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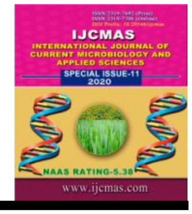

Review Article

Precision-Smart Water Technologies for Improving Water Use Efficiency and Water Productivity under Concept of Sustainable Farming as in Climate Change Situations

Raghuvir Singh Meena[1], Ganga Ram Mali[2], Komandla Venkatkiran Reddy[3], B. Sri Sai Siddartha Naik[4], Somdutt[5], Tirunagari Rupesh[6], Jitendra Singh Bamboriya[7] and Swetha Dhegavath[8]

[1]Department of Agronomy, RCA, MPUAT, Udaipur, Rajasthan, India
[2]KVK Gudamalani, AU Jodhpur Rajasthan, India
[3]Department of Agronomy, College of Agriculture Rajendranagar, PJTSAU, Hyderabad, Telangana, India
[4]Department of Agronomy, RCA, MPUAT, Udaipur, Rajasthan, India
[5]Directorate of Research, SK Rajasthan Agricultural University, Bikaner Rajasthan, India
[6]Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi, India
[7]Soil Science and Agricultural Chemistry, MPUAT, Udaipur, Rajasthan, India
[8]Department of Soil Science and Agricultural Chemistry, PJTSAU, Hyderabad, India

**Corresponding author*

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A B S T R A C T

Water is considered as the most critical resource for sustainable agricultural development worldwide. Irrigated areas will increase in forthcoming years, while fresh water supplies will be diverted from agriculture to meet the increasing demand of domestic use and industry. Furthermore, the efficiency of irrigation is very low, since less than 65 % of the applied water is actually used by the crops. Worldwide water management in irrigated and rain-fed agriculture is becoming more and more complex to overcome the expected water scarcity stress. The sustainable use of irrigation water is a priority for agriculture in arid areas. So, under scarcity conditions and climate change considerable effort has been devoted over time to introduce policies aiming to increase water efficiency based on the assertion that more can be achieved with less water through better management. Better management usually refers to improvement of water allocation and/or irrigation water efficiency. Agricultural practices, such as soil management, irrigation and fertilizer application and disease and pest control are related with the sustainable water management in agriculture and protection of the environment. Socio-economic pressures and climate change impose restrictions to water allocated to agriculture. In addition to this, challenges of global warming and climate change would have to be met through the judicious application of water in agriculture through climate-smart water technologies. Agriculture is an important sector in India and many developing countries, providing huge employment opportunities to rural populations, and supporting them to achieve food and nutritional security goals. In this paper, an attempt has been made to address challenges of increasing food production and improving rural livelihoods, while safeguarding critical water resources for sustainable use through adaptive measures for effective water management, particularly in drought-prone regions and to facilitate an improved understanding of the potential implications of climate change and adaptation options for agricultural water management and thereby assist policymakers in taking up adaptation challenges and developing measures to reduce the vulnerability of the farming sector to climate change. An integrated approach needs to be implemented in agricultural water management through adoption of innovations such as water harvesting, micro-irrigation and resource conservation farming to increase water-use efficiency in agriculture and other critical services to humans and animals.

Introduction

Water is considered as the most critical resource for sustainable development in most Mediterranean countries. It is essential not only for agriculture, industry and economic growth, but also it is the most important component of the environment, with significant impact on health and nature conservation. Currently, the rapid growth of population along with the extension of irrigation agriculture, industrial development and climate change, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" methodology either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident. Global irrigated area has increased more than six-fold over the last century, from approximately 40 million hectares in 1900 to more than 260 million hectares (FAO, 1999). Today 40% of the world’s food comes from the 18% of the cropland that is irrigated. Irrigated areas increase almost 1% per year and the irrigation water demand will increase by 13.6% by 2025.

Water is considered as a powerful indicator of ecological sustainability and economic prosperity (Kumar *et al.,* 2013). Seventy percent of the Earth’s surface is covered with water but 97.3% of the total water on Earth is saline, and only 2.7% is available as fresh water (Kumar *et al.,* 2013). Almost 85% of all the water taken from rivers, lakes, streams and aquifers in India and in many of the developing countries is used for agriculture. The influence of global warming and climate change on the regional hydrological cycle would affect water resources and reduce the availability and reliability of water supplies in many places which are already subject to water scarcity.

Rain-fed agriculture will be primarily impacted due to rainfall variability and reduction in the number of rainy days. India has a net cultivated area of 142 million hectares (Mha), out of which, about 54% is rain-fed (Sikka *et al.,* 2016). The estimated impacts of climate change on cereal crop yields in different regions of India indicate that the yield loss could be up to 35% for rice, 20% for wheat, 50% for sorghum, 13% for barley and 60% for maize depending on the location, future climate scenarios and projected year.

On the other hand, 8-15% of fresh water supplies will be diverted from agriculture to meet the increased demand of domestic use and industry. Furthermore, the efficiency of irrigation is very low, since only 55% of the water is used by the crop (Fig. 1). To overcome water shortage for agriculture is essential to increase the water use efficiency and to use marginal waters (reclaimed, saline, drainage) for irrigation. In the 21st century, climate change has emerged as a significant challenge to agriculture, freshwater resources and the food security of billions of people in the world (Goyal and Rao 2018).

The per capita annual availability of water in India is expected to reduce to 1,465 m3 by 2025 and 1,235 m3 by 2050 (Kumar *et al.,* 2013). Projected impacts of climate change on hydrology and water resources may be different in different river basins depending upon the hydrological model, climate change scenarios and downscaling approaches used.

Studies on the impact of climate change have shown clear evidence for an observed change in global surface temperature, rainfall, evaporation and extreme events (Altieri and Nicholls 2017). The Fifth Assessment Report of the International Panel on Climate Change (IPCC) has reported on climate change and its observed consequences in South Asia

(IPCC 2014). The effect of variation in rainfall patterns may affect the natural recharge process, and increased temperatures may enhance crop evapotranspiration and irrigation demand in a different part of the world (Patle *et al.*, 2017). An analysis of ensemble probabilistic scenarios for India derived from more than 50 CMIP5-GCMs data for 2020, 2050 and 2080 indicated that the rise in minimum temperatures is projected to be more than the increase in maximum temperatures, whereas a rise in temperatures would be greater during Rabi season than during Kharif season (NICRA 2016).

Water resources and it's their in India

India has a geographical area of 329 million ha which amounts to 4,000 billion cubic metres (BCM) of water from annual precipitation. Due to large spatial and temporal variability in the rainfall, distribution of water resources in India is highly skewed in space and time. Surface and groundwater resources have played an important role in the socio-economic development of India. Groundwater is an important source of irrigation. The static fresh groundwater reserves of the country have been estimated as 1,082 BCM. The dynamic component which is replenished annually has been assessed as 432 BCM. The overall contribution of rainfall to the country's annual groundwater resource is 68% and the share of other resources, such as canal seepage, return flow from irrigation, recharge from tanks, ponds and water conservation structures taken together is 32% (CGWB, 2014). The primary sources of irrigation are canals, reservoirs and wells, including tube-wells. Groundwater provides about 61.6% of water for irrigation, followed by canals with 24.5% (CGWB, 2014).

There are 12 major river basins in India with an individual catchment area of more than 10 Mha and a cumulative catchment area of 252.8 Mha (Pathak *et., al*2014). The other rivers with a catchment area of more than 10 Mha are the Indus (32.1 Mha), Godavari (31.3 Mha), Krishna (25.9 Mha) and Mahanadi (14.2 Mha). The degree of development of ten river basins covering 75% of the total population will be over 60% by 2050. The total annual discharge in the rivers that flow in various parts of the country amounts to 1,869 km^3. Rivers do not remain at a high stage throughout the monsoon season, but only a spell of heavy rains lasting for a period of several hours to a few days may generate significant runoff in catchments. Due to the increasing population in the country, the national per capita annual availability of water has reduced from 1,816 cubic metres in 2001 to 1,544 cubic metres in 2011 (CWC 2015).

Green and blue water

Water resources are classified into green and blue water resources, and rainfall is partitioned into blue and green water resources via important hydrological processes. Green water is the large fraction of precipitation that is held in the soil and is available for plant consumption on-site, and it returns to the atmosphere through the process of evapotranspiration (ET).

