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Review article

TECHNOLOGY APPROACHES TO INCREASE THE WATER USE EFFICIENCY OF MAIZE UNDER CLIMATE CHANGE: A REVIEW

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ABSTRACT: Maize (Zea mays L.) is the third most important cereal after wheat and rice all over the world as well as in India. Global demand for maize will increase from 526 million tons to 784 million tons from 1993 to 2020, with most of the increased demand coming from developing countries (Rosegrant and Gerpacio, 1999).Climate change and water scarcity are the major factors affecting maize production in arid and semi-arid zones of the world. Innovations for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions. The current paper focuses on the novel approaches to increase the water use efficiency (WUE) in maize through a review of literatures on the topic. Enhancing water use efficiencies of rain-fed maize is a prerequisite for sustainable maize production, There are various techniques to increase water use efficiency in the rain fed ecosystem and the objective is to deliver 'more crop per drop'. The strategies to improve water productivity can be referred to both agronomic and engineering technologies and practices, as suggested by (Wallace and atchelor 1997). From an agronomic viewpoint, it examines planting date and planting geometry, tillage and residue retention, weed control, fertilizer use and modified irrigation practices as strategies to improve WUE, and includes comments on use of plastic mulch as means of improving WUE in maize.

Key words: Water Use Efficiency, Climate change, Biotechnology, partial root zone drying.

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INTRODUCTION

Globally, agriculture accounts for 80–90% of all freshwater used by humans, and most of that is in crop production. In many regions, this water use is unsustainable. The water is running around an increasingly scarce worldwide due to diverse reasons (Rosegrant, et al., 2002). With the fast decline of irrigation water potential and continued expansion of population and economic action in most of the countries situated in arid and semi-arid regions, the issues of water lack is required to be aggravated further (Biswas, 1993 and Rosegrant, et al., 2002). According to the International Water Management Institute (IWMI), Colombo, 75% of the world's population lives in areas characterized by physical water scarcity. One billion people live in rural areas with economic scarcity (IWMI, 2006). Grounded on the United Nation's medium population projections of 1998, more than 2.8 billion people in 48 countries will face water stress or scarcity by 2025. Arid and semiarid regions account for approximately 30% of the total area of the world (Sivakumaret al., 2005); 40 of the 48 countries in these neighborhoods are situated in western Asia, North Africa or sub-Saharan Africa. By 2050, 54 countries could face water stress or scarcity, accounting for about 40% of the projected global population of 9.4 billion people (UNESCO, 2002).

On global scale, water deficiency is the major factor limiting agricultural production. The increasing demand for food and water calls for a more efficient use in agriculture. Immediate steps should be needed for efficient and judicious utilization of this resource or else it will be difficult to sustain agricultural productivity as well as the demand of water for the survival of society. Farmers practices need to be critically observed and modified taking into view the perceptions, concerns and restrains of the farmers in adopting better tools and techniques.

Advances in irrigation engineering and agriculture practices that reduce losses through soil surface evaporation or run-off have played a substantial role in increased water productivity. Improvement of transpiration efficiency (TE) of crops, the inherent water use efficiency defined as biomass produced per unit water transpired through plants, might be another viable approach to increase water productivity (Condon et al. 2004). A better understanding of how water deficiency affects plant growth and yield production and of how water use and water- use efficiency in agriculture can be optimized is of great importance

Different technological strategies enhance the crop water use efficiency. With good management and adoption of appropriate practices improves agricultural water conservation and subsequent use of that water for more efficient crop production are possible under both dry land and irrigated area (Wang et al., 2004).Many agro-management practices have used for many years to improve the agro-cultural productivity (Li et al., 2001, Sharma et al., 2004, Govaerts et al., 2005).The work of various workers discussed above indicated that the appropriate management practices play significant role to increase crop productivity and water use efficiency under availability of water in both dry and irrigated areas.

Maize (Zea mays L)

It is one of the most important cereals both for human and animal consumption and is grown for grain and forage. Present world production is about 594 million tons grain from about 139 million ha (FAOSTAT, 2000, http://www.fao.org/nr/water/cropinfo_maize.html). In India, maize is the third most important food crops after rice and wheat. As indicated by development assess its generation is liable to be 22.23 M Tones (2012-13) mainly during Kharif season which covers 80% area. Maize in India, contributes nearly 9 % in the national food basket. More than half the maize of India is produced in four states of Madhya Pradesh, Andhra Pradesh, Karnataka and Rajasthan. It is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions and is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes 36 % (782 m t) in the global grain production. Successful cultivation markedly depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is to be grown.

