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Efficient Techniques to increase Water Use Efficiency under Rainfed Eco-systems

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ABSTRACT

Water is the prime mover in agricultural development in rainfed agriculture. For better use of water in agriculture in water-limited environments, efforts are needed from different research disciplines; agronomists, plant breeders, plant physiologists, plant biotechnologists, water engineers and others, to develop new approaches in water use. Among different approaches water productivity or water use efficiency (WUE) is an efficient approach.Water use efficiency can be increased by two ways, either by increasing yield or by saving water. Water use efficiency is affected by a number of factors like climatic conditions, edaphic factors, nature of plant and agronomic practices. There are various techniques to increase water use efficiency in the rainfed ecosystem. Many options to improve water use efficiency are available and the target is to produce more biomass with minimum possible amount of water.

Keywords: Water use efficiency, eco-system, consumptive use, rainfed

INTRODUCTION

Water plays an important role in agricultural development under rainfed condition. Continue population growth and the predicted impacts of climate change, including shifts in precipitation and glacier melt, makes the water challenge greater. It is particularly important for a large country like India, situated, as it is, in the tropical belt and experiences extreme variation in climate and rainfall across the country. Currently 65% of agriculture in India is rain dependent (Singh and Kumar, 2009 and Singh *et al.*, 2013b). There are extreme variations in rainfall, the westernmost part getting less than 100 mm annually and the easternmost part receiving 100 times more. Floods and droughts can strike the country simultaneously at different places. For better use of water in agriculture in water-limited environments, efforts are needed from different research disciplines: agronomists, plant breeders, plant physiologists, plant biotechnologists, water engineers and others, to develop new approaches in water conservation. For example, is it possible to find or develop crops that require less water and maintain high yield productivity? Among different approaches water productivity or water use efficiency (WUE) is an efficient approach. A crop with high WUE should have greater yield than a crop with low WUE (Meena *et al.*, 2013).Rain is the primary source of water. Although India receives a total precipitation of about 400 million hectare meters (M ha-m) annually, much is lost through evaporation and runoff, equalling 70 M ha-m and 180 M ha-m respectively. Hardly around 150 M ha-m enters in the soil. Of the total runoff of 180 M ha-m, the country has been able to harness about 20 M ha-m or so in major and minor projects. Quite a sizeable amount, i.e. 169 M ha-m of precipitation, flows through rivers into the sea.

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MATERIALS AND METHODS

Water Use Efficiency or Crop Water Productivity

The term 'efficiency or productivity' refers to output/ input ratio. If the ratio is more, the system is said to be more efficient or productive. Likewise, irrigation efficiency refers to the ratio of how much water utilized to how much water applied. Water use efficiency or productivity is the yield of marketable crop produced per unit of water used in evapo-transpiration.

WUE or CWP = Y/ET [Eq. 1]

Where,

WUE = water use efficiency or CWP is the crop water productivity (kg/ha-mm)

Y = marketable yield (kg/ha) and

ET = evapo-transpiration (mm).

Therefore, water utilization by the crop is generally described in terms of water use efficiency or productivity. It can also be defined in the following ways:

Crop water use efficiency (CWUE) or real crop water productivity (RCWP): It is the ratio of crop yield(Y) to the amount of water depleted by the crop in the process of evapo-transpiration(ET).

Crop WUE or RCWP =Y/ET [Eq. 2]

Field water use efficiency (FWUE) or apparent crop water productivity (ACWP): It is the ratio of crop yield(Y) to the total amount of water used in the field/ irrigation water applied (WR).

Field WUE=Y/WR [Eq. 3]

Crop yield can be defined in terms of total growth (i.e. dry matter production) or in terms of marketable product. In field WUE, 'Y' is the marketable crop yield in kg/ha and 'WR' the seasonal water requirement of the crop in ha-mm (Jalota *et al.*2006). This is sometimes called productivity of water. Water use efficiency can be increased by two ways, either by increasing yield or by saving of water.

Agriculture will continue to be the dominant consumptive user of water globally. As population and demand for food grows, it will be important to go for intensive agriculture that requires more water. Irrigated agriculture is far more productive than rainfed agriculture; there is equal need of increasing productivity of water (Singh and Kumar, 2009). Improvement in the water use efficiency of rainfed agriculture need to be developed. Due to scarcity of water, more crops per drop of water are needed.

