SOUVENIR

4th International Agronomy Congress

Agronomy for Sustainable Management of Natural Resources, Environment, Energy and Livelihood Security to Achieve Zero Hunger Challenge

November 22-26, 2016, New Delhi, India

IAC

Organizers

The Indian Society of Agronomy
Indian Council of Agricultural Research
New Delhi 110 012, India

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Indian Society of Agronomy · 1955

Collaborators

ICAR - IARI, New Delhi

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International Maize and Wheat Improvement Center

IRRI
International Rice Research Institute

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Trust for Advancement of Agricultural Sciences, New Delhi

ICARDA

National Academy of Agricultural Sciences, New Delhi

Published in November 2016

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Organizing Secretary
Fourth International Agronomy Congress
Indian Society of Agronomy
Division of Agronomy
ICAR-Indian Agricultural Research Institute
New Delhi 110 012, India

Printed at the Cambridge Printing Works, B-85, Naraina Industrial Area, Phase-II, New Delhi 110 028, India

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4th International Agronomy Congress (November 22–26): 1—11 (2016)

Talent search for quality human resource in agricultural sciences

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INTRODUCTION

Agriculture contributes nearly 14% to GDP and livelihood source of more than 50% of population in India. It is considered an engine for economic growth of the country as it provides raw material for major industries such as fibre, sugar, textiles, jute, food processing etc. Human resource development and its judicious deployment will be crucial for food nutrition, environment and livelihood security in future. Indian Council of Agricultural Research (ICAR) is the largest research, education and technology transfer system in the world in agricultural research sector. Human resource development and selecting the right person for the right job in an organisation like ICAR require constant realignment with changing organizational needs and technological paradigms. Agricultural Scientists Recruitment Board (ASRB) was established in 1973 as an independent body to recruit scientists and develop career assessment and promotion systems. Since its establishment, ASRB has constantly been revisiting, reforming and refining its various examination, recruitment and assessment related strategies for induction of human resource in agricultural and allied sciences. Resultantly standardised and codified eligibility parameters, specified syllabi standards, scientific and objective merit appraisal score card systems characterize the transparent present day working of ASRB. Vast expansion in scope and scale in the field of examination, selection and promotion has been one of the important features over this period of time. Innovative ICT technologies are being employed to achieve the highest standards of transparency, objectivity and efficiency. Incidentally, ASRB has already taken lead in this regard by adopting online registration of applications and payment and conduct of examinations.

Recruitment and promotion system

Agricultural Scientists Recruitment Board, an independent recruitment body for the Indian Council of Agricultural Research (ICAR) was established by the Government of India in 1973 with the then member of UPSC Dr M. L. Sahare as its founder Chairman. As per its mandate, the ASRB plays a key role in recruitment of best quality scientists and other management personnel for the ICAR headquarters and research Institutes across the country. In addition, the Board aids and advises the Council in evolving and implementing policies related to induction of human resource and its development including the Career Advancement Schemes (CAS) for ARS Scientists. Ever since its establishment, more than 43 years ago, the ASRB has consistently been endeavouring to reform and refine talent-search strategies to meet existing as well as emerging needs of the national agricultural research and education system (NARES). Looking to high standards maintained by ASRB in its recruitment system, delivery, transparency and efficiency, ICAR in the recent past entrusted all recruitment in the administrative, technical and supporting staff categories to the Board.

Agricultural Research Service (ARS) examination

History and changes over period

The Agricultural Research Service was created on 2nd October, 1975 with the major aims: foster co-operation in place of unhealthy competition; enable scientists to get the highest salary possible within the system while remaining rooted to work in their respective discipline/field, thereby eliminating both the undue importance attached in the past to research management posts and the quest for such positions purely for advancement of salary; promote an outlook where solving a specific field problem through interdisciplinary team work is regarded as the primary goal of research than the worship of a discipline or publication of papers; promote horizontal and vertical mobility and adequate attention to neglected and backward areas; link rights and responsibilities and instil through the five-year assessment system the conviction that dedicated and efficient discharge of responsibilities alone would be the means of securing professional advancement.

The first ARS examination was notified in 1975 and conducted in 1976. The ARS examination held in 1976 represented a very well thought out and comprehensive first ever talent search endeavour in agriculture and allied

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disciplines at the national level. As a unique feature, it had centres not only in India but also abroad at prominent international cities like London, Moscow and Washington. The philosophy behind this initiative was to attract talent from abroad.

Committees on ARS system

During the decade (2003 to 2014), many committees were appointed to suggest the revamp of ARS system. First such major committee (2005) headed by Dr R.A. Mashelkar recommended that: 5 yearly assessment system should be reintroduced; UGC system be discarded; ASRB should be like UPSC in all manners; suitable experts to be identified for interviews; short term hiring of scientists like Quick Hire System of CSIR. Task Group on Revamping and Refocusing of National Agricultural Research constituted by the Planning Commission and headed by Dr M.S. Swaminathan gave the following major recommendations in 2005: ASRB should function like UPSC; remove the distortions to restore the damaged 'scientist-centred system' of professional recruitment and advancement; decentralize assessment system and develop specific evaluation criteria for different fields like research, education, extension etc; Quick Hire System of CSIR should be introduced in ICAR; UGC pattern should be done away with. To implement these recommendations, a committee chaired by Dr J.C. Katyal, former DDG (Education), ICAR and then VC, CCSHAU, Hisar was appointed which recommended in 2006 that: revert back to S-1 to S-8 system with central pay scales for new recruits only; existing scientists to continue in UGC system without option to switch over to new system; different residency period of 3, 4 and 5 years for different grades; and no direct recruitment in S-2 and S-3 grades. Other committees constituted by ICAR and ASRB who examined the structure of ARS from time to time and gave recommendations included Dr Kirti Singh first and second Committee (2002 and 2004), Dr. Sawant Committee (2006), Dr Paroda committee on ARS (2009 & 2011), ARS committee (2011) and Dr Modayil committee (2012). The major recommendations given by these committees related to number of disciplines, syllabi, periodicity, number of papers, viva-voce, grouping of disciplines and related aspects.

Last major and comprehensive exercise for reforms in ARS was carried out by Dr Paroda committee on ARS (2011), which recommended a radical overhaul in ARS system, examination and qualifications being the main focus. Main recommendations regarding ARS/NET are: 56 ARS disciplines grouped under 7 core areas; 12 disciplines of general Engineering and Home Science to be excluded; 4 disciplines to merge in Soil Science, Genetics and Plant Breeding merged; all Extension and Economics disciplines merged respectively; Agricultural Physics to merge in Agricultural Meteorology; New disciplines like Spices, Plantation, Medicinal & Aromatic Plants, Fish Nutrition, Fish Health and Fish Genetics & Breeding; Renaming Forestry as Agroforestry; and Demerging Agricultural Structure & Process Engineering in two separate disciplines. These recommendations were examined by the ICAR-ARS Committee (2011), which reduced disciplines from 56 to 55 and approved the proposed qualifications. To implement this, ASRB Chairman appointed Dr M.J. Modayil Committee (2012) which further recommended delinking NET from ARS, holding NET examination twice a year in each of the 55 ARS disciplines instead of groups, having completely uniform syllabi for NET and ARS, and dispensing with pre-verification by the Board for issuing NET certificates. As of now, ARS is being conducted in 55 disciplines for inducting fresh agricultural scientists into the ICAR system. ARS Scheme had been changed over the years (Table 1). The current pattern is being followed since 2012.

When ARS was started in 1976, essay, general knowledge and paper on general agriculture were integral part of

Table 1. Changes in ARS exam pattern over the period (1975 to 2016)

Question Paper Type	Year				
	1976	1990	2005	2010	2012
Essay	100	—	—	—	—
GK (Objective Type)	100	200	—	—	—
Paper-I (General)	—	—	200	—	—
Paper-I (Professional)	200	200	—	—	—
Paper-II (Professional)	200	200	200	—	—
ARS Prelim (Objective)	—	—	—	*200	*150
ARS Main (Professional)	—	—	—	240	240
Viva-voce	100	100	100	60	60
Total	700	700	500	300	300

* Only for qualifying to ARS Main (Professional) examination

the examination system. However, over the period these papers were discontinued. There is a need to relook the examination system and include general knowledge and essay part of the examination system.

Trends in ARS examinations over the years 2006–2015

Table 2 below shows the number of ARS vacancies advertised and filled year-wise during last 10 years. The maximum number of vacancies advertised was in 2013. During the last about 10 years, against 3036 posts advertised, 2256 could be filled up, thus leaving almost 25% posts unfilled. Most of the posts which remained unfilled are constituted by the disciplines of agricultural statistics and some engineering subjects. The information in Table 2 reveals wide year to year variation in posts advertised. A long-term planning may be called for to rationalise this year to year variation so that passing out candidates each year have a level field of competition.

University-wise selected candidates in ARS

There is evidently huge disparity and variation in contributions to ARS among the SAUs vis-a-vis Deemed Universities of ICAR and among the SAUs themselves. While there could be many reasons like varying resources, opportunities, exposure, facilities; but inbreeding, poor teacher quality, teacher shortage etc. are also much to blame. Table 3 shows that out of 2256 recommended candidates, 77% were from top eleven State Agricultural Universities (SAUs) & ICAR Deemed to be Universities, 14% from rest of SAUs and only 9% were from General Universities. Of the 2256 candidates selected during last 10 years, 960 were from the four ICAR Deemed to be Universities. IARI, New Delhi (482 selections) followed by CIFE, Mumbai (243) topped the list. This imbalance requires redressal.

Table 2. ARS vacancies advertised and filled (2006–15)

Year	Total advertised	Total filled	Filled %
2006	160	145	90.6
2007	220	191	86.8
2008	283	249	88.0
2009	439	365	83.1
2010	290	214	73.8
2011	303	183	60.4
2012	431	319	74.0
2013	506	362	71.5
2014	307	228	74.3
2015	97	Under process	–
Total	3036	2256 (excluding 2015 ARS Exam)	74.3

State-wise selected candidates in ARS

About 84% of the successful candidates in ARS came from 11 states (Karnataka, Kerala, Tamil Nadu, Rajasthan, Uttar Pradesh, Andhra Pradesh, Bihar, Maharashtra, West Bengal, Odisha and Manipur). States like Punjab, Jammu and Kashmir, Gujarat, Sikkim, and Andaman & Nicobar Islands had very less representation in the list of successful candidates. Tamil Nadu (328) followed by Karnataka (239) contributed the maximum candidates to ARS during last 10 years.

Performance of female candidates in ARS (2006-2014)

Share of female candidates in ARS increased from 8% in 2006-07 to 37% in 2012-13 (Fig. 1). During 2013-14 and 2014-15 too the women candidates got 31% and 32% share of total selected candidates, respectively. This is a good sign and a welcome step towards gender empowerment in agricultural and allied sciences.

Recommendations of Brain Storming Workshop on Talent Search at NDRI, Karnal

A two days Brainstorming-cum-Workshop (January

Table 3. University-wise successful candidates in ARS (2006-2014)

S.No.	Name of university	Total	S.No.	Name of university	Total
	State Agricultural Universities			*Deemed to be Universities*	
1	TNAU, Coimbatore	173	1	IARI, New Delhi	482
2	UAS, Bangalore	134	2	CIFE, Mumbai	243
3	GBPUA&T, Pantnagar	130	3	IVRI, Izatnagar	155
4	ANGRAU, Hyderabad	77	4	NDRI, Karnal	80
5	UAS, Dharwad	66		Total	960
6	CCSHAU, Hisar	63		*Agricultural Faculty*	
7	CSAUA&T, Kanpur	32	1	BHU, Varanasi	45
8	KAU, Trichur	32	2	AMU, Aligarh	2
9	BCKV, Nadia	31	3	Visva Bharti	1
10	PAU, Ludhiana	30	4	Nagaland University	0
11	SKRAU, Bikaner	30		Total	48
	Top eleven SAUs	798		General Universities	134
	Rest of SAUs	316		Total	2256

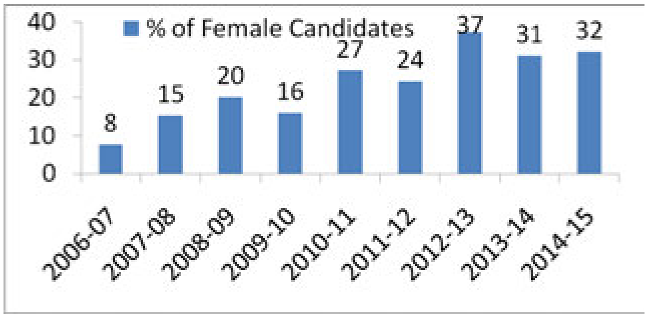

Fig. 1. Performance of female candidates in ARS (2006-2015)

16–17, 2015) was organized by ASRB at National Dairy Research Institute, Karnal (Haryana) on **"Optimizing talent search for the National Agricultural Research & Education System (NARES)"** to make the recruitment processes furthermore transparent, fair, objective, inclusive and effective in the larger interest of delivering the highest quality services to the farmers and the farm sector by the agricultural scientific community. The recommendations regarding ARS were:

- ARS examination must be held as a matter of course each year with a fixed calendar of dates. This would make the prospective aspirants to keenly look for the examination thereby enhancing and enriching the participation as well as the scale and quality of competition.
- Ways and means should be found to have the examination of ARS conducted regularly each year in each of the approved disciplines/ 'schools' of specializations irrespective of the availability or otherwise of the vacancies.
- ARS based recruitment may continue to be made as at the present centrally by ASRB, but instead of cadre based, the posts should be treated as institute based i.e. the institute on the strength of which these are born and so notified for filling up. This would encourage the much needed institute alignment allegiance and local research prospective as per the given institute's mandate. In addition, it would free the Council from tedious all time inter institutional transfer issues on one or the other ground as per individual reasons. Transfers to other institutes would then be open only through selections on duly advertised vacancies of a particular institute and thus at tuned to 'Institutional needs' instead of 'Individual needs' as at the present in most cases.
- Once reviewed and revised and put in place, the scheme of disciplines and syllabi of ARS & NET, should not be put to frequent changes. Such reasonable consistency would ensure stability and resulttantly attract the best quality human resource.
- To begin with in 1976, the ARS examination had well defined components of tests in Essay writing and General Knowledge. In the process of frequent changes over the years, both the above components have got completely eliminated. Focus on specialization is appreciable but in the context of emerging national and global research & technology paradigms, the need for general socio-economic understanding and communication skills can not altogether be ignored. While the component of Essay writing needs to be restored as such, in the case of General Knowledge, if not General Studies, at least a component

Table 4. State-wise candidates recommended in ARS (2006-2014)

S.No.	States Name	Total	S.No.	States Name	Total
1.	Tamil Nadu	328	18	Delhi	27
2.	Karnataka	239	19	Jammu & Kashmir	24
3.	Kerala	207	20	Pondicherry	22
4.	Rajasthan	192	21	Chhattisgarh	18
5.	West Bengal	184	22	Asom	18
6.	Bihar	157	23	Arunachal Pradesh	15
7.	Maharashtra	154	24	Punjab	15
8.	Uttar Pradesh	150	25	Meghalaya	13
9.	Andhra Pradesh	92	26	Nagaland	9
10.	Odisha	83	27	Mizoram	8
11.	Haryana	60	28	Gujarat	8
12.	Manipur	49	29	Sikkim	5
13.	Uttarakhand	37	30	Lakshadweep	3
14.	Madhya Pradesh	37	31	Telangana	2
15.	Himachal Pradesh	35	32	A& N Islands	1
16.	Jharkhand	33		Total	2256
17.	Tripura	31			

needs to be integrated on 'General Agriculture' to sensitise the aspirants on the basic knowledge on Indian and global agriculture in general for fostering a holistic understanding and aptitude in the field.

- A common cut off should not be applied in ARS across the disciplines. However discipline-wise/ 'school-wise' cut off should be applied coupled with the criteria of a fixed number of candidates per post in each category. A 'School' would each represent groups of related disciplines with their relevant basic sciences.
- To adequately cover all the emerging specializations, many of which cut across number of disciplines, the only viable and effective way is to consolidate and reduce the number of disciplines in case of both ARS & NET into limited number of specified broad groups or 'Schools' comprising related disciplines along with their relevant basic sciences.
- Large number of candidates sit in the all India open ARS competitive examination. A limited number in each discipline qualifies for the interview/viva-voce stage out of which a smaller number are finally recommended to ARS as per the notified vacancies every year. However, such candidates who are not finally recommended for appointment but have qualified and appeared in the interview/viva-voce too are nationally benchmarked in terms of their merit having made the cut through All India open competitive examination. It would, therefore, be proper that the SAUs use such candidate lists who are so nationally benchmarked in order to select candidates further at their level to posts like Assistant Professors and lecturers. Apart from nationally benchmarked merit, this would also act against the present malaise of inbreeding in SAUs that is already impacting their educational and in particular teaching quality standards.
- ARS being an All India Open Competition, the ASRB after subjecting the candidates to a rigorous examination and selection process, recommends the selected candidates in order of merit in each discipline and category against the given vacancies for appointment. It would, therefore, be fair and just that their posting is linked to merit and their choices within the available vacancies in their respective disciplines. Such merit linked postings would add to the competition and to the resultant quality and competence of the inducted human resource.

National Eligibility Test (NET) examination

History and changes over period

On the proposal of State Agricultural Universities (SAUs) and with a view to ensure high quality standards in national agricultural education, from 1990, ASRB took upon the responsibility to conduct National Eligibility Tests to provide certificates to qualifying candidates to become eligible for posts of lecturers in SAUs in Agriculture and allied disciplines. First NET examination was held in 1992 along with ARS examination at 22 centres. In the first NET, 786 candidates qualified. In 1994, ASRB was assigned SRF examination too. This was held in combination with the ARS/NET examination. At first, interviews were held by ASRB but later lists of qualifying candidates in examinations were forwarded to Education Division of ICAR to conduct interviews for award of SRFs. Last SRF examination held by ASRB was in 2004.

Trends in NET examinations over the years 2006-2015

The disciplines attracting the maximum candidates in NET examinations are given in Table 5. Agricultural Biotechnology followed by the subject of Agronomy attracted the maximum candidates. The other disciplines where the maximum candidates appeared during last 10 years include Soil Science, Agricultural Entomology, Food Science & Technology, Plant Pathology, Agricultural Microbiology, Horticulture and Crop improvement.

Table 5. Disciplines attracting the highest number of applicants (2006-2015)

Discipline	Appeared
Agricultural Biotechnology	17488
Agronomy	8639
Soil Science	7484
Agricultural Entomology	6813
Food Science & Technology	6806
Plant Pathology	6439
Agricultural Microbiology	6050
Horticulture	5563
Crop Improvement	5532

Pass percentage in NET

Significant year to year fluctuation in pass percentage of candidates was observed during last 10 years (Table 6). Only 5.6% of the total candidates appeared in 2006 qualified. The percentage of qualified candidates was the highest (23.8%) in 2010. There seems a strong need to improve upon the education system in SAUs to improve qualified percentage in NET examination.

Performance of women candidates

Number of male and female candidates qualified in NET examinations conducted during 2013-2015 is reported in Fig. 2. There seems an increasing trend in female candidates qualifying the NET examination.

Table 6. Pass percentage of NET (over the years 2006-2015)

Year	Candidates appeared	Candidates qualified	Qualified (%)
2005	12524	1760	14.1
2006	10973	618	5.6
2007	10070	2311	22.9
2009	12402	2623	21.1
2010	20605	4904	23.8
2011	20935	2342	11.2
2012	22537	1845	8.2
2013	20870	2596	12.5
2014 -I	14178	2712	19.1
2014-II	18415	4225	22.9
2015	21478	4148	19.3

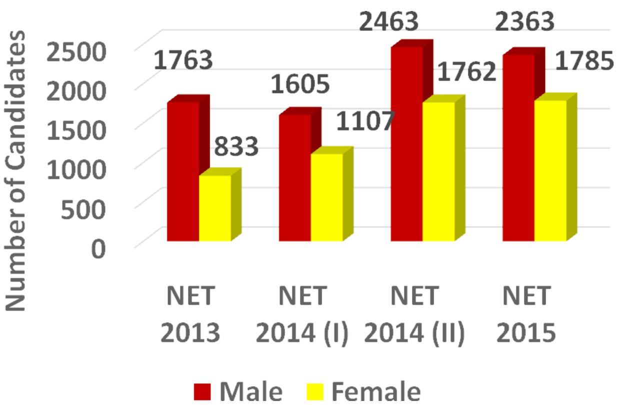

Fig. 2. Gender–wise details of successful candidates in NET (over the years 2013-2015)

University-wise trends in NET examination 2015

Out of 6,937 qualified candidates, 35% were from ten State Agricultural Universities and four Deemed to be Universities of ICAR and the remaining 35% from rest of SAUs and 30% from General Universities (Fig. 3).

The list of top ten contributing State Agricultural Universities is shown in Table 7 and ten least contributing State Agricultural Universities in NET 2014 is shown in

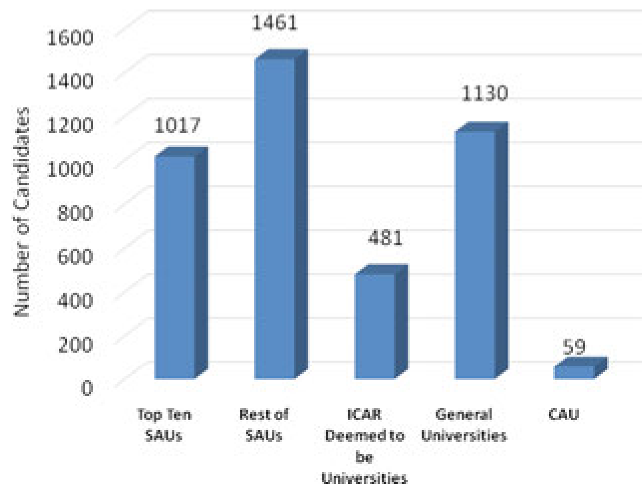

Fig. 3. Universities-wise performance in NET 2015

Table 8. Tamil Nadu Agricultural University, Coimbatore followed by University of Agricultural Sciences, Bangalore topped the list with 158 and 137 candidates, respectively.

Direct recruitment/ lateral entry to scientific positions

History and changes over period

Many posts at higher levels in ICAR were lying vacant in 1970s. ASRB was instrumental in bridging this initial management and leadership gap. Posts ranging from S-2 to Deputy Director General (DDG) were advertised and filled up. More than 270 such posts were filled up during the initial ten years through open advertisements. Posts in grades S-4 to S-8 were designated as Research Management Positions (RMPs). Before creation of ASRB, Class I and higher posts were filled at ICAR level, while lower posts were filled at Institute level. By filling up this managerial level gap, ASRB strengthened leadership culture in the system since recruitments were made at national level by evolving and applying uniform selection parameters and standards.

Table 7. Top ten contributing SAUs in NET 2015

S. No.	University	No. of qualified candidates
1	Tamil Nadu Agricultural University	158
2	University of Agricultural Sciences, Bangalore	137
3	Govind Ballabh Pant University of Agriculture & Technology	122
4	Acharya NG Ranga Agricultural University	103
5	University of Agricultural Sciences, Dharwad	94
6	Punjab Agricultural University	85
7	Chaudhary Charan Singh Haryana Agricultural University	83
8	Bidhan Chandra Krishi Viswavidyalaya	81
9	Dr YS Parmar University of Horticulture & Forestry	78
10	University of Horticultural Sciences, Bhagalkot	76
	Total	1017

Table 8. Ten least contributing SAUs in NET 2015

S. No.	University	No. of qualified candidates
1	UP Pandit Deen Dayal Upadhaya Pashu Chikitsa Vigyan Vishwa Vidyalaya evam Go Anusandhan Sansthan	10
2	Uttar Banga Krishi Viswavidyalaya	10
3	Agriculture University Kota	8
4	Uttarakhand University of Horticulture and Forestry	8
5	Birsa Agricultural University	6
6	Nanaji Deshmukh Veterinary Science University	5
7	Chhattisgarh Kamdhenu Vishwavidyalaya	4
8	Kerala University of Fisheries & Ocean Studies	3
9	Sri Konda Laxman Telangana State Horticultural University	2
10	Manyavar Shri Kanshiram Ji University of Agriculture and Technology	1
	Total	57

Table 9. Revised score card for screening

Criteria		Sr. Scientist	Pr. Scientist	HOD/HRS/PC/ NC/ JD of ICAR Inst. other than NIs/DUs	PD/DIR/ JDNI/ ADG	DDG/ DNI/ND
1.	Academic Qualification	15	6	2	2	2
2.	Experience in relevant field	10	10	12	15	15
3.	Service in Remote Areas/ Disadvantaged Areas (Difficult Areas)/KVKs*	6	5	3	2	2
4.	Recognitions & Awards/ Special Attainments	9	12	15	20	20
5.	Teaching/Research/ Extension	30	27	25	23	15
6.	Publications	20	25	25	20	20
7.	Institution Building/ Service functions/ Resource generation	10	15	18	18	18
8.	RMP Experience	0	0	0	0	8
	GRAND TOTAL	100	100	100	100	100

*Proposed benefit to be availed once during the service

Score card system

Score card system was initially adopted in June, 2002 on the recommendations of Sastry Committee for direct recruitment/ lateral entry posts of Sr. Scientists and up to Deputy Director Generals (DDGs) and Directors of National Institutes. 25 marks out of 100 were reserved for interview by the Selection Board. Initial Score Card had four major components: academic qualifications; experience; publications; and awards etc. Following were some major inadequacies experienced in the initial score card overtime.

- Marks assigned in the Score Card became deciding factor overriding the interview process
- 60% cut-off marks (45 marks out of 75), many time resulted in no candidate being able to make it for interview for a particular post
- Even for DDG level posts, marks obtained at 10 + 2 level were given weightage which appeared inappropriate
- Cases where a candidate screened for various posts applied and scoring different marks by different screening committees posed administrative issues

Eventually, the further refined score card adopted in the year 2007 had prescribed distribution of scores under various parameters specific to different posts having due regard to the weightage of a parameter appropriate to the level of respective post. Cut off marks were kept 45% for non-RMP and 50% for RMP positions and top 10 ranking candidates were called for interview subject to crossing minimum cut off marks. Pursuant to the recommendations of Dr Paroda Committee on ARS, the Score Card was further reformed and refined in 2012, and composite score card based on 10 parameters instead of earlier 14 parameters was brought into effect from 2013 onwards.

Score card for direct recruitment / lateral entry at each level has been revised to have adequate provisions to recognize and reward exceptional contributions at local grassroot level agriculture particularly for the scientists working in KVK's where such contributions may not receive due international recognition or publications for obvious reasons. An adequate and specific provision on the lines of 'remote areas' etc. has been made to recognize and reward such contributions in the score card to encourage and strengthen the grassroot level research, development and technology delivery systems and services to the farm sector. The revised score card being implemented from 2016 onwards is presented in Tables 9 and 10. The new score card will now have 8 parameters instead of earlier 10 parameters.

Attracting talent from abroad and outside the ICAR system

To tap exceptional talent, the existing eligibility criteria for direct recruitment / lateral selection to senior scientific positions provide for an alternative eligibility. However, this alternative eligibility for 'Eminent Scientists' has a further inbuilt condition requiring a prescribed length of RMP service. The parameters to identify 'eminence' are already comprehensively defined by the ASRB and the same appear in order. However, the mandatory RMP service requirement acts as a potent restricting factor in attracting exceptional talent from out of the scientists in the streams of professors or national professors both within India or abroad or those working abroad or in other scientific systems where there happen to be strictly no RMP positions. This virtually renders the alternative provision as ineffective in tapping exceptional talent from outside the normal institutional streams and hence does not really serve the intended purpose. While prescribing an appropriate total length of scientific service or even that in the grade and position of a Professor may not be out of place, the condition of RMP service needs to be removed altogether to attract and tap exceptional talent both from within the system and outside as well as abroad. The alternative eligibility conditions for the eminent scientists so provided as an alternative mode in the existing rules as such requires immediate revision on the above lines. In the recent past, 13 candidates working abroad were selected as senior scientists in ICAR laboratories by providing an alternate qualification window.

Re-visiting tenure renewal system

At the present, ICAR rules provides for 'tenure renewal' on RMP and senior RMP positions through a mechanism at ICAR level which though fairly elaborate but is rather 'Individual centric' instead of 'System centric'. In addition, the provision of tenure renewal on completion of first 5 years in itself has the potential to dis-

Table 10. Relative weightage of score card and interview marks in final selection

S. No	Rank	Score Card Marks	Interview Marks	Total
Non-RMP & Semi RMP Posts				
1.	Senior Scientist	70	30	100
2.	Principal Scientist	60	40	100
3.	HOD/HRS	50	50	100
4.	HOD NI/NC/JD/PC	50	50	100
RMP Posts				
5.	Dir./PD/ADG/JD NI/ ZPD	40	60	100
6.	DDG/Director NI/ND	40	60	100

Table 11. Scientists selected at senior scientist level from international organizations

Sl. No.	Name (Discipline)	Organisation
1.	Dr Savarani Tripathi(Plant Physiology)	USDA, HILO, USA
2.	Dr Vishal Singh Somvansi (Nematology)	Michigan State University, USA
3.	Dr Pranab Jyoti Das(Animal Genetics and Breeding)	Texas A and M University, USA
4.	Dr Poonam Jasrotia(Agri. Entomology)	Michigan State University, USA
5.	Dr M.B. Ratnaparkhe(Agri. Biotechnology)	Plant Genome Mapping Laboratory, Athens, USA
6.	Dr P. Natarajan Ananth	Ana Horna Consultants, Ethiopia
7.	Dr A.K. Singh(Agri. Biotechnology)	Univ. of Kentucky, Lexington, USA
8.	Dr B.L. Patil(Agri. Biotechnology)	Univ. of Basel, Switzerland
9.	Dr S.K. Onteru(Animal Biochemisty)	Iowa State University, Iowa, USA
10.	Dr P. Sivakumar(Veterinary Pathology)	Albany Medical College, New York, USA
11.	Dr A.K. Jukanti(Animal / Fish Nutrition)	ICRISAT, Hyderabd
12.	Dr A.K. Mall(Genetics and Plant Breeting)	IRRI, India Office, New Delhi
13.	Dr P.R. Kumar(Plant Physiology)	ICRISAT, Hyderabad

courage fostering of new talent within the institutes by potentially foreclosing the future avenues. The five year tenure on such positions normally presents a fair and adequate opportunity to an incumbent to cap his/her competence and contributions. Moreover, such a tenure would in any case add to the competitive profile of the incumbent to successfully look for higher positions which are open to him/her elsewhere in the system or compete again for the same position in an open selection. Therefore, in place of existing ‘Individual centric’ renewal provision there should be ‘System centric’ approach by re-advertising the post and holding open selection afresh where the existing incumbent too should be fully eligible to apply and compete on merit. This would not only permit developing and nurturing of the fresh talent but also impel aspirational achievements by such existing incumbents who would wish to seek second tenure by enhancing their own competitiveness as well as contributions to the system rather than through a non-competitive individual tenure renewal process, as in vogue at the present.

Three tier selection system

Present system of selections for RMP/senior RMPs is fairly well structured in terms of score card marks, distribution of marks for screening and interview process etc. However, research management having become an increasingly complex and intricate skill, the selection process now needs to be more attuned to draw out the best talent in terms of scientific acumen, management aptitude, man management skills and in particular the out of the box thinking approach to unforeseen situations. More often than not, such leadership traits are not possible to be assessed over a short span of interaction in a formal 20-30 minute interview and individual presentation. For such positions, therefore, a 360^{o}C appraisal of competencies suited to a particular position are already being adopted the world over. In the ICAR’s context, however, as a part of the much needed evolving selection process, it is high time now that at least the three tier selection process is tried for Senior RMP positions to begin with. To avoid any sudden shift and in the interest of continuity, an additional tier in term of an individual seminar on their respective short term/ long term vision at the concerned institution/ position is integrated into the existing process for the screened & shortlisted candidates. This would serve as an additional shortlisting process by a judging panel of 3-4 eminent experts prior to the final interview at the ASRB as at present. By further shortlisting the candidates for final interview, it would also enable more appraisal time per candidate to the Board adding value thereby to the selection quality. It is high time that ASRB/ICAR revise the relevant rules to integrate such a three tier selection process beginning with the senior RMP positions.

Career Advancement Scheme (CAS)

The ARS was conceived as Scientist Centred System and accordingly its most significant feature was merit promotions irrespective of occurrence of vacancies on the basis of rigorous periodic assessment by an external panel of eminent scientists headed by the Chairman, ASRB. Its underlying principle was that professional colleagues need not view each other as potential rivals for a vacancy in a higher scale. This scheme was called Five Yearly Assessment Scheme. It had two categories. The first category was for assessment of scientists in Grades S, S-1 & S-2 as per Rule 19 of ARS Rules for which criteria adopted included: professional performance in relation to duties & task assigned. It would be essential to lay emphasis on quality rather than a quantity of research work done; spirit of co-operation and team work; managerial/organization abilities/attributes; and personal/behaviour abilities/attributes.

The criteria adopted for assessment of scientists included: the material furnished in the Five Yearly Assessment Proforma; research project files maintained by the scientists; bio-data and career information (various posts held etc.) of the scientist throughout his service in the ICAR; ACR for past 5 years; and personal discussion, if so desired by the scientist. The assessment was meant to be through Peer Review System by constituting a Committee which will not have more than five members excluding Chairman, ASRB or his nominee.

Score Card System

The score card devised for performance evaluation of scientists effective from January 1, 2009 is given in Table 12.

As of now, If the assessment score is more than 75%, then promotion is granted; if it is between 73 – 75 %, then promotion is deferred; if it is less than 73%, then no promotion is granted. For this, scheme structure includes: work performance record (68 marks), ACR (12 marks), interview (20 marks).

CAS cases processed year-wise (2005-06 to 2015-16) and success percentage

A brief account of CAS cases processed, number of discipline and success rate is given in Table 13. Except in 2011-12, in all other years, success rate was more than 76%. The success rate during last four years remained above 86%. However, promotion rate varied in different disciplines.

Table 12. Summary of Score Card for performance evaluation effective from 01.01.2009

Assessment Period	4/5/6 years*						5 years						3 years						3 years						
Criteria	RGP 6000						RGP 7000						RGP 8000						RGP 9000						
	R	R+T	AIC RP	R+ EXT N	NA AR M	ZPD	R	R+T	AIC RP	R+E XTN	NA AR M	ZPD	R	R+T	AIC RP	R+E XTN	NA AR M	ZPD	R	R+T	AIC RP	R+E XTN	NA AR M	ZP D	ICAR HQ
Core Activities																									
1. Research	45	25	20	20	20	20	45	25	20	20	20	20	35	20	20	20	20	20	35	20	20	20	20	20	
(i) Research Activities	20	10	10	10	10	10	20	10	10	10	10	10	15	10	10	10	10	10	15	10	10	10	10	10	
(ii) Research Output/Technology spread & impact	25	15	10	10	10	10	25	15	10	10	10	10	20	10	10	10	10	10	20	10	10	10	10	10	
2. Capacity building/ monitoring/ evaluation/ reporting and institution building	10	10	25	10	15	25	10	10	25	10	15	25	5	5	15	5	10	10	5	5	15	5	10	10	
3. Teaching and Focars	—	20	—	—	20	—	—	20	—	—	20	—	—	15	—	—	10	—	—	15	—	—	10	—	—
4. Extn./AICRP/Activities Coordinated	—	—	10	25	—	10	—	—	10	25	—	10	—	—	5	15	—	10	—	—	5	15	—	10	45
Subtotal	55	55	55	55	55	55	55	55	55	55	55	55	40	40	40	40	40	40	40	40	40	40	40	40	45
Publication																									
(i) Research Papers	20	15	10	10	10	10	20	15	10	10	10	10	15	10	10	5	10	5	15	10	10	5	10	5	5
(ii) Other Publication	5	10	15	15	15	15	5	10	15	15	15	15	5	10	10	15	10	15	5	10	10	15	10	15	10
Subtotal	25	25	25	25	25	25	25	25	25	25	25	25	20	20	20	20	20	20	20	20	20	20	20	20	15
Peer Recognition	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8	8
Annual Assessment Report (AAR)	16	16	16	16	16	16	16	16	16	16	16	16	12	12	12	12	12	12	12	12	12	12	12	12	12
Interview	—	—	—	—	—	—	—	—	—	—	—	—	20	20	20	20	20	20	20	20	20	20	20	20	20
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

* With PhD - 4 Years; With Professional PG - 5 Years; General Science PG - 6 Years

Table 13. CAS cases processed year-wise (2005–06 to 2015–16)

Year	Number of cases processed	No. of disciplines	Success rate
2005–06	46	24	74%
2006–07	Cases could not be processed due to revision in CAS guidelines		
2007–08	452	46	83%
2008–09	206	45	76%
2009–10	–	–	–
2010–11	247	64	77%
2011–12	9	9	33%
2012–13*	749	57	86%
2013–14*	255	44	88%
2014–15*	195	45	88%
2015–16	254	48	91%

* Including deferred promotion

CONCLUSION

The success of second Green Revolution in India will largely be governed by the quality of human resource development, selection of right person for the right job, talent-retention and grooming in agriculture and allied sectors. Agricultural Scientists Recruitment Board (ASRB) was established in 1973 to select scientists and develop promotion avenues for scientists in ICAR. The Board during last 43 years maintained high standards in examinations, recruitment and career advancement of scientists which helped the country to create new records of production in agriculture including animal husbandry, horticulture and fisheries. Building upon the credibility of ASRB in terms of efficiency, transparency and output capabilities, ICAR in the recent past has decided to entrust all recruitment related work for administrative, technical and even supporting staff of the Council through ASRB. Several times, Department of Agriculture and Cooperation (DAC) and Department of Animal Husbandry and Dairying (DAHD) in the Ministry of Agriculture floated the idea of recruiting their technical and scientific staff through ASRB as it takes much longer to fill vacancies through UPSC. With the passage of time and new roles and responsibilities being envisioned, ASRB will need strengthening in terms of human resource, independence and autonomy. There is a strong need to relook ASRB's parity with UPSC as envisaged when ASRB was established. Creation of a Central/Indian Agriculture Service by having specialized wings of research, extension, development, education, foreign agriculture service, marketing and certification services is the need of the hour in the larger national interest. Granting professional status to agriculture at par with medical, engineering, veterinary, an Agriculture Council of India (ACI) may be established. To take up such responsibilities, the ASRB also needs to be further strengthened by reviving and restoring to its originally intended parity with the UPSC and by addition of more members and may be redesignated as 'Indian Agricultural Services Commission' in the near future.

4th International Agronomy Congress (November 22–26): 12–21 (2016)

Watershed management: Problems and prospects

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INTRODUCTION

Mankind is utilizing ecological services at a significantly higher rate than the Mother Earth can provide, thereby putting enormous pressure on natural resources, and bringing its very own existence as well as of all life forms on Earth into jeopardy. Sensible and sustainable uses of natural resources by mankind are essential for meeting needs of the present as well as future generations of all forms of life.

Land, which includes soil, biological and water resources, is one of the principal natural resources providing eco-services for sustenance of life. As per the first global assessment of human-induced soil degradation (GLASOD), out of the world's total land area of 13.5 billion ha, about 2 billion ha (15%) is degraded, mainly due to water erosion. In contrast to GLASOD estimate, as per the latest scientifically based approach, global assessment of land degradation and improvement (GLADA), 24% of global land is degraded. Though the global estimates of degraded area vary due to lack of credible data based on ground-truthing, the areas highlighted by the 2 analyses hardly overlap, clearly showing that land degradation is a global issue. It is estimated that, if this trend continues, 1.4%-2.8% of the total agricultural, pasture, and forestland would be lost by 2020, and declining yields (or increasing input requirements to maintain yields) can be expected over a much larger area.

Limited availability of water severely hampers expansion of global food production, and restricts economic development. The underground water reserves of world are depleting at an alarming rate. Most of the world's mid-latitude regions - those that already cover arid to semi-arid areas - are getting drier. Out of world's 37 largest aquifers, 21 which collectively provide water to more than 2 billion people, and are located in countries – Turkey, Syria and Iraq (the Arabian aquifer); India and Pakistan (the Indus and the Ganges–Brahmaputra basin); and Libya and Niger (the Murzuk-Djado Basin) – are world's most stressed aquifers and have passed 'sustainability tipping points'. Replenishing groundwater supplies will become even more difficult in the times to come. Since groundwater fuels agricultural productivity, its disappearance means that producing food for our growing population will become increasingly challenging, sooner rather than later.

Natural resource degradation is a major cause of global change in climate and life-support systems of human societies. Therefore, Natural Resource Management (NRM) has attracted world attention of highest order for, broadly, assuring sustenance of the ecological services that are life-support systems for all living organisms, and particularly, augmenting agricultural development, as agricultural research and external input-intensive technological innovations that had succeeded in ushering a population growth matching global agricultural productivity are now nearing their potential limits. The reasons for this alarming agricultural scenario are: (*i*) decreasing availability of new productive lands and usable water-resources, (*ii*) the alarming rates of on-going human-induced soil- and water-resources degradation, (*iii*) the increasing encroachment on and over-stressing marginal, fragile and degradation-vulnerable lands, (*iv*) the inability to enhance adoption of conservation-effective land-use systems at rates sufficient to overtake on-going degradation, and (*v*) continuing expansion of earth population at alarming rates.

India having the second largest population of the world (18%) owns only 2.4% of the world's land resource. As per harmonized database on land degradation, 120.72 million ha area of India is subjected to various forms of land degradation, with maximum (68.4%) contribution by water erosion (82.57 million ha). Potential erosion rates estimated for different states indicate that 49% area has erosion rate of >10 tonnes/ha/year while 13% area falls in very severe category (>40 tonnes/ha/year). However, the permissible soil-loss rate, depending on soil quality and depth, is estimated to vary from 2.5 to12.5 tonnes/ha/year. About 57% area of India has soil-loss tolerance limit of <10 tonnes/ha/year, while about 7.5% area has a soil loss tolerance limit of only up to 2.5 t/ha/yr. Further, soil-erosion risk estimates prioritized for various states indicate that major part of the total geographical areas of Nagaland (69%), Arunachal Pradesh (42%), Meghalaya (35%) and Uttarakhand (34%) fall under erosion-risk priority classes 1 and 2.

India owns 4.2% of world's freshwater resource but

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supports 18% of global human and 15% of livestock populations. The country has 668 km^3 of utilizable water resources and will face water deficiency of 229 km^3 in 2050 even under low-demand scenario, which would increase to 396 km^3 under high-demand scenario. Per caput annual water availability in 1951 was 5,177 m^3 (population 361 million). It reduced drastically to 1,820 m^3 (population 1,027 million) in 2001 and 1,545 m^3 (population 1,210 million) in 2011. By 2025, the per caput water availability will further drop down to 1,341 m^3; and to 1,140 m^3 in 2050. Based on the average requirement of water for various purposes, the situation is considered as 'water stressed' when per caput water availability ranges from 1,000 to 1,700 m^3 per year, and it is considered 'water scarce' when the availability reduces to less than 1,000 m^3 per year. As water availability varies widely within India as a result of rainfall, groundwater reserve and proximity to river basins, most of Indian States would reach water-stressed condition by 2020 and water-scarce condition by 2025. Hike in frequency of occurrence of droughts over the recent years is an indicator of the worst scenario in future.

The alarming magnitude of on-going and persistent natural resource and environmental degradation and its detrimental impacts worldwide indicate that fresh alternative strategies are needed for addressing natural resources management and environmental problems. Globally, there are sufficient resources of land and water to produce food over the next 50 years, but only if water for agriculture is better managed. This is so, because water is the most crucial input and acts as a catalyst to bring in ecological, social and economic revolution. Under conditions of limited water availability, 3 options exist for capturing additional water required to achieve higher food-production targets – (**a**) efficient management of blue water, i.e. water available in rivers, lakes, wetlands and aquifers to expand irrigation (blue water options), (**b**) better use of green-water, i.e. in-field rainfall, naturally infiltrated rainwater and harvested local runoff (green-water options), and (**c**) exploration of virtual (imported) water options. Green-water use is about 4–5 times greater than consumptive blue-water use in global crop production. Hence full green-to-blue spectrum of agricultural water-management options need to be exploited when tackling the increasing water gap in food production.

A holistic ecosystem-based approach is required for dealing with production and environmental objectives, which together are naturally in conflict with each other. This approach is easily imbibed in integrated watershed management, as a watershed is most appropriate ecosystem unit for planning and implementing land use that takes care of many environmental and production issues. As premised above, maintaining environmental integrity of whole ecosystem is a pre-requisite for truly sustainable land use. The definition of 'whole ecosystem' requires careful delineation of its boundaries to a spatial scale which allows a holistic expression of interdependencies and continuities between landscape elements. This scale as a smallest unit is a watershed.

WATERSHED: FROM MANAGEMENT TO DEVELOPMENT

Management of watersheds, not explicitly as a unit of planning, started 65 years ago (in 1949-50) in India with the establishment of Soil Conservation Department under Damodar Valley Corporation in Damodar-Barakar basin. The focus was mainly on bio-physical aspects. Establishment of network of Soil Conservation Research, Demonstration and Training Centres at 8 locations in 1954 sharpened research and capacity development for soil and water conservation on watershed basis. These centres experimented with 42 small watersheds from 1956 onwards, which provided impetus for taking up protection measures in 29 catchments on watershed basis under a newly launched River Valley Project in 1961–62. The watershed point in this transition was launching of 4 successful Operational Research Projects (ORPs) in 1974 that demonstrated integrated watershed-management approach with people's participation in real field settings. The 4 ORPs led to 47 model watersheds in different agro-ecological regions in 1983. These model watersheds showcased the ability of the approach in mitigating drought effects during 1987, which set into motion a number of nationally and internationally funded, state government-sponsored and NGOs supported watershed development projects that continued to grow in numbers over time. The approach has metamorphed over time from being top-down, techno-centric, compartmental, non-transparent, non-sustainable, and target-oriented to bottom-up, stakeholder-centric, converging, transparent and sustainable one. This transition is highly attributed to recommendations of the Government of India appointed Hanumantha Rao Committee of 1994 which shifted watershed planning from bureaucrats to local stakeholders to address problems of food security, equity, poverty, gender, land degradation and water scarcity. A major off-shoot of the recommendations was formulation of common guidelines for watershed development projects in 1995, which have been revised in 2001, 2003, 2008 and 2011 for collective action and community participation, including primary stakeholders through community-based organizations, NGOs and Panchayati Raj Institutions. During this transition, watershed, which is a land unit to manage water resources, has been adopted as a unit of planning to manage all natural resources of the catchment area.

