ISBN: 978-81-19149-59-9

15. Water Management Practices Under Climate Change

Sushanta Sarkar

Technical Officer, GKMS Project,
Bihar Agricultural College,
Bhagalpur, Bihar.

Abstract:

Water is considered as the most critical resource for sustainable agricultural development worldwide. Irrigated areas are increasing day-by-day, while fresh water supplies are diverted from agriculture to meet the increasing demand of domestic use and industry. Furthermore, the irrigation use efficiency is very low as less than 65 % of the applied water is actually used by the crops. Application of proper water management practices is a priority for agriculture in arid areas. So, under climate change and water scarcity conditions extra effort should be given over time to introduce policies aiming to increase water use efficiency through better water management practices. Better management usually refers to improvement of water allocation and efficiency of irrigation water. The former is related to adequate pricing, while the latter one depends on the type of irrigation method, scheduling of water application and weather condition. Different agricultural practices, such as soil management, irrigation application and disease-pest control are related with the sustainable water management in agriculture. The adoption of sustainable water management is not only a technological problem but involves many other considerations related to social behavior of rural communities, the economic constrains, legal and institutional framework. Sustainable water management in agriculture can be achieved by adopting different management practices, such as improvements in irrigation application, water pricing, reuse of wastewater, soil and plant practices, farmers' participation in water management and capacity building.

Keywords:

Irrigation, Water efficiency, Water reuse, Innovation, Capacity building.

15.1 Introduction:

Water is one of the most essential natural resources of the planet. Water is also the most critical resource for sustainable development in most of the developing countries. The quantities that are needed for drinking and sanitation purpose of humans are relatively small, and much larger quantities of water are required for many other purposes. It is essential not only for agriculture, industry and economic growth of a country, but also it is the most important component of the environment and ecosystem, with significant impact on overall wealth and nature conservation. Agricultural and industrial activities critically depend on a sufficient amount of fresh water that is withdrawn from rivers, lakes and groundwater aquifers.

Currently, the rapid growth of world population along with the extension of irrigation dependent agriculture, development of industrial sector and climate change are stressing the quantity and quality of the natural water systems. Due to the increasing problems, human have begun to realize that they can no longer follow "use and discard" methodology either with water resources or any other natural resources. As a result, the need for water management has become evident. Climate change has already started to affect the hydrological cycle and the availability of freshwater for agriculture. So, proper water management practices play crucial roles in the food production and the management of ecosystems. Over the last century global irrigated area has increased more than six fold from approximately 40 million hectares in 1900 to more than 260 million hectares in 2000. Today more than 40% of the world's food comes from the irrigated cropland which is 18% of the total cultivated crop land. Irrigated area is increased by almost 1% every year and the demand for irrigation water will increase by 13.6% by 2025 (Jensen, 1993). On the other hand about 8-15% of fresh water supply will be diverted from agricultural sector to meet the increased demand of domestic and industrial use. On the other hand the efficiency of irrigation is very low, only 65% of the applied water is used by the crop (Figure 15.1). So, to overcome shortage of irrigation water for agriculture, it is essential to increase the water use efficiency in the crop field and to use marginal water for irrigation.

