Chapter 13
Alternative and Non-conventional Soil and Crop Management Strategies for Increasing Water Use Efficiency

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Abstract Agricultural production is pivotal for sustainable supply of food, fiber and shelter. However, a complex plethora of biotic and abiotic factors coupled with climatic changes pose a major threat to sustainable crop production and global food security. Agriculture is the single major consumer of global fresh water resources, however, non-judicial use of fresh water and changes in the global hydrological cycle have put a significant pressure on fresh water resources from local to regional

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scales. There is an urgent need to devise both efficient as well as practical crop and soil management strategies to enhance water use efficiency (WUE) in agroecosystems. A combination of soil- and plant-based factors affect WUE in cropping systems. Depending upon the region, both conventional and modern tools are proposed and effectively being applied to increase WUE in various crops, especially in the regions under greater threat of fresh water deficiency for crops.

13.1 Introduction

Agriculture plays a key role in the lives of humans and the basic needs of them depend on agriculture such as food, fiber and shelter. Unpredictability of natural and climatic factors including temperature, rainfall and atmospheric CO_2, productivity of agriculture is under immense pressure to ensure food security. Due to high demand for crop production with the higher cost of energy and the decreasing trends in farm income, severe economic problems for sustainable agriculture has started to emerge (Shah and Wu 2019; Lobell et al. 2011).

Our agricultural systems are heterogeneous in terms of the socio-economic status with historical, political and ecological context that is crucial to formulate locally adjustable strategies for the sustainability and resiliency of agro-ecosystems in the near future (Koohafkan et al. 2012). The production of cereal crops has been boosted by modern agricultural science and molecular biology technologies over the past few decades through the development of new germplasm, but there are evidences of yield plateaus or decreasing yield gains rate in recent years (Shah and Wu 2019). So modern breeding technology and innovative crop management practices are considered to overcome the barriers for increasing the crop yield.

Agriculture sector is more sensitive among many systems which are affected by weather and climatic changes (Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). In last few years, the concept of food security has increased due to the negative impacts of climate change (Tripathi et al. 2016). Due to climate changes, food productivity has reduced and also increased in price of food (Bandara and Cai 2014). Similarly, the growing population of human accelerates the effects of climate change and it is estimated that global population will meet historic mark about 9.5 billion by 2050 (Fahad et al. 2018, 2019a, b). To fulfill the demand of this large population, excessive amount of food will be required from the present level. Developing countries are more prone to climate changes impacts due to their warmer climate, extreme weather events and lack of resources for adaptation methods (Singh and Singh 2017; Adnan et al. 2018; Akram et al. 2018a, b; Aziz et al. 2017; Habib ur et al. 2017; Hafiz et al. 2016, 2019; Kamran et al. 2017; Muhammad et al. 2019; Sajjad et al. 2019; Saud et al. 2013, 2014, 2017, 2016; Shah et al. 2013; Qamar-uz et al. 2017; Wajid et al. 2017; Yang et al. 2017; Zahida et al. 2017).

However, humans need to ensure maximal amount of crop production with minimum of environmental degradation, so no single option can completely fulfill the nutritional needs of abruptly growing human population. Changing are required in the production, processing, storage and distribution in agriculture to achieve higher food demands for growing population that will be environmental friendly and socially acceptable methods which was observed in previous major revolution such as green revolution (Godfray et al. 2010).

In adaptation strategies, the biggest challenge will be water scarcity for food production especially for such countries which have limited water and land resources. Increase in water requirements for agriculture, threats to natural water resources and climate change predictions, water scarcity and reduced availability of water for irrigation will be the biggest issues for crop production in the near future (Shah and Wu 2019). The great challenge will be to increase food production with less water, particularly in countries with limited water and land resources, by focusing on techniques and cropping systems for higher water use efficiency (WUE).

The significant observable climatic changes include warmer temperatures, irregular rainfall patterns and intensities, and increased frequency and severity of extreme weather events. In such conditions the need of water becomes more severe and water available for plant transpiration and biomass production depends upon resource level and crop management strategies including cultivar choice. Water available for plant transpiration and biomass production depends upon several factors such as resources (soil water contents, rainfall, irrigation) and crop management practices (water use throughout the growing season and cultivar selection). Climate changes are anticipated to induce warmer temperatures, alter the rainfall patterns and increase the frequency and severity of extreme weather events.

