Journal of AgriSearch 2(1): 7-13
Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)

Water Management Technologies in Agriculture: Challenges and Opportunities

ASHUTOSH UPADHYAYA*

Division of Land and Water Management, ICAR Research Complex for Eastern Region, Patna, Bihar (India)

ARTICLE INFO

Received on : 24.02.2015
Accepted on : 03.03.2015
Published online : 10.03.2015

ABSTRACT

In order to cope up with situations like excess or little availability of water leading either in flood or drought situation in the area, irrigation schedules and irrigation criteria have been developed for various crops under different agro-climatic conditions in order to apply adequate depth of irrigation at appropriate time. Research Institutions have standardized the design of gravity fed and pressurized irrigation methods suitable to soil, crop, and climate of the area. Technologies like in-situ moisture conservation, reduction in seepage loss in channels, rain water harvesting, surface and groundwater management, conjunctive use of water, multiple use of water, water and energy efficient irrigation devices, automation of micro-irrigation system etc. have also been developed and tested at various locations. This review work dedicated to the issues related to water management in holistic manner.

Keywords: Water management, LEWA, LEPA, micro-irrigation

INTRODUCTION

Water is a crucial input for augmenting agricultural production towards sustainability in agriculture. Therefore, expansion of irrigation resource was given top priority in five years plans leading to created irrigation potential of 93.9 Mha by 2001-02 out of an ultimate irrigation potential of 140 Mha. This is an achievement without parallel in the history of agricultural development anywhere in the world. No other country has attached so much attention to irrigation development as India in recent years. Irrigated agriculture has been the ultimate choice to increase food production. But it has been observed that introduction of facilities for irrigation has created problems also. Water loss in conveyance and distribution has been found to be as high as 50-70 per cent and losses in water courses alone are estimated to be about 20 per cent of water delivered at canal outlet, figures far greater than what was originally envisaged. Water losses at the farm are substantial depending upon the texture and other soil characteristics, irrigation method and cropping pattern etc. Indiscriminate irrigation in several commands had led to water logging and salinity problems. In most of the canal commands, water supply is supply-driven rather than demand-driven. It has been reported that water supply is inadequate, irregular, unpredictable and untimely, resulting in wide gap between supply and demand of water. Due to this either water users don't get adequate quantity of water at appropriate time or they get water more than their requirement. Both the situations of water scarcity or water abundance create adverse impact on agricultural production. Our country is blessed with fairly rich rainwater resource (about 115 cm per annum), but agricultural productivity of rainfed areas continues to be low and unstable. Management of rainwater assumes significance, both in low as well as high rainfall areas, for preventing rain-induced degradation and enhancing on-site and off-site agricultural productivity.

Under the situation of declining per capita water availability and quality degradation, water management assumes a great importance. Researchers are trying to answer questions like: how to irrigate? When to irrigate? How much to irrigate? and how to improve the water use efficiency so that with limited water resources more area can be brought under irrigation and achieve sustainable production. This needs sufficient attention to be paid to adopt the cost effective and efficient water management practices/technologies suiting to soil-crop-climate-socioeconomic status of the project area. In this article, an attempt has been made to highlight the latest water management technologies/practices developed and

Corresponding author Email: aupadhyaya66@gmail.com

experiences gained by various research institutes with a view to improve water and energy use efficiency and saving in time and money.

How to Irrigate?

From time immemorial it has been realized that water is just like blood to crop. Excess or much lower application of water are detrimental to crop and if water stress persists for a longer time the crop may die, so planning about methods through which water can be applied to crop becomes very important. Besides technical, physical, economic and social considerations influence the selection of irrigation system.