Realizing the importance of watershed development in conserving the natural resources of the country, as well as it being recognized as the engine of all-round rural development in the country, the Government of India has invested heavily on various watershed-based rural development programmes of 3 Central Ministries and other national agencies, including NGOs. Up to March 2007, about 56.54 million ha has been treated with an expenditure of ₹194.71 billion. Upto March 2012, about 79.19 million ha has been treated with an expenditure of ₹ 264.49 billion. During the XII Plan (2012–17), it has been planned to treat 25 million ha with ₹ 0.14 billion, and further 22 million ha area during the XIII Plan (2017–22).

Success stories

Fakot watershed

The watershed concept was operationalized from 1974 onwards through 4 famous Operational Research Projects (ORPs) at Sukhomajri and Nada (Haryana Shivaliks), Fakot (Uttarakhand Outer Himalayas) and G.R. Halli (Karnataka black and red soils) by the ICAR-Indian Institute of Soil and Water Conservation (formerly Central Soil and Water Conservation Research and Training Institute), Dehradun during 1975–86. The sustainability evaluation of ORP Fakot watershed development project revealed that the project has become self-sustainable and values of all beneficial attributes have continued to increase and values of detrimental factors (dependency on forest, runoff, soil loss and outmigration) are showing a declining trend even after financial withdrawal of the project (Fig.1). Food production increased by about 7 times, annual fruit production from negligible to 2,215 quintals, milk production by more than 8 times and gross returns from cash crops by more than 464 times. Niche-based diversified enterprize combinations for land use converted outmigration to immigration (Plate 1). Forest dependency decreased by 55 percentage points. The project was hugely successful in increasing productivity of crops and livestock, enhancing livelihood opportunities and entrepreneurial qualities of primary stakeholders, and improving ecology.

IWDP-Funded Watershed Development Projects

The Department of Land Resources, Ministry of Rural Development (MoRD), Government of India, under its

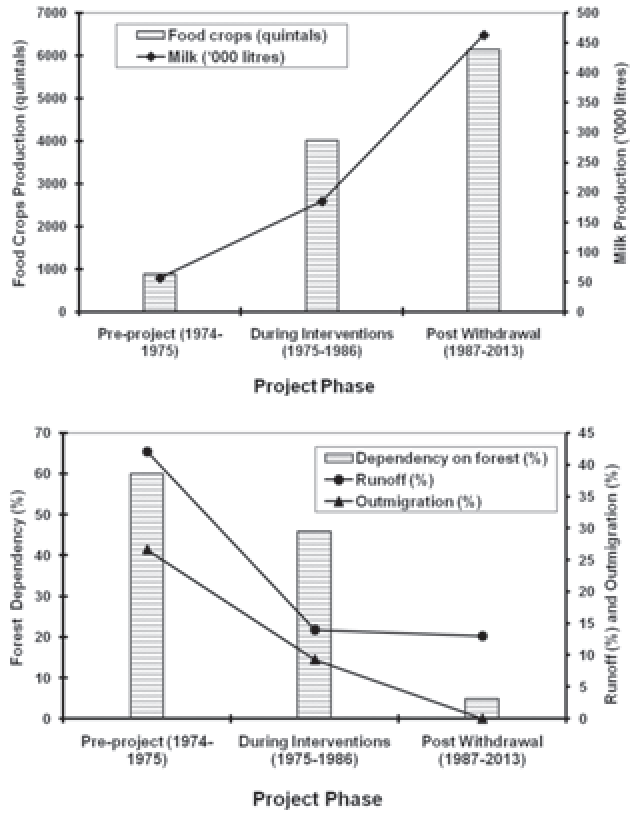

Fig. 1. Production and conservation impacts of watershed-management programme at different stages of development at ORP Fakot watershed

Plate 1: Cultivation of niche crops and good vegetative cover in ORP Fakot watershed

Integrated Wastelands Development Programme (IWDP) identified ICAR-Indian Institute of Soil and Water Conservation (formerly Central Soil and Water Conservation Research and Training Institute), Dehradun, as Project Implementing Agency (PIA) to develop 6 model watersheds located in 6 states representing different agro-ecological regions of the country in a participatory mode following Integrated Wastelands Development Programme (IWDP) guidelines. The watersheds taken for development were Aganpur-Bhagwasi, district Patiala (Punjab); Antisar, district Kehda (Gujarat); Badakhera, District Bundi (Rajasthan); Bajni, District Datia (Madhya Pradesh); Kokriguda, district Koraput (Odisha) and Salaiyur, district Coimbatore (Tamil Nadu). Need-based developmental interventions were undertaken in the watersheds as per the problems, needs and priorities of the watershed community and their technical feasibility. A mix of engineering and biological measures was adopted for treatment of the watersheds to make it cost effective within the prescribed norms. Community institutions such as Watershed Committee (WC), Watershed Association, SHGs and UGs were also established.

Watershed interventions on arable and non-arable lands in a participatory mode significantly reduced runoff and soil loss. Runoff from the watersheds reduced by 9 to 24%, while reduction in soil loss from these watersheds varied from 32% (Bajni) to 90% (Antisar) with an average of 72%. Various indicators employed to assess the impact of different activities showed significant improvement in biophysical, participatory and socio-economic attributes (Fig. 2). Overall Crop Productivity Index (CPI) increased by 12 to 45% with overall increase of 28% in the crop productivity. Crop Diversification Index (CDI) also increased by 6 to 79% in the watersheds, with average increase in CDI of 22%. With higher CDI, the risk in farming was minimized. Cultivated Land Utilization Index (CLUI) also improved significantly (2 to 81%), with an average value of 27%. The Induced Watershed Eco-Index (IWEI) showed 12% improvement indicating that additional watershed areas were rehabilitated through green bio-mass. Crop-improvement activities also generated sufficient permanent employment on their own fields, thus preventing their out migration for petty jobs. Overall, 7,278 (Kokriguda) to 51,461 (Antisar) additional man-days were generated during the project period in the watersheds. Thus on an average, 17,004 additional man-days of employment was generated in each watershed. However, the regular employment opportunities in the agriculture-related activities varied from 60 to 137 man-days per annum. Community organization had a catalytic effect on people's participation and contributions, which on an average occurred to the extent of 62 and 27%, respectively. Through employment and income-generating activities, average annual income per family increased by 8% (Antisar) to 106% (Kokriguda), with an overall increase of around 49% in the studied watersheds. In spite of drought conditions prevailing in some of the watersheds for few years, the projects were economically viable with overall benefit : cost ratio of 1.14 (Salaiyur) to 1.69 (Kokriguda). These model watersheds have showed that if proper watershed technology is transferred through a community-empowered institutionalized mechanism, it can play a vital role in agricultural development and overall rural transformation of India. The findings of these model watersheds created awareness and confidence among policy-planners and administrators in the country regarding the efficacy of participatory integrated watershed management projects.

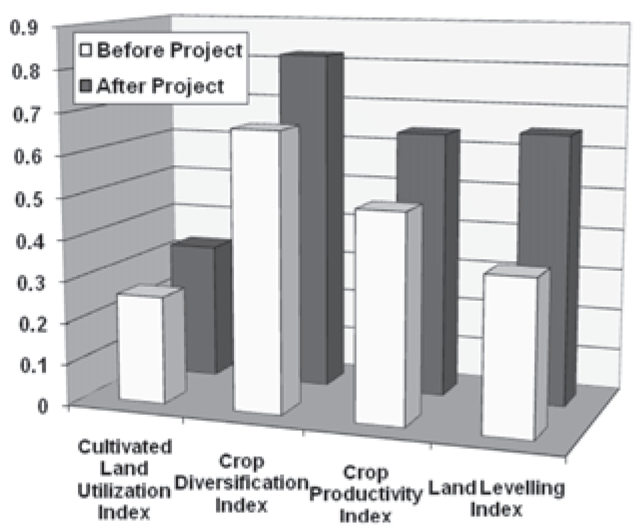

Fig. 2. Improvement in various parameters as an indicator of overall watershed development

Meta analysis of watershed-development in India

Under a project for comprehensive assessment of watersheds in India, macro-level evaluation of 636 micro watersheds was done through meta-analysis (Joshi *et al.*, 2008). The results of meta-analysis revealed that watershed programme is providing multiple benefits in terms of augmenting income, increasing crop yields, increasing cropping intensity (35.5%), reducing run-off (45%) and soil loss (1.1 tonnes/ha/year), augmenting groundwater, building social capital and reducing poverty.

A number of developmental activities are undertaken in the watersheds in a participatory mode through active involvement of the local community in order to promote employment for the local stakeholders. Works like land improvement, water-resource development and afforestation generate maximum additional casual employment. Crop-improvement activities also generate sufficient permanent employment on their own fields, thus preventing their out migration for petty jobs. The results revealed that the watershed programme is generating rural employment of 151 man-days/ha, on an average.

In terms of economic efficiency, watersheds generated an average benefit : cost ratio (B:C) of 2, and only 0.6% of watersheds failed to commensurate with the investment (<1 B:C ratio). The mean internal rate of return (IRR) from the watersheds investment was 27.4%. Thirty two per cent of watersheds showed a mean BCR of >2 and 27% of watersheds yielded an IRR >30%, which showed immense potential to scale up watershed programme in India.

PROBLEMS

The concept of watershed development started in India with a focus upon prevention of runoff and concomitant soil erosion to slow down siltation rates of reservoirs in medium and large river valley projects, and also mitigate flash floods. Now, it is widely considered to be the growth engine of rural development. Watershed development is a complex concept as it is not merely concerned with conserving soil, water and other natural resources, but is also with enhancing their productivity in a sustainable manner. This has implications about management of interface between different kinds of resources, interface between differently owned resources, and, exclusively, management of common property resources. Despite the success of watershed- development programmes in India, there are some critical problems that inhibit its potential to drastically change the rural scenario of India in many aspects.

Planning phase

Weak institutional arrangements at project level

Experiences have shown that institutional arrangements at project level, such as project implementing agency (PIA) or local community-based organizations (CBOs), viz. watershed association (WA) and watershed committee (WC), play a pivotal role in successful implementation as well as sustainability of watershed-development programmes. The National Rainfed Area Authority (NRAA) has given a set of broad guidelines for selection as well as formation of the community-based organizations. However, the practice of entrusting watershed development to fly-by-night non-government organizations (NGOs) or incomplete watershed development teams of government or non-government organizations is prevalent to a large extent. Such institutions are unable to create favourable environment for watershed development in rural settings which leads to passive receipt of soil- and water-conservation technologies. Non-involvement or poor functioning CBOs give higher priority to individual benefits over community-based activities. Many a times, local level conflicts are the outcome of poor performance of local-level watershed institutions.

Declining trend of primary stakeholders participation in different phases of watershed development projects

Studies indicate that participation of primary stakeholders in watershed-development programmes was the highest during project planning phase, medium during implementation phase, and the least in withdrawal phase. The first constraint listed above may be a major contributor to it, but lack of technical competency of watershed development team in selection of most appropriate intervention points on priority by adopting efficient conflict resolution techniques is also an equally paramount constraint.

Absence of well defined process for securing participation

Participation of watershed community is important for success of any watershed-development project. There is no well-defined process for securing participation based upon documentation of successful implementations at grass-root level. Such a process will help in achieving the stated physical, financial, institutional and policy-related goals. In most of the cases, community participation is realized in cash and generally deducted from wage payment made to the labourers and not from the actual beneficiaries of the activities.

Lack of policy or law against saboteurs

Natural resource management projects invariably require collective action by stakeholders having usufruct rights. Many projects ultimately fail due to non-cooperation or sabotage by few affluent stakeholders having vested interests, e.g. utilization of limited water available for drinking and domestic use, for construction purposes and non-payment of contributions, dues etc. Their activities lead to loss of public money and loss of opportunity by sincere stakeholders to improve their livelihoods. There should be policy or even a law to check such stakeholders for benefit of the maximum number of those stakeholders that sincerely embrace the project for all-round benefits. Though the Common Guidelines of Watershed Development have explicitly assigned this responsibility to the Panchayati Raj Institutions (PRI) with a provision of forced closure of the project, but unfortunately, it could not be legalized owning to poor cooperation from higher level PRIs.

Poor identification of key drivers for watershed development success

Development of watersheds occurs in different agro-ecological and socio-economic settings. Therefore, identification of some key elements for the success of a watershed-development programme, which can be an individual (a leader or government officer), group (PRI or CBO) or highest priority intervention or their combinations is essential for sustainability of the programme. It requires highest level of social as well as technical skill combinations for which available experts are rarely available.

Non-harmony of village and watershed boundaries

Watershed and village boundaries need to be harmonized as the biophysical interventions are based on natural boundaries of the watershed, but the participation is based on village boundaries which are man-made. Therefore, there are likely beneficiaries living outside watershed boundary or even vice-versa. This creates a problem in execution of the project activities. Therefore, the boundaries of the 2 entities need to be harmonized.

Implementation phase

Lack of managerial skills

A project manager has to encounter a number of constraints/ challenges during implementation phase even in a well-planned project. This increases with the increase in inequality among the project stakeholders. The problems faced during project implementation phase are more related to management and social aspects than technical aspects. These problems can be tackled effectively and efficiently through application of management principles rather technical principles. The competency of presently available leadership in this aspect is primarily based on experience but requires building their capacity in application of project management instruments right from planning to withdrawal phase of the project.

Lack of expert technical manpower in state departments

Presently, state governments are undertaking capacity-building programmes in various departments such as agriculture, forest, soil conservation, watershed management etc., through orientation/ refresher courses at state-level training institutes such as State Institute of Rural Development (SIRD) etc. Some states have specialized training institutions, while others have given this responsibility to State Agricultural Universities. Some NGOs like SAUs, MYRADA and OUTREACH are also engaged in imparting training in watershed management. However, the manpower trained at these institutions lack both in terms of quality and quantity. Quality wise, majority of training institutes have autonomous departments with little or no field experience in the management of natural resources and watersheds, which being a complex phenomenon requires multidisciplinary approach. The trainers engaged do not possess requisite technical and practical knowledge to effectively implement projects related to management of natural resources and watersheds following integrated multidisciplinary approach. Proper monitoring and impact evaluation, based on scientifically developed indicators, is also lacking. Therefore, the curricula and training modules for different levels of stakeholders are either inadequate or do not employ modern tools and procedures such as Remote Sensing and GIS. There is absence of networking mode of training and lack of demonstration sites of successful/ model watershed-management projects for better understanding of the concept or technologies. Quantity wise, based on latest watershed-development guidelines of Government of India, it has been estimated that about 6,649 and 7,617 batches of watershed-management-capacity building training courses with 25 participants in each batch and of duration ranging from 3 days to 3 weeks, depending on level of training, need to be organized annually during the XII and XIII Plans to cope up with huge demand of trained technical manpower in various departments/agencies. The guidelines for watershed-development projects implemented by Government of India since 1 April 2008 have a provision of 5% of the total budget of a project for capacity building. The earmarked budget is only sufficient to train members of watershed-development team, watershed committee and GS and is insufficient for training of higher level stakeholders. Therefore, state-level training institutes, such as SIRDs, need to be strengthened by employing faculty trained from centres of excellence such as ICAR-IISWC in the field of natural resources and watershed management.

Lack of knowledge about approaches for ensuring interface between primary stakeholders, local organizations and state

This knowledge is important for the watershed community to have partnerships with local political bodies, State Departments, and finance agencies. The knowledge will help in having a holistic participatory approach leading to enhanced efficiency, effectiveness and accountability.

Target approach instead of process approach

This phase is also dominated by technical competency of the WDT and transferring mechanism adopted during executions of the watershed-development interventions. Concurrent evaluation by the watershed-development team (WDT) works as a guide for it to gauge the probable level of targets to be achieved and modifications required, if any, in the selected interventions in the light of actual outputs and knowledge advancement. It was observed that presently, concurrent evaluation is mainly focussed on attainment of physical and/or financial targets set for the year, and not on processes to achieve them. Evaluation of output efficiency and processes followed are rarely done by the WDT or PIA. It hampers the approval of the modifications required in the detailed project report (DPR) based on real field-level situation analysis. Though this provision has been embodied in the common guidelines and the convergence of the schemes provide ample opportunities for incorporation of mid-term corrections based on concurrent evaluation, it is rarely being adopted.

Adoption of orthodox monitoring system

Monitoring is required for every phase of watershed-development projects, whether it is situation analysis during project formulation; knowledge of inputs, outputs, processes and constraints during implementation phase; and impact analysis after withdrawal of the project. However, the present project-monitoring system is a routine age-old practice and data generated are hardly of any use to evaluate the detailed project report indicate mid-course corrections, or properly assess the impacts and suggest policy measures for higher rate of success in future projects.

Withdrawal phase

Now there is growing evidence of project failures once the project implementing agency (PIA) which may be of government or non-government, withdraws from the project area. Projects have been reported to have done well in terms of conservation and production, but there is no documentary evidence that they sustained. Without proper participation of primary stakeholders, the benefits are not sustainable. After withdrawal, conservation structures are abandoned or they disappear, watershed institutions are disbanded, and the livelihood base of the stakeholders remains only marginally improved owing to continued adoption of some of the introduced improved technologies.

The common guidelines of watershed-development projects have stated about development of proper withdrawal strategies for sustaining created assets. However, it is silent about institutional arrangements, cost-benefit sharing mechanism, governing principles of watershed-development funds or revolving funds provided to the weaker sections of the society, and road map for upscaling the successful project interventions. Consequently, most of the project achievements start withering away after withdrawal of the project, and many of them lead to a conclusion that the project was a failure or not much of a success. To reverse the process, there is a dire need to identify the drivers for each of the above-mentioned aspects of watershed development through in-depth system research analysis to devise appropriate policy framework for creating intended large-scale impact through well-aware stakeholders. Specifically, the problems of withdrawal phase are:

Non-operational mechanism for transfer of watershed development fund after withdrawal

One of the mandatory conditions for selection of villages for watershed projects is people's contribution towards the Watershed Development Fund (WDF). These contributions are accepted either in cash at the time of execution of works or voluntary labour. A sum equivalent to the monetary value of the voluntary labour is transferred from the watershed project account to the WDF bank account which is distinct from the Watershed Committee (WC) bank account. User charges, sales proceeds and other contributions, disposal amounts of intermediate usufruct rights are also deposited in the WDF bank account. Income earned from assets created under the project on common property resources are also credited to WDF. The Secretary, Watershed Committee maintains a completely separate account of the income and expenditure amount of the WDF. Rules for operation of the fund are prepared by the Watershed Committee and ratified by the Gram Sabha. The WDF bank account is operated by the President of Gram Panchayat and any member from the SHG nominated by the Gram Sabha. Alternatively, the guidelines for the management and utilization of the WDF may be evolved by the concerned Nodal Ministry. Due to no definite guidelines for transfer of WDF to primary stakeholders' institutions after withdrawal, and involvement of huge sum deposited in the WDF account, there is reluctance of PIAs to hand over these accounts to the watershed institutions. As a result, huge amount is lying unused in the WDF accounts of the completed watershed projects that are to be utilized for sustaining the aspects of the projects after withdrawal of the PIAs.

Failure of engineering structures

Failed engineering structures have been seen from surveys carried out by research and development organizations due to improper design or poor maintenance. For example, in the hills of Uttarakhand and Himachal Pradesh, cement-lined open-gravity flow water channels constructed at substantial cost (as compared to underground PVC pipes) across contours of mountain slopes primarily for irrigation, but also for providing hydropower for water mills, or water for domestic uses (other than drinking) have been rendered unserviceable at many locations along their lengths. These are reported to be non-functional due to poor maintenance by the concerned State Departments or villagers, as it involves substantial cost.

Lack of policy for benefit sharing

Many a times benefits are derived privately by a few stakeholders due to collective action of majority of stakeholders. For example, water harvesting by construction of dams, ponds etc. through contribution from all leads to increase in water availability in privately owned wells. These stakeholders then sell water to other beneficiaries thus accruing profits due to the water-harvesting measures implemented in the watershed. For such cases, there should be a policy for equitable benefit sharing.

Incomplete economic evaluation of projects

Traditionally, economic appraisal of watershed-development projects has focussed on comparing the costs and benefits of a project over its life using benefit-cost analysis. An economic appraisal of a watershed project is complicated because it involves environmental impacts that are not easily valued and off-site impacts that are improperly understood. It also does not capture whether the project will be able to sustain after official withdrawal from the project, as it does not take into account the institutional aspects which underlie the management of watershed resources. Even if that is done, i.e. the projects aggregate social benefits are greater than aggregate social costs, it does not necessarily mean that everyone gains. Losers may threaten the success of a project by refusing to comply with rules of resource use.

PROSPECTS

The watershed-development programme of India has been evolving since its birth after the Independence of the country. The policies and guidelines for making the programme effective and sustainable are being regularly upgraded by the Government of India to match the problems being encountered by different stakeholders ranging from the primary stakeholders, mainly the watershed communities, to the State Level Nodal Agencies as well as the Central Ministries. The Government is investing heavily in the concept, because despite the earlier-stated problems, it has the potential to accomplish high agricultural growth, meet the food security targets, attain high level of rural development and boost the Indian economy while maintaining the functionality of the natural resources.

Mitigate production losses due to water erosion

Among negative impacts of soil erosion by water, loss in crop productivity by removal of top most fertile soil containing organic matter and other plant nutrients has a strong bearing on national food security. Following a systematic approach, on-site production and monetary losses due to water erosion for 27 major cereal, oilseed and pulse crops cultivated in rainfed areas of Indian states were estimated. The estimations were based on crop and agro-climatic region-specific productivity loss factors evolved by utilizing the experimental data, and extrapolated for 5 erosion categories ranging from less than 5 tonnes/ha/year to more than 40 tonnes/ha/year. They were then integrated with respective erosion category-wise potentially eroded rainfed area for each crop under each of the 3 major soil groups (alluvial, black and red) in a given state. The computed production loss of a crop was valued at its government minimum support/ procurement price. The country as a whole loses about 16% of its total production of cereal, oilseed and pulse crops, which in economic terms is equivalent to ₹205 billion, considering minimum support prices of 2011–12 (Fig. 3). Cereals contribute 66% to the total production loss followed by oilseeds (21%) and pulses (13%). In terms of per unit area production losses, India suffers a loss of 1.63 q/ha in productivity of rainfed crops, which is valued at ₹2,484/ha. There is now an urgency to minimize the production losses in rainfed areas of the country, as these losses can be enormous on cumulative basis to significantly affect the agrarian economy of the country over the years. The production losses need to be minimized and brought within permissible limits to prevent further decline in productivity levels by adopting appropriate soil- and water-conservation strategies depending on climatic, edaphic and physio-graphic condi-

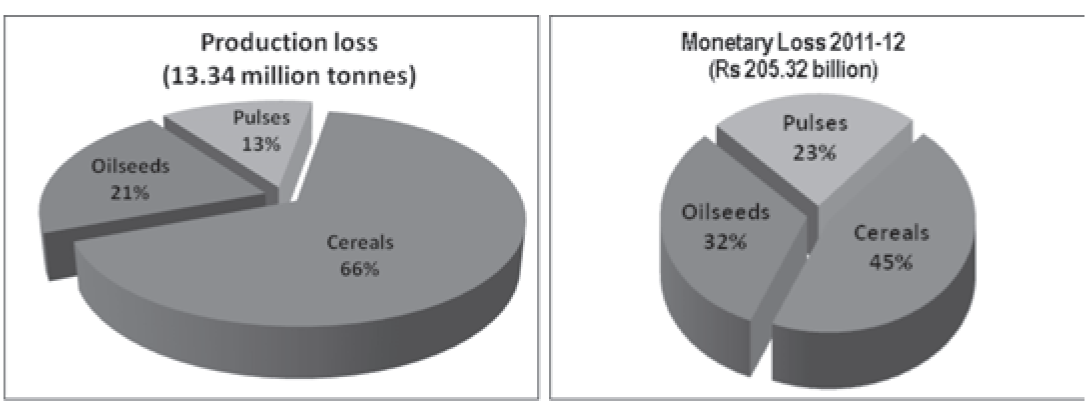

Fig. 3. Per cent production and monetary losses of cereal, oilseed and pulse crops in rainfed areas due to water erosion in India

tions and prevailing land-use systems. They include agronomic, mechanical and biological measures, which can be adopted following the concept of participatory integrated watershed management to achieve sustainability of production systems and ensure environmental security.

Augment water harvesting for productivity

It is estimated that by 2050, about 22% of the total geographic area and 17% of the population will face water scarcity. Water scarcity is the outcome of the ever-growing population, which results in higher demand for water in agriculture, industrial and domestic sectors. Consequently, share of agriculture sector in total water use may reduce from 78% at present to 68% in 2050 due to competing demands from other sectors. Groundwater, which is the major source of irrigation at present, is rapidly declining by about 1 m annually in the rice–wheat areas due to over-exploitation. During the decade from 1994 to 2004, the percentage of over-exploited blocks where groundwater extraction exceeded groundwater recharge, rose from 4% to 15%. Therefore, goals of enhanced food production and agricultural growth will have to be accomplished from declining availability of water, thus necessitating its efficient and optimal utilization. However, water availability, especially for agricultural purpose, can be substantially increased through watershed-development programme as water harvesting is an integral part of the programme; other activities of the watershed-development programme can be undertaken without watershed programme but not water harvesting. There is a potential to harvest about 24 million ha-m of rainwater through small-scale water-harvesting structures in different rainfall zones of India, of which, about one-fourth can be harvested in zones receiving rainfall < 1,000 mm/year. With this, an additional foodgrain production of about 60-65 million tonnes can be easily realized, along with multitude of physical to social benefits like enhancing crop productivity, food supply and income, increasing water and fodder for livestock, increasing rainfall infiltration, thus recharging shallow groundwater sources and base flow in rivers, reducing flood incidence, reducing soil erosion and sedimentation, and bridging water supply during droughts and dry spells.

Realize potential of rainfed agriculture

Under scenario of declining per caput net sown area (fallen from 0.33 ha/caput to 0.12 ha/caput during the period 1951 to 2011), which is well below the prescribed threshold limit of 2.0 ha of rainfed land or 1.0 ha of irrigated land required for a family of 5 to 6 members, and stagnant agricultural productivity, ensuring of food security will be a difficult challenge to face in the future. The average productivity of all foodgrains needs to be doubled from the current 1.8 t/ha to 3.4 t/ha to produce the estimated 450 million tonnes of food production from net sown area of 140 ± 2 million ha by 2,050. In the light of limited scope of increasing production from the irrigated sector, transforming rainfed farming into more sustainable and productive system through efficient use of natural resources provides the only viable alternative to the problem. India ranks first among the countries that practice rainfed agriculture both in terms of extent and value of produce from it. Out of an estimated 140.3 million ha net cultivated area, 79.44 million ha (57%) is rainfed, contributing only 44% to the total foodgrain production. It is estimated that even after achieving the full irrigation potential, around 40% of net cultivable area of 142 million ha will still remain rainfed. Rainfed agriculture supports nearly 40% of India's estimated population of 1,210 million in 2011. Cutting-edge and socially acceptable conservation and production technologies implemented through integrated participatory watershed-development approach, well supported by appropriate and forward-looking agricultural policies for promoting all-round development of agriculture sector with a focus on water conservation and soil health. This will usher in an era of "Evergreen Revolution", since the Green Revolution remained confined to irrigated lands only.

THE WAY FORWARD

Prioritization of critical areas for erosion control in watersheds

Earlier studies carried out in RVP catchments have established that by treating a fraction of the critically eroded area of a watershed, the soil loss can be reduced drastically. This needs to be further strengthened by more detailed studies in different agro-climatic situations and toposequences. Prioritization of critically eroded areas needs to be done to reduce the cost of treating a watershed in terms of capital and time.

Assessment of water availability at different watershed scales

A systematic approach with the help of modern tools, such as GIS and Remote Sensing, and procedures (watershed-scale hydrological models) is needed to critically assess water availability in watersheds at micro and macro scales in different agro-climatic regions of the country. Assessment of water availability will help in its better planning and utilization.

Identification, evaluation and refinement of water-harvesting techniques in different regions

Water harvesting is location specific and depends on hydrogeology, agro-climatic conditions and other watershed parameters of the area. Therefore, identification and evaluation of indigenous/non-conventional water-harvesting techniques is needed for further refinement, wherever feasible, to make rainwater harvesting suited to local conditions for easy adoption by the watershed communities.

Strategies for augmentation of groundwater recharge, its quantification and management

Over-exploitation of groundwater resources and a general decline in water table has given an impetus to ground-water-recharge techniques as well as the quantification of recharge affected by these techniques. Along with conventional methods of augmenting ground-water recharge, other several recharge techniques like recharge pits and shafts, injection wells, etc. need to be refined for improving the impact of these water-harvesting structures on ground-water recharge and their popularization in watershed programmes.

Quantification and valuation of intangible benefits and environmental externalities of watershed management programmes

Natural resource management (NRM) projects yield a variety of intangible benefits, which have long-lasting effects and impacts. Most of the evaluation studies hardly quantify them in physical terms. Efforts are required to develop ways and means for quantification and valuation of intangible benefits that are realized from NRM technologies and watershed-development projects.

4th International Agronomy Congress (November 22–26): 22–36 (2016)

Prospects of bringing second green revolution in eastern India

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ABSTRACT

The eastern region of the country holds promise for a Second Green Revolution (SGR), which can be accomplished through holistic management of land, water, crops, biomass, horticultural, livestock, fishery and human resources. The eastern region is unique for its suitability to the production of many agricultural commodities. The region has fertile soils and ample water resources, the 2 most important natural resources required for higher productivity. The majority of the areas in these states have a length of growing period of 240 days or more, which is adequate to support double cropping. Annual rainfall in the region varies from 1,000 mm to 2,500 mm. Average rainfall during the last 14 years was more than 2,000 mm in the Lower Gangetic Plains and 1000 mm to 1,250 mm in the Middle Gangetic Plains, and Plateau and Coastal regions. The eastern states accounts for 53% of 154.71 BCM of total available groundwater for future use. However, the groundwater draft is much less than the groundwater availability in most of the eastern states except Eastern Uttar Pradesh. Therefore, there is considerable scope for groundwater development in the region with due care of the high arsenic content in certain areas. Rice (*Oryza sativa* L.) is the major crop in the eastern region. However, abiotic stress such as drought, flood, submergence and salinity is the major factor constraining the productivity of rice-based cropping systems. Of the total 11.6 million ha rice-fallow area in the country, 82% lies in the eastern states. This offers a unique opportunity for enhancing the productivity through crop intensification. There is a great potential of organic farming in tribal dominated areas of Jharkhand, Odisha and Chhattisgarh, where organic farming by default is practiced. This region can be made sustainable with its orientation towards export market. In view of these facts, there is a need to harness the potential of the eastern region with suitable interventions. However, taking advantage of this potential would require institutional support and investment in development of suitable technologies. In addition to Bringing Green Revolution in Eastern India (BGREI), the Government of India has launched a mega programme through the Indian Council of Agricultural Research (ICAR) for bringing second Green Revolution (GR) in Eastern India. The second GR cell has also been established at the ICAR-Research Complex for Eastern Region, Patna, to coordinate the various researches, developmental and policy issues of the eastern states in collaboration with respective state governments, State Agricultural Universities (SAUs), ICAR and CGIAR institutes and other organizations. Besides, many new research institutes have been established in the region to give an added impetus to the programme.

INTRODUCTION

The first Green Revolution (GR) in India began in mid-1960s through the introduction of new high-yielding varieties of wheat (*Triticum aestivum* L. emend. Fiori & Paol.) responsive to application of irrigation and fertilizers. However, its benefits were mainly confined to north-western states of Haryana, Punjab and western Uttar Pradesh. It helped farmers of the region, having good irrigation network and increased the farm productivity substantially over the years. The synergy between the technology and public policy made the GR a grand success and turned India from ‘begging bowl’ to leading producer of foodgrains. Following the GR, India’s food grain production had increased from 82 million tonnes in 1960–61 to 264 million tonnes by 2013–14 (Table 1). The average productivity of rice (*Oryza sativa* L.) increased from 1,013 kg/ha to above 2,500 kg/ha, and of wheat from 850 kg/ha to over 3,000 kg/ha in the corresponding period. Thereafter, Indian agriculture witnessed all-round development, as a result of which horticulture production is now over 280 million tonnes, milk production about 132 million tonnes, fisheries 9.0 million connes and eggs about 70 billion. These achievements have placed India among the leading producers of these food items. However, the benefits of the first GR could not reach to the eastern states and other rainfed areas of the country, which contribute about 60% of the country’s total foodgrain production.

PRIORITY AREAS IN SECOND GREEN REVOLUTION

While the first GR was to ensure food security, as there was severe scarcity of food in the country, the second GR should aim at creating sustainable livelihood security for the poor and eradication of poverty by generating gainful

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Table 1. Progress in food grain production (million tonnes)

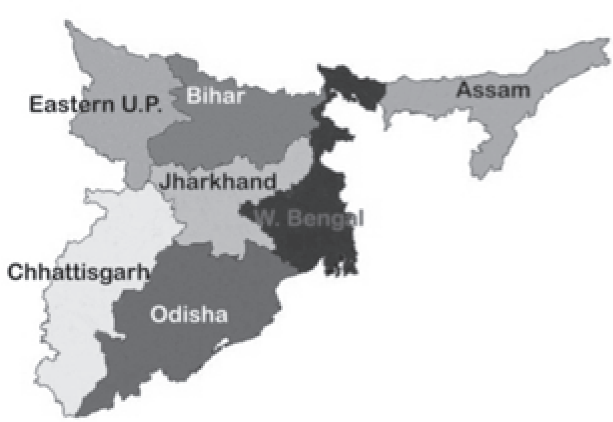
Item	1960–61	1980–81	2008–09	2013–14
Rice	34.58	53.63	99.18	106.54
Wheat	11.0	36.31	80.68	95.91
Course cereals	23.74	29.20	40.04	43.05
Total cereals	69.32	119.14	219.90	245.50
Total pulses	12.70	10.63	14.57	19.27
Total food grain	82.02	129.77	234.47	264.77

Source: DAC, GoI (2014)

self-employment. The second GR should focus on generation of employment for the small and marginal farmers and the landless, while enhancing agricultural production. Tree farming particularly horticultural interventions can also provide year-round employment to the stakeholders of the region. An equally important sector is livestock, which needs good support. A majority of the small farmers in Eastern region depend on livestock for supplementary income. Livestock is, by and large, well distributed among various sections of the communities unlike land holdings. Therefore, promotion of mixed farming with livestock can also generate employment for small and marginal farmers.

EASTERN INDIA AT A GLANCE

The eastern states of India, comprising Asom, Bihar, Chhattisgarh, Eastern Uttar Pradesh, Jharkhand, Odisha and West Bengal, occupy about 21.85% geographical area and support 34% human and 31% livestock population of India. The population density is 1.91-fold higher in eastern states compared to national average. Agriculture is the mainstay of economy in most eastern states, since 84% population living in rural areas depends on it for their subsistence. Of the total geographical area of 71.84 million ha in eastern states, the net sown area is 31.43 million ha (22.2% of the country) with a cropping intensity of 150% as against 141% of the national average. The region has about 2.73 million ha total area under water constituting



reservoirs, ponds, tanks and beels, oxbow lakes, brackishwater, etc. besides 15,046 km length of rivers and canals constituting about 18% of country's utilizable water resources (10% of surface water and 30% of groundwater). The average rainfall in eastern region varies from 1,091 to 2,477 mm with a regional average of 1,526 mm, which is sufficient and substantial for growing a variety of crops. However, the irrigated area in the region is 39% as against 45% of the national average. In eastern region, about 9.2 million ha land is monocropped with rice, and remains fallow after harvesting.

On average, eastern states contribute about 47% of the total rice production of the country, followed by vegetables (41%) and inland fisheries (34%). However, high population density (616 persons/km^2 compared to 382 persons/km^2 at national level), poor supply of electricity to the agricultural sector, lowest per caput income (₹26,047/annum compared to the national average of ₹38,904), maximum number of economically most backward districts (69 out of 150 at national level), and 32.1% population below poverty line (as against 21.9% of national average) in the region exert tremendous pressure on the natural resources of this region (Table 2).

The production levels of agriculture, livestock and fisheries have remained low due mainly to lack of location-specific production technologies, natural calamities like floods, waterlogging, drought, inadequate timely supply of critical inputs and social constraints. The eastern region has more than 40% cattle population, followed by goat (36%). The region produces 19.76% (26.17 million tonnes) of the total milk production (132.4 million tonnes), but the per caput milk availability is very low (150 g/day) as against national average of 299 g/day.

Soils

Soils of eastern states have low to medium organic carbon and available nitrogen contents. Available phosphorus is low to high and available potash is medium to high in eastern states (Table 3). Alluvial soils is the dominant soil type (covering 40.5% area of the region), followed by red and yellow soils (25.45%), red sandy soils (13.60%), red loamy soils (8.70%), *tarai* soils (6.05%), lateritic soils (5%), and grey and brown soils (0.70%). The region has about 7.5 million ha area under acidic soils (Naik *et al*. 2015). Likewise, sodic soils occupy an area of 3.81 million ha. A total of 4.05 m ha area is under wetlands in Eastern region. West Bengal has the highest area (1.1 million ha) under wetlands, followed by Asom (0.752 million ha). Among various Eastern states, Jharkhand has the lowest area under wetlands due mainly to Hill and Plateau agro-ecosystem. Of the total geographical area, 6.16 million ha, i.e. 8.58% is under wastelands in Eastern states. Among

Table 2. Potential of natural resources in the Eastern region vis-à-vis national average

Natural resources	Eastern region	India	Percentage
Total geographical area (million ha)	71.84	328.73	21.85
Net sown area (million ha)	31.43	141	22.20
Net irrigated area (million ha)	14.36	65.3	22.00
Cropping intensity (%)	150	141	-
Wetland area (million ha)	4.05	15.3	26.50
Total fresh water area (million ha)	2.92	6.92	42.22
Marginal farmers (<1 ha) (%)	67.00	62.88	-
Large farmers (>10 ha) (%)	0.46	1.02	-
Total population (million)*	406	1210	33.54
Population density (no/km^2)	616	382	-
Rural population (%)	81.54	72.18	-
BPL (%)	32.10	21.90	-
Annual groundwater availability (BCM)	145.12	399.25	36.35
Groundwater draft (%)	36.00	58.00	-

Census of India, 2011; Source: Bhatt *et al*. (2011)

Table 3. Nutrient status of soil in different agro-climatic regions of eastern states

Agro-climatic region	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Lower Indo-Gangetic Plains	Low (0.47)	Low to medium (116–450)	Medium to high (23.5–32.6)	Medium (260–295)
Middle Indo-Gangetic Plains	Low (0.26)	Medium (276–372)	Medium (10–13.3)	Medium to high (120–354)
Eastern Plateau and Hills Region	Low (0.45)	Low to medium (147–353)	Low to medium (6.9–16.2)	Medium (180–280)
Eastern Coastal Plains and Hills	Medium (0.65)	Low to medium (201–350)	Medium to high (11.3–35.9)	Medium to high (205–301)

Source: Bhatt, 2015

Table 4. Nutrient consumption in eastern states

State	Nutrient consumption (kg/ha)			
	N	P_2O_5	K_2O	Total NPK
Assam	36.24	9.99	19.19	65.41
Bihar	124.88	27.44	12.55	164.87
Chhattisgarh	63.08	28.72	8.43	100.22
Eastern Uttar Pradesh*	115.18	29.63	4.06	148.86
Jharkhand	65.72	13.79	2.94	82.45
Odisha	63.05	23.71	11.37	98.13
West Bengal	74.09	28.11	28.97	131.17
Eastern Region (Average)	77.46	23.06	12.50	113.02
All India (Average)	85.79	28.85	10.75	125.39

Source: Bhatt (2015)

various states, Jharkhand has the highest area under wastelands (14.84%), followed by Asom (11.20%) and Odisha (10.69%).

Nutrient consumption

Total nutrient (N, P and K) consumption in eastern states has been reported to be 113.0 kg/ha as compared to 125.4 kg/ha at the national level (Table 4). Within the region, Bihar exhibited the highest (165 kg/ha) consumption of NPK, followed by Eastern Uttar Pradesh (148.86 kg/ha) and West Bengal (131.17 kg/ha). On an average, total NPK consumption was the lowest in Asom, followed by Jharkhand and Odisha. Use of nitrogen has increased during the recent past in the region, particularly in the states like Bihar and Eastern Uttar Pradesh (range 115.0–125.0 kg/ha). Moderate use of N (range 63.0-74.0 kg/ha) has been recorded in Hill and Plateau and also in West Bengal. Asom, however, still has the lowest consumption of nitrogen (36.2 kg/ha). Irrespective of years, the average N consumption has been estimated to be 66.07 kg/ha in eastern states as compared to 74.09 kg/ha at the national level. Application of phosphorus did not improve much in eastern states during the recent past. However, Odisha, Bihar, Chhattisgarh, Eastern Uttar Pradesh and West Bengal has the consumption rate of phosphorus to the tune of 23.7–29.6 kg/ha. Use of potassium was found consistent in case of West Bengal where it is estimated to be 33.0 kg/ha and thereby indicating about 3-fold higher consumption of potash than the national average. States like Asom, Bihar and Odisha also indicated higher use of potash.

Groundwater

Eastern states are reservoir of groundwater resources. Net annual availability of ground water has been accounted for 138.78 Billion Cubic Meter (BCM) in the region as against 398.16 BCM at the national level (Table 5). However, groundwater draft is very poor across the states (39.23%) as against 61.55% at the national level (Bhatt *et al*., 2015). Poor groundwater draft was compared with energy supply, i.e. electricity to the agriculture sector in the region, and it was observed that supply of electricity to the agriculture sector in eastern region is merely 6.6% as compared to 21% at the national level. Only 2 states (Chhattisgarh and Eastern Uttar Pradesh) have ensured 17% supply to the agriculture sector and in rest of the states, the energy supply to agriculture sector is virtually negligible.

Eastern states account for 53% of 154.71 BCM of total available water for future use. Groundwater development in these states, except in Uttar Pradesh is quite low (Fig. 1), and these states also have lower groundwater development (22–43%) than the national average (61%). Therefore, there is considerable scope for groundwater development in the region with due consideration of water quality (problem of high arsenic content).

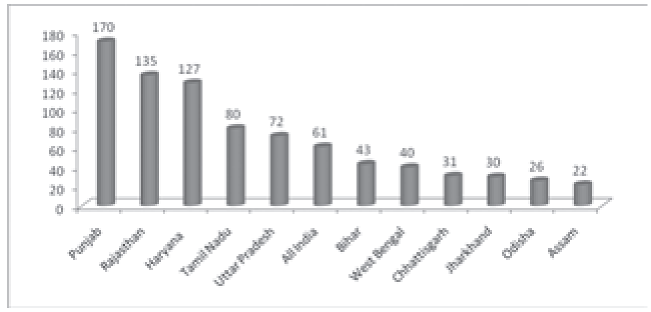


Fig. 1. Groundwater development (%) in selected states (*Source:* NITI Ayog, GoI, 2015)

Water productivity

Although there are enough rainfall and groundwater in eastern states, the water productivity (0.37 kg/m^3) is very low as compared to Punjab (>1.0 kg/m^3) (Fig. 2). There are only two states-Eastern Uttar Pradesh and West Bengal, where average water productivity has been found 0.50 kg/m^3 for food production. Similarly, for integrated fish-farming system, estimated water productivity is 0.25 to 0.35 kg/m^3.

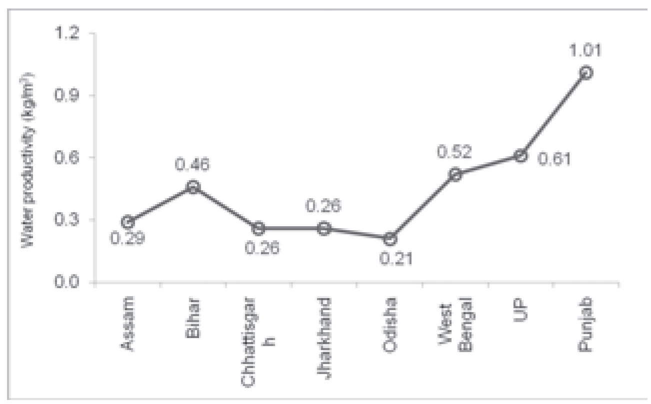


Fig. 2. Water productivity in eastern states (Source: Bhatt, 2015)

Table 5. Groundwater (GW) utilization (BCM) in eastern region

States	Annual replenishable GW	Net annual GW availability	Annual GW draft	Stage of GW development (%)	GW availability for future irrigation
Asom	28.52	25.79	3.49	13.53	22.14
Bihar	29.34	26.86	11.95	44.49	14.10
Chhattisgarh	12.42	11.63	4.05	34.82	7.44
Jharkhand	6.31	5.76	1.86	32.29	3.69
Odisha	17.58	16.69	4.73	28.34	11.64
Eastern Uttar Pradesh	27.29	25.47	17.68	69.41	7.58
West Bengal	29.25	26.58	10.69	40.22	15.38
Eastern Region	150.91	138.78	54.45	39.23	81.97
India	432.72	398.16	245.10	62	154.71

Source: Central Ground Water Board (2014), Pathak *et al*. (2015)

Agricultural mechanization

Based on 17th livestock census-2003, there were 3.39 lakhs and 0.65 lakh tractor and power tiller, respectively, in eastern states which is only 17% as compared to national level. Same ratio has been recorded in case of laser-land leveler and seed-cum-fertilizer drills. Although there are large number of diesel-pump sets in eastern states (34% of India), higher pumping cost due to increasing price of diesel has limited the functioning of pumping sets. Use of electric pumps is very less due to limited availability of electricity. Number of drip irrigation system and micro irrigation system is also very less in the region.

