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Review Article

Ways to Maximize the Water Use Efficiency in Field Crops – A review

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ABSTRACT

Yields of field crops in Indo-Gangetic plains of India have decreased due to the advent of increasing water scarcity in this century. The water is a very limiting input in this region for the crop production; its efficiency is quite low in the range 30–40 per cent, thereby about 60–70 per cent of irrigation water is lost during conveyance and application. Irrigation farming, the greatest water user of all, has been made responsible for inefficient water use. There is also not available new land for agriculture to meet the demand of ever increasing population in terms of food and clothing. On the other hand, irrigation farming more and more has to compete with other interests for dwindling resources in water. Therefore, there is need to increase the yields and water use efficiency in water limited environments. Thus, this review will focus on the various water economization practices, irrigation scheduling based on consumptive pan evaporative, land configuration, selection of crop, varieties, intercropping, moisture conservation practices, use vegetative barriers, use of transpiration suppressants according to the availability of water. In this article is also discussed the ecological aspect of water, depletion of groundwater resources, the concept of water use efficiency, need to improve the water use efficiency, factors to enhancing the water use efficiency which will help to sustain the resources of water and productivity of crops. This review article would be useful to convey the importance to work out the water use efficiency to indentify the efficient management practices, crop varieties/hybrids to get the higher productivity with the availability of water. With good management and adoption of appropriate practices improved agricultural water conservation and subsequent use of that water for more efficient crop production are possible under both dry land and irrigated area.

Introduction

Water is one of the most valuable resources for the survival of civilization. However, the agriculture sector is the largest consumer of water resources in Indo-gangetic plains. Assured supply of water is necessary for sustainable agriculture. However, farmers of Indo-gangetic plains are using water irrationally. Though water is a precious and scarce resource, its efficiency is quite low in the range 30–40 per cent, thereby about 60–70 per cent of irrigation water is lost during conveyance and application. Also, intensive agriculture and rice–wheat cropping pattern are prevalent in these areas. Lack of awareness among the farmers about the consequences of irrational use of water and lack of appropriate tools and instruments for regulated and uniform application of the desired quantity of water at th greenerventures.net e appropriate time are among the major causes of low water-use efficiency at the field-level. This has ultimately led to a decline of the water resources. Immediate steps should be taken for efficient and judicious use of this resource; else it will be difficult to sustain agricultural productivity as well as the requirement of water for the survival of society. Farmers' practices need to be critically observed and modified taking into view the perceptions, concerns and constraints of the farmers in adopting better tools and techniques.

The impact of green revolution had made India self reliant in food grains production. Now, it has imposes the great threat to the sustainability of existing cropping system due to the exploitation of natural resources. The rice-wheat is the predominant cropping system of Indo-gangetic plains. The problems associated with the Indo-gangetic plains are removal of residues, burning of residues, depletion of underground water, low fertility, low organic matter content, low productivity, poor microbial activity, environmental pollution. The Indo-gangetic plains experiences high temperature, moisture stress, frequent heat waves coupled with extreme competition with domestic and industrial demand. This has made water most expensive input which underlines importance of the economization of water. Of the various water economization practices, irrigation scheduling based on consumptive pan evaporative, land configuration, selection of crop, varieties, intercropping, moisture conservation practices, use vegetative barriers, use of transpiration suppressants according to the availability of water.

With good management and adoption of appropriate practices improved 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 favorable effects of various mulches and transpiration suppressants on water use efficiency and grain yield of perlmillet reported by Dahiya and Singh (1977). Plant density per unit area is another important factor governing yield of rainfed crops. Bhardwaj et al. (1971) and Pal and Kaushik (1972) suggested that a row spacing of 50 cm x 15 cm having 1,50.000-2,00,000 plants/ha is optimum for pearlmillet. The productivity of wheat genotypes depends largely on the prevailing weather conditions and soil moisture regime during crop growth period. Temperature affects growth and development of wheat to a great extent and decides production potential and optimum seeding time in each agro-ecological region of the country. Higher temperature critical plant development stages limits productivity at later sowings (Mahajan and Nayeem, 1990). Adequate soil moisture is required for normal development of wheat crop at all stages of growth which can be created by timely scheduling of irrigation (Prihar, 2000). Choice of crop cultivar is also vital production input as all the cultivars of wheat can not perform equally well under timely and late sown condition (Singh et al., 1998). The insufficient irrigation facilities in arid and Semi-arid areas were identified as the major reason of productivity decline of the crops. It is universally acknowledged that wheat growth and yield increase significantly with water availability. However, such increase in production does not result in similar trend in water use efficiency (Pal et al., 1996). Tillage, irrigation and fertilizer constitute the major components of energy input in a crop production system. With increasing energy input costs, it becomes imperative to evolve energy efficient crop management system. There are some reports that within certain limit water and nutrients substitute for each other (Prihar et al., 1985a, 1989) and tillage increases efficiency of water of fertilizer use (Sharma, 1985, Eck and Unger, 1985). 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.

Ecological aspect of water

Water is a vital component of agriculture and a major part of fruits, vegetables and cereal foods consumed by humans, their food grains fed to animals that are used as human food and food / vegetation to sustain animals to work in human many parts of world. For centuries humans have been concerned with efficient use of water in production of crops. The ability to grow crops and manage their needs for water is necessary for the civilization. Both quality and quantity are important for mankind. Quality of water is being deteriorated by dumping of wastes, domestic sewage, industrial effluents etc. Excessive uses of agro-chemicals render water unsuitable for human consumption. Excessive withdrawal of underground water particularly in rice-wheat system in Indo-gangetic plains, excessive wastage in industrial and domestic usage is the cause of concern. Greater efficiencies of water use in agriculture, recycling of water through water treatment plants in industries can play a catalytic role in saving this valuable resource. Without appropriate management, irrigated agriculture which is a major part of agriculture can be detrimental to the environment and endanger sustainability.

Over the years, the increase in population has resulted in increased demand of water for irrigation, industries, domestic use which caused excessive withdrawal of underground water and has been increased from about 2800 km^3 per year in 1977 to about 4200 km^3 per year in 2005 and may rise to 5200 km^3 per year in 2025. Further, with increasing population and more wastage of water cause declining of water table has resulted in drastic reduction in per capita water availability. The per capita available water has declined from about 10018 m^3 in 1975 to about 6500 m^3 in 2000 and the trend continues till date (www.worldbank.org and www.census.gov)

In agriculture, the stress on irrigation is going to be increased day by day to meet the food needs of rapidly growing world population. The world population increased from 3 billion in 1959 to 6 billion by 1999, a doubling that occurred over 40 years and is currently increasing by about 80-85 million people per year. The Census Bureau's latest projections imply that population growth will continue into the 21st century, although more slowly. The United Nation projections that the world population in 2050 could be 7.3 to 10.7 billion if the reproduction fertility declines and it will be 14.4 billion if the world's population continues to increase at the present rate. The thing of concern is that major population growth is in developing world including Asia where the natural resources are already under threat (Annoymous, 2009). Asia had more than 60 per cent of total irrigated area of the world's 263 million hectare total irrigated area in 1996 (FAOSTAT, 1999).