Irrigation Methods

There are various irrigation methods like surface irrigation methods (From traditional Border, Check-basin and furrow irrigation to Cablegation and Surge irrigation), and pressurized irrigation methods (from sprinkler, micro-sprinkler, drip, to Low Energy Precision Application (LEPA) and Low Energy Water Application (LEWA) methods). All the methods have their capabilities and limitations and can be recommended after taking into account physical, economic and social considerations. In case of Border irrigation, depending on soil type, slope and inflow rate border dimensions have been standardized under Indian conditions. Similarly, recommended values of the area of the check basin for different type of soils and inflow streams have also been computed after experimentation. Furrow irrigation is suitable for areas with water scarcity. The size and shape of the furrows depends on the crop grown, soil type, equipment to be used and spacing between crop rows. The size and shape of the furrows can be modified widely to suit the crop planting, irrigation system, and management of saline soils and use of saline water. The crop planting on the side of the ridge gives better results for vegetable crops. The planting on the top of the ridge is preferred in high rainfall regions and planting at the bottom of the furrow is preferred in low rainfall regions.

Surge irrigation

Surge irrigation is the recent development in surface irrigation methods. Under surge irrigation, water is applied in the border intermittently and not on continuous basis. It increases the advance rate. It has been introduced and evaluated for field use. Extensive experiments covering a wide range of long furrow specifications, inflow discharges, cycle ratio and number of surges with different test crops, like maize, sunflower, sorghum, groundnut have established the supremacy of surge irrigation over continuous flow. It was reported that surge irrigation was found to be discernible with 40 per cent water saving, 25 per cent yield increase, 20 per cent land saving, 40 per cent labour saving (for irrigation), ease for the labour in night hours and saving of 1250 per ha on tillage. The cost increase is only marginal. The water use efficiency was highest (8.23 & 13.13 kg/ha-cm) under surge irrigation than check basin, short strip and long furrow with continuous flow.

Cablegation

The cablegation system is an advanced, automated surface irrigation method that can be easily adapted for many different types of field crops, orchards and trees. It is designed to automatically apply a predetermined quantity of water to field at a declining rate. The water application rate is designed to closely match the infiltration characteristics of soil to minimize deep percolation and run off losses. Compared to blocked-furrow irrigation method, atleast more than 50 per cent water savings can be achieved. Properly designed cablegation systems can attain water application efficiencies of over 80 per cent. The system requires a person to turn on the water supply and control the rate into the stilling tank. This may take about an hour. Once started, the cablegation system will irrigate the entire field automatically. Once the plug reaches the end of the pipe, the irrigation water supply is stopped. The plug is un-hooked and the rope is wound manually. Both these operations could be carried out by the farmer eliminating the need for additional labour to irrigate the field. Loam to clay-loam soils that have low infiltration rates are most appropriate for this system. The soils that reach their basic intake rate in less than 15–20 minutes are more suitable for this method of irrigation. The system could also be installed in soils having higher infiltration rates provided the furrow lengths are shorter than 50 m. The land slope and water flow rate to each furrow will determine the maximum length of the furrow for the particular type of soil. The aim is to minimize deep percolation losses. Cost per acre is also less (annualized cost is 2500). Land that has a gentle slope between 0.1 to 0.5 per cent is more suitable. Land with higher slope can be used after the furrows are formed on benched terraces having gentle slopes.

Pressurized Irrigation Systems

Under pressurized irrigation systems, in sprinkler and micro-sprinkler irrigation, water is delivered through a pressurized pipe network to sprinklers, nozzles or jets, which spray the water into the air, to fall to the soil like artificial "rain". These systems, when properly spaced, give a relatively uniform application of water over the irrigated area. These systems are usually (there are some exceptions) designed to apply water at a lower rate than the soil infiltration rate, so that the amount of water infiltrated at any point depends upon the application rate and time of application, but not the soil infiltration rate. The sprinklers and micro-sprinklers work well at right operating pressure recommended by the manufacturer. The uniformity of water distribution is affected if the system is operated at higher or lower pressure and under windy conditions.