RESULTS AND DISCUSSIONS

Factors affecting Water Use Efficiency

Climatic Conditions: Efficient techniques to mitigation climate change to improve agricultural system productivity through efficient carbon sequestration and improved production technologies (Singh *et al*., 2012b). Weather affects both crop yield and evapo-transpiration. Evapo-transpiration (ET) is an evaporative process largely controlled by climatic factors, it is influenced by the weather elements in following ways: (i) **temperature:** an increase in temperature brings about an increase in the rate of evapo-transpiration. (ii) **Relative humidity:** when the relative humidity is high, the rate of evapo-transpiration decreases. This is because the atmosphere is saturated with moisture. (iii) **Solar radiation:** Incident solar radiation and adverted heat provide energy for the evaporative process. (iv) **Wind velocity:** when the wind is stagnant the rate of ET remains normal, when it is blowing gently the rate increases because it removes moisture from the vicinity and when the wind is blowing violently the rate of transpiration decreases because it creates hindrances in the outward diffusion of water vapours from the transpiring parts due to closing of the stomata.

Edaphic Factors: Edaphic factors are the major detriment of the water use efficiency (Singh *et al*., 2014). Soil texture is the combination of 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 macropores and micropores

Nature of the Plant: There are considerable differences between plant species to produce a unit of dry matter per unit amount of water used resulting in widely varying values of WUE. There are also differences in WUE between varieties of the same crop. 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 photosynthates to economically harvested plant parts. Varieties also differ in their adaptation to environment, resistance to pests and diseases and management levels. Selection of properly adopted crops, with good rooting habits, low transpiration rates and improved energy consumption in photosynthesis will increase WUE (Singh *et al*., 2008).

Agronomic Practices:

Planting pattern: Planting patterns have a direct effect on yield, solar energy capture, and evaporation and thus an indirect effect on water use efficiency. Planting pattern influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Two important planting patterns are square planting and rectangular planting. It is reasonable to expect that square arrangement of plants will be more efficient in the utilization of light, water and nutrients available to the individual plants than in a rectangular arrangement. There has been a gradual trend to avoid widely spaced crop rows. A narrowing of rows generally means a more uniform distribution of plants over a given area, thus making the plant canopy more effective in intercepting radiant energy and shading weeds. An added advantage is the reduction in rain drop impact on soil structure in the surface layer. Different planting patterns are followed to suit different cropping systems, thus, suitable rotational cropping and intercropping techniques should be adopted in order to maintain the crop yield (Meena *et al*., 2013 and Singh *et al*., 2013a).

Planting date: Sowing/planting should be done at those times which will avoid probable stress periods during anthesis of the crop, or by manipulating the ratio of early to late season water use. In arid and semi-arid regions planting date is an extremely important cultural practice in efficient water use. One of the main reason for choosing the optimum dates for sowing is to ensure good germination by placing the seed in the optimum moisture zone (Singh *et al*., 2013a)The dates also indicate the right type of climate for the shoot growth and optimum utilization of moisture by the roots under normal rainfall conditions (Singh *et al*., 2012c). Gulati and Nayak (2002) conducted a field experiment at Orissa having treatment combinations of 4 irrigation levels and 6 dates of planting. Cane yield and water requirement were maximum at 1.2 IW/CPE treatment but water use efficiency was recorded maximum at 0.6 IW/CPE. In planting dates, October planting recorded the maximum cane yield, water requirement and WUE over delayed planting.

Plant population: Higher yield potential is made possible by the favourable water regime, the higher soil fertility level and the genetic potential of new varieties, could be achieved only with appropriate adjustments in plant population. To obtain maximum possible yield, it is essential for the crop to utilize as efficiently as possible all the available production factors: water, nutrients, light and CO_2. Plant density has a direct effect on yield, more favourable the conditions, under which the crop is grown, the greater will be the plant density required to exploit fully the potential to achieve maximum yield. Highest yield and WUE is possible only through optimum levels of soil moisture regime, plant population and proper fertilization (Singh *et al*., 2012a and Singh *et al*., 2013a).