In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc

Water Requirements of Maize

Maize is a considerably more water-efficient crop than C3 plants, Water use efficiency (WUE) of maize is roughly twofold that of C3 crops grown at the same sites. Its transpiration ratio (molecules of water lost per molecule of CO_2 fixed) is 388, corresponding to 0.0026 in WUE (Jensen 1973), while that of wheat is 613, soybean 704.Even though maize makes productive utilization of water, it is considered more susceptible to water stress than other crops because of its unusual floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem. Maize has different responses to water deficit according to development stages (Cakir 2004). Drought stress is particularly damaging to grain yield if it occurs early in the growing season (when plant stands are establishing), at flowering, and during mid to late grain filling (Heisey and Edmeades 1999). At the seedling stage, water stress is likely to damage secondary root development. During stem elongation(after floral initiation) leaves and stems grow rapidly, requiring adequate supplies of water to sustain rapid organ development, water stressed plants being shorter and with reduced individual and cumulative leaf area (Muchow 1989). The most critical period for water stress in maize is ten to fourteen days before and after flowering, with grain yield reduced two to three times more when water deficit coincides with flowering compared with other growing stages (Grant et al. 1989). During this period, ear growth is susceptible to competition from other organs that are still growing as its growth is source limited, often leading to low grain number per ear and occasionally barren ears. Grain yield of maize suffering water stress at flowering and during grain fill is highly correlated with kernel number per plant (Bolanos and Edmeades 1996) indicating the importance of adequate water supplies during flowering.

Effect of drought stress on different growing stages of maize

The experiments conducted in green house to study the effect of drought stress on the vegetative and root growth of maize and it was found that drought stress reduced shoots and root growth (Ramadan et al., 1985). Photosynthesis directly relies on relative water contents and leaf water potential. In the photosynthetic mechanism drought affects photo-system-II more extremely as compare to photo-system-I. In this way free high energy electrons are produced in the leaf. These uncoupled electrons transport results to photo-oxidation of chlorophyll and loss of photosynthetic ability occurs. Photosynthesis directly depends on relative water contents and leaf water potential Decrease in relative water contents and leaf water potential decreases the speed of photosynthesis (Lawlor and Cornic, 2002).

Drought disturbs the series of developmental processes such as growth, organ development, flower production and then grain filling. As the drought situation prevails stomata closes progressively as a result of which photosynthesis and water use efficiency terminated to decline. The enzyme activity is also dependent on moisture availability. This decrease in photosynthetic CO2 fixation activates the molecular O2 for extensive production of reactive oxygen species (ROS). These reactive oxygen species (ROS) damage the chloroplast and cell membrane. ROS are mainly produce in chloroplast which is the superoxide radicals (O-2), hydrogen peroxide (H2O2) and singlet oxygen (1O2) during the process of photosynthesis (Asada, 2000). Chloroplast produce high amount of ROS, when plants are under environmental stresses like drought, chilling, deficiency of fertilizer nutrients and salinity (Foyer et al., 1994; Asada, 2000; Vranovaet al., 2002). These reactive oxygen species (ROS) are extremely harmful causes membrane damage, damage chlorophyll then leads to necrosis and chlorosis development. The period from one week before silking to two weeks after silking is quite important because abortion of ovules, kernels and ears may occur. Drought stress during this period initiates this process (Uhart and Andrade, 1995), Andrade et al. (2000).

Water use efficiency (WUE)

It is the ratio of crop yield (Y) to the amount of water used by the crop forevapotranspiration (ET). The more crop yield that's produced per unit of water the greater is the WUE.

$$WUE = \frac{Y}{ET}$$

Physiological Water Use Efficiency (PWUE)

The physiological WUE is calculated in terms of the amount of CO2 fixed per unit of water transpired

$$PWUE = \frac{\text{Rate of Photosynthesis}}{\text{Rate of Transpiration}}$$

Need to improve the water use efficiency

Crop WUE is an especially important considerationwhere irrigation water resources are limited or diminishingand where rainfall is a limiting factor. Additionally,recent increases in energy prices have many irrigatedproducers asking how to manage inputs to maximizeefficiency of their water resources. Regardless of thesituation, it's crucial that growers get the most out of everyinch of available water, whether that water comes throughirrigation, rainfall, or both. World demand for food, feed, and fiber is increasing and production is being pushed into more arid environments.