Sprinkler and micro-sprinkler irrigation systems can be used for almost all crops (except rice and jute), particularly close growing crops and on most of the soils. It is however, not suitable for fine textured soils and particularly suitable for sandy soils and undulating topography. Compared to gravity fed irrigation method water saving in Sprinkler irrigation is of the order of 20-30%. Some of the limitations of the sprinkler irrigation are high initial cost, more power requirement, clean water, stable electric and water supply, and high winds, which distort the water distribution pattern.

Trickle irrigation, which may be considered as revised form of pitcher irrigation is the slow, frequent application of water to the soil though emitters placed along a water delivery line. The term trickle irrigation is general, and includes several more specific methods. In drip irrigation system the water is conveyed under pressure through pipes to the field where it drips slowly onto the soil surface through emitters or droppers, located close to the plants.

Drip irrigation is best suited for tree, vine and row crops. The main limitation is the cost of the system, which can be quite high for closely-spaced crops. Complete cover crops, such as grains or pasture cannot be economically irrigated with drip systems. Water saving in drip irrigation as compared to gravity fed irrigation system has been reported to vary in the range of 40-60% (Pandey *et al*., 2012b). Some of the limitations of drip irrigation are: high initial cost, localized water application, clogging of drippers, requirement of constant water and power supply, high level of know-how and sensitivity to damage by sun, rodents or birds, farm animals and implements. But studies of Srivastava and Upadhyaya (1998) showed that energy requirement for pumping water from varying groundwater depths for drip irrigation reduced substantially as compared to gravity irrigation system.

Recent Developments in Pressurized Irrigation Systems

To overcome some of the limitations of Sprinkler, micro-sprinkler or drip system, such as high cost, high-energy requirement, need of technical expertise by user etc. various attempts have been undertaken. A brief review of work is presented below.

LEPA Systems

Low Energy Precision Application (LEPA) systems (developed at Texas A & M, USA) are similar to linear move irrigation systems, but are different enough to deserve separate mention of their own. The lateral line is equipped with drop tubes and very low pressure orifice emission devices discharging water just above the ground surface into furrows. This distribution system is often combined with micro-basin land preparation for improved runoff control (and to retain rainfall which might fall during the season). High efficiency irrigation is possible, but requires either very high soil intake rates or adequate surface storage in the furrow micro-basins to prevent runoff or non-uniformity along a furrow.

LEPA Type Micro Sprinkler

Under AICRP on Water Management, Agronomic Research Station, Chalakudy of Kerala Agricultural University has developed a LEPA type micro-sprinkler. Visalakshi *et al*. (2000) reported that it is suitable to irrigate vegetable, horticultural, medicinal and ornamental plants consists of a sprinkler head made of small piece of LDPE pipe (5 to 8 cm) with diameter (8-12 mm) having nozzles of 1 mm diameter drilled on opposite sides of pipe piece, 5 mm away from both the ends, which are plugged by end caps. A hole of 4.4 mm diameter is drilled at the center of the pipe to insert the micro tube pin connector. A 6 mm diameter, 1.0 m long micro tube is attached to the above sprinkler head unit at the center through the pin connector. The other end of micro tube can then be attached to lateral, again through another pin/tap connector. The micro tube with the sprinkler head unit is tied to a riser pipe, fixed near the plant to be irrigated. Since these units are light in weight, the energy required to rotate the unit along with water is considerably small and the pressure required for operation of these units is only 0.3 to 1.0 kg/cm^2 to give discharge rate of 30-45 lph. The area of coverage varies from 3.0 to 5.0 sq. m. The life of system is expected to be 8 to 10 years and cost of this system is reported as 12,000/-per hectare.

LEWA System

To address small holder irrigation, attempts were initiated under the Team of Excellence on Pressurized Irrigation Systems, sponsored by NATP at ICAR-RCER, Patna through a project entitled "Pressurized Irrigation Systems" to develop a low cost water and energy efficient water application device. According to Singh *et al*., 2009 and 2010, LEWA device is made of 25 mm diameter and 40 cm long piece of PVC pipe having 1.5 mm diameter holes with different spacing and orientation in two opposite directions. It is characterized with high application rate, which is greater than the infiltration rate of the soil of testing site to attain high sub-surface uniformity. It operates satisfactorily at an operating pressure of 0.4- 0.6 Kg/cm2 at its nozzle head to deliver a discharge of 0.25-0.3 lps. The throw diameter of LEWA is between 6 and 8 m and sub surface uniformity more than 90%. LEWA with proper modification and system development can be one of the promising answers for low cost irrigation technology package especially suiting to small farm conditions.