Fertilization: When soil moisture tension is low, the abilities of plant to absorb nutrients and the soil to supply them are optimal and therefore, nutrient availability is at its highest level (Singh and Kumar 2009). A field experiment was conducted byKumar and Rana, 2007 on moisture conservation and nutrient management practices in pigeon pea – greengram intercropping system under rainfed conditions on sandy loam soil at New Delhi in rainy season 2004-2005. Application of 40 kg P_2O_5 + 25 kg S/ha + 500 g /ha phosphorus solubilizing bacteria recorded maximum values of pigeon pea –equivalent yield, and hence higher water use efficiency than control and sole application of fertilizers. Singh *et al.* (2013c) reported that judicious application of nutrient not only improve lentil production but also improve resistance power of the crop to fight against disease pests as well as soil fertility, especially in case of lentil crop under rainfed situation

Techniques to increase Water Use Efficiency

Agronomic Management Practices:

Tillage practices for moisture conservation: Tillage influences crop yields and water use efficiency. The principal effects of tillage are the preparation of seedbed conducive to the germination of seed and growth of seedling, conservation of soil moisture in unirrigated/ rainfed areas that influence infiltration characteristics of the soil and providing adequate soil depth for optimum root growth, proper placement of seeds and fertilizers in the soil and inter-cultivation for weed control. Deep tillage (deep ploughing and sub-soiling) is considered beneficial to conserve the monsoon rainfall (Meena *et al*., 2013). The general objectives of deep tillage are to break through plough soles and layers compacted by excessive use of heavy implements, impermeable soil horizons or other barriers to the movement of moisture and growth of roots through the soil profile.

Mulching: About 69-70 per cent of the rainfall is lost through evaporation. Different types of mulches are stubble mulch, soil/dust mulch, straw mulch, plastic mulch and vertical mulching**.** Stubble mulching is based on stirring the soil with implements that leave considerably effective part of the vegetative material, crop residues or vegetative litter on the surface as a protection against erosion and for conserving moisture by favouring infiltration and reducing evaporation (Rana *et al* ., 2003). Further, Singh *et al.* (2012d) reported that the maximum growth, flowering, yield and yield attributing characters were recorded with black plastic mulch, due to soil temperature regulation and soil moisture conservation followed by bio mulch and poor plant performance in without mulch. Rashidi *et al.* (2009) also reported that black plastic mulch has pronounced effect in increasing yield and yield components in tomato in timely and late planted crop in comparison to without mulch.

Intercropping: Intercropping systems are generally recommended for rainfed crops to get stable yields. The total water used in intercropping system is almost the same as for sole crops, but yields are increased, thus water use efficiency is higher than sole crops (Singh *et al.*, 2013d). It is found that good agronomic practices (not only improve better utilization of water bat also proved an eco-friendly tool for sustainable management of plant diseases under changing climate scenario (Singh *et al.*, 2012c and Singh *et al.*, 2013b). A field experiment was conducted by Bharti *et al.* 2007 during winter season of 2002-03 and 2003-04 at Pusa in Bihar to study the effect of inter cropping system. Among the treatments maximum water use efficiency (on the basis of maize equivalent yield) was obtained with maize + potato (Table 1).Another experiment was conducted by Khan, 1997 at SKUAST-K Shalimar to study the effect of mulching and legume intercropping on maize. It was concluded that intercropping of maize with legume crops resulted in higher yield thereby higher WUE and mulched treatments had higher water use efficiency over sole maize and without mulching, respectively.

Direct Seeded Rice (DSR): It is an efficient method of water saving in rice. There is enough data to support that if field is properly levelled and weeds are controlled properly then DSR can give equivalent yield as puddled transplanted rice (PuTPR). The experiment shows that PuTPR requires about 20 % more water than DSR and water requirement is more in PuTPR at establishment & vegetative phase. Several problems of PuTPR which are minimized in DSR are Puddling-ponding, frequent irrigation, cracks in puddled soil (Jat *et al.*, 2006).

Seeding Equipment: The seeding equipment designed for rainfed areas to place the seed in firm moist soil. The moisture in the surface layer of the seed bed in dry areas is evaporated quickly. Germination of seeds may be adversely affected if the seeds are sown at shallow depths of 4 to 5 cm, as in rainfed areas(Singh *et al.*, 2014).

