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Review Article

Agronomic Approaches to Improve the Water Productivity in Wheat (*Triticum aestivum*)

Jagroop Kaur[1*], G. S. Buttar[2] and Jagmohan Kaur[3]

[1&3]Dept. of Agronomy, [2]Directorate of Extension Education, Punjab Agricultural University, Ludhiana, Punjab (141 004), India

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Correspondence to

**E-mail*: jagroopsekhon@pau.edu

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Abstract

The present scenario of water shortage for agriculture, forced us to produce more from unit quantity of water to meet the food security of ever burgeon population. The underground water table is declining at an alarming rate and water scarcity for irrigation is of great concern especially in Indo-Gangetic plains. The water use efficiency can be increased by doing various agronomic manipulations. In this paper, the effect of sowing methods, mulching and irrigation scheduling has been discussed which impacted water use efficiency in wheat crop. The review suggested that furrow irrigated raised bed planting system (FIRBS) is proved one of the most effective water saving methods which helps in substantial saving of irrigation water. This method decreases irrigation water use without sacrificing economic yield and hence increases the water productivity. These days application of mulch is gaining importance to enhance water use efficiency along with improving soil health. Mulching is useful in conserving soil moisture by minimizing soil evaporation to a great extent. It also improves the microclimate and crop growth and yield. Another option to manage irrigation water can be proper irrigation scheduling. It results in optimum use of irrigation water. The literature shows that there is a considerable saving of irrigation water by scheduling the irrigation water viz., when to apply, how much, etc. Different scientists use different approaches of irrigation scheduling for judicious use of irrigation water in wheat crop.

1. Introduction

Increasing demand for food along with scarcity of water raised the issue of need of increase in water use efficiency (WUE) in agriculture. Water saving becomes the utmost need of the hour. Water use can be reduced by better water management to ensure more crop production from unit^{-1} quantity of water. Of the several practices used for improving water use efficiency (WUE), furrow irrigated raised bed planting system (FIRBS) has been found to save considerable amount of irrigation water in major soil types (sandy loam to loam soils) of Indo-Gangetic plains (Aggarwal and Goswami, 2003; Sayre and Hobbs, 2004). Planting on permanent broad beds with residues increased WUE than conventional planting in this region (Das et al., 2016). WUE can be improved by increasing plant transpiration and decreasing soil evaporation. Surface applied mulches can be effectively used to check soil evaporation (Devkota et al., 2015). In addition to it, mulching is beneficial to moderate soil temperature, improve soil physical (Ram et al., 2013a; Habte et al., 2014), chemical (Benjamin and Isaiah, 2009; Iqbal et al., 2011) and biological (Liu et al., 2012) properties, provide a favorable food source for soil microorganisms that can enhance the degradation of organic matter, prevent the soil salinity from flowing back to surface and check the direct beating action of rains, thus leading to control of soil erosion, etc. Mulch application is proved to be useful in conserving moisture and increasing productivity in wheat (Chakraborty et al., 2008; Ram et al., 2013a; Qin et al., 2015). Irrigation scheduling is a need of the hour to save irrigation water as the water scarcity becomes increasingly serious. Being the prime natural resource for assured crop production, water has to be used judiciously and in scientific manner. So, different agronomic manipulations viz., different sowing methods, mulching and irrigation schedules can greatly affect the water use and water productivity in wheat crop.