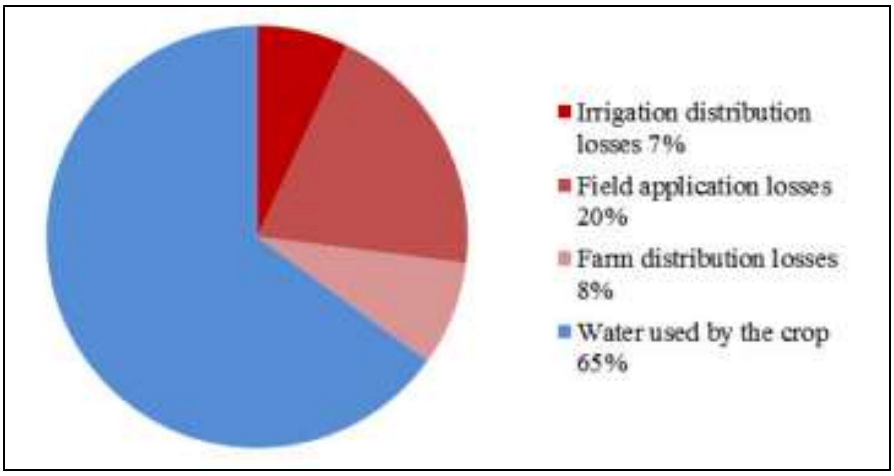

Figure 15.1: Water Losses in Agriculture

15.2 Water Management and Climate Change:

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), climate change is a significant threat to all nations, in particular, developing nations that are dependent on agriculture for subsistence. Climate change appears as an additional threat to water security because changes in rainfall and other climatic variables due to climate change leads to significant changes in fresh water supply in many regions (6–11). However, the effect of climate change on water resources is uncertain for different reasons. Observed data and a number of climate projections show that changes in water quantity and quality due to climate change are expected to impact negative affect on food security and increase the vulnerability of poor farmers, especially in arid and semi-arid regions. In many countries, agricultural production is already being adversely affected by climate change (FAO, 2016a). Higher temperature, less supply of water, more frequent occurrence of droughts and floods are likely to reduce yields in many areas. However, there are many non-climatic factors such as expanding population and urbanization, increasing competition for natural resources, improvement in agronomic management practices, technological innovations, global economic growth, trade and food prices that strongly influence agricultural production. These non-climatic factors have more instant impacts on water resources than those caused by climate change (Bates *et al.*, 2008). For this reason, it is more important to understand the current status of water management before assessing the impacts of climate change. From agricultural water supplies to flood management and ecosystem protection, climate change is affecting all aspects of water resource management. Rising average air temperature, loss of snowpack, frequency of flood events and rising sea level are some of the impacts of climate change that have broad implication for water resource management.

15.3 Water and Agricultural Production:

Currently about 70% of the total water used in agriculture is mainly applied for irrigation. Although irrigation has been practiced from the ancient era, most of the irrigated lands were introduced in the 20^{th} century. In the 1980s, the global rate of increase in irrigated area slowed considerably due to high cost of irrigation system construction, depletion of irrigation water, soil salinization and the problems of environmental protection. However, as the world population is increasing at a rapid rate, irrigation has an important role in increasing land use efficiency. Thus in the future, irrigated farming is expected to expand rapidly with subsequent increase of water demand for irrigation.

Irrigation is not sustainable if water supply is not reliable, especially in the areas where water scarcity is the major problem for development of irrigation. So, extra Effort is needed to find economically suitable crops which can grow using minimal water, to use management practices that can minimize losses of water by evaporation from the soil and percolation of water beyond the depth of root zone and also to minimize losses of water from storage and delivery systems. Nowadays, during a period of dramatic changes in uncertainty of the water resources there is a need to provide encouragement and support to farmers to move from their traditional high-water demand cropping system and irrigation practices to modern technologies, less water demanded cropping systems.

Under scarcity of available water considerable efforts have been devoted over time to introduce different policies aiming to increase water use efficiency based on the assertion that can be achieved using less water through better management practices. Better management practices usually refer to improvement of allocate and irrigation water efficiency. The former is related to adequate pricing, while the latter depends on the type of irrigation method, timing of water application and prevailing weather condition. The yield response curve of any specific crop depends on various factors, such as weather condition, soil type and the reduction in the agricultural inputs like fertilizers and pesticides (Figure 15.2). Therefore, it is difficult for a farmer to tell whether the yield loss is due to water deficit or not. Over-irrigation can cause water-logging condition for the crop, loss of nutrients due to leaching or deep percolation, contamination of the aquifers from washout agrochemicals, favourable environment for development of diseases, reduction of crop yield, increase in production cost also can create temporal water shortage to other farmers.

