REPORT OF THE SHORT-TERM STUDY

A DECADE OF RESEARCH IN DEVELOPING WATER WISE TECHNOLOGIES FOR VARIOUS CROPS IN INDIA

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PREFACE

Water, an elixir of life, is essential to all the living matter on the earth, be it humans, animals or plants. The growing population and changes in the climatic conditions will tremendously impact the demand on this finite, inelastic and renewable source of water within the next few years. Besides, water has been categorized as inadequate although its mismanagement and pollution have added to the dimensions of inadequacy. Recently observed vicious circle of shortage, excess and shortage within a period of six months in 2016 as well as highly polluted surface and ground water resources are pointers to the current state of management and pollution in the country. Unfortunate part is that in spite of our enhanced knowledge on the subject, we indulge in business as usual approach once the immediate problem is over by putting it under the carpet as if it will not stare us the next time. Another drought or flood jolts us again to the reality.

The vicious circle can only be broken if concerted efforts are made by all stakeholders through storage and reuse of excess water (management of flash floods) coupled with demand management in all sectors of economy. Agriculture being the most important water consuming sector, it is at the core of research in the field of water management. Solutions for a better use and management of this resource are needed to overcome the large spatio-temporal variations with huge potential of impacting agricultural productivity. This report looks at various technologies that have been developed, are being applied or are on the shelves of the research organizations that can play a major role in demand management in agriculture, which consumes more than 80% of the total water used.

The review has been categorized under the following heads:

Water audit and policy issues
Crop neutral technologies
Crop specific technologies

These are further sub-categorized under land leveling, drip irrigation, sprinkler irrigation, irrigation scheduling and deficit irrigation plant bio-regulators amongst the crop neutral technologies and rice, wheat, sugarcane and other crops such as cotton, groundnut, maize and potato amongst the crop specific technologies. Although, hydrological issues have been left out or few discussed, issues such as conjunctive use of surface and groundwater resources and integration of multiple uses of water including irrigation and drainage, aquaculture and livestock etc. have been included with few abstracts on water quantity and quality issues also finding their way in this compilation.Management options for a scenario of water resources aberrations due to climate change are included as it is the most topical issue in current researches on water management. A total of 271 abstracts are included out of a total of more than 500 abstracts that were scanned during the study.

The abstracts of the research papers and bulletins etc. have been used as these are published in the journals. As such these may not be reproduced as such because the intent here has been to analyze these abstracts to arrive at some meaningful conclusion derived in the background and recommendation section.

While compiling the abstracts and preparing the report, I received tremendous help from a number of individuals and organizations. I take this opportunity to thank Dr. D.K. Sharma the former and Dr. P. C Sharma, the current director of ICAR-CSSRI, Karnal for allowing me to take up this study at ICAR-CSSRI and to provide all the required facilities. I am thankful to the National Academy of Agricultural Sciences for the financial support to pursue this study, since it has a special fascination for me and is quite dear to my heart. I had the opportunity to visit and discuss some of the emerging location specific issues and technologies with water management experts at Rahuri, Ludhiana, Hisar, New Delhi and other places. I thank all those who have spared their valuable time for discussions and providing relevant literature. I also place on record my sincere gratitude to my family members who have ungrudgingly allowed me to snatch their quality time on several occasions.

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Background and Recommendations

Irrigation is a vital component of agriculture to minimize weather related fluctuations in crop productivity and ensure sustainable agriculture. India is one of the major irrigation practitioners along with China and the USA. While 80% of utilized water is being diverted to irrigated agriculture in India, sustainability of this practice is increasingly being questioned because of the declining water resource availability, declining water quality and incomplete assessment of the future scene of water scarcity in the country mainly due to climate change effects. Although, this year nature jolted the country through a vicious circle of scarcity-excess-scarcity, we are now again at square one with business as usual approach to water woes. On the other hand, a number of technologies have been developed through scientific intervention and applied to conserve water in agriculture especially for crops that are considered to be the water loving crops. The major lacuna is that these technologies are not spreading as fast as it should have been. Our food security concerns and sustaining the environmental health of the nation depends upon how effectively 'More crop per drop' mantra is implemented so that water from the agriculture sector can be diverted to meet the booming demand in other sectors of economy. This study therefore, was proposed with the following objectives:

- To conduct a review of about 300 papers published on water wise technologies during the last one decade.
- To prepare a review of crop specific water wise technologies with specific references to the water saving potential
- To identify and prepare a review of crop neutral technologies to prioritize their application and to identify need for crop specific researches, if needed
- To prepare a set of recommendations on region specific applications and further research

Identification of Technologies

Water use efficiency in irrigated agriculture can be enhanced by increasing the output per unit of water through varying aspects such as agronomic, engineering, management and institutional. These aspects with some specific examples are:

Agronomic: Selection of optimum cropping pattern, less water intensive crops, enhance moisture conservation, reduce water percolation and evaporation, crop residue managements, mulching, conservation tillage and planting patterns, etc.;

Engineering: Irrigation systems design by laying hydraulically and geometrically efficient systems to reduce application losses and/or improve distribution uniformity, lining of canals, furrow irrigation, pressurized irrigation, etc.;

Management: Demand-based irrigation scheduling, participatory irrigation management, multiple use of water, etc.;

Institutional: Participation in irrigation schemes, operation and maintenance, appropriate water pricing, machinery banks, financial institutions, capacity building of farmers' organizations etc.

These option individually or together reduce losses of water to unusable sinks, reduce water degradation (environmental aspects), and reallocate water to higher priority uses (societal aspects). Based on the experience and discussions with colleagues, technologies were identified and categorized for review as follows:

General	Crop neutral technologies	Crop specific technologies
Audit on-farm water use Policy issues	Land leveling Drip irrigation Sprinkler irrigation Alternate furrow irrigation and its variations Local adaptation of drip irrigations Plant bio-regulators Irrigation scheduling and deficit irrigation	Rice Wheat Sugarcane Other crops such as cotton Groundnut, maize and potato

As per the proposal more than 500 abstracts were reviewed and 271 are collated to extract the published information on these aspects.

General Observations

Food security in India is jeopardized as it is threatened by declining water availability and decreasing factor productivity. Although diverse and location specific factors determine the water availability, decreasing resources (e.g., falling groundwater tables, silting of reservoirs), decreasing quality (chemical pollution, salinization) and increased competition from other sectors such as urban and industrial users are more prominent. Therefore, farmers and researchers are looking for ways to decrease water use in rice production to about half of the current use without compromising the yield. It emerges that the most appropriate strategies to be adopted might vary over time and space but need to be designed carefully with the involvement of the farmers, and had to be resolutely forward-looking and perhaps revolutionary.

- On-farm water measurement and audit is not even in its infancy and needs to be popularized for best use of the available water.
- Steps to introduce water measurement and cost recovery on volumetric basis should be initiated. Initially, it may begin with a hybrid system wherein water is supplied to stakeholders´ group on volumetric basis while the group may share water as per the existing *warabandi* system
- Water course, field channel lining and underground conveyance systems needs to be popularized with appropriate subsidy norms
- Since surface irrigation would continue to dominate the irrigation scene, steps to ban flood or field to field irrigation systems in favour of appropriately designed surface irrigation methods should be initiated
- Integrating micro-irrigation systems with canal irrigation through the introduction of community reservoirs or otherwise as a government policy initiative
- Modifications in *warabandi* system to match with advanced irrigation scheduling methods and/or critical growth stages

- Demand management strategies needs to be popularized in rain fed, canal, tank and groundwater irrigated lands.

Water Audit and Measurement

Water Measurement and audit are closely linked and cannot be separated out. A good water audit must have accurate measurement of water in terms of its rate or total volume at various locations in the system so that an accurate water balance and components of wasteful use and their locations can be identified. Since suggestion to declare agriculture as an industry are emerging, this issue assumes greater significance. The main observation that emerged during the review is that very little work has been reported both on water measurement as well as on water audit especially at on-farm scale. To popularize this as a means of water conservation, sensitization of the policy planners, officers of the line departments and farmers needs to be undertaken on priority.

