agricultural practices involving zero-tillage and residue recycling over conventional tillage (CT) without residue recycling in rice-fallows of Western Odisha. In absence of sufficient crop residues, stored soil moisture is lost through capillary rise from lower to upper soil layers and subsequent evaporation. Sasikala *et al*. (2014) got higher monetary return by dibbling the seeds 3 days after pre-sowing application of paraquat with fenoxaprop-p-ethyl @ 75 g/ha in zero-till sown rice-fallow blackgram. Zero-till crop is established by use of zero-till seed drill after harvesting of rice. Amuthaselvi *et al*. (2019) reported 39% higher seed yield of blackgram sown with zero-till seed drill (588 kg/ha) compared to that sown with CT (423 kg/ha) and benefit: cost (B: C) ratio of 5.2 and 3.9 with ZT and conventionally sown crop, respectively, at Tiruchirapalli, Tamil Nadu. Productivity of rice-fallow crops depends on tillage practices adopted in preceding rice. Kumar *et al*. (2020) reported higher yield of rice-fallow crops, viz. chickpea, lentil, safflower, linseed, rapeseed (*Brassica napus* L.) and Indian mustard under zero-till direct-seeded rice (ZTTR) and ZT-DSR rice with residue retention than zero-till transplanted rice with or without residue retention and puddle transplanted rice (PTR) with or without residue retention at Patna, Bihar.

Reduced tillage

Crop is sown under reduced tillage by giving 1 or 2 ploughings. Kar and Kumar (2009) reported the maximum grain yields of 580, 630, 605 and 525 kg/ha from lathyrus, blackgram, pea and greengram, respectively, with reduced tillage treatment. On the other hand, they recorded 34–4% lower yields with CT compared to reduced tillage. Singh *et al*. (2014b) reported higher yield of Indian mustard with reduced till practice along with application of water hyacinth mulch @ 2 t/ha under rainfed conditions of Mirzapur in eastern Uttar Pradesh. Under reduced tillage, capillary rise is checked due to functioning of ploughed furrow slice as soil or dust mulch. Hence soil moisture is conserved. Singh and Satapathy (2019) reported higher seed yield, rice-equivalent yield and net return from rice–linseed system, closely followed by rice–lentil and rice–rapeseed under minimum tillage in rice fallows in shallow lowlands in Assam.

Conventional tillage

Under conventional tillage system, crop is sown after repeated tillage operations for preparing a friable, powdered and levelled seed bed. Mishra and Singh (2011) reported higher yields of Indian mustard, lentil and chickpea under conventional tillage and that of field pea under zero tillage. Field pea and Indian mustard proved the most economical under zero and conventional tillage, respectively. Bhowmick *et al.* (2013) reported higher seed yield of conventionally till chickpea with closer spacing (30 cm) than wider spacing (45 cm) under rainfed condition. Singh *et al.* (2015) found cultivar response in lentil to method of crop establishment. He recommended lentil variety 'Pusa Vaibhav' both for zero and conventional tillage after unpuddled transplanted rice and cv. 'Mallika' for zero tillage for puddled transplanted rice. Kar and Kumar (2009) reported 34–44% lower yields of pulses under conventional tillage compared to reduced tillage due to higher loss of conserved soil moisture under the conventional tillage. Conventional tillage deteriorates physic-chemical and biological properties of soil.

Some promising sequence cropping systems (zero till/ reduced till/ conventional till) popular in RIFAs along with constraints and interventions to improve performance are given in Table 6.

Seed priming

Seed priming is a method to improve the rate and uniformity of germination. The process favours physiological advancement of the seed. It is a simple and low-cost hydration technique in which seeds are partially hydrated to a point where pre-germination metabolic activities start without actual germination, and then re-dried until close to the original dry weight (Singh *et al*., 2015). A seed primer can be applied with other seed treatments (such as fungicides, pesticides and herbicides) making it a convenient part of normal farm practice. The process of seed priming, or imbibing, takes no more than a few minutes, so it is both time and cost-effective. In rice-fallows, the crops are sown under unfavourable soil-moisture conditions. Hence, priming is helpful. Nawaz *et al*. (2013) reviewed the works on different types of seed priming and sunmmarized the advantages as better crop germination, earlier seedling emergence, better stand establishment and crop competition against weeds, higher degree of tolerance to drought, avoidance of time and capital consuming re-sowing and ultimately higher crop yield under stress condition. Hussain *et al.* (2016) described it as a controlled hydration technique that triggers the normal metabolic processes during early phase of germination before radicle protrusion, ensures higher and synchronized germination of primed seeds primarily due to reduction in the lag time of imbibitions, favours enzyme activation and build-up of germination enhancing metabolites, helps in metabolic repair during imbibition and osmotic adjustment.

Many workers (Singh *et al.,* 2015; Hussain *et al*., 2016; Siyami *et al*., 2018; Mondal and Bose, 2019) have described about different types of seed-priming techniques. These are: (i) hydro priming (use of water doubles the volume of seed) refers to soaking the seeds in water before sowing and may or may not be followed by air drying of the seeds, (ii) halo priming (use of salt solution) refers to soaking of seeds in solution of inorganic salts, i.e. NaCl, KNO_3, $CaCl_2$ and $CaSO_4$ etc., the treatment of seed with salt is done in order to improve germination and decrease saline intolerance, (iii) chemical priming – the treatment of seeds with priming agents such as NaCl, $CaCl_2$, thiourea, hydrogen peroxide, abscisic acid, ABA, potassium nitrate etc., (iv) osmo priming (use of osmotic solution – PEG) is achieved by soaking of seeds for a certain period in solution of sugar, PEG etc followed by air drying before sowing. Osmo-priming not only improves seed germination but also enhances crop performance under non-saline or saline conditions, (v) hormo priming or hormonal priming is the pre – treatment of seeds with different hormones like GA_3,

Table 6. Sequence cropping systems for rice-fallow areas in India

Situation	Constraints	Interventions
West Bengal (Eastern India) Rice–lentil	Rapid moisture depletion from lentil field	PTR for better soil-moisture retention, zero-till lentil with rice stubble as surface mulch or 20 cm anchored stubble
Eastern UP (Eastern India) Rice–chickpea	Poor soil physical properties under PTR, moisture deficit to chickpea due to tall and late rice, stubble removal	NPTR, dwarf and medium-duration rice, stubble (30 cm) retention), INM (5 t FYM/ha) + NPK
Chhattisgarh (Central India) Rice–chickpea	Moisture deficit to chickpea due to tall and late rice (Mahsuri), Medium duration chickpea cv. 'JG 130'	Medium duration rice cv.'Swarna'-early chickpea cv.'IG 226', rice stubble anchored (30 cm) or as surface mulch, PTR
Meghalaya (Northeast India) Upland rice fallow Rice–lentil	Rapid depletion of soil moisture	Rice-stubble anchored (20 cm) or as surface mulch, local rice 'Kbalum'fb. lentil cv.'DPL 62'
Meghalay (Northeast India) Lowland rice fallow Rice-lentil	Growing long duration rice cv. 'Mendri' fb. Medium high biomass lentil cv 'IPL 406'	Medium rice cv. 'Shahsarang 1' fb. Lentil cv. 'DPL 81', rice stubble anchored (20 cm) or as surface mulch

Source: (Singh *et al*., 2017) Fb., Followed by, PTR, puddled transplanted rice; NPTR, non-puddled transplanted rice kinetin, ascorbate etc., which promotes the growth and development of the seedlings, (vi) nutrient priming is a technique in which *seeds* are soaked in a mineral *nutrient* solution with subsequent re-drying to the initial moisture, (vii) redox priming (viii) physical priming refers to physical treatment of seed such as magnetic field and laser radiation, (ix) sand matric priming (use of moist sand) is done by treating seeds with moist sand, and (x) bio-priming is done by treating seeds with beneficial micro-organisms like *Trichoderma asperellium* Samuels *et al.*. It is a new technique of seed treatment that integrates biological (inoculation of seed with beneficial organism to protect seed) and physiological aspects (seed hydration) of disease control. It is recently used as an alternative method for controlling many seed and soil borne pathogens.

Gupta and Bhowmick (2005) recommended sowing of sprouted seeds of *utera* lentil or sowing of sprouted seeds or seed soaking with 2% KH_2PO_4 solution for 6 h of utera lathyrus for higher seed yield. Bhowmick (2010) reported lentil seed yield increase of 30.0 and 19.6%, respectively, by use of sprouted and KH_2PO_4 soaked seeds in rice–lentil *utera* cropping system. Bhowmick *et al.* (2014a) reported the maximum grass pea seed yield of 1,022 kg/ha with use of sprouted seeds closely followed by seed priming with 2% KH_2PO_4 solution with seed yield of 965 kg/ha. Bhowmick *et al.* (2014b) reported that seed priming (seed soaking in water for 8 hours) resulted in significantly higher grain yield (1,129 kg/ ha) of chickpea over the use of non-primed seeds (848 kg/ ha).