Table1. Irrigated area and per capita availability of irrigated area in the world

Year	Irrigated Area (M ha)	Irrigated area per thousand person
1950	94.0	37.2
1955	114.0	41.4
1960	135.0	44.6
1965	165.0	45.0
1970	168.0	45.6
1975	188.0	46.4
1980	209.0	47.2
1985	225.0	46.5
1990	246.0	46.4
1995	264.0	46.3
2000	278.0	45.5
2005	284.0	43.6
2006	286.0	43.3
2007	287.0	43.0

Source: Brown (2001) and U.N. FAO, Resource STAT.

In addition to growth rates, another way to look at population growth is to consider annual changes in the total population. The annual increase in world population peaked at about 88 million in the late 1980s. The peak occurred then, even though annual growth rates were past their peak in the late 1960s, because the world population was higher in the 1980s than in the 1960s. The world population growth rate rose from about 1.5 percent per year from 1950-51 to a peak of over 2 percent in the early 1960s due to reductions in mortality. Growth rates thereafter started to decline due to rising age at marriage as well as increasing availability and use of effective contraceptive methods (Annoymous, 2009). As the world's population has increased since 1960s, the irrigated land area has also been increased such that per capita irrigated land has been increased from 0.0372 in1950 to 0.0472 ha/person in1980 but it was started declining from 0.0465 in 1985 to 0.043 in 2007 (Table 1). Irrigated land comprises about 15 percent of arable land in the world and produced 36 percent of food. Nearly 70 percent of grains in China and 50 per cent of grains in India are harvested from irrigated lands (Brown 1999). In India, the major grain production is from Indo Gangetic Plains where the main reason for high productivity includes irrigation facilities along with fertile soil and high yielding varieties. FAO estimated (1988) that almost two thirds of the increase in crop production that is needed in developing countries in the coming years must come from increased yields per unit area, $1/5^{th}$ from increase in the arable land and remaining $1/8^{th}$ from the increased cropping intensity. The $2/3^{rd}$ of increase in arable land is from increase in irrigated land. Rhodes (1997) also concluded that the required food production in developing countries must primarily come from irrigated land.

Bhaduri (2008) reported that in the recent past, it has been observed not much change in the gross sown area of food grains in India. In fact, the average gross sown area for food grains was 127 million hectares during 1980-1990 and it has reduced to 123 million hectares in 1990 –2000. The projection, based on time trend, suggests that the gross sown area of India will increase slowly till 2010 and then it will start declining. It is clear from the table 2 the gross sown area would be 128 million hectares in 2010, 125 million hectares in 2025 and in 2050 it would be 112 million hectares. With attainable increase in irrigation and fertilizer according to time trend, the production of food production will be around 271million tons in 2050 and according to higher growth rate scenario the production of food grains would be 322 and 334 million ton in 2025 and 2050 respectively. This is a supply side projection. India's consumption of food grains can change dramatically as economy grows. As projected, if more land is brought under irrigation, then farmers would response more too economic factors like price, and we could expect a projection figure. From the above analysis it is evident that supply response of food production is greatly influenced by irrigation and fertilizer usage. Irrigation is a crucial factor for reducing the fluctuation in food production in last decade. It is however, true that now with over 50% of the area under rainfed, rainfall is still one of the most important factors determining average yield. Due to vagaries in rainfall, we observe fluctuation in yield. In year 2000 out of 89 million tonnes of rice production nearly30 million tonnes were produced in the unirrigated area. In case of wheat, out of 56 million tonnes only 6 % of the total production comes from rain fed area.

Table 2: Projected values of gross sown area and production of food grains in 2010, 2025 and 2050.

Year	Gross sown area of food grains (million hectare)	Production of food grains According to time trend (million tons)	Production of food grains if the growth of irrigation is 50 % more per year (million tons)
2010	128.25	235.98	271.89
2025	125.06	268.88	322.65
2050	112.72	271.65	334.79

Source: Bhaduri (2008)

Depletion of Groundwater Resources in Punjab

The state of Punjab, in common parlance known as 'Food Grains Bowl' of the country, is the largest surplus state in terms of food grains. It has a total geographical area of 50.36 lakh hectares out of which almost 83 per cent is under cultivation with cropping intensity of 189 per cent (Government of Punjab, 2005). The agriculture in the state is highly intensive in terms of use of land, capital, energy, and all other agricultural inputs, including irrigation water. This is the reason that, with only 1.5 per cent of geographical area of the country, the state produced about 21 per cent of wheat, 12 per cent of rice and 11 per cent of cotton of their respective national production in 2004-05. But, this increase in agricultural production has been at the cost of unsustainable use of resources like land, water and chemical inputs, the externality of which is being faced now, presently, a major concern of the state is the rapid decline of water-table. About 77 per cent area of the state is facing the problem of falling water table (Hira et al., 2004). To meet the present level of crop production, the demand for water far exceeds its supply from different sources (Government of Punjab, 2005). The excess demand is met through over-exploitation of groundwater due to which the groundwater table is successively going down. Therefore, an efficient use and management of agriculture resources, especially water, has become absolutely necessary to sustain intensive agriculture and income of farmers in the state by preserving the scarce natural resources. Keeping these facts in view, measures had been taken to access the irrigation efficiency at the farm levels and also the extent of water depletion with time and its consequences in Punjab.

Punjab agriculture is primarily based on intensive irrigation using surface as well as groundwater resources, since rainfall hardly meets 20 per cent of the irrigation requirements. Intensive agriculture has led to a serious imbalance in the use and availability of groundwater resources. The total surface water availability at different head works is about 1.80 million hectare metre (M ha-m) per annum (Government of Punjab, 2005). Out of this, 0.35 M ha-m is lost during conveyance and only 1.45 M ha-m is available at the outlet that irrigates about 1.0 M ha land. The remaining 3.24 M ha land is irrigated using groundwater. The total sustainable availability of groundwater is 1.68 M ha-m per annum. The current crop production pattern dominated by paddy-wheat crop rotation requires 4.37 M ha-m of irrigation water per annum, against the total supply of 3.13 M ha-m per annum from both surface and annual recharge of groundwater resources, leading to a net deficit of 1.24 M ha-m (Government of Punjab, 2005). Consequently, the deficit is being met by overexploitation of the groundwater reserves through tube wells. The over-exploitation of groundwater has played havoc with the groundwater resources of the state. It has been found that out of 138 development blocks in the state, 84 blocks were marked as 'dark' (rate of exploitation: 85 percent of the rechargeable capacity), 16 blocks as 'grey' (rate of exploitation: 65-85 percent) and 38 blocks were 'white' (rate of exploitation: less than 65 percent) on the basis of groundwater availability and pumping (Groundwater Year Book, 2004).