To overcome the problem of water scarcity, soil and crop management practices should be adopted like we should improve the soil water holding capacity, techniques that would extract more water from soil profile with the help of roots or decrease in leaching of water, this all results in improving the ability of water use by the crops and suppose to improved crop yield. Better soil management practices also increase the organic matter of soil that results in improved water holding capacity. Soil management practices that improve the soil water holding capacity, enhance the ability of roots to absorb more water from the soil and decrease in nutrient leaching losses could all potentially have positive impacts on WUE, assuming these changes result in a concurrent increase in crop yield. Improved soil management practices that increase the organic matter content of the soil would have a positive impact on the soil water holding capacity (Hatfield et al. 2001).

13.2 Crop Production, Food Security and Global Climate Change

In the next few years it is estimated that human population will reach to approximately 9 billion that results in the need of 70–100% more food (Godfray et al. 2010; Tscharntke et al. 2012). In Asia much food is demanded due to increase in population and better capita with in communities having high income (Reardon et al. 2003). High production of food is necessary to fulfill the demand of population. However, resource limitation to poor households may limit food security through market and non-market channels even when food is surplus at global scale. For agriculture-based economies, food security is strongly dependent on local food availability and majority of food producers exchange food for cash, other commodities or labor, and the food accessibility component is of critical importance, especially in relations to diversity in dietary diversity requirements and nutrition (Gregory et al. 2005).

According to estimation of FAO, in 1996 population who was suffering from chronic hunger increased from 800 million to over a billion. Some regions with large population, highly poverty and large inadequate agricultural areas are due to improper market rates and high fluctuation in climate. Due to high variability in rainfall season and because of poverty, farmers avoid to grow crops which depend on rain. Climate change is of particular significance for these countries, which already grapple with global and regional environmental changes and significant inter annual variability in climate (Arndt and Bacou 2000; Haile 2005). Climate variability affects water cycle, production of crop and land degradation (Sivakumar and Ndiang'ui 2007). Due to competition among land, water, labor and capital for better improvement in productivity food insecurity has increased in several regions.

13.3 Effects of Climate Change on Agriculture

According to IPCC, low emission scenario even a 2 °C change in temperature affects farming system (Easterling et al. 2007). Climate change has ability to effect food production, crop productivity, livestock and fishery system. People who suffer already from food security are at high risk due to climate change (Liverman and Kapadia 2010) and because of it, it is difficult to nourish nine billion people till 2050 (Godfray et al. 2010). One reason of climate change is emissions of greenhouse gases and it has, directly or indirectly, effects on production of crops used as food, health of animals, changes in the pattern and interchange among food products. Farmers are more vulnerable to climatic instabilities because they face problem in availability and quantity of water enough for their requirement. High temperature on daily basis decreases the growth period of the crops. Precipitation and runoff from snow melting on mountains brought floods in some areas while droughts in others due to different weather events. It is difficult to make plans for such changing in water available resources and the depletion or recharging of aquifers along with such large population, urbanization and land use changes patterns (Duran-encalada et al. 2017). The alarming situation of water resources is going to becoming the main issue among the natural resources of twenty-first century. Therefore, we have to devise sustainable approaches or unconventional water resources for water management that fulfills the water requirement required for crops. Being society, we have to use appropriate plans and schemes, through which agricultural users adopt advanced irrigation techniques and practices to enhance irrigation potency and water productivity in agriculture (Evans and Sadler 2008).

13.4 Global Water Demand and Crop Production in Agro-ecosystems

In the future, the nations that are vulnerable to climate change impact will have to face more unpredictability in available water resources. On global level, only seven countries were water-stressed conditions for agricultural production in 1955, the number rose to 20 in 1990 and it is expected that by the year 2025, additional 10–15 countries shall among the list of water-stressed countries. According to different predictions 2/3rds of the global population could face water stressed conditions (Gosain et al. 2006). If we look at globally, many Arab countries rely upon the international water bodies to fulfill their demand. Arab countries don't have excess supply of water; that's why they mostly rely upon natural precipitation and water conservation techniques to fulfill their requirement. Nearly 190 billion people of different countries like Eritrea, Uganda, Rwanda, Burundi, Congo, Tanzania, Kanya, Sudan and Egypt are depended on Nile river basin. It is very difficult to adopt any strategy for the countries who depend on Nile river because they are among the most 10 poorest countries of the world because it requires investment. The areas of middle East and the OSS (Observatory of the sahara and the Sahel), with very least natural water resources will be affected the most (Misra 2014).