The process by which a fraction of green water is consumed by plants is known as transpiration and the process through which an amount of green water returns back to the atmosphere directly from water bodies and the soil surface is known as evaporation. Blue water is the portion of precipitation which enters streams and lakes, and also recharges groundwater reserves. Humans can consume blue water directly for domestic and industrial use, and also for food production off-site (away from the area it originates).

Water and agricultural production

Agriculture currently uses about 70% of the total water withdraw, mainly for irrigation. Although irrigation has been practiced for millennia, most irrigated lands were introduced in the 20th century. The intensive irrigation could provide for the growth of irrigated areas and guarantee increased food production. In the 1980s, the global rate of increase in irrigated areas slowed considerably, mainly due to very high cost of irrigation system construction, soil salinization, the depletion of irrigation water-supplying sources, and the problems of environmental protection. However, as the population is growing at a rapid rate, irrigation is being given an important role in increasing land use and cattle-breeding efficiency. Thus, irrigated farming is expected to expand rapidly in the future with subsequent increase of water use for irrigation.

Irrigation is not sustainable if water supplies are not reliable. Especially in areas of water scarcity the major need for development of irrigation is to minimize water use. Effort is needed to find economic crops using minimal water, to use application methods that minimize loss of water by evaporation from the soil or percolation of water beyond the depth of root zone and to minimize losses of water from storage or delivery systems. Nowadays, during a period of dramatic changes and water resources uncertainty there is a need to provide some support and encouragement to farmers to move from their traditional high-water demand cropping and irrigation practices to modern, reduced demand systems and technologies.

It is well known that crop yield increases with water availability in the root zone, until saturation level, above which there is little effect. The yield response curve of specific crops depends on various factors, such as weather conditions and soil type as well as the reduction of the agricultural inputs like fertilizers and pesticides (Fig. 2). Therefore, it is difficult for a farmer to tell at any given moment whether there is a water deficit or not. Since overabundant water usually does not cause harm, farmers tend to “play safe” and increase irrigation amount, especially when associated costs are low.

Influence of climate change and groundwater withdrawal

Groundwater supports about 60% of irrigated agriculture and is the major source of irrigation in the arid and semi-arid regions of the country (Patle *et al.,* 2017). Groundwater levels have declined tremendously during the last three decades in many parts of the country due to overexploitation mainly in the agriculturally intensive irrigated areas. Decreased groundwater irrigation would have severe detrimental effects on many basins, and groundwater extraction ratios of many basins are significantly high. The recharge patterns in these basins indicate that the groundwater use is not sustainable. The level of groundwater development is very high in the states of Delhi, Haryana, Punjab and Rajasthan, where groundwater development is more than 100% (Patle *et al.,* 2017). This implies that in these states, the annual groundwater consumption is more than the annual groundwater recharge.

In the states of Himachal Pradesh, Tamil Nadu and Uttar Pradesh and the Union Territory of Pondicherry, the level of groundwater development is 70% and above. In the rest of the states, the level of groundwater development is below 70%. Over the years, the usage of groundwater has increased in areas where the resource was readily available. In India, about 52% of irrigation consumption across the country is extracted from groundwater; therefore, it can be an alarming situation with a decline in groundwater and increase in irrigation requirement due to climate change (Pathak,2014).

Globally, the rate of groundwater abstraction is increasing by 1% to 2% per year (WWAP,2012). If the world continues to use water at the current rates, it is estimated that demand could exceed supply by as much as 40% by 2030, putting both water and food security at risk. Demands on agricultural water are likely to increase in future as domestic, industry and environmental uses of water continue to grow. Therefore, judicious utilisation of available water resources in agriculture, given the due concern for water storage, conveyance and distribution, needs to be planned for the sustainability of agriculture throughout the water-scarce countries. Large-scale adoption and use of drip, sprinklers and conjunctive water use irrigation methods need more attention, particularly for small and marginal farmers.

Precision-smart water management technology in sustainable agriculture to enhance water productivity and water use efficiency

Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact. Its adoption involves technological problems, social behavior of rural communities, economic constrains, legal and institutional framework and agricultural practices.

However, this frequency depends upon the irrigation method and therefore, both irrigation scheduling and the irrigation method are inter-related.

Localized irrigation

Localized irrigation is widely recognized as one of the most efficient methods of watering crops. Localized irrigation systems (trickle or drip irrigation, micro-sprayers) apply the water to individual plants by means of plastic pipes, usually laid on the ground surface. With drip irrigation water is slowly applied through small emitter openings from plastic pipes with discharge rate ≤ 12 l/h. With micro-sprayer (micro-sprinkler) irrigation water is sprayed over the part of the soil surface occupied by the plant with a discharge rate of 12 to 200 l/h. The aims of localized irrigation are mainly the application of water directly into the root system under conditions of high availability, the avoidance of water losses during or after water application and the reduction of the water application cost less labour.

Irrigation scheduling

Irrigation scheduling is the decision-making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crops' water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply (Fig. 3). In water scarce regions, irrigation scheduling is more important than under conditions of abundant water, since any excess in water use is a potential cause for deficit for other users or uses.

Irrigation scheduling techniques and tools varies greatly and has different characteristics relative to their applicability and effectiveness. Timing and depth criteria for irrigation scheduling can be established by using several approaches based on soil water measurements, soil water balance estimates and plant stress indicators, in combination with simple rules or very sophisticated models. Many of them are still applicable in research or need further developments before they can be used in practice.

Most of them require technical support by extension officers, extension programmes and/or technological expertise of the farmers. However, in most countries these programmes do not exist because they are expensive, trained extension officers are lacking, farmer's awareness of water saving in irrigation is not enough and the institutional mechanisms developed for irrigation management give low priority to farm systems. Therefore, in general, large limitations occur for their use in the farmers' practice. A brief description of irrigation scheduling techniques with reference to their applicability and effectiveness are reported below.

Soil water estimates and measurements

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to assess the availability of soil water for plant growth: by measuring the soil water content and by measuring how strongly that water is retained in the soil (soil water potential). The accuracy of the information relates to the sampling methods adopted and to the selection of locations where point observations are performed due to the soil water variability both in space and depth. Soil water estimates and measurements used for irrigation scheduling include: soil appearance and feel, soil water content measurement (TDR), soil water potential measurement (tensiometers, soil spectrometers and pressure transducers), remotely sensed soil moisture.

Climatic parameters

Climatic parameters are widely used for local or regional irrigation schemes. Weather data and empirical equations that, once they are locally calibrated, provide accurate estimates of reference evapotranspiration (ETo) for a given area are used. Then, crop evapotranspiration (ETc) is estimated using appropriate crop coefficients. Information may be processed in real time or, more often, using historical data. These techniques include evaporation measurements for ETo calculation, assessment of crop evapotranspiration using climatic data (air temperature, RH, wind speed, sunshine hours) and remote sensed ET.

Crop stress parameters

Instead of measuring or estimating the soil water parameters, it is possible to get a signal from the plant itself indicating the time of irrigation but not defining the irrigation depths. This message can either come from individual plant tissues, where a correct sampling is required, or from the canopy as a whole. Therefore, crop stress parameters are useful when irrigation depths are predefined and kept constant during the irrigation season. Crop water stress parameters include leaf water content and leaf water potential, changes in stem or fruit diameter, sap flow measurement, canopy temperature, remote sensing of crop stress.

Soil - water balance

The aim of soil water balance approach is to predict the water content in the rooted soil by means of a water conservation equation:

Δ (AWC × Root depth) = Balance of entering + outgoing water fluxes,

where AWC is the available water content. Soil water holding characteristics, crop and climate data are used by sophisticated models to produce typical irrigation calendars. This approach can be applied from individual farms to large regional irrigation schemes. However, it needs expertise, support by strong extension services or links with information systems. Its effectiveness is very high, but depends on farm technological development and/or support services (FAO, 1999).

Effective irrigation scheduling

It is recognized that appropriate irrigation scheduling should lead to improvements in irrigation management performance, especially at farm level. The farmer should be able to control the timing and the depth or volume of irrigation. However, the practical application of the techniques and methods has been far below expectations. The dependence on a collective system implies social, cultural and policy constraints.