Nutrient management

Nutrient management is highly challenging in pulses and oilseeds grown after rice in RIFAs due to limited stored moisture restricting nutrient mobility in soil and uptake by plants. Thus, RIFAs can be regarded as being both hungry and thirsty during the winter. There is no scope for splitting of fertilizer dose for top-dressing or side-dressing after sowing. Crop nutrient demand is fulfilled by green-manuring/ application of organic manure to preceding rice, application of fertilizer need of pulse/ oilseed in terminal stage of rice as diammonium phosphate, seed-nutrient priming, basal application and foliar feeding. Nutrient priming works well, because it puts nutrients inside the seed analogous to fertilizing the seed which is a very efficient process. The process of imbibing nutrient ensures that the uptake of nutrient is immediate, reliable and effective. The research works established efficacy of basal application of recommended dose of fertilizer, foliar spray of urea, DAP, micronutrients and growth-regulators in enhancing yield of pulses and oilseeds grown under residual soil-moisture conditions. Rao *et al*. (2006) reported 24 and 56% increase in yield of Indian mustard with application of micronutrients, viz. boron + molybdenum over recommended NPK and FYM alone. Shashikumar *et al.* (2013) reported the maximum values of growth parameters, yield attributes, seed yield, net return and benefit: cost (B : C) ratio with of recommended dose of fertilizer (RDF) as basal application and foliar spray of 40 ppm NAA + 0.5% chelated micronutrient + 2% DAP given at 35 and 50 days after sowing (DAS) and application of RDF as basal dose + 0.5% chelated micronutrient + 2% DAP given at 35 and 50 days after sowing DAS. These 2 treatments, being at par, recorded the maximum uptake of P and K by crop and the maximum available N and P in soil. Bhowmick *et al.* (2013) reported better growth and higher seed yield of chickpea with foliar spray of 2% urea solution twice at flower initiation and 10 days thereafter than application of 2 rounds of either 3% KCl or simple water spray. Quddus *et al*. (2014) reported the maximum grain yield of lentil with application of 3.0 kg Zn and 1.5 kg boron (B)/ha in the Low Ganges River Floodplain of Bangladesh. Kar *et al*. (2015) reported the maximum seed and stick yield of winter niger (*Guizotia abyssinica* L.) with application of straw mulching @ 7 t/ha and boron spraying @ 0.2% borax at branching and flowering stages. Rao *et al.* (2015) reported higher yields of greengram with application of KNO_3 @ 1% under receding soil moisture condition compared to other foliar sprays. Vijayakumar and Jalaluddin (2016) recommended application of NPK and foliar spray of mono ammonium phosphate (0.5%) or pulse wonder (1.0%) at peak flowering stage coupled with seed treatment with *Rhizobium* and phosphobacteria @ 600 g each/ha for the maximum grain yield and B : C ratio in horsegram [*Macrotylona uniflorum* (Lam.) Verd.] under north-western zone of Tamil Nadu. Das *et al*. (2016) reported significant increase in yield of pulses in acidic soils of north-east by liming @ 2 t/ha or furrow liming @ 200–500 kg/ha. Patil *et al*. (2018) reported blackgram grain yield increase from 0.88 to 1.06 t/ ha (20% increase) and net returns from ₹15,450/ha to ₹21,960 (42% increase) with application of pulse magic (developed by The University of Agricultural Sciences, Raichur, Karnataka, in 2014) containing 10% N, 40% P, 3% micronutrients and 20 ppm PGR at 50% flowering stage. Promising nutrient-management practices for pulses and oilseeds in RIFAs of India comprise *in-situ* green-manuring or application of FYM to preceding rice, application of N and P requirement as DAP towards terminal phase of preceding rice, basal application and foliar feeding to pulses and oilseeds (Table 7).

Soil-moisture management

Moisture is the presence of a liquid, especially water, often in trace amounts. Soil moisture is held under force or tension, unlike free water. Due to lack of post-monsoon

Table 7. Agro-ecosystem and state-wise nutrient-management for *utera* and sequence cropping rice fallow areas

State and RIFA	Cropping system	Promising treatment	Remarks
West Bengal	Rice + lathyrus (*utera*)–sesame	*In-situ* green manuring of *dhaincha* and /or FYM @ 10 t/ha along with 75% or 100% recommended dose fertilizer to rice and sesame	Mondal and Ghosh (2005)
Berhampur, West Bengal	Rice + lathyrus (*utera*)	Placement of 10-25-20 N-P_2O_5-K_2O kg/ha between rows of standing rice along with foliar spraying of 2% DAP or 2% urea at flowering	Gupta and Bhowmick (2005)
Murshidabad, West Bengal	Rice + Lathyrus(*utera*)	Foliar spraying of 2% urea or 2% DAP in lathyrus	Bhowmick *et al.* (2014)
Patna (eastern India)	Rice–lentil sequence cropping	Application of 30 kg sulphur and 6 kg zinc/ha to rice	Singh *et al.* (2013)
Eastern Uttar Pradesh (eastern India)	Rice–chickpea(sequence cropping)	Recommended dose of NPK + FYM @ 5 t/ha to rice	Singh *et al.* (2017)
Naira, Andhra Pradesh	Rice-fallowgreengram	Soil application of 50 kg $ZnSO_4$/ha along with foliar application of 0.2% $ZnSO_4$ at panicle emergence to *kharif* rice, foliar application of 0.2% $ZnSO_4$ to rice-fallow greengram at flowering	Kumar *et al.* (2018)
Annamalai nagar, Tamilnadu	Rice-fallow blackgram	Foliar application of 2.0 % DAP + 40 ppm NAA + 0.5 % $ZnSO_4$ + 1.0 $FeSO_4$ twice (pre-flowering + flowering) + soil inoculation of phosphobacteria	Ganapathy *et al.*(2008)
Annamalai nagar, Tamilnadu	Rice-fallow blackgram	Foliar application of 2% DAP + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ + 0.1% boric acid + 0.05% sodium molybdate + 0.05% cobalt chloride in blackgram	Suhathiya and Ravichandran (2018)
Coimbatore, Tamilnadu	Rice + blackgram(*utera*)	Basal application of N and P fertilizers @12.5 : 25 kg/ha as DAP (10 days prior to harvest of rice crop) to blackgram and foliar spraying of 2% DAP + 1% KCl at flowering and pod-filling stage	Geetha and Velayutham (2009)
Aduthurai, Tamil Nadu	Rice+blackgram(*utera*)	Application of DAP @ 50 kg/ha to preceding rice at last irrigation, sowing paira blackgram 3–4 days after application of DAP (7days before harvest of rice) and foliar spraying of 2% DAP + 1% KCl at 30 and 45 DAS or foliar spraying of 2% DAP. + 1% KCl at 30 and 45 DAS	Ramesh *et al.* (2016)