Sustainable water management is one of the greatest that our society is facing in the twenty-first century (World Economic Forum 2013). Water scarcity is the point at which all the users have combined effects on the supply or quality of water under fundamental institutional arrangements to the extent that the demand for all sectors and users, including the environment, cannot be satisfied fully with the available water resources. Global demand for potable water may increase by 55% till 2050 (UN Water 2006). Three key factors that will drive the future global water demand are: (1) population growth, (2) increasing wealth and (3) changing diet preferences. Till 2050, it is expected that world population to increase to 9.3 billion and 10.1 billion by 2100 (Hoekstra 2013). Increased income growth for many countries is also expected at the same time. In developing countries, income growth is linked with increased water consumption because of changes in the demand of water for food production, as well as for sanitation. As income growth swaying lifestyle preferences, it is also expected to change diet preferences. For example, in many regions demand is forecasted to shift mostly from cereal-based consumption to increases in vegetable oils and meat that are higher water-intensive commodities. As it is predicted that population will become double in the next 50 years that results in increase the consumption of vegetable oils and meat therefore the demand for food and feed crop will be doubled (UN Water 2006).

Therefore, agricultural activity holds the largest share in global water use. In the agricultural sector the share of water use rises sharply from the 1940s and by 2000 was estimated at 70 per cent of global total water consumption. This share of water use varies by region, and where agriculture is the major economic activity, estimates of agricultural water use range from 40% in countries that have developed economies and import food from other countries (UN Water 2006). In most parts of the world, production of agriculture is rain-fed. Irrigated land occupies around 20% of the world agricultural land, however, has expanded 117% since 1961 (FAO 2011). The world's largest consumptive water extraction is in irrigated agriculture sector. Irrigation water use depends on the crop water necessities and also the water accessible to crops. Agricultural production is the biggest water-consuming area where rice, wheat, roots and tubers, pulses and fruit and vegetables make up the major irrigated crops for global food supply. Irrigation water use pattern are different between crops and regions. Crops for livestock, pasture feed and other grain production require the highest levels of water application relative to lower water use product for irrigated fruit and vegetable crops. For a person's daily diet approximately 2000-3000 litres cu_3 of water is required to produce enough food. Irrigation has been growing strongly over the past 60 years. From the 1940s to 1960 different irrigation practices was adopted named as 'Green Revolution'. In terms of hectares of irrigated land, the largest irrigating countries are India, China, the USA and Pakistan respectively. From 1998 to 2030 it is predicted that irrigation has been expand by 20 per cent in developing countries while agricultural water demand increased by 14 per cent in the same time period (Wheeler et al. 2015).

In several regions of the world, climate changes have wide ranging impacts on each the water and agricultural sector (Falloon and Betts 2010). Global climate change has potentially strong effects on temperatures, annual rainfall patterns, and regional rainfall distribution cycle and increases in water demand. A number of these changes could already be occurring, though predictions of regional impacts are problematic at the best. Variations in climatic conditions is a significant problem for producers because they have started to experience decrease in the quantity and quality of water. The crops that grow at rates proportional to heat units are going to shorten growing season because of locally and high daily temperatures. Change in the temporal precipitation patterns and availability of water from mountain snowmelt have changed from historical norms, resulting in more intense and extreme weather events including droughts and floods (Evans and Sadler 2008). Continuous unmanaged water extraction from aquifers, in those countries that are already most vulnerable in terms of water resources, is due the use of strong technological instruments like deep tube wells and pumps. The natural balance of recharge and discharge of water bodies like rivers and canals is disturbed and this is because of excess drafting of water by these pumps (Misra 2014) (Fig. 13.1).