Operational holdings

The total area of operational holdings, which was 31.87 million ha during 2000–01 increased to 33.96 million ha during 2010–11 in eastern states. During the same period, the number of operational holdings increased from 37.89 million to 47.19 million, thereby indicating a net increase of 9.29 million of operational holdings. In the absence of land consolidation in entire eastern region, there was significant increase in number of operational holdings. While the area of operational holdings increased in Eastern India, at the national level it decreased by 17.89 million ha during 2010–11 as compared to 2000–01.

This contrasting regional feature has made the agricultural development more challenging in all the eastern states. Since there was significant increase in the number of operational holdings, the average size of holding was reduced from 0.84 ha to 0.72 ha during 2010–11 as compared to 1.18 ha at the national level. Within the region, the average size of more than 1 ha is reported for the states like Asom, Chhattisgarh, Jharkhand and Odisha. However, the fragmentation increased significantly in Bihar where the average size of holding has come down from 0.58 to 0.39 ha during 2010–11. As per the agro-climatic zones, the data indicated that the average size of the holding ranked in the order of Hill and Plateau region (1.19 ha) > lower Gangetic plains (0.94 ha) > middle gangetic plains (0.50 ha).

Area, production and productivity of food grains

The area under foodgrains in eastern region (35.68 million ha) is about 28.3% of the total foodgrains area of the country and contributes 27.86% in total foodgrain production. Among eastern states, Eastern Uttar Pradesh has the maximum area (7.90 million ha) and production (18.52 million tonnes). However, West Bengal has the highest foodgrain productivity (2.73 tonnes/ha) (Table 6). The average productivity of *kharif* and *rabi* crops in eastern Uttar Pradesh and West Bengal is higher than that of the national average (Fig. 3).

Cropping intensity

The crop intensity in the region is higher (150%) than the national average (141%). Within the region, eastern Hill and Plateau states (Chhattisgarh and Odisha) have the cropping intensity of 118% as compared to 159% of rest of the states. Among various eastern states, West Bengal has the highest (186%) and Odisha the lowest (115.6%).

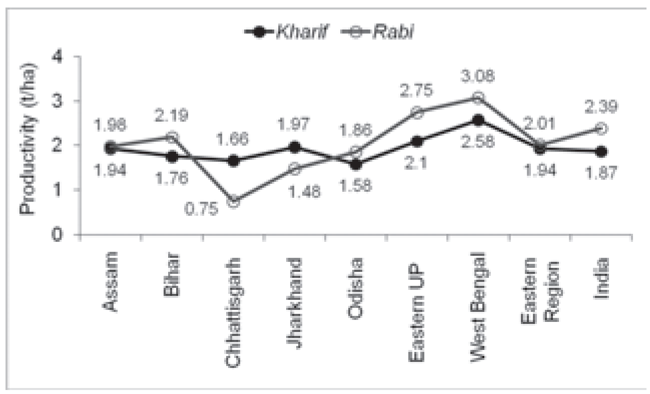


Fig. 3. Productivity of *kharif* and *rabi* crops in eastern states (Source: Bhatt, 2015)

Table 6. Area, production and productivity of foodgrains in eastern region (2013–14)

States	Area (million ha)	Production (million tonnes)	Productivity (tonnes/ha)
Assam	2.53	4.94	1.95
Bihar	6.67	13.15	1.97
Chhattisgarh	4.95	7.58	1.53
Jharkhand	2.24	4.19	1.87
Odisha	5.15	8.33	1.62
Eastern Uttar Pradesh	7.90	18.52	2.34
West Bengal	6.24	17.05	2.73
Eastern region	35.68	73.76	2.07
India	126.04	264.77	2.10

Source: DAC, GoI (2014)

Per caput availability of food grains

Availability of total foodgrain per caput has decreased over a period of a decade in the region in spite of the fact that it has increased at the national level. Excepting Jharkhand, all the states have shown decreasing trend in foodgrain availability at individual level. On an average, per caput food availability in the eastern states was accounted for 476.2 g/day as against 582.6 g/day at the national level. States like Chhattisgarh and Eastern Uttar Pradesh have the per caput availability of total foodgrains higher than the national average (733.7 and 636.6 g/day, respectively, in Chhattisgarh and Eastern Uttar Pradesh).

Fodder production

So far in fodder production is concerned, excepting Eastern Uttar Pradesh, other eastern states did not exhibit any systematic programme of fodder production. While 7.77 million ha area is under fodder crops at the national level, eastern states have only 0.32 million ha under fodder crops which accounts for 4.1% area under fodder crops. However, eastern states have 1.68 million ha area under permanent pasture and other grazing lands as against 10.3 million ha at the national level. Chhattisgarh and Odisha are the leading states which contribute 81% of the total pasture and other grazing lands in Eastern India.

Seed replacement

On an average, seed replacement rate in eastern states is low. It ranged from 32% in rice, 37.3% in wheat, 69.81 % in maize and < 20% in pulses.

FUTURE SCENARIO OF EASTERN REGION

The growing demand for foodgrains, vegetable, fruits, milk, poultry, fish and meat as well as cash crops is posing newer challenges to agriculture. The demand for food will depend largely on income growth and food consumption patterns. Total human population for the eastern states has been projected to be 556.24 million (Table 7).

There are variable estimates projecting the future demand for cereal commodities. The projected growth in income, urbanization and change in consumption pattern are likely to have a great impact on food security. The demand for foodgrains production for 2050 in the eastern region is estimated to be 84.42 million tonnes.

Eastern states are likely to be worst hit by climate change (Abdul Haris *et al.,* 2015). Significant decline in wheat production is expected by 2050 due to climate change. It may result in price rise jeopardizing food and nutritional security. Simulation studies showed decreasing trends of potential yields of rice and wheat in the Indo-Gangetic Plains with increasing minimum temperature. It is reported that an increase in minimum temperature by 2°C could decrease rice yield by about 0.75 tonne/ha in the high-yielding areas and about 0.06 tonne/ha in the low-yield coastal regions (Sinha and Swaminathan, 1991). However, rice productivity can be maintained and slightly improved with medium-duration varieties. Simulated yield of *rabi* maize may increase from 8 to 11 % by 2020 and 14 to 25% by 2050, respectively. Rice area in Eastern Region may increase slightly (from 21.7 million ha to 22.9 million ha by 2050), with 18% increase in production and 12.2% increase in productivity, respectively.

For wheat, although the area is projected to increase by 24% in 2050, the productivity may decline by 20%. However, there is scope for improving the productivity through adoption of improved varieties tolerant to abiotic stresses, adjustment in time of planting, duration and methods of planting etc.

The projected production of pulses and oilseeds is estimated to be 4.84 and 2.12 million tonnes, respectively, by the year 2050 compared to 2.77 million tonnes of pulses and 2.12 million of oilseeds during the year 2011 implying that production and productivity of pulses are expected to increase nearly by 75% from eastern states.

Table 7. Rural urban population in Eastern India 2011 and projected in 2050 (million numbers)

States	2011			2050		
	Rural	Urban	Total	Rural	Urban	Total
Asom	26.78	4.38	31.16	33.71	7.19	40.90
Bihar	92.07	11.73	103.8	139.74	21.88	161.62
Chhattisgarh	19.60	5.93	25.53	23.16	10.95	34.11
Jharkhand	25.04	7.93	32.97	32.28	13.43	45.71
Odisha	34.95	6.99	41.94	37.80	10.66	48.46
Eastern Uttar Pradesh	62.68	17.79	80.74	86.91	31.35	118.26
West Bengal	62.21	29.13	91.34	60.03	47.15	107.18
Eastern region	323.33	83.88	407.48	413.63	142.61	556.24

Source: Office, RGI (2011)

The area under fruit crops in Eastern India is 1.44 million ha with total fruit production of 17.07 million tonnes against a projected demand of 17.8 million tonnes. By the year 2050, the projected fruit production would be 22.6 million tonnes with the help of large-scale area expansion and productivity-improvement programmes. However, a deficit of 1.6 million tonnes of fruits is projected by 2050.

Likewise, as of now, the total vegetable production in eastern India is estimated to be 71.78 million tonnes from 4.27 million ha area. With a projected production of 90.4 million tonnes by 2050, eastern India will have a vegetable surplus of 30.0 million tonnes and the region will play a major role in fulfilling the vegetable requirement of other parts of India. However, it will require a significant investment and efforts to strengthen the infrastructure for transportation and post-harvest management.

In case of milk, the projected demand would be 60.41 million tonnes as against the supply of 48.92 million tonnes by 2050. Demand for meat products is likely to be 6.08 million tonnes against the likely supply of 3.12 million tonnes. Demand for eggs would be 99.32 billion against a likely supply of 37.81 billion. Total fish requirement is projected to be 6.06 million tonnes by 2050 as against the current production of 2.71 million tonnes. However, it is expected that the region would be self-sufficient to meet out the fish requirement.

CHALLENGES

Eastern region faces multiple challenges: it has to produce more food and fibre to feed a growing population with a smaller rural labour force, skewed distribution of operational holdings, land degradation, imbalance use of water and nutrients, low fertilizer consumption, low productivity, low level of mechanization, climate-change impact, non-remunerative prices and post-harvest losses (Bhatt *et al*., 2011). Small (< 1 ha) and fragmented land-holdings limit the adoption of improved technologies. The total water demand is projected to increase 900 BCM and the groundwater withdrawal from 303 BCM in 2000 to 423 BCM by 2050. The coastal areas are vulnerable to sea-water intrusion and cyclones. Further, the wetlands, which occupy an area of 4.05 million ha, need restoration for sustainable food production and conservation of biodiversity.

The declining per caput land and water availability in agriculture would limit the food requirement of the burgeoning population by 2050 in the eastern states to a great extent. Water productivity is also very low (0.37 kg/m^3) in the region. Although the region has 165 million bovines, the crossbred cattle population is less than 5%. This sector has been almost neglected and its synergistic role in the farming practices has not been realized so far. The region also lacks quality feeds and fodder resources besides adequate animal- health-care mechanism. In case of fisheries sector, the total area under ponds and tanks in the eastern states is about 0.668 million ha with total fish production of only 1.43 million tonnes.

Low productivity in floodplain wetlands, 9.2 million ha of rice-fallow land, 7.5 million ha acidic and 3.81 million ha sodic soils also limits the crop productivity. Monocropping, particularly in the Hill and Plateau region and Eastern Himalayas, is one of the major constraints to increase the cropping intensity. The wastelands/ degraded lands (6.16 million ha) also need rehabilitation through agroforestry and horticulture interventions. Restoration of coal-mining areas in the states like Jharkhand, Chhattisgarh and Odisha also needs to be addressed in the long run.

STRATEGIES

Management of rice fallow

About 9.2 million ha of land in the eastern region is monocropped with rice, and remains fallow after rice harvesting. A second crop of oilseeds, pulses, vegetables and fodder crops can be raised through effective utilization of residual moisture and appropriate rainwater management/ conservation technologies in rice-fallow areas. Pasture management and agroforestry with deep-rooted fodder crops in integrated farming system mode of food production, along with crop diversification is the need of the hour.

Natural resources management

Soil management needs to maintain soil cover and return organic matter to the soil along with chemical fertilizers, i.e. integrated soil-fertility management (ISFM) and microbial inoculants. It would be the best option for ensuring long-term soil sustainability and biodiversity conservation. Micronutrient deficiency, particularly zinc, iron, boron, manganese, copper and sulphur, also need to be addressed in the soils of Eastern Indo-Gangetic Plains (EIGP).

Furthermore, organic carbon pools and C/N dynamics in the soils need to be studied, as they are components of the global carbon cycle. Amelioration of acidic soils is posing major challenge, particularly in the Hill and Plateau regions and Eastern Himalayan region. Residue management in soil would help to improve physico-chemical properties of soil, particularly in EIGP. Nutrient-and water-use efficiency has to be improved for long-term sustainable production. Conservation agriculture needs to be strengthened in rice–wheat ecosystem. Since the region has large area under wastelands/ degraded lands, rehabilitation of such areas through agroforestry and horticultural interventions is also required for soil fertility build up, biomass augmentation and livelihood sustainability.

The eastern states receive average rainfall of 1,526 mm (varies from 1,091 to 2,477 mm); however, its distribution is very erratic. On an average, the region receives 18% of the country's utilizable water resources. The ultimate irrigation potential in Eastern Region has been accounted for 33.65 million ha-m; however, the utilization of the created irrigation potential is only about 65%. The region also has about 4.05 million ha of wetlands, which are, by and large, underutilized. The use of groundwater for agriculture is low mainly due to the paucity of energy. The share of electricity to agriculture sector is hardly 0.50 (Jharkhand) to 15.49% (Chhattisgarh) indicating that power is one of the main constraints to increase food production in the Eastern Region (Rai *et al*., 2009). Integrated water resources management strategies for rainwater harvesting and on-farm water management along with conjunctive use of rain, surface and groundwater, multiple use of irrigation water, use of water-saving and energy-efficient devices are the need of the hour in this region.

Agro-biodiversity conservation

Introduction of high-yielding varieties for ushering second Green Revolution in eastern states may pose a threat to agro-biodiversity of the region. Conservation of important agri-horti and multipurpose tree-crop germplasm would help to achieve sustainable development, particularly in the projected climate-change scenario. Traditional food crops including oilseeds, pulses, tuber crops, lesser-known potential wild edibles etc. need to be conserved for sustainable food production in eastern region.

Reduction in post-harvest losses

According to the Food Corporation of India, some 23 million tonnes food cereals, 12 million tonnes fruits and 21 million tonnes vegetables are lost each year, with a total estimated value of 240 billion rupees. A recent estimate by the Ministry of Food Processing is that agricultural produce worth 580 billion rupees is wasted in India each year. Necessary steps need to be taken to reduce these losses.

Livelihood improvement of landless farmers

Although eastern states have only 21.85% geographical area of the country, it has very high number of economically most backward districts. Livelihood of landless and under-privileged people of Eastern region is one of the major challenges ahead. Eastern states accounts for about 45% of the total under-privileged people at the national level. The livelihood options of these people need to be explored.

System-mode production

Eastern states have ample scope for increasing productivity in system mode, wherein the synergy of crop–livestock–fish–agroforestry–horticulture could be harnessed. Productivity of the system, however, will depend on recycling of renewable farm resources, which calls for integrating livestock, fish, poultry and duckery so as to develop sustainable production systems (Kumar *et al.*, 2015). Hence research strategies should aim at productivity enhancement, diversification, minimization of production losses through risk management, processing and value addition, and commercialization based on market intelligence.

***Makhana* cultivation in cropping and farming system mode**

Makhana (*Euryale ferox* Salis.), a unique crop of the Eastern Region, is grown in about 13,000 ha of water-bodies with a popped *makhana* production of 9,360 tonnes. Its cultivation, however, is constrained by shrinking water-bodies on the one hand and the skill required for collection of nuts, roasting and popping of nuts on the other. The institute has developed technology for *makhana* cultivation in a cropping-system mode, which has resulted into higher productivity with less water requirement and reduction in drudgery associated with *makhana* nut harvesting (Kumar *et al.* 2014). Adoption of this technology could bring 1.10 million ha of waterlogged areas under *makhana* cultivation, which otherwise remained unutilized or under-exploited. Promising strain of *makhana* has also been identified which has a productivity of 2.8 to 3.0 tonnes/ha compared to 1.4 to 1.6 tonnes/ha for the traditional cultivars. The technology of integrated farming of *makhana* with fish and water chestnut [*Trapa natans* L. var. bispinosa (Roxb.) Makino, developed by the institute, is also gaining popularity among the farmers, particularly in north Bihar. Although production technologies for *makhana* are available now, its mechanization is still a major challenge. Therefore, development of a prototype for *makhana* grading and popping is essential for achieving value-addition in this important crop.

Integrated farming system

Integrated farming system (IFS) is generally considered relevant to the rural poor. The emphasis in such system is on optimizing resource utilization rather than maximizing the productivity of a certain component in the system. The concept of IFS has come into picture in order to achieve food and nutrition security at household and even at individual level besides generating employment opportunities, increasing cropping intensity and net income of the farming family, and conservation of natural resources (Kumar *et al*., 2013). Integrated farming system, also involves agricultural intensifications, diversification and value-addition. It helps improve physical and economic access to food, thereby sustaining food security.

Organic farming

Some regions of the eastern states are moving towards adopting the policy of organic food production systems. Since the demand of organic food is increasing in markets, there is a need to strengthen the research on organic farming in specific crops. There is a great potential of organic farming in tribal-dominated areas of Jharkhand, Odisha and Chhattisgarh, where organic farming by default is practiced. These regions can be made sustainable with its orientation towards export market.

Synergistic role of livestock in farming systems

Eastern states contribute about 31% of the total livestock and 27.2% of total poultry population of India respectively. Livestock has been an integral component of all farming situations, implying its role in risk avoidance and providing some insurance against failure of crop/enterprise in adverse climatic conditions. The synergistic roles of livestock need to be understood in order to develop location-specific integrated farming systems for long-term sustainable production. Aspects relating to balanced feeding, based on locally available feed resources, mineral supplementation, deworming and vaccination, green fodder supply, maintaining improved breed, reproductive management, etc. need to be addressed for animal-husbandry practices to be profitable in different farming situations.

Integrated fish farming

The Eastern Region has 4.05 million ha of wetlands and 2.92 million ha of freshwater bodies, where fish-cum-duck, fish-cum-chicken, fish-cum-cattle, fish-cum-goat, fish-cum-pig, fish-cum-buffalo integrations are promising. It will play an important role in increasing employment opportunities, and income of rural populations. Such integrations are also feasible for *taal*, *chaur* and *maun* areas of Bihar. On an average, the fish production could increase by 3–4-fold when integrated fish farming is practised. However, quality-seed production, brood management, diversification in aquaculture, standardization of stocking density of composite fish culture for diverse agroclimatic zones need to be studied and validated (Bhatt *et al*., 2012).

Conservation and sustainable use of floodplain wetlands

Eastern states have extensive freshwater wetlands, locally known as *beels*, *mauns*, *tals*, *chaurs*, *jheels* and *pats* in the states of Asom, West Bengal, Bihar and Uttar Pradesh. These natural water-bodies are integral part of rivers and are formed as a result of the rivers changing their course. These floodplain wetlands are one of the prime resources for inland fisheries besides production of agricultural crops. These water-bodies, however, are highly sensitive and fragile and need eco-friendly management to support the biological wealth. Considering the limited scope of capture fisheries from coastal waters and natural inland waters like rivers and estuaries, greater emphasis must be given for aquaculture and culture-based fisheries from reservoirs and floodplain wetlands to meet the targeted fish requirement of 6.06 million tonnes by 2050 as against the present level of 2.92 million tonnes for the Eastern region. A systematic and integrated approach for fish culture in small and big reservoirs/rivers/*chaurs*/*mauns* on watershed approach supported by scientific studies is needed.

Scaling up water productivity

Promotion of technologies related to multiple uses of water, on-farm water management, irrigation water management including irrigation methods for small holder irrigation, management of flood prone/ water congested/ waterlogged areas, rainwater harvesting, groundwater recharging techniques and participatory watershed management in rainfed areas are required to augment water availability and improve productivity per drop of water in Eastern region.

Agroforestry interventions

Sustainability of production in the Eastern region could be achieved through agroforestry, particularly in the rainfed Hill and Plateau region. Agri-silviculture, agri-horticulture, agri-horti-silvi-pastoral and silvi-pastoral systems hold promise for biomass augmentation, soil fertility build up, moisture conservation and availability of minor forest produce. Since tribal communities of the region rely heavily on forests for their subsistence, location-specific agroforestry systems need to be developed. Multi-storied agroforestry and horticulture models are already gaining popularity in the region. The region also has a large area under degraded lands (6.16 million ha) and rehabilitation of such areas through suitable agroforestry models and integrated watershed management should be given priority.

Conservation agriculture

Puddling in transplanted rice and excessive tillage in subsequent wheat crop, have changed the soil physical conditions of the region drastically (Mondal *et al.,* 2016).

Conservation agriculture practices like direct sowing, laser levelling, retention of residues and minimum tillage hold promise in conserving moisture, nutrients and energy and thereby reducing the cost of cultivation apart from maintaining and improving carbon stock in the soil (Khan *et al*., 2011; Laik *et al*., 2014). There is potential to convert 2–3 million ha area under conservation agriculture in eastern region. Long-term studies are, however, required for adapting different crop production systems, including maize and pulses under conservation agriculture. Suitable varieties of different crops for conservation agriculture also need to be evolved.

Harnessing green energy

The annual average Direct Normal Irradiance (DNI) in the Eastern Region varies between 4.0 and 5.5 KWh/m^2/day. There is scope for harnessing this abundant natural resource through photovoltaic technology (Rahman and Bhatt, 2014). The efficiency of photovoltaic technology, however, is reported to be in the range of 10–16%, which needs to be improved to make its use in various agricultural production systems. Biofuels, including biodiesel from palm oil and ethanol from sugarcane, sweet sorghum, corn, etc. need to be explored.

Secondary agriculture, value addition and marketing

Post-harvest losses are very high, particularly in perishable commodities. Lack of market availability within reasonable distance from the production site and poor road network, storage and transportation infrastructure further adds to the problem. Except few crops, the potentialities for agro-based or bio-based industries have not been realized due to lack of infrastructure. Recently, agro-industrial potentialities of crops like *makhana*, maize (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], potato (*Solanum tuberosum* L.), litchi (*Litchi chinensis* Sonn.) etc. have been recognized. Tuber crops such as yams (*Dioscorea* spp.), sweet potato [*Ipomoea betatas* (L.) Lam.], taro [*Colocasia esculenta* (L.) Schott], tapioca (*Manihot esculenta* Crantz) etc. can be used as source of carbohydrate, starch and protein not only for human consumption but also to sustain the traditional animal husbandry practices. Besides, sericulture, mushrooms, floriculture, apiculture, natural gum and resins opens great scope for widening of agro-based enterprises. Fibre crops such as jute (*Corchorus* spp.), mesta (*Hebiscus cannabinus* L.), banana (*Musa* sp.), flex (*Linum usitatissimum* L.), sunhemp (*Crotolaria juncea* L.) etc. are also important. Agro-waste such as paddy husk, rice bran, rice straw, sugarcane bagasse, pressmud, vermicompost, etc. can be good materials that require urgent consideration for development. Keeping these facts in view, there is ample opportunity in developing secondary agriculture, primary processing, value-addition and increasing shelf-life of farm produce, so as to improve upon the livelihood of the large population, particularly the landless farmers' of eastern states.

Mechanization

Like other parts of the country, the Eastern region also faces acute labour shortage for agricultural operations, and non-availability of manpower during peak crop season is a growing problem. In small and marginal farms, except for tillage, other operations such as sowing/ transplanting, weeding, cotton picking, harvesting and threshing, etc. are normally manually performed. Mechanization also imparts capacity to the farmers to carry out farm operations, with ease and freedom from drudgery, making the farming agreeable vocation for educated youth as well. Therefore, development of need-based tools and implements need to be given priority to achieve timeliness and improves productivity and input-use efficiency.

Government initiatives for bringing second Green Revolution in eastern states

The Government of India had launched the strategic initiative 'Bringing Green Revolution in Eastern India (BGREI) for the second Green Revolution in 2010–11, which is still continuing. Improving the productivity of rice in water-rich eastern India is an important component of BGREI. The ICAR has established Indian Agricultural Research Institute (IARI), Hazaribag in Jharkhand, Indian Institute of Agricultural Biotechnology, Ranchi and National Research Centre on Integrated Farming at Motihari in Bihar, to further strengthen the agricultural research for the eastern region. To give an added impetus to the programme, the ministry of Agriculture and Farmers' Welfare, GoI, has launched a mega programme through the Indian Council of Agricultural Research (ICAR) in 2016 for bringing second GR in Eastern India. The second GR cell has also been established at the ICAR-Research Complex for Eastern Region, Patna, to coordinate the various researches, developmental and policy issues of the eastern states in collaboration with respective state governments, SAUs, ICAR and CGIAR institutes and other organizations.

Following major events have been organized so far towards bringing 2nd Green Revolution in Eastern States:

1. Agri Summit, 2013-A Step Towards Second Green Revolution. 8-9 April 2013 ICAR Research Complex for Eastern Region, Patna
2. Workshop for Identifying the Production and Technological Gaps in Middle IGP Regions on 7 October 2015 at Patna
3. Brainstorming Session on "Agro-Forestry for Reha-

bilitation of Water Congested Ecologies in the Eastern States on 5 April 2016 at Patna

4. First meeting of Second Green Revolution on 3 May 2016 at Patna
5. State Coordination Committee Meeting of Jharkhand on 7 June 2016 at Ranchi
6. State Coordination Committee Meeting of Odisha12 July 2016 at Bhuwaneshwar
7. State Coordination Committee Meeting of West Bengal on14 July 2016 at Kolkata.
8. State Coordination Committee Meeting of Uttar Pradesh on 27 July 2016 at Lucknow
9. State Coordination Committee Meeting of Assam on 2nd August, 2016 at Guwahati
10. State Coordination Committee Meeting of Bihar on 4 August 2016 at Patna
11. State Coordination Committee Meeting of Chhattisgarh on 5 August 2016 at Raipur

Based on deliberations and discussions in the above meetings, following issues have emerged out.

Policy

- The ICAR has already constituted Steering Committee, Technical Coordination Committee and State Level Coordination Committees for monitoring of SGR programme vide Office Order No. 34(1)/2016-Cdn.(Tech.), dated 07/04/2016, however, Hon'ble Union Minister of Agriculture and Farmers' Welfare, Government of India desired to have the District Coordination Committee(s) in each state involving KVKs, ICAR Institutes and other Institution located in the district. The District Coordination Committee(s) shall interact quarterly in order to apprise to State Coordination Committee(s).
- Since integrated farming system mode of food production system would address the issue of food and nutritional security besides mitigation of climate change impact on agriculture, the location-specific IFS models need to be developed so as to replicate them in each KVK, demonstration farms of SAUs and ICAR Institutions located in the region. There is also need to identify, document and propagate the potential tribal farming systems of the region.
- Since quality seed material, particularly in case of pulses and oilseeds, is one of the major constraints to improve the productivity in rice-fallow area, there is need to develop a seed chain of newly developed varieties in each state. Further, the 10 years old varieties, which still have the yield potential and resistance to the incidence of insect-pests and diseases, need to be re-notified to ensure the availability of quality seed material. Microbial approaches such as rhizobium inoculants and phosphorus-solubilizing bacteria should be adopted to improve the pulse productivity, especially in rice-fallow area. In addition to this, timely requisition of breeder seed requirements by various state governments of Eastern region is also need of the hour to ensure the supply of quality seeds.
- Since eastern states have more than 75% marginal and 160 million resource-poor farmers there is an urgent need for resource inventorization, prioritization and orientation of research and development programmes for small-holdings need to be incorporated in policy and planning.
- Each Eastern state should have MoU with National Seed Corporation in order to ensure the supply of quality seed materials.
- Agricultural Mechanization Development Centres need to be established in each Eastern state, particularly for strengthening the small-farm mechanization.
- To have skilled manpower in modern engineering tool, a National Institute of Advanced Agricultural Engineering should be established in the Eastern states.
- There is a need to take a stock of technologies needed for bringing Second Green Revolution besides the technologies already available with the Institutes, so as to identify the gaps which could be fulfilled through convergence and better synergies across the disciplines and institutions.
- Since the region has more than 95% non-descript cattle and buffalo population, there is an urgent need of genetic improvement through indigenous cattle like Sahiwal, Tharparkar and Red Sindhi (in case of cattle) and Murrah (in case of buffalo) in order to improve upon the milk productivity. Each Eastern state shall establish the Bull Centres of improved indigenous breeds besides Semen Storage Centres for the supply of quality semen.
- For increasing the income of landless households, improved backyard poultry and duck-production units need to be established in each state in order to develop a supply chain. However, parent stock need to be arranged by NARS.
- The region has international boundaries with Nepal, Bangladesh and Bhutan. Hence, preparedness to tackle transboundary diseases in livestock need to be developed, particularly in the state like Asom, West Bengal, Bihar and Eastern Uttar Pradesh.
- Keeping in view the commercial importance of ornamental fishes, National Research Centre on Ornamental Fish needs to be established for technology development and dissemination related to ornamen-

tal fishes.

- Diversification, value-addition, improving storage infrastructure and market linkage is prerequisite in agriculture and fishery sector for better returns and economic upliftment of poor farmers. Farmers' producer companies may be promoted in commodity-based identified clusters/ areas for streamlining production, processing and marketing.
- Processed foods are in great demand owing to change in food habit, per caput income, small family size and increased working women population. Hence food processing and packaging has great scope in eastern region with relatively cheaper labour force.
- Agriculture-related policies, such as disaster management, food security; land and water etc. should be synergistically converged at the grassroots level. Institutional adjustment and interministrial convergence are needed to ensure judicious implementation. Development of climate-smart agriculture should be mainstreamed into the policy with suitable investment and financing provisions.
- Sugarcane should be included in agriculture and the restrictive regulations in sugarcane sector needs to be minimized, so that farmers can get subsidy and strengthening of jiggery industry in Bihar and Uttar Pradesh. Provision of subsidy for mechanization of sugarcane cultivation.
- Inclusion of women farmer in the overall planning of agriculture development and the need for gender sensitization and gender-friendly farm implements and linking them with the market, processing unit and value chain. Ornamental fish production is also one of the important ventures for women empowerment.

Research

- Soils of Eastern Indo-Gangetic Plains are fertile but deficient in micronutrients (Zn, Fe, Cu, Mn, B etc). Multi-micronutrient deficiencies are also emerging in the area. Site-specific nutrient-management options, therefore, should be developed to improve the soil fertility. About 35% soils have also been found deficient in sulphur. It needs to be corrected for higher yield in oilseed crops. Amelioration of acidic (7.50 million ha) and sodic (3.81 million ha) soils is also required to increase the food production.
- Location-specific and resource-based integrated farming system mode of food-production system together with conservation agricultural practices needs promotion for sustainability, food and nutritional security and employment generation in the projected climate change scenario.
- Diverse cropping systems including oilseeds, pulses and millets and alternate farming systems for different agro-ecological regions need to be introduced.
- Development of long-duration (> 140 days) water-logging-tolerant cultivars for *kharif* season and of short-duration (< 130 days) with high salt-tolerant variety for *rabi* season to reduce water use and overcome salt stress; different land shaping models such as farm pond, paddy-cum-fish, deep furrow and high ridge and medium furrow and shallow ridge for rainwater harvesting and reducing salinity build up in the soil with a long-term perspective to improve the productivity of coastal areas.
- Ground-water problems (presence of arsenic, fluorides, and iron etc.) be tackled before there appear as major issues.
- Medium-duration high yielding varieties (HYV) of rice and wheat need to be developed and popularized in the region, so as to escape moisture stress and terminal heat.
- Mission mode approach may be adopted in developing robust hybrid seed production system. Apart from private sector, ICAR Institutions, KVK's and Agricultural Universities may be well equipped to balance the market forces and meet the increasing demand of hybrid seed at affordable cost.
- Rice-fallow management is need of the hour in most Eastern states. Suitable pulse/ oilseed crop need to be promoted not only for sustainability of the production system but also for soil fertility management. Rainwater harvesting and management need to be developed and popularized to have a regular crop after rice instead of *utera* crop.
- Tillage and irrigation cost in rice–wheat cropping system, particularly in Eastern Indo- Gangetic Plains, is the limiting factor for profitability to the farmers. Laser-land leveling, unpuddled mechanical rice transplanting, direct-seeded rice, zero tillage with residue and raised bed planting are some of the options to maintain long-term sustainable production system.
- Eastern states, particularly West Bengal and Bihar, significantly contribute to the national basket for fruits and vegetables. On an average, eastern states contribute 20.0% and 46.0%, respectively, to the total fruit and vegetables production at the national level. Eastern region is expected to enhance further the vegetable and fruit production. However, post-harvest losses need to be minimized through scientific handling, transport, storage, processing and value-addition.

- Resilient dryland farming system need to be developed reducing vulnerability of drought, floods, high temperature and infestation of insects and pests.
- Eastern states contribute 31.14% to total livestock population. However, 95% of the total livestock is non-descript type hence the productivity is very low. Appropriate livestock-improvement strategy should be put in place. Balanced feeding with locally available resources, mineral mixture, animal-health care, studies on soil-animal-plant continuum etc. is required for sustainable animal husbandry practices. The livelihood of landless farmers can be improved, particularly with goat and swine husbandry besides backyard poultry and duck farming.
- Location-specific and resource-based integrated farming system mode of food production system together with conservation agricultural practices needs promotion for sustainability, food and nutritional security and employment generation in the projected climate-change scenario.
- Package of practices need to be developed for cultivation of improved varieties of tuber crops, particularly in tribal farming practices.
- Adaptation strategies, such as gene restriction, altered agronomic practices, diversification, integrated farming systems, efficient use of natural resources etc. to meet farm-level situation and out scaling innovations for impact on small-holder farmers, small-scale entrepreneurs, rural youth and women for long-term sustainable and resilient farming need to be studied.
- Strategic research on methane emission in rice production and livestock husbandry needs to be addressed.
- Focus of research and development should be on increasing productivity of small and marginal farms, agro-processing and entrepreneurship for increasing income and employment.
- Timely planting of crops must be ensured to realize potential yields through appropriate mechanization and assured timely availability of quality seed, fertilizer, pesticide, irrigation, farm machinery, electricity and diesel etc.
- Alternate sources of energy, particularly solar energy, should be harnessed for agriculture, agro-processing and rural living since Eastern states is blessed with 250–300 bright sunshine days/year.
- Protected cultivation and technologies for producing more from less land and water need to be developed and popularized.
- Well-tested GM technologies with adequate safeguards need to be permitted.
- Introduction of superior germplasm for increasing the production and productivity in the livestock sector
- Strategic research on use of antihelmintic and antimicrobials with proper nutritional supplementation to reduce the problems of parasitic infestation and nutritional deficiency particularly in goats needs to be initiated.
- Standardization of seed, feed and disease management in fisheries sector should be carried out.
- Development of fish feed, prepared from locally available materials to reduce the cost of feed as well as waste.

Development

- Large productivity gap exists in the region. The productivity and total food production could be easily doubled through quality seed supply (15–20%), timeliness in operations (20–25%), improved water-management practices (15–20%), integrated nutrient management (20-25%), pest control (10–15%), post-harvest handling and storage (15–20%).
- Staggered Community nursery may be promoted for timeliness of planting and subsequent agronomic management which is required for improving rice–-wheat system productivity at least by 20%.
- Quality seed alone can increase productivity by 15–20%. The seed-replacement rate in most of the crops, particularly pulses and oilseeds, is extremely low (<10%), which affects adversely their productivity. It needs to be increased. This is even more critical in the rainfed agri-ecosystems, particularly in Hill and Plateau region. Hence seed production may be evolved in participatory/PPP mode and even truthfully labeled seeds may be produced and distributed.
- On-farm demonstrations and training on seed production, processing and storage technology may be adopted along with implementation of Seed Village Plan. Models of seed production like—production through progressive farmers for meeting local demands through sale/ exchange, production through progressive farmers with buy-back arrangement by an institution, seed production and marketing through farmers' association, promotion of institution-led farmers' seed company for seed production and its marketing may be adopted for large scale and timely supply of quality seeds.
- Hybrid seed production, particularly in rice and maize, need to be developed and popularized on large scale. Short-duration hybrids will help, particularly in mitigating the effect of floods (starting from

end of August, especially in the lowland ecologies) in the states like Bihar and Eastern Uttar Pradesh. Promoting single-cross hybrid in maize for different seasons and agro-ecological situations of Bihar can further improve the productivity by 10%.

- For improving yields in waterlogged areas, surface, sub-surface and vertical drainage be put in place. Micro-reservoirs can curb run-off and resulting erosion. It is predicted that with time annual rainfall may increase but number of rainy days may decrease necessitating handling excess water through scientific drainage besides rainwater storage in micro-reservoirs, etc.
- Water conserving technologies like, proper scheduling of canals (40–60% saving), designing check basins (10–30% saving), zero tillage (20–30% saving), precision leveling (15–20% saving), drip irrigation (40–60% saving), ridge/ furrow or raised/sunken beds (20–25% saving) etc. can improve the irrigation efficiency considerably. Groundwater recharge also be given due importance.
- Conservation of wetlands, renovation of silted ponds and other water-harvesting structures, and conjunctive use of surface and groundwater is required to improve water availability and water-use potential in flood and drought-prone areas.
- Culture fisheries and scientific management of natural water-bodies/ wetlands can improve the productivity at least by 50%. Multiple-water use technologies may be promoted on large scale to improve water productivity.
- Reclamation of degraded lands through drainage, agroforestry and horticultural interventions should be widely promoted in the region. Efforts also be made to popularize lac, sericulture, apiculture for livelihood improvement, particularly of tribal farmers.
- Entrepreneurship development through capacity building is need of the hour for small, marginal and landless farmers, service providers, input suppliers etc. Human resource development is also vital for scientific, technical and field-level functionaries to equip them with forthcoming agricultural challenges.
- Since, 80% farmers of the eastern states are small and marginal, small farm mechanization implements, like power tiller, weeder, small-scale planters, mechanical transplanter for rice, seed drills, maize sheller, wheel hoe, sprayers, reaper etc. should be made available preferably through custom-hiring and agri-service centers.
- Under the emerging challenges of unpredictable weather, climate streams and variability, volatility of markets, empowering farmers with real-time access to information in the farm easy to understand and adopt is needed at the door steps of the farmers and hence the use of ICTs and knowledge networks have to play critical role.
- Modernization of sugar mills along with the establishment of model jaggery units at strategic locations as well as capacity building of farmers for manufacturing quality jaggery.
- Launching a regional feed and fodder security mission (FFSM) in the line of Technology Mission on Horticulture and NFSM.
- Emphasis need to be given on skill-development programme to attract rural youths in agriculture.
- Livestock-development agencies need to be strengthened, particularly in the field of quality bull rearing.
- Revitalization of cooperative societies and institutional mechanism for organized credit, marketing and other services is required.
- Lack of quality seed is one of the major constraints in fisheries sector for which quality brood management is need of the hour. Establishment of brood bank in every state for at least 10 species of fish.
- Entrepreneurship development through capacity building in fisheries sector is need of the hour for small, marginal and landless farmers.

CONCLUSION

The Eastern region of India is rich in natural resources. However, its potential could not be harnessed in terms of improving agricultural productivity, poverty alleviation and livelihood improvement. It is rightfully thought that the second Green Revolution would be started in the Eastern Region to ensure food security of the nation. To achieve this, the large untapped production reservoir should be exploited through an appropriate blend of technologies, services, input and output rising policies and above all farmer's participation.

The Green Revolution in India indeed has led to substantial increase in foodgrain production, but over-exploitation of natural resources and indiscriminate use of inorganic fertilizers and pesticides have created threatening problems of declining factor productivity, soil salinity, sustainability, loss of biodiversity, water scarcity due to lowering of groundwater table, environmental pollution, pest resurgence, land degradation, etc. Therefore, the advantages of the GR have now been masked by the problems posed by it. Nevertheless, the eastern region of the country holds promise for a second Green Revolution, which can be accomplished through holistic management of land, water, crops, biomass, horticultural, livestock, fishery and human resources. However, in second GR, it is the need of the hour to shift from fertilizer- and pesticides-based conventional agriculture practices to natural and renewable resource-based sustainable agriculture, which is low-priced, environment friendly and emphasizes on the conservation of natural resources.

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4th International Agronomy Congress (November 22–26): 37–46 (2016)

Water management in agriculture: An overview

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ABSTRACT

Water is a critical input for sustainable agricultural development. Though irrigation development has received high priority in the successive five year plans, but the growing gap between Irrigation Potential Created (IPC) and Irrigation Potential Utilized (IPU), and low overall irrigation efficiency (around 38%) of the major and medium irrigation projects is the major cause of concern. Unplanned development and management of water resources has also resulted in many negative environmental problems such as waterlogging and salinity in many canal commands, decline in groundwater levels, deterioration of groundwater quality, seawater intrusion in coastal areas, etc. The anticipated impact of climate change and climatic variability with frequent occurrence of extreme events such as drought and floods may further worsen the water-scarcity situation and agricultural productivity. Several technological options such as conjunctive use of rain, surface and groundwater resources, precision technologies for irrigation and farming practices, optimum irrigation scheduling, adoption of resource-conservation technologies including laser land levelling, and deficit irrigation strategies are available for enhancing water productivity and sustainable water-resources management. However, for successful transfer of water–management technologies, there is a need for enabling institutional arrangements, policies and water governance. This paper presents an overview of different approaches for efficient use of water resources and maximizing agricultural water productivity.

INTRODUCTION

Water is critical for human survival, agriculture, socio-economic development, healthy ecosystem, and sustainable development. It is also at the heart of adaptation to climate change. All the great ancient civilizations be it Mesopotamian, Egyptian or Indus flourished along the rivers as water is the most important natural resource. The history of irrigation development in India can be traced back to prehistoric times. Vedas, ancient Indian writers and ancient Indian scriptures have made references to wells, canals, tanks and dams. These irrigation technologies were in the form of small and minor works, which could be managed by small households to irrigate small patches of land. In the south, perennial irrigation may have begun with construction of the Grand Anicut by the Cholas as early as second century to provide irrigation from the Cauvery River. The entire landscape in the central and southern India is studded with numerous irrigation tanks which have been traced back to many centuries before the beginning of the Christian era. In northern India there are a number of small canals in the upper valleys of rivers which are very old. At the time of independence net irrigated area of India under British rule which included Bangladesh and Pakistan was 28.2 Mha. After partition net irrigated area in India and Pakistan was 19.4 million ha and 8.8 million ha, respectively.

Globally, the potential availability of water has decreased from 12,900 m^3/capita/year in 1970 to less than 7,000 m^3 in 2000 and is projected to be as low as 5,100 m^3 per capita by the year 2025. However, this has wide geographical variations. In densely populated Asia, Africa, Central and Southern Europe, current per capita water availability ranges between 1,200 and 5,000 m^3. By the year 2025 about 3 billion people will be in water stress category with 1,700 m^3 of available water. With increase in population from 361 million in 1951 to 1.21 billion in 2011 in India, per capita annual water availability has declined from 5,177 m^3 in 1951 to 1,508 m^3 by 2014. The per capita water availability in the country is expected to reduce further to 1,465 m^3 and 1,235 m^3 by 2025 and 2050, respectively, under high population growth scenario (Kumar *et al.,* 2005). The situation may further deteriorate, if anticipated impact of climate change on hydrology and water resources are also considered.

India with a geographical area of 329 million ha supports more than 18% of the world's population with just 4.2% of the world's freshwater resources. The country receives annual precipitation (including snowfall) of 119.4 cm amounting to about 4,000 billion cubic meter (BCM) of water that generates an average annual runoff of 1,869 BCM. However, due to physiographical, technological, and socio-political constraints, utilizable water resources of the country has been assessed as 1,121 BMC only,

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which includes 690 BCM of surface water and 431 BCM of groundwater. Out of 690 BCM of surface water, so far about 253.4 BCM of storages are built through major and medium irrigation projects. Another 51 BCM of storage are under construction/ consideration. Similarly, out of 431 BCM of groundwater resource, about 360 BCM of groundwater is expected to be available for irrigation, out of which present usage is about 222 BCM. The projected total water demand of the country is estimated at 1,447 BCM by the year 2050 which is more than the present availability of utilizable water resources (Table 1) (CWC, 2010). In that the share of agriculture itself will be 1,072 BCM. Thus, there is a need for proper planning, development and management of water resources. Further, the availability of water for agriculture in India is projected to decline from 84% in 2010 to 74% by 2050. Therefore, producing 350 million tonnes food grain from shrinking water resources would put existing water sources under immense pressure. It has been estimated that about 1% annual increase in water productivity (quantity per unit consumptive water use) would meet additional water demand for grain production and its further increase to 1.3% would satisfy all crops water demand. Present low crop water productivity provides enough scope for improving present crop water productivity through scientific agricultural water management practices, and the demand of water from other sector can be met with present water resources.

Table 1. Annual requirement of water by different uses (in BCM)

Different uses of water	2025	2050
Domestic	62	111
Irrigation	611	807
Industry	67	81
Energy	33	70
Others	50	76
Total	843	1180

Source: Kumar *et al.* (2005)

As the total projected demand for irrigation sector will be more than the present level of utilizable water resources, the challenge will be (i) more production from less water by efficient and productive use of utilizable water resources in irrigated areas, (ii) increased production from sub-productive challenged ecosystems, i.e., rainfed and waterlogged areas, and (iii) making use of grey water (waste water) for agriculture production. In addition, there is need for improving productivity of two sub-productive challenged ecosystems rainfed and flood-prone/ waterlogged areas through efficient irrigation and drainage network development in rainfed areas and combined approach of engineering, crop selection, crop management and aquaculture practices in waterlogged areas would be critical. Better water governance, effective implementation of participatory approach, public–private participatory mode and involvement of private sector would also be important in this direction.

Irrigation and agriculture scenario

In India, irrigation development has received high priority in the successive five year plans, and has the second largest irrigated area in the world. The ultimate irrigation potential of the country through major, medium and minor irrigation projects has been assessed at 139.9 million ha by conventional storage and diversion works. A total irrigation potential of 113.53 million ha, against 22.6 million ha at pre-planning period, has been created by the end of XIth Plan. Total water use in agriculture at current level of development is of the order of about 525 BCM which is about 83% of total present water use in the country. This may get progressively reduced to about 75% in future due to increased demand of other sectors. India has net sown area of 140.88 million ha and its gross sown area is 195.25 million ha with cropping intensity of 138.67. As per the latest available statistics (2011–12), irrigated and rainfed area of the country is estimated at around 46 and 54% of the net sown area, respectively. In absolute term, the net irrigated area is 65.26 million ha with gross irrigated area of 91.53 million ha. About 60% of country’s foodgrain production is contributed from irrigated agriculture.