The Concept of Water Use Efficiency (WUE)

In general term efficiency is used to quantify the relative out put obtainable from a given input. So, water use efficiency is output obtained by inputting the known amount of water in general terms. The water use efficiency (WUE) can be described on various scales from leaf of a plant to farm level (Sinclair *et al* 1984). 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 (Frank et al., 1987) WUE is expressed in equation as follows:

$$\text{Water Use Efficiency (WUE)} = \frac{\text{Dry weight accumulation}}{\text{Water lost through transpiration}} \quad \text{--------------} \quad 1$$

(Heitholt, 1989)

$$\text{Water Use Efficiency (WUE)} = \frac{\text{Dry weight accumulation}}{\text{Water lost through evapo-transpiration}} \quad \text{-------------} \quad 2$$

(Most common method)

WUE can be expressed on basis of vegetative growth or reproductive growth and basis must be stated. Different units can be used in numerator or denominator of the equation. Old units were pounds or tons of dry weight produced per acre inch of water evapotranspired. Then it was expressed as kilograms of dry weight per kilogram of water transpired. Now it is expressed as kilograms of dry matter produced per m^3 of water evapotanspired.
New gas analyzers can measure photosynthetic rate and transpiration rate of individual leaves or of a part of individual leaf as small as 6 cm^2. We can express water use efficiency on a leaf basis as

$$\text{Leaf water use efficiency (LWUE)} = \frac{\text{The steady state } Co_2 \text{ exchange rate (Photosynthetic rate)}}{\text{The transpiration rate}} \quad \text{---------} \quad 3$$

So, at biological level it is carbohydrate formed through photosynthesis from CO_2, sunlight and water per unit of transpiration. WUE can be based either on water loss through evapotranspiration (ET) or transpiration from crop. The difference is important because suppression of soil water evaporation and prevention of weed transpiration can improve ET efficiency. WUE is inverse of transpiration ratio which was used earlier and is proposed by Brown (1999) as upcoming benchmark for expressing yield and it is amount of water required to produce a unit of crop yield. Often term WUE becomes confounded when used in agriculture. Bos (1980, 1985) proposed that WUE for irrigation be based on yield produced above the rainfed or dry land yield divided by net evapotranspiration (ET) difference for the irrigated crop. His expression can be written as

$$ET_{WUE} = \frac{(Y_i - Y_d)}{(ET_i - ET_d)} \quad \text{------------} \quad 4$$

$$I_{WUE} = \frac{(Y_i - Y_d)}{I_i} \quad \text{-----------} \quad 5$$

He expressed the discriminate rate of irrigation in WUE and symbols denoted as: Y_i - yield and ET_i - ET for irrigation level I, Y_d - yield and ET_d - ET for equivalent dry land or rainfed plot, I_i - amount of irrigation applied for irrigation level i.
The water use efficiency is difficult to determine precisely, so in some situations a bench mark WUE

(WUE $_b$) is used by many irrigation practitioners. It can be defined as

$$WUE_b = \frac{\text{Yield (Usually economic yield)}}{P_e + I + SW} \qquad \text{----------} \quad 6$$

Where as: P_e - effective rainfall, I - irrigation applied, SW - soil water depletion from root zone during growing season.

The denominator is surrogate estimate for the water used to produce crop, depending upon the neglect of percolation, ground water use and surface runoff. Howell *et al* (1990) presented an expression for field WUE as

$$WUE = \frac{(HI \ X \ DM)}{E} \qquad \text{----------} \quad 7$$

$$\frac{\{T(I - WC)[1 + WC]\}}{(P + I + SW - D - Q - E)}$$

Symbols denoted as: HI - harvest index, DM - dry matter in g/ m^2, T - transpiration in mm
WC - standard water content used to economic yield (in fraction i. e. 0.15 – 0.155 is for corn and 0.14 is for other cereals), E - soil water evaporation in mm, P - precipitation in mm, I is irrigation in mm , SW - soil water depletion from root zone in mm, D - deep percolation below the root zone in mm Q is surface runoff in mm

Wang *et al* (1996) offered a new term called general efficiency (Eg) based on the ratio of transpiration to sum of volume of applied water and volume of deficit expressed as

$$Eg = \frac{\alpha \ Ea \ Es}{(Ea + Es - Ea \ Es)} \qquad \text{------------} \quad 8$$

Where as: Eg - general irrigation efficiency fraction, α - transpiration fraction of ET (T / ET)
Ea - application efficiency fraction, Es - storage efficiency fraction

Defining WUE for irrigation can be complex as scale of importance for water resources may shifts for example from plant to field to broader hydrological water shed to irrigation district and water components may not be so precisely defined at the same time. But all these above equations put an insight to different parameters which can be important at various different sites and at various times according to one's requirement. All these parameters can be used by manipulating them to improve the WUE. But in general terms the water use efficiency at crop level or at farm level is best to describe WUE.

Ways of maximizing this efficiency for optimum productivity in irrigated field crops has been a central theme of plant and environmental interaction studies. Obviously, any factor that increases yield will increase water use efficiency. Likewise, any factor reducing evapo-transpiration that has no deleterious effect on yield will increase water use efficiency (Eastin and Sullivan, 1984).

Need to improve the water use efficiency

Improvement in water use efficiency in agriculture is essential because of irrigation sources are declining, energy costs make irrigation more expensive to deliver, world demand for food, feed, and fiber is increasing and production is being pushed into more arid environments.

Enhancing the water use efficiency

Varieties

The yields and water use efficiency of cultivars/hybrids of crops differed significantly. Those varieties/hybrids produced more than the water use should be grown under the limited water areas to increase the water productivity per unit area. Shivani et al. (2001, 2003) and Behera et al (2002) reported that wheat cultivars HUW 234 and Lok 1 had higher water use efficiency. Similarly, Chand and Bhan (2002) reported that Varsha sorghum was distinctly superior in water use efficiency in terms of grain production as well as dry matter production to CSV 13 and CSV 15. Similar findings were also reported by Singh et al. (2004) in chickpea of genotype Avarodhi, Awasthi et al. (2007) and Panda et al. (2004) Indian mustard varieties of Vaibhav and SEJ 2, Kumar et al. (2003) and Rathore et al. (2008) in pearlmillet hybrid of HHB 67-2, HHB 94 and HHB 117, Hooda et al. (1999) in field pea variety of HFP-8712, Patel et al. (2008) in cowpea variety of GC 4, respectively. Similar observations were also reported in summer moong varieties by Soni and Gupta (1999). It shows that the variety/hybrid should be evaluated for water use efficiency before to release in particular area according to the availability of water.

Time of Planting

Time of sowing is the non-monitory input which is not only ensures the higher yields but also optimum utilization of the applied resources. Choice of crop cultivar is also a vital production input as all the cultivars of wheat cannot perform equally well under timely and late sown condition (Singh et al., 1998). Shavani *et. al.* (2001and 2003) observed that water use efficiency of timely seeded wheat was maximum and decreased by 4.6, 25.8 and 45.4 percent in moderately late (7 December), late (21 December) and very late (7 January) seeded wheat, respectively (Table 3). Similar results were also observed by Pal *et.al.* (1996) and reported that timely sown (November 24) wheat crop gave 27 percent higher grain yield and 18 percent higher water use efficiency as compared to late-sown (December 18) wheat crop. These results are in conformity with the findings of Singh and Mahey (1998) in sunflower, Panda et al. (2004) and Awasthi et al. (2007) in Indian mustard and Patel et al. (2008) in cowpea. In early sowing the productive phase was comparatively longer which resulted in higher seed yield. Decreased water use efficiency under delayed sowing was mainly due to proportionately higher reduction in seed yield of the crop compared to the consumptive water use.