CROP NEUTRAL TECHNOLOGIES

Laser Land Leveling

Importance of accurate field grading has been known since long back but decision on this vital farming operation was left to the farmers. It has now emerged that precision land leveling improves irrigation uniformity, irrigation efficiency and as a result the productivity of land and water. Although wide variations have been noticed in the results presented in this write up, on an average, water saving to the tune of 15-20% (17.5%) and a yield increase from 10-15% (12.5%) can be achieved in the case of wheat crop. Since the technology is crop neutral, it can also be safely assumed that water saving and yield increase will be achieved in all other crops as well. As per an assessment made by Chakraborty *et al.* (2012) this technology can be extended to 80 M ha. The real challenge is how fast it can be achieved? Since, farmers are already convinced of its financial viability, institutional support needed to expand this technology can fast track the application. This support must be provided at the door steps of the farming community through service providers either in the government set-up or through private partners or through machine banks (Self help groups, SHGs). It seems to be the only way forward especially to ensure the participation of small farmers. It is heartening to note that the process has begun on a right note. The number of laser levelers in Punjab, Haryana, Uttar Pradesh, Bihar and other states are steadily increasing. For example; in Punjab alone number of laser land levelers have increased from just 8 in 2005 to 6250 in 2011 i.e. @ 780 lasers per annum. An assessment made by CIMMYT in 2013 has put the number of laser units in India ~25000 of which > 17000 in NW India

Emerging Problems from the Service Providers

According to a survey conducted by the author recently, farmers are questioning the water saving aspects of laser land leveling. The author could find out the following reasons for the issue raised by the farmers.

- The laser land levelers used by some of the service providers level the fields as table top slowing down the flow on lands that were earlier graded.
- Such a change in grade also restricts the flow especially when the crop is growing, towards 2nd irrigation onwards.

It calls for training of service providers before and after the purchase of equipment so that they purchase suitable equipment and use it properly. In the absence of this, a beneficial technology may lose its sheen.

Emerging Problems to the Service Providers

Following major problems are encountered by the service providers:

- During the initial years, clients might be spread over large area resulting in high opportunity cost in travel time. This results in loss of income.
- Since the farmers in some locations are resource poor, recovery of money might pose problem.
- Since the technology is in its infancy, the service provider has to act as an extension worker to convince the farmers of the need of laser land leveling.

Drip/Sprinkle

A cross-section of the farmers interviewed revealed that

- Drip/sprinkler irrigation saves water and increases crop yield but not to the extent as was claimed during sensitization workshops.
- There is increase in gross income as well as net income upon adopting drip irrigation.
- There is reduced labour requirement but labour engagement cost per labour is more as a trained labour is required to operate and look after the system.

Observations

Potential for micro-irrigation (both sprinkler and irrigation) is quite large in India. It has been endorsed by the document brought out by INAE (Chakraborty et al., 2011). However, having listed many economic and other intangible benefits, the growth of area under micro-irrigation has not been appreciable as compared to its potential. Although recently area under irrigation has shown a significant increase, the question still is whether this tempo can be maintained when the subsidies are withdrawn. Given the vast potential benefits and fast decline of irrigation water potential in the country, a number of technical and policy interventions are required to be introduced so as to increase the adoption of micro-irrigation in India. Some specific interventions needed are presented below:

MI is a capital intensive technology and requires huge investments. Besides, it requires a complete changeover from traditional crops to crops suited to micro-irrigation. Thus, unless loans and marketing facilities are ensured, farmers may not be inclined to switchover from surface irrigation to MI.

Most farmers are interested in getting higher yields and enhanced profits. Saving in water or other issues such as crop quality etc. does not fascinate them in the initial stages. Even in the water scarce areas farmers do not respond to water saving. Most questions revolve round the expected increase in the yield. The extension worker must be equipped with such information while sensitizing the farmers.

While calculating economics of the system usually benefits are overestimated while costs are underestimated. For example amongst the benefits either the crop yields under conventional system are underestimated or the yields under drip/sprinkler irrigation are overestimated. Experimental plots being small there could be a systematic error in upscaling the yield for larger areas. Amongst the costs, dealership margins, transport and installation costs are often ignored or underestimated. It results in blowing up of B:C ratios or other economic parameters. When such advantages are not achieved by the farming communities, they feel disheartened.