An important challenge facing the irrigation sector in India is the growing gap between Irrigation Potential Created (IPC) and Irrigation Potential Utilized (IPU), and uneven distribution of water over the length of the canal system. India has invested ₹ 400,000 crore in the major and medium irrigation projects since independence to create irrigation potential of 113 million ha, but the potential utilized is only 89 million ha and this gap between IPC and IPU is growing by the day. The percentage of IPU to IPC remained above 90 up to VIIth plan, but subsequently declined to 86% in IXth Plan, 84% in Xth Plan and 77% in the XIth Plan. The overall irrigation efficiency of the major and medium irrigation projects is estimated to be around 38%. Efficiency of surface irrigation system can be improved from about 35–40% to around 50–60% and that of groundwater from about 65–70% to 72–75% (Planning Commission, 2009). It is estimated that with 10% increase in the present level of efficiency in irrigation projects, an additional 14 million ha area can be brought under irrigation from the existing irrigation capacities. The prevailing inequity, irregularity and non-reliability of canal water supply and poor efficiency at conveyance, distribution and application of irrigation are considered as one of the major cause for the low productivity (1.5–4.0 t/ha against achievable 5–6 t/ha) of irrigated agriculture. Over irrigation in some of the canal command areas has also resulted in waterlogging and salinity. Being major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water which can be utilized either for extending irrigated area or diverting saving to other sectors. The performance of the irrigation sector thus needs an improvement through improved water delivery and application systems. The National Water Mission, institutionalized under the National Action Plan for Climate Change, has set the target to improve the efficiency of water use by at least 20%. Area under micro-irrigation has increased from merely 0.23 million ha in 1985–86 to 7.73 million ha in 2014–15 and needs to be further intensified for improving the overall efficiency.

The growth in source-wise irrigated area (Fig. 1) clearly shows how groundwater, largely from tube–wells, has become the main source of irrigation. It has played a major role in the success of green revolution and contributes over 60% to the total irrigated area of the country. The stage of groundwater development for the country as a whole is 62%, but there is a wide inter- as well as intra-regional disparity. The non-judicious pace of groundwater development is leading to over-draft and steep decline in water-table at several places. Over exploitation of groundwater has reached at alarming levels in Punjab, Haryana, Rajasthan and Tamil Nadu. The Punjab–Haryana region could lose its production potential in a few decades if current patterns of groundwater extraction and pollution, soil salinization, and rice (*Oryza sativa*)–wheat (*Triticum aestivum* L.) monoculture persist. A recent estimate (CGWB, 2014) reveals that in 16% of the blocks (Mandals/Talukas), the annual extraction of groundwater exceeds annual recharge. In 3% of the blocks, it is more than 90%, but within 100% of net annual groundwater availability (critical units). Groundwater extraction in such blocks needs to be better regulated. Conjunctive use of surface and groundwater is desirable to fulfil the irrigation requirements of crops by judiciously utilizing the water from both the sources. The optimal conjunctive use of the region’s surface and groundwater resources would help in minimizing the problem of waterlogging and groundwater mining. The conjunctive use also facilitates the use of saline groundwater which can not be otherwise used without appropriate dilution. Strengthening of knowledge base on geology and aquifer characteristics, hydrology of surface and groundwater, and existing surface and groundwater facilities is required to develop appropriate conjunctive use system.

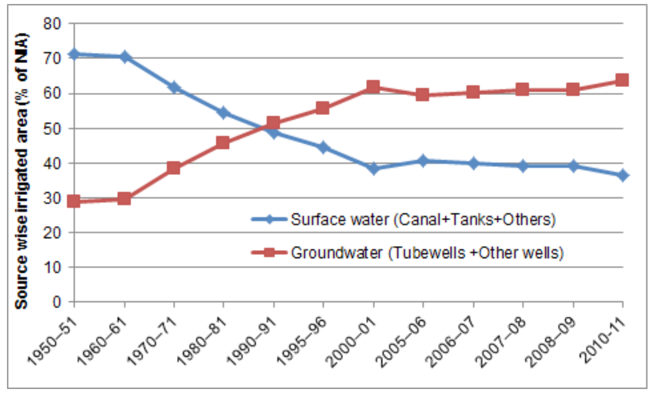

Fig. 1. Growth of groundwater irrigated area
Data source: IDFC (2011), and GoI (2015)

TECHNOLOGICAL OPTIONS FOR WATER MANAGEMENT

To meet the challenges of water scarcity, a paradigm shift from maximizing productivity per unit of land area to maximize productivity per unit of water consumed is required. Greater emphasis is needed on ‘demand side’ management with sustainable water resource management aiming at achieving efficient and equitable use of water, and encouraging conservation and protection of water resources.

Technological options for irrigated agriculture

The Indian Council of Agricultural Research (ICAR) through the Indian Institute of Water Management (IIWM), Bhubaneshwar, AICRP on Irrigation Water Management and Consortia Research Platform on Water, besides other water related institutions/ organizations is addressing issues related to judicious use of water ensuring higher crop productivity in the country. The ICAR has developed cost-effective, location-specific scientific technologies, viz. rainwater harvesting and recycling, multiple use of water, conjunctive use of rain, surface and groundwater resources, smart and precision technologies for irrigation and farming practices, optimum irrigation scheduling, resource-conservation technologies, development of land drainage and reclamation of problem soils to enhance irrigation water use efficiency and water productivity in Indian agriculture. Some of the technological options for improving water use efficiency and agricultural water productivity are described below:

Canal irrigated areas

Assured irrigation in synergy with other technological and policy factors has played a catalytic role in the growth of Indian agriculture over the years. The contribution from irrigated agriculture is about two-thirds of overall agricultural production. Because of the yields augmenting impact, irrigation development has always been the priority area of national agricultural development strategy of the government with massive financial support.

Performance evaluation of irrigation systems: Space-borne remote-sensing measurement can provide information on agricultural and hydrological conditions of the land surface for vast areas at regular intervals. An application of remotely sensed data in the Sone Low Level Canal (SLLC) system in India for assessing irrigation system performance have been used to evaluate the extent of cultivated area, water availability and its distribution, crop yield performance and water productivity for each branch canal and distributaries of the SLLC system for comparative evaluation (Ambast *et al.*, 2008). Though the capability of satellite remote sensing to monitor agricultural and hydrological conditions of the land surface has undergone major improvements in the past decade, it remains underutilized by practicing water-resource managers.

Conjunctive use of canal and groundwater: In the arid and semi-arid regions, where canal water availability is scarce and groundwater quality is marginally poor, conjunctive use of waters is quite common. Earlier studies for conjunctive use of canal water with saline water were conducted for well-designed treatments of cyclic and blending mode of irrigations under controlled conditions (Sharma and Rao, 1998). However, canal water supply is highly unreliable and inadequate in the region that leaves limited scope for application of recommendations emerged from earlier studies. In another study, SWAP model has been calibrated and validated in the Kaithal irrigation circle, Haryana in the northwest India (Mandare *et al.,* 2008) to accommodate farmers' fields observation on canal water availability and groundwater applications to suggest water management options for improving productivity of wheat crop during the *rabi* season. Further, there is a need to assess long-term impact of various combinations of saline water applications in different wheat-based crop rotations feasible in the region.

Irrigation scheduling: Judicious use of water resources is *sine-qua-non* for enhanced productivity, improved economy and environment. It becomes all the more critical when water supply is scarce. By adopting optimum irrigation schedule, substantial amount of water can be saved and the yields can be increased. Water productivity of rice can be enhanced through reducing large amounts of unproductive water losses during the crop growth and using the rainwater more efficiently. Several studies have shown that the intermittent irrigation with ponding depth of 7±2 cm of water in the rice fields 3 days after disappearance (DAD) of previously ponded water is the most optimum irrigation schedule for the entire period of rice growth. This practice of intermittent irrigation could save 23 to 65% of water as compared to traditional method of growing rice under continuous submerged condition in different agro-ecological conditions of India. Further, productive water use largely depends on the quality of the land levelling accomplished by the farmers. Precision land levelling becomes even more important when both the quality and the quantity of available water are limiting. Such a situation exists in the northwest India, where protective canal irrigation supported by good/ marginal quality groundwater is in vogue. In such situations, use of saline/ alkaline water supplies often requires the application of smaller depths at relatively more frequent intervals (Mandare *et al.,* 2008). Since the total depth of water applied per irrigation is greatly influenced by the quality of land levelling, it is important to achieve precision land levelling for efficient irrigation. Salinity and non-uniformity in irrigation water have much the same effect on the yield-water response function and both result in consuming larger volumes of irrigation water to produce the same yields as can be obtained with non-saline water and uniformly applied water.

Deficit irrigation supplies: The yield response of a given crop depends on weather conditions, soil type, and use of agricultural inputs like fertilizers and pesticides. Under limited water availability condition, irrigation strategies based on meeting the partial crop water requirements should be adopted for more effective and rational use of water. The adoption of deficit irrigation such as regulated deficit irrigation and controlled late-season deficit irrigation are becoming an accepted strategy for water conservation and to reduce the amount of water used for crop production. Under regulated deficit irrigation, crop is exposed to certain level of water stress either during a particular period or throughout the growing season. The resulting yield reduction may be offset with the benefits gained through diverting the saved water to irrigate other crops/ irrigating more area for which water would normally be insufficient under conventional irrigation practices. In order to improve irrigation system performance, Ambast (2001) suggested a suitable rotation schedule for SLLC, based on the impact of various possible rotational schedules. The alternative cropping patterns have been evaluated for their water productivity and economic returns.

Groundwater irrigated areas

Presently, groundwater is the largest source of irrigation. The strategies for accelerating the development of groundwater within the replenishable limits of groundwater for its sustainable use can be drawn based on supply management or demand side management are described below:

Groundwater augmentation by artificial recharge: The augmentation of groundwater can be done by maximizing surface ponding for groundwater recharge, rejuvenation of traditional surface water bodies and enhancing incentives for water conservation and artificial recharge. The artificial recharge of groundwater needs to be undertaken in areas where groundwater levels are declining on regular basis, where substantial amount of aquifer has already been desaturated, where availability of groundwater is inadequate in lean months and where salinity ingress is taking place. The artificial recharge techniques can be broadly categorized as: (i) direct surface techniques such as percolation tanks, flooding, stream augmentation, ditch and furrow system and over irrigation, (ii) direct sub-surface techniques such as recharge pits and shafts, injection wells or recharge wells, dug well recharge, bore hole flooding, natural openings and cavity fillings, (*iii*) combined surface and sub-surface techniques such as basin or percolation tanks with pit shaft/wells and (iv) indirect techniques such as induced recharge from surface water source and aquifer modification.The existing village tanks which are normally silted and damaged can be modified to serve as recharge structure. In alluvial as well as hard rock areas, there are thousands of dug wells which have either gone dry or the water levels have declined considerably. These dug wells can be used as structures to recharge. The groundwater, storm water, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of artificial recharge, are reduced. In Urban areas, the roof-top rainwater can be conserved and used for recharge of groundwater. This approach requires connecting the outlet pipe from roof-top to divert the water to existing wells/ tubewells or specially designed wells. The urban housing complexes or institutional buildings have large roof area and can be utilized for harvesting roof top rainwater to recharge aquifer in urban areas.

Reducing crop water demand: The reduction in crop water demand can be done by promoting innovative techniques and uses such as conjunctive use of surface and groundwater, promoting precision irrigation and water-saving crop-production technologies, rationalization of subsidizing electricity for irrigation including system of pricing and/or incentives for groundwater use, use of hydrogel, appropriate policies / regulatory mechanism and governance.

Conjunctive use of canal and groundwater: It provides a greater control on timeliness of irrigation and should be encouraged by making adequate energy available to farmers at a reasonable cost and appropriate time. In order to ensure sustained availability of groundwater, average annual with drawals should not exceed average annual recharge. Where freshwater is in short supply, groundwater of marginal quality could be advantageously used in combination with good-quality water or for alternate irrigations. Recommendations concerning use of saline and sodic water prescribed by All India Coordinated Research Project on Management of Salt-affected Soils and Use of Saline Water in Agriculture of The Indian Council of Agricultural Research from field experiments are now available and should be used. Development of conjunctive use system requires knowledge regarding geology of groundwater basin and aquifers, hydrology of surface and groundwater, existing surface and groundwater facilities and storage and transmission characteristics of the basins. Although efforts have been made to model groundwater use, optimization and build future scenario using simulation models in the country, but these are required to be further strengthened.

Pressurized irrigation system: The water-use efficiency under conventional flood method of irrigation, which is predominantly practiced in Indian agriculture, is very low due to substantial conveyance and distribution losses. A number of demand management strategies and programmes have been introduced to save water and increase existing low water-use efficiency in Indian agriculture. One such method is pressurized irrigation system, which includes both drip and sprinkler method of irrigation. Pressurized irrigation system is proved to be an efficient method in saving water and increasing water-use efficiency as compared to the conventional surface method of irrigation, where water-use efficiency is only about 35–40%.

The field experiments conducted across the country under All India Coordinated Research Project on Water Management have indicated saving of irrigation water depending on the soil type, e.g. in clay, the saving is from 30 to 48%, leading to increased area by 1.4 to 1.9 times; in sandy loam, from 40 to 50% saving with 1.7 to 2.0 times increased irrigated area; in silt loam, from 55 to 61% water saving with 2.2 to 2.6 times enhanced irrigated area; in silty clay loam 38 to 47% water saving leading to 1.6 to 1.9 times enhanced irrigated area and in clay loam from 21 to 39% with 1.3 to 1.6% irrigated area (Table 2). Also, the water saving in sugarcane was the maximum with silt loam soil, followed by sandy loam and the least in clay loam soil. This indicated that the drip irrigation was more effective in the soil with poor water retention and higher drainage rate (AICRP IWM, 2015).

Drip irrigation along with fertilizer (fertigation) reduces the wastage of water and chemical fertilizers, and subsequently optimizes the nutrient use by applying them at proper place and time, which finally increases the water and nutrient-use efficiency (Table 3). Moreover, the effi-

Table 2. Water saving and increase in cultivated area with drip irrigation

Centre and State	Test crops	Soil type	Water saving (%)	Increase in area (times)
Dapoli (MS)	Brinjal	Lateritic	38	1.6
Navsari (Gujarat)	Onion	Clay	30	1.4
	Turmeric		32	1.5
	Brinjal		40	1.7
	Chillies		48	1.9
Bhawanisagar (Tamil Nadu)	Jasmine	Sandy loam	50	2.0
	Sugarcane		40	1.7
	Tomato		42	1.7
	Banana		48	1.9
Madurai (TN)	Sugarcane	Clay loam	21	1.3
	Redgram		39	1.6
Kota (Rajasthan)	Onion	Clay loam	23	1.3
	Garlic		22	1.3
	Turmeric		23	1.3
Faizabad (Uttar Pradesh)	Sugarcane	Silt loam	59	2.4
	Marigold		55	2.2
	Cowpea		61	2.6
Palampur (Himachal Pradesh)	Broccoli	Silty clay loam	47	1.9
	cauliflower		38	1.6

cacy of water-soluble fertilizers will be affected directly by soil moisture in the root-zone depth. The restricted root development with drip irrigation also shows preference for fertigation over conventional method. The initial experiments conducted across the country have indicated superiority of fertigation over conventional method depending on soil type. In sandy-loam soil, the increase in yield due to fertigation was from 47 to 50%, in clay loam from 32 to 87%, in silty clay loam around 14%, in silt loam around 34% and in clay from 28 to 59% over conventional fertilizers.

Ground water governance: The Punjab Preservation of Sub-soil Water Act-2009 is an effort to conserve groundwater resource by mandatory delay in the transplanting paddy beyond 10th June to escape periods of high evapotranspiration demands. Analysis showed that implementation of the Act saved about 172 million kWh of electricity and about 7.2% of annual groundwater draft. State of Haryana also passed a similar act for the mandatory delay

Table 3. Fertigation vs conventional method of fertilizer application

Centre and State	Test crop	Soil type	Yield (kg/ha)		Yield increase over conventional method (%)
			Conventional method	Fertigation	
Dapoli (Maharashtra)	Brinjal	Lateritic	1,876	3,234	72
Jorhat (Asom)	Assam lemon	Sandy loam	10,100	14,880	47
Palampur (Himachal Pradesh)	Broccoli	Silty clay loam	7,400	8,440	14
Navsari (Gujarat)	Onion	Clay	28,740	45,690	59
	Turmeric	Clay	13,100	16,800	28
	Round melon	Clay	12,000	15,300	28
	Sugarcane	Clay	140,000	183,000	31
	Tomato	Clay	48,000	68,000	42
Bhawanisagar (Tamil Nadu)	Coconut	Sandy loam	10,974 nuts	16,461 nuts	50
	Sugarcane		115,300	171,700	49
Madurai (Tamil Nadu)	Red Gram	Clay loam	1,108	1,515	37
Kota (Rajasthan)	Onion	Clay loam	16,350	24,960	53
	Cabbage	Clay loam	17,756	23,373	32
	Garlic	Clay loam	6,953	10,575	52
	Turmeric	Clay loam	14,670	27,360	87
	Bitter Gourd	Clay loam	21,226	30,139	42
Faizabad (Uttar Pradesh)	Marigold	Silt loam	161	216	34

in transplanting rice. *Jyotigram* in Gujarat, as suggested by the International Water Management Institute (IWMI), for separation of electricity supply to villages and pumps is another example policy instrument for reduced over-pumping of groundwater.

Resource conservation technologies: In the post-green revolution era, the issues of conservation have assumed greater importance in view of widespread resource degradation problems and the need to reduce production costs, increase profitability and make agriculture more competitive. The new challenges demand efficient resource use and conservation receive high priority to ensure that earlier gains are sustained and further enhanced to meet the emerging needs. There are many resourceconservation technologies like zero tillage, bed planting etc. which have shown promise in enhancing water productivity. No tillage wheat after harvesting of rice is the most effective RCT in the Indo-Gangetic plains in India, and saves irrigation water by about 25% due to faster flow across the non-tilled fields and less soil water evaporation loss compared to tilled soil.

Strong policy is needed to disseminate water-efficient agricultural practices like laser-land leveling, conservation agriculture, short-duration rice varieties and to diversify cropping patterns, bed planting and alternate furrow irrigation, underground pipeline conveyance of irrigation water, appropriate tillage systems including resource-conservation technologies and surface retention of crop residues for mulching etc. Moreover, the practice of flood irrigation should be discouraged and priority be given for micro-irrigation. Such practices need to be extended through extension services and enabling policies so that large areas are covered within a reasonable time.

Recently launched Flagship Programme, *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY), envisaged to provide irrigation access to each farm, is a major step forward in this direction. The PMKSY has converged ongoing schemes of the governments like Accelerated Irrigation Benefit Programme (AIBP) of the Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR, RD&GR), Integrated Watershed Management Programme (IWMP) of Department of Land Resources (DoLR) and the On Farm Water Management (OFWM) of Department of Agriculture and Cooperation (DAC). Preparation of District Irrigation Plan (DIP) is at the heart of this scheme.

Technological options for rainfed agriculture

Rainfed agriculture is complex, diverse and risk-prone and is mostly affected by climate change and variability of rainfall. Rainwater management is the most critical component of rainfed farming. Rainfed areas accounts for 56% of total cultivated area and contributes only 47% to national food basket. But rainfed farming will remain the mainstay for the livelihood support of millions of small and marginal farmers across the country. Under current practices, yield under irrigated agriculture almost reached a plateau and nearly 40% of total cultivated area of the country would remain rainfed even after achieving the ultimate irrigation potential. The successful production of rainfed crops largely depends on how effectively surplus runoff is harvested, stored and recycled for supplemental irrigation and soil moisture is conserved *in-situ*. Further, the climate change is posing a major challenge for rainfed agriculture and the constraints in further expansion of irrigated area in the country. The rainfall extremes and high-intensity rain events witnessed in recent years are likely to cause large spatial and temporal variations in the amount of surplus runoff available for harvesting. In some areas, there could be increased runoff and more potential for harvesting, while in other areas it might decrease.

On-farm reservoir (OFR)

Rainwater harvesting and efficient water use are inevitable options to sustain rainfed agriculture in future (Ambast *et al.,* 1998). Different states have initiated special programmes for OFR in order to ensure the sustainability and to improve livelihoods of people. Despite these experiences, the adoption of OFR at the individual farm level has been very low, particularly for drought proofing through life saving irrigation of rainy (*kharif*) season crops. Renovation of old and silted community ponds for water conservation as well as groundwater recharge and monitoring of the effectiveness of OFR constructed under various watershed development programmes will be helpful to strengthen rainwater conservation in the country. Crop diversification with low-water requiring crops like pulses, oilseeds along with *in-situ* soil-moisture conservation are the important practices to improve production and productivity of crops in rainfed areas. Several promising soil-and water-conservation measures for various rainfall zones in India are listed in Table 4.

Tank-cum-well system: A tank-cum-well system was conceptualized for micro-level water resources development on watershed basis for plateau areas with slope of 2 to 5%. This involves construction of tanks and wells in series along the drainage line in a watershed. The excess runoff water is stored in the tank and this can be used for meeting the irrigation requirement in the post-monsoon season and supplemental irrigation requirement in the monsoon season (Srivastava *et al.,* 2009). The economic analysis of the system in the first 3 years of its existence revealed that 97.75% of investment can be recovered in

Table 4. *In-situ* soil-and water-conservation measures for various rainfall zones

Seasonal rainfall (mm)			
<500	500–700	750–1,000	>1,000
• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Mulching • Scoops • Tied ridges • Off-season tillage • Inter-row water harvesting • Small basins • Contour bunds • Field bunds	• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Scoops • Tide ridges • Mulching • Zingg terrace • Off-season tillage • Broad bed and furrow • Inter-row water harvesting • Small basins • Modified contour bunds • Field bunds	• Broad bed & furrow (Vertisol) • Conservation furrows • Sowing across slopes • Tillage • Lock and spill drains • Small basins • Field bunds • Vegetative bunds • Graded bunds • Zingg terrace	• Broad bed & furrow (Vertisol) • Field bunds • Vegetative bunds • Graded bunds • Level terraces

Source: Venkateswarlu *et al.* (2015)

three years by adoption of improved package of practices, taking up additional cropping and multiple use of tank.

Some of the conservation practices listed above are temporary in nature and can be implemented by the farmers every year before the onset of monsoon, cost being nominal. Few measures such as contour and graded bunding, continuous, contour or staggered trenches, water harvesting structures and drainage line treatment are covered under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). The National Mission for Sustainable Agriculture (NMSA), which is one of the eight Missions under the National Action Plan on Climate Change (NAPCC) also seeks to address issues regarding sustainable agriculture in the context of risks associated with climate change. National Mission for Sustainable Agriculture (NMSA) has also four major programme components, e.g. rainfed area development, soil health management, on-farm water management and climate change and sustainable agricultural modeling and networking.

Management of waterlogged/ flood prone areas

Management of waterlogged areas depends on drainage points availability and suitability for crop/ aquatic crop/ fish production. For understanding waterlogging situation, it is essential to understand concept and definition of waterlogging. In general term, stagnation/ pooling of water on the land surface for significant duration is normally understood as waterlogging. However, from agriculture point of view, it is described as a situation of adverse air-water proportion in subsoil root zone, with respect to a crop due to water stagnation or high water-table along with its acceptable level of productivity response. A more comprehensive definition of waterlogging was suggested by the National Commission on Agriculture (1976). On the other hand, floods and surface waterlogging are the most common problems in eastern India. The heavy south-west monsoon causes rivers to overflow their banks, often flooding surrounding areas. Among eastern states, Bihar is highly prone to floods (about 70% area is flood affected, particularly north Bihar). The approach to the problem should be to mitigate waterlogging during the monsoon period, increase productivity of the waterlogged areas by crop diversification, and create irrigation potential for increasing the cropping intensity. The following action plan is suggested to deal the issues:

(i) Waterlogging due to water congestion during monsoon to a great extent can be solved by construction of micro-reservoirs along low order streams to intercept runoff, reduce peak flow, enhance groundwater recharge and create irrigation potential for increasing agricultural production.

(ii) Large perennial waterbodies such as *Chaur, Taal* etc. can be turned very productive with proper planning for alternative/ multiple use of water. A multipronged strategy should be developed for development of these waterbodies for its multiple utilization as sink during monsoon and water source during post–monsoon for pisciculture, duckery and cultivation of aquatic crops viz., makhana (*Euryale ferox* Salis.), water chestnut *(Trapa bispinosa* Roxb.) and swamp taro [*Colocasia esculenta* (L.) Schott].

(iii) Micro-water resources can be developed in coastal waterlogged areas with installation of very shallow tubewells up to a depth of 10 m, filter point wells, and small subsurface water harvesting structures. The project on land shaping-cum-fresh water reservoirs can be undertaken in these areas to store rainwater and harvest subsurface water through small ponds, to develop land to mitigate/ reduce water congestion within the mini catchment and to promote diversified cropping by irrigation.

(iv) Integrated farming systems and multiple use of water provide great opportunities for enhancing water productivity of agriculture and livelihood at various scales by integrating fisheries, livestock, aquatic crops, horticulture etc. with crops into the existing irrigation and water use systems/water infrastructures. Evidences of such multiple use systems (MUS) could be found in canal and groundwater irrigated, rainfed, waterlogged, coastal and hilly areas/ watersheds. To enhance productivity of seasonally waterlogged lands in canal commands, study was undertaken at ICAR–RCER, Patna, with three different options, namely, *(i)* secondary reservoir fed by canal seepage and supplemented by tubewell, *(ii)* fish trenches-cum-raised bed for fish-horticulture production, and *(iii)* rice–fish culture using nylon-pen under waterlogged area. For the secondary reservoir concept, 2 reservoirs (control and reservoir with water exchange due to routing of water) were constructed in the seasonal waterlogged area. Multiple uses of water by fish culture in reservoir, horticulture (two tiers: banana/ guava/ lemon and vegetables) on bunds, routing water to cereal crops, and duck rearing were evaluated (Sikka *et al.,* 2008). The results indicate about 2.7- to 6-fold increase in water productivity by integrating different components over the traditional rice–wheat system. Water productivity was the maximum (₹15.02/ m^3) in the secondary reservoir (with exchange of water) where fish + fruits + vegetables + duckery were integrated with rice and wheat, as against ₹2.42/ m^3 in rice–wheat system alone. The economic analysis indicates that integrating fish in rice–wheat system gave net income of ₹29,694/ha, 6% higher over the traditional rice–wheat system, fetching ₹27,965/ha/year. Under seasonally waterlogged areas up to 1 m depth, a system of fish trenches-cum-raised beds based horticulture + fish system generated a net income of ₹80,951/ha/year, 189% higher over traditional rice–wheat system. Under seepage-fed secondary reservoir supplemented with groundwater, a system of horticulture on bunds + fish + duckery gave net returns of ₹132,590/ha/year, 374% higher over traditional rice–wheat system.

Multiple water use-based farming system approach with on-dyke horticulture and fish–prawn–poultry system in farmer's field in Odisha provided an excellent opportunity to productively use waterlogged area. The farmers converted 2.47 ha waterlogged area into 1.64 ha of pond and 0.83 ha of raised embankment. While pond area was utilized for fish and prawn culture, 21 m wide embankment was used for planting mango (*Mangifera indica* L.), teak (*Tectona grandis* L.f.), coconut (*Cocos nucifera* L.), banana (*Musa paradisciaca* L.), papaya (*Carica papaya* L.), pineapple (*Ananas cosmosus* (L.) Merr.], mushroom etc. Net water productivity of multiple use system was estimated to be ₹7.5/m^3 against ₹0.95/m^3 for lowland rainfed paddy alone and ₹6.0/ m^3 with vegetable production (Samra *et al.,* 2003).

THE OPPORTUNITIES

There are ample opportunities that will revolve around efficient as well as productive utilization of available water both in terms of food per unit of water and energy requirement, waste water utilization, sustainable and quality recharge of groundwater, reduction in water use of crops, and productive utilization of land and water resources in challenged eco-systems. Some of the recent developments that will provide new opportunities of reworking on agricultural water management are:

- The sensor technology along with communication technology is being upgraded continuously. A simple and rugged sensor technology for estimating on-field surface irrigation requirement and coupled with control system will be a breakthrough in irrigation management.
- A major problem in pressurized irrigation system is clogging of drippers, high energy requirement and higher cost. Advances in material science will provide new materials which will be helpful in dealing with these problems. Development of pressurized irrigation system for high-water requiring crops, i.e. rice and sugarcane, will be another opportunity.
- Safe reuse of waste water in agriculture to bridge the gap between availability and demand will become a more viable option in coming decades. Biotechnology and material science research are underway to develop new organisms, materials which can convert the waste water for various qualities for food/ fodder/ timber production.
- A major challenge is the planning and designing of filters for groundwater recharge structures. Advancement in material science has potential for developing filters which can take care of this problem, and this will alter the paradigm of groundwater recharge research.
- Water use-efficient cultivars of different crops through biotechnological approach is one of the major areas of development.
- Deficit irrigation can achieve greater economic returns per unit of water for a given crop. Aerobic rice is an emerging agronomical production system that uses less water and needs standardizing water-management practices.
- Use of modern tools like remote sensing, GIS and

modelling tools will also be intensified for up-scaling of the technologies at higher level including application of smart ICT-based methods.

CONCLUSION

Water has been and will remain a critical resource which is being affected by increasing population, industrialization, urbanization, pollution, deforestation and above all climate change. Certainly the business as usual approach will not suffice. Thus it is essential to visualize the future scenario and prepare strategies for equipping ourselves with technologies which will provide sustainable solutions for managing water in changing scenarios. Application of remote sensing as demonstrated for evaluating canal water supply and water productivity in the Sone Low Level Canal system has a great potential in other major irrigation projects for their performance evaluation and to explore the possibility of improvement.

For successful transfer of water-management technologies, there is a need for enabling institutional arrangements, policies and water governance. Since the use of productivity-enhancing inputs in agriculture is often influenced by the available irrigation water regime, the other extension services need to be complemented for implementing efficient crop planning, synchronization of farm operations, linking farmers to other sources of knowledge, support and services and establishing effective forward and backward linkages for sustainable water management. In summing up, integrated agricultural water management combining skills and knowledge of water, soil and agronomic interventions together with enabling institutional and policy support is required for sustainable development.

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4th International Agronomy Congress (November 22–26): 47–52 (2016)

Technologies for resilient rainfed agriculture systems

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INTRODUCTION

Rainfed agroe-cosystems occupy a significant place in Indian agriculture covering about 80 million ha, in arid, semi-arid, and sub-humid climatic zones, constituting nearly 56% of the net cultivated area. These areas contribute almost 100% of forest products, 84–87% of coarse grain cereals and pulses, 80% of horticulture, 77% of oilseeds, 60% of cotton (*Gossypium* sp.), and 50% of fine cereals including rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L. emend. Fiori & Paol.), maize (*Zea mays* L.), sorghum [*Sorghum bicolor* L.) Moench] etc. (Srinivasarao *et al*., 2015). Further, rainfed regions support 60% of livestock and 40% of human population and contribute 40% of foodgrains and several special-attribute commodities such as seed spices, dyes, herbs, gums etc. Due to yield plateuing in irrigated area in most of the crops, the second green revolution must therefore explicitly embrace rainfed areas with special focus on pulses and oilseeds to ensure nutritional security and agricultural sustainability. In rainfed regions, wide spectrum of agro-ecological conditions exists in different parts of country which are suitable for growing these crops throughout year.

MAJOR CHALLENGES

The major challenges of rainfed agriculture would be to sustain the livelihoods of the small and marginal farmers, who are dependent on agriculture despite increased climate variability and shrinking land holding size. Failure to address these challenges will lead to substantial shift of rural youth to service sector resulting in huge manpower shortage in farming. The growing preference for commercial crops even in less-endowed areas will put further pressure on land and water resources and enhances the risk. The challenge therefore lies in balancing the land use and cropping pattern as per the resource endowment and the shifts in the crop choice due to market forces. Some of the challenges like retaining area under the nutritious cereals can be converted into opportunities with growing awareness on the health benefits of these crops.

Droughts and famines are the general features of rainfed agriculture in India. The risk involved in successful cultivation of crops depends on the nature of drought (chronic and contingent); it's probable duration, and periodicity of occurrence within the season. Long-term data for India indicate that rainfed areas experience 3–4 drought years in every 10-year period. Of these, two to three are in moderate and one or two may be of severe intensity. The occurrence of the drought is very frequent in the sub-divisions like West Rajasthan, Tamil Nadu, Jammu and Kashmir and Telangana. Very high incidence of drought (>20%) is observed in a few districts in Rajasthan and Gujarat. The incidence is relatively low in the Western ghats, Eastern and North-Eastern India (Fig. 1; Rama Rao *et al*., 2013).

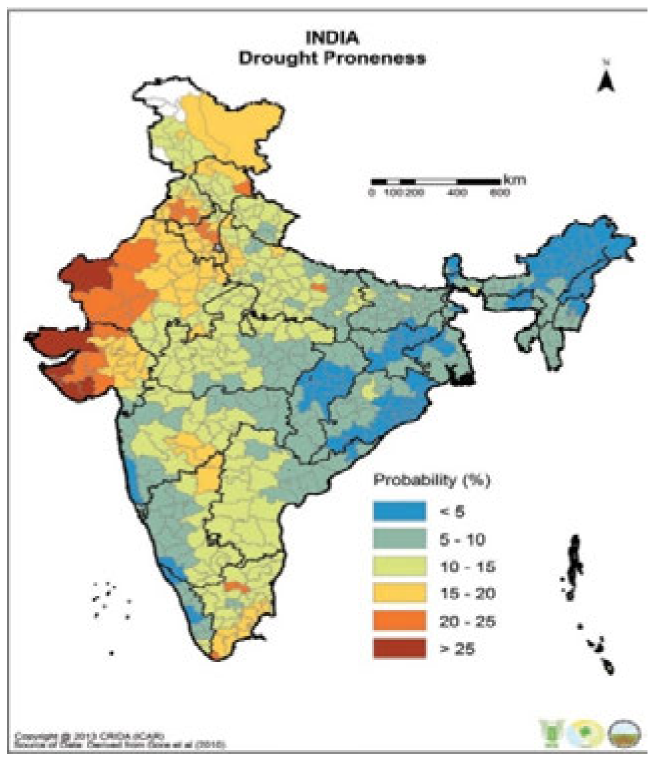

Fig. 1. Probability of drought occurrence in different parts of India

Agricultural production in India is closely linked to the performance of summer monsoon (June to September) which contributes about 75% of the annual precipitation (Fig. 2). Apart from the inter-annual variability in summer

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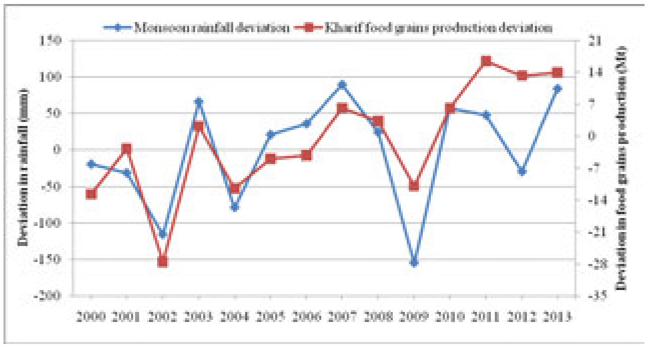

Fig. 2. Monsoon rainfall *vs.* deviation in foodgrain production during rainy season (*kharif*) during different years

monsoon rainfall, occurrence of many of the hydro-meteorological events is found to influence Indian agriculture at different spatial scales. Extreme climatic events such as drought and floods occurring in the same crop-growing season can seriously undermine our efforts to enhance production using current technology.

Similarly, edaphic constraints like poor water- and nutrient-retention capacity, low soil organic matter (SOM) make rainfed agriculture highly vulnerable and less resilient, requiring a different outlook and strategy. Severe soil organic carbon (SOC) depletion is a major constraint in rainfed agro-ecosystems because it directly influences soil quality, crop productivity and sustainability (Srinivasarao, 2011). The soil organic carbon, which is a seat of major soil processes and functions, is < 5 g/kg in rainfed soils, whereas the desired level is 11 g/kg. Soil crusting in red and black soils; shallow depth, poor drainage in heavy textured soils of Madhya Pradesh, Maharashtra, Chhattisgarh, Northern Karnataka and Eastern Maharashtra; sodic soils of Haryana, Tamil Nadu and Andhra Pradesh; universal deficiency of macro- and micro-nutrients (Zn, B) are major issues. Change in rainfall intensity could cause more soil erosion. Unlike irrigated systems, harnessing the synergy between soil moisture and applied nutrients in rainfed crops is a major challenge due to erratic distribution of rainfall.

While climate change impacts agriculture sector in general, rainfed agriculture is likely to be more vulnerable in view of its high dependency on monsoon and the likelihood of increased extreme weather events due to aberrant behavioor of south–west (SW) monsoon. Aberrations in SW monsoon which include delay in onset, long dry spells and early withdrawal, all of which affect the crops, are likely to further increase in future. The warming trend in India over the past 100 years has indicated an increase of 0.6°C, which is likely to impact many crops, negatively impacting food and livelihood security of millions of farmers dependent on agriculture. During the past decade, frequency of droughts, cyclone and hailstorms increased, with 2002, 2004, 2009, 2012, and 2014 being severe droughts. Frequent cyclones and severe hailstorms in drought-prone areas have become common. Eastern part of the country is affected by sea-water intrusion. There are already evidences of negative impacts on yield of wheat and paddy in some parts of India due to increased temperature, water stress and reduction in number of rainy days. Significant negative impacts have been projected under medium-term (2020–2039) climate change scenario, e.g. yield reduction by 4.5 to 9%, depending on the magnitude and distribution of warming.

PERFORMANCE OF RAINFED AGRICULTURE

A large proportion of coarse cereals, pulses and oilseeds and a significant proportion of rice are grown under rainfed conditions. However, there is a sharp increase in area under maize and cotton at the cost of coarse cereals like sorghum and pearl millet [*Pennisetum glaucum* (L.) R. Br.] primarily because of higher returns. Such changes in crop patterns will have implications on fodder availability for livestock. This trend is likely to increase even further by 2030 (Raju *et al*., 2010). During the last decade (TE 1998–99 to TE 2008–09), the area sown to coarse cereals fell by 8% (from 31 to 28 million ha), whereas production increased by 20% and productivity from 1,042 to 1,357 kg/ha because of the yield gains. The area under pulses did not show much change between TE 1998–99 and TE 2008–09, as it stagnated at about 23 million ha and the production increased by about 0.5 million ha (3%). There was a marginal improvement in yield from about 612 to 632 kg/ha during this period. Similarly, during the last decade, the area, production and productivity of oilseeds increased by 2.6, 16.1 and 13.1% respectively. All the 3 crop groups, coarse cereals, pulses and oilseeds, whose production is largely rainfed, witnessed significant production and productivity growth during the last decade and compared favourably with that of rice and wheat. However, in many cases the production growth rate did not exceed the population growth rate, which has implications for food security.

Another study by Suresh *et al.* (2014) revealed that the rainfed crops in general registered positive growth for area and production from 1980–81 to 2011–12. Growth in area and production for oilseeds and pulses in general was better during period I (1980–81 to 1995–96) compared to period II (1995–96 to 2011–12). As far as yields are concerned, period II turned out better for most of the crops (Table 1). Growth in production was higher during period I for all the crops except pearl millet, groundnut (*Arachis hypogaea* (L.) and cotton. During 1980–81 to 2011–12, all the crops registered positive growth in the representative

Table 1. Growth (% per year) in area, production and yield of major rainfed crops in selected states, across time periods

Crop	Area			Production			Yield		
	PI	PII	Overall	PI	PII	Overall	PI	PII	Overall
Bajra	-0.4	1.3 [a]	0.1	3.0	6.7 [b]	4.2	3.5	5.2 [b]	4.1
Jowar	-1.2 [a]	-2.5 [a]	-1.9 [a]	1.3	-2.8 [b]	-1.3 [a]	2.5 [b]	-0.2	0.6
Groundnut	-0.8	-0.3	-0.2	-1.4	4.3	2.9 [b]	-0.7	4.6 [c]	3.1 [a]
Rapeseed/mustard	12.7 [a]	0.9	5.3 [a]	14.6	3.7 [b]	7.1 [a]	1.6 [b]	2.6 [a]	1.7 [a]
Soybean	19.7 [a]	1.8 [a]	8.8 [a]	25.5 [a]	3.1 [a]	11.3 [a]	4.9 [a]	1.3	2.3 [a]
Sunflower	19.4 [a]	0.8	4.5 [a]	17.2 [a]	1.3	4.8 [a]	-1.8 [c]	2.2 [b]	0.3 [a]
Chickpea	1.8 [a]	1.3 [b]	1.5 [a]	3.9 [a]	2.0 [b]	2.9 [a]	2.0 [a]	0.7	1.4 [a]
Redgram	3.6 [a]	1.0 [a]	1.7 [a]	3.0 [a]	2.6 [b]	2.5 [a]	-0.5	1.6	1.1 [b]
Cotton	0.3	1.1 [a]	1.0 [a]	4.8 [a]	8.0 [a]	5.7 [a]	4.5 [b]	6.8 [a]	4.6 [a]

PI, PII and overall corresponds to periods 1980–81 to 1995–96; 1995–96 to 2011–12; and 1980–81 to 2011–12 respectively. The superscripts a, b and c indicate statistical significance at 1, 5 and 10% levels respectively.
Source: Suresh *et al*. (2014)

states. The overall yield growth ranged from as low as 0.3% in case of sunflower (*Helianthus annuus* L.) to as high as 4.6% in case of cotton. Period II registered higher growth than that of period I for all the crops except sorghum, soybean [*Glycine max* (L.) Merr.] and chickpea (*Cicer arietinum* L.).

RESILIENT RAINFED TECHNOLOGIES

The ICAR-Central Research Institute for Dryland Agriculture (CRIDA) and All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in association with State Agricultural Universities, Technical Universities and Research Institutes of the Indian Council of Agricultural Research (ICAR) have developed location-specific technologies for rainfed farming during past 4 decades and these technologies are being upscaled into ground-level implementation through various government departments. Improved water storage through *in-situ* moisture conservation and stored runoff are basics for bringing resilience to drought or moisture-stress conditions often encountered by the rainfed crops. Other strategies for bringing resilience are through soil management, resilient intercropping systems, drought-tolerant short-duration cultivars, suitable farm implements for small holdings, fodder systems, integrated farming systems etc.

Rainwater conservation and harvesting

The strategy of rainwater management in arid and semi-arid regions consists of selection of short-duration and low-water requiring crops and conserving as much rainwater as possible, so that crops can escape moisture stress during the growing period. In addition to *in-situ* conservation, efforts need to be made to divert the surplus water into storage structures which can be used either as standalone resource or in conjunction with groundwater for meeting the critical irrigation requirements. In relatively high rainfall regions, the strategy is to conserve as much rainwater as possible and to harvest the surplus water for life-saving irrigation and also for enhancing the cropping intensity and to maximize returns from the harvested water. Apart from enhancing the availability of water by various methods, increasing the water-use efficiency should be the focus by arresting various kinds of losses associated with utilization of water.

In-situ soil- and water-conservation practices improve soil structure and soil porosity, increase infiltration and hydraulic conductivity, and consequently increase soil-water storage which helps the crops to withstand moisture stress. These measures are more feasible and practical proposition under most situations and can be adopted by an individual farmer with less draft and amenable even for a small holder. The yield improvements with these technologies varied from 20 to 40%, depending on rainfall and its distribution. Broadbed and furrow (BBF) and ridge-furrow technology implementation have saved soybean and maize crops during 2013 from heavy rains in Malwa regions of Madhya Pradesh and Vidarbha region in Maharashtra, and crops without these interventions completely failed. Based on the success of these technologies, the Government of Maharashtra is implementing these *in-situ* moisture-conservation measures in large scale under Dryland Farming Mission of Maharashtra state. Based on extensive research conducted at various locations in the country, several *in-situ* moisture-conservations practices have been recommended (Table 2) and many of these practices are being adopted in a significant area in the country.

Frequent occurrence of mid-season and terminal droughts of 1 to 3 weeks consecutive duration during the main cropping season happens to be the dominant reason for crop failures and low yields. A critical appraisal of the existing rainwater availability shows that about 114 km^3 of

Table 2. Location specific *in-situ* moisture conservations practices

Practice	Crops/cropping system	Remarks
Compartmental bunding	Winter (*Rabi*) sorghum sunflower, safflower, chickpea, maize, pearl millet, cotton	The impact of the practice is more during sub-optimal rainfall years. It also significantly controls run off. This practice is adopted on more than 800 ha in Northern Karnataka
Conservation furrow	Fingermillet/ groundnut + pigeonpea (8 : 2),soybean + pigeonpea (4 : 2), cotton + soybean (1 : 1)	Opening of conservation furrow enhances *in-situ* moisture conservation, thus the crops can overcome the effect of dry spells resulting in increased rainwater-use efficiency, better perfor mance of crops and additional net returns.
Broad bed and furrow (BBF)	Soybean, groundnut	BBF system helps draining out of excess water from the black soils. Further, the rainwater conserved in the furrows helps in better perfor mance of crop during long dry spells.
Ridges and furrows	*Rabi* sorghum, pigeonpea + rice	The practice conserves 30–45% more moisture than farmers' practice, retains it for longer period and increases crop yield. This practice is adopted in 60% of sorghum area in Solapur district.
Ridge planting	Pearl millet	It provides enough aeration and porosity to soil for enhanced root growth, safe disposal of excess rainwater and reduction in soil loss apart from moisture conservation during low rainfall period.
Set furrow	Pearlmillet–sunflower, pigeonpea + groundnut (2:4)	Conserves more moisture and make it available for longer time to the crops. This helps to overcome the effect of drought.
Inter-plot rainwater harvesting	Sunflower,sorghum,chickpea	This practice makes possible to take up two crops even in drought years mainly by allowing rainfall infiltration into the soil profile.