RIFA, Rice-fallow area; DAP, diammonium phosphate; DAS, days after sowing

rainfall, the *rabi* crops in rice-fallow depend pre-dominantly on stored soil moisture and/or supplemental irrigation. The evapo-transpiration demand is low during the period due to prevalence of low temperature. *Monjappa and Koppad (2002) got higher yield of greengram, cowpea and groundnut with protective irrigation compared to crops grown under residual soil moisture.* Moisture-conservation technologies should be developed and promoted to facilitate growing of pulse crops in hostile environment of rice-fallows to meet the growing demand of pulses in the country (Ali *et al*., 2014). Singh *et al*. (2014a) reported yield increase of 20, 34 and 40% in groundnut, lentil and rapeseed, respectively, after applying 2 life-saving irrigations in rice-fallows of Tripura. Bandyopadhyay *et al*. (2015) have computed climate, AESR and soil-wise water requirement fulfilled by residual soil moisture and possibilities of growing crops without irrigation and with 1 or 2 irrigations in eastern India. In most of the AESRs of eastern India, pulse and oilseed crops like greengram, blackgram, Sesame (*Sesamum indicum* L.) and Indian mustard can be grown successfully on residual soil-moisture content. Bandyopadhyay *et al*. (2016) reported 1–4% higher soil water content in relay lentil with the long (20 cm) rice stubble than the short (10 cm) and recommended retention of rice stubble of 10 or 20 cm height for conservation of soil moisture and successful raising of lentil after short- and long- duration rice. Praharaj *et al*. (2016) recommended supplemental/ life-saving irrigation at critical stages of pulses to achieve the potential yield. Singh *et al*. (2017) reported that, soil-moisture depletion pattern was relatively lower in lentil by residue retention at a higher cutting height, i.e. 30 cm in comparison to 15 cm with better and higher crop cover in the former in rice + lathyrus relay cropping system under RIFAs in Eastern Plateau of India. Supplemental irrigation is possible through construction of on-farm water-harvesting structures or exploitation of groundwater. According to GoI (2019b), the average stage of groundwater development in India is 58%. Groundwater development in eastern and central plain states are 43 and 42%, respectively, as against 98% in North Western Plains states. The states with sizable rice-fallow areas, viz. Andhra Pradesh, Assam, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh, Maharashtra, Odisha, Uttar Pradesh and West Bengal, have groundwater development to the extent of 44, 11, 46, 28, 70, 55, 44, 55, 42, 70 and 45%, respectively, as against 166, 140, 137 and 120% in Punjab, Rajasthan, Haryana and Delhi. Rainfall contributes nearly 67% of total annual groundwater recharge. Owing to high rainfall in rice-growing areas, there is scope for further increase in groundwater recharge and development. Lack of electric supply hinders lifting of groundwater from tube-wells. Use of solar pump is promising. Switch over from oil and electricity-based tube-well to solar-power irrigation system wells reduced reliance on grid supply, checked wastage of precious water and ensured real-time water management in crops (Baladi and Shah, 2018). Rice-fallow areas are high-rainfall areas and about an 80% rainfall occurs during 4 months from mid-June to mid-October. About 25–40% rain water is lost as run-off. Gupta *et al*. (2016) suggested for construction of small pond-like structures at the corner of field in the size of 120 m^3 (15 m × 8 m × 1 m) for storing runoff water and use of mobile sprinklers for providing life-saving irrigation at critical growth stages (25 and 40 DAS) to rice-fallow greengram and blackgram in Odisha, Tamil Nadu and Karnataka.

Weed management

The weed flora and intensity differ based on the method of crop establishment. Ratoon rice and escaped weeds pose serious threat to ZT/ *utera* crops. Many workers have reported efficacy of quizalofop ethyl @50 g/ha at 15-20 DAS in controlling rice stubbles and grassy weeds. Quizalofop-p-ethyl inhibits action of *acetyl CoA* carboxylase (ACCase) responsible for fatty acid biosynthesis in plants (weeds) leading to mortality of weeds. Imazethapyr @ 100 g/ha at 15–20 DAS controls mixed flora of weeds. This weedicides inhibits action of acetolactate synthase (ALS) responsible for bio-synthesis of the branched chain amino acids (valine, leucine and isoleucine) in plants (weeds). Many works have reported satisfactory weed control in conventionally till pulse and oilseeds crops by use of pendimethalin, a dinitroanilin herbicides, inhibiting micro-tubule assembly formation in weeds and checking cell-division. Promising weed-management practices for pulses and oilseeds raised as *utera*, ZT and conventional till crops in RIFAs of India are given in Table 8.

The post-emergence herbicides used in pulses and oilseeds kill grassy weeds. When grassy weeds are controlled, broad-leaf weeds pre-dominate, particularly in *paira*/ zero-till crops. So far, limited work has been done on post-emergence herbicides for effective control of dicot weeds in pulses and oilseeds. Some effective herbicides should be identified for post-emergence control of broadleaved weeds.

Harvest and post-harvest care

The post-harvesting process is divided into 7 stages, comprising harvesting, threshing, drying, storage, processing, packaging and transportation (Mohan *et al*., 2011). Pulses and oilseeds should be harvested at physiological maturity to avoid shattering losses. Pulses are harvested when grain moisture content varies from 15 to 20%. Grain needs drying to optimum moisture content before storage. Sharon *et al*. (2015) reported invasion of visible mould around the hilum of blackgram seeds at higher moisture content of 15 and 18% irrespective of storage temperature.

In absence of care, losses occur at different post-harvesting stages (Table 9) and estimated losses varied from 25 to 50% in pulses (Lal and Verma, 2007).

Drying is a particularly important post-harvest operation for safe storage, processing, and preservation of pulses. Pulses are harvested at higher moisture; therefore, drying of pulses to a safe moisture level is critical for improving the storage time of pulses. Pulses are more difficult to store than cereals, and they suffer much greater damage from insects and microorganisms.

Strategy and suggested policy measures

Ghosh *et al*. (2016) recommended holistic crop-management approaches, viz. no-till cropping, relay cropping, residue retention, mulching, seed-priming, farm-pond establishment, for life-saving irrigation and micronutrient application for substantially improving the survival and performance of pulses in rice-fallows. Rampal (2017) proposed the policy measures pertaining to production, consumption and price policy to ensure pulse security (40 g per day) in India. Production policy aims at increasing domestic production to make up for the 4 million tonnes deficit, considering demand-supply gap in pulses. Policy for ensuring consumtion and avoiding malnutrition envisages for distribution of pulses through public-distribution system in other states in similar pattern as prevalent in Tamil Nadu, Andhra Pradesh, Telangana, Chhattisgarh and Himachal Pradesh. Pricing policies encompass announcement of Minimum Support Price (MSP) well in advance before the onset of monsoon, so as to send the right signal to growers for crop planning, assured procurement and creation of procurement centres in production zones. Constraint-wise interventions and suggested policy measures have been shown as flow charts (Figs. 2, 3, 4 and 5). Important policy support needed for greening rice fallows are adequate fund provision for development of stress resistant/ tolerant varieties, promotion of on-farm water-harvesting structures, groundwater recharge and exploitation, solar-power water-lifting units and mobile sprinklers, establishment of village-level Custom Hiring Centres (CHCs), creation of procurement centres, declaration of minimum support price (MSP) before *kharif* season, strengthening village committees for crop protection, creation of farmer producer organizations (FPOs) and institutional arrangement for supply of seed, fertilizer and plant-protection chemicals.

Impact of greening rice-fallows in winter

Rice-fallow states in India accounted for about two-

Table 8. Weed management in rice-fallow pulses under *utera*, zero till and minimum/conventionally till cropping

Location	Crop	Promising treatment	Remarks
		Utera cropping	
Berhampur, West Bengal	Lathyrus	Hand-weeding at 45 DAS or 2 manual weeding at 30 and 50 DAS or application of oxyfluorfen @ 50 g/ha as post-emergence spray at 30 DAS were found promising	Gupta and Bhowmick (2005)
Aduthurai, Tamil Nadu	Blackgram	Imazethapyr 75 g/ha + quizalofop ethyl 75 g/ha as early post emergence at 20 (10 days after rice harvest) DAS in black gram sown 10 days before rice harvest	Ramesh and Rathika (2015)
		Zero till cropping	
Jabalpur, Madhya Pradesh	Pea	Pre-emergence application of pendimethalin 1.0 kg/ha	Mishra and Singh (2011)
Madurai, Tamil Nadu	Blackgram	Pre-sowing application of paraquat @ 0.5 kg/ha with post-emergence application of either fenoxaprop-p-ethyl @ 75 g/ha or cyhalofop butyl @ 100 g/ha at 15 DAS	Sasikala *et al*. (2014)
Bhubaneswar, Odisha	*Toria*	Glyphosate 1.0 kg/ha (PPD)	Parida *et al*. (2020)
		Conventional till cropping	
Murshidabad, West Bengal	Lentil	Use of 25% higher seed rate + hand-weeding at 30 DAS or pendimethalin 0.75 kg/ha as pre-emergence spray + hand-weeding at 40 DAS or application of pendimethalin 1.0 kg/ha as pre-emergence spray	Bhowmick *et al*. (2010)
Jabalpur, Madhya Pradesh	Indian mustard, lentil and chickpea	Pre-emergence application of pendimethalin 1.0 kg/ha	Mishra and Singh (2011)
Varanasi, eastern Uttar Pradesh	Lentil	Pendimethalin 1.0 kg/ha followed by mechanical weeding at 45 days after sowing	Lhungdim *et al*. (2013)
Supaul, Bihar	Lentil	Pendimethalin 1.0 kg /ha as pre-emergence and quizalofop-p-ethyl @40 g/ha as post-emergence spray	Singh *et al*. (2018)