During field surveys stakeholders who are provided with the technology free of cost often blow up the benefits. Even if the technology is provided through subsidy, the overstating of the facts cannot be ruled out. Therefore, the field survey teams have to be very cautious in using the information provided by the farmers while projecting the benefits etc.

Unlike surface irrigation that has been learnt by the farmers through their long experience, they feel handicapped in using the advanced technologies. Farmers' knowledge in the operation and maintenance of the MI systems is very limited and often they face problems related to clogging of the filters and drippers.

Agro-practices for drip and sprinkler irrigation have not been popularized as much as in the case of surface irrigation. Often the farmers experience difficulty in knowing how frequently to irrigate the fields, how much water needs to be applied and when and how to fertigate. They opine that technical support for operation and maintenance should be available at the farm through upscaled extension system. Institutional support should be provided for liquid fertilizers, improved marketing facilities and access to more credit to expand the area under MI.

Large areas have been covered in the country but no attempt is being made to reduce the cost of the systems. While companies may not be interested in cost reduction but other stakeholders should compile the experiences where cost reductions have been made. MI companies, experts and farmers should sit together to identify the ways and means of reducing the cost. For example; there is good scope for reducing the system cost by slight modifications in the agro-techniques to suit small and medium farms like paired row planting. Therefore, micro-irrigation system should be tailor made, i.e., planned and designed based on location specific parameters. Standard procedure provided under subsidy scheme may not always help to reduce the cost of the system. Enough orientation needs to be given to the manufacturers/dealers/farmers such that the most economic crop specific design can be made.

The method has limitations in hot arid areas. Fine textured soils that have a slow infiltration rate cannot be irrigated efficiently in hot windy areas. Besides, water must be clean, free of sand and debris. Canal water often poses this problem. Moreover, canal water needs to be stored and subsidy on storage reservoirs in many cases is conditional.

Many farmers have adopted drip irrigation because of the subsidy. Once the system completes its life, some of the farmers do not replace it with drip irrigation since second subsidy on the same area is inadmissible. They opt for surface irrigation. To justify the switchover, they argue that their plants have now established so there is no need of the drip.

Sprinkler irrigation is an attractive, less complex technology. It can be easily adopted by the farming communities if adequate incentives are provided. The Government of Rajasthan and many other states like Gujarat are making it compulsory to irrigate with micro-irrigation systems. Community reservoirs are being created for use of stored water using sprinkler irrigation. Subsidy on solar pumps is also attracting farmers to use ground water with sprinkler irrigation. It is believed that if such incentives are sugar coated, more and more areas can be brought under this technology.

Constraints

The main constraints for the wide adoption of drip/sprinkler irrigation are:

- Lack of financial resources with small and marginal farmers
- Poor institutional support
- Lack of intense management skills required in the use of the system
- Limited extension support
- Dependence on manufactures for technical guidance
- Inadequate research information for many crops
- Apprehensions about longevity of system components due to poor quality materials
- Low key efforts for transfer of technology
- Reluctance to use for low value crop such as food grains

A major limitation of lack of financial resource has been taken care of by the government, which provides nearly 80% subsidies on the purchase of drip irrigation. It is believed that private firms will rise to the occasion and take care of several limitations that are in their purview.

Policy Issues

There is need to relax the farm size limitation in providing MI subsidies.

Both drip and sprinkler irrigations are driven through the state and central government sponsored subsidy schemes. In order to earn quick profits from the subsidy programs, many companies are marketing sub-standard components in the market. Often the sub-standard components affect the working condition of the system which creates enormous doubts in the farmer’s mind about the functioning of the system. It is to be ensured that only good quality components having the certification of Bureau of Indian Standards (BIS/ISO) are supplied to the farmers (Kulkarni 2005; GOI, 2004).

There has been a significant development in sprinkler technology all over the world. Several variations of sprinkler irrigation system, with improved design and components are available in those countries, where it is popularly used. Efforts should be made to manufacture such improved sprinkler systems in India.