Source: Srinivasarao and Gopinath (2016)

runoff is generated from 28 million ha of rainfed area in central and eastern India. About 25 million ha of rainfed area can be provided with 1 supplemental irrigation (10 cm), with an estimated harvestable surplus of 28 km^3 during a normal year and about 20 million ha during a drought year (Sharma *et al*., 2010), which can enhance the production by 28–36 million tons during drought and normal monsoon periods. The available runoff can be harvested and utilized broadly for 2 purposes—to provide supplemental irrigation to the standing summer (*kharif)* crop to offset mid-season dry spells/ terminal drought (flowering–grain filling stage) or facilitate sowing of the next winter (*rabi)* crop. Provision of critical irrigation during this period has the potential to improve the yields by 29 to 114% for different crops. Critical irrigation to high-value vegetables, fruit and flower crops would contribute higher benefit : cost ratio and results in higher rainwater use efficiency.

Soil management

Dryland soils are not only thirsty but also hungry. Without regular application of organic manure and recycling of crop residues, it is difficult to maintain and sustain productivity and ensure high responses to NPK fertilizers. Applications of recommended quantity of fertilizers and integrated nutrient management (INM) practices have shown to increase the productivity of several rainfed crops up to 15–32%. Some recommended practices for soil-fertility management include diverse crop rotations with legumes, and INM involving addition of farmyard manure (FYM), use of groundnut shells (GNS) and other crop residues (CRs), green leaf manuring (GLM), etc. For each tonne of soil organic carbon improvement, productivity enhancement ranging from 50 to 300 kg/ha was recorded among different agro-ecoregions. Soil health card (SHC)-based nutrient application improves nutrient-use efficiency, input cost and higher net returns in rainfed agriculture.

Indian soils not only show deficiency of NPK but also of secondary nutrients (S, Ca and Mg) and micro-nutrients (B, Zn, Cu, Fe, Mn etc.) in most parts of the country. Balanced nutrient application to crops based on the nutrient requirement to produce a unit quantity of yield, the native nutrient-supplying capacity of soil and specific targeted yield improves crop yields while minimizing nutrient losses and cost of cultivation. For example, in Andhra Pradesh and Telangana, balanced nutrition was demonstrated in 8 districts to address nutrient deficiencies which existed within farmers' fields. The results were quite promising. In Warangal, cotton yields reached 1.6 tonnes/ha with balanced nutrition registering an increase in yield by 10 to 25% over farmers' practice. Further, farmers in this district achieved 30 to 40% yield improvements in most of the crops owing to balanced nutrition (Srinivasarao *et al*., 2010).

Resilient crops and cropping systems

Selecting suitable crops and varieties will not only help increase production of a single crop but also will help increase cropping intensity. Many criteria have been set out for selecting a crop variety to meet the requirement of rainfed areas. Based on the analysis of long-term climatic data in terms of probability of the onset of monsoon, withdrawal of monsoon, and occurrence of dry spells, effective cropping seasons have been worked out for different regions of the country. These will serve as a good guide in selection of efficient crops and their sowing time. Research on intercropping systems has focused on identification of potential crop combinations for increased productivity, profitability and risk minimization. Further, production technologies involving defining of base and companion crop combinations, plant population, nutrient management, etc. have been standardized for intercropping systems suitable for different agro-climatic conditions. There is also scope for accelerating rainfed agriculture growth through diversification into high-value crops and horticulture.

With the available dryland technologies like rainwater management, choice of crops, short-duration varieties, and other agronomical practices, a greater portion of drylands can be put under intensive cropping systems including relay cropping and double cropping. Double cropping is also possible with rainwater harvested in farm ponds which is used for establishing winter crop. A number of new double cropping systems involving millets, legumes and oilseeds have been evolved for different agro-climatic regions of India.

Contingency crop planning

Contingency crop planning is essentially aimed at stabilization of crop output in the situation of late onset of monsoon, mid-season and terminal droughts. Contingency planning covers different drought situations, i.e. late onset of monsoon (delay by 2–8 weeks); mid-season drought (at vegetative stage, at flowering/ fruiting stage) and terminal drought (early withdrawal of monsoon). The ICAR-CRIDA, AICRPDA and All India Coordinated Research Project on Agrometeorology (AICRPAM) in association with SAUs have developed district-level agricultural contingency plans for 620 districts so far. These plans are intended to benefit district authorities and line departments in the event of weather aberrations, and help understand various contingency measures. The suggested drought-contingency measures include change in crop/cropping systems, crop management, soil nutrient and moisture-conservation measures.

Agro-forestry systems

Large number of tree-based systems were developed based on rigorous experimentation after the initiation of systematic research at the National Research Centre for Agroforestry, Jhansi and at All India Coordinated Research Project on Dryland Agriculture (AICRPDA), Hyderabad. The experimental results were also field tested and the proven systems are being scaled up through developmental programmes such as Integrated Watershed Development Programme, Mahatma Gandhi National Rural Employment Generation Programme, National Horticulture Mission, etc. Owing to the multifarious advantages associated with the tree systems, the acceptance of these systems is observed and the area under these systems is gradually expanding. The total area under agro-forestry in India is reported to be about 25.32 million ha out of which 7 million ha in irrigated regions and 13 million ha in rainfed regions (Dhyani *et al*., 2013).

Integrated farming systems

One of the major approaches for drought mitigation and building farm resilience is through spreading risks and creating buffers, i.e. not putting 'all fruits in one basket'. The farming systems approach is considered as important and relevant, especially for the small and marginal farmers as location-specific IFS will be more resilient and adaptive to climate variability. For example, in an on-farm trial involving different small and marginal farmers in Anantapur district of Andhra Pradesh, it was found that farmers having crop production alone incurred losses due to complete failure of crops, namely groundnut and pigeonpea [*Cajanus cajan* (L.) Millsp.] as a result of drought/prolonged dry spells in both the years (2010 and 2011). However, integration of livestock rearing with crop production gave higher economic returns compared to crop production alone for both marginal and small farmers (Gopinath *et al*., 2012).

On-station and on-farm research in different regions of the country has resulted in identification of a number of sustainable and profitable IFS models for rainfed areas. In general, in regions with rainfall of 500 to 700 mm, the farming systems should be based on livestock with promotion of low-water requiring grasses, trees and bushes to meet fodder, fuel and timber requirements of the farmers. In 700 to 1,100 mm rainfall regions, crop-, horticulture- and livestock-based farming systems can be adopted depending on the soil type and the marketability factors. Runoff harvesting is a major component in this region in the watershed-based farming system. In areas where the rainfall is more than 1,100 mm, IFS module integrating paddy with fisheries is ideal.

Small-farm mechanization

Timeliness of operations has a significant role for increased germination and required plant population, good crop stand and sustained productivity of crops. Large areas in rainfed regions remain fallow or planted late due to poor access to farm machinery which results in low crop productivity. Hence improved access to the farm machinery for sowing, harvesting etc. and other operations is an important adaptation strategy to deal with climatic variability such as late on-set of monsoon, mid-season and terminal droughts and also contributes to timely sowing of post-rainy crops. The energy requirement of major farm operations in dryland agriculture was worked out and the optimal combinations of biological and mechanical energies have been identified. A number of efficient low-cost farm implements were designed for various opera-tions. This reduced 20–59% operation cost, saved 45–64% in operation time, saved 31–38% seed and fertilizer and increased productivity of dryland crops by 18–53%. In the recent past, custom-hiring of agricultural machinery is seen as an appropriate institutional arrangement which can promote mechanization of agricultural operations on small farms. For the first time, a systematic attempt has been made under the National Innovations on Climate Resilient Agriculture (NICRA) to set up 1 custom-hiring centre each at the 130 climatically vulnerable villages across the country.

CONCLUSION

In India, rainfed regions contribute substantially towards foodgrain production and 57% of total net sown area is rainfed spread over 177 districts of the country. Uncertainty of rainfall, increasing frequency of droughts, mid-season droughts, decrease in number of rainy days, extreme and untimely rainfall, and natural calamities such as hail storms, and their frequency is increasing in recent years, are making rainfed farmers more vulnerable. Several location-specific and resilient technologies have been developed during the past 40 years. These technologies have potential to enhance the yields significantly and some of them are designed to meet various weather-related contingencies effectively. The actual yields under farmers' situation are low-leaving large yield gaps. Though the crop-productivity levels on farmers' fields in some of the soil orders such as Vertisols and Inceptisols are high in comparison to Aridisols; the yield gaps are also high for these crops due to the higher production potentials in Vertisols and Inceptisols. The constraints for achieving the potential productivity can be broadly grouped in to technology/ resource related, knowledge and institutional and related to socio-economic aspects. Of these, the constraints related to technology and resource can be effectively addressed with the available technologies which can contribute to improvement of the productivity significantly under rainfed conditions. There is a need to upscale these technologies through KVKs, Agriculture Technology Management Agency (ATMA) and several national/ state programmes of the Governments for realizing the productivity enhancements and large-scale impacts.

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4th International Agronomy Congress (November 22–26): 53–58 (2016)

Achieving food and nutritional security of farm households through integrated farming systems under changing climate

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ABSTRACT

The Indian population of 1.326 billion is increasing at the rate of 1.6% per annum and is expected to touch 1.705 billion by 2050 (UN, 2015). Besides, increasing population, soil degradation (5-–10 million ha/year), desertification (6 million ha/year) coupled with declining irrigated area per person (1.3%/year) and forested area (0.78%/year) in India are the challenges which need to be addressed together in system perspective. Around 129 million farm holdings exist in the country, out of which 86% are small and marginal. On an average, when 5-member family is considered, the total population of farm households works out to 645 million which is about 50% of the population. Despite of being one of the leading producers of foodgrains, every year around 1% of population is added under food-insecure category which is mainly due to poor food affordability. The domestic food price level index which is an indicator of the relative price of food in a country, is almost double (4.68) of world index (2.85) in India. The domestic food price volatility index (8.4) with higher per caput food/energy supply variability (28 kcal/caput/day) highly influenced the affordability of the food to the poorer section of the country. The share of food expenditure of poor, i.e. proportion of food consumption over total consumption (food and non-food) for the lowest income quintile of the population in the country is still high (65% during 2010) in comparison to developed country. With 108% average energy-supply adequacy, share of dietary-energy supply derived from cereals, roots and tubers is higher (59%) than the world share (52%). The situation of the average protein supply (59 g/caput/day) and supply of protein of animal origin (12 g/caput/day) also limited in the country as compared to world average (79 g/caput/day). Hence the prevalence of undernourishment becomes permanent social stigma in India since time immemorial and still stands with 15.2% (2014–16) of the total population (FAO, 2016).

The consumption pattern is also undergoing major change with the improvement in per caput income, especially in urban areas. Besides, other population growth, urban migration, mechanization and labour-saving devices highly influenced the nutritional scenario. The diets of poor people in developing countries like India are mainly cereal based such as rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend. Fiori & Paol.). A very meagre amount of vegetables and animal foods are consumed with the staple food. These foods are expected to supply a range of essential vitamins and minerals in sufficient quantity to compensate nutritional deficiencies arising out of eating only staple foods items. Added to these are undesirable dietary habits and practices, fixed attitudes and perceptions shaped by tradition and socio-cultural influences that could adversely affect nutritional status. Considering this, the food and nutritional security of the population by increasing agricultural production and making them available to the rural population both in quality and quantity is the need of the hour. Agricultural intervention and farming systems research in India have been largely focused on enhancing production, productivity and profitability of crop and animal resources without much emphasis on better nutritional outcomes.

Availability of sufficient man-power within the family, capable of hard work, and full-time devotion for farming are considered to be the strength of small farms in India. However, the fragmented holdings, low level of literacy and low-risk bearing ability due to poverty are often their weaknesses that expose them to vagaries of farming. The opportunities available are the availability of low interest loan and subsidies from government agencies, presence of more than 1 enterprize and also easy addition of livestock through family labour. The threat will be the unpredictable weather changes. A diversification of small farms is essential to reduce risks associated with biotic and abiotic stresses, market-price fluctuations and high-input costs and meet with requirement of family and market (food, fodder, fuel, fibre and fertilizer). Such a change may help sustained and improved income, employment and standard of living besides providing diversified products to the market. Therefore, this requires a paradigm shift in agricultural research through integrating locally available farm resources along with restoration of environment, i.e. Integrated Farming Systems.

INTEGRATED FARMING SYSTEMS APPROACH

The integrated farming systems (IFS) approach is considered to be the most powerful tool to enhance the profitability of farming systems, especially for small and marginal farm-holders. Past experience has clearly demonstrated that the income from cropping alone is hardly sufficient to sustain the farmers' needs. With enhanced consumerism in rural areas, farmers' requirement for cash has also increased due to their rising standard of living, especially with small and marginal farmers. Therefore, farmer's income and food requirement must be augmented and supplemented by adoption of efficient secondary or tertiary enterprizes like animal husbandry, horticulture (vegetables/ fruits/ flowers/ medicinal and aromatic plants), apiary, mushroom cultivation, fisheries etc. However, these IFS will be required to be tailor-made and designed in such a manner that they lead to substantial improvement in energy efficiencies at the farm and help to exploit synergies through adoption of close cycles. These systems are also to be socially acceptable, environment friendly and economically viable.

NEED FOR COORDINATED EFFORT

On-station and on-farm coordinated research in farming system is essential to find way out to overcome constraints across the country and develop locally available resource-centric models. The identified successful model of a particular region will pave its spreading to other region. All the time-tested technologies generated by commodity-based research institutions will be brought under the umbrella of farming systems and delivered to the farmers through All India Coordinated Research Project on Farming Systems Research (AICRP on IFS). The ICAR-Indian Institute of Farming Systems Research (IIFSR) is therefore implementing IFS research from April 2010 at 75 centres. Thirtytwo centres are working on the farming systems model development for small-holders, mainly for experiential learning, demonstration and modelling the resource flow. Thirtyone on-farm centres, located in the districts, work directly with the farmers through module-based interventions in farmer-participatory mode. In each location, 30 marginal holders and 6 small holders are covered for farming system model development. Twelve subcentres work additionally on cropping or farming systems.

The ICAR-IIFSR, Modipuram. has established 38 on-station integrated farming system models in 14 agro-climatic regions for research, extension, education and business (bankable projects). Similarly, refined 63 existing IFS through on-farm farmer-participatory research. Seven on-station IFS models were established under West Coast Plains and Hills Agro-climatic Zone, whereas 9 on-farm farmer participatory refined integrated farming systems models established for the Lower Gangetic Plains. Location-specific components were given major weightage for their inclusion in the IFS model. The major components of the IFS models are location-specific cropping systems, livestock components (Cow/ buffalo/ poultry/ duck/ goat/ pig) + fisheries + horticulture (fruit orchard intercropped with vegetables) + complementary/ supplementary enterprizes such as apiary, mushroom, bio-gas + compulsory integration of kitchen garden, boundary plantations and vermicompost.

FARMING SYSTEMS TYPOLOGY

Analysis of benchmark data of 735 marginal households across the 30 National Agricultural Research Project (NARP) zones indicates existence of 38 types of farming systems. Out of this, 47% of households have the integration of crop + dairy, 11% have crop + dairy + goat, 9% households have crop + dairy + poultry systems and 6% households have only crop component. In terms of number of components integrated by marginal households, 52% households are practicing only 2 components, while 7% have only 1 component. Remaining 41% households have components ranging from 3 to 5. Scope exists in the 59% of marginal households for intentional integration of allied enterprizes for improving the per capita income. Though the mean holding and family size of marginal households having up to 2 components and more than 2 components remains almost same (0.82 ha with 5 no's in 2 component category and 0.84 ha with 5 no's in > 2 component category), the mean income level is much higher (₹1.61 lakh) in the farms having more than 2 components (e.g., crop + dairy + goat; crop + dairy + goat + poultry; crop + dairy + goat + poultry + fish etc.) than with farms having 2 or less components (₹0.57 lakh only in crop alone, dairy alone, crop + dairy, crop + goat etc.). Diversification of 1 and 2 component systems (crop alone, dairy alone, crop + dairy, crop + pig, crop + poultry, crop + fisheries, crop + horticulture, crop + goat, dairy + goat) in the 59% marginal household is essential to augment the per caput income.

Farming-system characterization has been completed in 39 districts in 13 states to identify the production- and policy-related constraints in different farming systems. Among them, lack of improved variety seed and high incidence of pest and diseases are the top 2 production-related constraints. However, high cost of inputs ranked first while labour shortage during peak period as well as lack of technical know-how ranked second among the top 2 policy-related constraints were common in all the districts.

Average area and family size in the region was taken for developing on-station integrated farming system models and family size varied from 4 (West Coast Plains and

Hills) to 8 (Middle Gangetic Plains), while area under IFS model varied from 0.20 ha (Kerala) to 1.45 ha (Rajasthan). A higher mean net returns (₹2, 37,607/year) was recorded from on-station IFS model, comprising cropping systems (0.70 ha) + dairy (2 buffalo) + horticulture (0.25 ha) + vermicompost (0.01 ha), whereas it was the lowest (₹66,597/year) in West Coast Plains and Hills region. The maximum mean net returns (₹268,106/ha/year) were recorded at Ludhiana (Punjab) with IFS model having the components of cropping systems (0.64 ha) +dairy (2 cows) + horticulture (0.20 ha) + fishery (0.20 ha) + agroforestry (0.03 ha) + vermicompost (0.005 ha) + apiary (5 boxes). Under homestead-farming systems developed at Karmana (Kerala), having the components of cropping systems + dairy (1 cow + 1 buffalo) + vermicompost recorded net returns of ₹20,360/annum from 0.20 ha. Further, IFS models, developed at across different agro-climatic regions provides 2 to 3 times higher income than existing farming systems, besides meeting the household demand of food, fodder, fuel sufficiently. It also reduces the dependency on fibre and chemical fertilizers from the market to the extent of 65–80%.

ON-FARM REFINEMENT OF EXISTING FARMING SYSTEM MODELS

On-farm refinement of existing farming system models for marginal farmers were undertaken with the involvement of 616 numbers of farmers, and the average model area was 0.49 ha in Middle Gangetic Plains region and 0.93 ha under West Coast Plains and Ghats. The lowest net returns (₹11,333/year) from the unit of IFS model were recorded with very low input cost (₹8,500/year) with a model having crop + dairy as components raised on 0.20 ha in coastal saline NARP zone of Lower Gangetic Plains. A net return of ₹294,999/year was recorded from on-farm model having field crop + dairy + goat + poultry + *Azolla* + vermicompost + mulberry silk rearing as components in 1.14 ha in Eastern Dry NARP zone of Southern Plateau and Hills Agro Climatic Zone, and the highest average return (₹137,307/year) from the IFS model was also recorded under the same agro-climatic region. The lowest average net returns of ₹44,575/year were recorded under North-East Alluvial Plain of Upper Gangetic Plains. Agro-climatic region wise net returns from unit area were calculated and it was found that under East Coast Plains and Hills condition, the maximum net returns to tune of ₹ 166,181/ha can be achieved. In total, 735 households have adopted the integrated farming system model (on-farm) based on location-specific components on their total area of 657 ha across 21 states. The highest area (131 ha) of adoption was recorded under Central Plateau and Hills covering 98 households.

APPROACHES OF FARMING SYSTEM DIVERSIFICATION

Intensification and diversification of crop component of farming system

The strategy to produce more from less specially to ensure high income for small holders can be achieved through bio-intensive complimentary cropping systems, in which land configurations are used to accommodate 2 or more crops of synergistic nature at a time in the same piece of land. This type of system offers scope to improve resource-use efficiency of water and nutrients besides ensuring natural management of weeds, pests and diseases. Ten bio-intensive complimentary cropping systems were evaluated for higher productivity and profitability. The bio-intensive system of raising maize, *Zea mays* L. (for cobs) and cowpea, *Vigna unguiculata* (L.) Walp. (vegetable) in 1:1 ratio on broad beds (BB) and *Sesbania* in furrows during the rainy season (*kharif*), mustard [*Brassica juncea* (L.) Czernj. & Cosson] in furrows and 3 rows of lentil (*Lens culinaris* Medikus) on broad beds in the winter season (*rabi*) and 3 rows of moongbean [*Vigna radiata* (L.) R. Wilczek] on beds in summer was found to be remarkably better than others. This system gave the highest yield of 24 tpnnes/ha as rice equivalent with a system productivity level of 50.2 kg grain/ha/day and profitability of ₹500/ha/day (Gangwar and Ravisankar, 2013). The complimentary effects could be exploited in broad bed and furrow (BBF) system as the furrows served as drainage channels during heavy rains in the rainy season and 35 tonnes/ha green foliage was incorporated for *in-situ* green manuring 45 days after sowing. This intensification could save up to 30% of irrigation water as water was applied only in furrows.

Based on multi-location studies at 37 on-station and 31 on-farm centres, efficient alternative cropping systems with agronomic management practices were identified for different agro-climatic zones, having potential productivity ranging from 16 to 35.2 tonnes/ha/year. Some of the successful models practiced by farmers with slight improvement promises 4 to 6 times higher net income to farmers than existing farming systems. Farmers perception on climate change and integrated farming systems as adaptation measure towards changing climate by involving 1,260 farm households revealed that adaptation index was higher for field crops/ cropping systems and livestock than horticulture crops. Yield gap of 1.5 to 2.7 tonnes/ha exists in rice between farmers and recommended practice in Eastern, Southern plateau and hills regions and West coast plains and Ghat region, while it ranged between 1 and 1.3 tonnes/ha for maize in Western Himalayas and Eastern plateau and hills regions in *kharif* season. In *rabi* season, yield gap ranges from 1.1 to 1.3 tonnes/ha for rice in Southern Plateau and hills regions and Gujarat plains and hills regions; however, the yield gap in wheat was higher in Western Himalayan region. Addressing these issues by management of location-specific constraints in general gave 30–40% more yield than farmers practice in different cropping systems.

Diversification of other components of farming system for higher income

Rice-based farming system comprising several crop components including rice–pea (*Pisum sativum* L.)–okra [*Abelmoschus esculentus* (L.) Moench] and sorghum [*Sorghum bicolor* (L.) Moench)–berseem of Egyptian clover (*Trifolium alexandrinum* L.)–maize (*Zea mays* L.), dairy, poultry and fishery was the most suitable and efficient system. This diversified system recorded higher system productivity and profitability under irrigated ecosystem of eastern Uttar Pradesh (Singh *et al.,* 2006). The land-based enterprizes such as dairy, poultry, fishery, mushroom, biogas etc. were included by Behera and Mahapatra (1999) to complement the cropping programme and to get more income and employment for small farmers of Odisha. Nearly 9% higher net returns (₹58,367) were realized from investment of ₹49,286 in 1.25 ha area, besides generating 573 man days of employment. A resource-use efficiency of ₹2.18 per rupee invested ensured better livelihood of small farmers. A range of water-management practices for crop–fish system are available to strengthen resilience to climate variability. Crop-fish integration in the unlined on-farm reservoirs is technically feasible and economically viable as compared to lined system for increasing the agricultural productivity. The water productivity and farm income were higher in crop–fish system in rainfed lowlands than to the sole system of any of these 2 independent components (Sinhababu, 1996). Integration of farming components comprising field crops, vegetables, floriculture, poultry, fishery and cattle in the lowlying valley areas gave higher net returns (₹2.11 lakh/ha) and benefit : cost ratio of 2.5 besides ensuring additional employment generation of 221 man-days (Ravisankar *et al.,*2006) fulfilled the objectives of integrated farming systems from the limited land and water resources.

Diversified farming system models

Farming system models can be synthesized using the primary (collected directly from farm households on basic characteristics), secondary data (available from agricultural and livestock census) and research results from on-station and on-farm experiments to improve the productivity and profitability. The cropping systems were modified to include pulses, oilseeds, vegetables and fruits to meet the family demand. The area allocation to each of the component was also quantified accordingly. The synthesized cropping system included sugarcane (spring) and onion (*Allium cepa* L.)–ratoon (12% area, 0.12 ha), rice–potato (*Solanum tuberosum* L.)–wheat or marigold (*Tagetes* sp.) (0.15 ha) and *dhaincha* [*Sesbania cannabina* (Retz.) Poir.] (26% area, 0.30 ha), maize (cob) and pigeonpea [*Cajanus cajan* (L.) Millsp.]–wheat (11% area, 0.13 ha), and sorghum–rice–Indian mustard (0.21 ha) and oat (*Avena sativa* L.) (0.07 ha) and berseem (0.07 ha) (28% area, 0.35 ha). Pigeonpea and Indian mustard were added mainly to produce adequate pulses and oilseeds for the family. The livestock component of 2 buffaloes and 1 cattle was kept as such, but provision for producing sufficient green fodder was kept by including oat and berseem in the cropping system. To enhance the income and recycle resource, complementary enterprizes such as apiary, vermicompost (0.7% area, 100 m^2) and *karonda* (*Carissa carandas* L.), citrus (*Citrus* sp.), jackfruit (*Artocarpus heterophillus* Lam.), bael (*Aegle marmelos* Correa ex Koen.) and *subabul* (*Leucaena leucocephala* L. de Wit) as boundary plantation were incorporated. *Karonda* serves as the live fence and produces fruits which can be used to make pickles. Further, it can also protect the farm from blue bull or stray animals. Mixed plantation of fruits including mango (*Mangifera indica* L.), guava (*Psidium guajava* L.), peach and pear intercropped with seasonal vegetables like brinjal (*Solanum* ***melongena*** L.) and tomato (*Solanum lycopersicum* L.) (16% area, 0.20 ha) and fishery (7.5% area, 0.08 ha) was added as income-supplementing activities in the model. A 7-member family having 5 adults and 2 children requires cereals (1,550 kg), pulses (200 kg), oilseeds (130 kg), vegetables (900 kg), fruits (200 kg), milk (1,120 litres) and fish (154 kg) per annum as per the ICMR standards to provide its food and nutritional requirement. It has been observed that the synthesized model for the 1.2 ha is able to produce sufficient quantity of these produces required for this 7-member family. Apart from this, the system also generates marketable surplus of cereals (3,585 kg), oilseeds (106 kg), vegetables (3,200 kg), fruits (2,218 kg), milk (5,001 litres) and fish (276 kg) and thus ensures sufficient income for the family, besides improving the availability of these products for the market. The fodder requirement of 2 buffalos and 1 cattle is around 27 tonnes of green fodder and 5.5 tonnes of dry fodder per annum, but existing system produced only 21 tonnes of green fodder. In the improved farming system, it increased to 36 tonnes green and 6.4 tonnes dry fodder per annum which is the main reason for additional production of milk. The total production in terms of sugarcane-equivalent yield in the improved system was found to be

108 tonnes per annum compared to 56 tonnes per annum only in the existing system (Fig.1). The net profit increased by 88%, while the cost of the new system increased by 35%. Internal supply of nutrients was found to be 204 kg N, 136 kg P_2O_5 and 186 kg K_2O/ha as against only 100 kg N, 40 kg P_2O_5 and 100 kg K_2O/ha in the existing system. In the improved system, it is estimated that 65, 85 and 100% of N, P_2O_5 and K_2O requirement can be met within the farm. Further, the recycled resources are expected to supply sufficient level of micronutrients. Employment for the family increased from 360 to 625 man-days ensured year round farm employment even at household level.

Crop, horticulture, dairy, goat, fish, duck and boundary plantation family farming model at Sabour, Bihar

FAMILY FARMING MODEL FOR NUTRITION AND INCOME

Crop, horticulture, dairy, goat, fish, duck and boundary plantation family farming model at Sabour, Bihar

A 1 ha area with 5-member family, farming model comprising crop (0.78 ha), horticulture (0.14 ha), dairy (2 cows) and goat (11), fish (0.1 ha) + ducks (25) and boundary plantation of *subabul* (225 plants) and moringa (50 plants) was developed for the Alluvial Plains zone in Middle Gangetic Plainss region in South Bihar (Fig. 2). This model provided round-the-year income (from ₹ 13,160 (September) to 51,950 (April)/ha/month. The diversified cropping systems [rice–wheat–moongbean (grain + residue incorporation), rice– maize + potato–cowpea (fodder), rice–mustard–maize (grain) + cowpea (fodder), sorghum + rice bean [*Vigna umbellata* (Thumb.) Ohwi & Ohasi)–berseem or oat–maize + cowpea (fodder) and seasonal vegetables, viz. brinjal, tomato, cauliflower [*Brassica oleracea* Var. *botrytis* L.], cabbage (*B. oleracea capitata* L.), vegetable pea, okra, lettuce (*Lactuca sativa* L.), grown in 0.78 ha area could meet the full family requirement of cereals (1,100 kg), pulses (95 kg), oilseeds (125 kg), fruits [guava and papaya (*Carica papaya* (L.)] (185 kg) and vegetables (640 kg) and livestock requirement of 29.5 and 6.6 tonnes of green and dry fodder per year. The model also meets the requirement of milk (550 litres), egg (900) and fish (120 kg). Besides meeting the family and livestock requirement, the model produced marketable surplus of cereals (4,810 kg), vegetables (986 kg) and fruits (35 kg), milk (4,243 litres), egg (950) and fish (124 kg) which resulted in steady income. The model also ensured fuel wood availability of 4 tonnes/year for the family and could add enriched vermicompost (4 tonnes) and manure (2.3 tonnes) to improve the soil health. The value of recycled products and by-products of model

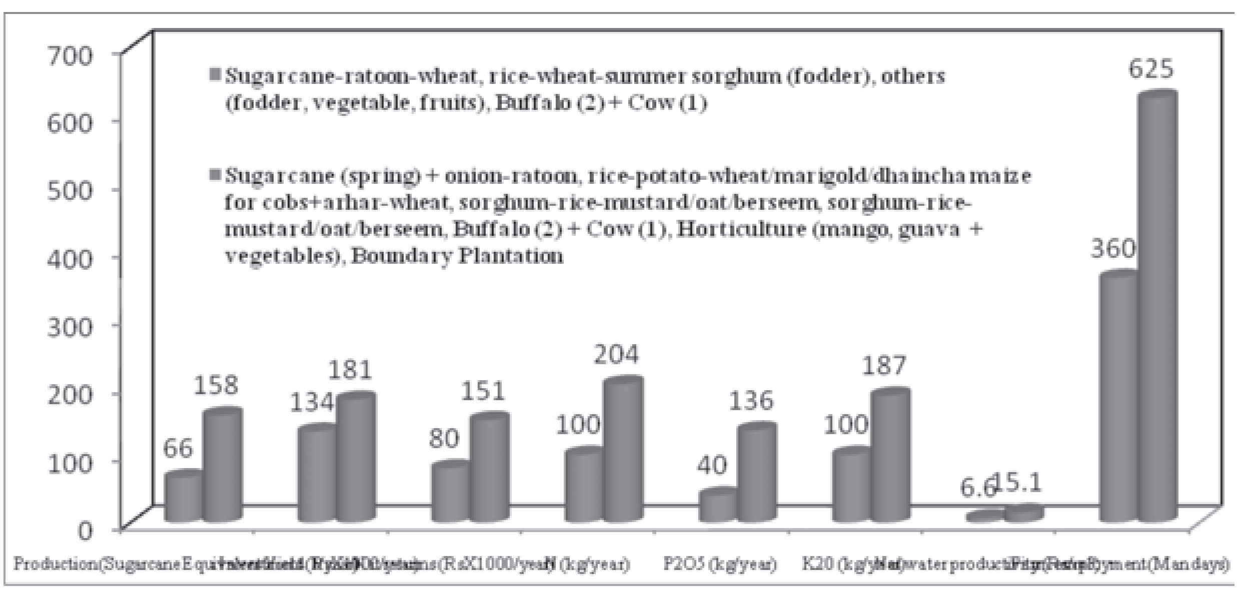

Fig. 1. Production, cost, returns, recycling and employment of existing and diversified system in Western Plain Zone of Uttar Pradesh

worked out to be ₹1.29 lakh which reduces the total cost (₹3.1 lakh) of the model by 42%. The family labour (730 man-days) contributed to save 37% of cost. Hence, only 21% (₹0.68 lakh) of total cost is involved in the form of inputs purchased from the market. A total net returns of ₹ 3.14 lakhs, being 3.2 times higher than existing pre-dominant crop and dairy system of the zone (DARE /ICAR, 2015).

CONCLUSION

It can be concluded that diversification of existing farming systems with changes, addition or improvement of crop and livestock components and inclusion of horticulture, kitchen garden, primary and secondary processing, boundary plantations are essential to improve on-farm income of small holders with environmental restitution. This also paves way for meeting with the household demand of balanced food, improved recycling of nutrients and water besides increasing the on-farm employment for family. Diversification of existing farming systems clearly demonstrated the advantages in terms of production increase and employment generation. It has been successfully demonstrated that productivity gain is often 2 to 3 times more and increase in net returns is 3 to 5 times more with improved systems. Further, resource saving of 40 to 50% can also be ensured besides enhancing the income of household to the level of at least Rs. 400 to 500/day. Additional employment generation of 70 to 80% is also possible. Improved diversified systems also ensure household nutritional security.

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4th International Agronomy Congress (November 22–26): 59–68 (2016)

Indigenous materials for increasing efficiency of fertilizer nitrogen

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INTRODUCTION

Fertilizer nitrogen continues to play a vital role in consolidating the gains of Green Revolution in India, thus forms a key component to address food security of the country. The second most important factor responsible for increased food/ cereal production has been the fertilizer nitrogen (Prasad and Shivay, 2015). The journey to food security in India is weaved around high-yielding crop varieties and improved agronomic practices while addressing the issues of biotic and abiotic stresses. Our agronomists played a critical role of stabilizing and enhancing the performance of improved as well as traditional crop varieties. Among various agronomic practices, fertilizer use, especially of N has been the centre of attention and research in the country. While it has been argued that India needs more and more N fertilizers to support its food production and an estimate of 22-25 million tonnes of N fertilizer production has been projected (Prasad, 2007), scientists are increasingly looking at improving the N-use efficiency by crops as a necessary tool not only to economize N fertilizer use but also arrest environmental degradation.

The N content in Indian soils continue to be low, ranging from 0.02% to 0.1% (Prasad, 2007); a possible explanation is that enough organics are not introduced into the agro-ecosystems and the applied N fertilizers are soluble and thus easily lost from the system. While the debate on the availability and feasibility of increased additions of organics razes on, it has become a bare necessity to maintain and enhance food production through the use of chemical fertilizers, especially of N.

FATE OF APPLIED NITROGEN IN INDIAN AGRICULTURE

There are principally 3 routes through which applied fertilizer N flows in agro-ecosystems:

(i) Crop removal, (ii) N losses from soil-plant system and (iii) N storage in soil

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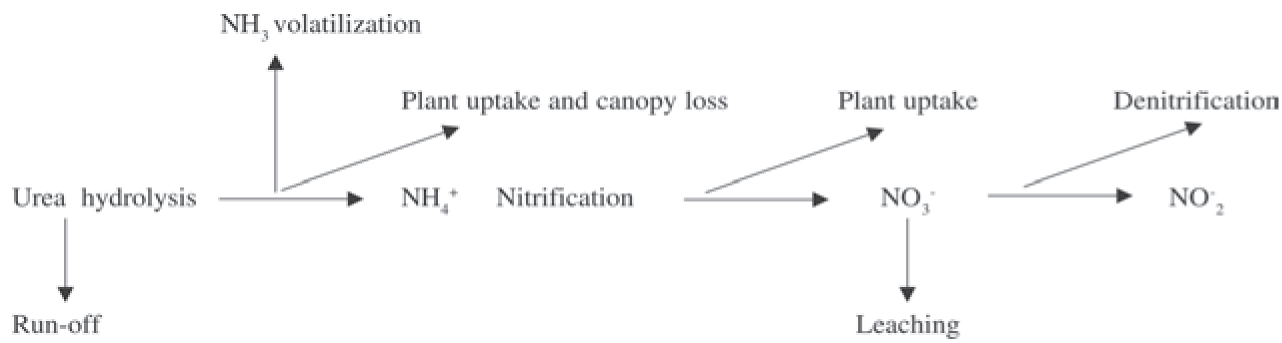
Crop removal

Most field crops recover 25-50% of applied N (Prasad, 2013). Cereals remove 20 to 75 kg N/tonne grain and nearly 27-51% N harvested by the crops is contained in stover (Prasad, 2007); the values vary according soil-climatic factors and agronomic management. While these values throw light on the N use by crops, surprisingly, unit N required to produce unit grain has increased over the years. Studies conducted at IARI have shown that 16.2 and 20.1 kg grain/kg N of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend Fiori & Paol) are produced respectively (Prasad, 2007) and these figures have further declined to 11.4 and 6.2, respectively, based on the analysis of data from the trials on farmers' field by the ICAR-The Indian Agricultural Statistics Research Institute (IASRI) (cf. Prasad, 2007). Therefore, it is safe to conclude from this research that in India, the field crops, especially rice and wheat will continue to need more N additions to maintain and further increase production levels. However, this trend is not sustainable economically and environmentally in future.

Nitrogen losses from soil-plant system

Nitrogen is lost from soil-plant system through several mechanisms such as run-off, leaching, denitrification, NH_3 volatilization, loss from crop canopy. In India, urea is the major source of N accounting to >80%. However, urea itself, being soluble is lost easily from soil besides creating favourable soil pH conditions for NH_3 volatilization. The possible pathways of urea movement in soil-plant system is briefly described here.

Whenever urea is surface applied to the crop fields and heavy rains fall soon after application, a part of the applied urea is lost through run-off. These losses are estimated to be about 10 kg N/ha (Katyal, 1989). However, these values may vary depending on rain-fall intensity, soil conditions, slope, crop cover and others. The regions having most run-off loss of urea are sloping lands in the mountainous tracts in Himalayas and Konkan belt of Maharashtra, where rice is the crop grown during the rainy season. Unfortunately, data on run-off losses of urea from crop fields based on field studies are lacking and we are missing vital data which may be a major pathway in monsoon dependent Indian agriculture where urea is mainly



broadcast applied.

Ammonia volatilization losses of N could be important in many situations where urea is the main source of N. Urea on hydrolysis, is converted to ammonium carbonate which readily raises pH of the local soil sites and is prone to conversion to NH_3 gas which volatilizes readily. In India, our country, most farmers broadcast urea, making it vulnerable to immediate losses through NH_3 volatilization. Several estimates put these losses to values ranging from 8 to 30% (Prakasa Rao and Bhat, 1984; Sudhakara and Prasad, 1986; Prasad, 2007). The main issue has been the method of estimation of NH_3 volatilization; semi-open chamber methods (Prakasa Rao and Bhat, 1984) do give a fair idea of such losses, though not quantitatively. Deep placement of urea in soil can largely reduce such losses (Prakasa Rao and Puttanna, 1987; Katyal *et al*., 1987). Thus deep placement of nitrogen should receive as much attention as the placement of phosphorus (Devasenapathy and Palaniappan,1995; Prasad, 2013).

Nitrification of N fertilizers produce NO_3^- which is soluble and prone to leaching losses. Leaching of nitrates have several agricultural and environmental implications (Prakasa Rao and Puttanna, 2000, 2006). Once again, methodologies adopted to assess nitrate leaching have not improved over the years and still researchers depend on qualitative estimates to evolve better agronomic interventions. Under irrigated conditions in light-textured soil-nitrate leaching could be substantial (Bijay-Singh and Sekhon, 1976). Pot culture studies with rice have shown that under intensive low-land conditions, even NH_4^+ is leached out in light-textured soils; leaching of N was 17% and 15% from ammonium sulphate and urea, respectively, and could be reduced with such agronomic interventions as use of nitrification inhibitors, neem-cake (Prakasa Rao and Prasad, 1980). Studies have shown high magnitude of nitrate leaching losses in rice–wheat cropping systems in north-west India (Bijay-Singh *et al*., 2007). Pathak *et. al.* (2004) suggested that 15-16% of applied N could be lost through leaching.

Where submerged soil conditions prevail such as in low land rice, nitrates are converted to N oxides by denitrifying bacteria as:

$$NO^-_3 \text{ denitrifying organisms} \longrightarrow N_2, N_2O$$

The N oxides readily are released to the atmosphere and this process is called denitrification. Prasad and Lakhdive (1969) showed in a laboratory experiment that N is lost through denitrification under submerged conditions. Several researchers have reported useful estimates of denitrification losses ranging from 10 to 50% of applied N in India (Krishnappa and Shinde, 1980; Katyal *et al*.,1985; Mosier *et al.*, 1990, Aulakh *et al*., 2001; Pathak *et al*., 2004). Quantification of denitrification losses from crop fields remains a challenge and an average loss of about 25 kg N/ha with the application of 120 kg N/ha is reported (Ladha *et al*., 2005). Nitrogen losses are the highest under alternate wetting and drying cycles (Prasad and Rajale, 1972; Prasad, 2011).

Nitrogen can also escape from plant canopy. Wetselaar and Farquhar (1980) suggested that N in the form of NH_3 could be lost from plant canopy during plant senescence. Not much information is available on this subject in India. However, N balance studies using ^{15}N have provided some knowledge on the movement of N in soil-plant systems in India (Katyal *et al.*, 1985; Goswami *et al*., 1988).

Nitrogen storage in soil

Most of the N stored in soils is in organic forms; inorganic forms of N are highly reactive and are subject to easy movement and lost from the agro-ecosystems. High temperatures and heavy rainfall during the monsoon season render easy decomposition of soil organic matter in India. While it is a constant struggle to maintain and increase soil organic matter in Indian soils, the question of storing N in soils has been elusive. Generally, N content in soils is as low as 0.02% N (Krishnamoorthy and Govindarajan, 1977) to 0.3% N (Manickam, 1965) in India. The main issue is not as much as estimating N status of Indian soils, but to retain soil organic matter levels such that Indian soils are not grossly deficient in N. Methods such as alkaline permanganate hydrolysable N were developed for assessing N availability in Indian soils (Subbiah and Asija, 1956) but provide very high values. More realistic values of N release from soil organic matter are provided by mild calcium hydroxide hydrolysis of soil (Prasad, 1965), but this method has not been widely tested in India and deserves attention.

Thus, Indian scientists have greatly contributed to our knowledge on the N dynamics in Indian soils. However, quantifications of N budget have largely remained elusive and empirical. Agronomists are greatly benefitted by the knowledge so far created for their ultimate objective of enhancing N-use efficiency by crops.

Nitrogen use efficiency in India

Nitrogen use efficiency (NUE) in Indian agriculture is very low. Various estimates, using apparent N recovery methods and ^{15}N techniques, show that the N recovery by wheat is less than 40% and that of rice even lower (Yadvinder -Singh *et al*., 2007). Clearly, this scenario is unsustainable both for the economy and environment. Scientists have been working on methods to improve NUE by crops. On an average, the recovery of fertilizer N in India ranges from 20 to 50% for rice (Prasad *et al*., 1998a).The global average recovery efficiency of fertilizer nitrogen (REN) by cereals is 55% (Ladha *et al.*, 2005), although it could be as low as 21% for rice in some cases (Katyal *et al.*, 1985). As reviewed by Ladha *et al.* (2005), average recovery efficiency of ^{15}N for cereal crops was 44% in the first growing season and total recovery of ^{15}N fertilizer in the first and 5 subsequent crops was only around 50% worldwide.

The NUE for cereal crops is about 33% (Ladha *et al.,* 2005). Ladha *et al*. (2016) constructed a top-down global N budget for maize (*Zea mays* L.), rice, and wheat for a 50-year period (1961 to 2010). Cereal grains and above-ground straw contained a total of 1,551 Mt of N, of which 48% was supplied through fertilizer-N. The N output was estimated to be 3,306 Mt, of which the crop harvested 47%, whereas the remaining 53% or 1,755 Mt of N input was lost. In addition, soil-N declined by about 68 Mt. In order to economize N fertilizer use in Indian agriculture while minimizing adverse environmental effects, Prasad (2007) suggested the following measures:

1. Reducing N losses from farm fields,
2. Developing and using more efficient N fertilizers,
3. Adopting integrated nutrient management (INM) or supplying N through sources other than chemical fertilizers,
4. Balanced fertilizers, and
5. Better agronomy of crops.

Better agronomy of crops includes such measures as good crop husbandry, proper methods of N application as placement, foliar and proper time of N application which include N applications based on right crop physiological stages, using such methods as chlorophyll meter, leaf colour chart.

Prasad *et al.* (1971) reviewed research on the use of slow-release N fertilizers and nitrification inhibitors in agriculture. Subsequently, many researchers have published the merits of nitrification inhibitors and modified urea materials such as urea supergranules, in crops like rice. However, most of these materials have not been adopted by farmers due to reasons of cost and availability.

In countries like India, traditional knowledge such as, traditional plant types and varieties, traditional sources of nutrients and pest-control measures, use of waste materials and products, use of locally available plants, minerals and animals have a great potential to address the issues of agriculture. It is in this context that scientists in India started searching for indigenous materials which have a potential to improve NUE. Bains *et al.* (1971) discovered that neem-cake obtained from the seeds of *Azadirachta indica* neem or margosa increased the efficiency of urea. Rajendra Prasad and group of researchers pioneered the work on the nitrification inhibitory action of neem products and their role in increasing NUE in crops. Thus started the quest of Indian scientists to search and evaluate indigenously available materials for enhancing NUE by crops.