13.5 Water Use Efficiency: Concept and Application

Human needs water for their drinking purposes, industrial activities, agriculture, hygiene and recreational activities, for these activities availability of excess water resources is necessary. As the water resources changes due to changes in precipitation patterns, droughts and decreases in water aquifer; negative impacts are seen on the development of any society. However, water availability as well as water quality both considered as the essential risk assessment parameters and predictions relevant with global climate change (Duran-encalada et al. 2017). In agricultural system, due

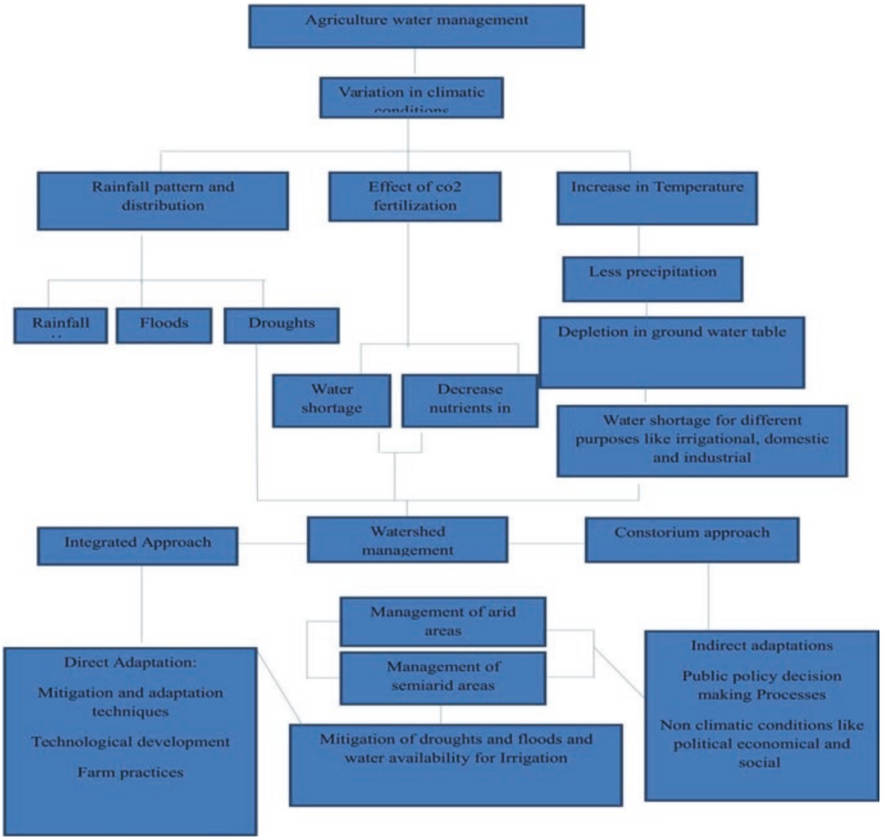

Fig. 13.1 Schematic diagram of water management strategies in agriculture

to low or irregular annual rainfall, water is becoming the most limiting factor. To meet the higher food demand and obtaining higher yield, high irrigation is necessary in such variable climatic conditions but fulfilling of these requirements water table and water quality both are decline. Therefore, to achieve higher crop productivity and efficient water use proper and sustainable irrigation strategies should be execute in agriculture system (Fang et al. 2010.).

Use of water in an efficient way is becoming an important question in such variable climatic conditions because of higher demand of water use and better environmental quality by human beings (Hatfield et al. 2001). In terms of agriculture system, water use efficiency (WUE) is generally defined as grain yield production per unit evapotranspiration (Fang et al. 2010). Water use efficiency (WUE) is also described as the crop yield per unit of water consumed. Water use efficiency can be expressed as:

$$\text{Water use efficiency}\ (\text{WUE}) = \text{Dry weight production} / \text{Evapo} - \text{transpiration} \quad (13.1)$$

Crop WUE is especially an important strategy in agricultural areas where water availability is limited or diminishing. Variations in WUE among many varieties is imperative which cannot be the changed with gene development. However, WUE could be enhanced under water-stressed conditions by increasing evapo-transpiration rates and transpiration and by improving crop harvest index (Zhang et al. 2012). Change in climatic conditions could also change WUE and it is a common observation that climate change adversely affect plant growth and WUE of the crop plants. The effects of WUE are seen on the leaf, plant and canopy level in response to changing climate.