2. Effect of sowing Methods, Mulching and Irrigation Schedules

2.1. Sowing methods

The furrow irrigated raised bed-planting system (FIRBS) proves beneficial as compared with conventional flat planting with a saving of ~48% of irrigation water (Kumar et al., 2010; Mollah et al., 2009) combined with enhanced water use efficiency (Singh et al., 2010; Waraich et al., 2010). The water use efficiency (WUE) was recorded the maximum under the bed sown crop having six rows as compared to conventional flat sowing (Waraich et al., 2010). In loamy sand soil, bed planting in wheat recorded 19.2% lower water use and 22.6% higher WUE than flat planting in maize-wheat system, however, grain yield did not differ significantly between bed and flat plating (Ram et al*.,* 2012). Similarly, he observed 23% higher WUE in wheat planted on raised beds as compared with flat layout in soybean-wheat system (Ram et al., 2013b). In Hisar, on an average 4.88 t ha^{-1} grain yield and 2.09 kg m^{-3} water productivity with 40% water saving was observed under furrow irrigated bed planting systems as compared to 5.28 t ha^{-1} grain yield and 1.26 kg m^{-3} water productivity under flat planting (Kumar et al., 2010). In another study in Bangladesh, bed planting was done in 70, 80 and 90 cm wide beds and found that 70 cm wide beds increased grain yield of wheat up to 21% over conventional flat method coupled with saving of irrigation water upto 41–48% (Mollah et al., 2009). Maurya and Singh (2008) recorded highest water-use efficiency in bed planting than conventional and rota drill methods. Buttar et al. (2006) at Bathinda, Punjab, revealed that wheat productivity $unit^{-1}$ of irrigation water applied was more in bed planting method (1.51 and 1.28 kg m^{-3}) than flat planting (1.46 and 1.22 kg m^{-3}) during 2002–03 and 2003–04, respectively . Singh et al. (2010) at Ludhiana found lower water consumption (460.8 mm), higher water use efficiency (9.91 kg ha^{-1} mm^{-1}) and grain yield (4.50 t ha^{-1}) of bed planted wheat than conventional (464.8 mm, 9.50 kg ha^{-1} mm^{-1} and 4.42 t ha^{-1}) and zero tillage (468.0 mm, 9.34 kg ha^{-1} mm^{-1} and 4.37 t ha^{-1}), respectively. Higher bulk density of 0–15 cm soil layer (1.54 g cm^{-3}) and infiltration rate (18.50 cm) and lower root density (2358.9 g m^{-3}) was recorded under zero tillage than conventional (1.49 g cm^{-3}, 16.26 cm and 2400.2 g m^{-3}) and bed planting (1.48 g cm^{-3}, 16.79 cm and 2716.9 g m^{-3}), respectively .

Bed planting lowered wheat yields than conventional practices, however, irrigation reductions were achieved in bed planting (Ahmad et al., 2014) and found that zero tillage wheat performed slightly better both in terms of irrigation water application (3% reduction) and crop yields (5% increase). Ghazanfar et al. (2010) reported the highest grain yield under flat planting (6.5 t ha^{-1}) as compared to bed planting method but water consumption (25.9 l m^{-2}) recorded was the lowest in bed planting (60 cm). Similar results were also reported by Ozberk et al. (2009). Choudhury and Singh (2010) reported that grain yield in bed-planted wheat with two rows per bed reduced by 15–18% as compared to conventional flat system with 20 cm row spacing. However, irrigation water requirement was less (24–42 mm) in bed-planted wheat. Extraction of soil profile water for meeting the actual evapotranspiration (AET) was also 9 to 15% less in beds and the water use efficiency between the bed and flat system was quite comparable.

In China, He et al. (2008) showed that permanent raised beds (PRB) significantly increased soil water content up to 30 cm depth by 7.2 to 10.7% and soil temperature up to 5 cm depth by 0.2 to 0.9 °C during the wheat-growing period relative to conventional tillage (CT) and zero tillage (ZT) treatments. Bulk density in 0–10 cm soil layer under PRB was also 5.8% less than flat planting treatments. Mean wheat yields and irrigation water use efficiency (~18%) over 3 years on PRB plots were greater as compared to CT and ZT treatments. Singh et al. (2012) also recorded about 22.7% higher water use efficiency of wheat planted on raised beds than under flat layout. Singh et al. (2006) found that root characters like area (10.5 cm^2) and length (48.1 cm) were highest in bed planting, followed by conventional and zero tillage at tillering as well as flowering stages. The highest grain yield of 3.7 t ha^{-1} was obtained in zero tillage, followed by conventional tillage (3.4 t ha^{-1}) and bed planting (3.2 t ha^{-1}). Highest water-use efficiency (375 kg ha^{-1} cm^{-1}) was recorded with bed planting.

It is thus clear from the literature that bed planting saves substantial amount of irrigation water and improves water use efficiency of wheat crop without any reduction in grain yield.