The rate of subsidy needs to be restructured for water-intensive and less water-intensive crops. Special subsidy program may be introduced for water-intensive crops like sugarcane, banana, vegetables, etc. or even rice crop now. Differential subsidy rates can be fixed based on the types of crops and the rate of consumption of water. Similarly, higher subsidy should be provided for water scarce regions where exploitation of groundwater is very high. For a speedy growth of micro-irrigation, a special package scheme can be introduced where priority can be given to providing bank loans for digging wells and electricity connection (pump-set) for those farmers who are ready to adopt micro-irrigation for cultivating any crop.
Groundwater is the major source of water being used for drip method of irrigation in India. Unlike other countries, water from surface sources (dams, reservoirs, etc.) is used only in

limited areas with drip/sprinkler method of irrigation. Since water use efficiency under surface sources is very low owing to heavy losses through conveyance and distribution, farmers should be encouraged to use water from surface sources for drip method of irrigation. This can be done by allocating a certain proportion of water from each irrigation projects only for the use of micro-irrigation.

One of the important reasons for the low spread of this technology even in the water scarce area is the availability of highly subsidized canal water as well as electricity for irrigation pump sets. Appropriate pricing policies on these two inputs may encourage the farmers to adopt this technology. In a canal irrigation system, if major shift is desired from surface irrigation to pressurized irrigation system, water supply schedule needs to be modified from on-off mode to continuous mode, reduction of turbidity to desirable level and modifying system to provide surface irrigation to rice crop in the monsoon season and pressurized irrigation to suit different crops of the command in post monsoon season. The technical and economic feasibility of these interventions require studying the real field conditions.

To conclude, the potential area for MI is estimated based on the present cropping pattern and irrigation coverage of different states in India. This potential area may not be the same say after 10 or 20 years because of changes in the parameters that determine MI potential. The potential area available for MI is governed by factors such as cropping pattern, irrigation coverage, groundwater scarcity, price of canal water, price of electricity as well as its supply (in hours) for agriculture, technology development in MI, proactive policy (subsidy and other incentives) of the state and central governments. In case farmers shift the cropping pattern more in favour of horticultural crops because of their higher profitability, the potential area for MI might increase significantly in the future. Similarly, if the depletion in groundwater in different regions aggravates further, it might also encourage the farmers to shift the irrigation method from flood to MI methods. What will be the potential area for DI and SI if cropping pattern changes drastically in favor of high-value horticultural crops in another 10 years? Does the potential for MI change if one estimates it under different scenarios of groundwater depletion? Will the potential area for MI change if full cost pricing is introduced in canal water and electricity supplied for irrigation pump sets? One may be able to find some interesting results if comprehensive analysis is carried out.

CROP SPECIFIC TECHNOLOGIES

Rice

Since rice is the most water loving crop with its feet remaining in water for most of its growing season, a basket of technological interventions have been developed. These range from simple to complex and no investment to high investments resulting in saving of water to more than 50% in some cases. Although the water saving is not additive if more than one technologies are adopted simultaneously, yet synergetic effects have been seen in several of these technologies.

- Time of transplanting
- Control on cultivation of *Sathi Dhan*
- Grow short duration varieties
- Cultivation of Basmati rice
- Use of residual soil moisture after rice
- Management of last irrigation to rice

- Rain water conservation in rice fields
- Alternate wetting and drying (Name differently such as irrigate at hair crack drying stage, irrigation scheduling)
- Direct seeded rice
- Laser land leveling
- Minimize water requirement for field preparation
- SRI cultivation
- High tech precision agriculture, application of sprinkler and drip irrigation
- Crop diversification
- Integration of rice fish culture
- Water recycling and conjunctive use
- Genetic improvement in rice

Some 'Key Observations' for the rice crop are:

- All papers reveal that laser land leveling can reduce the water requirement of rice although its impact on rice yield is not proven universally; in few studies improvement in rice yield is reported. For wheat, both water saving and increased crops yield have been reported although the quantum of both varies widely. It has been proved that it is crop neutral technology.
- Alternate drying and submergence (wetting) also reported as cyclic submergence or irrigation at hair crack formation stage is probably the easily applicable and no cost technology that need to be advocated for large scale field applications. Location specific thumb rules must be made available; one of these being that irrigation of the fields should be initiated after 1-4 days of water disappearance depending upon the soil type. As much as 50% of water can be saved under many situations with this simple technology. This technology reduces the methane production from rice fields as well. The impact of this and other irrigation schedules on methane production has been covered under few studies.
- Water saving in aerobic rice has been reported in all the studies yet no unanimity is emerging on crop yield. The results vary from loss in yield by few percentage points to equal or higher yield by few percentage point. On the other hand, higher net benefits have been reported in all the studies because of the reduced cost of cultivation. Both agronomic management and a suitable variety with appropriate traits are needed to achieve maximum potential under DSR.
- Several studies have shown the potential of sprinkler and drip irrigation in aerobic rice cultivation. Integration of two technologies can help to save more water. A study shows that the water saving potential could increases to about 54% in aerobic cultivation with sprinkler irrigation from about 30% in aerobic rice alone. Potential of water saving in wheat is also highlighted if sprinkler irrigation is used for wheat crop as well in a rice-wheat rotation. The reported yield under drip irrigation is less than the conventional yield although water productivity is
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- Provision of adequate drainage facilities to drain excess water is recommended for higher water use efficiency but it can be achieved successfully by strictly following the irrigation schedule of alternate drying and submergence (wetting).
- Several studies have highlighted water saving potential by withholding last irrigation to rice crop several days before the harvest and going up to 15 days before the crop harvest.
- In a recently organized brain storming session on SRI cultivation, it is lamented that yield variability under SRI management is larger than conventional and other techniques. Can it

be attributed to management risks associated with SRI cultivation? It may be because of this reason that adoption of technology is sluggish.

Wheat

For wheat crop either in rice-wheat cropping sequence or otherwise, following strategies have been devised to reduce the water requirement.

- Relay cropping after rice
- Zero tillage
- Bed-furrow planting system
- Laser land leveling
- Sprinkler and drip irrigation
- Deficit irrigation
- Crop diversification
- SWI (System of wheat intensification equivalent to SRI in rice)

Some 'Key Observations' emerging for the wheat crop are:

- All papers reveal that laser land leveling helps in water saving and higher yield.
- Bed furrow planting helps to save water yet crop harvesting problems have emerged since the combine owners refuse to harvest the crop.
- There is a great scope for sprinkler irrigation but yields are lower in drip irrigation.
- Pre-sowing irrigation can be saved by following relay cropping in rice-wheat rotation.
- Zero tillage saves water, reduces cost of cultivation, yield either at par or slightly higher, it should accompany by residue management, people shifting towards minimum tillage

Sugarcane

Paired-row trench planting at 30: 120-cm-row spacing or furrow irrigated raised bed (FIRB)
Drip irrigation
Restriction of the crop in the command (Diversification)
Irrigation scheduling as per recommended IW/CPE ratios
Skip furrow irrigation
Trash mulching
Laser land leveling

Cotton

Delay in first and last irrigation
Alternate skip furrow irrigation (ASFI) or Permanent skip furrow irrigation (PSFI)
Minimum tillage
Mulching
Intercropping
Drip irrigation
Laser land levelling
Potato

Drip irrigation and micro-sprinklers
Mulching

Irrigation scheduling as per IW/CPE ratios
Laser land leveling
Drought tolerant varieties

Maize

Drip irrigation
Ex-situ mulching with crop residue
Laser land leveling
Zero tillage
Permanent raised bed system
Regulated deficit irrigation

Some 'Key Observations' emerging for other crops are:

- All papers reveal that laser land leveling helps in water saving and higher yield.
- Bed furrow planting helps to save water.
- There is a great scope for drip irrigation resulting in water saving and higher yields.
- Trash mulching saves water in sugarcane and organic and synthetic mulches in potato.
- Yields under deficit irrigation are usually lower.