In this article, we focus on some groups of indigenously available materials on which research has been conducted and also, products derived for large-scale adaptation in the country. The different classes of indigenous materials for nitrification-inhibitory properties and their use in enhancing NUE are broadly listed as:

1. Neem and pongamia products
2. Pyrites
3. Essential oils and terpene compounds

Neem and pongamia

Reddy and Prasad (1975) were the first to report nitrification-inhibiting property of neem; urea treated with neem-cake inhibited nitrification by 40 and 74 % at the end of 1 and 2 weeks of incubation, respectively.The nitrification-inhibitory properties of neem were confirmed by several studies done later across the country. As regards neem-cake coated urea (NCU), data are available from a large number of experiments on different crops and have been summarised by Prasad *et al*. (1993). The average increase in yields of wheat, potato (*Solanum tuberosum* L.), sugarcane, cotton (*Gossypium* sp.) and finger millet were 6.9, 10.5, 15.5, 10.3 and 5.3%, respectively. Prakasa Rao *et al*. (1985) reported that neem-coated urea increased herb and essential oil yields of an aromatic plant, citronella (*Cymbopogon winterianus*) in a 2-year field study carried out in a sandy-loam soil of semi-arid tropical region. Prasad *et al*. (2007) described the evolution of neem-coated urea research in India and its efficiency in increasing NUE in a variety of crops in India. Singh and Singh (1984) from Pantnagar reported that cummulative loss in 20 days as ammonia from N applied @ 150 ppm as urea was 22% and was reduced to 19% when urea was blended with neemcake (1: l w/w). Prakasa Rao (1996) has shown that neem coating of urea has reduced NH_3 volatilization losses in a citronella field; from 38% with ordinary urea to 29% with NCU (Fig 1). Prakasa Rao and Prasad (1980) found that leaching as nitrate was reduced from 11% to 8.7% of applied urea-N when urea was coated with neemcake. Research at the IARI under the leadership of Rajendra Prasad (Prasad *et al.,* 1993; 1999a,b; 2002; 2007; Shivay *et al.,* 2001) led to the development of neem-coated urea (NCU), its on-farm confirmation by others (Thind *et al.*, 2010) and feedback by the famers has led to its manufacture of NCU in India on a large scale (Table 1).

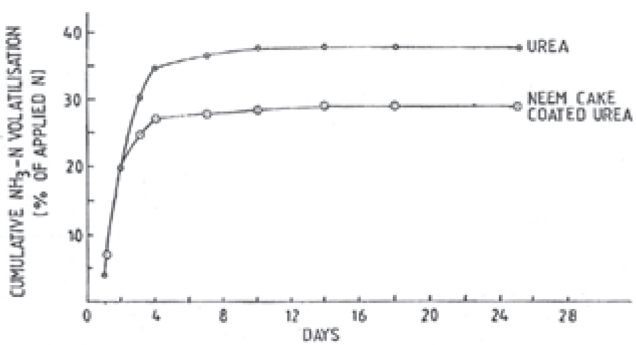


Fig 1. NH_3 volatilization losses from urea and neem coated urea applied to soil (Prakasa Rao,1996)

Research to identify the active constituents responsible for the nitrification-inhibitory properties in neem was initiated at the Division of Agricultural Chemicals, IARI, New Delhi. Devakumar (1986) found that a group of compounds known as meliacins were responsible for inhibition of nitrification by neem. Of the 5 meliacins screened, desacetylnimbin caused uniformly higher ammonium-N concentration and lower nitrate-N production. The general order of nitrification-inhibiting potency was: desacetylnimbin, salanin, desacetyl salanin > azadarachtin, nimbin. Kumar *et al*. (2007b) found in a soil-incubation experiment that the meliacins content in neem oil directly affected the nitrification-inhibition. Among neem-oil components, coating of prilled urea with meliacins proved beneficial over the other neem oil components – FFA, pure oil, saturated and unsaturated fractions – especially in respect of growth, yield attributes, grain and straw yields, agronomic efficiency and apparent N recovery in lowland rice. Across all the neem-oil components, a coating thickness of 500 mg/kg on to prilled urea was sufficient to realize the higher yield and NUE of lowland irrigated rice (Kumar *et al.*, 2011).

In order to develop a product from neem, collaborative efforts were made by scientists and industry (Devakumar, 2016). Division of Agronomy, IARI, first developed neemcake-coated urea using coal tar solution in kerosene (1 kg in 1 litre, enough for 100 kg urea) as sticker to hold the finely powdered neemcake. This technique could not go to the industrial level due to high requirements of neemcake; a factory producing 1,000 tomes urea per day would need 200 tonnes of neemcake per day (Prasad *et al*., 2002). Production of (bulky) neemcake-coated urea in factories required 0.1–0.2 tonne neemcake per ton urea, which involved lots of transport and application costs and hence could not be used by the farmers eventually. Quality assurance of the neemcake-coated urea is another problem. As an alternative of neemcake, use of 0.5–5.0 kg neem-oil per tonne urea can serve the purpose and may be used successfully for coating of urea. Also, the Indian fertilizer industry was poised to take up neem-oil-coated urea(NOCU) as a value-added fertilizer and the Government of India was interested to formulate quality standards for NOCU. Considering the advantages of NOCU, the Government of India wanted to include it in Fertilizer Control Order (a government document which contains the specifications of fertilizer materials) and then subsidize its price to the farmers. Research has shown that coating of prilled urea (PU) with 1,000 mg neem-oil/kg PU was a better source than uncoated PU or PU coated with higher concentration of neem-oil, i.e. 2,000 mg neem-oil/kg PU (Kumar *et al.,* 2011). Suri (1995) developed primary equipment for coating urea prills with neem emulsion on the conveyer belt carrying prills from the prilling tower to the storage unit. Suri *et al*. (1998) reported improving urea storage and handling quality including anti-caking by coating of urea with a neem microemulsion. A technique involving neem-oil microemulsion was then developed at the IARI and patented (Saxena *et al*., 2003) for coating urea, and this technique was tested at KRIBHCO's Hazira plant (Suri *et al*., 2000) and later at Shriram's Kota plant. Recently, Government of India has allowed the urea manufacturers to convert their entire urea production as neem coated urea (GoI, 2015).

Thus, persistent efforts of agronomists to translate research into practice, the support of chemists to identify the active constituents of neem and efforts of the fertilizer industry to develop a scalable technology for the neem-coated urea product have resulted in the launching of the neem-coated urea in India. Policy support of the Government of India to make neem-coating mandatory for urea

Table 1. Grain yield and apparent nitrogen recovery (ANR) increase by using neem-coated prilled urea products in rice under different field studies conducted at Indian Agricultural Research Institute (IARI), state agricultural universities and at farmers' field

Neem-coated prilled urea products	Coating thickness	Place of field study (rice)	Increase in grain yield over prilled urea alone (%)	Increase in ANR[a] over prilled urea alone (%)	References
Neemcake-coated urea	200 g neemcake powder/kg urea	[b]IARI Research Farm	5.4	15.2	Prasad and Prasad (1980)
Neemcake-coated urea	200 g neemcake powder/kg urea	IARI Research Farm	14	19.4	Sharma and Prasad (1980)
Neemcake-coated urea	200 g neemcake powder/kg urea	IARI Research Farm	No increase	13.5	Prakasa Rao and Prasad (1982)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	36	Not reported	Prasad *et al.* (1998b)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	7.5	Not reported	Prasad *et al.* (1999b)
Pusa neem microemulsion- coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	12-13	Not reported	Prasad *et al.* (2001)
Neem oil emulsion-coated urea	0.5 kg neem-oil/tonne urea	Farmers' field IARI Research Farm	6-12 7.7-10.9	11.75	Shivay *et al.* (2001)
Pusa neem microemulsion-coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	4.5	5.6	Singh and Shivay (2003)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	Not available	8.2	Kumar and Prasad (2004)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	11.9	Not reported	Kumar *et al.* (2007a)
Neem-oil coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	12.5	22.7	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	1.0 kg neem-oil/tonne urea	IARI Research Farm	15.7	27.7	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	5.0 kg neem-oil/tonne urea	IARI Research Farm	15.1	15.5	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	0.5 kg neem-oil/tonne urea	PAU Ludhiana Research Farm	5.6	6.7	Thind *et al.* (2010)

[a]Apparent Nitrogen Recovery (ANR) = 100 [N uptake in N treatment (kg/ha)–N uptake in control (kg/ha)] / Amount of nitrogen applied (kg/ha).
[b]Indian Agricultural Research Institute, New Delhi, India.

production and setting in place the quality standards through the FCO have made it possible for wide use of this technology. Government allowed fertilizer firms to produce 100% neem-coated urea – a move aimed at helping farmers boost income and reducing subsidy bill by up to Rs 6,500 crore (Business Standard, 7 January 2015). The Government of India on 12 May 2003, issued a notification indicating FCO Amendments to include specifications of neem-coated urea to be produced by M/s National Fertilizers Ltd. (NFL). However, it was clarified that Government of India has decided to permit all the manufacturers who wish to manufacture neem-coated urea at their factories (Baboo, 2014).

Other natural product, Karanjin, from *karanja* (*Pongamia glabra*) etc. has been tested for its efficiency as nitrification inhibitor (Sahrawat *et al*., 1974). However, due to lack of extensive field evaluations and a product suitable for field application, this material has not found favour with our farmers.

IRON PYRITES

Iron pyrite is chemically known as iron disulphides (FeS_2) and is commonly called as '*fool's gold*'. Large quantity of iron pyrite (22% S) deposit is found in Bihar and is used to reclaim alkaline soils (Verma and Abrol, 1980). Furthermore, it is used to overcome S deficiency which is widespread in the country (Biswas *et al.,* 2004).

For the first time, Blaise and Prasad (1993) reported nitrification-inhibitory activity of iron pyrites. However, significant nitrification inhibition comparable to the commercial nitrification inhibitors was observed at high rates of application (Blaise *et al.,* 1997). Besides the nitrification inhibition, pyrites retarded NH_3 volatilization from fertilizer urea (Blaise and Prasad, 1995; Blaise *et al.,* 1997). In separate laboratory experiments, Reddy and Sharma (2000) and Shivay *et al*. (2005) reported reduction in NH_3 loss by mixing urea and pyrite compared to urea alone. Mixing 1 part of urea with 4 parts of pyrite brought down NH_3 loss from 29.3 to 14.5% of the applied fertilizer-N (Fig. 2). Reddy and Sharma (2000) also observed mixing urea with pyrites increased the apparent N recovery of sunflower in a pot culture experiment.

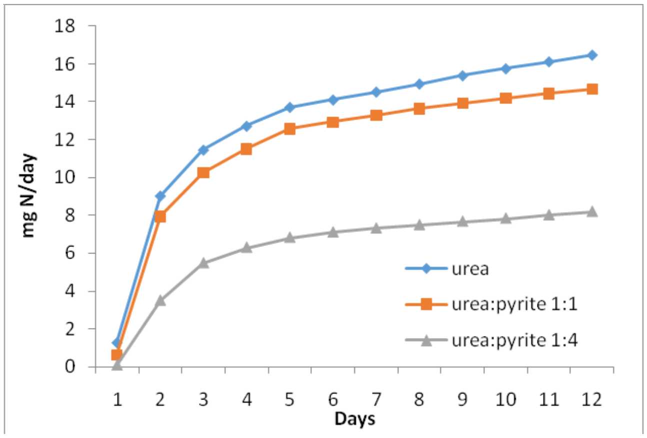


Fig. 2. Effect of pyrite on NH_3 loss from urea Source: Adapted from Shivay *et al*. (2005)

Most of the urea fertilizer is broadcast applied, in the country, especially to the grain crops grown at close row spacing. When urea is broadcast applied, potential for NH_3 loss is the highest. Under such situations, mixing urea with pyrite and broadcast application lowers the potential for NH_3 volatilization (Fig. 3). Placement is the best option compared to surface broadcast or incorporation. The acidity produced on oxidation of pyrites remains within the vicinity of the urea with the placement method of urea-pyrite mixture (Blaise *et al.,* 1996b). On the other hand, when the mixture is incorporated into the soil, there is a possibility of physical separation. Besides retarding NH_3 loss, iron pyrites reduces denitrification losses under waterlogged conditions (Blaise *et al.,* 1996a).

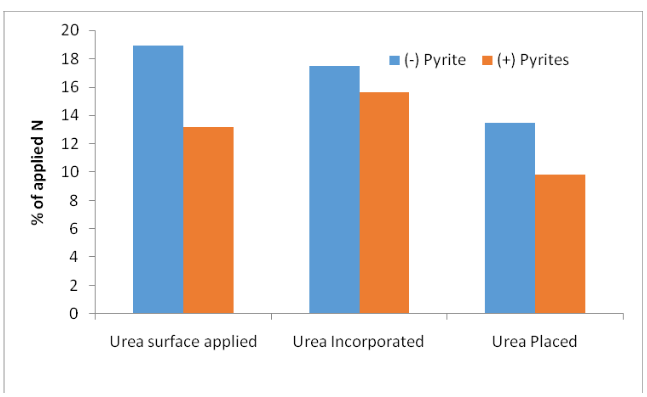


Fig. 3. NH_3 loss from urea as influenced by method of application and pyrite addition (Source: Adapted from Blaise *et al.,* 1996b)

Most of the commercially available nitrification inhibitors enhance NH_3 volatilization loss due to accumulation of NH_4^+ (Prasad and Power, 1995). On the other hand, iron pyrites have a dual advantage: *(i)* nitrification inhibition and *(ii)* NH_3 loss reduction. Pyrites on oxidation produce H_2SO_4 which prevents the rise in *p*H in the urea microsite and favours high exchangeable NH_4^+ concentration. Similarly, elemental S inoculated with *Paracoccus verutus* with urea was reported to reduce NH_3 loss ranging from 3.8 to 46.4% in the sandy calcareous soils of the United Arab Emirates (Soaud *et al.,* 2011). However, elemental S is quite expensive and iron pyrites can be considered as a cheaper alternative. Furthermore, it can be used in organic farms wherein commercial nitrification or urease inhibitors may not be acceptable. The dual advantage of pyrites, inhibiting nitrification and reducing NH_3 volatilization, can be achieved only with a high level of application (Blaise *et al*., 1997).

Pyrites hold promise for increasing NUE in Indian agriculture. However, more field evaluations are necessary to confirm their efficacy. Considering the bukiness of the product, further efforts are required to develop a usable product of iron pyrites-urea and perhaps, its use is easy in the geographical regions of its availbility. Logistical and economic evaluation by the industry in collaboration with scientists may help to bring this product to field use.

ESSENTIAL OILS AND THEIR BY-PRODUCTS

Essential oils are obtained by steam distillation of aromatic plants; a wide variety of aromatic crops are grown in different parts of India (Prakasa Rao, 2009). Essential oils have a variety of applications in perfume, fragrance and pharmaceutical industries. Basically, essential oils contain terpene compounds which are responsible for their activity. A number of terpenes such as menthone, isomenthone, carvone, thymol, terpene, puleagone etc. present in essential oils were found to posses antimicrobial properties (Patra *et al*., 2001).

Patra *et al.* (2002) evaluated the performance of 2 natural products, *Mentha spicata* oil and Nimin® (tetranortriterpenoids), an alcohol extract of neem (*Azadirachta indica*) cake as nitrification inhibitor in comparison with DCD as coatings on prilled urea for their performance in Japanese mint (*Mentha arvensis*) (Table 2). The natural products significantly increased the herb and essential oil yield of mint compared to prilled urea and were found as effective as DCD.

Kiran and Patra (2002) compared the nitrification inhibition potential of DCD coated urea, *Mentha spicata* oil, dementholised oil (DMO) and terpene-coated urea and their performance in wheat. Significant increase in grain and straw yield, N uptake and apparent N recovery, was

Table 2. Influence of different treatments on dry-matter yield, N accumulation, apparent N recovery in Japanese mint

Treatments level of N (kg/ha)	Coating material	Dry-matter yield (Mg/ha)	N uptake (kg/ha)	Apparent N recovery (%)
Control (0)	-	5.48	87.64	-
100	None	7.53	120.4	32.76
	MS oil	8.01	128.2	40.56
	Nimin	8.73	140.0	53.06
	DCD	9.88	161.1	73.46
200	None	9.90	135.01	23.72
	MS oil	11.86	166.0	39.21
	Nimin	12.82	192.3	52.33
	DCD	16.24	227.4	69.88
300	None	10.58	148.6	20.31
	MS oil	12.09	185.3	32.54
	Nimin	12.63	209.5	40.62
	DCD	12.49	212.9	41.75

MS, *Mentha spicata*
Source: Patra *et al* (2002)

observed with the application of the natural materials. All the 3 coating materials retarded nitrification of urea applied to soil significantly, throughout the growth period of wheat as compared to DCD-coated urea as well as uncoated urea. Apparent N recovery in wheat with the application of these materials was 39.61, 37.27 and 32.3% with DMO, *Mentha spicata* oil and terpene, respectively.

Patra *et al*. (2002) in laboratory and greenhouse experiments observed that *Artemisia annua* had both urease and nitrification-inhibitory properties. Ethanol extract of *Artemisia annua*, a natural source of artemisinin, a herbal precursor of anti-malerial drug, acts as both nitrification inhibitor and urease inhibitor. Field experiments to evaluate the relative performance of *Mentha spicata* oil and *Artemisia annua* oil in comparison with DCD have shown increased fertilizer-use efficiency in Japanese mint (*Mentha arvensis*) and succeeding crop of Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson] (Kiran and Patra, 2002). The nitrogen-use efficiency was in order of *Artemisa annua* oil-coated urea > DCD-coated urea > uncoated urea.

De-mentholized oil is a by-product in mentha oil industry where menthol is the main product. Greenhouse and field experiments were conducted to elucidate the nitrification-inhibitory properties of mint oil and DMO (Patra *et al.*, 2001). The DMO has been observed to enhance the nitrogen-use efficiency in rice and wheat by 30-55% indicating that more economical urea products could be developed for their agronomic efficiency. Studies to evaluate the performance of raw medicinal and aromatic plant materials (*Mentha spicata, Artemisia annua*) in comparison with Nimin® and DCD have shown that these materials significantly increased the herb and essential oil of *Mentha arvensis* and N-use efficiency (Kiran and Patra, 2003).

Thus, the research has thrown open some possibilities of utilizing raw matrials of some medicinal and aromatic plants, essential oils and their products and by-products for inhibition of nitrification of urea in soils and for increasing NUE. Extensive agronomic evaluations of such materials in diverse agro-climatic regions and crops, economic formulations, product development to suit field applications are needed to utilise these natural products in agriculture.

CONCLUSION

Future for the use of indigenous materials for improving NUE in Indian agriculture holds a great promise considering the success story of neem-coated urea. However, consistent efforts in the following areas are needed to exploit the benefits of indigenous materials for higher NUE in agriculture:

- Fundamental research to isolate and characterize active consituents of promising plant/animal materials
- Agronomic evaluation of identified materials following uniform protocols of experimentation in diverse agro-climatic regions and crops/ cropping systems
- Meta-analysis of field data from such studies to derive region / crop-specific recommendations to facilitate product launch
- Product development and industrial upscaling through scientists-industry collaborations
- Policy support by government
- Role of media and extension agencies in propagation of technologies
- Screening of indigenous materials for enhancing N-use efficiency

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4th International Agronomy Congress (November 22–26): 69–73 (2016)

Precision pressurized irrigation systems for higher water productivity in rice

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INTRODUCTION

In Asia, which supports about 60% of the world's population, food security is challenged by increasing food demand and threatened by declining water availability. Rice is the most important staple food in Asia even today and provides on an average 32% of total calorie intake. In Asia, more than 50% of all water used for irrigation is for rice. In Asia, about 55% of the rice area is irrigated and accounts for 75% of the global rice production.Tuong and Bouman (2003) estimated that by 2025, 2 million ha of Asia's irrigated dry season rice and 13 million ha of its irrigated wetland rice may experience "physical water scarcity" and the rest of the approximately 22 million ha of irrigated dry season rice in South and Southeast rice may suffer from "economic water scarcity". However, to keep up pace with the population growth, income induced demand for food and changing dietary preferences in most low-income Asian countries, it is estimated that rice production has to be increased by 56% over the next 30 years (IRRI, 1997). Thus, Asia's present and future food security depends largely on the irrigated rice production system. However, the water productivity of rice is low, and growing rice requires large amount of water. The rice growers believe that it requires standing water during the growing season to maximize yields. This practice results in seasonal water inputs for lowland flooded rice that may vary from 1650 to 3000 mm depending upon soil texture and climatic conditions (Tuong and Bouman, 2003) with on-farm irrigation efficiencies ranging between 23 and 70% (Kijne and Kuper, 1995).

Presently, the sustainability of irrigated rice production is threatened by global "water crisis". The reasons for this are diverse and location-specific, but include decreasing water quality (chemical pollution, salinization), declining water resources (e.g., falling groundwater tables, silting of reservoirs), and competing demand from urban and industrial sector. Because of the increasing scarcity of water, the costs of its use and resource development are increasing as well. For food security and livelihood of rice producers and consumers, it is essential to ''produce more rice with less water'' (Bouman *et al*., 2007). Reducing water input in rice production can have high societal and environmental impact if the water saved can be diverted to areas where competition is high. A reduction of 10% in water used in irrigated rice would free-up 150,000 million m^3, corresponding to about 25% of the total fresh water used globally for non-agriculture purposes.The scientists and rice producers are keen to produce more rice with less water by water saving technologies and for higher water productivity.

How much water does rice use?

Many people ask the question, "how much water does it take to produce 1.0 kg of rice?." The answer to this question lies in the definition of "water use" and of "rice." Unlike other upland irrigated dry crops, low land rice uses water in three ways – through transpiration losses from plant surfaces, free water evaporation from standing water layer, and combination of seepage and percolation losses at the field level. Pot experiments and greenhouse studies at the IRRI revealed that rice plants grown under a range of water applications transpired 500 –1,000 liters of water to produce 1 kg of rough (unmilled) rice. According to Mom (2007), the estimated water use in the form of ET of all rice fields in the world is estimated at some 859 Km^3/year. Thus with a global rough rice production of around 600 million tons, it takes an average of 1,432 liters of evapotranspired water to produce 1 kg of rough rice. Further, rice field water use to account for ET, seepage & percolation, on an average about 2500 litres of water need to be supplied irrespective of the source *viz.,* rainfall and/or irrigation to a rice field to produce 1 kg of rough rice (ranges from 800 to 5000 litres) (Bouman, 2009).

The field experiments at Rajendranagar, P.J.Telangana State Agricultural University (PJTSAU), indicated that the seasonal water requirement ha^{-1} of low land rice, SRI and drip irrigated aerobic rice was 1670 m^3, 1260 m^{3}and 771.6m^3, respectively (Fig. 1). A comparison of water requirement of lowland flooded rice and aerobic rice system clearly showed that surface drip irrigated aerobic rice system can save about 38.7 to 53.8 per cent of water. Zimmerman (2011) reported that drip irrigated rice used 3205 m^3 ha^{-1} less water than flooded paddy rice system. Sprinkler irrigation to replace evapotranspiration losses in rice reduced water use by 30–70% (Humphreys *et al.*, 1989). The microsprinkler irrigated aerobic rice saved 63 – 78% of water as compared to seasonal water use under flooding (1900 mmha^{-1}) (Gurusamy, 2010).

The savings, of course, dependon the soil and environmental conditions, and the attainable on-farm irrigation efficiency. The typical attainable field irrigation application efficiency for different irrigation methods that assumes irrigations are applied to meet the crop need were reported to vary from 85 to 90% per cent for surface and subsurface drip and 65 to 75 per cent for sprinkler (Keller and Bliesner, 2000) in comparison to 30 to 62 per cent for conventional surface gravity irrigation systems.

Water saving technologies in rice

Tuong *et al*. (2004) and Humphreys *et al*. (2004) have reviewed a number of rice production systems that are designed to reduce water use and increase water productivity. These systems include continuous soil saturation, alternate wetting and drying (AWD) irrigation, ground cover systems, internal drainage, SRI, aerobic rice system, furrow irrigation, rice cultivation on raised beds, controlled irrigation technology and non-flooded mulching cultivation. It was reported that SRI and AWD systems have high water productivity with a water saving of 20% without any compromise on crop productivity. However, water requirement of these production systems is also very high as land preparation consists of soaking, followed by wet ploughing or puddling of saturated soil. Further, when standing water is kept in the field (5–10 cm) during crop growth in SRI and AWD, large amount of water (about 15–20%) is lost through seepage and percolation depending on the soil texture. Every drop of water received at the farmer's field by way of rainfall, surface irrigation or pumped from aquifers, is valuable and needs to be used effectively.

These novel methods of water management are effective in reducing water use, mainly from a reduction in losses from deep percolation and from excessive evaporation, but there are constraints to their use such as increased costs, the need for precise control over the irrigation water and some loss in grain yield (Tuong *et al*., 2004). While many studies have shown that flooding is not necessary to maintain high grain yield in rice (Tuong *et al*., 2004), the grain yield decreased when soil water content was below saturation as rice appears to be sensitive to water supply. Under declining soil moisture (measured as % of the available soil water), most of the crops maintain transpiration up to 30% of available soil water after which the rate declines from around 70% of available soil water (Lilley and Fukai, 1994). More information is needed on the response to rice to changes in the supra optimal water supply of the conventional flooded system.

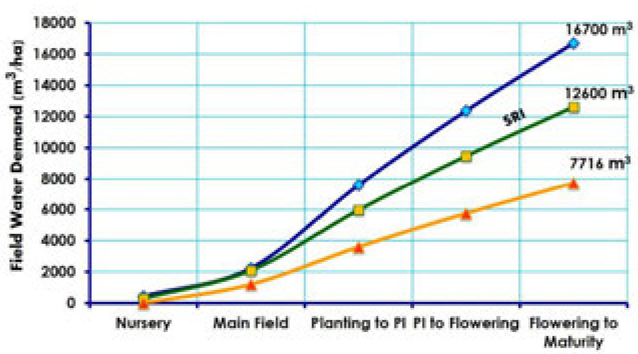

Fig. 1. Field water use in low land, SRI and surface drip irrigated rice

The rice production system combined with overhead sprinkler systems and microirrigation systems (surface & subsurface and microsprinkler systems) without constant standing water innon-puddled soils, referred to as 'aerobic rice'production systemis considered to be one of the most promising technologies in terms of both water saving and water use efficiency (Humphreys *et al*., 2004; Medley & Wilson, 2008; Vories *et al.,* 2010) and suitable for water scarcity rice growing regions of the world. However, attempts to reduce water in rice production system may result in yield reduction and may threaten food security in Asia. Reducing water input for rice will change the soil from submergence to greater aeration. These shifts may have profound – and largely unknown – effects on the sustainability of the lowland rice ecosystem. Our challenge is to develop socially acceptable, economically viable, and environmentally sustainable novel water saving technologies that allow rice production to be maintained or increased

Drip and sprinkler irrigated aerobic rice

Rice has long been believed that to be an aquatic plant, or at least a hydrophilic one. Evidence shows this view to be incorrect. The studies by International Water Management Institute (IWMI) indicated an evidence on this relationship. A fundamentally different approach to reduce water inputs in rice is to grow like an irrigated-dry upland crop, such as wheat or corn using modern irrigation systems (WTC, 2012). Some of the specific benefits of using modern sprinkler and drip irrigation systems in aerobic rice cultivation compared to lowland flooded rice are:

(a) Potential savings in water due to increased beneficial use of available water – Irrigation water requirements are generally less with sprinkler, surface and subsurface drip irrigation of rice than with conventional continuous submergence and systems of rice intensification owing to partial wetting (irrigation of small portion of soil), elimination of seepage (S) and percolation (P) losses and reduced irrigation irrigation runoff from the field (Medley and Wilson, 2008). The savings, of course, depend on the soil, environmental conditions, and the attainable on-farm irrigation efficiency.

(b) However, sprinkler irrigation is subjected to water loss by wind drift, increased evaporation, or poor application uniformity, especially with strong winds.

(c) Higher capacity to capture the incident rainfall in the soil profile during the crop growing season due to higher infiltration of water in to an unsaturated soil since there is no standing water in the field (Praveen Rao, 2009).

(d) Direct seeding in dry soil eliminates completely water required for wet land preparation (puddling) and soil compaction problems enabling successful cultivation of crops in rice fallows adopting conservation tillage practices (WTC, 2012; Vories *et al.,* 2010).

(e) Controlled high frequency water application at a predetermined amounts (i.e., according to daily water needs of rice) and at constant rate maintains high soil water potential (low soil water suction) in the crop root zone with the elimination of wide fluctuations in the soil water content (Eissa *et al.,* 2010).

(f) Drip irrigation has the potential for reducing high electricity bills/energy costs due to reduced water pumping hours owing to higher on-farm irrigation efficiency i.e., increased beneficial use of water balance components; savings in operational labour costs from not constructing and destroying levees (Vories *et al.,* 2010), automation and simultaneous application of water, fertilizer etc.

(g) Easier harvests due to quicker drying of soil and not having to work around levees.

(h) Maintaining dry foliage, which retards the incubation, development and spread of many plant pathogens); less incidence of brown plant hopper and sheath blight incidence was reported in drip irrigated rice.

(i) Drip irrigation offers considerable flexibility in fertilizer application (Praveen Rao, 2009; Kumar, 2011). Besides fertilizer, other crop protection chemicals such as herbcidies (Ginevskii and Zayats, 1988), insecticides (Schwankl and Prichard, 2001), fungicides (Olsen *et al.,* 1987), and air can be injected through drip to improve rice crop performance.

(j) Reduction (about 50-times) in bioaccumulation of arsenic in rice kernels (Spanu *et al.,* 2012). Additionally, Kallenbach *et al.,* (2007) reported that conversion to subsurface drip irrigation has the potential to reduce greenhouse gas emissions.

(k) Cultural operations such as seeding, harvesting, spraying etc., can be highly mechanized owing to dry soil surfaces (Huaqi *et al.,* 2003).

(l) Drip irrigation due to its ability to maintain higher soil water potential (or low soil water tension) in the crop root zone reduces the sensitivity of rice to salinity in soil and water. Additionally, micro-leaching reduces the concentration of salts in the root zone by moving the salts away from the root zone to the edges of the wetted perimeter (Praveen Rao, 2009).

Despite observed successes and possible field advantages, some limitations/problems have been encountered with sprinkler and drip irrigation systems. These include vulnerability to wide spread non-availability of specific varieties to suit drip irrigated aerobic rice farming situations, vulnerability of drip emitters to clogging, lack of skill and operational constraints among small and marginal rice growers, higher system costs, micronutrient (Fe & Zn) deficiencies, increased root-knot nematode populations and termite attack (Kreye *et al.,* 2009; WTC, 2012).

Sprinkler irrigated rice

Several studies evaluated the feasibility of sprinkler irrigation in rice (Westcott andVines, 1986) using commercial rice cultivars recommended for lowland flooded cultivation. Irrigation water requirements were 20–50% less than in flooded rice, depending on soil type, rainfall, and water management. The drought-resistant rice cultivars produced similar yields under both (flooded & sprinkler) conditions, but their yield levels were much lower (5–6 tons/ha). Highest yielding cultivars (producing 7–8 tons/ha under flooded conditions), however, had yield reductions of 20 – 30% compared with flooded rice.

The successful cultivation of rice with supplemental sprinkler irrigation to minimize the effect of dry spells was reported from Brazil by Stone *et al.* (1990) with traditional upland varieties which resulted in high yields but with great variation among experiments, due mainly to lodging. Moreover, production costs per kg of grain were 138% higher than the conventional upland system, and only 4% less than the irrigated system. These studies emphasized the need for a new system of aerobic rice with improved varieties with lodging resistance, harvest index, and input responsiveness. Subsequently, the new aerobic rice varieties developed over 2-decades breeding programme were well adapted to the sprinkler irrigated system, achieving yields greater than 5 – 6 tons/ha, making this system economically competitive. Alteration in plant type brought about a change in crop management practices (viz. row spacing of 20 cm and 90 kg N/ha (Stone and Pinheiro, 1998). As the new aerobic varieties are more prone to drought stress, water has to be supplied whenever soil moisture tension in the top 15 – 30 cm of soil varies between 25 – 30kPa.

The area in the savanna region covered by center pivot sprinkler system now amounts to 300,000 ha, and the aerobic rice area under this system continues to grow (Pinheiro *et al.,* 2006). Vories *et al.* (2010) reported comparable rice yields of 9.7 and 10.1 tons/ha for center-pivot irrigated and flooded rice on a producer's field in Arkansas, respectively. Total pesticide, fertilizer, and estimated irrigation, costs were $817/ha and $601/ha for the conventional flood and centrepivot fields, respectively.

Drip irrigated rice

Drip irrigation and fertigation of crops is now widely recognized as one of the most efficient methods of watering crops (Ayars *et al.,* 2007) and it represents a definite advancement in irrigation technology. Drip and microsprinkler irrigation systems apply water slowly on or below the soil surface as discrete or continuous drips, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line adjacent to the plant row (ASAE, 2001).

The drip irrigation technologies are primarily promoted as means to save water in rice culture and to avert the water scarcity crises (Farooq *et al.,* 2009). At Madurai, in sandy clay soil, drip irrigation scheduling equivalent 150% evaporation replenishment from USWB Class A pan evaporimeter (PE) produced a grain yield of 5.62 t/ha (Annual Report-AICRP WM, 2008). Another advantage of the drip irrigation could be through the use of chemigation, applying nutrients and insecticides directly to the rootzone through the subsurface drip irrigation system (Zimmerman, 2011). Thus, when drip irrigation at 150% PE was supplemented with fertigation of 100% recommended dose of fertilizer improved the rice yield to 6.77 tons/ha. On the other hand irrigating the crop at 100% PE had detrimental effect on the crop performance and reduced the yield by 39.4% (Annual Report-AICRP WM, 2008).However, the grain yields between drip irrigation regime @ 200% PE and flood irrigation five days after disappearance of ponded water were comparable (Vijayalakshmi, 2010). Similarly, rice yield was comparable between surface irrigation of 5cm once in 3 days and microsprinkler irrigation at 200% PE (Gurusamy, 2010). The subsurface drip-irrigation appears to be a valid alternative to conventional flood rice culture based on water savings and yield. However, factors that may affect the commercial viability of this system include system costs, tillage practices, long-term stability of the dripperlines, and rutting during harvest (Ottis *et al.*, 2006). Benefits of such a system included the elimination of levees, elimination of airplanes for pesticide and fertilizer applications, and substantial water savings. However, response of rice to drip irrigation and fertigation varied with variety (Zimmerman, 2011). At St. Croix, USVI in dry season with drip irrigation 'Cybonnet' and 'Neptune' varieties produced similar or better yields than flood irrigation. On the other hand, the variety 'Bengal' produced more rice under the flooded paddy system then the drip irrigation.

CONCLUSION

It is clear that the pressurized microirrigation systems not only save water in rice production systems but also contribute to higher productivity,cost effectiveness and higher energy use efficiency compared to conventional irrigation methods.These modern technologies have to be popularized for wider application towards sustainable rice productivity.The present policies like PMKSY(Pradhan Mantri Krsihi Sinchayee Yojana) at country level and some state level policies like Telangana State Micro Irrigation Project (TSMIP) are aimed to address higher water productivity in agriculture. However, the twin challenges of "*present water scarcity*" and "*future competing demands for water" calls* for a country level Policy with *Mission Mode Project on Higher Water Productivity in Rice Production Systems* with short term, medium term and long term goals, timelines and outcomes with an orientation to achieve sustainable rice productivity and for food and livelihood security of the large population in India.

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4th International Agronomy Congress (November 22–26): 74–85 (2016)

Contributions of ICAR-IGFRI in raising livelihood of livestock farmers in India

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India possesses around 513 million heads of livestock and the importance of livestock in Indian agriculture is well documented. These livestock not only provide food security through supply of milk, meat and self-employment of both men and women but also plays an important role in livelihood of resource-poor farmers. The livestock are less affected by the climate change and their growth is also higher than crop husbandry. The growth in livestock sector is also demand-driven, inclusive and pro-poor. Incidence of rural poverty is less in states where livestock accounts for a sizeable share of agricultural income as well as employment. In India livestock production system is primarily characterized by low input-low output. The livestock population is increasing and its feed requirements as well. There is an urgent need to meet the demand of increasing number of livestock and also to enhance their productivity, for which availability of feed resources have to be increased. Looking at the vast gap between the demand and supply position (Table 1), it is necessary to put adequate efforts to transfer the potential forage technologies developed by the ICAR-IGFRI and other research organizations in the country to farmer's field in order to increase the production and productivity of good-quality fodder. Moreover, grassland resources are very important in many parts of the country, especially in arid, semi-arid and hilly regions. The grasslands and grazing lands serve as major forage resource base for livestock in such regions. But on account of increasing grazing pressures, misuse and neglect, the present condition of grasslands/ grazing lands is far from satisfactory. Even there is shrinkage in area on account of pressures on lands for other activities. Hence a holistic approach is also required for grassland development. In fact, to make livestock farming economically attractive, milk/ meat production and productivity has to be enhanced. This is possible only by making available good quality fodder resources in adequate quantity from both arable and non-arable lands, since forage resources are the least-priced source of nutrients for livestock feeding.

ICAR-INDIAN GRASSLAND AND FODDER RESEARCH INSTITUTE (IGFRI)

The IGFRI, a premier institute of forage resource development in Asia, was established in 1962 to initiate organized research in the field of grasses, grasslands and fodder crops. All India Coordinated Research Project (AICRP) on Forage Crops was added in 1970 to coordinate multi-location testing programme at national level involving different agro-ecological conditions. The Institute undertakes research, extension and other developmental activities towards development of forage resources in the country. It conducts basic, strategic and applied research with the objective to enhance forage productivity, develop new cultivars and improved forage-production practices and efficient forage utilization for the benefit of millions of livestock farmers. The Institute is of multi-crop and multi-disciplinary nature, thus enabling it to have more holistic approach in targeting at quality-forage production for increased livestock productivity and sustainable agricultural development with equal concern for environment, gender and livelihood issues. Over more than 5 decades of its existence, the Institute has shown remarkable development and expertize in different areas of forage production, processing, utilization and human resource

Table 1. Demand and supply estimates of dry and green forages (million tonnes)

Year	Demand		Supply		Deficit as %	
	Dry	Green	Dry	Green	Dry	Green
2015	519.7	834.0	460.4	557.9	11.41	33.10
2020	530.5	851.3	467.6	590.4	11.85	30.65
2025	549.3	881.5	483.8	638.9	11.92	27.52
2030	568.1	911.6	500.0	687.4	11.98	24.59

Source: IGFRI-Vision 2050

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development. Indeed, the journey of institute since its inception can be divided into few phases (Singh *et al.*, 2013).

Phase I (1962–75): An era of establishment and research initiatives

Recognition of the importance of grasses and fodders in the agricultural economy of country, the widening gap between supply and demand of forage necessity for animal production, the diversity and complexity of the problems and the inadequacy of existing organization undertaking such studies at that time, led to the realization of the need for establishment of the IGFRI. Shri P.M. Dabadghao was appointed Special Officer and the institute was established covering an area of 575 ha at the Livestock-cum-Agricultural Farm, Bharari (Jhansi) in 1962. The first survey of grasslands of India was conducted under his able leadership and published in 1973, which revealed 5 major grass covers based on distribution and species dominance, and described as *Sehima-Dichanthium* type, *Dichanthium-Cenchrus-Lasiurus* type, *Phragmites-Saccharum-Imperata* type, Themeda-Arundinella type, and Temperate Alpine type. During that period the UNDP Project on grassland and forage development in India was in operation at the institute which also supported research activities.

Phase II (1975–85): Research, collaboration and extensions

The institute took the responsibility of formulating programme and monitoring research on all aspects of grasslands and forage crops for various agro-climatic regions. The Institute also made various research collaborations with national and international agencies. The Institute got AICRP on Forage Crops having its main and subcentre in various parts of the country. The AIRCP on Forage Crops project was charged with the responsibility of formulating technical programme and monitoring research on all aspects of forage crops at different centers in various agro-climatic regions of the country. It housed research centers of AICRP on dryland agriculture, agroforestry, under-utilized and under-exploited plants, prototype testing and feasibility and national seed project. Research collaboration at international level was started through two international projects, viz. IDRC-IGFRI Silvipasture operational research project, and PL-480 project on weed management and research on food–fodder production system.

Phase III (1985–95): New challenges in research, development and extensions

During this period (1985–95), great strides were made in research on fodder production and its utilization. But the institute was still facing serious challenges on forage production. Keeping in view the national priorities a shift was made in research areas to augment forage production from the lands which were not being otherwise utilized for other crops. The stress were laid on speedy transfer of forage-production technology as this was the only way to meet this challenge through public involvement. During the period two advance techniques *viz.*, Biotech in forage crop research and remote-sensing techniques in grassland survey and mapping, were started. For conducting research in various agro-climatic regions the Institute initiated 2 regional stations, one at Avikanagar, Rajasthan and another at Dharward, Karnataka. There was breakthrough in research, development and extension activities under different programmes. Varieties, namely 'Bundel Anjan l' of Anjan grass (*Cenchrus ciliaris*L.), 'JLP 4' of field bean (*Dolichos lablab*), 'Bundel Dinanath 2' of Dinanath grass (*Pennisetum pedicellatum* Trin.) and 'Bundel Jai 822' of oat (*Avena sativa* L.) were released for cultivation in the country. Similarly, 'JHO 829' of oat, 'IGFRI 212 1' of guar [*Cymopsis tetragonoloba* (L.) Taubert], 'Bundel Lobia I' and 'Bundel Lobia 2' of cowpea [*Vigna unguiculata* (L.) Walp.] and 'IGFRI 56 2' and 'JHP 4' of Dinanath grass were recommended for release. Projects like NMWD seed project, DST project on tissue culture and fodder in floodplain of Rapti Basin, IDRC-IGFRI project, Indo-UK collaborative research project and watershed-based programme (Tejpura and Lakara-Karari) were initiated, besides designing of NARP training course of 30 days duration for scientists/ professors. Institute organized different National Symposium/ Workshop and Third International Rangeland Congress and got international recognition as premier research institute for fodder and grassland research.

Phase IV (1995–2005): Leading grasslands and fodder research in India

The Institute concentrated its efforts for further advancing the research on evolving high-yielding disease and pest-resistant varieties of fodder crops and pasture species for different agro-climatic situations, agro-techniques for maximizing forage production for different resource areas and maximization of seed production of forage/ pasture species. Major thrust was on the biomass production from marginal and degraded lands through better management of pastures, utilizing selected plant species aiming at sustainability of the production system. The research work on post-harvest technology, and design and development of improved farm implements progressed well. Many of these refined technologies were demonstrated to the end-users for adoption. Indeed, this was a period of renaissance with the advents of modern techniques and research approaches; institute shifted its approach to multidisciplinary and farming-system mode. The divisions were reorganized from 12 to 7 multi-disciplinary research divisions. To strengthen the research in temperate and sub-temperate regions of the country, one regional station was established at Palampur in Himanchal Pradesh in addition to regional station of Srinagar (Jammu and Kashmir). During this period, institute made some remarkable achievements through satellite-remote sensing and GIS-based Grassland survey and mapping, Ram Madhi watershed development, studying of biodiversity and soil microbes associated with forage-farming system, integrated pest management, adopting biotechnological approaches for forage crop-improvement etc., besides international collaborations like Indo-UK, IGFRI-ICRA and Indo-Australia.

Phase V (2005–2015): New dimensions in research, development and extensions

This was the period when institute expanded its technologies in extreme remote areas of temperate/ alpine regions of Himalaya. Projects on Watershed development, Farming system research and Pasture development in high hills were designed and executed in such a way to sustain the livelihood support of marginal farmers and pastoral communities. The Institute together with AICRP on FC made significant inroads in developing the forage resources and released 13 improved varieties of fodder crops and grasses. Fodder improvement was taken as a part of Fodder Mission Programme in collaboration with all the stakeholders. Priority was given for development of seed standards for range grasses and range legumes, quality-seed production of range species, eco-friendly low-cost storage of forage seeds and development of seed-coating technology for yield enhancement. Studies on carbon-sequestration potential and assessment of micro-climatic changes for companion crops in tree-based alternate land-use system management were conducted. A large number of national, international and inter-institutional programmes and consortium research platforms were initiated. The Institute in collaboration with RMSI organized 23rd International Grassland Congress in 2015 and received Best Research Institite, 2015 Award from ICAR, New Delhi, for its achievements, contributions and recognitions at national and international levels.

FORAGE TECHNOLOGIES

IGFRI has developed and demonstrated many suitable technologies for maximizing forage and seed production in different agro-climatic situations and under various land-use systems, development of rangelands/ pastures and even livestock. Various post-harvest technologies and machines for fodder cultivation and their efficient utilization have been developed and popularized (Ghosh and Mahanta, 2014). These are all linked with the livelihood improvement of poor and under-privileged livestock farmers

Forage: genetic diversity and seed production

A rich diversity of germplasm (around 9,000) are being maintained at the IGFRI, Jhansi, collected through explorations and procured through germplasm exchange. More than 200 varieties of 30 fodder crops, range grasses and legumes have been released under forage-breeding and improvement programme (Table 2). Eco-friendly pest management in forages with botanicals (neem formulations) and bio-pesticides have also been developed and validated in major forage crops.

The demands of nucleus, breeder and TFL seeds of various forage species have been catered by the institute. It was observed that breeder seed production of forages was 15–20% higher than indents received from DAC during the last few years. Indeed, there was the significant increase in seed production at the IGFRI after the mega seed project came into existence. Additionally, the institute supplied/sold rooted slips of various planting materials/ forages during the last couple of years.

A large number of demonstrations on rainy season (*Kharif*) crops namely cowpea, maize (*Zea mays* L.), rice bean, sorghum (*Sorghum bicolor* L.), pearlmillet [*Pennisetum glaucum* (L.) R. Br.], and winter (*rabi*) crops,

Table 2. Forage crop variety released/ identified during the recent past

Forage	Varieties
Guinea grass	'Bundel Guinea' ('JHGG 04 1'); 'JHGG 08 1'('BG 4')
Sehima nervosum	'Bundel sen ghas 1' ('IGS 9901')
Chrysopogon fulvus	'Bundel Dhawalu Ghas 1' ('IGC 9903')
Heteropogon contortus	'Bundel Lampa Ghas 1' ('IG HC 03 4')
Oats	'Bundel Jai 991' ('JHO 99 1'), 'Bundel Jai 2004' ('JHO 2000 4'), 'Bundel Jai 992' ('JHO 99 2')
Pearl millet (Bajra)	('JHPM 05 2)

Cowpea ('BL 4') 'IL 1177'

viz. berseem (*Trifolium alexandrinum* L.), oat, lucerne (*Medicago sativa* L.) and perennial grasses, viz. NB Hybrid, *Cenchrus* spp. and Guinea grass [*Panicum maximum* B.K Simon & S.W.L. Jacobs], etc. were conducted. This brought continuity in the farmer's efforts of improving the fodder production and availability. By tapping the resources/ funds of both state and central governments such RKVY, AFDP, ATMA, state schemes etc., trainings, demonstrations, on-farm trials and participatory seed production were significantly enhanced. Indeed, during the last 5 years, the IGFRI produced and supplied 333 tonnes of breeder/TFL seed including 21.4 tonnnes of grass seed, apart from 7.5 million rooted slips to various government agencies, milk cooperatives, farmer unions, forest department, animal husbandry farms and farmers throughout the country. Moreover, 106 tonnes forage seed was produced in participatory mode from 4 states, namely Uttar Pradesh, Madhya Pradesh, Rajasthan and Bihar.