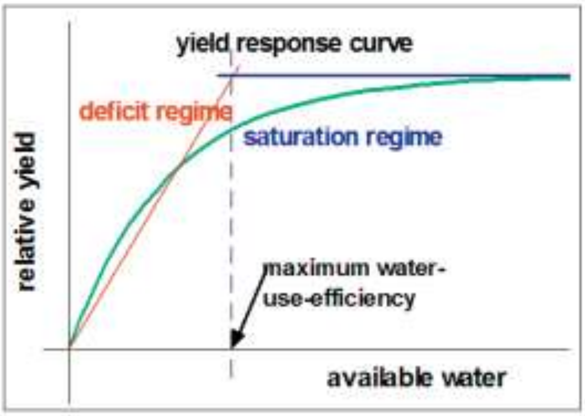

Figure 15.2: Plant Yield Response to Water

15.4 Water Management in Agriculture:

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

Under water management practices most attention is given to irrigation scheduling (when to irrigate and how much water to apply) giving minor importance to irrigation method (how to apply the water in the field). Many parameters like climatic condition, water availability in the soil, crop growth stage and its sensitivity to water stress determine irrigation frequency (when to irrigate). However, the frequency depends on the irrigation method and both irrigation scheduling and irrigation method are inter-related.

15.4.1 Localized Irrigation:

Localized irrigation is widely used as one of the most efficient methods of irrigation (Keller and Blienser, 1990). Localized irrigation systems such as trickle or drip irrigation, micro-sprayers apply the water to individual plants by plastic pipes usually laid on the ground surface. With drip irrigation system water is applied through small emitter openings from plastic pipes with a slow discharge rate of ≤ 12 l/h). With micro-sprayer or micro-sprinkler irrigation system water is sprayed over the crop plants with a discharge rate 12 to 200 l/h. The aims behind the localized irrigation are mainly the application of water directly into the root zone under the condition of low water availability, the avoidance of water losses during or after water application and the reduction of the water application cost because of less labour requirement.

Studies in diverse countries like India, United States, Israel and Spain have shown that drip irrigation can reduce water use by 30 to 70% and raises crop yield almost by 20 to 90% (Postel *et al.,* 2001).

Combination of water saving and higher yield typically increases the water use efficiency at least by 50% that makes drip irrigation system a leading technology in the global challenge of increasing crop production in the face of climate change and serious water scarcity.

Although the area under localized irrigation has expanded 50 times over the last two decades, it still represents less than 6% of the world's total irrigated area. The main reasons to its less expansion are the initial high investment cost (ranging from 1500 to 2500 € per hectare) and the high sensitivity to clogging.

Improvements in localized irrigation aiming to reduce the volume of water applied and increase the water use efficiency, the use of micro-sprayers in the soils having high infiltration rate, the adjustment of timing and duration of water application according to the soil and crop characteristics, the control of pressure and discharge variations, the use of appropriate filters and emitters, the adoption of proper maintenance, automation, chemigation (easy control of weeds and soil borne diseases) and fertigation (efficient fertilizer application).

15.4.2 Irrigation Scheduling:

Irrigation scheduling is a decision making process for deciding when to irrigate the crops and how much water to apply. It forms the sole means for conserving water and it is the key to improve the performance and sustainability of the irrigation systems. It requires good knowledge about the water requirements of the crops and the characteristics of soil and crops that determines when to irrigate and how much water to apply (Figure 15.3).

In most of the cases, the farmer's skill determines the effectiveness of the irrigation scheduling at the field level. By adopting appropriate irrigation scheduling runoff, deep percolation and leaching out of fertilizers out of the crop root zone can be controlled, water logging can be avoided, water and energy saving can be done as less water is used, higher yield can be obtained and rising of saline water table can also be avoided. Irrigation scheduling is more important in water scarce regions than under condition of abundant water, since any excess use of water is a potential cause for deficit for other uses or users.

Irrigation techniques and tools vary greatly and have different characteristics relative to their applicability and effectiveness. Timing and depth of irrigation scheduling can be decided by using several approaches based on measurement of soil water, soil water balance and plant stress indicators in combination with different models.

However, many of these models need further developments before they can be used in practice. Most of them require technical support by extension programmes, extension workers and technological expertise of the farmers. However, still in most of the countries these programmes do not exist because they are expensive, trained extension workers are lacking, farmer's knowledge and awareness of water saving in irrigation is not enough and the institutional mechanisms developed for irrigation management give low priority to the actual farming systems. Therefore, large limitations occur for their use in the farmers' practices. A brief description of irrigation scheduling techniques is reported below.

