Water Resources Management for Enhancing Crop Productivity, Agricultural Sustainability and Food Security

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Keywords
Water Resources: Water Productivity; Agricultural Sustainability; Food Security

Synopsis
Adoption of proven and efficient water management technologies are essential to maximize crop production and minimizing gap between irrigation potential created and utilized. Application losses due to conveyance, methods and scheduling of irrigation also are effective in this direction. Selection of crop(s) and crop sequence(s) also played an important role for enhancement of water use efficiency through crop cultivation and related agronomic practices. Conservation, distribution and utilization of irrigation water are the basic parameters of on-farm water management. Optimum scheduling of irrigation, suitable method adoption, conjunctive use of rain, surface and ground water for crop cultivation having improved agro-technology adoption and provision of drainage. Application of proper amount of water at proper time increased the water use efficiency and crop yield maximization with given amount of water reducing evaporation and deep percolation. Scheduling of irrigation with limited water availability is a big challenge to the irrigation experts that needs rigorous research. It is considered the irrigation system as a complex socio-technical phenomenon that involved interaction between a physical, environmental and technological in the process of adoption. However, the participatory action research appeared to be more effective and communicative measures in the developmental processes. It is described that the participatory action research as a method of merging both developmental intervention and research activities as an effort to involve the users in systemic process of change to make the socio-technical system more effective and efficient. Majority of the farmers are reluctant to apply irrigation scheduling technologies as they do not expect a net benefit, out of its application. Some workers elaborated their work on-farm participation and encouraged the farmers to adopt irrigation scheduling as cost-benefit approach. They formulated user-friendly format for a wide variety of crops irrigated in South Africa. The on-farm irrigation management and irrigation service is improved considerably by involving farmers in water management practices and introducing an acceptable water-saving irrigation schedule for growing crops and increasing agricultural production. On-farm water management with emphasis on active participation of the farmers at each and every stage is the corner stone of success.

INTRODUCTION

Water is an essential requirement for sustaining the environment and supporting life and agricultural sector is the major user of the water resource. Despite fact that more than two-third of the earth's surface is covered with water, currently, near about 450 million people in 29 countries are facing water shortage and at least 20 percent more water would be required to meet the total water requirement for additional 3 billion populations by 2025. Amongst the total available water about 97.5 percent of is not available due to its salinity of ocean-sea and 2.49 percent is locked up in ice and only 0.01 percent is technologically available and economically accessible water either in form of surface or ground water sources for human uses including water in river, lake and water bodies (Table 1). As the water is running out due to indiscriminate uses, water resource stands one of the major crises and a threat of dire consequences resulting from poverty, hunger, eco-system destruction, climatic changes tying together other severe world problems are inevitable. As much as two-thirds of the world population could be water stressed by 2025. In this context, conservation of water for agricultural and industrial sectors has got paramount importance. It is stated that agricultural water management must be integrated with an adequate address to water conservation and transfer of water to uses with higher economic return as well as environmental benefits.

Table 1: World water availability pattern

Forms of water	Per cent availability
Sea and Ocean	97.208
Ice and Iceland	2.150
Atmospheric water	0.006
Ground water (Under the ground)	0.625
Surface water (Lake, River, Pond)	0.001

WATER RESOURCES

Precipitation is the main source of water that varied differently within agro-ecological zones. The amount of annual rainfall exhibits certain typical characteristics of distribution. India received about 80% of the total annual rainfall within three-month time in 80% of the area and average annual rainfall comes about 1170 mm in comparison to 800 mm world average. The total rainfall hours as estimated about 200 hours wherein more than 50% occurred within 20-30 hours time. The wastage of water mainly through run-off became unavoidable. The infiltrated part of rainfall usually converted in to soil water that used by the crops/vegetations, part of which evaporated and rest gone down as ground water or appeared as springs and streams wherein the major part flown as run-off on the land surface. Only about 20 percent of run-off water could be possible to utilize effectively. As a consequence, more that one-third of total area became drought prone in our country.

STATUS OF GROUNDWATER

It is reported that nature's way of storing water is under ground, where about 98% of the entire world's liquid and fresh water occurs. And mostly 2% occurs in streams and lakes, which often are fed by groundwater as a dependable source, less affected by the vagaries of climate. Indiscriminate use of groundwater particularly with introduction of high irrigation responsive photo-insensitive short duration rice varieties through out the year caused a drastic depletion of the ground water table and posed a complicated problem. Groundwater reservoir was primarily replenished by the annual precipitation received in a particular area. The rate of entering water to ground water reservoir was depended on pattern of rainfall, run-off, stream flow, permeability of the soils and earth materials present prior to reach the water up to the zone of saturation. The total water resource of the country comes about 400 million ham and total amount of surface flow through out the year in our country is estimated as about 180 Mham, out of which about 105 Mham comes from annual rainfall (Table 2 and 3). The estimated ground water recharge per year is about 67 Mham, out of which about 50 Mham comes from rainfall. Hence there is enough scope to increase the amount of rechargeable ground water adopting ways and means. Introduction high yielding irrigation-responsive varieties of rice and intensive cropping system three to four crops in a year in the same peace of land required huge amount of water. The water was supplied from ground water resources. The deep and shallow tube wells were dug indiscriminately. As results, the depletion of water table occurred to be severe.