The main constrains are the lack of flexibility, either due to rigid schedules or the system limitations, the non-economic pricing of water (price covers less than 30% of the total cost), the high cost of irrigation scheduling (either for technology and/or labour), the lack of education and training of the farmers, the institutional problems, the behavioural adaptation, the lack of interactive communication between research, extension and farmers and finally the lack of demonstration and technology transfer.

The effective application of any irrigation scheduling method and effective implementation of the corresponding delivery schedule are subject to the physical capability of the collective system for delivering water according to this schedule and to the capacity of the management for operating the system properly.

Fertigation

The application of fertilizers through the irrigation system (fertigation) became a common practice in modern irrigated agriculture. Localized irrigation systems, which could be highly efficient for water application, are also suitable for fertigation. Thus, the soluble fertilizers at concentrations required by crops are applied through the irrigation system to the wetted volume of the soil. Possible disadvantages include the non-uniform chemical distribution when irrigation design or operation are inadequate, the over-fertilization in case that irrigation is not based on actual crop requirements and the excessive use of soluble fertilizers.

Deficit irrigation practices

In the past, crop irrigation requirements did not consider limitations of the available water supplies. The irrigation scheduling was then based on covering the full crop water requirements. However, in arid and semi-arid regions increasing municipal and industrial demands for water reduce steadily water allocation to agriculture. Thus, water availability is usually limited, and certainly not enough to achieve maximum yields. Then, irrigation strategies not based on full crop water requirements should be adopted for more effective and rational use of water. Such management practices include deficit irrigation, partial root drying and subsurface irrigation.

Regular deficit irrigation

Regulated deficit irrigation (RDI) is an optimizing strategy under which crops are allowed to sustain some degree of water deficit and yield reduction. During regulated deficit irrigation the crop is exposed to certain level of water stress either during a particular period or throughout the growing season. The main objective of RDI is to increase water use efficiency (WUE) of the crop by eliminating irrigations that have little impact on yield, and to improve control of vegetative growth (improve fruit size and quality). The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under conventional irrigation practices.

RDI is a sustainable issue to cope with water scarcity since the allowed water deficits favour water saving, control of percolation and runoff return flows and the reduction of losses of fertilizers and agrochemicals; it provides for leaching requirements to cope with salinity and the optimization approach leads to economic viability. The adoption of deficit irrigation implies appropriate knowledge of crop ET, of crop response to water deficits including the identification of critical crop growth stages, and of the economic impact of yield reduction strategies. Therefore, appropriate deficit irrigation requires some degree of technological development to support the application of irrigation scheduling techniques.

Partial root drying

Partial root drying (PRD) is a new irrigation technique, first applied to grapevines that subject one half of the root system to dry or drying conditions while the other half is irrigated. Wetted and dried sides of the root system alternate on a 7-14-day cycle. PRD uses biochemical responses of plants to water stress to achieve balance between vegetative and reproductive growth. During water stress development the vine's first line of defence is to close its stomata to conserve moisture. One of the principal compounds that elicit this response is the abscisic acid (ABA). As soil water availability falls following the cessation of irrigation, the ABA is synthesized in the drying roots and transported to the leaves through the transpiration stream (Loveys *et al.,* 1999). Stomata respond by reducing aperture, thereby restricting water loss. Improvement of WUE results from partial stomatal closure. However, an inevitable consequence is reduced photosynthesis. With PRD, switching the wet and dry sectors of root zone on regular basis, this transient response was overcome.

PRD has been successfully applied with drip irrigation in grapevines (Dry *et al.,* 2000), with subsurface irrigation in grapevines and even furrow irrigation in pear, citrus and grapevines. The cost of PRD application varies according to the irrigation system employed and whether it is applied to new or existing vineyards. In pre-existing irrigation systems an additional line must be added. The additional cost of installing PRD is economical where the cost of irrigation water is high and as water becomes an increasingly valuable and scarce resource. In these areas the true environmental cost of water justifies the implementation cost of PRD.

Subsurface drip irrigation

Subsurface drip irrigation (SDI) is a low-pressure, low volume irrigation system that uses buried tubes to apply water. The applied water moves out of the tubes by soil matrix suction. Wetting occurs around the tube and water moves out in the soil all directions.

The potential advantages of SDI are:

a) water conservation, b) enhanced fertilizer efficiency, c) uniform and highly efficient water application, d) elimination of surface infiltration problems and evaporation losses, e) flexibility in providing frequent and light irrigations, f) Reduced problems of disease and weeds, g) lower pressure required for operation.

The main disadvantages are the high cost of initial installation and the increased possibility for clogging, especially when poor quality water is used. Subsurface irrigation is suitable for almost all crops, especially for high value fruit and vegetables, turfs and landscapes.

Agricultural practices

Agricultural practices, such as soil management, fertilizer application, and disease and pest control are related with the sustainable water management in agriculture and the protection of the environment.

Agricultural practice today is characterized by the abuse of fertilizers. Farmers very rarely carry out soil and leaf analyses in order to clarify the proper quantity and type of fertilizer needed for each crop and they apply them empirically. This practice increases considerably the cost of agricultural production and is potentially critical for the deterioration of the groundwater quality and the environment.

Agrochemicals (herbicides and pesticides) are also excessively used, endangering the quality of the surface water and negatively affecting the environment. Plant-protection products (pesticides) are often used preventively, even when there is not real threat in the area.

There is a large variety of traditional and modern soil and crop management practices for water conservation (runoff control, improvement of soil infiltration rate, increase soil water capacity, control of soil water evaporation) and erosion control in agriculture, some of which apply also for weed control (Pereira *et al.,* 2002).

Effort should be made in their rational use of chemicals for pest and weed control in order not to further pollute the environment. The soil management consists of, Soil surface tillage, which concerns shallow tillage practices to produce an increased roughness on the soil surface permitting short time storage in small depressions of the rainfall in excess to the infiltration.

Contour tillage, where soil cultivation is made along the land contour and the soil is left with small furrows and ridges that prevent runoff. This technique is also effective to control erosion and may be applied to row crops and small grains provided that field slopes are low.

Bed surface profile, which concerns cultivation of wide beds and is typically used for horticultural row crops.

Conservation tillage, including no-tillage and reduced tillage, where residuals of the previous crop are kept on the soil at planting. Mulches protect the soil from direct impact of raindrops, thus controlling crusting and sealing processes.

Conservation tillage helps to maintain high levels of organic matter in the soil thus it is highly effective in improving soil infiltration and controlling erosion.

Mulching with crop residues on soil surface which shades the soil, slows water overland flow, improves infiltration conditions, reduces evaporation losses and also contributes to control of weeds and therefore of nonbeneficial water use.

Increasing or maintaining the amount of organic matter in the upper soil layers, since it provides for better soil aggregation, reduced crusting or sealing on soil surface and increased water retention capacity of the soil.

Addition of fine material or hydrophilic chemicals to sand/coarse soils. This technique increases the water retention capacity of the soil and controls deep percolation. Thus, water availability in soils with low water holding capacity is increased.

Control of acidity by liming, similarly to gypsum application to soils with high pH. This treatment favours more intensive and deep rooting, better crop development and contributes to improved soil aggregation, thus producing some increase in soil water availability. Adoption of appropriate weed control techniques to alleviate competition for water and transpiration losses by weeds.

Enhance water use efficiency through climate-smart water management technologies

Water-smart agricultural technologies integrate traditional and innovative practices, technologies and services that are relevant for a particular location to adopt climate change and variability (CIAT, 2014). Location-specific water-smart technologies, either individually or in combination, have substantial potential to reduce climate change impacts on water resources with proper planning and implementation. A meta-analysis carried out for crop simulation under several climate scenarios showed that farm level adaptations could increase crop yields by an average of 7 to 15% and water saving from 25 to 50% when compared to without adaptation (Challinor *et al.,* 2014).

Simple adaptation measures such as changes in crop sowing dates and adoption of irrigation technologies can result in higher yields with less variation than without adaptation. Altieri and Nicholls (2017) reported that traditional management systems combined with the use of agro-ecologically based management strategies (bio-diversification, soil management and water harvesting) could prove the only viable and robust path to increase the productivity, sustainability and resilience of agricultural production under predicted climate scenarios. In view of the above, there is an urgent need to determine the impacts of climate change on crop production and water to develop possible innovative climate water-smart adoption technologies.