The cost of production (in laboratory) of LEWA nozzle comprising of the rotating mechanism was estimated to be 50/-. It is very well suited to field crops such as rice, wheat, pulses, oilseeds etc. It can operate at 4-6 m of static water head stored in a storage tank also. Initially LEWA has been tested on HDPE and fixed PVC pipe networks, but considering the cost implications several quality of flexible pipes ranging from 15 –70 per meter have been tried and initial observations reflect that due to low operating pressure requirement these pipes can be used successfully. The costs of the pipe have direct implications on its life span hence users have option to opt as per their capacity and choice. Field tests of LEWA on rice when compared with wild flooding resulted in 30 to 50% of water and energy saving whereas on wheat it indicated 10-15% of water saving and 30-50% of energy saving over sprinkler. Some problems of leakage from joining of LEWA device with riser pipe and its detachment at higher pressure as well as stability were observed, which have been rectified by changing the material and changing the design.

Automation of Micro-Irrigation System

An automized micro-irrigation system consists of three integral components i.e. sensors, control valves and monitoring software/decision support systems. A good quantum of work has been carried out in Maharashtra on cotton through automized drip irrigation at Dr. Punjabrao Deshmukh Krishi Vidyapeeth, Akola and Marathwada Krishi Vidyapeeth, Parbhani. Taley and Shekhar (2000) presented a case study on computerized drip irrigation project for cotton –growing on large scale. At Mahatma Phule Krishi Vidyapeeth, Rahuri, an automized drip irrigation system 'Vardan' was tried in pair-row planted sugarcane. The system was controlled by solenoid valves and gypsum blocks were used as soil-moisture sensor. Luthra *et al*., (1997) developed an automized irrigation system wherein tensiometer was used to sense soil moisture deficit; later Luthra *et al*., (2000) designed and developed an efficient valve control system for automation of drip irrigation and fertigation. Joshi (2000) and Reddy *et al*., (2000) described automation in micro-irrigation, schematically. Abraham *et al*. (2000) tried two automated drip irrigation systems based on soil electrical conductivity and leaf air temperature difference in Okra and observed that the systems maintained the designed soil moisture content and air-leaf temperature differential throughout the study period. Details of Indian experience on automized irrigation have been presented by Chaudhary and Batta (2004).

Irrigation Scheduling and Methods

After careful selection of suitable irrigation method it is important to know the time and amount of irrigation application. There may be mainly two situations: (i) when adequate water is available on demand, and (ii) when only limited water is available. In both situations, time and depth of water application depends on soil-water-plant-atmosphere relationship. There are number of approaches like (i) Transpiration approach, (ii) Soil-water content approach, (iii) Available soil moisture depletion approach, (iv) Soil moisture tension approach, (v) Meteorological approach, (vi) Plant indicators approach based on visual plant symptoms, plant water content and water potential, leaf diffusion resistance, plant temperature and critical growth stages of different crops. Yadav *et al*. (2000) reported that for most of the crops and crop sequences at various locations, information regarding critical crop growth stages and their sensitivity with respect to water and yield had been generated in the country and the most common approach of irrigation scheduling in our country is still based on the ratio of IW/CPE due to simplicity in understanding and application. In India for rice generally two types of irrigation practices for scheduling irrigation are followed. These are continuous submergence, and intermittent submergence, which include rotational and occasional submergence. Irrigation with 7 cm water 3 days after disappearance of ponded water in rice saves around 35% water without significant reduction in yield. Irrigation schedules in rice that alternate wetting and drying or saturation till tillering followed by maintenance of 5.0-7.5 cm of water thereafter could save 50% of water as compared to continuous submergence without affecting the yield. In case of rainfed upland rice, deep ploughing and subsoiling across the slope help in conserving moisture in wet season, which enables enhanced root growth and extraction of soil moisture from deeper layers.

