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Full Research Article

# Improving Water Use Efficiency of Rice-Wheat Cropping System by Adopting Micro-Irrigation Systems

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**Abstract**

Rice-wheat is the predominant cropping system and contributes more than 70% of food grain production in India. However, major problem in this system is depletion and deterioration of water resources. Therefore, efforts must be focussed on reversing the trend in water resources depletion by adopting efficient irrigation technologies. The prevalent irrigation methods are less efficient due to more water losses through leaching and evaporation. Micro irrigation can be an effective tool for improving water use efficiency. The study was carried out with an objective of improving the WUE in rice-wheat cropping system with four irrigation methods in wheat crop viz check basin, drip, sprinkler and drip+rainport and three irrigation systems in rice (check basin, drip and sprinkler) at Indian Institute of Wheat and Barley Research, Karnal during 2012-13 and 2013-14. Irrigation treatments significantly affected the grain yield of both the crops. The highest grain yield of wheat (5752 kg ha$^{-1}$) was obtained in check basin irrigation during 2012-13 followed by drip+rainport (5614 kg ha$^{-1}$). However, the WUE of check basin method was minimum (1.32 kg m$^{-3}$). During 2013-14, highest yield was obtained in drip+rainport (5545 kg ha$^{-1}$) followed by drip irrigation (5475 kg ha$^{-1}$) with the WUE of 1.57 and 1.55 kg m$^{-3}$ respectively. In rice, significant higher grain yield (4028 and 4683 kg ha$^{-1}$) was recorded in drip followed by sprinkler irrigation. The study concludes the maximum WUE in wheat under drip+rainport treatment and in rice it was under drip irrigation treatment.

## 1. Introduction

Available fresh water resources are subjected to an ever-increasing pressure due to extensive demand for agricultural, industrial and domestic usage. The availability of quality water is decreasing with time, hence water scarcity in arid and semi-arid regions is a major concern for agricultural authorities around the world (Sharafi et al., 2011). India's per capita water availability will reduce sharply to 1341 cubic meter by 2025 and further down to 1140 cubic meter by 2050 (GoI, 2009). Long-term perspective in paucity of fresh water resources, especially in arid and semi-arid area, highlights an urgent solution for innovative irrigation strategy and agricultural water management. As the competition for the finite water resources on earth increases due to growth in population and affluence, agriculture is facing the intensifying pressure to improve the efficiency of water used for food production. Irrigated agriculture is the main user of the available water resources. About 70% of the total water withdrawals and 60-80% of the total consumptive water use are consumed through irrigation (Huffaker and Hamilton, 2007). The conflict between increase in global food demand and decrease in water resources has to be resolved. Food security can be achieved possibly through irrigated agriculture since irrigation on an average double the crop yield in comparison to rain-fed farming. The irrigated area should be increased by more than 20% and its crop yield should be increased by 40% by 2025 to secure the food grain production (Lascano and Sojka, 2007). Therefore, the scarce water resources should be used optimally resulting in higher efficiency and to achieve this goal, improvement in agricultural water management is a key factor.

Several investigations have been conducted to gain experiences in irrigation of crops to maximize performances, efficiency and profitability. However, exploring the water saving irrigation techniques are still continued (Sleper et al., 2007). Full irrigation by check basin methods are being widely used by farmers in abundant as well as in scarce areas of water availability. By this method, crops receive full evapo-transpiration requirements to produce the maximum yield but now-a-days, full irrigations are considered a luxury use of water that can be reduced with minor or no effect on profitable yield (Kang and Zhang, 2004). The amount of irrigation reduction is crop-dependent and generally accompanied by no or minor yield loss that increases the water productivity (Ahmadi et al., 2010b). The pressure of using water in agriculture sector has been increasing over years which aim for ways and means to improve the water use efficiency so as to take full advantage of the available and depleting water resource. Therefore, adoption of modern irrigation techniques is of great importance to increase the water use efficiency. Drip irrigation is the most effective way to convey directly water and nutrients to plant roots which not only save water but also increases the crop yield. Surface irrigation methods are utilized for more than 80% of the world's irrigated lands but its field-level application efficiency is only 40-50%. In contrast, drip irrigation efficiency ranges between 70-90% as surface runoff and deep percolation losses are minimized (Postel, 2000). Hence, tendency in recent years has been towards conversion of surface to micro irrigation (drip and sprinkler irrigation) owing to its higher efficiency. Irrigation scheduling is very critical to increase the efficiency, as over irrigation reduces water use efficiency, while inadequate irrigation causes water stress and consequently reduction in grain yield. The global food security is challenged by increasing demand for food against the declining water availability for agriculture. Rice and wheat are the main cereal crops globally and rice-wheat system is the backbone of India's food security. Therefore, efficient use of irrigation and fertilization system is a must for maximizing the production in the context of food security as well as sustainability. In the milieu, the present study aims to evaluate the impact of micro irrigation on water use efficiencies in rice and wheat crops.