Strategies to increase water use efficiency in Maize

Genotype improvement

- Drought-adaptive improvement through breeding
- Drought-adaptive improvement through modern biotechnology

Eco-friendly agronomic practices for improving water use efficiency

- Selection of varieties
- Early sowing
- Method of Sowing
- Inter cropping

Management actions related to increasing soil water retention.

- Mulching
- Tillage
- Weed control

Application of soil amendments or conditioners

- Organic Manures
- Fertilizers

Water saving irrigation strategies

- Irrigation Management and scheduling
- Controlled alternate irrigation (CAI)
- Partial root zone drying
- Precision Irrigation

Chemical methods for increasing water use efficiency

- Anti transpirants
- Reflactants:
- Growth retardant
- Stomatal closing type

Microbial amendments in enhancing water use efficiency

- Organic Matter Decomposition
- Biological N2 fixation
- Humus formation

Drought-adaptive genotype improvement

Improvement of productivity through breeding schemes :

Breeding and selecting crop cultivars that make more efficient use of water while maintaining productivity and crop quality has been a long-term goal of production in agriculture. The relevant morphological and physiological attributes include resistance to wilting, rapid maturity, short anthesis-silking (in maize) interval, deep root systems, waxy cuticle, heavy glaucousness or dense pubescence, leaf-water retention, stay-green characteristics, osmotic adjustment, cellular membrane stability and high harvest index. The stomatal behavior of plants in drying soil can be regulated by long distance signals provided by plant hormones such as abscisic acid, xylem sap pH, and inorganic ions that provide the shoot with some measure of water availability Davies et al.,(2002).These traits can be modified through breeding, such as pedigree breeding, backcross breeding, bulk-population breeding, recurrent selection, and gene transference using biotechnology Xiao et al., (2004).

Improvement through modern biotechnology

The science of biotechnology provides researchers with new tools to better understand plants and develop better hybrids. A deeper understanding of a plant's genetic structure is vitally important because understanding how plants work can help us address issues facing the human. The plant DNA sequence provides the instructions for a leaf to be a leaf, or a plant to resist a particular disease. One biotechnology tool, transformation, gives scientists the ability to improve products in ways not possible through conventional breeding. If genes for a valuable trait are available from other sources, researchers are able to integrate those genes into the maize germplasm, and thus offer improved products.

Introducing foreign DNA to maize potentially increases genetic variation within the species as well as increasing the speed and precision with which genes for specific traits can be introduced. Transformation methods are becoming more routine and genes coding for Osmoprotectants, such as glycine, betaine, proline, and mannitol have been identified and engineered into several crop species, including rice Nguyen et al.,(1997).

Recombinant DNA can be used to explore and understand the role of genes. This approach could be used to attempt to directly manipulate one or more genes to improve crops WUE and resistance to water deficit. Molecular mechanisms by which plant cells withstand dehydration have been investigated using a number of 'models'. Molecular tools such as markers and transgenes promise to improve the rate of accumulation of desirable drought-adaptive alleles without adversely affecting the specific and general combining abilities in drought susceptible genotypes that have other desirable characteristic species (Bohnert and Cushman 2000, Bartels and Salamini 2001**).**

Eco-friendly agronomic practices for improving water use efficiency

Selection of varieties

The yields and water use efficiency of cultivars of crops differed significantly. High water use efficiency (WUE) occurs in some cultivars of corn (Zea mays L.) and could be a useful trait to improve yield under water deficit environments. These variations are due to variations in their genetic build-up which affects both morphological traits controlling the rate of transpiration and water absorption by roots from the soil and the physiological functions responsible for photosynthesis, respiration, translocation of photo synthates to economically harvested plant parts. Varieties also differ in their adaptation to the environment, resistance to pests and diseases and management levels. Selection of properly adapted crops, with good rooting habits, low transpiration rates and improved energy consumption in photosynthesis will increase WUE (Singh et al., 2008).