Table 9. Type of losses at different post-harvest stages in pulses

Stages of operation	Type of losses
Late harvest	Shattering losses, losses due to attack of birds and other pests
Insufficient drying of grain	Losses due to development of moulds and insects
Improper threshing	Broken grains and threat of insect development at a later stage
Poor storage	Losses caused by combined action of insects, moulds, rodents and other pests
Improper milling	Broken and powdering loss
Transport	Quantitative loss
Defective packaging	Quantitative and qualitative loss

Source: Lal and Verma (2007)

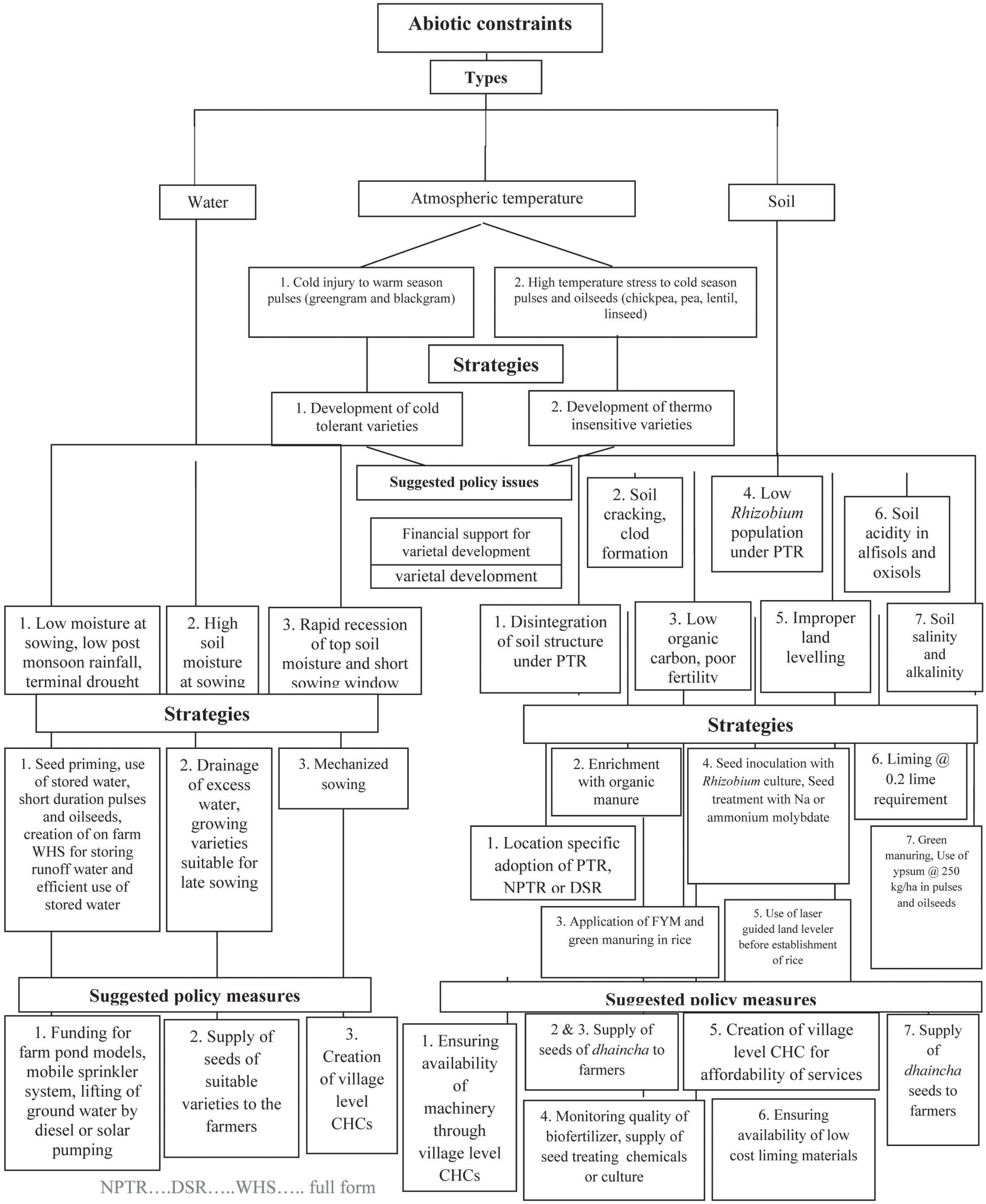

Fig. 2. Abiotic constraints, strategies and policy measures

NTPR, Non puddled transplanted rice; DSR, Direct seeded rice; WHS, Water harvesting structure; CHEs, Custom Hiring Centre

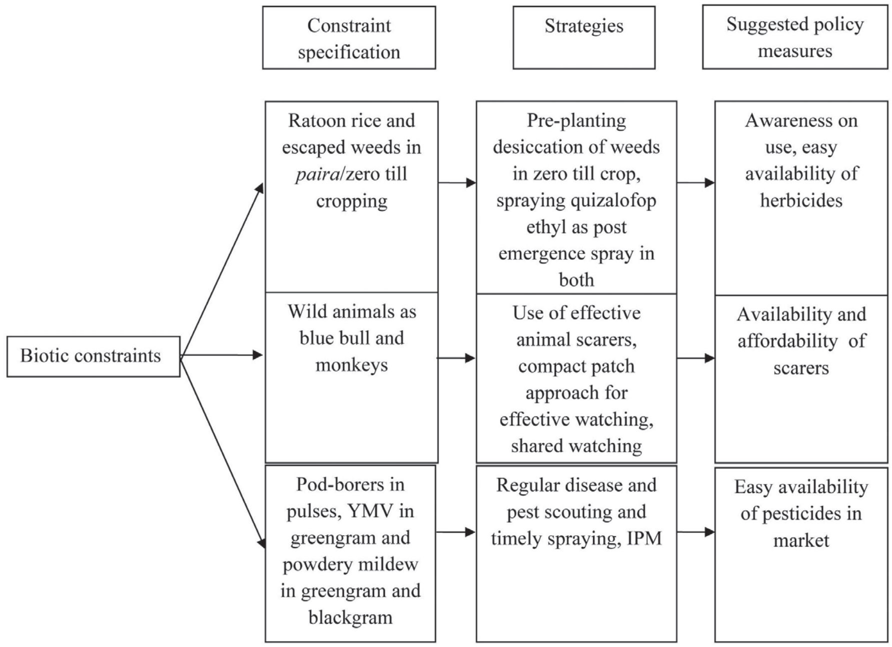

Fig. 3. Biotic constraints, strategies and suggested policy measures (YMV, Yellow Mosaic Virus; IPM, integrated pest management)

thirds of pulses area and contributed more than a half of total production in early 1960s, but the share of area and production declined to 31 and 34%, respectively, in late 1990s (Joshi *et al.,* 2002). According to Kumar *et al.* (2019), greening of 3 and 1 m ha of rice-fallows during the winter is possible through pulses and oilseeds, respectively. An analysis by Singh *et al.* (2013) showed that eastern states are much more deficient in production of both the non-food items like oilseeds and pulses to fulfil their own requirements. India accounts for 33% of the world area and 22% of the world production of pulses. (Choudhary *et al.,* 2014), due to stagnation in production, the net availability of pulses came down from 60 g in 1951 to 41.7 g/day/person in 2012, although the Indian Council of Medical Research recommends 65 g/day/capita. The country imports 2–3 million tonnes pulses annually to meet the domestic pulses demand. Slow growth in production of pulses in India (mere 1% per annum for the period 1970 to 2013) compared to population growth (2% per annum) resulted in increasing demand-supply gap and in turn rising prices and declining per capita consumption in spite of growing pulse imports (Ahlawat *et al.*, 2016). Green revolution also adversely affected the acreage of pulses causing displacement by rice–wheat system leading to shift of pulse crops in marginal dry lands in the country, resulting in decline in the yield of pulses during last few decades (Sharath *et al*., 2019). They linked import demand for pulses to income, price and urbanization. At present, India has reached near self-sufficiency in pulses. The oil import exerts greater burden on foreign-exchange reserve of the country than

Table 10. Production, import and export of total pulses during 2009–10 to 2017–18

Year	Area (m ha)	Production (mt)	Yield (kg/ha)	Import		Export	
				Quantity (mt)	Value (₹ in crores)	Quantity (mt)	Value (₹ in crores)
2009–10	23.28	14.66	630	3.75	10,629	0.100	408
2010–11	26.40	18.24	691	2.78	7,513	0.209	870
2011–12	24.46	17.09	699	3.50	9,448	0.174	1,068
2012–13	23.26	18.34	789	4.01	13,345	0.203	1,285
2013–14	25.21	19.25	764	3.18	11,037	0.346	1,749
2014–15	23.55	17.15	728	4.58	17,063	0.222	1,218
2015–16	24.91	16.32	655	5.80	25,619	0.256	1,656
2016–17	29.45	23.13	786	6.61	28,523	0.137	1,278
2017–18	29.99*	25.23*	841*	5.61 P	18,749 P	0.180 P	1,470 P

Source: GoI (2019a); *4th Advanced Estimate; P, Provisional pulses. The edible oil is the third largest import item after crude oil and gold. There is a need to bring more rice-fallow areas under oilseed cultivation.