Technologies for Efficient Use of Water

Upadhyaya and Khan (2009) discussed that the efficiency of irrigation water can be increased by its judicious use on the farm. The on-farm water management including in-situ moisture conservation, reduction in seepage loss through lining material and improvement in conveyance efficiency of irrigation channels, application efficiency, scheduling of irrigation, change in crop establishment and other management practices, and multiple use of irrigation water increases the water use efficiency and crop productivity.

In-Situ Moisture Conservation

Use of cowpea, lantana, daincha, paddy husk, paddy straw, grass, black polythene etc. were tried as mulch at different location under AICRP on water management in order to conserve in-situ moisture. Research experience has proved that use of mulch is an effective technology of in-situ moisture conservation and it helps in reducing water requirement of crop from other sources besides maintaining good crop yield.

Reduction of Seepage Losses through Lining Materials

Use of plastic sheet Silpaulin, 250 micron thick LDPE film have been found as effective lining material over brick and cement concrete lining to control seepage from channels and ponds at Dapoli, Almora and Palampur. Undoubtedly, lining is effective in reducing the seepage loss but technical skill and precautions are required in jointing and fixing of lining material to make it viable and acceptable by users.

Rain Water Harvesting

Maximum storage and utilization of rainwater resource reduces the irrigation cost drastically. Mishra *et al*. (1997) studied the effect of bund height on water, soil and nutrient conservation and rice yield under the agro-climatic conditions of Bhubaneswar. No reduction in crop yield was observed even at rainfall storage depth of 20 cm. Khepar *et al*. (1999) have shown that increase in rainfall storage depth from 10 to 15 cm significantly reduces the depth of irrigation water applied, runoff (excess rainfall) and increase in deep percolation. The crop yield did not differ significantly under different storage depths. A simple technology to store and utilize the rainwater is to raise the bunds of about 25 cm around farmers' fields. This technology was tried in farmers' fields and following benefits were reported (i) Arrests the rainwater in the fields during monsoon. Allows rice crop to utilize maximum rainwater and reduces the irrigation requirement through other source of irrigation, (ii) Arrests the soil and nutrients in the fields by minimizing the runoff. This practice reduces soil deposition in drains resulting in increase in their bed levels and thus more water spillage and spread in the area and (iii) Bunds help in storing the rainwater on the land surface and replenishing the ground water below the land. This results in rise of ground water, which can be utilized for irrigation during non-monsoon period.

Surface Water Management

In surface water management, the water available at the surface through canal, tanks, ponds or other sources needs strategic planning. Several workers have reported problems related to water release, allocation, distribution, and utilization in the command of Patna main Canal. The main problem in the canal commands as reported by the farmers also, is non-availability of canal water when it is required and excess flow of water when it is not required. Due to this some of the command is over-irrigated whereas others don't get water as per their requirement. In nut-shell there is a large gap between supply/ availability and demand/requirement of water. Under such situation spatial and temporal crop water requirement in the canal command can be computed and given to Water resources department in order to inform the water users well in advance about time and quantity of water to be released from canal. If water users know about the water deficit, they can plan about meeting out this deficit through other water resources. Thus, the gap between availability and requirement can be reduced to a great extent. Singh *et al*. (2004) reported that involvement of wider group of constituencies in water management could lead to more effective participatory water management. Through training camps, farmers may be educated and made aware about the proper utilization of available water. It was reported that encouragement for formation of Water Users Associations in canal commands and establishing linkages with Water resources department (Water suppliers) through frequent meetings, dialogue and discussion could help in appreciating the problems and seeking the solutions in participatory mode.