Best management practices in agriculture and technologies, namely, minimum tillage, different methods of crop establishment, nutrient and irrigation management and residue incorporation can improve crop yields, improve the water and nutrient use efficiency and minimise the emissions of greenhouse gases from agricultural activities. Similarly, water smart technologies, namely, micro-irrigation, furrow irrigated raised bed, rainwater harvesting structure, reuse wastewater, cover crop method, partial root dry (PRD), deficit irrigation, greenhouse, laser land levelling and drainage management can also help farmers to reduce the impact of climate change and variability (Altieri and Nicholls, 2017). National Initiative on Climate Resilient Agriculture (NICRA, 2016) has suggested several interventions such as adoption of scientific water conservation methods, precise estimation of crop water requirement, irrigation scheduling, groundwater recharge techniques, use of drought tolerant varieties, adjusting the planting dates, modifying the fertiliser and irrigation schedules and adopting zero-tillage which may help farmers to achieve satisfactory crop yields, even in deficit rainfall and warmer years. It is therefore imperative to promote water saving practices in irrigated as well as rain-fed agriculture on a large scale.

Many factors influence the extent of adoption of smart water technologies such as socio-economic characteristics of farmers, the bio-physical environment of a particular location, and the attributes of new technologies

(Campbell *et al.,* 2012). The identification, prioritisation and promotion of available water-smart technologies considering local climatic risks and demand for technology are significant challenges for scaling out smart water technologies in diverse agro-ecological zones. Problems of water scarcity could adequately be addressed through the adoption of smart water management interventions and modern irrigation technologies to enhance water use efficiency by involving the combination of area-specific approaches for both supply and demand side management. In view of the above, this paper brings together the current technical knowledge for the successful implementation of smart water technologies for climate-smart sustainable agriculture.

Climate/precision water smart technologies for rainfed and water limited situations

Current status and importance

Eighty per cent of the cultivated area worldwide is rain-fed and contributes to nearly 60% of the world's food production (Wani *et al.,* 2012). In India, the rain-fed cropped area comprises 53% of the total agricultural land, that is, 75 Mha. A large fraction of canal command areas has reached a plateau in terms of productivity, and there is a growing concern with regard to feeding a rapidly growing population. The option of increasing arable land has been exhausted, and there are limited opportunities for irrigation expansion.

However, evidence shows that a large yield gap exists in Asia and Africa between current productivity and achievable potential, with farmers' yields being a factor of twofold to fourfold lower than the achievable yields. Studies involving rain-fed agriculture show opportunities for enhancing food production through enhanced WP by adopting appropriate soil, water and crop management options. The vast potential of rain-fed agriculture needs to be unlocked through knowledge-based management of soil, water and crop resources to increase productivity and water use efficiency (WUE) through sustainable intensification.

Potential for enhancing WUE

A linear relationship is generally assumed between biomass growth and vapour flow (ET), which describes WP ranging between 1000 and 3000 m3 t^{-1} for grain production. It is recognized that this linear relationship does not apply for the lower yield, up to 3 t ha^{-1}, which is the yield level of small-scale and marginal-scale farmers in dry land/rain-fed areas. The reason is that improvements in agricultural productivity, resulting in increased yield and denser foliage, will involve a vapour shift from non-productive evaporation (E) in favour of productive transpiration (T) and a higher T/ET ratio as transpiration increases (essentially linearly) with a higher yield.

In temperate arid regions, such as West Africa and North Africa, a large portion of the rainfall is generally consumed by farmers' fields as productive green water flow (45–55%), resulting in higher yield levels (3–4 t ha^{-1} compared with 1–2 t ha^{-1}), 25–35% of the rainfall flows as non-productive green water flow and the remaining 15–20% generates blue water flow. Agricultural water management interventions in the watershed in the Indian SAT converted more rainfall into green water and also reduced the amount of run-off by 30–50%, depending on rainfall amount and distribution. There is vast untapped potential in rain-fed areas using appropriate soil and water conservation practices (Anantha and Wani, 2016).

Data obtained from long-term experiments conducted at ICRISAT's heritage watershed site have shown that due to Integrated Water Resources Management (IWRM) interventions, the average crop yield is fivefold higher than that by traditional farming practices. Similar results were also recorded at Adarsha watershed, Kothapally, Southern India, where implementing IWRM interventions enhanced crop yields almost twofold to threefold than those in the baseline situation (Karlberg *et al.,* 2015). Yield gap analyses carried out for major rain-fed crops in semi-arid regions in Asia and Africa and rain-fed wheat in West Africa and North Africa revealed large yield gaps which were a factor of twofold to fourfold lower than achievable yields.

Climate water-smart technologies for national and international applicability

To tackle the challenges of increasing food production and improving rural livelihoods, necessary measures should be undertaken for effective water management in rain-fed and irrigated regions. An integrated approach needs to be adopted for agricultural water management through adoption of innovative technologies with national and international applicability, such as rainwater harvesting, sprinkler and drip irrigation, laser land levelling, floating agriculture, floating solar panels, resources conservation farming, conveyance of water through underground pipeline systems, etc. Some important water-smart technologies are explained as follows.

Water harvesting

The term water harvesting infers the collection of inevitable runoffs, efficient storage of harvested water, its application and optimum utilisation for maximising production. Rainwater harvesting aims to minimise the effects of variations in water availability and to enhance the reliability of the agricultural output (fig 4). Water harvesting may be operated by collecting water in ponds, tanks and other storage tanks created for the specific purpose. Rainwater harvesting structures consist of dugout ponds, embankment type ponds, check dams, etc. Agronomic and engineering measures are beneficial for rainwater harvesting. For arable land at farm level, it may be done through agronomic methods such as contour cultivation, mulching, trench plantation, furrow irrigation, deep tillage, contour farming, raised bed techniques of cultivation, ridges, etc.

On the other hand, engineering techniques include contour bunds, graded bunds, bench terraces, contour trenches, conservation ditches and broad bed and furrow systems, etc. Similarly, rainwater harvesting from the roofs of houses in urban and rural areas and rainwater harvesting from the sloped roofs of low-cost and hi-tech polyhouses are increasingly important, especially in the northeastern hill states of India. Rainwater harvesting (RWH) is an adaptation strategy for people living with high rainfall variability both for domestic supply and to enhance crops, livestock and other forms of agriculture. IPCC (2014) advocated that rainwater harvesting structures are extremely important for mitigating the impact on agriculture and increasing agricultural productivity.

Furrow irrigated raised beds

Raised beds of 1 to 1.5 m width alternating with furrows are often constructed for growing vegetables, medicinal and aromatic and cereal crops (Fig. 5). Two rows of plants are usually raised on two sides of a bed or ridge. A furrow runs between two rows of the adjacent ridges of beds and supplies water to the plant rows. The method ensures saving a large amount of water. The surface soil of beds or ridges remains dry, and the creeping plants and their fruits are not damaged. Water from the furrow moves laterally into the soil below the bed or ridge to meet the crop need. It prevents the accumulation of salts at the base of plants and reduces the salt injury to crops in areas where raised bed and furrow salt is a problem. This method offers a more effective control over irrigation and drainage as well as rainwater management during the monsoon.

Precision land levelling

Precision land leveling is a proven agricultural on-farm technology that not only reduces farm irrigation needs but is also highly useful to reduce irrigation time and increase water use efficiency. A more levelled and smooth soil surface reduces the consumption of seeds, fertilisers, chemicals and fuel. The use of a laser leveller for land levelling has increased many-fold in some states – Haryana, Punjab, Uttar Pradesh and Madhya Pradesh, etc. precision levelling could save 20–25% of irrigation water. Most of the farmers in the Haryana state of India hire the equipment on an hourly basis. Farmers pay between 600 and 700 rupees per hour to use the machinery. Wakchaure *et al.,* (2015) reported that precision levelling significantly improved the soil and canopy micro-environment and favoured increasing the sorghum yield by 27–73% and substantially saved irrigation water (30.9%) compared to unlevelled fields.