Table 3. Effect of date of sowing on the grain yield and water use efficiency in wheat (Pooled data of 1995-96 and1996-97)

Time of sowing	WUE (kg/ha mm)	Grain Yield (q/ha)
Timely (21 Nov)	8.87	33.01
Moderately late (7 Dec)	8.46	27.67
Late (21 Dec)	6.58	20.65
Very late (7 Jan)	4.84	13.24
CD (P=0.05)	-	2.25
Cultivars		
HUW 234	7.54	23.72
K 9006	7.14	23.55
CD (P=0.05)	-	NS

Source: Shavani *et. al.* (2003)

Shifting the planting/transplanting time of crops from high to low evaporative (ET) demand periods is likely to reduce groundwater use, thereby enhancing WUE. Time-trends of deficits between rainfall and pan evaporation in Punjab and other areas of the region indicate that crops growing during hot and dry months of April to mid June will have greater irrigation needs due to high ET demand, and little or no rainfall. This concept has implications for increasing WUE in rice and spring sunflower. For example, ET demand of June 1transplanted rice is 620 mm against 520 mm for June 21 transplanted crop. Similarly, January-sown sunflower matures earlier than February sown crop, and requires less water leading to higher WUE (Hira, 2004).

Method of Planting

Planting pattern has a direct effect on 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 crop without affecting the yield of crop. Singh (1996) and Mahey et al (2002) reported that consumptive use of water by wheat crop was highest under reduced tillage followed by zero tillage and conventional tillage. However, the water use efficiency was highest under conventional tillage followed by zero and reduced tillage. There was not much difference in water use and water use efficiency under zero and conventional tillage. However, Grevers et al. (1986) obtained higher water us efficiency in zero tillage as compared to conventional tillage.

Planting crop on raised beds is a practice for increasing water use efficiency. The crop is sown with drill or planted on beds and water is applied in furrows. The comparable or higher yields are obtained with saving of about 25-30 percent water. This had been practiced in different crops like wheat, sarson, soybean and rice. Kaur (2006) reported that water use efficiency of wheat planted on beds was highest followed by conventional and zero tillage. Similar results reported by Kaur (2003) in normal sown crop, Parihar (2004) in late sown wheat, Kumar et al. (2004) in rice, Ali and Ehsanullah (2007) in cotton, Zhang *et.al.* (2007) in winter wheat, Idnani and Gautam (2008) in summer greengram and Mahey et al. (2008) in soybean. However, Aggarwal and Goswami

(2003) and reported that water use by wheat crop was lower, whereas grain yield and water use efficiency were higher under treatment where 3 rows of wheat was sown on 37.5 cm wide beds separated by 30 cm furrow as compared to the conventional flat sowing and 2 rows sown on bed (Table 4). Sowing of 3 rows of wheat on 37.5 cm wide bed alternating with 30 cm wide furrows in alluvial sandy-loam soils resulted in better soil physical environment, resulting in better root growth, reduced irrigation requirement because of furrow irrigation, significantly higher grain yield and increased water use efficiency compared with conventional flat sowing system with flood irrigation. The similar results were reported by Limon et al. (2000), Hobbs (2001).

Table 4. Effect of planting technique on the grain yield and water use efficiency in wheat

Planting technique	Water use (cm)	WUE (tonnes/ha-cm)	Grain yield (kg ha-1)
Bed planting (2 rows/bed)	27.7	0.153	4223
Bed Planting (3 rows/bed)	28.6	0.186	5306
Flat bed	32.5	0.157	5085
CD (P=0.05)	-	0.27	269

Source: Aggarwal and Goswami (2003)

Jat and Gautam (2001) reported that sowing of bajra in ridges and furrows 45 cm apart resulted in higher seed yield as compared to paired row sowing and uniform row sowing (45 cm). Ridge and furrow sowing also resulted in maximum water use efficiency.

Gill et al., (2006) reported that better water use efficiency and water productivity were observed in direct seeded rice. Parihar (2004) total water use increased with the increase in number of irrigation. Irrigation scheduled 1 day after infiltration of ponded water required more number of irrigations than the other seepage period. However, rice grown under puddle condition required less number of irrigation to mature than that grown in un-puddle condition. It was observed that irrigation requirement was more under un-puddle condition as compared to puddle condition. Water use efficiency was the highest with puddling and transplanting followed by puddling and line sowing of sprouted seed of rice. The lowest water use efficiency was obtained with line sowing of sprouted seed under un-puddle condition.

Table 5. Rice grain yield and water use under different planting techniques.

Planting technique	Grain yield (q/ha)	Irrigation water (cm)
Flat transplanted (33 plt/m^2)	80.5	210
Bed transplanted (33 plt/m^2)	78.8	140
Furrow transplanted (33 plt/m^2)	83.9	140
Direct seeding 2R / bed	51.3	140
CD (P=0.05)	8.8	-

Source: Kumar et al. (2004)

However, Ghadage et al. (2005) reported that the water use efficiency of cotton was more in paired row planting (90 cm x 105 cm) because this method consumed less water than the water used by normal method (120 cm x 90 cm). Sagarka et al (2002) reported that water use efficiency of winter cotton was significantly higher under alternate furrow method than the surface method. This because of the fact that in alternate furrow method water is applied in alternate furrows so half quantity of irrigation water is required compared to surface method. Similar results were reported by Ramesh (1977) and Singh (2002a) in sugarcane.

Singh and Mahey (1998) studied the effect of planting methods on the grain yield and water use efficiency in sunflower on sandy loam soil of Ludhiana during 1992-93. It was observed that sowing of sunflower on the southern side of E-W ridge resulted in 17.9 percent increase in seed yield as compared to the flat sowing. Higher soil temperature on the southern side at germination stage helped in quicker germination, better speculative soil conditions and aeration which were also responsible for higher yield in the former method of sowing. The emergence of seedlings was more rapid on the ridges due to 4-6 °C higher soil temperature on the S-side of the ridges. Ultimately LAI, dry matter accumulation and better yield contributing characters on ridge sowing resulted in higher water use efficiency on ridge sown crop.

Row spacing/row orientation

Narrow row spacing and crop geometry can result in higher yields and water use efficiency. Karrou (1998) reported that rain water use efficiency of durum wheat in semi arid environment of Morocco decreased when row spacing was increased from 12 to 24 cm due to closer crop canopy which resulted in less evaporation losses and more yields in narrow row spacing. Jones (2007) reported that Twin-row spacing as an alternative planting practice for corn silage production in the Shenandoah Valley leads to greater corn silage yields through greater water use efficiency and faster canopy development. Patil and Sheelavantar (2000) observed that sowing of sorghum in furrows 60 cm apart or in compartmental bunding (3m x 3m) resulted in significantly higher grain yield and higher water use efficiency as compared to the flat sowing (Table 6). Rathore *et al* (2008) observed that bajra crop geometry of 45cmx 12cm had the higher water use efficiency owing to larger crop canopy. This was mainly due to higher yield under this plant density owing to proper utilization of nutrients as well as moisture under optimum population. Similar results reported by Satyajeet and Nanwal (2007).

