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More crop per drop: Ways to increase water use efficiency for crop production: A review

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Abstract
Water is the most crucial input for agricultural production. Vagaries of monsoon and declining water table due to over exploitation of water have resulted in shortage of fresh water supply for agricultural use, which calls for an efficient use of this precious resource. In the background of shrinking water resources and competition from other sectors, the share of water allocated to irrigation is likely to decrease by 10 to 15 per cent in the next two decades. Thus, producing more with less is the only option. One of the ways of alleviating water scarcity is by enhancing its use efficiency or productivity. Strategies for efficient management of water for agricultural use involves reduction in water losses in conveyance and distribution system through periodic maintenance, applying the right quantity at right time, participation of farmers in water management, right cultivation techniques and irrigation practices including increased use of water saving devices like sprinkler and drip, precision levelling, provision of proper drainage channels, conjunctive use of surface and ground waters and moisture conservation practices. In this paper, we have discussed various ways of enhancing use efficiency and productivity of water in agricultural production system. These include: better utilization of stored soil moisture by adjusting time and method of sowing, improved planting patterns reducing evaporation loss of soil moisture by mulching, intercropping, supplemental and deficit irrigation provided to crops at critical growth stages, removal of nutrient constraints by supplying optimum fertilizer inputs and improved irrigation methods like sprinkler and drip irrigation.

Keywords: Water use efficiency, crop management practices, crop production, irrigation water

Introduction
Water plays an important role in agricultural development under rainfed condition. Continuous population growth and the predicted impacts of climate change, including shifts in precipitation and glacier melt, makes the water challenge greater. In the background of shrinking water resources and competition from other sectors, the share of water allocated to irrigation is likely to decrease by 10 to 15 per cent in the next two decades. As of now irrigation sector consumes about 83% of the total water use which may reduce to about 72% by 2025 (Mo WR, 2014) [19].

The concept of Water Use Efficiency (WUE)
In general term efficiency is used to quantify the relative output obtainable from a given input. So, water use efficiency is output obtained by inputting the known amount of water in general terms. 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. WUE is expressed in equation as follows:

WUE = Y/ET

Where,
WUE = water use efficiency (kg/ha mm of water)
Y = marketable yield (kg/ha)
ET = evapo-transpiration (mm)

Enhancing the water use efficiency
1. Selection of crop
It should be done on the basis of availability of water under rainfed crops. WUE of different

crop varies differently because of many reasons, like C4 plants are more water efficient as compared to C3 plants as they lack photorespiration and have various adaptive mechanisms to water scarcity condition, apart from this climate, soil and crop characteristics are also responsible for variation in water use efficiency of different crops.

Table 1: WUE of some important field crops in India

CROP	WUE (kg/m^3)
Rice	0.30-0.54
Wheat	0.58-2.25
Maize	0.49-1.63
Chickpea	0.40-4.02
Mustard	0.41-0.98
Sugarcane	3.25-7.83
Cotton	0.17-0.40

Source: Yadav *et al*. (2000) [46]

2. Varieties

The yields and water use efficiency of cultivars/hybrids of crops differs significantly. Those varieties/hybrids which have ability to produce more yield than the water used should be grown under the limited water areas to increase the water productivity per unit area. Shivani *et al*. (2001, 2003) [38, 37] and Behera *et al*. (2002) [4] reported that wheat cultivars HUW 234 and Lok 1 had higher water use efficiency. Similar findings were also reported by Singh *et al*. (2004) [43] in chickpea for genotype Avarodhi, Awasthi *et al*. (2007) [2] and Panda *et al*. (2004) [21] reported that Indian mustard varieties such as Vaibhav and SEJ 2, Kumar *et al*. (2003) [16] and Rathore *et al*. (2008) [34] in pearl millet hybrid HHB 67-2, HHB 94 and HHB 117, Hooda *et al*. (1999) [9] in field pea variety HFP-8712 and Patel *et al*. (2008) [25] in cowpea variety GC 4, respectively.

3. Time of Planting and tillage practices

Time of sowing is a non-monitory input which is not only ensures the higher yields but also optimum utilization of the applied resources. 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) [39] 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) [42]. In another field experiment highest grain yield, WUE and net productivity of used water was recorded under early sowing with minimum tillage (table 2). Gulati and Nayak (2002) [8] 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. Hence, during dry season when water is not available, particularly in tail reach, early sowing of crops with minimum tillage can increase the water productivity by utilising residual soil moisture.

Tillage modifies hydrological properties of the soil and influence the root growth, canopy development of crops, water extraction pattern and transport of water and solutes. Conservation tillage practice stores more plant available moisture than the conventional tillage practices.