13.6 Factors Affecting Water Use Efficiency

13.6.1 Soil Factors

- Soil water available contents
- Crop irrigation techniques

13.6.2 Plant Factors

- Crop species and cultivars
- Plant breeding and biotechnology (Singh et al. 2017)

13.7 Conventional Water Management and Water Use Efficiency

Many adaptation strategies such as the adaptation of regulated deficit irrigation in crop production, the use of novel water-saving practices, enforcement of laws and policies in water resource management have been used to save water in agriculture (Chen et al. 2018). Similarly with these techniques, some strategies that could also be used in water management such as redesigning of whole irrigation systems for greater efficiency, water that is degraded could be used again by successfully treating, minimizing evaporative losses, implemented site-specified applications, installation of managed-deficit irrigations, utilize engineering approaches to reduce water losses via leaching to unrecoverable sinks (Evans and Sadler 2008). For the maximum production of crops, among many affective approaches strip-intercropping is uses for improvement of water use efficiency in which early and cool season crop is grown with a late warming season, two crops in the same field. It has been investigated that enhancement of soil water conservation and use of available soil water and crop yield for whole system improved by implementation of intercropping (Chen et al. 2018). Intercropping is beneficial for WUE because it makes more efficient use of the natural resources such as land, light, water and nutrient with simultaneous benefits of promoting biodiversity, productivity, resilience and stability of agroecosystems (Singh and Singh 2017).

Other agronomic management practices are also helpful in water use efficiency like tillage practices for moisture conservation and enhancing crop yields. There are many positive effects of tillage in agricultural field such as providing most favorable condition for seed germination, proper growth of seedling, conserve soil moisture in unirrigated areas that enhance soil infiltration characteristics, facilitate sufficient soil depth for maximum root growth and fully placement of seeds and fertilizers in soil and control of weed in field. Deep tillage is beneficial for the monsoon rainfall (Meena and Singh 2013).

13.7.1 Selection of Crop and Variety

In rain fed areas, suitable crops and their varieties acclimatize the total amount and distribution of available water and agronomic practices are most important factors for the success of agriculture (Singh et al. 2009).

13.7.2 Planting Techniques/Methods

Suitable planting technique is another important practice in agronomic method for increasing the water use efficiency. For rainy season crops, the broad bed and furrows practices done in field. The field has prepared in ridges and furrows for some crops like maize, vegetables etc. Mostly the plantation of sugarcane is done in trenches and furrows. For the facilitation of two-way inter-cultivation, some crops are grown with equal intra-row and inter spacing such as tobacco, chilies and tomatoes (Singh et al. 2012).

13.7.3 Weed Control

The removal of weeds from the crops is one of the effective management techniques for water use efficiency. Their elimination in crops is necessary because weeds compete for the available resources like soil nutrients water and light. Water is the most limiting factor in agriculture except the high rainfall areas and the removal of weeds is necessary in water scares countries because for weeds the requirements of water is high as compared to nutrients than that of crops.

13.7.4 Rain Water Harvesting

Rain water harvesting is also an important technique through which we can enhance water use efficiency because the main problem in water management is seen at the time of seeding of the crops. For example, if the excess water is saved and stored for the sowing of other crops it will be beneficial for the proper germination of other crops. The major problem of water management is faced at the time of seeding of the crop. Management practices that helps in increasing infiltration, soil water management and decreases water loses as a result of evaporation, evapotranspiration and runoff enhances waters ability to retain in fields. There are two types of water harvesting in situ and ex situ water harvesting. The benefit of in situ water harvesting is not only to conserve soil, fertility and vegetation but also seen in periods of low rain fall when the available water is low for crop plants. The in situ water can be used then which results in high water available to the crops In ex situ water harvesting, water is stored and applied to the fields when the crops are facing dry spells and are at critical grown stages as additional water. In ex situ water harvesting water pond are formed by forming wall around the water coarse or by making a pit.

13.8 Alternative Soil and Crop Management Strategies

Increased in water demands for agriculture pose a significant threat to natural water resources and climate change scenarios strongly suggest water deficiency and reduced allocation of water to irrigation is predicted to happen in very near future. Water use efficiency can be improved through changing soil management practices that include altering soil properties to maximize water availability to plants because better monitoring of plants and soil health are the important components of improving WUE.