Ground Water Management

Development of rigid PVC tube wells, improved propeller pumps, improved foot valve, chain pumps for water lifting in tribal areas, efficient reflux valve, safety device against overheating of diesel engines, low cost well screens for shallow tube wells are some of the water use efficient technologies developed under AICRP on optimization of ground water utilization through wells and pumps. Proper selection, care and timely maintenance of pump, motor suction and delivery pipes and other accessories/attachments not only improves the efficiency of the system but life of the system also increases. Singh *et al*. (2008) emphasized on community participation for better technology adoption in order to enhance agricultural productivity. Singh *et al*. (2004) reported that demonstrations through various means of communication under ICAR-DFID Project accelerated adoption of optimization of rice transplanting time. It not only improved rice-wheat productivity but also encouraged groundwater utilization in the project area. Timely raising of rice nursery using tube well water, registered 2.5 times increase in groundwater market. Routing of pumped water for irrigation through a reservoir or tank and integrating with horticulture, fishery & livestock is another example of technological push to encourage ground water utilization for improving water productivity in the region.

Conjunctive Use of Water

In order to explore the possibility of conjunctive use in canal command, a simple decision support tool has been developed by Upadhyaya (2012) in visual basic (both in Hindi and English), which is capable enough to convince the water users about conjunctive use under the situation when increase in yield leading to monetary benefit is more than additional cost incurred in providing irrigation through ground water. The tool is being tested for various situations like (i) owning tubewell, (ii) Renting pumping set and (iii) purchasing water. For conjunctive use of saline and canal water, it has been suggested by CSSRI, Karnal that under the short supply of canal water, when the farmers are forced to pump saline ground water or drainage waters to meet the crop water requirements, water from the two sources can be applied either separately or after mixing. Allocation of two waters separately, if available on demand, can be done either to different fields, seasons or crop-growth stages such that higher salinity water is not applied to sensitive crops or at sensitive growth stages.

Multiple Uses of Water

Bhatnagar *et al*. (2004) and Pandey *et al*. (2012a) reported that multiple use of water in waterlogged/water stagnated area by routing the canal or ground water through a fish pond-cum-secondary reservoir and planting vegetable or fruit plants on the bunds is widely accepted technology among farmers. By weekly exchange of water, fish harvest up to 10 t/ha as additional income can be obtained. If an integrated farming system is followed in which output of one system (like excreta of animals and birds) is input to other system (fish in the pond), the nutritional value of water for fish, crops, fruits and vegetables increases resulting in increase in production and income many folds.

Water management technologies communicated by ICAR Research Complex for Eastern Region, Patna and adopted in the canal command. Some of the water management technologies communicated and adopted by large number of farmers in the canal command are :(i) Installation of low cost wooden gates on outlets of distributary for better control on water and its efficient utilization (ii) Raising bund height (from 7.5-15 cm to 25-30 cm) around rice fields to conserve rainwater in their fields and reducing pressure on canal.(iii) Advancement of rice transplanting time by 15-30 days by raising nursery in the last week of May to the middle of June and transplanting the crop between the last week of June and middle of July (iv) Multiple uses of water, which has been adopted by the SHGs and farmers of the project area under four situations i.e. (i) Pen culture for fish cultivation in waterlogged areas, (ii) Rice-fish cultivation in seasonally waterlogged areas (iii) Rice-fish cultivation in irrigated areas, and (iv) fish cultivation in local depressions/pits. This technology has not only helped the SHGs and farmers in improving their income and livelihood but their understanding has also developed. (i) One of the recent water application devices developed at ICAR Research Complex for Eastern Region, Patna is Low Energy Water Application (LEWA) device, which operates at 0.4-0.6 kg/cm^2 pressure. It can be used for irrigating rice, wheat and other close growing crops. The developed device has resulted in reduced overall energy requirements and high water and nutrient-use efficiency of the system as compared to other pressurized irrigation systems. (ii) Zero tillage for wheat establishment as it saves 25 to 30% of water in first irrigation as compared to conventional method of wheat sowing. It also saves time, energy and money. (iii) Raised bed furrow method of wheat establishment in water scarcity area as it saves 40-45% of water compared to conventional method of wheat establishment with only 10% reduction in yield (iv) Deep tillage by tractor mounted disk plough after every three years in the fields immediately after wheat harvesting not only breaks the hard layer formed below the soil, but also improves the soil structure, infiltration characteristics, soil pulverization, soil temperature and reduction in weed growth (v) Boro-rice can be sown in waterlogged areas equipped with irrigation facilities (vi) Efficient and water saving irrigation methods considering shape, size and slope of land, type of soil, crop, climate and availability of water source.