Table 6. Effect of method of planting on grain yield, consumptive use and WUE in Sorghum

Treatments	Grain yield (kg/ha)	Consumptive use (mm)	WUE (Kg/ha cm)
Flat sowing	1276	272	46.79
Sowing in furrow (60 cm)	1603	275	58.36
Compartmental Bunding (3m x 3m)	1567	273	57.22
CD (P=0.05)	124.7	-	-

Source: Patil and Sheelavantar (2000)

Hooda et al., (1999) reported that maximum water use efficiency of field pea was noticed under 30 cmx10 cm followed by 40 cmx10 cm. This is on account higher grain yield under 30 cmx10 cm treatment and water use is directly related to grain yield and consumptive use of water. However, Singh et al. (2004) reported that wider row spacing of 45 cm in chickpea had more total moisture and moisture use efficiency than narrow row spacing of 30 cm. Legere and Schneiber (1989) reported similar results in soybean that narrow row spaced crop transpired less water in comparison to wider row spaced crop.

1.4 Seed rate/plant population

Soil water evaporation is reduced with higher planting density. In humid regions where rainfall exceeds evapo-transpiration, plant densities can be increased with a concomitant increase in yield. However, in semi arid areas where soil moisture is deficit the thicker stand are avoided. The desirable plant density which could be supported by available moisture up to production of economic part and not initial biomass only is recommended for these situations. Pandey *et al* (1988) observed that higher plant density (2,00,000 plants/ha) of rainfed pearlmillet gave higher consumptive use, rate of moisture use and water use efficiency as compared to the lower plant density of 1,00,000 plants/ha, owing to larger crop canopy. In spite of the higher consumptive use, the higher WUE under higher plant density could be attributed to the beneficial effect of increased evapo-transpiration on yield. Karrou (1998) observed that the lower seed rate of 200 kernals/m^2 gave the highest grain yield and WUE of durum wheat, which was statistically at par with 300 kernals/m^2 but significantly better than 400 kernals/m^2 (Table 7). The decreased seed yield and WUE with higher seed rate due to higher plant population resulted in earlier exhaustion of water causing terminal stress which resulted in reduced seed yield and decreased WUE. Under low population, water might have been used more rationally through out the growing season which resulted in higher seed yield and WUE. Singh et al. (2003) reported that water use efficiency of wheat was higher at higher population density (15 cm, 205 kg seed/ha) than low population density (22 cm, 140 kg seed /ha)

Table 7. Effect of plant population and row spacing on grain yield and WUE of durum wheat in semi arid region

Treatment	Grain yield (kg/ha)	Rain water use efficiency (kg/ha mm)	Water use efficiency (kg/ha mm)
Row spacing			
12 cm	4020	9.5	7.8
24 cm	3380	8.0	5.5
CD 5%	274	1.1	1.5
Plant population (kernels/m^2)			
200	4010	9.5	5.3
300	3825	9.1	6.4
400	3270	7.7	6.8
CD (5%)	323	1.6	NS

Source: Karrou (1998)

Fertilizer

Fertilizer use can also have a very marked effect on crop yield and water use efficiency. Nitrogen, phosphorus, combination of chemical fertilizer with organic fertilizer or chemical fertilizer with biofertilizer has been shown to increase growth and development in both dry and irrigated areas. Kumar et al. (2000) reported that there was a progressive increase in water use efficiency of summer groundnut with increased level of fertilizer application and it was recorded to be higher with the use of organic and inorganic sources of fertilizer. Similar results were reported by Rathore et al. (2008) in pearlmillet. Kumar et al. (2003) reported that increasing levels of N from 0 to 150 kg/ha application markedly improved the water use efficiency of pearlmillet. These results corroborate the findings of Tomar et al. (1995) and Singh et al. (2003). Tetarwal and Rana (2006) reported that the highest water use efficiency, consumptive use and rate of moisture use were recorded with 80 kg N + 40 kg P_2O_5/ha, followed by 40 kg N + 20 kg P_2O_5/ha and the control. It might be due to that increase in pearlmillet –equivalent yield was more than the corresponding increase in consumptive use of water due to fertility level. The increased activity, growth and proliferation of root system due to greater translocation of photosynthates to roots owing to balanced nutrition might have resulted in extraction of more moisture from deeper soil profile.

Patil and Sheelavantar (2000) reported that application of nitrogen increased the yield, water use efficiency and yield component of sorghum. Ghosh et al. (2003) reported that application of 75 % NPK and poultry manure 1.5 t/ha recorded the highest water use efficiency of rainfed sorghum.

Kibe and Singh (2003) reported that water use efficiency of wheat was increased with addition of N fertilizer to a maximum with 100 kg N/ha (Table 8). This is because of applied higher N results in higher grain yield which is proportionally more than the increase in water use thereby resulting into higher water use efficiency. Tomar et al. (1993) and Mishra et al. (1994) also reported similar findings. Sarma et al. (2005a) reported the maximum water use efficiency of wheat at 187.5 kgN + 10 tFYM/ha + Azotobacter. Mishra et al. (1994) also observed similar results. Chaudhari et al. (2009) reported that maximum consumptive use of water, water use efficiency and water expense efficiency were registered with 60 kg N/ha + *Azotobactor* liquid culture in amaranth. This might be done to luxurious vegetative growth of crop when nitrogen requirements are fulfilled. Appreciable increase in water use efficiency and water expense efficiency were observed with *Azotobactor* treatments either liquid or powder form combined with nitrogen over nitrogen alone. Similar findings were reported by Arya and Singh (2001).

Table 8. Water use efficiency as influenced by Nitrogen levels

Nitrogen (Kg/ha)	Water use efficiency (kg grain/m^3 water used)	
	1999-2000	2000-2001
0	1.09	1.12
50	1.30	1.35
100	1.46	1.52

Source: Kibe and Singh (2003)

Parihar (2004) reported that the highest water use efficiency of rice was recorded with 120 kg N/ha which was 16.77 % higher than 80 kg N/ha. However, Ramakrishna et al. (2007) reported that maximum water use efficiency and field water use efficiency of rice with 150 per cent N of recommended fertilizer dose (25 per cent substituted by FYM) and Luikham et al. (2004) reported that with the application of 4 splits of N as 17, 33, 33 and 17 % at 7 days after transplanting, 21 days of after transplanting, panicle initiation and first flowering + green manure of Sesbania rostrata at 6.25 t/ha which was closely followed by 4 splits as 25 % each as basal, panicle initiation and first flowering and 3 splits as 50, 25 and 25 % basal at active tillering and panicle initiation.

In another study, Rathore et al. (2007) reported that use of chemical fertilizer at 50, 75 and 100 per cent of recommended dose of fertilizer (20 kg N + 17.5 kg P/ha) to rain fed cluster bean (*Cymoposis tetragonoloba*) recorded 14.9, 32.7 and 36.2 per cent higher water use efficiency over control. Integration of chemical fertilizer at 50 per cent of RDF with *Rhizobium* and phosphate-solubolyzing bacteria (PSB) registered 30.1 and 22.6 per cent higher water use efficiency over control. Kumar and Rana (2007) reported that application of 40 kgP_2O_5/ha + 25 kg S/ha + phosphate-stabilizing bacteria (PSB) recorded the maximum values of pigeonpea-equivalent yield, nutrient uptake, water use efficiency and net returns. Singh et al. (2004) reported that application of 40 kg S/ha to chickpea resulted in higher water use efficiency than no sulphur and 20 kg S/ha.