Early Sowing

Early sowing of crops is a very important mean of maximizing crop yield and WUE. In fact, increasing the early growth of the canopy when the soil surface is usually damp and the vapour pressure deficit is low has proved effective in increasing WUE. Bonari et al., (1989) found that an early sowing of ten days increased the yield of 54, 35 and 17% for maize, soybean and sunflower, respectively (Table.1). Hence also biomass and yield water use efficiencies, increased significantly in all the crops except of sunflower, although the water use in early sowing was higher than in the normal sowing. Differently, (Perniola and Rivelli, 1997) dealing with sunflower found that the increase in yield water use efficiency was strictly linked to the decrease in the amount of water used, as effect of a reduced evaporation from the soil.(Table.1)

In dry land crop production, the time of sowing may have a significant effect on the optimization of soil water use by ensuring that the growth of the crop has adjusted to the available soil water. Early-sown crops have the advantage of a longer growing season than later-sown crops, though the latter are sown under more favorable conditions of soil water supply. A longer growing season reduces the risk of water stress during grain filling. Early sowing also takes advantage of the flush of nitrates produced at the onset of the rains. Makatiani., (1970b) showed that delaying sowing for three weeks after the onset of the rains reduced maize yields by 76% during a season in which rainfall was below average and by 21% during a season in which rainfall was above average.

Method of sowing

The planting pattern of the maize has a direct effect on its yield, solar energy capture and soil water evaporation and thus an indirect effect on water use efficiency. The correct method of planting according to the site moisture availability or other factors can help to increase the yield or reduce the total irrigation water to be applied to maize crop without affecting the yield. The most common is equal row spacing pattern, of about 60-90 cm row spacing and different intra row plant spacing producing different plant population densities

Intercropping

The cultivation of two or more species in the same field at the same time (intercropping) can boost productivity per unit land area. Inter cropping maize with cowpea has been reported to increase light interception in the intercrops, reduce water evaporation, and improve conservation of the soil moisture compared with maize alone (Ghanbari et al., 2010**).**Intercropping is a practice to have an opportunity to diversify cropping system by making the multiple land use possible utilizes water and other resources more effectively and also provides a cover against the failure of one crop particularly under the rain fed situations. Any factor that increases yield will increase water use efficiency. Likewise, any factor reducing evapotranspiration that has no seriously deleterious effect on yield will increase water use efficiency (Eastin and Sullivan, 1984). Higher water use efficiency has been reported for maize-soybean and maize-mung bean (De and Singh, 1981), maize-cowpea (Hulugalle and Lal 1986), Maize + potato Bharati et.al.,(2007), pearl millet + green gram and pearl millet + cowpea (Goswami et al. 2002) inter crops in relation to their respective mono crops (Table.2).

Consumptive use and rate of moisture use were more eminent in the intercropping system than sole crop because both the crops absorbed more moisture during the crop period. Parihar et al., (1999) and Singh et al. (2004) reported that rice-coriander-maize+cowpea and rice-lentil-maize + cowpea and had the lowest water use resulted in the highest water use efficiency in flood prone and semi-deep water situation, respectively.(Table 2)Source: Bharati et.al.,(2007) The cropping system of corn mixed with grasses was proposed to make full and efficient use of water in grain and forage feed production practices (Lei et al., 2003). The results showed that WUEs in the mixed cropping fields of corn grasses were much higher than those in the fields where only corn or grass was grown.

Table-1: Effect of early sowing on biomass water use efficiency, yield, water use efficiency and total water used of field-grown crops.

Crop		Above ground biomass (kg m-3)	Yield WUE (kg m-3)	Total Water used (mm)	Determination of water used		References
Sun flower	Normal sowing		0.7	487	Seasonal irrigation volume + rainfall	Matera, Basilicata	Rivelli&pemiola, 1997
	Early sowing		1	385			
Maize	Normal sowing	4	1.9	457			
	Early sowing	4.5	2.3	582	Drainage lysimeter with variable water table		
Soybean	Normal sowing	2	1	457		Pisa. Toscana	Bonari et al., 1989
	Early sowing	2.3	1.2	547			
Sunflower	Normal sowing	1.8	0.6	452			
	Early sowing	1.7	0.6	537			

Table 2. Water requirement and water use efficiency of winter maize as influenced by inter-cropping systems

Inter-cropping System	Water requirement		Water use efficiency on the basis of maize-equivalent yield (kg/ha-cm)	
	2002-03	2003-04	2002-03	2003-04
Sole maize	50.86	44.38	213.73	237.41
Maize + potato	50.98	44.33	526.16	597.62
Maize + rajmash	50.6	43.76	352.77	348.59
Maize + toria	50.88	44.28	247.26	264.74
CD (P=0.05)	0.26	0.31	31.01	35.32