In this context, it was very much important to have the access as much as the excess water could be added to under ground reservoir during the period high to medium rainfall; the possibilities of occurrence of flood would be drastically reduced. And as the water table would come to rise, the re-cycling of water during the period of drought would become easier and safer. There was clear indication that several soil conservation and water-harvesting measures could increase the ground water recharge up to a certain limit. In India, groundwater recharge from open wells and pits are very common practices in Orissa, Gujrat and Rajasthan. That's why greater exploitation of ground water prior to rainy season provided scope of greater quantity to infiltrate during high rainfall period. The use of surface water would become also to be more effective and helpful to mitigate the arsenic like problems. As the possibility of contamination of arsenic are very less in surface water; only the flowing surface water is the safest source that is free from arsenic. In this context, it is essential to add ground water as much as possible taking all possible measures for its purification (avoiding all sorts of contamination following de-germs chambers to be constructed for the purpose) and taking off water at need without hampering the water table depletion.

Table 2. Demand and supply of water resources in India

Demand and supply	Km^3
Amount of surface water resources	1880
Amount of usable surface water	690
Amount of usable ground water	418
Total usable water	1108
Water demand in 2002	780
Water demand in 2025 (Estimated)	1200

Table 3. The water resources scenario in India

Annual Average Precipitation	1140 mm
Total Available water	400 million ha
Net area sown	145 million ha
Gross cropped area	175 million ha
Irrigated area	70 million ha
Water demand for irrigation	46 million ha

India is one of the few countries in the world having abundant water resources as evident from demand and supply of water resources in the country. Water resources demand is lesser than supplies. But water scarcity became evident from frequent occurrence of drought at different locations of the country mainly due to lack of proper conservation and maintenance as well as uneven distribution of annual rainfall. As it was not possible to harvest excess rainwater during heavy to medium peak rainfall period, either that caused the disasters in form of flood or flown to the sea and ocean or followed by drought in the period when there is no possibility of occurring rainfall. The erratic and uneven distribution of annual rainfall coupled with lack of proper water harvesting technologies along with improper management of water resources at different locations of the country is responsible for such situations.

IRRIGATION POTENTIAL

The irrigation potential of the country was reportedly created about 22.6 mha with a food grain production of 50 million metric tons in the year 1951 and that reached 96.9 mha having food grain production of 200 million tons resulting per capita food grain production is about 200 kg/year/person. The gap between irrigation potential whatsoever created at the huge investment of national exchequer and its utilization started from the year 1960, is also becoming wider and that was serious concern of the researchers, policy makers and planners.

IRRIGATED AGRICULTURE

The effect of supplemental water application as irrigation for crop production as it needs during rainless period is well established throughout the World. The plant has life, so it requires water for growth and development to give us proper quality and good yield. Water is required for metabolic activities including solublization, absorption and translocation on the way of bio-chemical processes in photosynthesis, respiration and transpiration. The objective of irrigation management is different where availability of water is abundant that of limited or restricted water supply. The former is associated with yield increase per unit of land, irrespective of amount of water used for the purpose, where, later is to increase crop yield per unit of water use. Water requirement of crops and crop response to water use vary with different physiological growth stages. The certain growth stages are more sensitive to water stress situation. So particularly, where water supply is scarce or limited, it is necessary to take account of application of water to the critical growth stages with respect to moisture requirement to get higher water use efficiency. If the crop suffers from water shortage during this period, either quality or yield of the crop reduces drastically. The optimum moisture conditions in the soil profiles are very much essential to maintain for getting the qualitative and quantitative standard of the crop output.

CROP WATER REQUIREMENT

The demand for water to crop usually comes from evaporation and transpiration, which is commonly known as consumptive use, associated with unavoidable conveyance losses during application and some special needs during land preparation and transplanting. The supply of water to meet the crop needs usually come from effective rainfall, irrigation water application and contribution from storage moisture at the soil profile.

Equationally, WR=IR+ER+S where WR= Water Requirement, IR= Irrigation Application, ER= Effective Rainfall and S= Storage moisture in soil profile

So, IR=WR-(ER+S)

To calculate the water requirement of the crop, it is essential to know the existing moisture status of the soil at sowing and harvesting on which the crop is growing. It needs the knowledge of root system and rooting habit of the particular crop and procedure to determine the moisture content in the different soil profile up to root zone depth of the crop. The crop usually extracts moisture for essential activities through root system. Water comes up to the tip of the leaves to complete the food production processes and goes down to the root again.