Floating solar power plants

Floating solar power plants are a new emerging technology throughout the world. Solar panels are fastened to a rigid buoyant structure. Floating solar plants float on top of a body of water such as reservoirs, wastewater treatment ponds, etc. These solar panels are naturally cooled, and due to the increase in the temperature of panels being less as compared to rooftop solar power panels they give a higher performance. Floating solar panels are a source of clean, renewable electricity and help to minimise greenhouse gases. The floating solar panel structure shades the body of water and reduces evaporation from these ponds, reservoirs and lakes (Taboadaa *et al.,* 2017). Another advantage of using floating solar power plants is that the ecology of the water body is not affected and it also reduces evaporation losses to about 70%. Thus, it helps to preserve water levels during extreme summers (Taboadaa *et al.,* 2017).

According to Hassan and Pierson (2016), in many parts of Australia, the annual average evaporation exceeds the annual precipitation by more than five times. A high rate of evaporation and a prolonged drought period is a significant threat to water availability for agricultural production. Covering of water bodies using recycled clean plastic containers as floating modular devices helps to mitigate evaporation. The concept of floating solar power plants is increasing in the US, China, Japan, the UK, India and many more countries. Floating solar power plants are a new and emerging concept in India and have immense potential for overcoming the problem of energy and water crises in future.

Floating agriculture

Floating agriculture is an indigenous technique of farming which involves planting crops on soil-less floating rafts. This technique has enough potential to help farming communities in the flood-prone regions during floods and long-term waterlogged conditions (Chowdhury and Moore, 2017). Historically, these rafts were made of composted organic material, including water hyacinth, algae straw and herbs. Water hyacinth (aquatic weed) is commonly used for constructing floating beds in different regions of Bangladesh.

The floating gardens are used for agricultural production, for example, vegetables and spices for local communities. Because prime nutrients such as nitrogen, potassium and phosphorus are abundant in the floating beds, there is almost no need for fertiliser. Additionally, water prevents vermination and almost no pesticides are applied. The productivity of floating vegetable cultivation is estimated to be ten times higher than on similar sized land-based agriculture. Floating cultivation would help to mitigate this situation and reduce the pressure on arable lands by turning the flooded and waterlogged areas into productive ones.

According to Chowdhury and Moore (2017), floating agriculture has greatly supported farming communities to adapt to adverse waterlogged conditions by allowing vegetable production for daily consumption, income generation, community mobilisation along with providing food and nutrition security in Bangladesh.

Re-use of wastewater in agriculture

Due to water scarcity in the agriculture sector, recycling of wastewater is becoming more popular to augment water demand for agriculture in many parts of arid regions of the world (Alrajhi *et al.*, 2017). Re-use and recycling of municipal wastewater and industrial effluent are significant to minimise the pollution load in the receiving water and the reduction in the requirement of freshwater for various uses. Re-use of municipal wastewater after treatment is necessary to meet industrial water requirements and is being used for horticulture, watering of lawns and even for flushing public sewers and toilets. Freshwater resources can be preserved using municipal recycled wastewater and stormwater for irrigation. Phytorid is a wastewater treatment constructed wetland technology for the treatment of municipal, urban, agricultural and industrial wastewater. The system is based on specific plants, such as elephant grass (*Pennisetum purpurem*), cattails (*Typha sp*.), reeds (*Phragmites sp*.), Cannas sp. and yellow flag iris (*Iris pseudocorus*), normally found in natural wetlands with filtration and treatment capability. Some ornamental, as well as flowering plant species such as golden dhuranda, bamboo, Nerium, colosia, etc., can also be used for treatment as well as landscaping purposes.

Deficit irrigation

Partial root drying (PRD) is a new irrigation and plant growing technique which improves water use efficiency without significant yield reduction. PRD involves alternate drying and wetting of subsections of the plant root zone by exploring the plant physiological and biochemical responses (Alrajhi *et al.*, 2017). It requires part of the root system being exposed for drying soil while the remaining part is irrigated normally. The wetted and dried sides of the root system are alternated with a frequency according to soil drying rate and crop water requirement. PRD irrigation technology is widely used in horticultural crops. Abdelraouf (2016) found that PRD is promising for application in arid regions for saving water of up to 50% from crop water requirements without reduction of crop yield.

Drip irrigation/ sprinkler irrigation

Technology of more crops per drop of water Drip irrigation is one of the advanced methods of irrigation by which water can be supplied directly into the root zone of the soil. There are several methods of pressure irrigation, such as sprinkler irrigation, centre pivot and LEPA, microjets, drip/micro- or trickle irrigation and surface or subsurface irrigation. Drip irrigation systems are more efficient than other surface irrigation methods in terms of water savings, yield and water use efficiency. There is an increase in crop yields and reduction in the cost of fertilisers, pesticides and power for irrigation when using this method of irrigation. Thus, drip irrigation minimises conventional losses such as deep percolation, runoff and evaporation. The total potential of micro-irrigation in India is estimated at around 69.5 Mha. However, the coverage of micro irrigation is only 7.7 Mha (FICCI 2016). Under drip irrigation the area covered was 3.37 Mha while sprinkler irrigation total coverage area was 4.36 Mh.

Plastic mulching

Plastic mulching, a technique to cover the soil around the root zone of a plant with a plastic film, is a useful practice to restrict weed growth, conserve moisture and reduce the effect of soil-borne diseases. The states in India that have played a dominant part in implementing the mulching activity in horticulture are Manipur (21%), Assam (20%), Uttarakhand (17%) Meghalaya (13%) and Nagaland (12%), with a combined share of about 83% in the total programme of mulching. Plastic film mulch is one of the most extensively used forms of plasticulture, and it is currently used on a vast scale in China, India, Israel and Italy. While plastic mulch is used to enhance water savings of micro-irrigation in developed countries, its adoption in developing countries is often independent of micro irrigation technology. China accounts for 40% of the world's plastic mulch use. Plastic mulch performs a variety of functions, including soil disinfestation by solar energy (solarisation); covering the soil for heat collection; preventing the growth of weeds; minimising evaporation and escape of fertiliser; repelling or attracting insects; and manipulating soil temperature. Gao *et al.*, (2019) carried out a metaanalysis to quantify and analyse the effects of plastic film mulching and residual plastic on yield and water use efficiency (WUE) of maize, wheat, potato and cotton in China. They reported a significant increase in crop yield (24.32%) and WUE (27.63%). Use of plastic mulching increases the potato yield by 30.62% and WUE 30.34% in China.

Cloud seeding

Cloud seeding has been applied to many agricultural areas around the world where rain is scarce and needed for crop survival. It is a form of weather modification or making artificial rain from clouds. It is also used to suppress hail, and has been practised in Israel for the last 30 years and is being used in many other countries. Originally, seeding with the aid of silver iodide began with the use of ground incinerators. The process has been improved, and special aircraft are used for this purpose, including the use of brine as the seeding material.

Bangsund and Leistritz (2009) analysed the economic impacts of cloud seeding on agricultural crops in North Dakota and reported that the cloud seeding increased the amount of precipitation and reduced the risk of hail in the western North Dakota counties. The attempts helped to improve agricultural production and were a huge economic benefit to the region. Cloud seeding is also helpful to prevent the development of hail storms which cause severe damage to crops.

Greenhouse technology

Greenhouse crops are one of the most innovative modern agriculture technologies. Use of greenhouses is useful in conserving water while simultaneously enhancing agricultural productivity (fig: 6) Greenhouses offer a stable alternative to traditional open-air farming practices, as they allow for consistent, year-round crop growth, all while reducing water usage (Connor and Mehta 2016). It is one of the highest human-made forms of agricultural activity, because of its intense technological and bio-agronomic input in confined portions of the farm environment.

Greenhouse farming reduces water consumption as compared to open-air agriculture, mainly due to reduced evapotranspiration rates inside greenhouses. Use of drip irrigation systems improves the efficiency of water usage. By increasing the efficiency of irrigation, drip irrigation systems reduce water usage by 30–50% when compared with regularly used surface irrigation.

Retaining stubble/low till technique

Retaining stubble/low till is a technique widely applied in China. In this technique, stubble from one crop is left on the field after that crop is harvested. The low till method can improve water use efficiency by reducing soil evaporation and increasing yields in comparison to traditional agronomic techniques.

Hydroponics and aeroponics

The hydroponic technique replaces the conventional method of growing plants in soil. In this method, the liquid nutrient medium is provided for the growth of plants. It minimises the use of fertiliser and irrigation but requires continuous monitoring of plants. The benefits of hydroponic agriculture include less growing time, minimal disease, higher yields and water efficiency.