Future Challenges

Since water resources are diminishing, the need of the hour is to utilize these resources effectively and efficiently. Only then it is possible to produce more food from the available water resources. To achieve this goal there is a need to focus our research efforts on the following issues

(i) Automation of irrigation systems

(ii) Development of decision support systems for judicious utilization of rain, surface and groundwater resources.

(iii) Revival of old indigenous water storage or use technologies and their integration with latest technologies

(iv) Development of cost effective water management technologies/practices suitable for small landholders.

(v) Impact of climate change on available water resources and coping up strategies.

(vi) Factors affecting water productivity and implementation of interventions, which can improve water productivity in various agro-climatic zones.

(vii) Minimizing gap between water supply and water demand by establishing linkage between water suppliers and water users

(viii) Capacity building and training of water users and water suppliers to create awareness about use of this precious resource.

(ix) Development and transfer of socially acceptable and economically viable sustainable water management technologies in farmers field for effective implementation and up scaling in participatory mode.

CONCLUSION

Water saving and water use efficient technologies can be developed and implemented by stakeholders in participatory mode. In past many water conservation technologies have been developed and tested at the experimental farm but only few of them have been modified and up-scaled after testing at farmers' field. Thus, we have to go a long way in implementation of water saving and water use efficient technologies for judicious utilization and management of water resources in order to enhance agricultural production, and maintaining environmental, social and economic security in the country.

REFERENCES

Abraham N, Hema PS, Saritha EK and Subramannian S. 2000. Irrigation automation based on soil electrical conductivity and leaf temperature. *Agricultural Water Management* **45**: 145-57.

Bhatnagar PR, Singh AK, Upadhyaya A and Sikka AK. 2004. Promoting multiple uses of water – experiences of aquaculture. Poster presentation in Policy Consultation Workshop of DFID NRSP Research Projects R 7830/7839 on Realising Potential: Livelihoods, Poverty and Governance, August 3-4, 2004, New Delhi.

Chaudhary SK and Batta RK. 2004. Future of automation in irrigation water management. *Journal of Indian Water Resources Society* **24** (2): 36-46.

Joshi AB. 2000. Automation in microirrigation systems. In Microirrigation (Singh et al., eds). Proc. Int. Conf. On Micro and Sprinkler irrigation Systems, Jalgaon, 178-86.

Khepar SD, Sondhi SK and Taneja DS. 1999. Optimum development and management of ground water resources for sustainable agricultural production. Paper presented at Brain-storming Session-cum-Workshop on AICRP on Optimization of Ground Water Utilization through Wells and Pumps 4-5 Dec. 1996, held at JNKVV, Jabalpur: pp 13.

Luthra SK, Kalidhonkar MJ, Singh OP and Tyagi NK. 1997. Design and development of an auto irrigation systems. *Agricultural Water Management* **33**:169-81.

Luthra SK, Kalidhonkar MJ, Singh OP and Tyagi NK. 2000. Design and development of an efficient valve control system for auto irrigation set up. In Microirrigation (Singh *et al*. eds). Proc. Int. Conf. on Micro and Sprinkler irrigation Systems, Jalgaon, 174-77.

Mishra A, Ghorai AK and Singh SR. 1997. Effect of dike height on water, soil and nutrient conservation and rice yield, Pub. 5., WTCER, Bhubaneswar.