13.8.1 Increasing Soil Stored Water at Plant Sowing

Increased crop water availability and evapotranspiration can be achieved stored by enhancing the soil water retention capacity. Through the mechanism of deep tillage (e.g. paraplowing) during fallow-periods, with the view of increasing infiltration and reducing runoff, soil water retention capacity could be achieved. This practice is sometimes efficient and sometimes inefficient such as this practice yield limited-benefits in swelling clay soils. Clayey soil cracks under high temperature in summer and maintaining the high evaporation demand during in autumn period makes this practice inefficient. In comparison to shallow tillage or no-tillage, ploughing could lead to sub-soil desiccation in deeper layers during dry periods whereas more water is stored during wet periods. The areas where soil water conservation is important, more soil water storage is generally achieved by soil management techniques such stubble-mulching and minimum-tillage which have positive effects on promoting water infiltration and reducing evaporation.

13.8.2 Increasing Soil Water Extraction

When there is high condition of soil moisture soil tillage is a beneficial approach that encourages the root system to explore more soil volume which ultimately leads to higher transpiration (Hoad et al. 2001). Fertilizer application can also improve the cumulative water utilization by plants in small amounts by facilitating water extraction from depth and/or the amount of water extracted from specific soil layers. As water availability becomes limited along the depth gradient in dry regions, crop species and varieties with deep root system are recommended in such areas (Hoad et al. 2001). However, two problems are faced in such areas: (1) During the season, a rapid decline in stored water and a below-optimal distribution of water transpiration, and, (2) as root development progresses the wetting front in dry areas, it is highly unlikely that deep water reserves will be utilized each year.

13.8.3 Mulching Application

Soil water conservation in crop lands can be achieved using mulching technique which is considered the simplest and widely applied technique. In this method, layer of organic material is placed at the soil surface with the objectives to reduce soil moisture loss through evaporation. In addition, mulching can have other benefits such as reduction in weeds and increase in organic matter which enhance crop yields (Kimaro 2019).

13.9 Optimizing Seasonal Water Use Patterns

13.9.1 Crop Rationing

For the improvement of yield and water use efficiency, crop rotation is usually considered a sustainable approach because it also decreases soil erosion. By changing soil structure and aggregation, crop rotation improves soil quality and crop productivity (Singh and Singh 2017). The implementation of this practice changes water balance by decreasing crop water needs to the amount available for it from rain and irrigation. The main objective of this approach is to save water for the sensitive conditions by leaving enough water for grain filling.

13.9.2 Drought Tolerant Cultivars

The use of drought resistance crop cultivars and species is also beneficial adaptation method to increase WUE under water-deficient drought conditions. The agronomic parameters beneficial in plant breeding to develop drought resistance have been documented in relations with the target environmental factor. For example, the major traits for adapting to cold season grain legume species under low-rainfall Mediterranean-type climates are early flowering, pod and seed formation before the start of the terminal drought. Rapid development together with early ground cover and DM production allows greater water use in the post-flowering period: examples are pea and faba bean, as compared with other legumes (Debaeke and Aboudrare 2004).

13.10 Conclusions

Under the era of global environmental changes such as global climate change, increasing population and natural resource degradation, sustainable water management is one of the major challenges of the twenty-first century. With respect to food security, climate change is anticipated to affect the world disproportionately with stratifying patterns because the worst effects will be observed on poor, resource-limited and food insecure nations. As the population is increasing at a higher rate so it is necessary to increase agriculture production to meet societal needs; but the productive irrigated land and available water is declining. Thus, great challenge as a result of this, will be to increase food production with less water, especially in those countries that are with limited water and land resources, by promoting techniques and cropping systems of higher water-use efficiency. Therefore, water use efficiency could be enhanced by a number of methods like selection of crops and variety, agronomic practices, conservation tillage practices and moisture conservation practices. Advanced irrigation techniques and state of the art engineering delivery systems are also required to be fully implemented for successful deficit irrigation strategies. Precision agriculture tools such as site-specific water and nutrient applications could also play an important role.

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