Climate-resilient forage production

Forage-production technologies for different situations have been developed for enhancing fodder production in arable lands. This includes intensive forage production for different agro-climatic situations (75–255 tonnes green fodder/ha/year), sustainable forage-production from rainfed lands (50–80 tonnes green fodder/ha/year), integrating forages in existing cropping systems, forage production technology for specific situations like under plantation crops, rice fallows and non-competitive land use and forages from acidic, salt-affected and waterlogged situations.

In non-arable lands, grassland-restoration techniques based on ecological approaches, e.g. protection for vegetation recovery, soil and water conservation, reseeding, improved range-management techniques and grazing management have been developed. Silvipasture systems have been designed and developed for optimizing land productivity, conserving plants, soils and nutrients and producing forage, timber and firewood on a sustainable basis for degraded lands under different situations. Forage-production potential of silvi-pasture in arid and semi-arid varied in the range of 2.5–3.0 and 4.0–7.0 tonnes dry matter/ha respectively. Hortipasture system, which integrates pasture (grass and/or legumes) and fruit trees, is also an alternate land-use system in arid and semi-arid regions. During the last few decades, the IGFRI has developed several technologies for higher productivity (3-5 tonnes dry matter/ha) and adopted in large scale.

Efficient feeding systems

Forage-based feeding systems have been developed keeping in mind the type of animals, species, breeds, level and stages of physiological production etc. Forage-based feeding systems sustained moderate level of growth (400 g/day) of dairy heifers and milk yield up to 10 kg/day in lactating animals providing a balanced rations of dry forages (straw/dry grass), green fodder/legume hay with minimum energy source. Methane-emission inventories have been developed for ruminant animals and it was observed that methane production (g/kg digestible dry matter) was lower (20.3–24.4) from green fodders compared to dry forages (27.67–47.37). Polymeric polyphenolic compound isolated from *jamun* ('EJ 5') also reduced *in-vitro* methane production from 35.77 to 7.51 and 23.03 to 12.26 ml/g digestible dry matter in wheat straw and oat straw, respectively. Area-specific mineral mixture for improvement in productive (19% more milk yield) and reproductive performances in dairy animals of Central India has been formulated. Protocol for organic milk production has been developed in indigenous breeds of cattle (Sahiwal, Gir and Tharparkar) with sustainable use of natural resources. Improved grazing-management practices, viz. rotational and deferred rotational, have been recommended for overall sustainability of the systems and better productive performances in animals.

Farm mechanization and post-harvest management

Several low-cost farm implements, suitable for various operations in the context of forages, have been developed. These include bullock-drawn multicrop seed drill; bullock- and tractor-drawn channel-cum-bund former, weeder-cum-mulcher, pitter discer, seed-pelleting machine, grass-seed collector, rotary-grass mower, rotary-flail mower and hay drier. A seed drill for berseem and chickory seed separator, have also been designed and developed in collaboration with the ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal. Commendable efforts were made for bailing and densification crop residues/ dry grasses, leaf meal-processing technology and cover and plinth storage system for bales. Complete feed blocks feeding increased the live weight gain (35%) and milk yield (14–15%) in animals. Improvements of low-grade forages were made through fibrolytic enzyme treatment and urea-ammoniation, and later its mechanization during threshing.

Exploitation of non-conventional forage resources

Inadequate availability of feed/ fodder resources is a major limiting factor in improving the production performances of our animals. We cannot think of meeting the nutritional requirements of animals from the kind of feed resources that are conventionally available and needs judicious exploitation of non-conventional feed resources also. There are number of non-conventional feed/ fodder resources that can supplement green herbage to ruminant animals under varied management situations. Efforts were made to improve the basket of feed resources through evaluation of non-conventional/ underutilized feed resources like azolla (humid and subhumid conditions), turnip (*Brassica rapa* var. *rapa* L.) and fodder beets (intensive management system), cactus (semi-arid and arid condition) and fodder sugarcane for their inclusion and effective utilization in animal diets (Fig 1). Under animal-feeding trials, it was observed that a substantial amount of nutrient requirements can be met through such non-conventional fodder resources to improve the productivity of animals without any adverse effects.

Impact

A huge technological pool was created recently by development of 61 varieties of forage, several forage production and protection technologies at national/ zonal levels for advancing the cause of forage research and solving various locations-specific problems in the country. These technologies have the potential to increase productivity by 10–20% and also provide better-quality fodder in less time and space. In the last five years, a total of 5,609 FTDs were conducted to popularize fodder technologies throughout the country. It generated interest among the farmers and sensitized them about fodder crops and their utility. The average yield enhancement through various technological interventions was 10–25%. The spread ratio for various interventions varied from 1 : 3 to 1 : 7. Adoption of new fodder varieties of berseem, oat, NB hybrid, Guinea, Deenanath, cowpea and *guar* in different villages of Uttar Pradesh, Madhya Pradesh, Chhattisgarh and Rajasthan helped in enhancing fodder production on their farms. It not only increased milk production but also gave 15 to 20% higher returns to farmers owing to sale of surplus milk.

UP-SCALING OF TECHNOLOGIES FOR FARMER'S WELFARE AND NEW INITIATIVES

At Bundelkhand region

Bundelkhand region of India has the largest population of poor people and it has assumed high priority for development. People of the marginalized community are now starving from hunger and are migrating from rural areas. Therefore, government is making efforts to increase the productivity of agriculture and allied activities in the region by drought mitigation and has provided Bundelkhand package, but it has not considered the lakhs of cultivators/ farmers who are dependent on livestock for their livelihood. Livestock sector is still neglected or not able to fetch the required attention to increase livestock productivity which is a major source of income generation of the farming communities.

Under various outreach programme of the IGFRI, participatory rural appraisals (PRA) were conducted and location-specific problems were identified. A multi-disciplinary team of scientists were constituted to identify the best possible solution on the basis of resources available and technologies were tailored and implemented through outreach programmmes like:

Establishment of 'Adarsh Chara Gram'

The programme was started in 3 villages, about 30 km away from the Institute, with the objective to develop a learning centre and role model for livestock communities for their overall development. The aim of this programme was to visualize the impact of forage and livestock technologies in large area at farmer's field and take farmer decision and opinion in adaptation of the technologies. The development of farming-based models for the livelihood improvement of small and marginal farmers was the

Fig 1. Cactus (*left*) and fodder beets (*right*) as non-conventional forage

key strategies. The traditional farming systems (FS) were growing crops only (FS-I), animal husbandry only (FS-II) and crops plus animal husbandry (FS-III). As an intervention, 2 new systems (FS-IV: crops + animal husbandry + fodder/fruit tree and FS-V: animal husbandry + fodder/seed production) were introduced to enhance forage and livestock production (Fig. 2 and 3). Fodder technologies like cereal–legume intercropping, round-the-year fodder production, forage on bunds, cultivation of fodder sorghum, hortiasture systems, cactus and azolla cultivation, silage preparation, urea treatment of crop residues, area-specific mineral supplementation, providing seeds of improved fodder varieties etc, besides animal health camp were introduced. Intercropping (2 : 1) of oat with berseem yielded 127.4 tonnes/ha green fodder within a span of 120 days and was found suitable for quality-fodder yields and cereal–legume mix silage making. Perennial Guinea grass-based cropping system provided scope for round-the-year fodder supply of 140–160 tonnes/ha. Perennial Guinea grass based cropping system had also positive impact on soil organic carbon restoration compared to seasonal crop-based system.

Impact

Now 20% farmers have surplus fodder and they are supplying it to cooperative dairy on payment basis. Rest of the farmers are meeting their forage requirement and saving money on purchase of wheat straw. Farmers growing fodder are earning around ₹ 2,200 to 54,000/farmer/annum through savings on purchase of concentrate, straw and green fodder, increased milk production, sale of green fodder, selling of fodder seed and rooted slips etc. Indeed, there was increase in family income from 14.2 to 41.3% under different farming systems. Interventions also led to increase in area under fodder production, number of animals and their productivity.

Interventions implemented under NICRA

National Initiative on Climate Resilient Agriculture (NICRA) project was also initiated to enhance resilience of agriculture including livestock production of Bundelkhand region to climate change and climate vulnerability through strategic research and technology demonstration. Following interventions were implemented on the basis of problems identified.

- Real-time contingency plan implementation in a participatory mode
- Rainwater harvesting (*in situ* and *ex situ*) and efficient use
- Efficient energy use and management through custom hiring

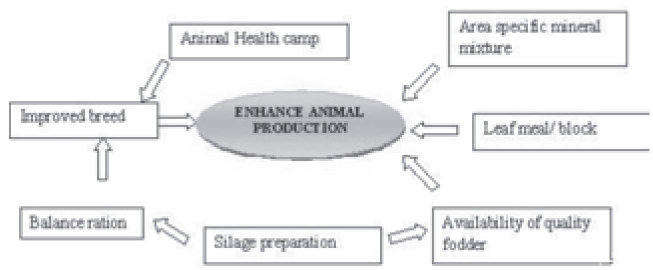


Fig 3. Model adopted to enhance animal production

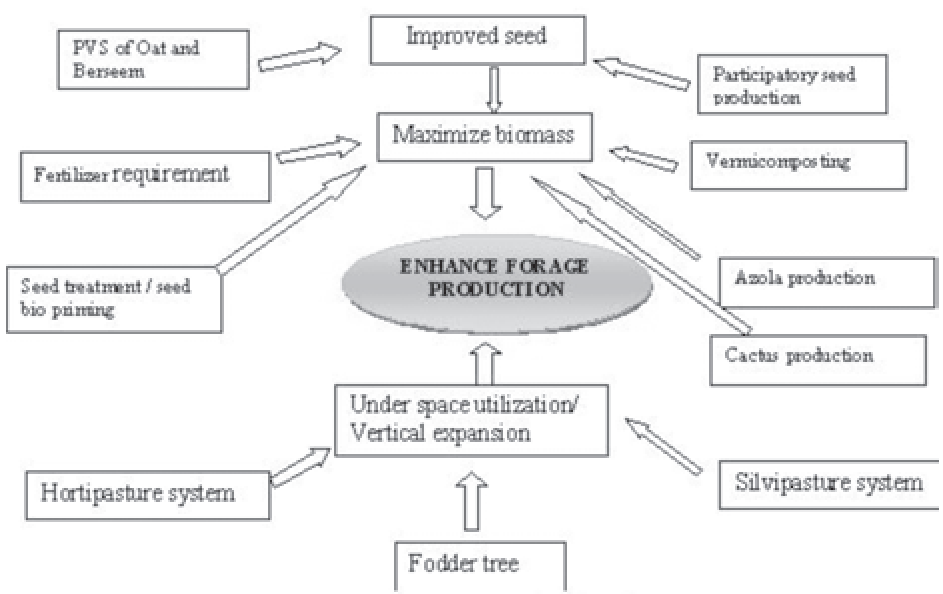


Fig. 2. Model adopted to enhance forage production

- Farming systems for alternate land use and climate resilience

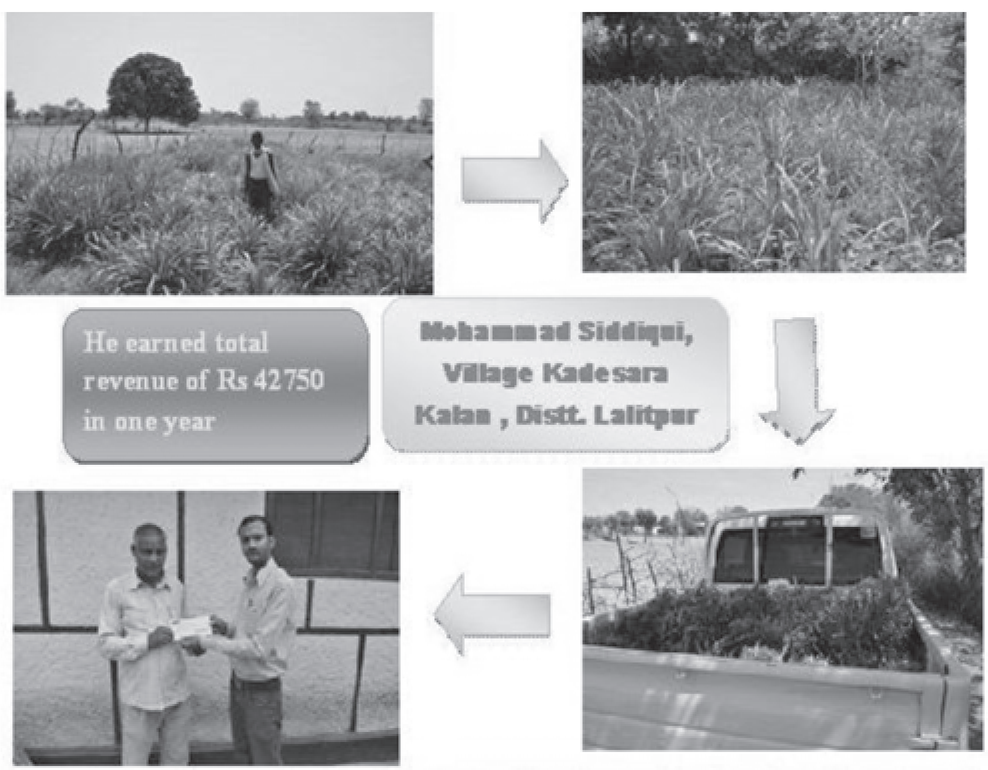
A check dam constructed in the village with catchment area of 90 ha and command area of 20 ha, brought 11.6% additional cultivable wasteland area under cultivation. It increased water-table in the wells by 10.1 feet in November and 12.0 feet in the month of May. The area under vegetable crops increased from 1.2 to 11.3% of command area. The availability of irrigation facility promoted the diversification towards pulses and other high-value crops including fodder crops and entrepreneur development. The cropping intensity improved from 116 to 248%. The overall improvement in crop productivity was 12–37%, besides increase in milk productivity in dairy animals by 11–20%. As a result, farmer's family income (per family basis) increased from ₹ 6,760 to ₹ 8,200. Entrepreneurship on forage production was also emerged (Fig. 4).

Improvement in Bhadawari buffalo

Bhadawari buffalo, the indigenous bovine queen of Chambal and the pride of Uttar Pradesh, is known for high milk fat content. This became a good source of livelihood of farming community of Bundelkhand region. But during the last 3 to 4 decades, farmers have adopted breeding of local Bhadawari with Murrah buffaloes for higher milk yield with the consequence that Bhadawari buffalo is now at the verge of extinction. Hence to conserve this breed of buffalo/gene pool, a conservation and improvement programme on Bhadawari buffalo was initiated as a ICAR-sponsored network programme. Under the programme, improved Bhadawari bulls and frozen semen were distributed/sold to various agencies (Government/Non-Government agencies/farmers) for natural mating/artificial insemination in breeding tracts to increase their population (Fig 5) and thereby increasing the livelihood of resource poor farming community.

Impact

Now buffaloes are getting inseminated in appropriate time at farmer's door; hence calving interval has been reduced. Due to reduced calving interval, farmers are getting more number of calves per animals and getting regular milk. It has improved employment generation from 71 to 176 family labour-days per year when compared to farmers with desi buffaloes. It also increased family income from ₹2,325 to ₹ 8,756, besides improvement in socio-economic attributes like health and schooling of children. Indeed, Bhadawari buffalo fits well to far-off inaccessible areas and ravines where milk procurement is difficult. Buffaloes in these areas are doing well in sustaining *ghee* making industry having longer storage-life.



Production of NB Hybrid and guinea grass nursery developed as enterprises

Fig. 4. Entrepreneur emerged with the efforts of the IGFRI, Jhansi

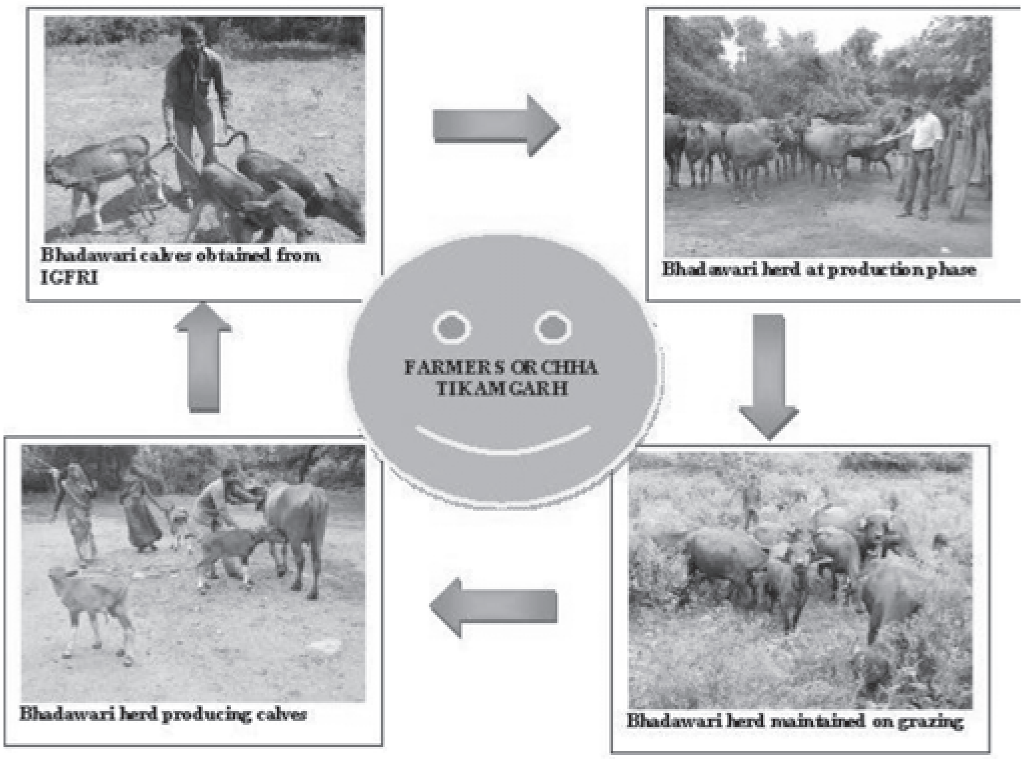


Fig. 5. Case study: Establishment of new Bhadawari herd by a farmer at Orchha, Tikamgarh

Establishment of model villages

The encouraging impact of 'Adarsh Charagram' led upscaling those activities in other villages of Bundelkhand region. The IGFRI constituted different interdisciplinary teams, comprising of 3 to 4 scientists to select villages and implement livelihood-improvement activities under model village programme. These teams selected totally 60 villages, spread across 3 districts of 2 states. In Jhansi district of Uttar Pradesh, 32 villages, the highest number, were selected and 28 villages belonged to Datia (23) and Tikamgarh (5) districts of Madhya Pradesh. Activities related to improvement of livestock, fodder production, women empowerment, forage-seed production and income generation etc were taken up. The impact of these activities was perceived as very good.

Farming system-based interventions such as integrated crop-management package, round-the-year forage-production systems, forage on bunds, balanced ration, use of farm machinery and women-friendly drudgery-reducing tools, processing and value-addition etc. increased the productivity, profitability and employment opportunities in adopted villages. There was 8.33% shift towards farm-level diversification, specifically on crop + animal husbandry to avoid the risks and vulnerabilities in adopted villages compared to only 3.33% in non-adopted villages. Demonstration of improved farm machinery and implement conducted in villages reduced seed rate with better germination and there was horizontal transfer to more than 500 ha area of wheat sown with seed-cum-fertilizer drill in the adopted villages. Awareness regarding the importance of area-specific mineral mixture among the farmers was created through demonstrations-cum-trainings. Progressive farmers are now providing area-specific mineral mixture supplement to their livestock. Farmers have benefitted in terms of better productivity and health of animals.

At National level

The centres of theIGFRI and AICRP on Forage Crops, Centres located in different states are actively collaborating with line departments of respective states to popularize various fodder technologies, conductance of farmers trainings, forage-technology demonstrations and participation in trainings programme which have created huge impact and awareness among various stakeholders about fodder technologies. Moreover, following outreach programmmes were also implemented at national level for improvement of forage and grassland production, leading to improvement in farm income/ livelihood.

National initiative on fodder-technology demonstration through 100 KVKs

Realizing the crux of the problem of forage shortage in every region, there was necessity of launching systematic and comprehensive FTDs for whole country. Accordingly, a National Initiative on Fodder Technology Demonstration (NIFTD), in a mission mode, was taken up for acceleration of fodder production in different parts of the country. The programme addressed issues of fodder-seed production, area expansion of green fodder, fodder conservation and efficient utilization, establishment of fodder seed bank at various locations, capacity building and extension. In fact, it was a combined effort of the IGFRI, Jhansi and SMD (Extension), ICAR, New Delhi and 100 Krishi Vigyan Kendras (KVKs) under 8 ATARIs.

A meticulous technical programme was prepared after making a detailed discussion with all stakeholders (KVKs, ATARIs and IGFRI scientists) and executed. In all 8 zones, around 9,000 kg improved varieties fodder seed was provided to farmers through selected KVKs during *kharif* and *rabi* season. More than 3,000 demonstrations were made on fodder/ seed production and fodder conservation and utilization technologies over the farmer's fields. The farmers were found very enthusiastic about fodder yield and support made by concerned KVK personnel. To record the progress and for guidance of farmers, a team of scientists from KVKs and IGFRI regularly visited the farmers' fields. The progress was found highly satisfactory. It was found that there was a huge demand for improved fodder technology and fodder seed. The farmers have adopted the different technological modules under NIFTD enthusiastically. The fodder output from the cowpea ('Bundel Lobia 2') ranged from 350 to 400 q/ha and for oat ('JHO 822'), the output as green fodder ranged from 430 to 450 q/ha. Farmers even grow the Bajra Napier Hybrid grass with the help of drip-irrigation system. Farmers were given bajra Napier hybrid ('CO 4') and perennial fodder sorghum ('CO FS 29') as planting materials. Crops were cultivated with facilities for irrigation following standard agronomic practices. Green fodder yields varied from 40 to 55 t/ha during the establishment year itself. It increased the availability of green fodder at farmer's household, which also positively affected the health of animals. It increased daily milk yield by 10 to 20% from dairy animals through their improved nutrition.

Under the module on forage production from silvi and hortipasture systems, demonstrations were conducted involving different types fodder like Stylosanthes, hedge lucerne, fodder horsegram, and fodder cowpea etc in Karnataka. They were cultivated under mango/ hebbevu (*Melia dubia*) plantations and produced a substantial quantity of green forages as a secondary product. Demonstration on urea treatment of crop residues/ straws under the module on forage conservation and utilization, were given to famers having lactating cows. Paddy straw was chaffed and treated with urea and then kept under air-tight conditions for enrichment. Urea-treated straws were fed to lactating cows where it resulted increase in milk yield (8 to 12%) and fat contents. It had positive impact on body weight of animals, as there was increase in body score of animals. Livestock farmers also observed that there was on untoward incidences on health of animals, otherwise being apprehended by the farmers. Livestock farmers were given demonstration on the utility of supplementing area-specific mineral mixture (ASMM) to dairy animals. Lactating crossbred cows were supplemented ASMM @ 1.0 kg/ month, besides their daily rations of forages and concentrates. Supplementation of ASMM resulted in improvement in daily milk yield as well as reproductive performances. Indeed, it improved conception rate and brought regularity in oestrus cycle of breedable female animals. Demonstrations were also carried out on silage making. Available surplus fodder from fodder sorghum/ South African tall maize were chopped and put into polythene silage bags/ plastic drums and kept under airtight condition for conversion into silages. Those silages were fed to lactating animals during the lean period for sustenance of animal productivity. This helped in mitigating the fodder demand, and also balancing and formulating total mixed rations for dairy animals.

Fodder production for tribal farmers

Under tribal subplan (TSP), interventions were implemented at Dhar and Jhabua districts of Madhya Pradesh,, Banswara district of Rajasthan, and Nandurbar district of Maharashtra. Agricultural, animal husbandry, poultry and fodder related interventions were demonstrated to uplift the socio-economic condition of tribal farmers in adopted villages. Tribal farmers were provided with fodder seeds (maize, MP Chari seed, pearl millet, clusterbean, dolichos and oat) for demonstration, besides 100 tribal farmers were provided with high-value indigenous Kadaknath poultry chicks. Improved varieties of oat fodder were introduced in Leh, Kargil of Jammu and Kashmir. Introduction of improved varieties resulted in additional production of about 3 to 19% in different crops, besides increasing awareness, knowledge and skill among the tribal farmers where livestock is an important source of livelihood.

Establishment of community grasslands

Grassland development on common properties resource (CPR) of about 70 ha in Soda village, Rajasthan in collaboration with *Jal Grahan Samiti*, Soda and Indian Institute of Rural Development (NGO) was taken. Technical support along with seed/rooted slips of Anjan grass (*Cenchrus ciliaris* L.), Dhaman grass (*C. setigerus* Vahl), Dinanath grass (*Pennsetum pedicellatum* Trin.) and saplings of fodder tree subabul [*Leuceana leucocephala* (Lam) de Wit], ardu (*Ailanthus excelsa* Roxb.) and neem (*Azadirachta indica* A. Juss.) were supplied. The fodder production from grassland enhanced tremendously as compared to natural grasses. Demonstration of tractor-operated portable belling machine was conducted for belling of the grass produce at the site. The MoU is signed between the IGFRI and *Jal Grahan Samiti* for overall development of the area and development of this site as model grassland for training and exposure to *Goushalas*, *Jal Grahan Samities*, watershed department, forest department and other developmental agencies.

IGFRI has taken up many steps to increase the quality fodder for livestock of North-Eastern Hills region. For livelihood improvement of poor pastoral communities, recently efforts were made for temperate pasture development through introduction of *Dactylis glomerata* L. and *Trifolium repens* L. at Lhagyala Gonpa, Morshing and Merkmu, Mandala in West Kameng district of Arunachal Pradesh. In Sikkim also, three sites were selected at Ravon, Zeema farm (Lachen) and Thangu for development of sub-temperate, temperate and alpine pasture under north Sikkim. Temperate grasses, viz. *Dactylis glomerata* and *Trifolium repens*, were transplanted to assess their suitability and production potential and found successful. About 3.0 ha under different grasses namely bajra napier hybrid (‘CO 2’, ‘CO 3’ and ‘CO 4’), guinea grass (‘BG 2’) and setaria grass (‘PSS 1’) was developed as fodder grass rooted slip/ seed bank at Jorhat, Asom. Mother nursery of BN hybrid (‘CO 3’ and ‘CO 4’), setaria (‘PSS 1’) and guinea grass (‘BG 2’) were raised for further multiplication at Barapani, Meghalaya. After collecting 4,000 rooted slips of setaria grass (‘PSS 1’) from AAU, Jorhat, they were planted directly on farmer’s field in the Mynsain village, Meghalaya in collaboration of ICAR-RC for NEH Region, Barapani. Bajra Napier hybrid (‘CO 1’, ‘CO 2’ and ‘CO 3’ varieties) was planted in mother nursery for further multiplication and transfer on farmer’s field at Imphal, Manipur.

Forage seed programmme

The availability of quality-fodder seed is one of the major stumbling blocks for the spread of fodder technologies to the end-users. Though sufficient quantities of breeder seed is being produced by the Research organizations like the IGFRI, SAUs, due to lack of proper multiplication mechanism at public and private sector seed-production organizations, the availability of certified seed is still an impediment in fodder crops. Hence, the IGFRI supplied TFL seed of various forage crops, although primary mandate of the Institute is to produce breeder seed. Since grasses are not in formal seed chain, only TFL seed is being produced and supplied to various government, non-government and farmer organizations including the farmers directly (Fig. 6). The TFL seeds of cultivated fodder were spread almost throughout the country with wider reaches than breeder seed. Since breeder seed is GoI indent based, it was restricted but TL seed owing to its direct usage by farmers was spread to many parts of the country including north-east region. Among 24 states to which TL seed was supplied, the maximum was for Uttar Pradesh (47%) followed by Bihar (18%), Haryana (14%) and others. Presence of IGFRI headquarters in Uttar Pradesh has probably made it more approachable to farmers and other organizations.

During the last 5 years, a total quantity of 2,244 q of

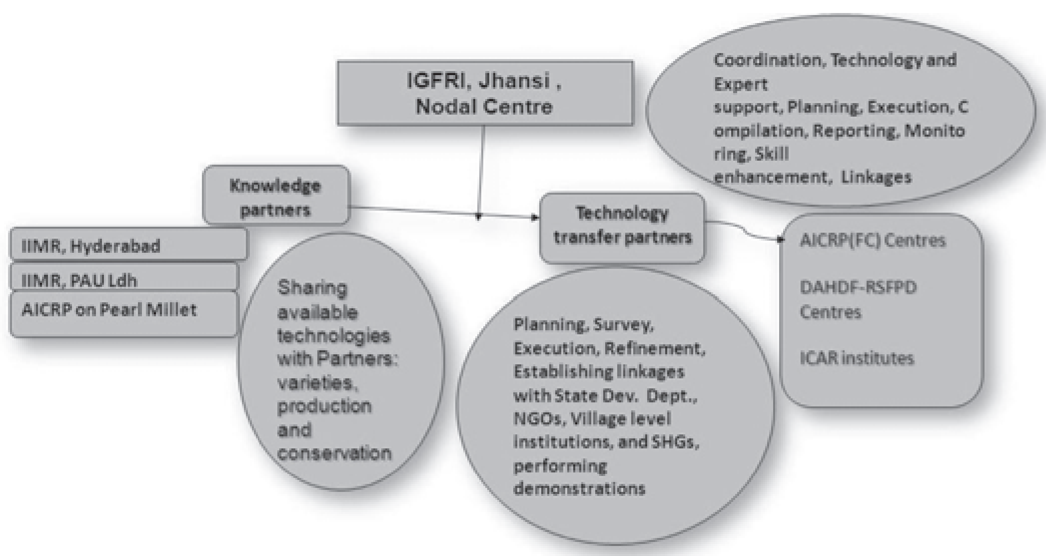


Fig. 6. Linkages developed among the partners to mitigate forage deficits

TFL seed of cultivated fodder was supplied to farmers and other agencies. Assuming that on an average TFL seeds were supplied at the rate of 448 q per year, a minimum area of 750 ha was under fodder crops with an estimated seed rate of 60 kg/ha. This helped in production of 30,000 tonnes of green fodder per year (when considered @ 40 tonnes/ha). The huge availability of green fodder to livestock also helped in increased livestock production.

From entrepreneurial point of view, the IGFRI took initiative to train the farmers for seed-production aspects and thereby involved in the livelihood improvement. Farmers of different villages of Jhansi and Datia districts were selected for berseem seed production in a participatory mode. The farmers were encouraged to take up seed production of berseem crop (varieties: 'Wardan', 'Bundel berseem 2' and 'Bundel Berseem 3') with the aim to inculcate the knowledge of berseem seed production among farmers and improving the availability of quality seed in locality. The average seed production was 209 kg/ha, with the average total cost of production of ₹45,530/ha. The average gross and net returns obtained were ₹89 129 and ₹43,599/ha respectively. The benefit : cost ratio was 1.96. A small group comprising of 5 farmers were even formed to take care of marketing of produced seed. The farmers sold the seeds at ₹130/kg to other farmers thereby convincing them to take up berseem-seed production as entrepreneurship.

CRITICAL ISSUES AND FUTURE CHALLENGES

The forage-resource development is a more complex issue than food and commercial crops. Lack of momentum in fodder development in the country owes much also to poor organizational structure. Keeping in view the huge livestock population and their nutritional security, the area under fodder cultivation should not be less than 10% of the gross cropped area. Moreover, during the recent past, perspectives and perceptions regarding the most appropriate roles and functions of grasslands have been changed. There are numerous regional, national and global issues with which utilization of grasslands are associated. These include the function of grasslands to provide social and cultural needs for many rural societies, their role in reducing greenhouse gas (GHG) emissions, as water catchments, and the preservation of ecosystem biodiversity. Thus grasslands are of such major importance resources, they need to be better managed in order to best fulfil those functions. Giving due emphasis on following aspects/issues are expected to strengthen the availability of forage resources-

- Integrating fodder crops with food crops, vegetables and other cash crops to increase the production of forage in the country.
- Investment in forage-resource development and incentives like crop insurance at subsidized rate, support price and compensation in event of damage from natural calamities should be provided to farmers.
- There is need for identification, evaluation and domestication of forage halophytes, and utilization of saline water in water-scarcity areas for forage production.
- Aquatic and waterlogged areas, need to be exploited for aquatic forage production such as para grass [*Brachiaria mutica* (Forssk.) Stapf], coix (*Coix lacryma-jobi* L.) etc.
- The issue of availability of good-quality seed of improved varieties of forage crops needs to be handled. Some out of the box solutions like establishing producer companies, market linkage with private sector agencies etc. are required. Involvement of the ICAR institutions, SAUs, State agencies, Private sector along with farmers' participation in a holistic manner is required to address this issue in proper perspective.
- There is a need to revive the age-old practice of integrating multi-use tree component in the agri-practices through policy and agri-practices reforms.
- Growing forages on 'bunds' or fodder tree-based boundary plantations under non-competitive land-use approach
- A comprehensive strategy for rejuvenation of grazing land and common area resources is required like encouraging establishment of cooperatives for forages and pasture management.
- Formulation of National Grassland Authority, which will take care the issues of development, protection and restoration of grasslands including its research and development components.
- Even promoting area/ situation specific hydroponic green fodder production.
- A system of inventory and assessment (covering both yield and quality) of forage resources in major forest types is also desirable with an in-built system of monitoring and periodical updating.
- Exploiting non-conventional/ underutilized fodder resources that can provide green herbage to animals under varied management condition, hence efforts should be made to improve the basket of fodder resources.
- Establishment of fodder bank with appropriate network is required for easy access to information and availability of materials at shortest distance. The fodder banks should also needs to be established near forest areas

CONCLUSION

Farmers generally compare the economics of forage with other agricultural crops. Although growing forages on agricultural lands is least attractive, unless they own better quality of livestock. Thus in forage cultivation, the return is mainly influenced by the quality of livestock. So it is always better to promote fodder production in the areas where livestock husbandry is progressing well and the productivity of animals is quite good. There is also a need for developing a fodder market in the long run, where farmers can sell the surplus forage. A fair market can motivate the farmers to study the price movement and cultivate fodder, provided the prices realized are remunerative (Hedge, 2010). However, now it is reality that forage technologies developed under the umbrella of the IGFRI, have created mass awareness and brought confidence among the farmers and livestock keepers in the country. The improved technologies not only have given options to the end-users but also increased production per unit area and better-quality forage and livestock-management practices which have contributed significantly in increasing milk and meat production to a current level of more than 140 and 6 million tonnes, respectively. This also resulted improvement in livelihood of livestock keepers/ farmers.

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4th International Agronomy Congress (November 22–26): 86–90 (2016)

Improving farmers prosperity in coastal ecosystems of India through integrated farming system

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ABSTRACT

The agriculture growth during the recent past is in a very slow phase compared to industrial development. The negative trend in productivity of major crops is affecting future food demand. The increase in net sown area is not possible due to slight shift of area for other purposes like industrialization and urbanization. To achieve positive growth rate in agriculture, especially in coastal ecosystem, a holistic approach is the need of the hour. The goal of sustainable agriculture is to conserve the natural resource base, protect the environment and enhance prosperity for a longer period. Farming systems is a set of agro-economic activities that are interrelated and interact with each other in a particular agro eco-system. Integrated farming system (IFS) is a judicious mix of one or more enterprises along with cropping having complimentary effect through effective recycling of wastes and crop residues and encompasses additional source of income to the farmers. The IFS activity is depends on inter-dependent, inter-related and inter-linking production systems, based on crops, animals and related subsidiary professions. It is a rich source of species diversity, helps in soil building, preserving and improving ecological condition essential to long-term sustainability. It also enhances soil-nutrient cycling and prevents proliferation of pests. In all the ecosystems, IFS approach with location-specific models offers gainful employment and is highly profitable and sustainable. Along with IFS, the soil and water conservation, integrated nutrient management, agroforestry, increase in nutrient-use efficiency processing and value addition are need of the hour.

Key words : *Ecosystems, Integrated Farming Systems, Rice, Sustainability*

INTRODUCTION

The agriculture growth rate in the recent past is in a very slow phase in spite of the rapid economic growth in our country. During the last 3-Five-Year Plans, the capital investment in agriculture was less than 10%. This has reflected in the productivity of major crops which is either static or declining in most parts of the country. According to the Economic Survey of India, 2012, the growth rate of foodgrain production decelerated to 1.2% during 1990–20011, lower than the population growth of 1.6%. It is projected that in our country population will touch 1,370 million in 2030 and to 1,600 million by 2050. To meet the demand, we have to produce 289 and 349 million tonnes of foodgrains during the respective periods. The current scenario in the country indicates that area under cultivation may further dwindle and more than 20% of current cultivable area will be converted to other purposes by 2030.

The operational farm holding in India is declining and over 85 million out of 105 million are below the size of 1 ha (Mahapatra and Bapat, 1992). Because of the ever-increasing population and decline in per caput availability of land in the country, practically there is no scope for horizontal expansion of land for agriculture. Only vertical expansion is possible by integrating farming components, requiring lesser space and time and ensuring reasonable returns to farm families. The Integrated farming system (IFS) therefore assumes greater importance for sound management of farm resources to enhance the farm productivity and reduce the environmental degradation, improve the quality of life of resource-poor farmers and maintain sustainability. In order to sustain a positive growth rate in agriculture, a holistic approach is the need of the hour. The goal of sustainable agriculture is to conserve the natural resource base, protect the environment and enhance prosperity for a longer period of time. Farming system is a set of agro-economic activities that are interrelated which interact among themselves in a particular agrarian setting. Farming system is a mix of farm enterprises to which farm families allocate resources to efficiently utilize the existing enterprises for the productivity and profitability of the farm. These farm enterprizes are crop, livestock, aquaculture, agroforestry and agri-horticulture (Sharma *et al*., 1991).

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In such diversified farming, though crop and other enterprises coexist, the thrust is mainly to minimize the risk, while in IFS a judicious mix of one or more enterprises along with cropping there exist a complimentary effect through effective recycling of wastes and crop residues which encompasses additional source of income to the farmer. The IFS activity is focused around a few selected interdependent, interrelated and interlinking production systems based on crops, animals and related subsidiary professions. Tiwari (1993) observed that, in the IFS the yield would be inherently more sustainable because the waste of one enterprise becomes the input of another, leaving almost no waste to pollute the environment.

An agro-climatic zone is a land unit of major climate, suitable for a certain range of crops and cultivars, whereas an ecological region is an area of the earth characterized by distinct ecological responses to macro-climate, as expressed by soils, vegetation, fauna and systems (FAO, 1983). The ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) has classified the country into 21 zones in the agro-ecological maps with 6 ecosystems, viz. arid, semi-arid, sub-humid, humid-per humid, coastal and island ecosystems. Though subsistence level of IFS was practiced in all the ecosystems studies revealed that scientific interventions have resulted in higher productivity and resource conservation.

'Green Agriculture' refers to a variety of integrated farming practices that emphasize the use of naturally and sustainably produced soil nutrients and cultivation of diversified crops and livestock husbandry in a manner that enhances overall farm productivity in balance with local, regional and global environmental resources. These practices improve water-use efficiencies and control soil erosion by promoting minimal disturbance of the topsoil and maintenance of adequate ground covers of organic matter. In aggregate, green farming practices increases agricultural productivity, reduces vulnerability to price volatility of fossil hydrocarbon resources and improves agricultural resilience and adaptability to changing climate conditions. Green agriculture also encompasses a range of social equity benefits that improve farmer livelihoods while producing and preserving beneficial ecological services.

INTEGRATED FARMING SYSTEM

Homestead-based farming system

Homestead-farming system is an age-old production system. The traditional homestead-farming system in the coastal ecosystem with its highly diverse crop and animal components has been a low-input sustainable system evolved with nature, socio-economic, ecological and cultural aspects of the people. Homestead farming is the most common in IFS and may be defined as an operational unit which is adjacent or surrounds the farmer's home with a wide array of crops/ trees with or without livestock and other subsidiary income-generating activities for subsistence and for marketable surpluses. The major constraints in homestead farming are its complex entity which varies according to the taste of the farmers. It is a form of low-input management subsistence model and since the situations within a small area differs considerably, models for different resource base is essential for homestead-based IFS.

Coconut-based farming system

Coconut (*Cocos nucifera* L.) is the most common crop of coastal ecosystem. It is cultivated from very small holdings to big plantations. Coconut-based farming system (CBFS) involving cultivation of compatible crops in the interspace of coconut and integration with other enterprises like dairy, apiary etc. offer considerable scope for increasing productivity and employment. The CBFS is an important farming practice among the small and marginal farmers, to maximize land use, farm productivity and profitability. A number of researchers have confirmed the suitability of CBFS in coconut fields (Nair, 1979; Bavappa, 1990). Perennial crops like coconut which occupy the land continuously for several decades, utilize the natural resources only to a limited extent producing <10% of potential dry matter produced in the tropics (Nelliat *et al*., 1974).

Coconut-based integrated farming systems

The coconut-based IFS studies conducted at the CPCRI, Kasaragod and Kayamkulam, revealed that the grass–legume fodder from coconut garden in the ratio of 3 : 1 (30 to 40 kg) could support 4 milch cows/ha. The total output from 1.04 ha IFS model in 1994-95 was 19,125 nuts, 9,275 litre milk, 526 kg poultry, 50 Japanese quail bird and 400 kg fish. The economic analysis revealed that the total variable cost for the system was ₹159,939. The gross and net returns/annum from the system was ₹207,169 and ₹66,678 respectively (Reddy and Bidappa, 2000). The IFS with small farmers (0.2 ha and less) developed through linear programming, comprising 43 enterprises and with a cropping intensity of 161, provides a cost benefit : ratio of 1:2.5 (Jacob and Nair, 1998). The crop livestock components selected in the models interact synergistically to increase the productivity and generate higher net returns.

Rice-based integrated farming systems

Rice (*Oryza sativa* L.) fields in the coastal area are typical wetland ecosystem with numerous significant ecological and economic functions that benefit the society. There is a continuous surge for diversified cropping primarily on economic considerations. Crop diversification is a practical means to increase crop output under different situations. It is intended to give wider choice of production in a given area to expand production-related activities on various crops. The common practice of adding more crops to the existing system is referred as horizontal diversification which broadens the base of the system. This multiple cropping has helped to achieve production potential up to 30 tonnes/ha/year with an increase in cropping intensity by 300 to 400% (Varughese *et al*., 2007). Crop diversification is influenced by factors, viz. *(i)* resource-related factors including irrigation, rainfall and soil fertility, *(ii)* technology-related factors covering seed, fertilizer, storage, processing and marketing, *(iii)* household-related factors covering food and fodder self-sufficiency requirement as well as investment capacity, and *(iv)* institutional- and infrastructure-related factors. Farm size and tenancy arrangements, research, extension and marketing systems and government-regulatory policies also effects, the above. The cropping system in different agro-climatic zones has been adopted by the farmers after long experience based on suitability of soil, profitability, availability of market and water control (irrigation/drainage). Techniques, viz. relay cropping, intercropping, mixed cropping; minimum tillage, weed control and use of chemical inputs have helped not only in reducing cost of production but also its sustainability over a longer period. Scientific cropping systems can actually result in increased soil productivity by improving the physical, chemical and micro-biological properties of soil and increased soil fertility.

STRATEGIES TO ACHIEVE SUSTAINABILITY IN COASTAL ECOSYSTEM

Production and use of organic compost fertilizers

A fundamental element of sustainable farming is the production and use of organic fertilizers made with biomass wastes, crop residues, tree litter, livestock manures and other photosynthetically produced matter. Improved capture and management of organic nutrient flows enable farmers to return soil nutrients and organic humus to their fields; thus reducing the amount of synthetic fertilizer that may be needed for higher crop production. Increasing soil organic carbon (SOC) levels also improves soil structure; enhances its water percolation and retention capacities and sequesters significant amounts of CO_2 that helps in reducing GHG levels in the atmosphere.

More efficient and precise application of inputs based on soil condition and crop-growth cycle

Current high intensity-input farming practices often apply excessive amounts of fertilizer and other inputs that are not effectively converted into higher crop yields. The over-application of such inputs generally results in significant environmental pollution from chemical leachates in freshwater sources and GHG emissions and are often accompanied by occupational health hazards to farmer workers and their families. Furthermore, the excessive use of pesticides and herbicides can lead to unintended suppression of non-targeted species that provide biodiversity and other agricultural benefits. Many farmers begin to use improved 'time release' fertilizers; nitrogen inhibitor-treated fertilizers; and and real time nutrient management practices using leaf colour chart something missing

Improved rainwater capture and watershed management

Practices that maintain organic ground covers on fields will retain rainfall and reduce evaporation losses. There are also a variety of complementary techniques that contour landscapes to capture rainwater and reduce water runoff and soil erosion. These practices include the integration of vegetative and riparian buffers; field terracing on steeply sloped terrains and agroforestry intercropping to decrease water runoff. Community watershed management initiatives are successfully replenishing and maintaining groundwater tables and are providing potable water supplies to rural communities. Farmers are also adopting more efficient irrigation techniques; such as drip irrigation and the use of system of rice intensification (SRI) practices that reduce the frequency of flood irrigation of paddies and increases overall rice yields.