So before going to apply irrigation, it is very important to know:

- The crop which the farmer wants to grow with its rooting habits;
- The physiological critical growth stages; and
- The existing moisture status of the soil profiles up to root zone depth.

WATER BALANCE

It is very important to harvest excess rain water as runoff during medium to heavy rainfall period for its utilization in crop production during rainless period and development of rainfed agriculture through scientific management of rain water, particularly in the East African countries. The gains of water would come from total rainfall over period of application of water as irrigation. The losses constitute a total runoff (R), downward draining (D), Evaporation (E) and Transpiration (T). Thus the balance sheet shows as Surplus and Deficit over a particular period and it uses to give a changed situation of stored moisture in the soil profiles as well as in the plants.

Equationally,

Gains = P (rainfall) + I (Irrigation); Losses = Runoff (R)+ Down ward Drain (D) + Evaporation (E) + Transpiration (T); Gains-Losses = S + V where,

S and V are changed moisture status in soil profiles and plants, respectively.

Water use for crop production

To get proper understanding on water use, it needs experimentation and observation on the basis of scientific information on these aspects mentioned above. Only the research findings on water requirement of crops and irrigation water use for crop production would lead to formulate a guide lines on effective utilization of irrigation potential whatsoever it has it has been created. The economic and judicious water application was also ensured by these guidelines. So the entire principles of irrigation, its theories and practices, depends on:

1. How much water to apply? i.e. Measurement of irrigation water;
2. When to apply the supplemental water as irrigation? i.e. proper timings and scheduling of irrigation application; and
3. How best to apply irrigation? i.e. methods of water application to the crop for sustainable production.

MEASUREMENT OF IRRIGATION WATER

Establishing the water requirement of crops excluding it from rainfall occurred and moisture present in the soil profile, the requirement is determined. The total amount of water to be supplied as irrigation is usually divided with time of intervals through out the growth period, which indicates the amount of irrigation to be applied at each irrigation. It mainly depends on the rooting habits of the crop and moisture holding capacity of the soil, so it is very important to determine moisture content of the soil profile and also it is very pertinent to know moisture-holding capacity of the soils.

Soil sample placed in dry air oven at 105 to 110 ºC temperature for 16 to 18 hours up to a constant weight, it gives moisture amount, multiply it with soil depth from where the soil sample was collected (cm) and apparent specific gravity (bulk density, g/cm^3), the moisture content in the soil profile can be determined. This value is subjected to change with tillage operation, cropping pattern and manure application. So it is advisable to check on the bulk density values of the soil, time to time, before calculation of the moisture content in the soil profile.

The followings are the preconditions of irrigation water measurement or amount of water to be applied at each irrigation:

- Occurrence of rainfall, if any;
- Calculation of soil moisture and bulk density;
- Rooting habit of the crop to know effective root zone depth; and
- Moisture holding capacity of the soil at each soil depth.

The moisture holding capacity is commonly known as field capacity and subtracting it from moisture content of the soil profiles, the amount of water can be measured directly by water meter. There are several indirect methods of measuring irrigation water like orifice, v notch, parshall flume. These are very simple devices to measure irrigation water to crop field during its application, which needs only calibration with time factor.

IRRIGATION SCHEDULING

It is equally important to fix up the time intervals of water application to crop field. Several criteria are usually deployed to find out the proper timings of water application. The soil tensiometer, resistant or gypsum block, neutron moisture meter used to give information on moisture status at particular root zone depth of soil profile which indicated moisture availability in any specific zone. These equipment as well as moisture depletion method could be employed to make irrigation schedule of a crop. The cumulative daily evaporation value from any standard open pan evaporimeter also may be used as indices to irrigate the crop at proper timings. But when the water supply is limited, application of water at identified critical growth stages used to make the irrigation schedule to the crop.

WATER APPLICATION METHODS

Selection of appropriate method of irrigation water application to the crop field is depended on soil type (clay, silt, sandy loam, loam etc), topography (undulating or flat), sources and amount of water available, crop to be grown and management practices adopted. The appropriate method would lead to give good storage and distribution efficiency.

Surface, subsurface, sprinkler and drip (trickle) are commonly classified methods where the surface method includes border strip, check basin and furrow according to field lay out and availability of water through gravity flow. Surface methods are usually employed to comparatively flat or leveled land with gentle slope having advantages of gravity flow by selecting suitable water lifting devices or making diversion from continuous flow of water from perennial sources.