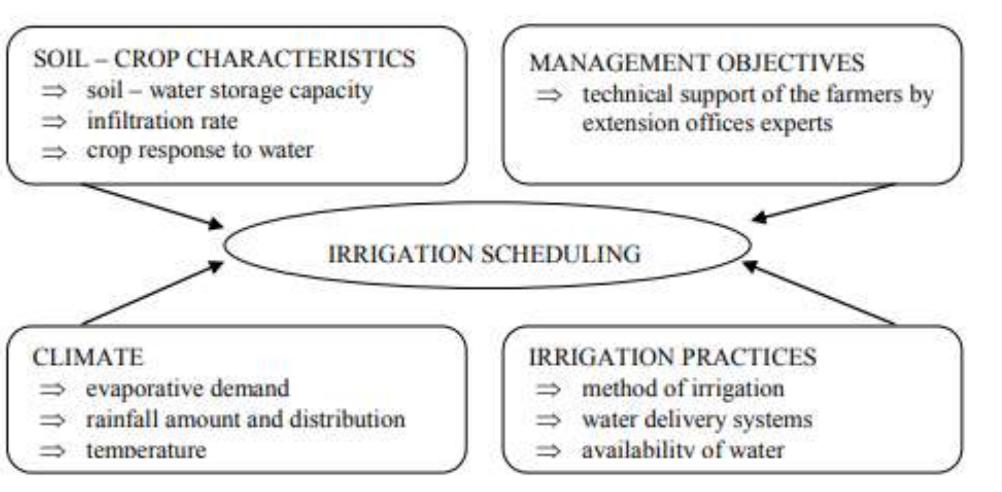

Figure 15.3: Irrigation Scheduling Components

A. Soil water estimates and measurements:

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to measure the availability of soil water for the plants: by measuring the soil water content and soil water potential (how strongly soil water is retained in the soil). The accuracy of the information depends on the sampling methods and to the selection of location. Soil water estimates and measurements used for irrigation scheduling include: measurement of soil water content and soil water potential with tensiometers, soil spectrometers or pressure transducers, soil appearance and feel, remotely sensed soil moisture.

B. Crop Stress Parameters:

Instead of estimating or measuring the soil water parameters, it is possible to receive a signal from the plants itself indicating the time of irrigation. This message can either come from an individual plant tissue (where a correct sampling is required) or from the whole canopy.

Crop stress parameters include canopy temperature, leaf water content and leaf water potential, sap flow measurement, changes in stem or fruit diameter and crop stress identified by remote sensing (Deumier *et al*., 1996; Itier *et al.*, 1993).

C. Weather Parameters:

Local or regional weather parameters are widely used for scheduling irrigation. Weather data and empirical equations that are locally calibrated are used to estimate accurate reference evapotranspiration (ETo) for a given area and then crop evapotranspiration (ETc) is estimated using appropriate crop coefficient according to the crop growth stage for a particular crop. On the basis of the crop evapotranspiration rate irrigation scheduling is done. This technique reduces the excess use of water.

D. Soil – Water Balance:

The aim of soil water balance approach is to measure the water content in the crop root zone by water conservation equation: Δ (AWC × Root depth) = Balance of entering + outgoing water fluxes, where AWC is the available water content. Climate data, soil and crop characteristics are used to produce typical irrigation scheduling calendars by sophisticated models.

This approach can be applied for individual farms and also for large regional irrigation schemes. However, it needs expert persons, support by extension services and link with information systems. Its effectiveness is high and depends on technological development and support services of the farm. Some examples of commercial software based on soil-water balance approach for irrigation scheduling are IMS (Hess, 1996), SIMIS (FAO, 1999b). MARKVAND, SALTMED (Ragab, 2002).

E. Effective Irrigation Scheduling:

It is proved that appropriate irrigation scheduling can lead to improvement in irrigation water use efficiency, especially at farm level. The farmers should control the timing and the depth of irrigation. However, the practical application of the irrigation methods has been far below expectation.