Behera et al. (2002) reported that fertilizing the cotton crop at 160 kg N/ha recorded significantly higher water use efficiency than lower levels of nitrogen, 120 and 80 kg/ha. It might be due to higher seed cotton yield obtained under higher nitrogen level. Reduction in nitrogen dose tended to decrease water use efficiency; it was partially because of marked decline in transpiring surface, less stomatal conductance and less extraction of available soil moisture in plant. These results are in line with the findings of Fangmeier et al. (1985)

Irrigation

Chandrasekharaiah et al. (1985) at Dharwad reported the average maximum water use efficiency of wheat was recorded at 0.3 IW:CPE ratio and it was decreased with the increase in IW:CPE ratio from 0.3 to 0.9. In another studies were reported by Prihar and Tiwari (2003) in Chhattisgarh and Singh et al (2003) in north-western Rajasthan. They reported that total water use was lowest while water use efficiency was highest at 0.6 IW:CPE ratio. Similar results were reported by Patel et al. (2008) in cowpea. Nadeem et al. (2007) reported that maximum water use efficiency of wheat was recorded at IW:CPE ratio 1.25, which was statistically on a par with that at IW:CPE ratio 1.0 (Table 9). The increase in water use efficiency with increase in irrigation level might be due to greater grain yield. These results are in consonance with those of Singh and Bhan (1998). Kaur (2003) observed that water use efficiency was highest in wheat crop which received irrigation based on IW:CPE ratio of 1.0 . Similar findings were reported by Khatri et al (2001) in Haryana and recorded that maximum water use efficiency under 3 rows of bed with 45 cm bed width and irrigation applied at 1.0 IW:CPE ratio to bed planted wheat. Kaur (2006) reported that water use efficiency was higher when irrigation applied at IW:CPE ratio of 1.2 followed by 0.8 and 1.0 IW:CPE ratio. Similar results were reported by Sharma et al (1990) at Ludhiana. They revealed that water use efficiency was lower with frequent irrigations in wet year, but in dry year, water use efficiency increased with the increase in irrigations number.

Kibe and Singh (2003) reported that water use efficiency of wheat was the maximum with 2 irrigations given at crown root initiation stage and flowering stages in the first season and with one irrigation given at crown root initiation stage in the second season, followed by no post-sowing treatment. On the other hand, crop receiving no post-sowing irrigation treatment gave the lowest grain yield, but also used soil water more economically by regulating there stomatal opening and physiological activities towards grain production (Slatyer, 1967). Similar findings were reported by Mishra et al. (1994), Pal et al. (1996a, 1996b) and Chandra and Ashok (1990) in wheat. However, Shavani et al. (2001 and 2003) reported that wheat crop received 4 irrigations at the crown root initiation, maximum tillering, boot and milk stages recorded the maximum water use efficiency and were higher than that of 2 and 3 irrigation. Similar results were reported by Pal et al. (2001). However, Jal (1985) at New Delhi and Prihar and Tiwari (2003) at Chhattisgarh recorded that water use efficiency of wheat decreased with the increase in number of irrigation. However, Sarma et al. (2007b) reported that the water use efficiency of wheat was higher with limited irrigation (One each at crown-root initiation and flowering stage) and decreased with adequate irrigation (One each at crown-root initiation, late tillering , late jointing, flowering and milk stages) condition. This means that production of grain per mm of water used decreased with increase in water supply and the relative increase in the grain yield of wheat has not been in proportion to the increase in consumptive use, thereby resulting in decrease in water use efficiency under adequate irrigation. Behera et al (2002) in Madhya Pradesh reported that maximum water use efficiency of wheat was obtained when one irrigation applied at late jointing stage.

In another study, Singh (1996) reported that application of first irrigation at 4 weeks after sowing of wheat resulted in more consumptive use of water as compared to 6 weeks after sowing. But water use efficiency was higher when irrigation was applied at 6 weeks after sowing than that of 4 weeks after sowing on loamy sand soil.

Ramakrishna et al. (2007) reported that maximum irrigation water use efficiency and field water use efficiency were obtained with 3 days drainage followed by 1 day drainage and the least with continuous water submergence in rice. It is obvious that irrigation water use efficiency and field water use efficiency are the functions of the ratio of economic grain yield to water applied and water requirement of the crop. Wahab et al. (1996), Luikham et al. (2004) and Mehla et al. (2006) reported increasing water use efficiency of **rice** crop with wider irrigation intervals. Dawood et al. (1990) reported that water use efficiency in respect of grain yield was higher in irrigating crop once in 4 days followed by irrigation once in 2 days and immediate irrigation after disappearance of ponded water. Results showed that continuous submergence or irrigation one day after disappearance of water in rice consumed more water than irrigation at three days after disappearance of water.

Bharati et al. (2007) reported that water use efficiency of maize was the highest with the application of irrigation at 0.6 IW: CPE ratio as compared to 0.8, 1.0 and 1.2 IW:CPE ratio. Similar results were reported by Kumar et al. (2000) in summer groundnut**.** These results confirm the findings of Parihar and Tripathi (2003). However, Taha and Gulati (2001) reported that groundnut water use efficiency was the maximum with 0.2 IW:CPE ratio compared with 1.4 IW:CPE ratio. These results confirm those of Parihar et al. (1999b) and Dutta and Mondal (2006) in summer ground and Kharif groundnut.

Reddy et al. (2008) reported that higher water use efficiency of pigeon pea was recorded with 0.3 IW: CPE as compared to 0.6 and 0.9 IW: CPE ratio. Maintenance of favorable moisture and absence of water logging were the critical factors for higher yield in rabi pigeonpea (Kantwa et al. 2005).

Singh et al. (2004) reported that highest consumptive use of water was recorded with 2 irrigations at pre-flowering and pod-development stages of chickpea**,** while maximum water use efficiency in the control. In another study, Singh et al (1998) reported that water use efficiency of chickpea decreased with increase in number of irrigation given after pre-flowering stage. Maximum water use efficiency was noted under irrigation at pre-flowering stage and control during first and second year, respectively. Decrease in water use efficiency of with two irrigations was based on the fact that the proportionate increase in grain yield was less than increase in the consumptive use of water. The results are in agreement with those of Maity and Jana (1987) in gram, lentil and pea.

In another study, Panda et al. (2004) at New Delhi, reported that the highest water use efficiency was recorded under no irrigation and irrigation at flowering followed by irrigation at flowering + one at pod development stage of Indian mustard. The lower water use efficiency associated with irrigation treatment might be due to a greater expense of water and comparatively less seed yield. This result substantiates the findings of Sharma and Singh (1993) and Hati et al. (2001). In another study, Phogat et al. (1997) reported that water use efficiency of raya was more with conserved moisture and decreased with each irrigation applied. This is because of the fact that increased yield due to frequent irrigation could not compensate for the crop evapotranspiration at adequate irrigation (Kumar et al., (1994) in mustard, Chandrabhushan (1996) and Zhang et al., (1998) in wheat**)**.