Sub-surface methods are not very common in practices due to its difficulties in lying out and required construction work. Sprinkler (overhead) method is application of water as similar to rainfall with rotary heads or perforated pipes under the pressure created to the nozzles, holds good to any bunch crops like cereals (other than rice) and oilseeds. The drip (trickle) methods involves carrying water through small diameter plastic tubes with drippers which emits water drop by drop near base of the plants/roots irrespective of topography and holds good and much economic to the horticultural crops like mango, guava, citrus even for coffee and banana. Though initial installation expenditure are more to the sprinkler and drip system, it would be more economic in the long run by increasing yield with much water saving, less power required, much saving in labourers and annual maintenance having effectiveness under any topographical situation at different landscape.

WATER CONVEYANCE AND IRRIGATION EFFICIENCY

Water from the sources, when it reaches to the crop field as irrigation, it requires any distributory system like watercourses or channels. It involves a loss of water through the distribution system associated with percolation, evaporation and losses occurred by runoff at borders and furrows. So the ratio of actual water that has been utilized as irrigation out of total water delivered from the source is known as irrigation efficiency. The ratio between the water stored in the root zone depth and the total water reached to the crop field is known as water application efficiency. The ratio between water stored in the root zone depth and the actual requirement of water prior to irrigation water application is known as water storage efficiency. These could be transferred and termed as operational or economic efficiency of the system.

ON-FARM WATER MANAGEMENT

Adoption of proven and efficient water management technologies are essential to maximize crop production and minimizing gap between irrigation potential created and utilized. Application losses due to conveyance, methods and scheduling of irrigation also are effective in this direction. Selection of crop(s) and crop sequence(s) also played an important role for enhancement of water use efficiency through crop cultivation and related agronomic practices. Conservation, distribution and utilization of irrigation water are the basic parameters of on-farm water management. Optimum scheduling of irrigation, suitable method adoption, conjunctive use of rain, surface and ground water for crop cultivation having improved agro-technology adoption and provision of drainage. Application of proper amount of water at proper time increased the water use efficiency and crop yield maximization with given amount of water reducing evaporation and deep percolation. Scheduling of irrigation with limited water availability is a big challenge to the irrigation experts that needs rigorous research. Trist (1980) considered the irrigation system as a complex socio-technical phenomenon that involved interaction between a physical, environmental and technological in the process of adoption. Whyte (1991) stated the participatory action research as more effective and communicative measures in the developmental processes. Korten (1980) described the participatory action research as a method of merging both developmental intervention and research activities as an effort to involve the users in systemic process of change to make the socio-technical system more effective and efficient. Majority of the farmers are reluctant to apply irrigation scheduling technologies as they do not expect a net benefit, out of its application (Annandale *et. al.* 1996). Westhurizen and Annandale, 1996 elaborated their work on-farm participation and encouraged the farmers to adopt irrigation scheduling as cost-benefit approach. They formulated uses friendly format for a wide variety of crops irrigated in South Africa. Cheng Xianjun,1996 reported that on-farm irrigation management and irrigation service thereby improved by involving farmers in water management practices and introducing an acceptable water-saving irrigation schedule for growing crops and increasing agricultural production. On-farm water management with emphasis on active participation of the farm at each and every stage (Belloncle,1988).

A series of on-farm water management research activities were conducted as a collaborative project of Indian Council of Agricultural Research, New Delhi and Ministry of Water Resources, Government of India in some of the selected command area either by package intervention or conducting component technology field trials in the irrigation command. Pramanik and Mallick, (1996) described on-farm participatory field trials brought positive improvements towards better water use efficiency following the recommended methods of water management practices in the farmers field in DVC command. Agarwal and Khanna (1983) also reported efficient soil and water management for enhancing agricultural productivity in Haryana. Dhindwal and Poonia (1994) reported the success story of on-farm water management in Haryana. Rajput (1993) also described that on-farm water management proved much more effective than that on-station field trials conducted at several states.

CONCLUSIONS

Water resources management is an important consideration to the researchers to address the issues like global climate changes, natural disasters, pollution, environmental degradation, soil health and food security to fit the system in mitigating occurrence of such situations. In addition to the procedures to be adopted for rainwater harvesting and it’s effective utilization, it is essential to explore the possibilities of inter basin transfer of water from surplus to deficit basin to increase maximum water resources to get full potential of irrigation development.

1. It is also essential to find out the ways and means to use the contaminated as well as reclaimed water for its effective utilization in crop cultivation;
2. Efficient utilization of water saving irrigation technologies for growing crops;
3. Introduction of supplemental and protective irrigation that could save at least 30% of irrigation water minimizing conveyance and other losses; and
4. Adoption of micro-irrigation could save 30-60% of water with 30-50% increased crop yield. Save water and increase the area under crop cultivation as well as more crop yield with less water application is the basic purpose of adapting integrated water resources management.

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