Table. 3: Water use efficiency as influenced by Nitrogen levels

Nitrogen (Kg/ha)	Water use efficiency	(kg grain/m3 water used)
	1999-2000	2000-2001
0	1.09	1.12
50	1.3	1.35
100	1.46	1.52

Moisture conservation practices

Mulching

Mulching known to influence WUE of crops by affecting the hydrothermal regime of soil, which may enhance root and shoot growth, besides it helps in reducing the evaporation (E) component of the evapotranspiration. Under moisture stress conditions, when moisture can be held over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield. Moisture conservation practices have been widely practiced as a mean of improving yields in water limited environment. Rajput and Singh., (1970) reported saving of water by mulches. Covering the soil with organic/inorganic materials(mulching) can minimize soil evaporative losses, suppress weeds and increase soil temperature, which may speed crop development**(**Nelson &Mele2006).Many organic mulches are locally sourced (commonly by-products from other industries such as farm yard manure, olive press residues and almond shells) and can be seasonal in their availability.

Nalayini et al. (2009) conducted field experiment at Coimbatore during 2002-03 and 2003-04 crop seasons during the winter (August-February). Cotton (Gossypiumhirsutum L.) followed summer (March-May), maize (Zea mays L.) crops using different thickness black polythene mulch film of 30,50,75 and 100 micron were evaluated against conventionally planted (no-mulch) cotton-maize cropping system for moisture conservation and enhanced crop production efficiency. This might be due to effective control of evaporation and control of weeds under polyethylene mulching.

Tillage

Tillage practices mainly influence the physical properties of soil viz., soil moisture content, soil aeration, soil temperature, mechanical impedance, porosity and bulk density of soil and also the biological and chemical properties of soil, which in turn influence the edaphic needs of plants viz., seedling emergence and establishment, root development and weed control. Tillage also influences the movement of water and nutrients in the soil and hence their uptake by crop plants and their losses from the soil-plant system.Result of various investigations from almost all world climatic zones, suggest that ploughing causes common soil-related problems of compaction, soil erosion, reduced water percolation and thus increased runoff and high energy and time requirements Titi.,(2003). While conservation tillage, including no-tillage, ridge tillage, mulch tillage, and any systems with at least 30% residue cover remaining after planting is generally designed to reduce soil erosion it also improves water infiltration, water storage and thus yield potential and improved WUE Hartkamp et al.,(2004).

Table 4 .Effect of fertilizer on grain yield and water-use efficiency of maize (Itabari 1991).

Treatment	Yield (kg ha^{-1})	WUE* (kg ha^{-1} mm^{-1})
0 kg N + 0 kg P2O5	4030	14.3
20 kg N + 20 kg P2O5	4970	17.6
40 kg N + 40 kg P2O5	4700	16.7
60kg N + 60 kg P2O5	5360	19
LSD (P=.0.05)	984.5	3.5
SE	±237.2	±0.8
CV (%)	10.4	10.4
* Water-use efficiency was determined using the total season's rainfall (282 mm).		

Weed control

Weed management is the most efficient and practical means of reducing transpiration. Weeds compete with crops for soil moisture, nutrients and light. Weeds transpire more amount of water compared to associated crop plants.In dry areas, however, the main objective of weed control is to increase the water supply available to the crop. But factors such as early sowing (affecting transpiration efficiency) and mulching (reducing soil evaporation) affect both weed infestation as well as crop water availability and use (Amor, 1991). Also other management practices such as tillage, seed density, fertilizer application, and crop rotations are interrelated with both weed control and water-use efficiency (Cornish &Lymberg, 1986; Durutanetai., 1991). To minimize the competition between weeds and crops for water, it is therefore important to adopt an integrated approach to the control of weeds. Rather than relying on only one method of weed control, several possible alternatives should be used in a systematic manner, thus increasing the chance of developing economic and sustainable farming systems which are also efficient in water use (Amor, 1991).

Vegetative barrier

Vegetative barriers play significant role to increase the yields than that of water used by the crop. Chand and Bhan, 2002 reported that water use efficiency of sorghum was appreciably improved due to different vegetative barriersover control. The maximum water use efficiency was recorded under Sesbaniasesbanfollowed by Leucaenaleucocephalaand Cajanuscajanbarriers. Minimizing water use efficiency was observed under the control crop. The increase in the water use efficiency may be attributed to appreciable increase in grain yield,which was in much greater proportion than the water use under different vegetative barriers.