In spite of fluctuations, there has been an increasing trend in area, production and productivity of pulses during 2009–10 to 2017–18. The import of pulses increased from 3.75 million tonnes valued at ₹10,629 crore (1 crore=10 million) in 2009–10 to 5.61 million tonnes valued at ₹18,749 crore in 2017–18 (annual increment of 6% in quantity and 10% in value) to meet domestic demand (Table 10).

Between 2009–10 and 2017–18, there has been no appreciable horizontal expansion in area under oilseeds, although there was slight increase in productivity and production. The country imported 6.73 million tonnes vegetable oil valued at ₹22,317 crore in 2009-10 which increased to 15.36 million tonnes valued at ₹74,996 crore in 2017–18 (annual increment of 16% in quantity and 30% in value over 8 years) to make up the deficit (Table 11).

Additional area of 3 m ha under pulses will amount to additional production of 2.5 million tonnes @ 841 kg/ha and saving of foreign exchange of ₹8,355 crore, considering import price in 2017–18. Additional 1.0 million ha under oilseeds will amount to oilseed production of 1.27

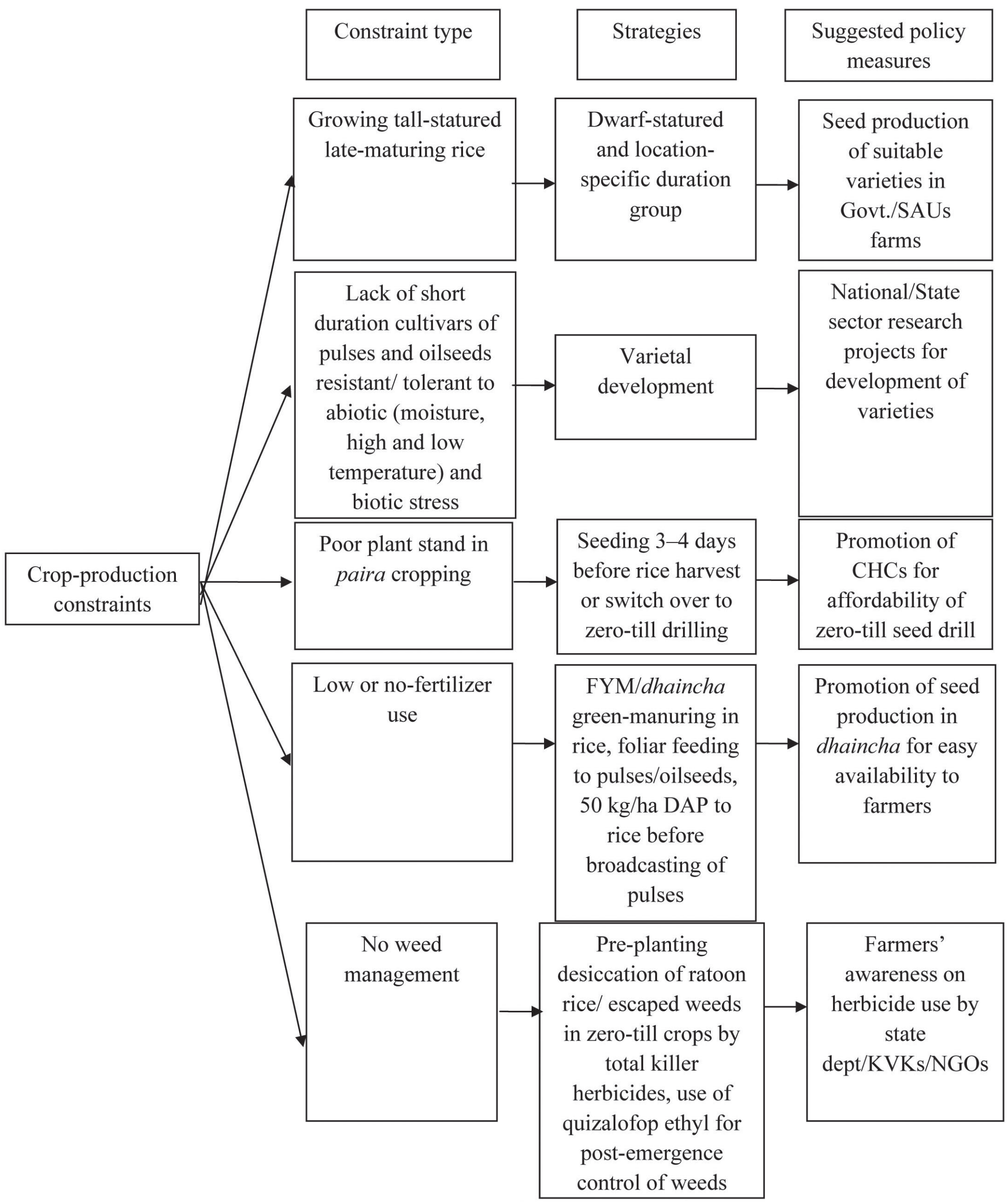

Fig. 4. Crop-production constraints, strategies and suggested policy measures

Table 11. Production of annual oilseeds, import and export of vegetable oil during 2009–10 to 2017–18

Year	Area(m ha)	Production (mt)	Yield (kg/ha)	Import		Export	
				Quantity (mt)	Value (₹in crores)	Quantity (mt)	Value (₹in crores)
2009–10	25.96	24.88	958	6.73	22,317	0.015	183
2010–11	27.22	32.48	1,193	6.04	25,920	0.014	115
2011–12	26.31	29.80	1,133	7.08	38,909	0.030	269
2012–13	26.48	30.94	1,168	9.61	53,562	0.036	469
2013–14	28.05	32.75	1,168	7.94	44,038	0.023	325
2014–15	25.60	27.51	1,075	12.73	64,890	0.424	580
2015–16	26.09	25.25	968	15.64	68,677	0.031	523
2016–17	26.18	31.28	1,195	14.01	73,039	0.061	780
2017–18	24.65*	31.31*	1,270*	15.36 P	74,996 P	0.037 P	566 P