Selection of crop and variety: Selection of crops and their varieties adapted to the total amount and distribution of water available and adoption of suitable agronomic practices are important factors in the success of agriculture in the rainfed areas (Singh *et al.*, 2008). Wide variations in the adaptability exhibited by crops to drought prone conditions, *viz.* uncertain and erratic pattern of rainfall could be utilized in the selection of crops and their varieties. In north India, the more efficient dry land crops are gram, mustard, barley, safflower and linseed. Wheat is the least efficient under rainfed conditions. Both linseed and safflower are promising in the east. In the Deccan plateau and in south India, sorghum, safflower and cotton are efficient. The principal pulse crops grown in rainfed areas are: gram (*Cicer arietinum*), arhar (*Cajanus cajan*), urd (*Phaseolus mungo*), mung (*Phaseolus radiata*), beans (*Dolichos sp.*), moth bean (*Vigna aconitifolia*). With the development of short-duration varieties of castor, mustard, cotton, arhar and other crops, several double-cropping and mixed cropping patterns can be standardized for different regions.

Planting techniques/methods: Another agronomic method for increasing water use efficiency is to follow proper planting techniques/methods. Broadbed and furrows (BBF) are formed for rainy season crops. For some crops like maize, vegetables etc., the field has to be laid out into ridges and furrows. Sugarcane is planted in the furrows or trenches. Crops like tobacco, tomato, chillies are planted with equal inter and intra-row spacing so as to facilitate two-way inter-cultivation (Singh *et al.*, 2012a).

Furrow irrigated raised bed (FIRB) planting: The judicious and safe use of inputs (fertilizer, water, herbicides) is having great importance (Singh *et al.*, 2014).

Table 1: Effect of intercropping system on yield and water use efficiency of winter maize

Treatments	Grain yield of maize (q/ha)		Maize equivalent yield (q/ha)		WUE on basis of maize equivalent yield (Kg/ha-cm)	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
Sole Maize	55.13	56.59	55.13	56.59	213.73	237.41
Maize+ Potato	51.67	52.80	123.48	140.07	526.16	597.62
Maize+ Rajmash	40.94	42.60	83.83	82.64	352.77	348.59

Source: Bharti *et al.* 2007

Crops are sown on 40 cm wide raised beds and irrigation providing in 30 cm wide furrows. It saves irrigation water by 25-35% and N and seed rate up to 25%. Furrow irrigated raised bed planting is more profitable than flat planting. Many advantages of growing wheat on furrow irrigated raised bed planting system over the conventional flat planting in the Indo-Gangetic plains have been reported by (Sayre and Hobbs 2004 and Ram *et al*. 2005). Kumar *et al*. 2010 also found that with furrow irrigated bed planting systems, on average 40 % water was saved as compare to flat planting.In an experiment maximum chickpea grain yield was recorded under raised bed planting which was significantly higher by 16.8% and 15.9% over flat bed technique, during 2005-06 and 2006-07 (Pramanik *et al*. 2009) (Table 2).

Table 2: Yield and water use efficiency of Chickpea as influenced by planting techniques

Planting techniques	Grain yield (t/ha)		Water use efficiency (kg/ha-mm)	
	2005-06	2006-07	2005-06	2006-07
Flat bed	1.84	2.01	10.27	9.72
Raised bed	2.15	2.33	12.06	11.33
CD (P=0.05)	0.11	0.16	-	-

Source:Pramanik *et al*. 2009

Weed control: One of the main management means of obtaining more efficient water use is the elimination of weeds in crops. Weeds compete with crops for soil nutrients, water and light. Except in high rainfall areas the primary concern is the water factor because the water requirement of weeds compared to nutrient requirement is greater than that of crop plants. A field experiment was conducted by Subramanyam *et al*. 2007 at Tirupati during winter (*rabi*) season of 2003-2004 to evaluate the efficiency of low dose herbicides under different puddling and water management practices on yield attributes and yield of transplanted rice. Among the weed management practices, Oxadiargyl 75 g/ha + hand weeding at 40 DAT recorded the highest yield with lesser weed density over weedy check. Highest water use efficiency was also recorded in the same treatment (Table 3).

Plant protection: An often overlooked means of increasing water use efficiency falls in the lot of entomologists, plant pathologists and plant breeders. Plant breeders are included because the development of resistant varieties is perhaps the most effective, economical and long lasting control for diseases and insects. Plant breeder seeks to prevent crop damage by selectively changing the genetic makeup of the plant. Efficient crop and water management also includes the judicious use of chemical pesticides. By proper use these can prevent insects and pests from disturbing the balance of nature in producing a healthy crop plant (Singh *et al*., 2012c).