## 2. Materials and Methods

Field experiments were conducted in rice-wheat system for two years (2012-13 and 2013-14) at the research farm of ICAR-Indian Institute of Wheat and Barley Research, Karnal, located at an altitude and longitude of 29°43′ N, 76°58′ E and 245 meter above mean sea level. The agro-climatic conditions of the location is characterized by sub tropical and semi arid conditions with hot dry summer (March-June), wet monsoon season (late June-mid September) and cool dry winters (November-February). Average annual rainfall of this area is 744 mm, of which about 80% is received during the monsoon. The mean maximum temperature ranges between 34-39 °C in summer and mean minimum temperature ranging between 6-7 °C in winter. The soil texture of experimental field was sandy clay loam with pH 7.3 (1:2.5 soils to water) and EC 2.0 $dSm^{-1}$. The soil was having 0.42% organic carbon (estimated by method of Walkley and Black, 1934), 189 kg $ha^{-1}$ available N estimated by kjeldahl method (Jackson, 1958), 17.6 kg $ha^{-1}$ available P (estimated by method of Olsen et al., 1954), and 162 kg $ha^{-1}$ available K estimated by flame photometer method (Rechards, 1954) at the beginning of the experiment. The experiment was laid out in split plot design with three replications. The experiment consisted of two main plot treatments (flat sown and raised bed planting) vis-à-vis four irrigation treatments for wheat (check basin/furrow irrigation, drip irrigation, sprinkler irrigation and drip+rainport) and three irrigation treatments for rice (check basin/furrow irrigation, drip irrigation and sprinkler irrigation) as sub plot treatments. Check-basin method of irrigation was imposed under flat sown conditions, whereas, furrow method of irrigation was kept for raised bed planting treatment. One additional irrigation treatment (drip+rainport) was scheduled for wheat to mitigate the terminal heat stress. Drip+rainport treatment taken under wheat crop in which overhead water was sprinkled for 15 minutes by sprinkler system whenever the day temperature crossed 30 °C at noon to mitigate the heat stress. This treatment was applied in wheat crop only, as terminal heat stress is not an issue with rice crop. The drip lines laid were 75 cm apart with drippers at 30 cm and a flow rate of 2.4 litres/hour/dripper. Wheat variety HD 2967 and rice variety Pusa Basmati 1509 were sown in rows at 20 cm apart. Rice was sown as DSR (direct seeded rice) using DSR seed drill machine. All recommended package of practices except irrigation and fertilizer application were carried out. Irrigation by drip and sprinkler systems were given at alternate days to compensate the evapo-transpiration losses of water. The amount of applied water was measured by the inbuilt water meter in pipe line of the system. In micro-irrigation systems, nitrogen-nutrient was applied as fertigation through ventury of micro irrigation system. Whole dose of required nitrogen was applied in four equal doses. Of them first dose was applied as basal through DAP and the remaining three doses were applied through urea as fertigation with fortnightly intervals. A filter was installed in the main line to prevent sediment from blocking the emitters. The treatment's plot had dimensions of 30×10 $m^2$. Plots in each replication were separated by a buffer zone of 2 m wide. An area 4×4 $m^2$ from each plot was harvested for estimating the grain yield.

## 3. Results and Discussion

### *3.1. Growth, Yield attributes, Yield and WUE of Wheat*

The results presented in (Table 1), revealed that during the first year of experiment, the plant height, earheads $m^{-2}$, grains $earhead^{-1}$, and harvest index were influenced by methods of planting and irrigation treatments. The maximum yield was recorded in check basin irrigation treatment (5752 kg $ha^{-1}$) with a minimum WUE (1.32 kg $m^{-3}$). It was followed by drip+rainport (5614 kg $ha^{-1}$) with the maximum WUE (1.54 kg $m^{-3}$) and sprinkler irrigation (5004 kg $ha^{-1}$) with 1.44 kg $m^{-3}$ WUE. Significant higher yield in check basin was obtained during 2012-13 due to favourable weather conditions and evenly distributed rainfall from December 2012 to April 2013 (203 mm) at the experimental site (Figure 1). Due to this, the impact of micro-irrigation system on crop yield has been minimized. During 2013-14, maximum grain yield was obtained in drip+rainport irrigation (5545 kg ha$^{-1}$), followed by drip irrigation (5475 kg ha$^{-1}$) with the water use efficiency of 1.57 and 1.55 kg m$^{-3}$ respectively, which were statistically at par. However, the maximum WUE (1.61 kg m$^{-3}$) was achieved in sprinkler irrigation. During 2013-14, the minimum yield (5042 kg ha$^{-1}$) and WUE (1.21 kg m$^{-3}$) has been recorded for check basin method of irrigation. In main plot treatments, flat sowing recorded significantly higher grain yield than raised bed planting in both the years of study (5490 and 5358 kg ha$^{-1}$). However, the WUE of raised bed sown crop was significantly superior to flat sown crop in 2013-14 only. On pooled data basis, the highest and significantly more yield was obtained in flat sown methods of planting (5421 kg ha$^{-1}$) and among irrigation treatments drip+rainport system produced the highest grain yield (5579 kg ha$^{-1}$) which was found significantly superior to all other methods of irrigations.