Source: GoI (2019a); *4th Advanced Estimate; P, Provisional

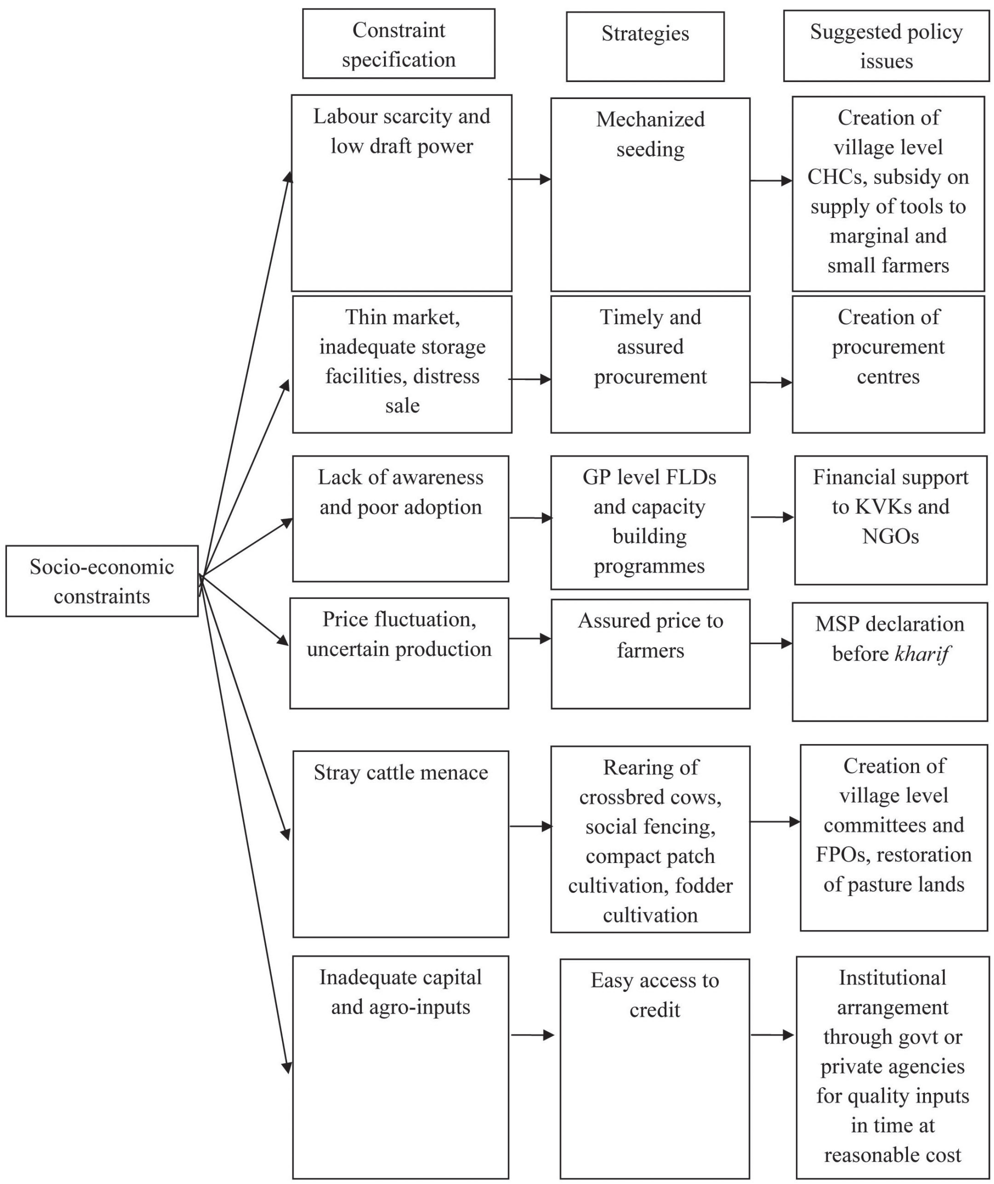

Fig. 5. Socio-economic constraints, strategies and suggested policy measures (GP, Gram Panchayat; FLDs, frontline demonstrations; KVKs, Krishi Vigyan Kendras; NGOs, non-government organization; MSPm minimum support price; FPOs, Farmer Producer Organisations)

million tonnes @ 1,270 kg/ha and oil production of 0.3175 tonne (considering oil recovery of 25%) valued at ₹1,550 crore at average oil import price in 2017–18.

Conclusion

The constraints in rice-fallow areas include abiotic (water, temperature and soil related), biotic, crop management related and socio-economic in nature. Choice of crop/ cropping system depends on climate, soil and length of growing season. Short-duration pulses and oilseeds are ideal rice-fallow crops. Appropriate seed priming would ensure germination and establishment of crops under rice-fallow environment. System approach involving both rice and succeeding pulses/ oilseeds for tillage, nutrient, water and weed management has to be adopted for efficient use of available resources. Productivity and profitability of pulses and oilseeds in rice-fallow areas can be maximized by constraint analysis, identification of promising interventions for strategic planning and suitable policy measurers.

REFERENCES

AAU. 2015. *Package of practices for rabi crops of Assam*. Assam Agricultural University, Jorhat and Department of Agriculture, Asom.

Ahlawat, I.P.S., Sharma, P, and Singh, U. 2016. Production, demand and import of pulses in India. *Indian Journal of Agronomy* **61**(Special issue): S33–S41.

Ali, M., Ghosh, P.K. and Hazra, K.K. 2014. Resource conservation technologies in rice fallow. (In) *Resource Conservation Technology in Pulses,* pp. 84–89, Ghosh, P.K., Kumar, N., Venkatesh, M.S., Hazra, K.K. and Nadarajan. N. (Eds). Scientific Publishers, Jodhpur, Rajasthan, India.

Ali, M., Gupta, S. and Sarker, A. 2015. Improving productivity of rice fallows. (In) Policy Paper 64. Pathak, H.C. (Eds). National Academy of Agricultural Sciences, New Delhi, India, pp.16.

Amuthaselvi, G., Dhanushkodi, V. and Eswaran, S. 2019. Performance of zero till seed drill in raising black gram under rice fallow. *Journal of Crop and Weed* **15**(1): 195–197.

Baladi, R.A. and Shah, M.A. 2018. Solar powered irrigation system for agriculture based on moisture content in the field and saving energy and water with optimum designing. *Asian Journal of Engineering, Sciences and Technology* **8**(1): 1–9.

Bandyopadhyay, K.K., Sahoo, R.N., Singh, R., Pradhan, S., Singh, S., Krishna, G., Pargal, S. and Mahapatra, S.K. 2015. Characterization and crop planning of *rabi* fallows using remote sensing and GIS. *Current Science* **108**(11): 2,051–2,062.

Bandyopadhyay, P.K., Singh, K.C., Mondal, K., Nath, R., Ghosh, P.K., Kumar, N., Basu, P.S. and Singh, S.S. 2016. Effects of stubble length of rice in mitigating soil moisture stress and on yield of lentil (Lens culinaris Medik.) in rice–lentil relay crop. *Agricultural Water Management.* **173**: 91–102.

Basu, P.S., Singh, U., Kumar, A., Praharaj, C.S. and Shivran, R.K. 2016. Climate change and its mitigation strategies in pulses production. *Indian Journal of Agronomy* **61**(Special issue): S71–S82.

Behera, U.K., Mishra, A.K., Bishoyi, B.S., Behera, S.K., Nayak, R.K., Ronanki, S. and Singh, S. 2014. Introduction of pulse crop in rice-fallow system through use of conservation agriculture practices in western Odisha. *Journal of Soil and Water Conservation* **13**(4): 318–323.

Bhowmick, M.K. 2010. Effect of planting time and seed priming on growth and yield of lentil under rice–*utera* system. *Journal of Food Legumes* **23**(2): 152–153.

Bhowmick, M.K., Bag, M.K. and Islam, S. 2014b. Integrated weed management in lentil (*Lens culinaris* Medikus). *The Journal of Plant Protection Sciences* **2**(2): 88–91.

Bhowmick, M.K., Dhara, M.C., Duary, B., Biswas, P.K. and Bhattacharyya, P. 2014a. Improvement of lathyrus productivity through seed priming and foliar nutrition under rice–*utera* system. *Journal of Crop and Weed* **10**(2): 277–280.

Bhowmick, M.K., Duary, B., Biswas, P.K., Rakshit, A. and Adhikari, B. 2013. Seed priming, row spacing and foliar nutrition in relation to growth and yield of chickpea under rainfed condition. *SATSA Mukhapatra - Annual Technical* **17**: 114–119.

Biswas, P. and Bhowmick, M. 2015. Crop diversification through pulses in the North-eastern Plains Zone of India. (In) *Diversification of Agriculture in Eastern India*. Ghosh, M., Sarkar D., and Roy, B. (Eds). India Studies in Business and Economics. Springer, New Delhi.

Chandana, P.K. and Mondal, S. 2020. Analyzing multi-year rice-fallow dynamics in Odisha using multi-temporal Landsat-8 OLI and Sentinel-1 Data. *GIScience and Remote Sensing* **57**(4): 431–449.

Choudhary, M., Ghasal, P.C., Choudhary, G.L., Prajapat, K. and Choudhary, H.R. 2014. Enhancing productivity and resource use efficiency of rice-fallow through introduction of pulses. *Popular Kheti* **2**(4): 19–21.

Das, A., Babu, S., Yadav, G.S., Ansari, M.A., Singh, R.,. Baishya, L.K., Rajkhowa, D.J. and Ngachan, S.V. 2016. Status and strategies for pulses production for food and nutritional security in north-eastern region of India. *Indian Journal of Agronomy* **61**(Special issue): S43–S57.

Das, A., Chowdhury, S., Layek, J., Ramkrushna, G.I., Panwar, A.S., Ngachan, S.V. and Buragohain, J. 2017. Agro-physical assessment of different pea (*Pisum sativum*) cultivars in lowland rice (*Oryza sativa*) fallow under no-till system for enhancing cropping intensity and productivity in mid hills of northeast India. *Indian Journal of Agricultural Sciences* **87**: 1,612–1,618.

Ganapathy, M., Baradhan, G. and Ramesh, N. 2008. Effect of foliar nutrition on reproductive efficiency and grain yield of rice-fallow pulses. *Legume Research* **31**(2): 142–144.

Geetha, P. and Velayutham, A. 2009. Refinement of nutrient management techniques for growth, yield and nutrient uptake of rice-fallow blackgram. *Madras Agricultural Journal* **96**(1–6): 163–166.

Ghosh, P.K., Hazra, K.K., Nath, C.P., Das, A. and Acharya, C.L. 2016. Scope, constraints and challenges of intensifying rice (*Oryza sativa*)–fallows through pulses. *Indian Journal of Agronomy* **61**(Special issue): S122–128.