Use of hydroponics in a controlled environment helps to achieve year-round production. Hydroponics uses substantially less water as compared to soil farming. The nutrient film technique (NFT) system of hydroponics is mostly used for the successful production of leafy and other vegetables with 70–90% savings of water throughout the world (Sharma *et al.,* 2018). Leading countries in hydroponic technology are the Netherlands, Australia, France, UK, Israel, Canada and the USA. Growers should be well-versed about plant growth, nutrient balances and cultural media characteristics.

Aeroponics is also a technique for growing plants in air and a humid environment without soil. This technique is an efficient way of controlling humidity, temperature, soil pH and water conductivity. In aeroponics, plant roots are suspended in the air. The main advantage of the aeroponics system is limited water consumption.

Adaptation strategie's

Potential impacts of climate change depend not only on climate per se but also on the system's ability to adapt to change. Depending on the vulnerability of individual crops in an agro-ecological region and the growing season, crop-based adaptation strategies need to be developed, integrating all available options to sustain productivity.

These available technologies could be integrated and used for reducing the adverse impacts of climate change and climate variability. Some possible adaptation strategies that are relevant to current climatic risks are described in Table 1.

Efficient use of water and its management in agriculture is very critical for adaptation to climate change. Under rising temperatures and fluctuating precipitation patterns, water will become a scarcer resource in several parts of the world. Therefore, the amalgamation of traditional wisdom and modern innovative water management and water saving techniques needs to be thoughtfully implemented for sustainable crop production in water-scarce areas. Serious efforts towards water conservation, water harvesting, improvement of irrigation accessibility and water use efficiency would help in the strategic planning and management of available water resources in the region. In situ and ex situ water conservation techniques, micro-irrigation systems and selection of appropriate need-based irrigation must be encouraged among the farmers with proper training and skill development.

The principles of increasing water infiltration by improving soil aggregation, decreasing runoff by using contours, ridges, vegetative hedges and reducing soil evaporation by using crop residue mulch could be employed for better management of soil–water. Development of technologies along with higher investments would help improve water management efficiency. Well-timed management of deficit irrigation can make a substantial difference in crop productivity in regions with limited access to irrigation. In the non-irrigated areas, water conservation and water harvesting techniques need to be disseminated as an alternative for poor farmers. However, the adoption of such practices will require investments in capacity building and agricultural extension.

Rainwater harvesting can meet water demand in water-scarce regions. Improved irrigation methods like drip irrigation, sprinkler irrigation and use of laser-aided land levelling methods can also help in increasing water-use efficiency. Laser aided levelling provides smooth and levelled fields, which allows proper water distribution with negligible water loss and facilitates uniformity in the placement of seed/seedlings and fertiliser. It also helps in plant stand, enhanced nutrient use efficiency and increased crop yield (Pathak *et al.*, 2014).

Water requirement varies from 775 to 3,000 mm according to climate, soil, crop and water management practices followed in a region (Patle et al. 2017). Water management in rice is possible through improved cultivation methods such as alternate wetting and drying (AWD), direct-dry seeding, aerobic rice, non-flooded mulching cultivation, and the system of rice intensification (SRI) which also helps to reduce the emission of greenhouse gases and saves water. Direct-seeded rice (DSR) could be a potential option for water saving and reducing CH_4 emission compared to conventional puddled transplanted rice. The system of rice intensification (SRI) appears to be a suitable and sustainable way of growing rice for resource-poor farmers, and besides, it also has the potential of being able to increase soil fertility through increased carbon pool and mitigation possibilities of greenhouse gases.

Policy analysis and suggestion's

There is an urgent need for strong policies and programmes to promote rainwater harvesting. These should target areas that are water scarce, those that have become highly dependent on groundwater, and where rapid declines in groundwater levels are taking place. Substantial funding is required for the creation of rainwater harvesting structures and given the costs and externalities involved, it calls for public support. Conditions of institutional success such as clear objectives, good interaction, adaptiveness, appropriate scale and compliance need to be addressed by the policies and programmes to ensure proper performance. The check dam movement in Rajasthan and Gujarat shows that community involvement in rainwater harvesting projects and activities is essential for success. It also shows that creating effective village institutions with active participation can go a long way in improving results.

Other experiences indicate that to improve the impact of rainwater harvesting, it is necessary to go beyond natural resource management to add productivity enhancement activities. These may include measures to improve water use efficiencies such as drip and sprinkler irrigation, and promotion of appropriate crops, varieties and modern inputs to enhance physical productivity and economic returns.

Recommendations for best irrigation practices

The major agricultural use of water is for irrigation and its supply is decreasing steadily due to competition with municipal and industrial sectors. Therefore, technological, managerial, policy innovation and human resources management are needed to increase the use efficiency of the available water. Sustainable water management in agriculture can be achieved by:

Reduction of water losses in the conveyance, distribution and application networks. Water leakages should be detected via advanced technologies, e.g. telemetry systems, GIS, remote sensing. Old water projects experiencing considerable water losses should be rehabilitated and modernized.

Improve the efficiency of irrigation system: Improvements in sprinkler irrigation systems (efficiency up to 85%) include the adoption or correction of sprinkler spacing, the design for pressure variation not exceeding 20% of the average sprinkler pressure, the use of pressure regulators in sloping fields, the monitoring and adjustment pressure equipment, application of irrigation during no windy periods, adoption of smaller spacing and large sprinkler drops and application rates in windy areas, the adoption of application rates smaller than the infiltration rate of the soil and careful system maintenance.

Increase water use efficiency: Can be achieved with the obligatory use of localized irrigation systems by the farmers (with or without subsidies), the proper irrigation scheduling according to actual needs of the crops, the establishment of a system for advising farmers on their irrigation schedules, the introduction of appropriate agronomical practices and the application of salinity management techniques.

Adoption of innovative irrigation techniques: In water scarce regions irrigation approaches not necessarily based on full crop water requirements like regulated deficit irrigation (RDI) or subsurface irrigation (SSI) must be adopted. Fertigation (efficient fertilizer application) and chemigation (easy control of weeds and soil born diseases) should also be promoted.

Water pricing policy: For proper water pricing volumetric water metering and accounting procedures are recommended. Progressive, seasonal and over-consumption water tariffs as well as temporary drought surcharges rates contribute to water savings and should be promoted.

Reuse of marginal waters (reclaimed or brackish) for irrigation: Reclaimed waters can be used under some restriction for irrigation of tree, row and fodder crops. In addition to water they provide the soil with nutrients, minimizing the inorganic fertilizer application. Treated sewage is looked upon with scepticism by farmers. They instead prefer to use surface and/or groundwater. Special effort should be given in educating farmers to accept treated sewage. In addition, the tariff for this source of water should be lower than the tariff of the primary sources.

Capacity building: The existing "capacity building" is poor. It requires an appropriate mix of competent personnel, technologically advanced devices and facilities, legal guidelines and administrative efficient and effective processes for the sustainable management of the water resources. It includes:

a. Education and training of professional, technical staff and decision makers and others, including non-public organizations, on a wide range of subjects related to sustainable water management.

b. Manpower build-up:

Institutions to be staffed with qualified manpower (managers, engineers, technicians, social scientists) that should be adequately compensated.

c. Facilities and procedures:

Water authorities at all levels of management should be equipped with technologically advanced devices and programs e.g. computers and software for the application of new techniques such as GIS, remote sensing etc. These advanced techniques facilitate the multi-sectoral information availability and use and help water managers in their decision- making.

d. Legislative changes to the fragmented and antiquated legislation should be promoted. Responsibility of water resources planning and operation, especially at the overall national level, should be under one institution for proper organization and non-conflicting actions by the various authorities.