Agroforestry methods and multiple/ intercropping rotations

Agroforestry techniques focus on the integration of purposely selected trees and bushes in the same field with a variety of cereal and cash crops. Farmers who adopt agroforestry often use N-fixing species that naturally produce fertilizers and whose leaf litter contributes to soil-nutrient enrichment. The tree canopies and root structures also helps to reduce soil erosion and excessive heat impacts and improve water retention. Furthermore, agroforestry can provide opportunities for locally managed sustainable fuel wood production that could support household cooking and heating energy needs.

Sustainability through IFS

The concept of sustainability in agriculture depends on the integration of 3 main factors, viz. environmental health, economic profitability and social and economic equity. On any farm, 4 natural ecosystem processes—energy flow, water cycle, mineral cycles and ecosystem dynamics—are at work (Sullivan, 2003). These processes function together, complimenting each other. Sustainable agriculture requires a system approach (Feenstra *et al*., 1997). System implies a set of interrelated practices organized into a functional entity. Farming system therefore designate a set of agricultural activities organized while preserving land productivity and environmental quality and maintaining a desired level of biological diversity and ecological stability. Sustainable agriculture in farming with efficient use of natural resources for increased productivity and production would result in improved farm income, maintenance of ecological balance, easy accessibility to food and social benefits and improved quality of life for farming communities. An agro-ecological approach is an appropriate method to understand the success of sustainable farming systems, and to identify ways to improve the productivity, profitability and resource-use efficiency.

Improved post-harvest storage to reduce waste and losses

In addition to implementing means to sustainably increase crop yields, farmers in the coastal ecosystem are also need to invest in household and cooperative scale grain-storage systems (e.g. metal silos and other structures that protect harvested grains from spoilage and losses to vermin) and improved produce packaging and handling systems. The use of higher-quality storage systems not only reduces post-harvest losses; they also enable farmers to have more options on when to sell their produce in order to earn higher prices than those that are offered immediately after harvesting time.

Increased farmer participation in value-added processing

In addition to sustainable cultivation practices, smallholder farmers need support in developing the capacity to qualitatively improve the value of their produce by applying quality control, sanitation and food-safety measures that are desired by consumer markets. These initiatives are particularly critical if smallholders are to succeed in supplying domestic urban and export markets with agricultural products.

CONCLUSION

It is concluded that the productivity of major crops are either static or declining in many parts of the country due to various reasons. To sustain food security, the approach of IFS is positive and will conserve the resource base through efficient recycling of residues within the system. The IFS models developed on ecosystems and sub-systems can be fine-tuned through farmer participatory trials with multilevel interventions of experts. The dissemination of such models will help in anchoring sustainability in agriculture.

FUTURE THRUSTS

- Quantification of biomass production under Integrated farming system (IFS) and its overall efficiency in attaining sustainability.
- Identification of efficient cellulolytic microorganisms for recycling of crop residues.
- Impact of IFS on the accumulation of carbon and carbon sequestration.
- Development of indigenous technology know-how (ITK) of IFS existing in the farming community and its scientific validation and popularization.
- Development of on-farm research to identify and adopt technologies for solving site-specific problems.
- Research and development in organic farming
- Investment on community soil and water conservation
- Establishment of small-scale industries
- Skill development in rural youth and farm women's.

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4th International Agronomy Congress (November 22–26): 91–103 (2016)

Role of ICAR-CSSRI in sustainable management of salt-affected soils—achievements, current trends and future perspectives

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SUMMARY

A range of constraints are adversely impacting the sustainability of agricultural systems across the world. While productive agricultural lands are being usurped by municipal and industrial sectors of the economy, freshwater resources face heavy risks of depletion and pollution. Adverse impacts of climate change on soil health, water availability and crop productivity are increasingly becoming noticeable. Given the fact that both prime land and water resources have shrunk over the years, it has become absolutely essential to harness the productivity of degraded lands and low-quality water to meet the growing food and nutritional needs of an expanding global population. Salt-affected soils constitute a significant proportion of global degraded lands; especially in arid, semi-arid and coastal regions where poor-quality saline and sodic water are also a severe obstacle to sustainable crop production. The ICAR-Central Soil Salinity Research Institute (CSSRI) has made earnest efforts since the beginning to address these challenges, to bring degraded and abandoned agricultural lands under crop production. Different salinity-management technologies have become highly popular among the farmers in salt-affected regions of the country. Concerted research efforts are underway to devise novel and low-cost interventions for increasing farmers' income in saline-affected environments. In this paper, a summary of past breakthroughs, latest developments and emerging constraints is critically analyzed to delineate the future course of action for sustainable salinity management in agriculture.

The role of modern technology in contemporary agricultural development is well established. In fact, modernization of agriculture in the large parts of the developing and underdeveloped countries in the second half of 20th century was essentially a manifestation of the improvements brought about by the technological change during the Green Revolution period (Pinstrup-Andersen and Hazell, 1985). The huge success of Green Revolution in Indian subcontinent and many parts of Africa is a testimony to the fact that adoption of improved production technologies improves the soil conditions, enhances the crop production and ensures handsome returns to the farmers (Varshney, 1989, Goldman and Smith, 1995; Niazi, 2004; Swaminathan, 2006). A blend of strategically chosen technologies—productive cultivars, chemical fertilizers, farm machinery and irrigation—transformed the agrarian landscapes in many parts of Asia and Africa, alleviating hunger and poverty risks and bringing significant improvements in the lives of rural poor (Goldman and Smith, 1995). Besides direct benefits in terms of high crop yields, technological innovations also ensured less drudgery and high returns to the human labour employed in farm operations (Giampietro, 1994). These technology-led improvements in soil productivity also implied that pristine and protected environments will not be encroached for the agricultural expansion (Niazi, 2004).

Despite huge contributions in augmenting crop production in many historically disadvantageous regions of the world, Green Revolution is often criticized for being insensitive to environmental sustainability (Singh, 2000; Lynch, 2007) and human health (Welch and Graham, 1999; Welch, 2002) concerns. While criticizing the contributions of GR towards enhancing the agricultural output, commentators ignore the fact that the problems of widespread hunger and starvation, especially in poor countries where GR took place, could have attained alarming proportions had there been no provision of high-yielding crops and other essential inputs to augment the crop productivity (Welch and Graham, 1999). The eventual impact of any external intervention is greatly influenced by the prevailing policy environment. A given technology is likely to give the best results under favourable working conditions that can be ushered through institutional reforms. While implementing such changes, it is important to remember the fact that quest to improve agricultural productivity through modern tools must be in sync with the larger social and environmental goals (Pinstrup-Andersen and Hazell, 1985). The proponents of GR never imagined the widespread ill-use of the prescriptions originally meant to overcome the food shortages by harnessing the productivity of fertile but underutilized crop lands. It

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is argued that by augmenting per unit crop productivity, GR technologies saved the precious wildlife and protected lands which could have been usurped for agricultural use (Niazi, 2004). Based on these facts, it seems correct to state that even during the early years of GR individual commercial motives far outweighed the sustainability concerns posing a grave threat to the ecological health in the ensuing decades (Swaminathan, 2006).

INTENSIVE CROPPING AND AGRICULTURAL SUSTAINABILITY

Based on the recent trends in food production, Welch and Graham (1999) discerned 2 distinct phases of technology-driven agricultural development in Afro-Asian countries in the second half of 20th century. The first phase, aptly referred to as '*production paradigm*' started in 1960s and was characterized by the use of fertilizer-responsive cultivars, intensive irrigation and farm mechanization to sustain the rising global food demands. Although agricultural intensification ensured quantum increases in the production of staple crops such as rice (*Oryza sativa* L.) and wheat [*Triticum aestivum* L. emend. Fiori & Paol.], it soon became evident that intensive cropping was detrimental to natural-resource sustainability and environmental integrity. Over the years, environmentalists started questioning the validity of GR practices that were perceived to be inimical to land and environmental health. Thus emerged the second phase called '*sustainability paradigm*'. Institutionalized in early 1980s, it was steered by the consideration that agricultural production and natural resource sustainability were inextricably linked domains and that future interventions to increase crop production must be compatible with the environmental ethos and needs of local communities that are likely to benefit from such actions. Dawn of the 21st century marked an increasing global attention on rampant malnourishment necessitating a '*new paradigm*' in agricultural production to devise the means and ways that can foster the balanced nutritional needs of a rapidly expanding global population, especially the marginalized sections of society, while ensuring the ecological balance (Pinstrup-Andersen and Pandya-Lorch, 1998; Welch and Graham, 1999).

After Independence, India faced a daunting challenge to feed her vast poor population. The food availability was critically low such that a large chunk of population faced extreme hardships in securing access to food even for subsistence needs. The fact that agricultural production was largely rainfed implied that adequate rainfall would determine the farmers' fortunes. It was due to this reason that droughts or prolonged dry spells caused severe food scarcity and starvation. In a dramatic turnaround, food production considerably increased—from 72.3 million tonnes in 1965–66 to 108.4 million tonnes in 1970–71. By any standard, it was an impressive gain transforming a net food importing country into a food surplus economy. Considering the flaws in traditional strategy involving land reforms and cooperative agriculture, Government of India made some outright changes in policy to usher in a yield revolution through technological interventions and policy initiatives in a short span of 3 years, i.e. from 1964–1967 (Varshney, 1989). During the last years of 1960s and throughout 1970s, sustained efforts were also made to remove policy obstacles and market distortions to encourage the farmers to grow more food with the aid of improved seeds and other essential inputs (Jha *et al*., 2007).

Semi-dwarf wheat and rice cultivars having tolerance to lodging were far responsive to irrigation and fertilizers than the traditional tall cultivars. The high yield potential of these improved cultivars was evident right since the beginning, i.e. around mid-1960s when the field demonstrations started in north-western states such as Punjab. Subsequent to their release, dramatic improvements in crop productivity occurred with lands earlier considered to be less productive now producing exceptionally higher yields. Shortly, it appears, farmers developed the idea that yield potential of these 'miraculous seeds' can be further enhanced by the incremental additions of nutrients and water. As a consequence, over-irrigation and indiscriminate fertilizer use became a rule rather than exception—a practice which even continues today. Swaminathan (1968, 2006) noted that imprudent nutrient and water-management practices had become pervasive well before the term Green Revolution itself was coined by Dr William Gaud of the US Department of Agriculture in 1968. Taking a note of the fact that over allocation of water, neglect of land drainage, heavy fertilizer and pesticide applications, frequent soil tilling, excessive withdrawal of fresh groundwater and replacement of local crops with high-yielding cultivars have become a norm in many irrigated lands of north-western India, he cautioned about the dire consequences of these practices way back in January 1968 (Swaminathan, 2006).

PRECAUTIONS IN TECHNOLOGY ADOPTION AND IMPLEMENTATION

The key message emerging from the foregoing discussion is that while technological interventions are necessary to address the shortfalls in agricultural productivity, utmost care should be taken to ensure that a particular technology (e.g. irrigation) is not indiscriminately used, as it may prove detrimental to agro-ecosystem sustainability in longer runs. The fact that dwarf wheat and rice cultivars used during GR gave the best results under optimal soil moisture and nutrient conditions was mistaken by the farmers' who wrongly assumed that heavy and repeated use of such crop inputs will keep increasing the grain yields. Pingali and Rosegrant (1994) argue that GR strategy in Asia essentially aimed at the intensive use of lowlands for long-term gains in rice productivity. Efforts to harness the productivity of such lands also implied lesser pressure on overstretched uplands, consistent incomes to the growers and the creation of rural employment opportunities. Initially, GR technologies seemed to be an appealing proposition to enhance the land value and strengthen the livelihoods of resource-poor farmers. However, stagnant and/ or declining rice yields by the mid-1980s questioned the lasting relevance of this approach. Besides volatility in global rice demands and prices, the intensification-induced factors such as repeated pest outbreaks, soil-nutrient depletion and massive land degradation emerged as severe problems, impacting the land sustainability and farmers' livelihoods in most of the lowland rice ecosystems.

Considering the extent of public investments and the nature of policy support, Pingali (2012) distinguished the first GR (1965–85) from the second or post-GR (1986–2005). While the first leg witnessed heavy public investments in crop breeding and irrigation infrastructure development and was characterized by a congenial policy environment, public support gradually diminished and virtually came to a halt in mid-2000s that, according to him, marked the end of GR era. It was an unwelcome development as declining public support can impede the future productivity gains in many poor and underdeveloped regions where agriculture still continues to be the main driver of economic growth. The success of GR in terms of higher yields, improvements in farmers' livelihoods and poverty reduction in countries that suffered from some of the devastating famines in the past was, by any standard, remarkable (Niazi, 2004). Fifty years down the line, many countries that witnessed immense growth in agricultural production during GR have become victims of many unintended side-effects that remain unaddressed (Hazell, 2009). In spite of these shortcomings, technology-based reforms are still considered important, albeit with caution, to ensure the food and nutritional security of a burgeoning global population in a sustainable manner through innovative approaches variously described as Sustainable Intensification of Agriculture (Tilman *et al*., 2011), Second Green Revolution (Lynch, 2007), Evergreen Revolution (Swaminathan, 2006), Redux Green Revolution (Pingali, 2012) and Gene Revolution (Raney, 2007).

AGRICULTURAL INTENSIFICATION, LAND DEGRADATION AND SALINIZATION

Numerous studies show that the human quest to produce more food for commercial motives has come at the expense of massive land and environmental degradation in many parts of the world (Matson *et al*., 1997; Vitousek *et al*., 1997; Tilman *et al*., 2002; Sharma and Singh, 2015). Intensive cultivation-induced erosion of fertile soils (Pimentel *et al.*, 1995), fast diminishing crop biodiversity (Benton *et al*., 2003), rampant surface water pollution (Stoate *et al*., 2001), deterioration in groundwater quality (Gregory *et al*., 2002) and massive salinity build-up in agricultural lands (Gupta and Abrol, 2000; Singh *et al*., 2012) are some of the well-documented examples that reveal the enormous damage caused by the water- and energy-intensive agricultural practices.

Rice and wheat crops together contribute about 45% of the digestible energy and 30% of total protein to the global human diet. Rice and wheat are grown in sequence on the same land in the same year over 26 million ha area in South and East Asia and in about 12 million ha in India (Gangwar *et al*., 2006). Unfortunately, heavy tillage and other intensive practices have caused severe erosion of fertile soils in the Indo-Gangetic plains of India synonymous with the rice–wheat cropping system (RWCS) (Singh *et al*., 1992). The realization that business as usual approach adopted since the GR days has become irrelevant in the changing scenario has necessitated the adoption of resource-conservation technologies—reduced tillage, innovative crop establishment methods, crop residue incorporation, efficient irrigation techniques and integrated nutrient management—to address the interrelated concerns of soil degradation, sustainability and profitability of RWCS for national food security (Gupta and Seth, 2007).

Continued reliance on a set of high-yielding cultivars in RWCS has accelerated genetic erosion leading to the disappearance of many locally adapted landraces which were earlier integral parts of human diets in different regions (Singh, 2000; Gupta *et al*., 2003). Biodiversity depletion disrupts many ecosystem services and causes the loss of valuable genetic stocks important for future crop improvement. Water has been a key driver of agricultural growth in the country. However, it is distressing to note that both surface and groundwater resources are facing heavy pollution risks. The alarming deterioration in water quality is evident by the fact that presently over 70% of the available surface water suffers from different organic and inorganic pollutants to varying degree. Again, toxic levels of water-soluble salts and minerals such as iron, fluoride and arsenic have been reported in groundwater from over 200 districts in 19 states of India (Murty and Kumar, 2011).

Massive salinization of agricultural lands is one of the most important facets of intensification-induced environmental degradation. Human-induced secondary salinization of soils has emerged as a severe environmental crisis in many irrigated and dryland regions of the world. Excess water and salt accumulation in root zone adversely impact the productivity of about 20% global irrigated lands (Munns, 2005). Over-irrigation and neglect of drainage lead to permanent water stagnation in cultivated soils turning them into wet deserts (Pimentel *et al*., 2004). This is the case with the Indo-Gangetic plains of Indian subcontinent where twin menaces of waterlogging and salinity have dealt a serious blow to agricultural sustainability and farmers' livelihood (Datta and De Jong, 2002; Bhutta and Smedema, 2007; Sharma and Singh, 2015). Under severe conditions, virtually no crop can be produced in the waterlogged soils leading to their abandonment (Singh and Singh, 1995). In most of the cases, formation of such damp soils is ascribed to the deep-rooted flaws in irrigation-development schemes that tend to ignore the importance of adequate drainage for sustainable land use (Janmaat, 2004).

As previously indicated, attempts to bring more and more lands under irrigation through the development of canal networks and establishment of tubewells at farmers' field was a key strategy during the GR period. Many a times, farmers' facing the problem of erratic supplies of canal water became overly dependent on groundwater irrigation. Initially, this approach proved useful in tackling the twin problems of waterlogging and secondary alkalization as well as in accelerating the speed of alkali soil-reclamation programmes in regions, having good quality groundwater. The gradual spread of RWCS in these areas, however, markedly changed the natural salt and water balance such that north-eastern parts of Punjab and Haryana states started showing decline in groundwater table while, the south-western parts developed many extensive pockets of secondary salinization (Gupta and Abrol, 2000). Based on a long-term study (1989–2010) in Haryana state of India, it was found that percolation from irrigated soils was mainly responsible for the development of shallow watertables with annual rate of groundwater rise being as high as 0.2 m in some locations. Some viable options to arrest the continuous rise in watertable include the conjunctive use of groundwater and canal water and reduction in rice area by adopting low-water-requiring crops (Singh *et al*., 2012).

Most of the aforementioned problems are likely to aggravate in the coming decades. Continued demographic expansion implies that intensive land-use practices may become more widespread with far reaching consequences. Although agricultural intensification has considerably increased the global crop harvests, it has come at the cost of unintended impacts on vital ecosystem services and functions (Matson *et al*., 1997). It is argued that the need to double global food production in the next few decades may prove detrimental, causing irreversible damages to soil, water and biodiversity resources imperative for and integral to sustainable human life on Earth (Tilman *et al*., 2002). The poor and developing countries such as those in south Asia may be worst affected by these unwarranted challenges that are likely to be further complicated by the global environmental change (i.e. changes in biophysical environment caused by the anthropogenic activities). Some of the major challenges that lie ahead include pervasive land use, extreme climate events, freshwater shortages and biodiversity loss. The extreme vulnerability of south Asian countries to such challenges is attributed to an apparent lack of technological and material resources necessary for effective adaptation (Aggarwal *et al*., 2004).

JUSTIFICATIONS FOR INVESTMENTS IN SOIL-RECLAMATION PROJECTS

The twin problems of **s**alinity and waterlogging have impacted agricultural production in arid areas since the inception of human civilization on Earth. In recent times, however, they have grown in propensity and increasingly threaten the sustainability of agriculture in different irrigation schemes across the world (Wichelns and Qadir, 2015). The problem of dryland salinity has also emerged as a formidable threat to sustainable crop production in many rainfed regions such as southern Australia (Lambers, 2003; Munns, 2005). One recent estimate revealed that salinity-induced global annual losses in agricultural production (about US $12 billion) may substantially exceed in the next few decades if efforts are not made to mitigate the salt stress in crop lands (Shabala, 2013). Appropriate technological interventions ensure handsome returns from the ameliorated soils that will otherwise remain unutilized. Although large-scale public investments in technology development and dissemination remain crucial, efforts by individual farmers or their co-operatives also bring significant improvements in the productivity of degraded lands. Successful demonstration of a given technology in the field proves catalytic to its adoption by the farmers. Once the farmers are convinced that a technology holds promise to address the problem, they make investments to reap the potential benefits (Sharma and Singh, 2015). These facts justify the need to invest in innovative salinity-management technologies. Global trends reveal that many research and development organizations are developing international linkages to accelerate the pace of salinity research. In the past few years, collaborations between public and private sectors have also significantly increased to develop cost-effective and environmental-friendly solutions for salt-stress alleviation (Rozema and Flowers, 2008).

While both prime lands and good-quality water resources are shrinking with time, degraded salt-affected soils (SAS) offer ample scope for agricultural expansion into marginal environments. Although vast tracts of SAS are seen as a bane to society, evidence is mounting that they can be transformed into valuable assets by investments in technology development and dissemination (Shukla and Misra, 1993). In particular, emphasis should be on the development of low-cost technologies to minimize the resource-poor farmers' dependence on costly external inputs (Sharma and Singh, 2015). Technology-driven productivity enhancements are particularly desirable in those regions where significant investments have already been made in irrigation and drainage infrastructure. Precise mapping of salt-affected lands is one of the pre-requisites for their utilization through strategic land-management plans. Availability of accurate information with respect to the severity of the problem is extremely valuable in adopting a context-specific soil-restoration technology. For example, moderately saline and sodic soils will require less investment to bring them into use than a highly degraded soil. Besides the extent of salt-affectedness, factors such as land topography, presence of hard subsoil, water quality, depth of groundwater and crops to be grown after reclamation significantly affect the cost of technological interventions (Qadir *et al*., 2014).

ROLE OF ICAR-CSSRI IN PRODUCTIVITY ENHANCEMENTS OF SALT-AFFECTED SOILS

It may be a mere coincidence that ICAR-Central Soil Salinity Research Institute (CSSRI) was established in 1969—a time when the initial impacts of GR technologies were becoming noticeable. The establishment of ICAR-CSSRI marked a two-pronged strategy of agricultural development by the Indian Government. While on one hand technological changes and policy initiatives were initiated to boost the productivity of fertile yet low-yielding soils, on the other there was an increasing emphasis on tapping the potential of degraded, SAS. Although attempts were also made in the past to bring marginal soils under crop production, most of them were temporary provisions and thus tangible improvements did not materialize. The realization that systematic researches were necessary to identify the causes of salinization for designing the effective remedial measures led to organized salinity research in India.

Besides the investigations being carried out at the headquarters at Karnal, 3 Regional Research Stations have also been established at Canning Town, West Bengal (February 1970), Anand, Gujarat (February 1989; subsequently relocated to Bharuch) and Lucknow, Uttar Pradesh (October, 1999), to study the causative factors and to develop appropriate solutions for the problems of coastal salinity, inland salinity in black soils region and alkali lands of Indo-Gangetic plains, respectively. In addition, All India Coordinated Research Project on Management of Salt Affected Soil and Use of Saline Water in Agriculture started during the Fourth Five-Year Plan under the aegis of Indian council of Agricultural Research, New Delhi also assists in salinity research through its adjunct centres located in different parts of the country (ICAR-CSSRI, 2015).

Since the beginning, it has been our constant endeavour to develop farmer-friendly technologies for the best productive utilization of SAS and poor-quality waters with greater focus on fragile agro-ecosystems in arid, semi-arid and coastal regions (Sharma and Singh, 2016). The Institute has developed a number of doable, critically acclaimed technologies for assured returns even from difficult-to-reclaim salt-affected lands across the country. Till date, over 2 million ha salt-affected area has been reclaimed using these technologies. An account of these technologies summarizing their strengths, weaknesses and impacts in farmers' fields are discussed under the following heads:

Gypsum-based reclamation of sodic lands

Gypsum is a widely used amendment for reclaiming the sodic soils having structural problems and impeded water flow. Gypsum treatment markedly improves soil physical conditions, as evident from better soil flocculation, aggregate stability and improved infiltration rate (Lebron *et al*., 2002). Alleviation of sodicity depends on the replacement of exchangeable Na^+ with Ca^{2+} by the addition of amendments such as gypsum ($CaSO_4.2H_2O$) and lime ($CaCO_3$) (Oster and Frenkel, 1980). Although lime ($CaCO_3$) is naturally found in majority of the sodic and saline-sodic soils of the world, it is sparingly soluble in water (0.0113%) and hence does not contribute to reclamation (Qadir *et al*., 1996). In contrast, high solubility of gypsum in water (0.26% at 25°C) makes it an effective reclamation agent (Hira and Singh, 1980). Addition of gypsum releases much higher quantities of Ca^{2+} than does an equivalent amount of lime (Oster and Frenkel, 1980). Although certain acids and acid-forming materials can solubilize the native $CaCO_3$ to supply adequate Ca^{2+} for the soil reclamation, high initial costs and safe-handling issues limit their potential applications (Qadir *et al*., 1996). Factors such as composition of the soil solution, temperature, gypsum fineness, hydraulic conductivity and original exchangeable Na^+ percentage (ESP) affect the dissolution of gypsum in sodic soils (Hira and Singh, 1980). When present in excess amounts in the form of large crystals, gypsum may prove detrimental to soil structure, as observed in many gypsiferous soils containing 10–35% gypsum (Al-Barrak and Rowell, 2006). Certain practices may enhance the efficiency of gypsum application in sodic soils. In Australia, for instance, deep tillage in gypsum-treated soils enhances its reclamation efficiency by hastening the water flux and salt leaching. In comparison, deep tillage without gypsum application often causes slumping and re-settling of soil (Hulugalle *et al*., 2010).

In India, sodic-soil reclamation has become virtually synonymous with the gypsum-based technology developed by the ICAR-CSSRI. Although an array of amendments such as gypsum, pyrite, sulphuric acid, nitric acid, aluminium sulphate, ferrous sulphate, pressmud and organic manures have been tested in sodic soils, only gypsum and pyrite have emerged as practically feasible amendments owing to their easy availability and low cost. Again, many field investigations have demonstrated the superiority of gypsum over pyrite as even a single application of gypsum before rice planting provs as effective as higher and repeated doses in the subsequent years. Although actual amount of gypsum to be applied depends on different factors, 10–15 tonnes gypsum proves sufficient to reclaim the upper 15 cm soil in 1 ha area for growing shallow-rooted crops such as rice, wheat, berseem or Egyptian clover (*Trifolium alexandrinum* L.) and barley (*Hordeum vulgare* L.) (Dagar, 2005). Over the past few decades, chemical amelioration of alkali soils in Indo-Gangetic regions of Punjab, Haryana and Uttar Pradesh has been well standardized. With the support of World Bank, European Union and other developmental agencies, India has reclaimed 1.95 million ha of alkali lands. Among sodicity affected states, Punjab has reclaimed the largest area (0.80 million ha), followed by Uttar Pradesh (0.73 M ha) and Haryana (0.35 million ha) (Sharma *et al*., 2016b). Although it is a proven technology, gypsum-based package has some implicit limitations. For example, it is increasingly becoming evident that agricultural-grade gypsum may not be available in required amounts in the future. Such a situation has enhanced the interest in easily available and least-priced amendments such as organic manures, pressmud and distillery spent wash. The initial results reveal that these low-cost amendments could partially substitute gypsum in future reclamation programmes (Sharma and Singh, 2015).

Sub-surface drainage of waterlogged saline lands

The history of world agriculture is replete with examples that reveal the importance of irrigation in sustaining the human food requirements since antiquity. It appears that even the ancient hunter gatherer societies knew the benefits of irrigation that allowed them to grow crops for a settled life. Besides depending on forest produce and animal meat for daily calorie needs, Indus valley people also cultivated the winter-season crops such as wheat and barley with the aid of irrigation. As crop production was not possible without assured water supplies, creation of the permanent sources of irrigation was indispensable (Chew, 1999). In medieval periods, the realization that irrigation enhances the soil productivity led to the creation of many canal networks by the Tughlaq and Mughal rulers during 14th and 15th centuries (Shahare *et al*., 2002). Arrival of British in India marked a new phase of irrigation development in the country. The colonial rulers were firmly convinced that irrigation development was a key to revenue generation in agrarian economies like India. Britishers saw irrigation as a 'high input-high output enterprise' and made heavy investments for expanding the canal irrigation. Many big ticket projects were also initiated to restore the canals that were in a state of despair (Shah, 2011). After country's partition in 1947, large irrigated areas became part of Pakistan requiring focussed action to develop irrigation infrastructure in independent India. Thus, special programmes were launched through a series of different five-year plans up to the 1990s to install a number of major irrigation projects. Presently, 1,248 major and medium irrigation schemes are operational in the country. It is pertinent to mention that while there was almost an equal emphasis on surface and groundwater development in the decades of 1960s, 1970s and 1980s, there was a sizeable increase in groundwater development in the last three decades partly because of subsidized electricity for water pumping (Gopalakrishnan and Kulkarni, 2007).

This account of irrigation development reflects only one side of the story. While creating the new sources of irrigation, least attention was given to ensure proper drainage to obtain sustainable results in terms of multiple cropping, high crop yields, generation of rural employment and increase in the land value (Gopalakrishnan and Kulkarni, 2007). Presently, salinity affects the productivity of about 2.95 million ha agricultural lands in the country. Although precise estimates regarding irrigation-induced and groundwater-associated salinities are not known (Sharma *et al*., 2016a), the problem is on rise and is adversely impacting the soil health and crop production in many regions of the country (Datta and De Jong, 2002; Gupta, 2002; Manjunatha *et al*., 2004; Ritzema *et al*., 2008). Assessment of salinity-induced production and monetary losses by ICAR-CSSRI revealed that total production losses at the national level (~5.66 million tonnes) resulted in a revenue loss of about ₹8,000 crores. Among the salinity affected states, the highest losses have been reported from Gujarat, followed by Maharashtra and West Bengal (Sharma *et al*., 2016a).

In such wet soils, water table remains 1.5–2.0 m below the soil surface. Besides high salt concentrations [saturation extract salinity (EC_e) above 4 dS/m at 25° C], plants also suffer from osmotic stress and limited oxygen supply to the roots that eventually prove detrimental to crop growth and yield. Chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+} are the predominant soluble salts in these soils. The ICAR-CSSRI, Karnal, in collaboration with the Netherlands has standardized the subsurface drainage (SSD) technology for the reclamation of waterlogged saline soils. In SSD system, perforated corrugated/ smooth PVC pipes are installed manually or by laser-controlled trencher machines mechanically at a desired design spacing and depth below soil surface to drain out the excess water and soluble salts from the affected area. These pipes are covered with gravel/ synthetic filter to prevent the clogging (Gupta, 2002; Sharma *et al*., 2016a). Success of a few manually laid pilot SSD projects during 1980s proved conducive to the commissioning of many large, mechanically installed projects in the states of Haryana, Rajasthan, Maharashtra, Karnataka, Gujarat, Punjab and Andhra Pradesh. Thanks to the availability of adequate funds under different government-sponsored schemes and the entry of private companies in a public–private partnership mode, key installation and operational constraints have been overcome resulting in fast spread of SSD technology in many salt-affected regions. Till date, about 66,500 ha waterlogged saline soils have been reclaimed with SSD in India (Table 1; Sharma *et al*., 2016a). The reclaimed soils exhibit marked improvements in soil health, crop productivity, cropping intensity and overall environmental quality (Sharma and Singh, 2015).

Despite these benefits, smooth establishment and operation of SSD projects suffers from constraints such as high-installation costs and the lack of farmers' active involvement in the maintenance and running of SSD sites (Ritzema *et al*., 2008). Again, in many cases, problems encountered in the safe disposal of saline drainage water hamper SSD adoption in the landlocked regions. A range of solutions have been recommended to overcome these obstacles. They include provision of evaporation ponds, bio-drainage, conjunctive use of fresh and saline water in irrigation and the use of salt-tolerant cultivars. Of these approaches, the last 3 have received considerable attention to enhance the acceptability of SSD technology at farmers' fields.

Biodrainage for watertable control

Many tree species exhibit high transpiration rate and thus have capacity to extract water from the deeper layers containing saline groundwater. Experimental results show the efficiency of such trees in water and salt removal under shallow watertable conditions. *Eucalyptus* trees removed about 53% of the highly saline water (12 dS/m) vis-à-vis control conditions and thus arrested salinity development in the root zone (Chhabra and Thakur, 1998). Strip plantations of *Eucalyptus tereticornis* Sm. prevented the development of shallow watertables and salinity, while adjacent fields lacking tree cover recorded an upward movement of water (Ram *et al*., 2007). Raised bed plantations of *Eucalyptus camaldulensis* Dehnh., *E. Fastigata* H. Deane & Maiden, *E. rudis* Endl. and *Corymbia tessellaris* K.D. Jo;; & L.A.S. Johnson decreased the groundwater level and salinity in an alkali soil (*p*H 8.4–9.1). Groundwater level decreased by 145 cm under *E. rudis* trees compared to 90 cm, 70 cm and 60 cm in *C. tessellaris*, *E. camaldulensis* and *E. fastigata*, respectively, over a period of four and half years. Based on overall performance in terms of growth, biomass production, transpiration rate and overall bio-drainage potential, *E. rudis* was identified as the best candidate tree for waterlogged soils of Indian Thar desert (Bala *et al*., 2014).

These observations tend to show the importance of different tree species in the productive utilization of soils having shallow watertable. This strategy is also suitable for difficult terrain and subsoil conditions characterized by poor fertility and low-water transmission. In most of the

Table 1. An estimate of area reclaimed by subsurface-drainage projects in different irrigation commands of India

State	Irrigation commands	Area (ha)
Haryana	Western Yamuna Canal, Bhakra Canal	10,000
Rajasthan	Chambal, Indira Gandhi Nahar Pariyojana	16,500
Maharashtra	Lift irrigation systyem of Krishna river; Neera canal command, uncommanded	3,500*
Karnataka	Upper Krishna, Tungabhadra, Malprabha, Ghatprabha	25,000*
Punjab	Sirhind Canal (South West Punjab)	2,500
Manual[1]	Andhra Pradesh (Nagarjuna Sagar, Krishna Western Delta); Gujarat (MahiKadana, UkaiKakrapar); Kerala (Acid sulphate soils); Assam (Tea gardens), Madhya Pradesh	3,000
Total		60,500

* In addition to the above Government-supported projects, SSD has been installed in more than 3,000 ha area each in Maharashtra and Karnataka by local farmers without Government support. [1]Small projects in different states.

cases, eucalyptus and popular are the preferred tree species for controlling watertable. Many other species such as *Salvadora, Tamarix* and *Prosopis juliflora* have also been found suitable for SAS. Either strip or block plantations of the recommended trees are suggested to intercept canal seepage. In contrast to SSD, it is a cost-effective approach and also does not involve regular monitoring to grow and maintain the tree plantations which are also significant from environmental (e.g., carbon sequestration) and economic (e.g. industrial demand of tree timber) perspectives (Singh *et al*., 2014).

Conjunctive use of saline and freshwater

As the disposal of saline effluents from SSD systems carries the risk of environmental contamination, the prospects of using drainage water in conjunctive mode with freshwater have been investigated. Saline drainage water (EC_{iw} 10.5–15.0 dS/m) was applied in alternation with canal water (EC_{iw} 0.4 dS/m) for irrigation of wheat crop in a sandy-loam soil. Rainy-season crops were not irrigated. The mean relative yield of wheat irrigated only with saline water was 74% of the yield with freshwater. First irrigation with canal water and the subsequent use of drainage water increased the yield to 84%. Cyclic irrigations with canal and drainage water resulted in 88–94% of the potential yields. Cyclic irrigations also did not cause any yield reductions in sorghum [*Sorghum bicolor* (L.) Moench] and pearl millet [*Pennisetum glaucum*)L.) R. Br.] crops (Sharma *et al*., 1994). Wheat yield reduced by 40% when saline drainage water (EC_{iw} 12 dS/m) was used for irrigation. Substitution of saline water with canal water at pre-sowing and first post-planting stages improved the seedling establishment, tillering and plant growth, resulting in yield improvements of 16–18% than continuous saline irrigation (Naresh *et al*., 1993).

In many arid and semi-arid regions, erratic canal water supplies necessitate irrigation with saline groundwater. The productivity of such soils can be significantly enhanced if saline water is effectively utilized to supplement the water supplies. It has been found that pre-sowing irrigation with normal water and remainder irrigations with saline water (EC_{iw} 8 dS/m) is practically feasible in wheat crop in such areas. Again, saline water (EC_{iw} 8-12 dS/m) can also be used to substitute at least 2 freshwater irrigations with nominal yield reductions in wheat (Chauhan *et al*., 2008). These findings reflect that conjunctive use of marginal quality and fresh water is possible in the winter season crops such as wheat. When freshwater is used at the sensitive-crop stages, yield reductions are minimal. This practice holds even greater significance in areas where rainfall is adequate to leach the salts accumulated in the previous season. Adoption of salt-tolerant varieties and agronomic practices such as manuring and mulching can further enhance the prospects of saline water use under such conditions.

Salt-tolerant varieties

As previously mentioned, a number of constraints have hindered the widespread adoption of gypsum-based package and SSD at farmers' fields. In particular, the problems caused by higher costs (e.g. purchase of amendment, installation of SSD) have necessitated the development of alternative strategies to harness the productivity of SAS in a cost-effective manner. Salt-tolerant crops and cultivars capable of growing in unreclaimed or partially reclaimed soils represent such a strategy. Salt-tolerant cultivars give stable yields and significantly reduce the need to apply amendments for enhancing the soil productivity (ICAR-CSSRI, 2015). Crop-improvement projects in the last 40 years have led to the release of different high-yielding and salt-tolerant cultivars in crops such as rice, wheat, chickpea (*Cicer arietinum* L.), Indin mustard [*Brassica juncea* (L.) Czernj & Cosson] and dhaincha (*Sesbania cannabina*) (Table 2). New genotypes of rice ('CSR 46'), wheat ('KRL 283') and Indian mustard ('CS 58') have been identified for release in the coming period. Many potential lines have also been identified for use as parents in crop improvement and/or for direct release as cultivars. Recognizing the necessity to promote crop diversification in salt-affected environments, research programmes have also been initiated to identify salt tolerant and high-yielding genotypes in fruit crops, viz. Mango (*Mangifera indica* L.), bael (*Aegle marmelos* Correa ex. Koen.), guava (*Pridium guajava,* L.), ber or Indian jujube (*Ziziphus mauriatiana* Lam.) and vegetables, viz. Tomato (*Solanum lycopersium* L.), okra [*Abelmoschus esculentus* (L.)

Table 2. Salt tolerant crop varieties developed by the ICAR-CSSRI

Crop	Variety
Rice	'CSR 10', 'CSR 13', 'CSR 23', 'CSR 27', 'CSR 30', 'CSR 36', 'CSR 43'
Wheat	'KRL 1-4', 'KRL 19', 'KRL 210' 'KRL 213'
Chickpea	'Karnal Chana 1'
Indian Mustard	'CS 52', 'CS 54', 'CS 56'
Dhaincha	'CSD 137', 'CSD-123'

Moench], capsicum (*Capsicum* sp.) and chilli (*Capsicum* sp.) crops. Although tangible success has been achieved in developing and disseminating salt-tolerant cultivars to the farmers' fields, the changing scenario has necessitated development of multiple stress-tolerant crops capable of growing in soils having two or more constraints (e.g., drought and salinity). In this regard, integration of frontier genomic tools such as marker-assisted breeding with conventional breeding is necessary to accelerate the pace of ongoing genetic improvement projects.

Land-shaping technologies

Unrestricted water and air flows, as found in normal soils, are essential for the optimum plant growth and development. Water-permeable soils are amenable to intensive land use and multiple cropping for assured returns to the farmers. A number of low-cost and simple earth manoeuvring techniques such as farm ponds and paddy-cum-fish model have been found practically feasible to enhance the value of waterlogged lands (Ambast *et al*., 1998). The twin advantages of land shaping include the prevention of surface-water stagnation in the wet season and the use of stored rain water for irrigation in the dry months. It is thus obvious that such soil-displacement techniques alleviate the severe problem of waterlogging in the rainy season and allow crop cultivation in the ensuing winter season; a practice that assumes significance for intensifying the land use in monocropped coastal saline soils (Mandal *et al*., 2013). Similar interventions in salinity-affected regions of Haryana and Uttar Pradesh have also shown encouraging results.

Presence of high residual sodium carbonate (RSC) in groundwater is considered unsuitable for agricultural crops. A study conducted at farmers' field in Kurukshetra district of Haryana indicated the potential of land-shaping practices in enhancing the productivity of high RSC water through aquaculture-based farming system. Renovation of the existing pond (0.4 ha area) for fish cultivation, creation of a nursery pond, creation of pond dykes to grow horticultural crops and neutralization of high RSC in water with gypsum considerably enhanced the returns from a land which was otherwise lying unutilized (Singh *et al*., 2014). At Nain Experimental Farm, Panipat, characterized by shallow, saline groundwater table, promising results have been recorded by the creation of farm ponds. Despite constraints such as low-water availability and severe salinity in the pond water (25 dS/m) fish growth was about 600–800 g in 1 year period (CSSRI, 2013).

Efficient irrigation techniques

Globally, irrigated agriculture uses about 75% of the total available water. The next 2 slots are occupied by the industrial and municipal sectors that consume roughly 20% and 5% of the global pool respectively (UNEP, 2002). Although it has rendered immense benefits to the human society, fresh water is increasingly becoming a scarce resource putting many crucial ecosystem services and human health at risk. Some of the factors that have aggravated the problem—ever-growing human population, relentless land conversions, increasing urban population and industrial development—are likely to become more damaging in the foreseeable future (Vörösmarty *et al*., 2010). Adverse impacts of climate change such as increase in temperature, low and erratic rainfall and reduced river flows are expected to fuel the growing water scarcity (Whitehead *et al*., 2009) and the limited water zones (e.g. arid and semi-arid areas) characterized by poor soils, salinity and dismal farmers' adaptive capacity can be worst affected by these changes (Sharma and Singh, 2015). Under these conditions, agriculture sector will have to increasingly rely on limited freshwater. In many cases, poor-quality water will be the only viable option for crop irrigation and soil-reclamation programmes (Qadir and Oster, 2004).

A set of crop- and soil-management strategies including the cultivation of low water-requiring crops, reduced irrigation frequency, adoption of water-use efficient micro-irrigation practices, use of salt-tolerant cultivars, conjunctive water use and the application of organic inputs are recommended to tide over the freshwater shortages (Minhas, 1996). Drip irrigation offers many advantages over conventional surface irrigation in terms of significant reductions in water use, simultaneous application of water-soluble fertilizers (fertigation) and the advantageous use of low-quality water. While using salt-affected water under drip irrigation, however, some changes in the routine practices (e.g. selection of salt-tolerant crops) become absolutely essential. As direct contact between the plant and saline water is avoided, drip irrigation significantly minimizes the salt-induced damage (Mmolawa and Or, 2000). In light of the fact that regular saline irrigation through drip may accentuate salt accumulation in surface soil, subsurface/ drip irrigation is recommended to push the salts into deeper soil, so as to minimize the damage to crop roots (Oron *et al*., 1999). In this method, water is placed below the soil surface at a water discharge rate similar to that of surface drip (Camp, 1998).

Another relatively new irrigation technique called deficit irrigation (DI), where irrigation is applied below the crop evapo-transpiration (ET_c) need, is becoming popular to economize water use in crops (Fereres *et al*., 2012). The DI could be of lasting relevance in the regions where rainfall is adequate to fulfil crop-water needs during certain critical stages; especially in fruit and vine crops (Fereres and Soriano, 2007). A shortcoming with this technique is that excess salts may accumulate even with the prolonged use of good-quality water. The DI in mandarin trees (*Citrus clementina* cv. 'Orogrande') at 50% of ET reduced water consumption by about 15% with no apparent decrease in fruit yield. Nonetheless, DI for 3 years even with normal water (EC_{IW} 1 dS/m) enhanced salinity in the root zone (Mounzer *et al*., 2013). Partial root-zone drying (PRD) is another such techniques in which irrigation is done in such a way that only half of the root-system is wet, while the rest remains dry (Sepaskhah and Ahmadi, 2010). One of the shortcomings of DI is that it requires prudent supervision to maintain the required soil-moisture status (Stoll *et al*., 2000).

Challenges ahead

The adverse impacts of climate change on agricultural production are increasingly becoming noticeable in different parts of the world. Most of the projected changes—rise in atmospheric temperature, sudden and heavy downpour, drying of streams and reduced water flows in rivers—can prove detrimental to agriculture in most of the arid and semi-arid tracts characterized by low soil fertility, predominance of saline aquifers and resource-poor farmers (Enfors and Gordon, 2007; Sharma and Singh, 2015). The problems of sea-water ingress and cyclonic storms have significantly increased in the last few years, posing threats to the sustainability of coastal soils (Yeo, 1998). High atmospheric temperature, evaporative loss of water and less rainfall are likely to accentuate salt accumulation in soil (Yeo, 1998). In the last few years, problems of resodification (i.e. reappearance of sodic patches in gypsum-amended soils; Gharaibeh *et al*., 2014) and resalinization of ameliorated saline soils (Valipour, 2014) have become widespread. Growing scarcity of freshwater will necessitate changes in the conventional soil-reclamation strategies where good quality is an indispensable input for salt leaching. In many cases, marginal quality water will be the only viable option for irrigation and soil amelioration (Oster, 1994; Qadir and Oster, 2004). Strong climate variability may lead to the emergence of multiple soil stresses that could prove lethal to even the salt-tolerant genotypes. Development of cultivars having tolerance to two or more soil constraints is thus becoming a priority in genetic improvement programmes (Sharma and Singh, 2015).

CONCLUSION AND FUTURE PERSPECTIVES

In light of the fact that productive agricultural lands and freshwater are diminishing with time, considerable attention has been paid to bring the marginal soils under agricultural production. Although conventional salinity-management practices have paid rich dividends, the emerging constraints have necessitated a paradigm shift from the business-as-usual approach to ensure consistent gains from the soil reclamation projects. In near future, precise salinity mapping will become more important to identify the lands having slight to moderate constraints so as to design low-cost interventions for their profitable use. An equal emphasis on developing alternative solutions is desirable to hasten the pace of reclamation, especially in areas still uncovered by the conventional technologies. As in past, strong research and academic collaborations with national and international partners will remain important to bring additional salt-affected lands under crops and vegetation in a speedy and cost-effective manner. The capacity building and skill development of different stakeholders—scientists, state officers and farmers—should be given renewed emphasis to upgrade their knowledge and skills for sustainable results in the future reclamation projects.

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