POLICY INTERVENTIONS

- There is a need to end the multiplicity of control on the water sector with a multi-disciplinary apex body
- Real time forecasting of weather and information on farm operations should be strengthened through technology up-gradation and institutional reforms.
- A sustainable agriculture system that conserves resources and enhances productivity, demands a strong knowledge base and a combination of institutional and technological innovations. Apparently, it calls for strengthening the various institutions and extension wings including establishment of one window system for all agricultural related inputs and information.
- On farm water storage either individually or in a community based reservoirs with pressurized irrigation can play a rejuvenating role in canal irrigation. Such facilities need to be implemented or subsidized by the government.
- Guidelines on Public Private Partnership must be made flexible to encourage forging of partnership between research organizations, government line departments and private entrepreneurs.
- There is a need to institute incentive mechanisms to encourage adoption of water saving technologies especially in areas where water is scarce or where groundwater is falling at alarming rates.
- Laws must be framed to institutionalize the stakeholders´ participation in irrigation water management in canal commands
- Water – energy nexus is now well understood to make policy and plans to strike a balance through tariff control of electrical power.
- There is a good scope to replicate the success stories of one place to another rather than build from scratch. Institutional arrangements need to be put in place to replicate the success stories.
- Policy framework for application of bio-regulators to minimize water requirement may be devised and released for practical applications.

- Solar energy should be tapped to the maximum for agricultural use through appropriate subsidy program. However, groundwater overuse concerns in this set-up must be kept in view while framing the policy guidelines.

Limitations of the Technologies

Interesting results are presented in a paper on ´Analysis of Four Decades of Research and Outreach Programs in India´. Out of 502 technologies released, only 110 technologies (22%) have been transferred successfully to farmers so far (See Abstract 269). Although the extent of area under these technologies could not be seen, it is not clear when the technology has been considered as successfully transferred. It is however clear that about 392 technologies or even more might be on the shelves of the research organizations. Following limitations have been noticed.

- Some of the technologies are half baked and are not well tested under farmers ‘fields.
- The cost components are not properly defined. Most of the times supplier's profits or contractor margins remain unaccounted in calculating costs or Cost: benefit ratios.
- The benefits in most cases are exaggerated through a number of calculations. Upscaling of experimental yields from small plots usually results in much higher yields than can be obtained from larger fields. Besides, price as prevailing in the retail markets are used to calculate either benefits or Cost: Benefit ratios. *Mandi* prices are much lower than the retail prices.
- Since the adoption of technology in a no resource constraint environment of research organizations is easier, no attempt is made to discuss the likely impediments in the adoption of technologies under the farmers´ resource endowments. Low investment capability, labour shortage, time at the disposal of the farmers, availability of inputs and other institutional support are often overlooked. In some cases even deep ingrained traditions and social customs may impose many restrictions in the adoption of technology.
- The repetitive work on various old technologies is being pursued at many places and same results are being reported over time. Such misuse of funds and human resource needs to be stopped for good.
- A large number of research journals have proliferated in the recent past mostly publishing reviews. Thus same technologies are being referred time and again without any value addition to the technologies.

Current Applications of Technologies

With support from Government of India and states, extension agencies and research organization several of the technologies have received widespread response from the stakeholders. Some of the technologies that have been extended to cover large agricultural lands are as follows.

Sprinkler irrigation (4.4 million ha, Grand Thomsom of India, 2016)
Drip irrigation (3.4 million ha, Grand Thomsom of India, 2016)
Zero tillage (2 million ha in IGP, Erenstein et al., 2008)
Direct seeding of rice
Laser land leveling
Time of transplanting (Whole of Punjab and Haryana)
Deficit irrigation
SRI (1 Million ha, Biswas, 2010)

RESEARCHABLE ISSUE

India's agricultural research and extension systems is an essential component for agricultural growth. These services have declined over time due to chronic underfunding of infrastructure and operations, slow replacement of aging researchers or broad access to state-of-the-art technologies. Current research must emerge from repackaging the time-worn packages of the past. Public extension services are struggling and offer little new knowledge to farmers. There is too little connection between research and extension, or between these services and the private sector. Policies, management practices and technologies needed at farm, system and basin level will require a multi-disciplinary approach, substantial investments in collection and analysis of new and relevant information and research, as well as constant evaluation of present approaches and practices.