Improvement of WUE in Maize by Modification of Agronomic Measures

Drought resistance for a crop can be affected by many agronomic measures. Some measures are critical for improving WUE, and can be achieved with relatively simple changes to production practices.

Application of soil amendments or conditioners

Poultry manure has long been recognized the most desirable organic fertilizer. It improves soil fertility by adding both major and essential nutrients as well as soil organic matter which improve moisture and nutrient retention.Farhad et.al.,(2009)

Fertilizers

There is a strong relationship between soil fertility and water use efficiency of the crop. A 15-year field experiment at the Changwu Ecological Station indicated that N is important in improving WUE and soil water use, while P plays an important role in increasing not only total soil water use but also water extraction from deep soil layer Dang (1999).

Application of nutrients facilitates root growth, which can extract soil moisture from deeper layers. Furthermore, application of fertilizers facilitates early development of canopy that covers the soil and intercepts more solar radiation and thereby reduces the evaporation component of the evapo-transpiration. Effects of nutrient-water interaction on WUE of groundnut crop were studied in Rabiseason. Mean water use efficiency in irrigated plots was significantly higher than that of un-irrigated plots. Both N and P significantly increased WUE over that of no-nutrient control. Application of N and P together was more beneficial than the application of either of the two or no nutrients. Interaction between irrigation and nutrients had the positive effect of WUE. In another field trial conducted in Khurda district, water use efficiency in summer sesame significantly increased with the use of recommended dose of fertilizers Singh et al.,(2008).The effect of complete and balanced fertility on WUEcan also be seen in a high yield corn study recentlyestablished in north central Kansas.

Kibe and Singh (2003) reported that water use efficiency of wheat was increased with addition of N fertilizerto a maximum with 100 kg N/ha (Table. 3). This is because of applied higher N results in higher grain yield, which isproportionally more than the increase in water use thereby resulting into higher water use efficiency.(Table-3) Source: Kibe and Singh (2003)

Edaphic Factors:

Edaphic factors are the major detriment of the water use efficiency (Singh et al., 2014). Soil texture is the combination of the relative proportion of sand, silt and clay, and has a direct role in the water holding capacity of soil. Soil depth represents the effective root zone depth. Another very important factor affecting water use efficiency is the soil structure. Soil aggregates influences the ratio of soil macro pores and micro pore

Mycorrhizae

Arbuscularmycorrhiza (AM) the symbiotic association between soil fungi and plant roots are known to protect host plants from the harmful effects of drought (Auge´, 2001; Ruiz-Lozano, 2003; Boomsma, 2008) and to improve the nutrient uptake and growth of plants under water stress conditions. The benefits of mycorrhizal fungi in improving the water use efficiency have been attributed to increase in nutritional status, especially P, of hosts, which in turnincreased the hydraulic conductivity of the roots (Nelson, 1987).

Various experiments under controlled and field conditions have shown, that the mycorrhizal colonization of roots increased drought tolerance of different crops such as maize (Sylvia et al., 1993; Subramanian et al., 1995), onion (Azco´n and Tobar, 1998), lettuce (Tobar et al., 1994a,b; Azco´n et al., 1996; Ruiz-Lozano and Azco´n, 1996), or red clover (Fitter, 1988). One of the mechanisms of the mycorrhizal symbiosis on host plant water balance is the increased root biomass and subsequently theplant size. In particular the mobilization and uptake of phosphorus are often related to an increase in plant size Subramanian (2006).

Application of Fertilizer and Organic Manure

In a study to quantify the effects of fertilizer on growth, yield, and water-use efficiency of maize, Itabari (1991) found that application of fertilizer increased grain yield and water-use efficiency of maize (Table.4).

Irrigation scheduling and Management

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.

WUE can be improved with better systems for water conveyance, allocation and distribution (Hamdy et al. 2003) and water loss can be drastically reduced by using advanced irrigation methods, including drip irrigation systems that allow water to be delivered precisely when and where it is needed. Average application efficiencies of different systems are surface (flood) irrigated, 60 to 90%; sprinkler irrigation, 65 to 90%; drip irrigation, 75 to 90% (Fairweather et al. 2003). Drip irrigation is an efficient method of providing irrigation water directly into the soil at the root zone of plants (Pandey et al., 2013). An experiment was conducted by Gupta et al., 2010 to investigate the response of lettuce to drip irrigation during Rabi 2007 at the experimental farm of SKUAST-K, Shalimar. The highest yield was recorded in treatment (80% ET through drip irrigation) but highest water use efficiency was observed in (60% ET through drip irrigation). Palada et al., (2007) reported that the differences in marketable yield were significant for cucumber, sponge gourd and brinjal in drip irrigation over hand watering while yard-long bean yield was statistically similar to both methods. Water use was significantly lower in drip-irrigated plots than plots under hand watering for cucumber and yard-long bean. The low water use and higher yields resulted in a consistent trend for higher water use efficiency in drip irrigated plots with significant differences for cucumber, sponge gourd and brinjal. Similar finding was also reported byPandey et al., (2013) while working on chilli with drip irrigation.