Table 2: Grain Yield, Evapotranspiration, WUE and Net Water Productivity in Horse Gram under different sowing time and tillage practices

Treatment	Grain Yield (kg/ha)	Total ET (mm)	WUE (kg m^{-3})	Net Productivity of water (Rs m^{-3})
Early sowing [1] with minimum tillage	1290	241.3	0.60	4.85
Late sowing [2] with minimum tillage	1060	182.8	0.53	4.30
Paira cropping [3] without tillage	750	188.6	0.40	2.93
CD (P=0.05)	130	21.4	0.06	0.37

[1] on 15th October, [2] on 1st November, [3] on 15th October, 10 days before rice harvest

Source: Singh *et al.* (2008) [44], Orissa

4. 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.* 2013b) [41]. Parihar *et al*. (1999) [24] and Singh *et al*. (2004) [43] 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. A field experiment was conducted by Bharti *et al.* 2007 [5] 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 3). Tetarwal and Rana (2006) [45] and Kumar and Rana (2007) [15] reported that one row of moth bean in paired row of pearl millet + and one row of green gram 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.

Table 3: Effect of intercropping system on yield and water use efficiency of winter maize

Treatment	Water requirement(cm)	Maize equivalent yield (q/ha)	WUE (kg/ha-cm)
Sole maize	56.9	55.1	213.7
Maize+ potato	51.0	123.5	526.2
Maize + rajmash	50.6	83.8	352.8
Maize + toria	50.9	57.7	247.3
CD (P=0.05)	0.3	7.4	31.0

Source: Bharti *et al*. (2007) [5]

Planting techniques/methods

Another agronomic method for increasing water use efficiency is to follow proper planting techniques/methods. Broad bed 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*. 2012) [40]. 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 of water. This had been practiced in different crops like wheat, sarson, soybean and rice. Jat and Gautam (2001) [11] 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). However, Ghadage *et al*. (2005) [6] 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 planting method (120 cm x 90 cm). Gill *et al*. (2006) [7] reported that better water use efficiency and water productivity were observed in direct seeded rice. Ridge and furrow sowing also resulted in maximum water use efficiency. Kaur (2006) [13] reported that water use efficiency of wheat planted on beds was highest followed by conventional and zero tillage. Similar results reported by Ali and Ehsanullah (2007) [1] in cotton, Zhang *et al.* (2007) [47] in winter wheat, Idnani and Gautam (2008) [10] in summer greengram and Mahey *et al*. (2008) [10] in soybean. In an experiment maximum chickpea grain yield was recorded under raised bed planting which was significantly higher by 16.8% and 15.9% over flatbed technique, during 2005-06 and 2006-07 (Pramanik *et al*. 2009) [26] (Table 4).

Table 4: Yield and water use efficiency of Chickpea as influenced by planting techniques

Planting techniques	Grain yield (t/ha)		WUE (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) [26], U.P.

6. Irrigation Scheduling

Under adequate water availability the main emphasis is on securing potential yield of the crops without wasting water. Whereas, under limited water supply, the objective is to achieve maximum WUE. Nadeem *et al*. (2007) [20] 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. The increase in water use efficiency with increase in irrigation level might be due to greater grain yield. Kibe and Singh (2003) [14] 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. Reddy *et al*. (2008) [35] 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 favourable moisture and absence of water logging were the critical factors for higher yield in rabi pigeonpea (Kantwa *et al*. 2005) [12]. Bharati *et al*. (2007) [5] 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. Idnani and Gautam (2008) [10] 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 green gram. Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction. The proper application of deficit irrigation practices can generate significant savings in irrigation water allocation and crops like cotton is well suited for deficit irrigation. Rao *et al*. (2016a) [29] reported that irrigation in cotton with drip irrigation at 0.8 ETC had significant benefits in terms of saved irrigation water without reducing yield (table 5).

Table 5: Effect of deficit irrigation on yield and water productivity of cotton

Deficit irrigation	Seed cotton yield (kg/ha)	Water Productivity (kg/m^3)
1.0 ET_C	2482	0.40
0.8 ET_C	2393	0.41
0.6 ET_C	1884	0.38
CD (P=0.05)	92	0.02

Source: Rao *et al*. (2016a) [29], Rajasthan

7. Moisture conservation practices

Moisture conservation practices have been widely practiced as a mean of improving yields in water limited environment. Raskar and Bhoi (2003) [32] reported that the water use efficiency of groundnut was higher with use of plastic film mulch with kaolin and was lowest in the control. It could be due to the reduction in the evapotranspiration with plastic film mulch and kaolin spray. Ghadage *et al*. (2005) [6] 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) [27] reported saving of water by mulches. Kumar and Rana (2007) [15] 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 + green gram), nutrient uptake and water use efficiency. In another study, Pandey *et al*. (1988) [22] reported that on rainfed land, 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 6). Rashidi *et al.* (2009) [31] 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 tomatoes grown without mulch.