Overall, the water use efficiency has increased through micro irrigation system by 16 and 33% during 2012-13 and 2013-14, respectively. Likewise, in raised bed planting the WUE increased by 8.39% during 2013-14. Micro irrigation system (drip and sprinkler irrigation) was found to be more efficient in comparison to surface irrigation methods (full irrigation approach) with water saving up to 33% under different planting methods. *Inter alia,* stress for water is the possible reason for the low yield obtained in surface irrigation methods. Indeed, the water stress was caused by the longer irrigation interval from February onwards which occurred during the stem elongation stage causing reduction in the number of productive tillers/ unit area (up-to about 3.7%). Insufficient irrigation water applied in March during the heading and flowering stage, that coincides with high evapo-transpiration, might have affected the grain formation viz spike length and 1000 grain weight (Table 1). Results are in close conformity with the findings of Zhang and Oweis (1999), who reported that the most sensitive stage of wheat to water stress from stem elongation to booting, followed by anthesis and grain filling. Water use efficiency has increased chiefly due to less amount of irrigation water used by micro-irrigation systems (16-33% less) over surface irrigation to harvest almost the equal amount of grain yield.

### *3.2. Growth, Yield attributes, Yield and WUE of Rice*

Results presented in (Table 2), revealed that planting and irrigation methods significantly affected the growth, yield attributes (panicles m$^{-2}$, grains panicle$^{-1}$, 1000 grain weight) and yield of rice crop. Maximum yield was recorded in drip irrigation treatment (4028 kg ha$^{-1}$) during 2012-13 which was significantly higher than the sprinkler irrigation (3488 kg ha$^{-1}$) and check basin method (3403 kg ha$^{-1}$) with the WUE of 0.52 kg m$^{-3}$, 0.42 kg m$^{-3}$ and 0.39 kg m$^{-3}$ respectively (Table 2). Under planting methods, yield was numerically higher in flat sown conditions (3866 kg ha$^{-1}$) than raised bed sown crop (3413 kg ha$^{-1}$). During 2013-4, the maximum grain yield was obtained in drip irrigation (4683 kg ha$^{-1}$) followed by sprinkler irrigation (3641 kg ha$^{-1}$) with the WUE of 0.44 and 0.40 kg m$^{-3}$, respectively. The estimated water use efficiency in check basin irrigation treatment (0.33 kg m$^{-3}$) was significantly lower than both micro irrigation treatments. Micro irrigation system (drip and sprinkler irrigation) was found to be more efficient with water saving up-to 33% across the cropping season and different planting methods in comparison to surface irrigation