Water saving irrigation strategies

Many results confirmed that the deficit irrigation strategy has the potential to save water for irrigation and optimize water productivity in agriculture. The term deficit irrigation describes an irrigation scheduling strategy that allows a plant's water status to decrease to the certain point of drought stress.

Currently, two deficit irrigation methods are in use: regulated deficit irrigation and partial root-zone drying (FAO, 2002). Both methods are based on the understanding of the physiological responses of plants to water supply and water deficit, especially the perception and transduction of root-to-shoot drought signals (Chaves et al., 2002; Morison et al., 2008; Stikic et al. 2010).

Regulated deficit irrigation

When water supplies are limited, the farmer’s goal should be to maximize net income per unit water used rather than per land unit. Deficit irrigation, by reducing irrigation water use, can aid in coping with situations where water supply is restricted. In field crops, a well-designed deficit irrigation regime can optimize water productivity over an area when full irrigation is not possible (Fereres and Soriano, 2007). The correct application of deficit irrigation requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest (English, 1990).

Partial root zone drying

New approaches for managing irrigation and improving water-use efficiency are tested alongside intensification trials. Among these approaches is the application of deficit irrigation strategies as an alternative tool, aimed at significant water savings while improving both fruit quality and water productivity. Regulation of vegetative growth by regulated deficit irrigation has been suggested for many crops (Chalmers et al. 1981; Behboudian and Lawes 1994; Ben Mechlia et al. 2002; Girona et al. 2004: Li et al. 1989;). Following some physiological research, an alternative approach – that of drying part of the root system while keeping the rest well watered has been proposed Stoll et al., (2000). Roots in drying soil send chemical signals to leaves, leading to a reduction in stomatal conductance and growth, and significant water saving. Partial root zone drying is a new irrigation technique that improves water-use efficiency in crop production without significantly reducing yield. Split-root experiment devised by Blackman and Davies (1985) would have suggested, drying part of the root system indeed can inhibit the stomatal opening to some degree but keep the shoot turgid at the same time. The shoot physiological measurements showed that if there is some part of the root system always exposed to the soil drying, the stomata of the plant can never be fully open. Obviously, such a result can be explained as the regulation by the root signal that is produced in the roots in the drying soil and transported to the shoots where leaf expansion and stomatal conductance are restricted (Davies and Zhang, 1991).

Precision Irrigation

There are different methods for irrigation scheduling viz., critical crop growth stages, feel and appearance method, soil moisture depletion approach, irrigation water at different cumulative pan evaporation method. Kang et al., (2000a) reported that soil drying at the seedling stage plus further mild soil drying at the stem-elongation stage is an optimum irrigation method for maize production in a semi-arid area.

Alternate furrow irrigation (one of the two neighboring furrows is alternately irrigated during consecutive watering) and controlled alternate partial root-zone irrigation (part of the root system being exposed to drying soil while the remaining part being irrigated normally) are also ways to increase WUE of maize (Kang et al. 2000b, Kang and Zhang 2004).

Chemical Methods

Reducing transpiration is the most effective means of increasing the amount of water available to the crop. Anti-transpirants have been tried with limited success because these may not be economical or practical.

Anti-transparent: Anti-transparent are the materials or chemicals that are used to reduce the transpiration. These chemicals reduce the transpiration either by closing the stomata or by forming the film on the leaf surface.. The most common type of anti-transparants is of four types:

1. **Stomatal closing type:** Most of the transpiration occurs through the stomata on the leaf surface. Some fungicides like phenyl mercuric acetate (PMA) and herbicides like Atrazine in low concentration serve as antitranspirants by inducing stomatal closing.
2. **Film forming type:** Plastic and waxy material which form a thin film on the leaf surface and result into physical barrier. For example ethyl alcohol, It reduces photosynthesis eg. Tag 9; S - 789 foliate.
3. **Reflectance type:** They are white materials which form a coating on the leaves and increase the leaf reflectance (albedo). By reflecting the radiation, vapour pressure gradient and thus reduce transpiration. Application of 5 percent kaolin spray reduces transpiration losses. Diatomaceous earth product (Celite), hydrated lime, calcium carbonate, magnesium carbonate, zincs sulphate etc.
4. **Growth retardant:** These chemicals reduce shoot growth and increase root growth and thus enable the plants to resist drought. They may also induce stomatal closure. Cycocel is useful for improving the water status of the plant.