GoI. 2019a. *Agricultural Statistics at a Glance* 2018. Directorate of Economics and Statistics, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

GOI. 2019b. *National Compilation on Ground Water Resources of India.* 2017. Central Ground Water Board, Department of Water Resources, RD and GR, Ministry of Jal Shakti, Government of India, Faridabad, Haryana.

GoO. 2020. *Odisha Agriculture Statistics.* 2014–15. Directorate of Agriculture and Food Production, Government of Odisha, Department of Agriculture and Farmers' Empowerment, Odisha, India.

Gumma, M.K., Prasad, S.T., Pardharsadhi, T., Rao, M.N., Mohammed, I.A. and Whitbread, A.M. 2016. Mapping rice fallow cropland areas for short-season grain legumes intensification in South Asia using MODIS 250 m time-series data. *International Journal of Digital Earth* **9**(10): 981–1,003.

Gupta, S. and Bhowmick, M.K. 2005. Scope of growing lathyrus and lentil in relay cropping systems after rice in West Bengal, India. *Lathyrus Lathyrism Newsletter* **4**: 28–33.

Gupta, S., Parihar, A.K., Rao, Y.K., Ravi, V., Iyanar, K. and Gupta, D.S. 2016. Rice-fallow cultivation in India: mungbean and urdbean (pocket guide). Extension Bulletin, p.44. AICRP on MULLaRP, ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh.

Hanif, N.A.K.A., Ramasamy, R., Davidson, S.J. and Pandiyan, M. 2017. Popularization of horse gram (*Macrotyloma unilorum*) in Vellore district of Tamil Nadu. *Journal of Krishi Vigyan* **6**(1): 148–150.

Hussain, S., Khan, F., Hussain, H.A. and Nie, L. 2016. Physiological and biochemical mechanisms of seed priming-induced chilling tolerance in rice cultivars. *Frontiers in Plant Science* **7**: 116.

Joshi, P.K., Birthal, P.S. and Bourai, V.A. 2002. *Socio-economic constraints and opportunities in rainfed rabi cropping in rice-fallow areas of India*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, pp. 58.

Kar, G. and Kumar, A. 2009. Evaluation of post-rainy season crops with residual soil moisture and different tillage methods in rice fallow of eastern India. *Agricultural Water Management* **96**(6): 931–938.

Kar, G., Singh, R. and Kumar, A. 2008. Evaluation of post rainy season crops and response to irrigation in rice (*Oryza sativa*) fallow under shallow water-table of eastern India. *Indian Journal of Agricultural Sciences* **78**(4): 293–298.

Kar, S., Halder, L., Saren, B.K. and Mandal, K. 2015. Effect of mulching and boron application on growth, productivity and water use of winter niger under red-lateritic belt of West Bengal. *International Journal of Applied and Pure Science and Agriculture* **1**(10): 1–8.

Kumar, A., Singh, R.K.P., Bharati, R.C., Chandra, N. and Kumar, U. 2017. Growth performance of principal crops in North Bihar during last four decades: Empirical evidences. *Journal of AgriSearch* **4**(2): 154–159.

Kumar, R., Mishra, J.S. and Hans, H. 2018. Enhancing productivity of rice fallows of estern India through inclusion of pulses and oilseeds. *Indian Farming* **68**(08): 7–10.

Kumar, R., Mishra, J.S., Upadhyay, P.K. and Hans, H. 2019b. Rice fallows in the eastern India: Problems and prospects. *Indian Journal of Agricultural Sciences* **89**(4): 567–577.

Kumar, R., Mishra, J.S., Rao, K.K., Bhatt, B.P., Hazra, K.K. and Hans, H. 2019a. Sustainable intensification of rice fallows of Eastern India with suitable winter crop and appropriate crop establishment technique. *Environmental Science and Pollution Research* **26**: 29,409–29,423.

Kumar, R., Mishra, J.S., Rao, K.K., Mondal, S., Hazra, K.K., Choudhary, J.S., Hans, H. and Bhyatt, B.P. 2020. Crop rotation and tillage management options for sustainable intensification of rice-fallow agro-ecosystem in eastern India. *Scientific Reports* **10:** 11,146.

Kumar, S.P., Murthy, K.V.R., Ramana, A.V. and Revathi, T. 2018. Yield and quality of rice- greengram system as influenced by zinc fortification. *International Journal of Current Microbiology and Applied Sciences* **6**(Special Issue): 2,597–2,605.

Lal, R.R. and Verma, P. 2007. *Post-Harvest Management of Pulses*, ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh, India.

Layek, J., Chowdhury, S., Ramkrushna, G.I. and Das, A. 2014. Evaluation of different lentil cultivars in lowland rice fallow under no-till system for enhancing cropping intensity and productivity. *Indian Journal of Hill Farming* **27**(2): 4–9.

Lhungdim, J., Singh, Y., Kumar, P. and Chongtham, S.K. 2013. Integrated weed management of lambsquarter and nut sedge in lentil. *Indian Journal of Weed Science* **45**(3): 192–197.

Maji, S., Das, A., Nath, R., Bandopadhyay, P., Das, R. and Gupta, S. 2019. Cool season food legumes in rice fallows: an Indian perspective. (In) *Agronomic Crops,* pp. 541–605, Hasanuzzaman, M. (Eds). Springer, Singapore.

Maruthupandi, K., Veeramani, A., Sanjevikumar, A. and Ramadas, S. 2017. Effect of methods and time of sowing on growth indices in rice-fallow blackgram (*Phaseolus mungo* L.) under machine transplanted rice system. *Advance Research Journal of Crop Improvement* **7**(1): 129–133.

Mishra, J.S. and Singh, V.P. 2011. Effect of tillage and weed control on weed dynamics, crop productivity and energy-use efficiency in rice (*Oryza sativa*)-based cropping systems in Vertisols. *Indian Journal of Agricultural Sciences* **81**: 129–133.

Mohan, R.J., Sangeetha, A., Narasimha, H.V. and Tiwari, B.K. 2011. Post-harvest technology of pulses. *Pulse Foods* **40**: 171–192.

Mondal, S. and Bose, B. 2019. Impact of micronutrient seed priming on germination, growth, development, nutritional status and yield aspects of plants. *Journal of Plant Nutrition* **42**(19): 2,577–2,599.

Mondal, S.S. and Ghosh, A. 2005. Integrated nutrient management on the productivity and nutrient uptake of crops in rice–lathyrus (as utera)–sesame cropping system under rainfed lowland ecosystem. *Journal of Crop and Weed* **1**: 12–16.

Monjappa, K. and Koppad, A.G. 2002. Performance of pulse and oilseed crops in paddy fallows with protective irrigation from farm pond in hill zone of Karnataka. *Journal of Farm Sciences* **15**(3): 575–576.

Nawaz, J., Hussain, M., Jabbar, A., Nadeem, G.A., Sajid, M., Subtain, M.U. and Shabbir, I. 2013. Seed priming – A technique. *International Journal of Agriculture and Crop Sciences* **6**(20): 1,373–1,381.

Parida, P., Behera, B. and Behera, S.D. 2020. Weed management in rice (*Oryza sativa*)-fallow for enhancement in productivity and profitability of rice–zero till *toria* (*Brassica campestris*) system. *Indian Journal of Agronomy* **65**(1): 10–16.

Patil, J.R., Thakur, V.S., Teggelli, R.G. and Deepak. 2018. Yield improvement of black gram through foliar application of pulse magic in North Eastern dry zone of Karnataka, *International Journal of Advanced Biological Research* **8**(1):

110–112.

Praharaj, C.S., Singh, U., Singh, S.S., Singh, N.P. and Shivay, Y.S. 2016. Supplementary and life-saving irrigation for enhancing pulses production, productivity and water-use efficiency in India. *Indian Journal of Agronomy* **61**: 249–261.

Quddus, M.A., Naser, H.M., Hossain, M.A. and Hossain, M.A. 2014. Effect of zinc and boron on yield and yield contributing characters of lentil in low Ganges river floodplain soil at Madaripur, Bangladesh. *Bangladesh Journal of Agricultural Research* **39**(4): 591–603.

Rahmianna, A.A., Adisarwanto, T., Kirchhof, G. and So, H.B. 2000. Crop establishment of legumes in rainfed lowland rice-based cropping systems. *Soil and Tillage Research* **56**: 67–82.

Ramesh, T. and Rathika, S. 2015. Weed management in rice fallow blackgram through post-emergence herbicides**.** *Madras Agricultural Journal* **102**(10–12): 313–316.