In study, Hooda et al., (1999) reported that maximum water use efficiency was found when irrigation was applied at 50 % flowering stage of field pea as grain yield was maximum with two irrigation were applied at 50 % flowering and pod formation stage.

Idnani and Gautam (2008) reported that irrigation at 80 mm cumulative pan evaporation recorded the highest consumptive use of water and rate of water use and irrigation at 200 mm cumulative pan evaporation resulted in the highest water use efficiency and the lowest consumptive use of water and rate of water use of greengram**.**

Ghadage et al. (2005) reported that the water use efficiency of cotton was higher due to each row and alternate row irrigation. This might be due to the significantly same seed cotton yield produced by irrigation techniques. However, Nalayini et al. (2006) reported that water use efficiency of **cotton** was highest with drip irrigation as than conventional irrigation during winter season. The scheduling of irrigation through drip at 0.8 Etc (Crop evapo-tranpiration) recorded the highest water use efficiency.

Thakuria et al. (2004) reported that cumulative water use and water use efficiency of spring **sunflower** were maximum with 4 irrigations as one each at seedling, button, flowering and seed developing stage under semi arid situation. In another study, Singh and Mahey (1998) compared the effect of cut off dates of irrigation as termination of irrigation at 100 per cent flowering, 10, 20 and 30 days after 100 per cent flowering in sunflower. They observed that the water use efficiency comparatively same under all treatments, range from 27.1 to 29.4.

Tripathi et al., (2009) reported that higher water use efficiency of coriander was achieved under 2 and 3 over 4 irrigations. A little increase in water use efficiency was also observed with application of 2 irrigations over 3 irrigations but differences were non-significant. Thus water use efficiency was increase with the increased in irrigations. This means that production of grain per mm of water used decreased with increase in water supply and the relative increase in grain yield of coriander has not been in proportion to the increase in consumptive use, thereby resulting in decreased in water use efficiency under more irrigations (Singh et al., 2002a,2002b) in **s**ugarcane and Lakpale et al., 2007) in **s**pices. However, Singh (2002a) reported that water use efficiency of sugarcane was highest with the irrigation applied at 0.9 IW:CPE ratio than that of 0.6 and 1.2 IW:CPE ratio in

Rajasthan. However, the highest water use efficiency of sugarcane was observed with 0.6 IW:CPE ratio under the trash mulching than that of 0.9 and 1.2 IW:CPE ratio Singh (2002b).

Inoculation

Inoculation can have a very marked effect on consumptive use and water use efficiency of legume crops. Singh et al. (2004) reported that inoculation of chickpea with Rhizobium + phosphate-solubilizing bacteria (PSB) significantly increased the consumptive use and water use efficiency over the single inoculation of Rhizobium or PSB and no inoculation, however, single inoculation with Rhizobium or PSB being at par, were significantly superior over control.

Weed control

Competition for water by weeds and the impact of weed growth on yields is well recognized. Herbicides use can reduce the effect of these factors**.** Singh et al. (2004) reported that weed free treatment in chickpea had low total moisture use and more moisture use efficiency than weedy check. Nadeem et al. (2007) reported that maximum water use efficiency of wheat was recorded in manual weed control which was statistically on a par with the post-emergence application of isoproturon + carfentrazone ethyl (Table 9). More water use efficiency in manual weed control was due to lower weed density, resulting in lesser loss of water by weeds and consequently more grain yield. The results are in line with those of Dhindwal et al.(1993) and Goswami et al. (2002). Reddy et al. (2008) reported that higher water use efficiency of pigeon pea with intercultivation at 25 and 50 days after sowing followed by imazethapyr and pendimethalin. This might be due to lower weed dry matter, weed density and higher seed yield observed in above treatments compared to fenoxaprop-p-ethyl.

Table 9. Water use efficiency of wheat as influenced by weed control practices and irrigation levels

Treatment	Water use efficiency (kg/ha-mm)	
	2002-03	2003-04
Weed control practice		
Weedy check	15.9	15.8
Pendimethalin (pre-em.) at 1.031 g ai/ha	18.6	18.1
Isoproturon +carfentrazoneethyl (post-em.) at 750 g ai/ha	19.8	18.6
Mannual hoeing (2)	20.7	20.6
CD (P=0.05)	1.3	2.3
Irrigation levels (IW:CPE ratio)		
0.50	15.1	14.3
0.75	17.4	17.7
1.00	20.9	19.6
1.25	21.6	21.4
CD (P=0.05)	1.3	1.5

Source: Nadeem et al. (2007)

Moisture stress

The moisture stress during the grand growth and reproductive stage reduces the duration of the crop resulted in less water consumption. Chaudhari et al. (2009) reported that water use efficiency and water expense efficiency of amaranth were elevated as moisture stress rose. The limited water supply under stress at active growth and grain filling stage reduced vegetative growth of the crop thereby less consumption.

Moisture conservation practices

Moisture conservation practices have been widely practiced as a mean of improving yields in water limited environment. Patil and Sheelavantar (2000) reported that formation of compartmental bunds and ridges and furrows improved the yield components of sorghum in the vertisols of Bijapur significantly over flat bed due to increased availability of moisture and nutrients. Application of subabul at 2.5 t/ha proved beneficial in increasing the yield and yield components over FYM at 2.5 t/ha and vermicompost at 1.0 t/ha. Similarly, Tetarwal and Rana (2006) reported that application of FYM at 5 t/ha + dust mulch + straw mulch recorded significantly higher pearlmillet –equivalent yield, nutrient uptake, water use efficiency and economics. In another study, Pandey et al. (1988) (On rainfed lands straw mulch, pre-sowing seed treatment with KNO_3 and kaolin spray on pearl millet (BK 560-230) greatly increased the grain yield (0.83, 0.74 and 0.49 t/ha), respectively and water use efficiency (2.25, 1.80 and 1.34 kg grain/ha/mm, respectively) compared with the untreated control (Table 10). Jat and Gautam (2001) reported that straw mulch and straw + kaolin application to pearl millet was superior to all other treatments in terms of yield, consumptive use and water use efficiency of rain fed pearl millet.

Table 10. Consumptive use and water use efficiency as influenced by mulch and transpiration suppressants (mean data of 1982 and 1983)

Mulch and Transpiration suppressant	Consumptive use (mm)	Water use efficiency (grain kg/ha-mm)
Untreated control	333	5.45
Straw mulch	316	7.45
Seed treatment with KNO_3	323	7.00
Borax spray	327	5.92
Kaolin spray	320	6.55
Attrazine spray	325	6.00

Source: Pandey et al. (1988)

Kumar and Rana (2007) reported that application of soil mulch +FYM 5 t/ha + Kaolin 6 % spray was found the best moisture conservation practice by recording the maximum values of pigeon pea- equivalent yield (pigeonpea +greengram), nutrient uptake and water use efficiency.