Microbial amendments in enhancing water use efficiency

Organic Matter Decomposition

Microorganisms such as bacteria, fungi and actinomycetes are the maindecomposers. As nematodes and protozoa feed upon microbial populations, theyconsequently affect organic matter decomposition. It is likely that such feeding ultimatelyliberates nutrients immobilized in microbial cells or reduces competition betweenmicroorganisms so that mineralization is actually accelerated. "These activities not onlyinfluence the general nutrition, health, and vigor of higher plants. The overall effectproduced due to activities of soil biota supports the healthy growth of plant and thusimproved production vis-à-vis enhanced water use efficiency.

Biological N2 fixation

Biological N2 fixation (BNF) is an important activity of microorganisms in soil. Thecontribution of legume-rhizobia associations alone is about 40 % of total 175 million tonsof BNF. In the presence of a suitable host the bacteria infect the plant roots and form rootnodules. Within these nodules, rhizobia fix atmospheric N2. Besides, there are number ofdiazotrophic bacteria, e.g. Azotobacter, Azospirillum, Herbaspirillum, Gluconoacetobacter,which fixes atmospheric N2 and improve the plant growth and water use efficiency.

Humus formation

Humus synthesis is one of the important activities of microorganisms in soil. Thebenefits of soil organic matter on water holding capacity are well known. Thus a soil rich in-organic matter may retain the water for longer periods for utilization by the plants and toavoid its loss through transpiration and leaching. Raverkaret.al., (2011) compared the wateruse efficiency under farmers, INM and organic farming practices for rice, wheat andvegetable pea in Uttrakhand. The irrigation use efficiency under farmers, INM and organicfarming practices for rice were 0.252, 0.276 and 0.254 q ha-1-cm, for wheat 1.16, 1.57 and1.35 q ha-1-cm and for vegetable pea 12.0. 16.6 and 13.6 q ha-1-cm, respectively. This alsoresulted in net profit to the farmers and improved soil quality.Various processes executed by the microorganisms,particularly the decomposition oforganic resides, formation of humus, application of PGPR, Nitrogen fixers and phosphate solubilising bacteriacontribute toward improving water use efficiency. However, further specific studies arewarranted to utilize the soil biota holistically for the enhanced water use efficiency.

Summary and conclusion

Water use efficiency is an important physiological characteristic that is related to the ability of crop to cope with water stress. In simple terms, it is characterized by crop yield per unit of water used. WUE can be defined as biomass produced per unit area per unit water evapo-transpired.

The biomass is usually determined as dry weight rather than as fresh weight, therefore the several methods are commonly used to determine water use efficiency. Water use efficiency is mainly relying on the economic yield of the crop rather than water use. Varieties of the maize have the differential water use efficiency. In the water limited areas grow the varieties that have more water use efficiency than that are having a low water use efficiency. But it has observed that the varieties are recommended without taking into account their water use efficiency. Economic yields depend upon the optimum time of sowing or planting. For higher water use efficiency and economic yield, the crop must be planted early for more yields with less water. Application of optimum dose of chemical fertilizer alone and its use with organic manure, vermicompost, biofertilizer helps to enhance the water use efficiency. Irrigation frequency, irrigation levels, irrigation regime, a period of percolation of water and cutoff date of irrigation play significant role in increasing water use efficiency. It is the most experienced that the high yielding varieties contributed a lot to bring the Green Revolution in India, but the problem created by green revolution can be redressed by developing the appropriate agronomic practices in combination with the new cultivars to increase the water use efficiency for the judicious use of water resources. It is clear that it is not just one factor has led to the higher water use efficiency, but rather the combination of conventional plant breeding strategies and biotechnology methods, appropriate fertilizer use, improved weed control, timely planting, seed rate, plant population, row spacing, crop geometry, vegetative barriers, intercropping, moisture conservation practices and increased the adoption of crop rotation.

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