The main constrains to effective implementation of crop-based and water-saving irrigation scheduling are the lack of flexibility either due to rigid scheduling or the system limitations, the high cost of irrigation scheduling (cost for technology and labour covers more than 30% of the total), the lack of education and training about the irrigation management among the farmers, the lack of interactive communication between researchers, extension workers and farmers and finally the lack of demonstration and technology transfer. One of the major obstacles to effective irrigation scheduling is the inability of delivery systems to deliver water at the farm with the flexibility and reliability required. In modern irrigation networks, water is available only on demand basis, although discharge may be limited due to technical or economic reasons. The farmers are free to select and adopt the irrigation methods which they consider more appropriate to their crops and farm conditions. However, in case of limited water supply or drought, proper effective irrigation scheduling must be minted to check excess water use. Finally, government and different agencies are making effort to disseminate knowledge, upgrade training at all levels, transfer technology, incite decision-makers to changes.

14.4.3 Fertigation:

The application of fertilizers through irrigation water is called fertigation which has become a common practice in modern agriculture. Localized irrigation systems which are highly efficient for water application, are also quite suitable for fertigation. The soluble fertilizers at required concentrations are applied through the irrigation system to the soil. But there are some disadvantages which include the non-uniform chemical distribution when irrigation designs are not adequate and the over-fertilization when irrigation is not based on actual crop requirement.

15.4.4 Deficit Irrigation Practices:

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

A. Regulated Deficit Irrigation:

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

The adoption of deficit irrigation needs appropriate knowledge on crop ET, crop response to water deficit including identification of critical crop growth stages and the economic impact of yield reduction strategies. Before implementing RDI it is necessary to know the crop yield response to water deficit during a particular growth stage or whole period. Crop yield response to deficit irrigation is explained by the equation $Y/Y_m = 1\text{-}K_y\ [1\text{-}ET_a/ET_m]$ (Stewart *et al*., 1977), where Y and Y_m are the expected and maximum crop yield, ET_a and ET_m are the actual and maximum ET, and K_y is the crop response factor. K_y gives an indication of whether the crop is tolerant to water stress and it depends on crop species, variety, growth stage and irrigation method. High yielding varieties are more sensitive to water stress. Crops or varieties with short growing periods are more suitable for RDI. Furthermore, to ensure successful RDI, the water retention capacity of the soil should also be considered. RDI must be applied during the period when shoot growth is rapid and fruit growth is slow. RDI can be applied successfully for row crops like potato, maize, soybean, sugar beet, sunflower and tree crops like grapevines, citrus, peaches, olives etc.

B. Partial Root Drying:

Partial root drying (PRD), first applied to grapevines, is a new irrigation technique that allows one half of the crop's root system to dry while the other half is irrigated. Wet and dry sides of the root system alternate on a 7-14 day cycle. During water stress grapevine's first line of defence is to close its stomata to reduce transpiration. The principal compound that regulates this response is abscisic acid (ABA). As soil water availability falls, the drying roots starts to synthesize ABA and transported it 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 closure of stomata. Switching of the wet and dry sectors of root zone on regular basis is necessary. PRD can be successfully applied with drip irrigation and even with subsurface irrigation in grapevines and with furrow irrigation in citrus and pear.

15.4.5 Subsurface Drip Irrigation:

Subsurface drip irrigation is a low-pressure, low volume irrigation system that uses buried tubes to supply water. The water moves out of the tubes by the soil matrix suction force. Wetting occurs around the tubes and then water moves out in the soil in all directions. The potential advantages of subsurface drip irrigation are: a) conservation of water, b) enhancement in fertilizer use efficiency, c) uniform and highly efficient application of irrigation water, d) elimination of surface infiltration problem and evaporation losses, e) flexibility in providing frequent and light irrigation, f) less weeds infestation, g) low pressure requirement for operation. The main disadvantages are: a) high cost of initial installation and b) increased possibility for clogging especially when poor quality water is used. Subsurface drip irrigation system is especially suitable for high value fruit and vegetable crops, turfs and landscapes. The tubes are installed below the soil surface either by digging the ditches or by special device pulled by the tractor. The depth of installation depends on soil characteristics and crop species ranging from 15-20 cm for vegetable crops and 30-50 cm for fruit crops.