Table 6: Consumptive water use and water use efficiency as influenced by mulch and transpiration suppressants in pearl millet

Mulch and transpiration suppressant	Consumptive use (mm)	WUE (kg/ha-mm)
Untreated control	333	5.45
Straw mulch	316	7.45
Seed treatment with KNO3	323	7.00
Borax spray	327	5.92
Kaolin spray	320	6.55
Atrazine spray	325	6.00

Source: Pandey *et al*. 1988 [22]

8. Irrigation Method

Efficient micro-irrigation methods like sprinkler and drip irrigation for utilization of available water in case of scarce in lean season developed mainly for high value horticultural and plantation crops could save up to 50 per cent of water and also increase the crop yield and quality substantially. To meet the ever-increasing demand of food with decreasing fresh water availability to agriculture, crops must produce more with less water. The use of pressurized irrigation technology could increase water-use efficiency and reduce cost. Results revealed that pressurized irrigation system i.e. MS, DS and their combination with check basin method resulted in significantly higher seed yield, production efficiency and B: C ratio as compared with check basic alone (table 7). SWI with drip emitters spaced at 30 cm is a promising adaptation for reducing wheat crop's demand for water and energy (Rao *et al*. 2016b) [30]. Santosh Kumari, 2012 [17] reported that drip irrigation along with black polyethylene mulch may prove a viable tool for source sink alteration, early stolon initiation for obtaining maximum yield with 50% saving of irrigation water in potato. Bandyopadhyay *et al*. (2010) [3] reported that when 20 cm irrigation was supplied up to flowering stage or 14 cm irrigation was supplied up to tillering stage, through sprinkler method in 4 and 3 splits, respectively at critical growth stages, it resulted in higher grain yield and WUE of wheat in a Vertisol than that in flood irrigation method.

Table 7: Effect of irrigation methods on Seed Yield and Water use efficiency (WUE) of Indian mustard

Irrigation system	Seed yield (t/ha)	WUE (kg/ha-mm)
Check Basin	1.51	12.7
Drip System	1.79	29.8
Micro Sprinkler	1.87	31.3
Micro Sprinkler + Check Basin	1.88	21.9
Drip System + Check Basin	1.68	19.8
CD (P=0.05)	0.21	2.1

Source: Rathore *et al*. (2014) [34]

9. Fertilization

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 bio fertilizer has been shown to increase growth and development in both dry and irrigated areas. Kumar *et al*. (2003) [16] reported that increasing levels of N from 0 to 150 kg/ha application markedly improved the water use efficiency of pearl millet. Tetarwal and Rana (2006) [45] reported that the highest water use efficiency, consumptive use and rate of moisture use were recorded with 80 kg N + 40 kg P2O5/ha, followed by 40 kg N + 20 kg P2O5/ha and the control**.** It might be due to that increase in pearl millet-equivalent yield was more than the corresponding increase in consumptive use of water due to fertility level. Behera *et al*. (2002) [4] 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. Kibe and Singh (2003) [14] reported that water use efficiency of wheat was increased with addition of N fertilizer to a maximum with 100 kg N/ha (table 8). Singh *et al*. (2004) [43] reported that application of 40 kg S/ha to chickpea resulted in higher water use efficiency than no sulphur and 20 kg S/ha. Parihar (2004) [23] 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. Sarma *et al*. (2005) [36] reported the maximum water use efficiency of wheat with application of 187.5 kg N + 10 t FYM/ha + Azotobacter. However, Ramakrishna *et al*. (2007) [28] 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) Kumar and Rana (2007) [15] reported that application of 40 kg P2O5/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.

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 [14]

Conclusion

To meet ever increasing demand for food with decreasing fresh water availability to agriculture, crop must produce more with less water. The main challenge confronting both rainfed and irrigated agriculture is to improve productivity or use efficiency of water and sustainable water use for agriculture. This can be achieved through (i) an increase in crop water productivity (an increased marketable crop yield per unit of water taken up by crop), (ii) a decrease in water outflows from the crop root zone other than that required by plants, (iii) an increase in soil water storage within the crop root zone through better soil and water management practices at farm and catchment scales, and (iv) reallocating water from low to high priority uses. Adoption of novel irrigation technologies for crop production and multi-uses of water with introduction of fishery, dairy and other enterprises in the farming can further enhance productivity and use efficiency of water in agriculture. Besides technological advancement, favourable public policy to create conducive socio-economic environment is required for enhancing water productivity in the agricultural sector of our country.

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