Need -based irrigation application

In general, farmers practise calendar-based irrigation scheduling that results in over irrigation and poor WUE. Due to inherent variability of bio-physical (soil hydraulic parameters, soil depth, etc.), topographical and land management (cropping sequence, time of sowing, etc.) factors, calendar-based irrigation scheduling does not always match with crop water requirement, resulting in reduced crop yield and poor WUE. Therefore, it is necessary to follow a need-based water application to optimize the available water resources. A decision support system called the 'Water Impact Calculator' (WIC) was developed at ICRISAT using strategic data collected at its research station (Garg *et al.*, 2016)

An ICRISAT-led consortium with local partners, non-governmental organizations and an irrigation company (Jain Irrigation Ltd.) evaluated the WIC by conducting farmer participatory field trials between 2010 and 2014 at different sites in India (e.g. Mota Vadala in Jamnagar, Gujarat; Kothapally in Ranga Reddy, Telangana; Parasai-Sindh watershed, Jhansi; Dharola Tonk, Rajasthan and the ICRISAT research station).

Irrigation was scheduled using WIC calculations and an exact quantity of water was applied as per the recommendations.

The gravimetric soil moisture content was measured at 0–15 cm, 15–30 cm, 30–45 cm and 45–60 cm soil depths at weekly intervals. Crop grain yield and above-ground biomass yield were estimated at the end of the crop harvest. WIC-simulated soil moisture was compared with measured data at different soils and rainfall regions.

Table.1 Adaptation management strategies to combat climate change

Agriculture adaptation strategies	Irrigation adaptation strategies
1.Assisting farmers in coping with current climatic risk • Improving collection and dissemination of weather information • Establishment of a regional early warning system of climatic risks • Promoting insurance for climatic risk management	1. Increasing the availability of useable water • Improving collection and dissemination of weather information • Water harvesting and storage • Increasing groundwater recharge • Recycling waste water
2.Intensifying food production systems • Bridging yield gaps in crops • Enhancing livestock productivity • Enhancing fisheries	2. Increasing the efficiency of water use • Laser levelling of irrigated area • Micro-irrigation • Adjusting crop agronomy
3.Improving land and water management • Implementing strategies for more efficient water conservation and use • Managed aquifer recharge • Exploiting the irrigation and nutrient supply potential of treated wastewaters. • Increasing the dissemination of resource conserving technologies	3. Groundwater management • Managing coastal ecosystems • Rationing electrical power supply Integration of surface and groundwater resource
4. Enabling policies and regional cooperation • Integrating adaptation in current policy considerations • Providing incentives for resource conservation • Securing finances and technologies for adaptation	4. Water transfer between basins
5.Strengthening research for enhancing adaptive capacity. • Evolving adverse climate tolerant genotypes • Evaluating the biophysical and economic potential of various adaptation strategies	5. Trans-boundary cooperation between different states.
6.Use of information and communication technology in water resource management.	