Ghadage et al. (2005) reported that the water use efficiency of cotton was more under the plastic film mulch due to the lowest water consumed by the crop under plastic film mulch. Rajput and **S**ingh (1970) reported saving of water by mulches. Mulches reduced evaporation by decreasing soil temperature and suppressing weed growth. Nalayini et al. (2009) conducted field experiment at Coimbatore during 2002-03 and 2003-04 crop seasons during winter (August-February). Cotton (Gossypium hirsutum 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. The water use efficiency of polymulched cotton was 43.2 kg/ha-cm as against of 16.6 kg/ha-cm for conventionally planted no mulch cotton crop. This might be due to effective control of evaporation and control of weeds under polyethylene mulching. Singh (2002b) reported that the increasing trend in water use efficiency of sugarcane was recorded with increasing levels of trash from 0 t 6 t/ha.

Raskar and Bhoi (2003) reported that the water use efficiency of groundnut was higher with use of plastic film mulch with kaolin and was lowest with the control. It could be due to the reduction in the evapotarsnpiration with plastic film mulch and kaolin spray. Awasthi et al. (2007). Reported that water use efficiency of Indian mustard was highest with the weeding, hoeing and paddy straw mulch at 20 days after sowing followed by weeding, hoeing and grass mulch at 20 days after sowing, weeding and hoeing at 20 days after sowing and control.

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 barriers over control (Table 11). The maximum water use efficiency was recorded under *Sesbania sesban* followed by *Leucaena leucocephala* and *Cajanus cajan* barriers. 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.

Table 11. Water use and water use efficiency of sorghum as influenced by vegetative Barriers

Vegetative barriers	Water use (mm)			Water use efficiency (kg/ha-mm)		
	1995	1996	Mean	1995	1996	Mean
Control	387	371	379	4.2	4.1	4.1
Sesbania	391	386	389	5.2	5.4	5.4
Leucaena	388	379	384	5.1	5.3	5.2
Pigeonpea	380	370	375	5.0	5.3	5.2
Vetiver	391	371	381	4.8	4.8	4.8
Cenchrus	400	378	389	4.4	4.4	4.4

Source: Chand and Bhan, 2002

Intercropping

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 rainfed situations. Any factor that increases yield will increase water use efficiency. Likewise any factor reducing evapo-transpiration 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-mungbean (De and Singh, 1981), maize-cowpea (Hulugalle and Lal 1986), Maize + potato (Bharati et.al. 2007), pearlmillet + greengram and pearlmillet + cowpea (Goswami et al. 2002) intercrops in relation to their respective monocrops.

Table 12. Water requirement and water use efficiency of winter maize as influenced by intercropping systems

Intercropping system	Water requirement (cm)		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	50.60	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

Source: Bharati et.al. (2007)

Tetarwal and Rana (2006) and Kumar and Rana (2007) one row of mothbean in paired row of pearlmillet + and one row of greengram between paired rows of pigeonpea recorded higher water use efficiency over sole crop, respectively. This might be due to higher grain yields of both the crops than the amount of water used for biomass production. Consumptive use and rate of moisture use were higher 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 (F) and rice-lentil-maize + cowpea (F) and had the lowest water use resulted in highest water use efficiency in flood prone and semi-deep water situation, respectively.

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 crop have the differential water use efficiency. In the water limited areas grow the varieties that have more water use efficiency than that are having low water use efficiency. But is has been observed that the varieties are recommended without taking in to 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 yield with less water. Crop establishment methods like zero tillage, reduced tillage, furrow irrigated raised bed with 2 rows or 3 rows help to increase the water use efficiency and produce the same economic yield of the crops as compared to conventional method which is required more water. Closer row spacing in wheat crop under arid and semi arid environment, sowing of maize with twin row spacing, sowing of sorghum in furrows 60 cm apart and optimum plant population which depend upon the seed used for raising crop with higher water use efficiency. 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, period of percolation of water and cut off date of irrigation play significant role in increasing water use efficiency. Interculture, use of herbicides and interculture followed by herbicide use can lower the weed dry matter, weed density and higher economic yield which resulted in higher water use efficiency. Water use efficiency and water expense efficiency were elevated as moisture stress rose. The limited water supply under stress at active vegetative stage and grain filling stage reduced vegetative growth of the crop thereby less consumption. On rainfed lands, straw mulch, pre sowing, seed treatment with KNO_3, kaolin spray and straw + kaolin application greatly increased the grain yield peralmillet. Use of polyethylene mulch in cotton-maize cropping system for moisture conservation and enhance crop production efficiency by effective control of evaporation and control of weeds. Higher water use efficiency of maize-soybean, maize mungbean, maize-cowpea, maize-potato, intercropping in relation to monocropping, provided that soil water is not limiting. Sugarcane crop planted in autumn season with various intercrops like wheat, toria, potato and vegetables like cabbage, onion, gallic, cucumber etc. planted on beds will improve the tonnage and quality of cane, help in advancing the crushing season of the sugar mills, generate additional returns from intercrop and fetch extra income to the farmers. Bed planting technique has made the system practically feasible, economically viable and proved helpful in minimizing the yield gaps in cane yield besides additional income from intercrops. Intercropping of pulses in spring planted sugarcane crops improves the soil health and additional returns from intercrops without affecting the sugarcane yield. Planting of intercrops on beds resulted in savings of irrigation water in terms of 25-30 percent less time taken to irrigate the crops. It is the 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 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.

Future thrust of research

Water use efficiency by crops can be enhanced by selection of crop, variety, agronomic practices like time of sowing, method of sowing/planting, seed rate, plant population, interculture, fertilizer and irrigation, intercropping moisture conservation practices as mulching, transpiration suppressants, moisture stress and vegetative barriers based on available water and increasing seasonal evapotranspiration.

- Selection of crops and varieties for high water use efficiency should be done on the basis of availability of water under rain fed, limited water and irrigated areas. Selection of crops and varieties should be evaluated with irrigation scheduling to see the water use efficiency before the recommendation for cultivation in the particular area.
- Agronomic practices like time of sowing, method of sowing/planting, seed rate, plant population, interculture, fertilizer and irrigation, intercropping should be evaluated with the irrigation levels for high water use efficiency and economic yield of crop. Optimum time of sowing/planting, seed rate, plant population, interculture, herbicide application, fertilizer facilitate better growth and development which resulted in higher crop yield and water use efficiency. Application of fertilizer facilitates root growth which can extract soil moisture from deeper layers. Further more facilitates early development of canopy that covers the soil and intercepts more solar energy and thereby reduces the evapotranspiration
- Conservation tillage practices like zero tillage; reduced tillage/minimum tillage utilizes more judiciously the plant available water than the conventional tillage when the other factors are similar.
- Moisture conservation practices like straw mulch, straw + kaolin and polyethylene mulching are reducing weeds dry matter and weed density which resulted in enhancing crop yield and water use efficiency in rainfed areas.

- On rainfed lands pre-sowing seed treatment with KNO_3 and kaolin spray greatly increased the grain yield and water use efficiency compared with the untreated control.
- Under the limited water conditions, in wider spacing crops and long duration crops the growing crops as intercropping enhance the productivity and water use efficiency
- Under rainfed conditions use of vegetative barriers particularly legume barriers improve the soil health and increase water holding capacity ultimately enhance the crop yield and water use efficiency
- With the increasing of water stress during the vegetative phase by reducing the vegetative stage and also reducing consumptive use of water which resulted in higher water use efficiency

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