15.4.6 Agricultural Practices:

Different agricultural practices such as soil management, fertilizer application and disease and pest control are related with the water management in a sustainable way to reduce water losses without hampering the environment. Today agricultural practices are characterized by the abuse of fertilizers. Farmers very rarely carry out soil and plant analysis to clarify the proper quantity and type of fertilizer needed for each crop because this process increases the cost of agricultural production. Agrochemicals, such as herbicides and pesticides are also excessively used endangering the quality of the surface water and negatively affecting the environment. There are a large number of traditional and modern soil and crop management practices for water conservation (like runoff control, improvement of soil infiltration, increase water holding capacity of soil, control of soil water evaporation) and erosion control in agriculture. The soil management practices consist of:

- **a. Soil surface tillage:** Shallow tillage practices are done to produce a rough soil surface which permits short time storage of the rainfall in excess to the infiltration.
- **b. Contour tillage:** Soil cultivation is done and small furrows and ridges are made along the land contour that prevents runoff. This technique is also effective to control erosion and may be applied to row crops and also to small grains where field slopes are low.
- **c. Conservation tillage:** No-tillage or reduced tillage is done where residues of the previous crop are kept on the soil. The crop residues act as mulch which protects the soil from direct impact of raindrops controlling crusting and sealing processes. Conservation tillage helps to maintain high organic matter level in the soil. It is also highly effective in improving soil infiltration rate and controlling soil erosion.

d. Mulching: Mulching with crop residues on soil surface slowdowns water flow over the field, reduces evaporation losses, improves infiltration rate and also contributes to weed control.

e. Organic matter: Increasing or maintaining the amount of organic matter in the upper layer of the soils provides better soil aggregation, increases water retention capacity of the soils and reduces crusting or sealing on soil surface.

f. Fine material or hydrophilic chemicals: Addition of fine material or hydrophilic chemicals to the coarse soils increases the water retention capacity of the soils and also controls deep percolation. Thus, water availability in the soils which have low water holding capacity is increased.

g. Acidity control: Acidity control of the soils by the application of lime and similarly application of gypsum to the soils with high pH favour more intensive and deep rooting, better crop development and improve soil aggregation, thus some increase in soil water availability.

h. Weed control: Adoption of appropriate weed control techniques is done to alleviate competition for available soil water and transpiration losses by weeds.

15.5 Recommendations for Best Irrigation Practices:

The supply of water for irrigating the crops is decreasing steadily due to competition with demands of municipal and industrial sectors. Therefore, human resources management, technology and policy innovation are needed to increase the use efficiency of the available water. Sustainable water management in agriculture can be achieved by:

a. Reduction of water losses: Water leakages from the water reserves should be detected via advanced technologies like telemetry systems, remote sensing, GIS etc. Old water projects experiencing water losses should be modernized and rehabilitated.

b. Improve the efficiency of irrigation system: Improvements in sprinkler irrigation system (efficiency up to 85%) include the correction of sprinkler spacing, use of pressure regulators, monitoring and adjustment of pressure equipment, the design for pressure variation not exceeding 20% of the average sprinkler pressure, application of irrigation during no windy periods, use of smaller spacing and large sprinkler drops, adoption of application rates smaller than the infiltration rate of the soil and proper maintenance of the system. Improvements in localized irrigation systems include reduction of the volume of water applied by using a single drip line for a double row crop to increase the water productivity, use of micro-sprayers in soils with high infiltration rate, adjustment of duration and timing of water application to soil and crop, control of pressure and discharge variations, use of appropriate filters to the water quality, adoption of automation and careful maintenance.

c. Increase water use efficiency: Increase in water use efficiency can be achieved with the use of localized irrigation systems by the farmers with or without subsidies, proper irrigation scheduling according to actual requirements of the crops, introduction of appropriate agronomical practices according to the climate and the application of salinity and acidity management techniques.

d. Adoption of innovative irrigation techniques: In regions with water scarcity, irrigation techniques not necessarily based on full crop water requirements like subsurface irrigation or regulated deficit irrigation must be adopted. Fertigation (efficient application of fertilizers) and chemigation (easy control of weeds and soil borne diseases) should also be promoted among the rural farmers.

e. Water pricing policy: An increasing block tariff charging system, that discourages water use levels exceeding critical water requirements of the crops, must be introduced. It will be the basis for promoting water conservation, reducing water losses and mobilizing water resources. But it could affect cropping patterns, efficiency of water management, income distribution and generation of additional revenue for operating and maintenance of water projects.