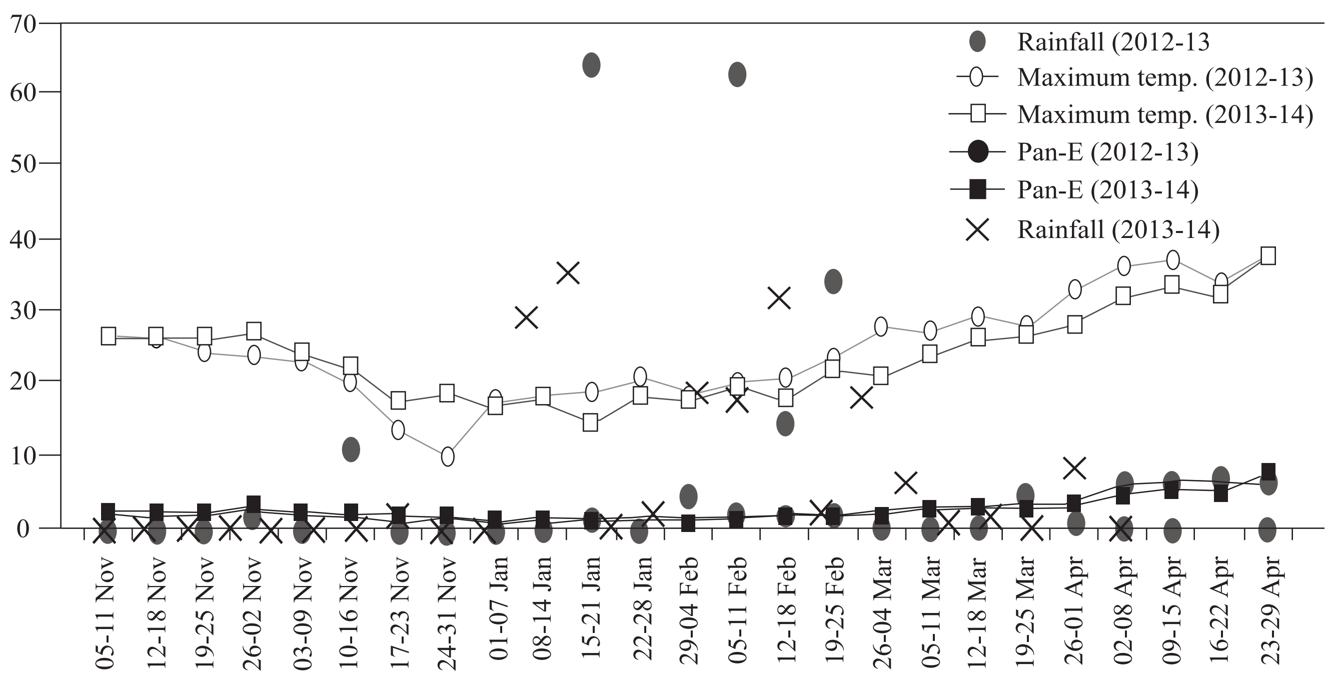


Figure 1: Meteorological data (rainfall, temperature and evaporation) during crop season of 2012-13 and 2013-14

Table 1: Effect of micro-irrigation on yield, yield attributes and water use efficiency of wheat under different planting and irrigation methods

| Treatment | Grain yield (kg ha$^{-1}$) | | Grain yield (kg ha$^{-1}$) | Biomass yield (q ha$^{-1}$) | | Harvest index (%) | | 1000-grain weight (g) | | Earhead m$^{-2}$ | | Grains earhead$^{-1}$ | | Plant height (cm) | | Water consumption (M$^3$) | | WUE (kg m$^{-3}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planting methods | 2012-13 | 2013-14 | Pooled | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| Flat sown | 5490 | 5358 | 5421 | 151 | 138 | 36.16 | 39.09 | 35.28 | 35.84 | 553 | 548 | 28.0 | 27.3 | 96.9 | 98.6 | 3756 | 3827 | 1.46 | 1.43 |
| Raised bed sown | 4984 | 5321 | 5153 | 133 | 133 | 37.58 | 40.30 | 35.91 | 36.34 | 526 | 524 | 26.3 | 27.7 | 98.1 | 99.8 | 3661 | 3448 | 1.36 | 1.55 |
| CD ($p$=0.05) | NS | NS | 272.3 | 4.59 | NS | NS | NS | NS | NS | 16.52 | NS | 1.54 | NS | 0.77 | 0.77 | NS | 427.4 | 0.003 | 0.038 |
| Irrigation methods | | | | | | | | | | | | | | | | | | | |
| Check basins | 5752 | 5042 | 5390 | 153 | 124 | 37.44 | 40.89 | 34.84 | 35.40 | 546 | 508 | 28.5 | 26.5 | 96.2 | 98.0 | 4351 | 4221 | 1.32 | 1.21 |
| Drip | 4579 | 5475 | 5028 | 136 | 138 | 33.64 | 39.96 | 36.29 | 36.71 | 530 | 560 | 25.2 | 27.8 | 98.3 | 100.0 | 3380 | 3523 | 1.35 | 1.55 |
| Sprinkler | 5004 | 5295 | 5149 | 138 | 131 | 36.34 | 40.48 | 35.51 | 35.98 | 543 | 523 | 26.2 | 28.5 | 97.0 | 98.3 | 3455 | 3288 | 1.44 | 1.61 |
| Drip+rainport | 5614 | 5545 | 5579 | 141 | 149 | 40.05 | 37.45 | 35.74 | 36.26 | 540 | 551 | 28.8 | 27.3 | 98.5 | 100.3 | 3648 | 3518 | 1.54 | 1.57 |
| CD=0.05 | 689 | NS | 317.8 | 6.27 | 12.97 | 1.92 | NS | 0.36 | 0.20 | NS | 11.29 | 2.23 | 0.67 | 1.04 | 0.60 | 402.86 | 303.9 | 0.014 | 0.083 |