2.2. *Mulching*

The application of mulch helps in conserving soil moisture and improves water use efficiency (Huang et al., 2005; Li et al., 2005; Verma and Acharya, 2004). Mulch helped in enhancing the water use efficiency of wheat by 21.6% as compared to non mulched treatment (Meena et al., 2011). Mulching significantly increased soil moisture contents at tillering (6–21%), booting (4–16%) and grain (2–24%) formation stage (Ahmed et al., 2007). Higher soil water content and increased yield of wheat with rice straw mulch was also reported by Sidhu et al. (2007); Rahman et al. (2005). Similarly, Mishra (1996); Shafiq et al. (1994) observed reduction in evapotranspiration and increased soil moisture conservation by use of mulches. In another study, the grass and *Gliricidia* mulches conserved highest moisture over no mulch. However, among the mulch treatments, grass mulch conserved highest moisture followed by *Gliricidia* and *Lantana*. *Gliricidia* mulch with its rich nitrogen content contributed towards higher crop yields as compared with grass and *Lantana* mulches (Chaudhary et al., 2003). Sarwar et al. (2013) at Faisalabad, showed that all mulching treatments viz., no mulch, animal manure @ 4 t ha^{-1}, rice straw mulch @ 4 t ha^{-1}, maize straw mulch @ 4 t ha^{-1}, wheat straw mulch @ 4 t ha^{-1} and burned rice straw after harvesting under zero tillage technique had significant influence on moisture retention percentage at tillering, booting and grain formation stages. Maximum average moisture retention (21.3, 13.1 and 17.4%)

was recorded with rice straw mulch @ 4 t ha^{-1} at tillering, booting and grain formation stages, respectively, before each irrigation as compared to no mulch. Higher weed biomass reduction (41 g) and maximum grain yield (5.2 t ha^{-1}) was also attained in rice straw mulch @ 4 t ha^{-1} treated plots parallel to other mulching treatments.

Plastic mulching could decrease evaporation from soil by 55% under 60% minimum soil water content (MSWC) treatment and water use efficiency (WUE) higher by 2 to 61% than no mulch and the difference increased with the decreasing of MSWC i.e. under low soil water content (Xie et al., 2005). Ghosh et al. (2012) showed reduction in run-off and soil loss by 44.8 and 36.8%, soil moisture conservation to the extent of 6.13 to 58.3 mm for wheat crop, the reduction of micro aggregates by 8 to 9% which increased basic infiltration rate and WUE and nutrient use efficiency of all major nutrients (N, P and K) increased by 40.9% and wheat equivalent yield increased by 9.0% respectively in treatment which received 3 organic sources+minimum tillage (MT)+3 times weed mulches+palmarosa as vegetative barrier (T_4) compared to inorganic sources+conventional tillage (CT)+panicum as vegetative barriers (T_1). The deep percolation loss of nutrient as determined by nutrient balance equation showed that maximum loss was incurred in T_1 (103 kg ha^{-1}) and minimum in T_4 (11.0 kg ha^{-1}).

Singh et al. (2011a) conducted a field trial in two years of contrasting rainfall pattern and found that mulch increased soil water content and this improved crop growth and yield determining attributes in low rainfall year and mulch suppressed whole of season soil evaporation by 35−40 mm.

From the above literature, is can be concluded that mulch application helps in conserving soil moisture and hence increases water use efficiency.

2.3. *Irrigation schedules*

Appropriate approach of scheduling irrigation is vital for saving the irrigation water and increasing the water use efficiency. Mahdi et al. (1997) at southwestern Colorado investigated the effective irrigation scheduling to manage water for spring wheat under five varying rates of water replacement (0, 0.33, 0.67, 1.0 and 1.33 ET) and observed that both grain yield and dry matter increased significantly with the increase in water application rates, up to 1.0 ET. Total water use efficiency (TWUE) and irrigation water use efficiency (IWUE) for grain yield were considerably greater at 0.33 ET than for other rates, whereas TWUE and IWUE for dry matter yield followed the order 0.33 ET>l.0 ET>0.67 ET>1.33 ET>0 ET. Bunyolo (2000) found that water use by wheat increased with shorter irrigation intervals. Singh et al. (2010) at Ludhiana, Punjab, recorded higher water use when first irrigation was applied at 2 weeks after planting (WAP) than that of 3 and 4 WAP. However, the highest yield and water use efficiency was recorded when irrigation was applied at 3 WAP. The highest water consumption and water use efficiency was observed when subsequent irrigations were applied at 1.2 Irrigation water: Cumulative Pan Evaporation (IW:CPE). Water content in soil increased with the reducing interval of first irrigation and with the increase in IW/CPE ratio from 0.8 to 1.2. Khan et al. (2007) reported that the highest yield and water use efficiency was obtained when crop was irrigated at five weeks interval than 3 and 6 weeks intervals.