- Across India, hydrological research is hindered by a lack of access to good-quality data. The government bodies that are custodians of hydrological, meteorological, environmental and agricultural data are reluctant to share information openly. Combined with bureaucratic hurdles, this means that Indian researchers must either use poor-quality data or turn to US or European records.
- Strengthening of basic and applied research to develop strategies for efficient management of on-farm water resources to enhance agricultural productivity on sustainable basis especially with respect to climate change.
- Researches on genetic improvement of crops to enhance water use efficiency and climate resilience must be initiated and strengthened in all the NARS organizations
- Researches on bio-regulators to improve WUE and their long-term health impact should be undertaken.
- Encouraging farmers to diversify to high value- low volume- low water requiring crops will be a significant factor for higher agricultural growth, particularly in water scarce regions. It should be integrated with agro-processing and building competitive value chains from producers to urban centers and export markets.
- Research should focus on the use of modern techniques such as nano- and biotechnology to improve water- and nutrient-use efficiency in crop plants.
- Researches need to be strengthened to develop and utilize unconventional sources of water that is dew, fog, snow, rain water, wastewaters and poor quality ground waters.
- Researches to promote seawater desalinization and tackle the problem of saline intrusions in the aquifers
- Most of the technologies lack a real cost-benefit analysis that would allow prioritization of solutions to be applied including in realm of demand and supply sides. Researches must address such issues to fill up the gaps.
- Plan, design and implement on-farm works (measuring structures, field channels, lining, piped conveyance, use of drip irrigation, etc.) to build few model farms as demonstration farms and develop procedures to measure performance of water saving technologies.
- Often productivity and WUE are interlinked but sometimes WUE can be increased with small penalty on productivity. What and where which one of the two is important needs to be identified and extended with clear cut guidelines.
- Since groundwater is dwindling fast at many places, there is a need for aquifer mapping and cooperative management of aquifers to overcome the depletion of the resource. Laws governing the groundwater need to be framed.
- Improve understanding and estimation, in quantitative terms, of climate change impacts on freshwater resources and their management including economic issues, to fulfill the

pragmatic information needs of water managers who are responsible for adaptation and to develop adaptation and mitigation strategies.

- Modelling research should have in depth focus on few models with the sole aim of expanding their application pan India so that water management scenarios are well analyzed and interpreted with a common base.

Establishment of Centers of Excellence and strengthening of Organizations

- To strengthen hydrological research and promote scientific decisions on water policy, the government must upgrade its data-collection, monitoring, and communication and storage networks, in terms of both technology and density. The government's Water Resources Information System is an excellent start. Now it needs to provide real-time data on stream flow, soil moisture, groundwater levels and evapotranspiration.
- India needs multidisciplinary centers of excellence to address questions on water-system response rates to climate change, coupled forecasting of intense precipitation and floods, medium-range weather forecasts for agricultural water management and water contamination. These centers should also train the next generation of researchers to use holistic approaches.
- There is strong case for strengthening central and state pollution control boards to enforce effluent standards.
- Strengthen WALMIs – build capacity in IMT and water management; modify training curricula and infrastructure to attract people.

Policy Issues

- Government needs to liberalize subsidy on water saving technologies and offer incentives for water saving to individuals and villages as a whole.
- NWM approach is not well integrated with the agricultural policy framework. It lacks sufficient horizontal coordination across government departments. The recent National Policy for Farmers and National Mission for Sustainable Agriculture are disconnected from the NWM. Policy framework to remove this disconnect must receive the highest priority.
- Government needs to promote watershed development as several win-win case studies in the states of Gujarat and Rajasthan and by Anna Hazare have shown that this approach is effective and profitable. Since it is local level initiative, it can be accomplished in a relatively short time.
- Review, discuss and redraft PIM Act and along with prepare draft charter for issuing to WUAs and establish WUA Regulatory Authority
- A radical change in the human resources engagements and management in water sectors calls for employment of new multi-disciplinary staff with change in staff attitudes from supply alone to service delivery, farmers as clients, partnership with water users etc.

Education and Extension

- Catch them young by connecting agricultural research with education in agricultural universities.
- There is a need to convey the messages of water saving through social networks, print and electronic media and popular science writers.

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