*Water applied by irrigation+water received by rainfall

Table 2: Effect of micro-irrigation on yield, yield attributes and water use efficiency of rice under different planting and irrigation methods

| Treatment | Grain yield (kg ha$^{-1}$) | | Grain yield (kg ha$^{-1}$) | Biomass yield (q ha$^{-1}$) | | Harvest index (%) | | 1000-grain weight (g) | | Panicles m$^{-2}$ | | Grains panicle$^{-1}$ | | Plant height (cm) | | Water consumption (M$^3$) | | WUE (kg m$^{-3}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planting methods | 2012-13 | 2013-14 | Pooled | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| Flat sown | 3866 | 4637 | 4247 | 74 | 85 | 51.97 | 54.68 | 27.50 | 30.2 | 749 | 715 | 26.8 | 24.2 | 92.9 | 92.8 | 8190 | 10545 | 0.48 | 0.44 |
| Raised bed sown | 3413 | 3251 | 3331 | 67 | 64 | 50.85 | 50.45 | 28.53 | 29.31 | 475 | 454 | 27.7 | 27.7 | 91 | 91.7 | 8057 | 9863 | 0.42 | 0.33 |
| CD ($p$=0.05) | NS | 122.8 | 554.58 | 1.36 | 4.63 | 1.18 | 3.69 | 0.59 | 0.20 | NS | 102.7 | NS | NS | NS | NS | NS | NS | 0.005 | 0.004 |
| Irrigation methods | | | | | | | | | | | | | | | | | | | |
| Check basins | 3403 | 3508 | 3455 | 68 | 67 | 49.94 | 51.83 | 28.94 | 28.94 | 574 | 587 | 28.0 | 26.5 | 90.2 | 92.2 | 8864 | 10621 | 0.39 | 0.33 |
| Drip | 4028 | 4683 | 4355 | 76 | 85 | 53.14 | 55.04 | 27.74 | 30.28 | 608 | 686 | 26.0 | 24.5 | 94.5 | 93.8 | 7805 | 10489 | 0.52 | 0.44 |
| Sprinkler | 3488 | 3641 | 3558 | 68 | 71 | 51.16 | 50.83 | 28.01 | 29.39 | 559 | 575 | 27.7 | 26.8 | 91.2 | 90.8 | 7702 | 9501 | 0.42 | 0.40 |
| CD ($p$=0.05) | 350 | 528 | 182.69 | 2.48 | 2.49 | 1.46 | 1.92 | 0.19 | 0.25 | 40.86 | 23.8 | NS | 1.08 | NS | NS | 230 | 242 | 0.004 | 0.005 |

*Water applied by irrigation+water received by rainfall methods. In DSR (direct seeded rice), more yield was obtained by micro irrigation systems, as rice field was maintained wet and well watered by drip and sprinkler irrigation systems against alternate wetting and drying which was experienced by surface irrigation methods. Further, water applied by surface irrigation methods caused alternate drying of rice field at all growth stages with high evapo-transpiration, which adversely affected the number of productive tillers unit$^{-1}$ area (Table 2) and grain formation (panicle length and 1000 grain weight).

Significant variations were recorded in production efficiency under different planting and irrigation systems coupled with fertigation. Proper water management through micro-irrigation helps the crop in quick utilization of the available nutrients resulting in higher growth and yield of wheat and rice as compared to surface irrigation. The higher assimilation of metabolizable carbon and N in plants due to congenial environment created by micro-irrigation systems in addition to increasing root absorption surfaces might have increased the production efficiency (Hao et al., 2008).

With micro irrigation, water saving up-to 50% was possible through maintaining available soil moisture at low water tension during entire growth period (Patel et al., 2006). Micro irrigation systems provide water to the plants which matches the crop evapo-transpiration demands and provide optimum soil moisture at critical growth stages resulting in high water use efficiency (Kipkorir et al., 2002).

## 4. Conclusion

Irrigation water application by micro-irrigation systems (drip and sprinkler) becomes the need of hour and practical. The results revealed that drip and sprinkler irrigation systems are efficient and could be adopted for irrigation in rice and wheat crops for improving the water use efficiency. Favourable water regime created by micro irrigation results in higher crop yield. Water sprinkling by rainport for 15 minutes in wheat crop whenever the temperature crosses 30 °C at noon helps to avoid the terminal heat stress.

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