Pandey AK, Singh AK, Singh SK and Kumar A. 2012a. Livelihood sustainability of small and marginal farmers of Bihar through multiple use of water for enhancing agricultural productivity. *Envi. & Ecol*. **30**(4A): 1529-33.

Pandey AK, Singh AK, Singh SK and Kumar A. 2012b. Improving strawberry productivity and quality through drip irrigation and polythene mulch in Bihar. *Envi. & Ecol.* **30** (3A): 760-63.

Reddy KS, Bhandarkar DB, Garg V, Singh DK and Singh RM. 2000. Automation of microirrigation systems. In Microirrigation (Singh *et al*., eds). Proc. Int. Conf. on Micro and Sprinkler irrigation Systems, Jalgaon, 187-94.

Singh AK, Sikka AK, Upadhyaya A, Bhatnagar PR, Dhanphule S, Singh M K and Singh SR. 2008. Scientific perceptions and community responses in a participatory water management endeavor. *Water Resource Management* **22:**1173-89.

Singh AK, Rahman A, Sharma SP and Upadhyaya A. 2009. Small holders' irrigation- Problems and options. *Water Resources Management* **23** (2): 289-302.

Singh AK, Sharma SP, Upadhyaya A, Rahman A and Sikka AK. 2010. Performance of low energy water application device. *Water Resources Management* **24**:1353-62.

Singh R, Gautam US and Sikka AK. 2004. Optimizing rice transplanting to use rainwater efficiently. Poster presentation in Policy Consultation Workshop of DFID NRSP Research Projects R 7830/7839 on Realising Potential: Livelihoods, Poverty and Governance, August 3-4, 2004, New Delhi.

Srivastava RC and Upadhyaya A. 1998. Study of feasibility of drip irrigation in shallow ground zones of eastern India. *Agricultural Water Management* **36**: 71-83.

Taley SM and Shekar VB. 2000. Computerized drip irrigation project for cotton-growing on large scale-A case study. In Microirrigation (Singh *et al*. eds). Proc. Int. Conf. On Micro and Sprinkler irrigation Systems, Jalgaon, 309-17.

Upadhyaya A. 2012. Exploring options for conjunctive use of surface and ground water in canal command of Bihar. Technical Bulletin No. R-36/PAT-24, ICAR Research Complex for Eastern Region, Patna, 22.

Upadhyaya A and Khan MA. 2009. Strategies for sustainable land and water resources management. Proceedings of the International Workshop Water quality research to evaluate the effects of agricultural conservation practices utilized in the United States and India. September 7-8, 2009, Macmillan Publishers India Ltd., New Delhi. 37-42.

Visalakshi KP, Sreekumaran V, Susheela P and Santhakumari G. 2000. A kit for LEPA type micro sprinkler. AICRP on Water Management Agronomic Research Station, Chalakudy, Kerala Agricultural University, Mannuthy, Thrissur.

Yadav RL, Singh SR, Prasad K, Dwivedi BS, Batta RK, Singh AK, Patil NG and Chaudhari SK. 2000. Management of Irrigated Agro-Ecosystem. In Natural Research Management for Agricultural Production in India. Yadav, JSP and Singh. G.B. (Eds). India Soc. Soil. Sci. Publ. Pp. 775-70.

Zhang A, Bian R, Pan G, Cui L, Hussain Q, Li L, Zheng J, Zhenga J, Zhang X, Han X and Yu, X. 2012. Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. *Field Crops Research* **127**:153-60.

Zimmerman A. 2010. Abiotic and microbial oxidation of laboratory-produced black carbon (biochar). *Environ. Sci. Technol*. **44** (4):1295-1301.

Zwieten van L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S and Cowie A. 2010. Effects of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility. *Plant and Soil* **327**:235-46.

Correct Citation

Upadhyaya A. 2015. Water management technologies in agriculture: Challenges and opportunities. *Journal of AgriSearch* **2**(1):7-13