f. Reuse of marginal waters *(*reclaimed or brackish) for irrigation: Reclaimed waters can be used under some restrictions for irrigation of trees and fodder crops. Treated sewage should be looked upon with skepticism by the farmers. They instead prefer to use surface or groundwater for irrigation. Special effort is needed for educating farmers to accept treated sewage. In addition the tariff for these sources of water should be lower than the tariff of the primary sources. This may not be difficult to achieve because the primary and secondary levels of treatment are regarded as sunk costs since they are required by the new WFD. When using low quality irrigation water like brackish or saline water an integrating approach for crop (salt tolerant varieties) field management (suitable tillage practices) and suitable irrigation system should be adopted.

g. Wider and effective participation of the public: Need wider and more effective participation of Government sectors and NGOs in decision-making and the preparation of water management plans, monitoring the implementation and generally in the management of water. The participation of these groups raises support on the part of the body politics and also promotes success in possible conflict resolutions.

h. Capacity building: The existing "capacity building" is under poor condition. It needs appropriate competent personnel, advance technologically based devices and facilities, legal guidelines, efficient administrative and effective processes for the sustainable management of the water resources. It includes:

- Education and training of professionals, technical staffs, decision makers and others including non-public organizations is necessary for sustainable water management.
- Institutions should be staffed with qualified manpower like managers, engineers, technicians etc.
- Water authorities should apply updated technologies, advanced devices and programs e.g. GIS, remote sensing etc. These advanced techniques help water managers in their decision- making.
- Water authorities should participate in the formulation of agricultural policies because the development of water and land should be fully integrated. In practice, agricultural decisions are water decisions and vice versa.

15.6 Conclusion:

Climate change already starts to hamper agriculture, especially in the areas under arid and semiarid climatic regions. Thus the reduction in rainfall and the increase in temperature cause reductions in yield and profit, as crops are impacted by water and heat stress. Under this perspective, implementation of appropriate adaptation and mitigation strategies will help to reduce these negative impacts ensuring the economic and environmental sustainability of the current agricultural system. Correct water management strategies or soil management practices of conservation agriculture are some of the measures recommended.

To identify those management strategies more suitable for each crop and location, a correct characterization of the agricultural systems will be critical. Thus crop phenology and its sensitivity to water or heat stress, soil characteristics, availability of water resources are some knowledge requirements that must be considered for implementation of water management practices under climate change.

15.7 References:

1. Deumier J.M., Leroy P. and Peyremorte P. (1996). Tools for improving management of irrigated agricultural crop systems. In: *Irrigation Scheduling: From Theory to Practice*, Proceedings ICID/FAO Workshop, Sept. 1995, Rome. Water Report No. 8, FAO, Rome.
2. FAO, 1999. The state of food insecurity in the world. Rome, Italy.
3. FAO, 1999b. Land and Water Digital Media Series no 6. (www.fao.org).
4. Hess T. M. (1996). A microcomputer scheduling program for supplementary irrigation. *Computers and Electronics in Agriculture* 15: 233 – 243.
5. Itier B., Flura D. and Belabess K. (1993). An alternative way for C.W.S.I. calculation to improve relative evapotranspiration estimates: results of an experiment over soybean. *Acta Hortic*., 335, 333-340.
6. Jensen M.E. (1993). The impacts of irrigation and drainage on the environment. 5th Gulhati Memorial Lecture. 15th ICID Congress, The Hague, ICID, New Delhi.
7. Loveys B.R., Dry P.R. and McCarthy M.G. (1999). Using plant physiology to improve water use efficiency of horticultural crops. *Acta Hort.* 537: 187-199.
8. Postel S., Polak P., Gonzales F. and Keller J. (2001). Drip irrigation for small farmers. A new initiative to alleviate hunger and poverty. *Water Intern.* 26 (1): 3-13.
9. Ragab, R. (2002). A Holistic Generic Integrated Approach for Irrigation, Crop and Field Management: The SALTMED Model. J. of Environmental Modelling & software, 17:345-361.
10. Stewart J.I., Cuenca R.H., Pruitt W.O., Hagan R.M. and Tosso L. (1977). Determination and utilization of water production functions on principal California crops. W-67 California Contributing Project Report, Davis, University of California, USA.