Figure.1 Water losses in agriculture

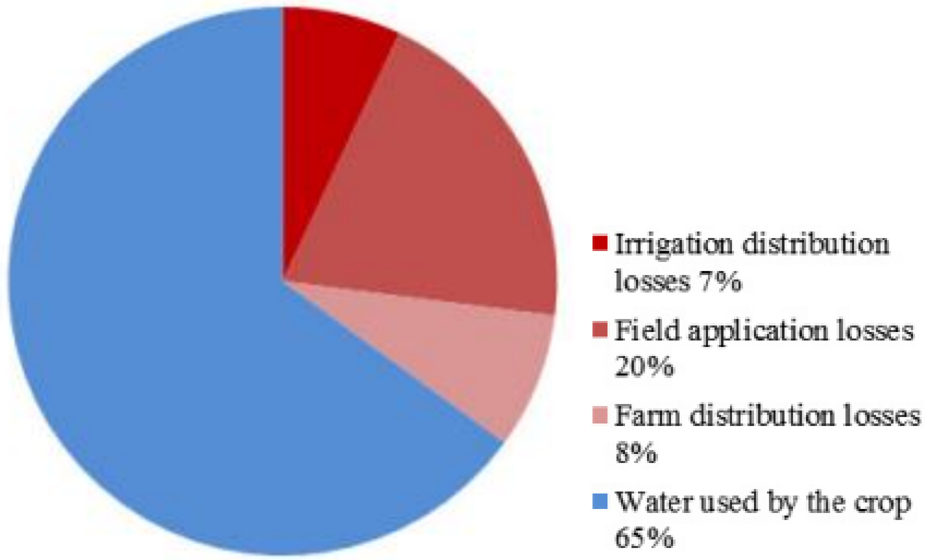

Figure.2 Plant yield response to water

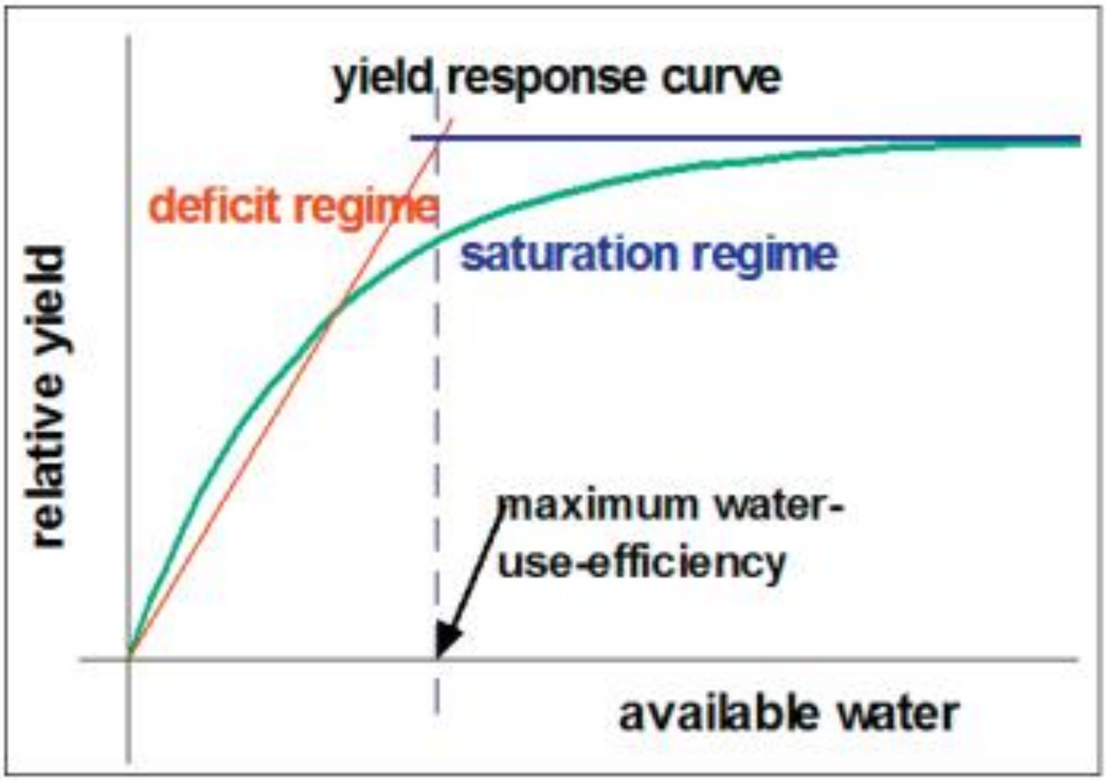

Figure.3 Irrigation scheduling components

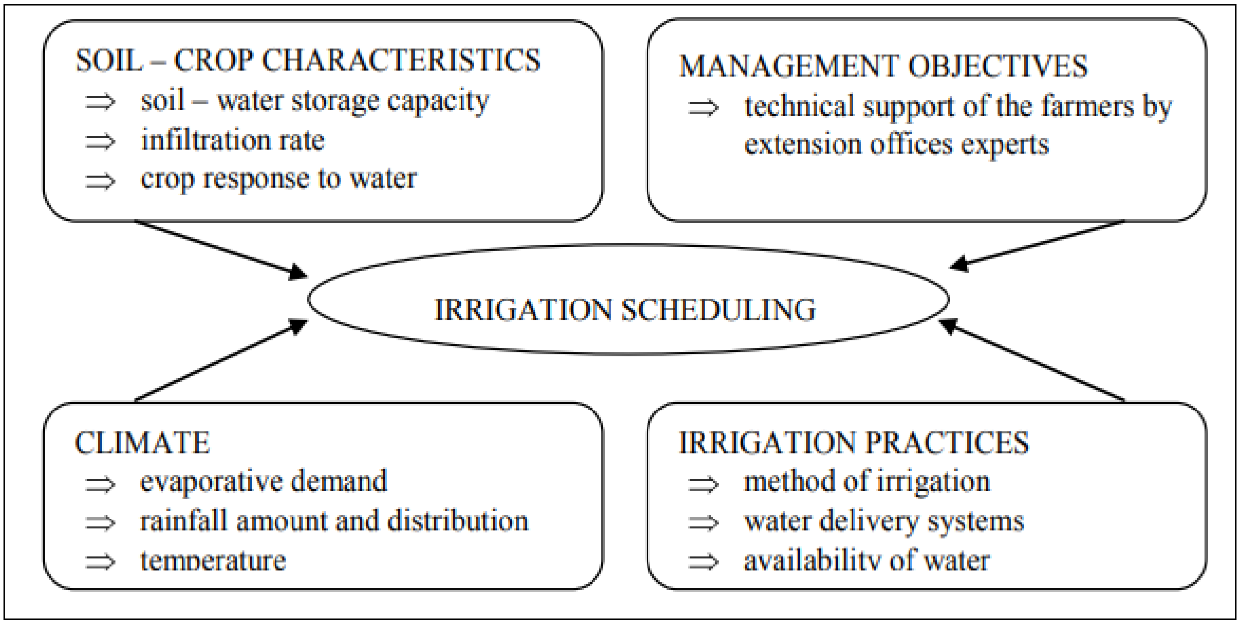

Figure.4 Rain water harvesting

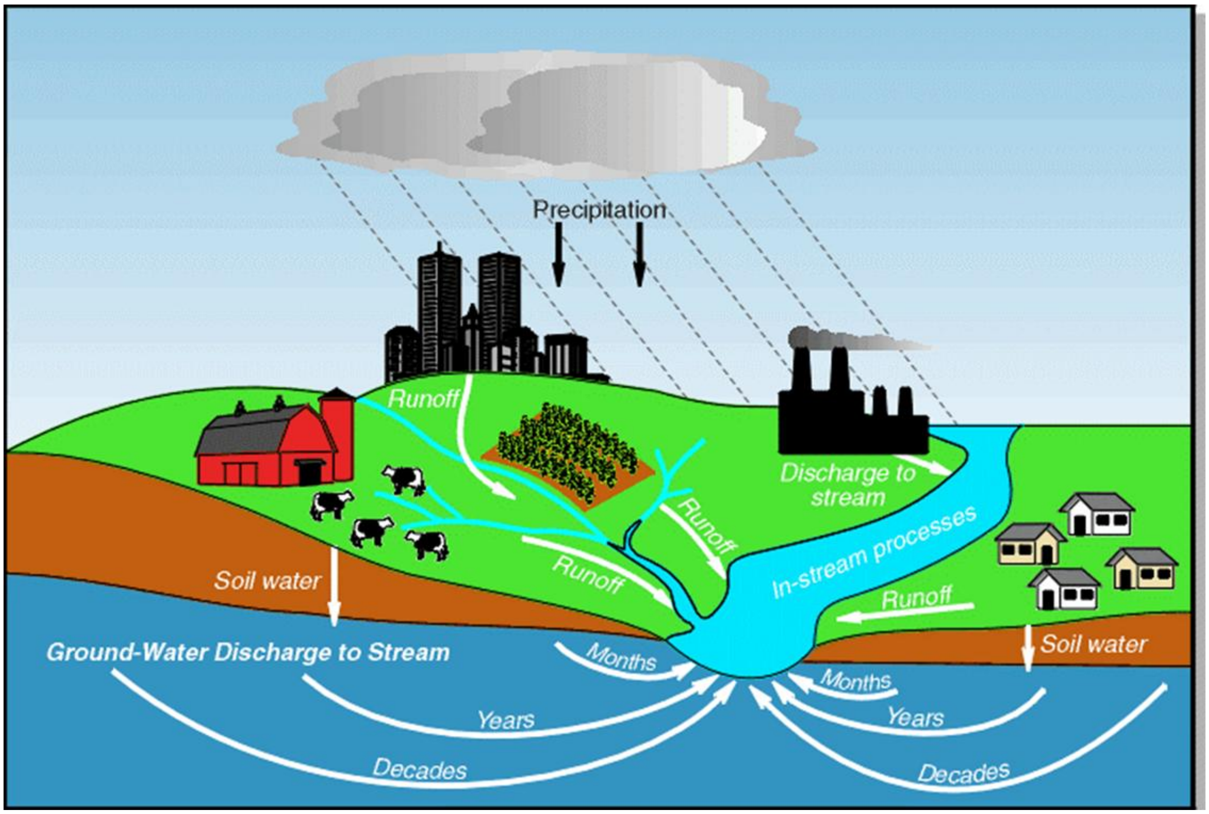

Figure.5 Furrow irrigated raised bed system.

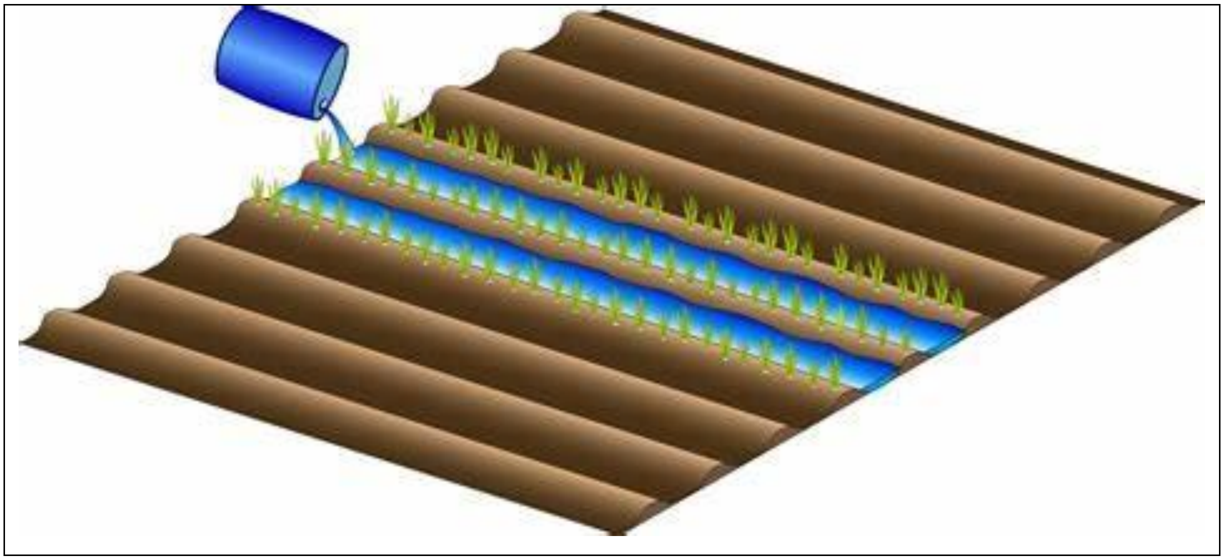

Figure.6 Greenhouse crops

In general, simulated soil moisture was found to be in good agreement with observed data. Based on minimum WIC inputs on soil type, soil depth, date of sowing and climatic data, the exact amount of water on specific dates was recommended in drip and flood/furrow irrigated fields. Crop yields were compared among WIC and traditionally managed fields. Farmers at pilot sites could save nearly 30% water due to need-based irrigation application (Garg *et al.,* 2016).

In conclusion, decreasing water availability, higher input costs and growing environmental concerns are issues that water resources managers will not be able to ignore in the future. Solutions will not be easy and are likely to be multifaceted. Managing water properly is certainly one of the major challenges of the 21st century. Water use in the agriculture sector has to reform to conserve water and other resources so that non-agricultural demand for water can be sustained. Efficient use of agricultural water can be ensured through different water-smart technologies to optimise productivity. There is a need to develop a policy framework for implementing the adaptation and mitigation options so that farmers are saved from the adverse impacts of climate change. To promote the adoption of climate-resilient strategies, we need to facilitate the transfer of climate water-smart technologies from developed to developing countries. Future agriculture has to be carried out smartly so that not only water but also other key input resources like labour, chemicals, etc. can be sustainably managed. Along with technological innovations, increased farmer awareness and the necessary policy support (e.g., water pricing and changes in water entitlements, etc. Will be essential to achieving the objectives.

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