Mishra et al. (1995) observed highest net water use (641 and 586 mm) in treatment where irrigations were given at Crown root initiation (CRI), maximum tillering, flowering, milk and dough stages under shallow water table i.e. 0.4−0.9 m deep (SWT) and medium water table i.e., 0.8−1.3 m deep (MWT) conditions, respectively, but not the yield (5.07 t ha^{-1}) and further concluded that irrigations applied at CRI and milk stages under SWT conditions and at CRI, maximum tillering and milk stages under MWT conditions were as effective as frequent irrigations i.e., at CRI, maximum tillering, flowering and milk stages and at CRI, maximum tillering, flowering, milk and dough stages. Sharma et al. (1990) recorded maximum water use efficiency (WUE) when three irrigations were applied at CRI, tillering and milk stages rather than at other growth stages and also observed that total ET increased with increase in irrigation frequency as ET increased from lower layers (15−30, 30−60, and 60−90 cm soil depth) when irrigation frequency was increased. Mubeen et al. (2013) observed that irrigation at tillering, stem elongation, booting and grain filling stage (ITSBG) gave higher grain yield (4.23 t ha^{-1}) followed by irrigation at stem elongation and booting stage (ISB) (3.60 t ha^{-1}), however ITSBG was statistically similar to ISB in radiation use efficiency (RUE) for grain yield (RUE_{GY}).

Salunkhe et al. (2015) recorded highest WUE in irrigation schedule of 0.8 IW:CPE followed by 1.0 and 1.2 IW:CPE. However, grain yield (3.94 t ha^{-1}) was significantly higher in irrigation schedule of 1.2 IW:CPE than all other treatments. Mahmood et al. (2002) irrigated wheat at 0.7, 0.9, 1.10 and 1.30 IW:CPE and obtained maximum production at 0.9 IW:CPE but WUE was maximum at 0.7 IW:CPE. Maurya and Singh (2008) reported highest consumptive use with 6 cm irrigation at 1.2 IW:CPE than 4 cm at 0.8 IW:CPE and 5 cm at 1.0 IW:CPE. Wang et al. (2012) observed that low irrigation treatment (0.6 of the estimated evapotranspiration-ET) produced significantly lower grain yield (20.7%), kernels number (9.3%) and straw yield (12.2%) than high irrigation treatment (1.0 ET), however, the WUE (4.25 kg ha^{-1} mm^{-1}) was higher under low irrigation treatment (0.6 ET) than that of 3.25 kg ha^{-1} mm^{-1} with high irrigation (1.0 ET). Patel and Upadhyay (1993) observed that grain yield of wheat recorded at 1.2 (4.30 t ha^{-1}) and 1.6 (4.40 t ha^{-1}) IW:CPE were at par but significantly higher than 0.8 IW:CPE (3.62 t ha^{-1}) with total water requirement of 300, 450 and 600 mm and number of irrigations were 6, 9 and 12 under IW/CPE ratio of 0.8, 1.0 and 1.2. Hundal and Rajwant (1993) found that wheat irrigated at IW/CPE of 1.0 upto maturity produced significantly higher grain yield (4.10 t ha^{-1}) than irrigation at IW/CPE of 0.5 (3.45 t ha^{-1}) and rainfed crop (2.63 t ha^{-1}) but at par with IW/CPE of 1.0 up to booting followed by IW/CPE of 0.5 up to maturity (3.80 t ha^{-1}). However, ET (mm day^{-1}) was more where irrigation was applied at IW/CPE of 1.0 upto maturity than rainfed crop at all the crop growth stages.