Ramesh, T., Rathika, S., Parthipan, T. and Ravi, V. 2016. Productivity enhancement in blackgram through refinement of nutrient management under rice-fallow condition. *Legume Research* 39 (1): 106–109.

Rampal, P. 2017. Situational analysis of pulse production and consumption in India. Leveraging agriculture for nutrition in South Asia (LANSA) Working paper series 2017(20): 1–46.

Rao, D.S.N., Naidu, T.C.M. and Rani, Y.A. 2015. Effect of foliar nutrition on water potential, photosynthetic rate, dry matter production and yield of mung bean under receding soil moisture condition. *International Journal of Applied Biology and Pharmaceutical Technology* **6**(2): 16–22**.**

Rao, K., Naidu, T., Jogi, G. and Subbaiah, G. 2006. Effect of foliar application of micronutrient on yield and yield attributes on Indian mustard (*Brassica juncea* L.). *Agricultural Science Digest* **26**(2): 144–146.

Rautaray, S. K. 2008. Productivity and economics of rice-based *utera* crops for lower Assam. *Journal of Food Legumes* **21**: 51–52.

Reddy, A.A. and Reddy, G.P. 2010. Supply side constraints in production of pulses in India: Case study of lentils. *Agricultural Economics Research Review* **23**: 129–136.

Reddy, K.R. and Reddy, P.S. 2017. Identification of rice fallows using remote sensing techniques: A case study in Telangana. *Agriculture Update* **12**(6): 1,724–1,729.

Sasikala, K., Boopathi, S.N.M.R. and Ashok, P. 2014. Studies on economic viability of weed management practices in zero till sown rice-fallow blackgram (*Vigna mungo* L.). *International Journal of Scientific and Research Publications* **4**(3): 1–5.

Sharath, S.Y., Kumar, S., Kar, A. and Arya, P. 2019. Econometric analysis of import demand of pulses in India. *Journal of Pharmacognosy and Phytochemistry* **8**(2): 131–135.

Sharon, M.E.M., Abirami, C.V.K., Alagusundaram, K. and Sujeetha, J.A. 2015. Safe storage guidelines for blackgram under different storage conditions. *Journal of Stored Products and Postharvest Research* **6**(5): 38–47.

Shashikumar, Basavarajappa, R., Salakinkop, S.R., Hebbar, M., Basavarajappa, M.P. and Patil, H.Y. 2013. Influence of foliar nutrition on performance of blackgram (*Vigna mungo* L.), nutrient uptake and economics under dry land ecosystems. *Legume Research* **36**(5): 422–428.

Singh, A.K. 2012. Probable agricultural biodiversity heritage sites in India: XIII. Lower Gangetic Plain or Delta Region. *Asian Agri-History* **16**(3): 237–260.

Singh, A.K., Manibhushan, Bhatt, B.P., Singh, K.M. and Upaadhaya, A. 2013. An analysis of oilseeds and pulses scenario in Eastern India during 2050–51. *Journal of Agricultural Science* **5**(1): 241–249.

Singh, A.K., Chakraborti, M. and Datta, M. 2014a. Improving rice-based cropping pattern through soil moisture and integrated nutrient management in mid-tropical plain zone of Tripura, India. *Rice Science* **31**(5): 299–304.

Singh, H., Jassal, R.K., Kang, J.S., Sandhu, S.S., Kang, H. and Grewal, K. 2015. Seed priming techniques in field crops – A review. *Agricultural Reviews* **36** (4): 251–264.

Singh, R., Babu, S., Avasthe, R.K. and Yadav, G.S. 2018. Crop diversification and intensification for enhancing livelihood security in Sikkim. ICAR-National Organic Farming Research Institute, Tadong, Gangtok, Sikkim, India.

Singh, R.N., Praharaj, C.S., Kumar, R., Singh, S.S., Kumar, N. and Singh, U. 2017. Influence of rice (*Oryza sativa*) habit groups and moisture conservation practices on soil physical and microbial properties in rice + lathyrus relay cropping system under rice-fallows in eastern plateau of India. *Indian Journal of Agricultural Sciences* **87**(12): 1,633–1,639.

Singh, K.M., Kumar, M. and Choudhary. S.K. 2018. Effect of weed management practices on growth and yield of lentil (*Lens esculenta* Moench). *International Journal of Current Microbiology and Applied Sciences* **7**: 3,290–3,295.

Singh, M.K., Singh, Y.K., Meena, R.A., Kumar, P., Rajput, B.S. and Nath, T. 2014b. Effect of tillage and mulch in mustard crop under rainfed conditions. *International Journal of Tropical Agriculture* **32**(1–2): 251–254.

Singh, N.P., Praharaj, C.S. and Sandhu, J.S. 2016. Utilizing untapped potential of rice-fallow of East and North-east India through pulse production. *Indian Journal of Genetics and Plant Breeding* **76**(4): 388–398.

Singh, P., Shahi, B. and Singh, K.M. 2017. Enhancing pulses production in Bihar: constraints and strategies for sustainable growth. *SSRN Electronic Journal,* pp.19.

Singh, S.K., Verma, S.C. and Singh, R.P. 2004. Residual effect of organic and inorganic sources of nutrients in lowland rice on succeeding lentil. *Indian Journal of Agricultural Research* **38**(2): 121–125.

Singh, S.S., Kumar, N., Praharaj, C.S. and Singh, N.P. 2017. Agrotechnologies for enhancing pulses production in rice-fallows. ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh 208 024, India, pp. 36.

Singh, S.S., Singh, A.K., Kumar, S., Mishra, J.S., Haris, A.A., Sangle. U.R., Bhatt. B.P.**,** Singh, S.K., Yadav, A., Singh**,** U.S. and Singh, S. 2015. Performance of lentil under rice–lentil under different tillage in drought-prone rainfed ecosystem of Bihar. *Journal of Agri Search* **2**(4): 263–268.

Singh, A.K., Meena, M.K., Bharati, R.C. and Gade, R.M. 2013. Effect of sulphur and zinc management on yield, nutrient uptake, changes in soil fertility and economics in rice (*Oryza sativa*)–lentil (*Lens culinaris)* cropping system. *Indian Journal of Agricultural Sciences* **83**(3): 344–348.

Singh, T. and Satapathy, B.S. 2019. Intensification of pulses and oilseeds in rice fallows. *Indian Farming* **69**(10): 31–34.

Siyami, R., Mirshekari, B., Farahvash, F., Rashidi, V. and Tarinelad, A. 2018. The effect of physical priming of seed on traits and yield of corn (*Zea mays* L.) under water deficit conditions in Iran. *Applied Ecology and Environmental Research* **16**(1): 617–627.

Suhathiya, K. and Ravichandran, M. 2018. Effect of foliar application of DAP and micronutrients on crop growth attributes and yield of rice fallow blackgram (*Vigna mungo* L.). *International Journal of Advanced Research in Biological Sciences* **5**(4): 72–76.

Veeramani, A., Padmanathan, P.K, Pandi, P. and Sridhar, N. 2018. Development and performance evaluation of rice-fallow pulse planter for wetland rice ecosystem. *International Journal of Management and Applied Science* **4**(1): 32–36.

Vijayakumar, M. and Jalaluddin, S.M. 2016. Physiological approaches for maximization of yield in horsegram (*Macrotyloma uniflorum* L.). *Journal of Chemical, Biological and Physical Sciences* **6**(3): 997–1,003.

Xu, Q., Liu, F., Chen, P., Jez, J.M. and Krishnan, H.B. 2017. β-*N*-Oxalyl-l-α,β-diaminopropionic Acid (β-ODAP) content in *Lathyrus sativus*: The integration of nitrogen and sulfur metabolism through β-cyanoalanine synthase. *International Journal of Molecular Science* **18**(3): 526.

Yadav, G.S., Datta, M., Saha, P. and Debbarma, C. 2015. Evaluation of lentil varieties/lines for utilization of rice fallow in Tripura. *Indian Journal of Hill Farming* **28**(2): 90–95.

Yadav, G.S., Lal, R., Meena, R.S., Datta, M., Babu, S., Das, A., Layek, J. and Saha, P. 2017. Energy budgeting for designing sustainable and environmentally clean/safer cropping systems for rainfed rice-fallow lands in India. *Journal of Cleaner Production* **158**: 29–37.

Yumnam, J.Y., Bhuyan, S.I., Khan, M.L. and Tripathy, O.P. 2011. Agro-diversity of East Siang-Arunachal Pradesh, Eastern Himalaya. *Asian Journal of Agricultural Sciences* **3**(4): 317–326.