Rain Water Harvesting: The major problem of water management is faced at the time of seeding of the crop. If the residual rain-water is conserved and is carried over for sowing of either wheat or maize, the timely germination of crop can be ensured as later rains are enough to take care of these crops. Management techniques that increase infiltration and soil water storage, and decrease water losses by runoff, evaporation and evapo-transpiration by weeds would lead to increase the amount of water retained in the soil for subsequent use by crops, as considered in *in-situ* water harvesting. Rain water harvesting will not only conserve the soil, its fertility and vegetation; but also could be utilized as supplementary irrigation that will be advantageous in enhancing total water supply

Table 3: Effect of weed management practices on the yield and water use efficiency of rice

Treatments	**Grain yield (t/ha)**		**Straw yield (t/ha)**		**Water use efficiency (kg/ha-mm)**	
	2003	2004	2003	2004	2003	2004
Unweeded check	4.02	4.18	5.37	5.59	2.25	2.30
HW Twice (20&40 DAT)	5.39	5.62	6.66	6.93	3.02	3.10
Oxadiargyl (75g/ha)	4.84	5.31	6.32	6.27	2.72	2.80
Cinmethylin75g/ha	4.47	4.66	5.65	5.88	2.53	2.62
Oxadiargyl (75g/ha)+HW (40DAT)	5.61	5.83	6.71	6.98	3.14	3.20
Cinmethylin75g/ha+HW (40DAT)	5.21	5.42	6.41	6.77	2.19	3.02
CD (P=0.05)	0.27	0.27	0.23	0.19	0.07	0.09

Source: Subramanyam *et al*. 2007

available to crop plants during low rainfall period (Singh, 1985). For *ex-situ* rain water harvesting, farm ponds are made either by constructing an embankment across water coarse or by excavating a pit. Runoff water is collected from a catchment and stored in farm pond. The stored water is utilized for supplemental irrigation during long dry spells at critical stages of crop growth. Farm ponds hold a great promise as a life-saving device for rainfed crops in low and erratic rainfall areas (Pandey *et al*., 2012). Faroda *et al.* 2007 experienced that a supplemental irrigation of 5-7 cm given to rainfed perlmillet or legumes at reproductive stage can make all the differences between success and failure of the crop.

Life saving irrigation through drip irrigation system: Drip irrigation is an efficient method of providing irrigation water directly into the soil at 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 with 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 by Pandey *et al*. (2013) while working on chilli with drip irrigation.

Mechanical Measures

Contour Farming: Contour farming involves ploughing, planting and weeding along the contour, i.e., across the slope rather than up and down. Contour lines are lines that run across a slope such that the line stays at the same height and does not run uphill or downhill. Experiments shows that contour farming alone can reduce soil erosion by as much as 50% on moderate slopes. However, for slopes steeper than 10%, other measures should be combined with contour farming to enhance its effectiveness. Contour ridges are used mainly in semi-arid areas to harvest water, and in higher rainfall areas for growing potatoes. Trash lines made by laying crop residues or "trash" in lines along the contour. Grass barrier strips planted along the contour with fodder grass such as Napier, or are left with natural grass. They are effective soil conservation measures on soils that absorb water quickly, and on slopes as steep as 30%.

Terracing: Terraces are used in farming to cultivate sloped land. Graduated terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease erosion and surface runoff , and are effective for growing crops requiring much water, such as rice. Natural terracing, the result of small-scale erosion, can occur where cattle are grazed for long periods on steep sloping pasture

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. Nearly 99 per cent of the water absorbed by the plant is lost in transpiration. The most common type of anti-transparants is of four types:

(i) 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. **(ii) 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. **(iii) 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. **(iv) 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 water status of the plant.

CONCLUSION

About 75% of the total cultivated area in the country depends on rainfall to sustain crop production; about 55% of the cultivated area would still continue to be rainfed. Despite the progress achieved in improving yield per unit of water used, major efforts still needed to deal with water shortage in order to increase food production and particular in regions where water is scarce (rainfed ecosystem). Success in dry or rainfed farming depends on moisture conservation practices, soil management, breeding new crop varieties for rainfed areas, choice of crop for maximum water use efficiency, optimum use of fertilizers, plant protection measures and other factors. Therefore, it is necessary to improve WUE in rainfed eco-systems to increase the economic crop production per unit of water and this goal cannot be achieved without implementation in field the different technologies for increasing water use efficiency in collaboration.

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