Yadav (1991) at Kota reported that six irrigations at 0.8 IW:CPE gave higher consumptive use as compared to three and four irrigations given at 0.4 and 0.6 IW:CPE, respectively. Higher WUE was obtained with four irrigations as compared to six irrigations. Yaghobi and Sharma (2009) showed significantly higher consumptive use with irrigation at 1.25 IW:CPE and 1.0 IW:CPE over irrigation at 0.5 and 0.75 IW:CPE. Whereas, water use efficiency was significantly higher at 0.5 IW:CPE. However, Sarkar (2005) recorded increased water use efficiency with increase in frequency of irrigation (0.8, 1.0 and 1.2 IW:CPE). Similarly, Rathore et al. (1991) also reported increased WUE with increasing irrigation frequency. Sharma (1994) also observed that an increase in IW:CPE resulted in greater relative growth rate, yield attributes and yield and maximum water use efficiency of 6.49 kg grain per mm of ET was recorded when irrigation was given at 1.0 IW:CPE than at 0.6 and 0.8 IW:CPE treatments. Bikrmaditya et al. (2011) compared two depths of irrigation water (D_1- 45 mm and D_2- 60 mm) and 4 IW:CPE ratios (I_1-0.8 IW:CPE, I_2-1.0 IW:CPE, I_3-0.6 IW:CPE during vegetative phase and 1.0 IW:CPE during reproductive phase and I_4-0.8 IW:CPE during vegetative phase and 1.0 IW:CPE during reproductive phase) and found that 45 mm irrigation resulted in 6.8 to 12.2% increase in WUE over 60 mm in two years of study and 19.7, 13.9 and 16.6% enhanced grain yield under I_2, I_3 and I_4 irrigation regimes, respectively, over I_1 irrigation schedule.

According to Walia and Cheema (1992), the grain yield, root weight and water use efficiency of wheat were highest with irrigation at four weeks after sowing+subsequent irrigations at 80 mm CPE. At Punjab Agricultural University, Ludhiana, Punjab, Singh et al. (2011b) observed that soil matric potential (SMP) based irrigation scheduling (irrigation when SMP decreased to -40 kPa at 15−20 cm soil depth for the first irrigation and at 40 cm for subsequent irrigations) reduced the number of irrigation by one than irrigation at IW/(CPE-rain)=0.9 (recommended practice) in mulched wheat crop for achieving the same yield. Prashar and Thaman (2005) reported grain yield of 5.5 and 5.4 t ha^{-1} during 2000-01 and 2001−02, respectively, which was significantly higher at 50 mm CPE irrigation scheduling as compared to 4.7 and 4.7 t ha^{-1} with 65 mm CPE irrigation scheduling and 4.49 and 4.54 t ha^{-1} with 80 mm CPE irrigation scheduling, respectively, however, it was statistically at par with 5.47 and 5.34 t ha^{-1} grain yield with 40 mm CPE. The water use efficiency was found to be decreasing with increase in quantity of irrigation water supplied. Idnani and Kumar (2012) at IARI, New Delhi, revealed that irrigation at CRI+100 mm CPE registered significantly more yield and yield attributing characters and highest water use efficiency than other schedules i.e. irrigation at CRI, CRI+200 mm CPE, CRI+150 mm and CRI+50 mm CPE. Behera and Panda (2009) compared three irrigation schedules viz., I_1=10% maximum allowable depletion (MAD) of available soil water (ASW); I_2=40% MAD of ASW; I_3=60% MAD of ASW and found that water use efficiency of the I_2 irrigation schedule was comparatively higher than the I_1 and I_3 irrigation schedules due to higher grain yield $unit^{-1}$ use of water. Therefore, irrigation schedule with 40% MAD of ASW could safely be maintained during the non-critical stages to save water without sacrificing the crop yield.

Thus, it can be concluded that irrigation schedules affects the water use and water use efficiency. The water use increases and water use efficiency decreases with increase in irrigation amounts.

3. Conclusion

Furrow-irrigated raised bed planting system helps in substantial saving of irrigation water over flat sowing method. Mulch helps in reducing soil evaporation and hence improves water use efficiency as compared with no mulch. Irrigation scheduling in wheat crop helps in enhancing irrigation water productivity.

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