



Development and evaluation of automation system for irrigation scheduling in broccoli (*Brassica oleracea*)

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The water availability for agriculture is shrinking with time which necessitates the efficient, productive and intelligent use of irrigation water (GoI 2016). Micro-irrigation system including sprinkler or drip irrigation has higher irrigation efficiency ranging from 75-95% (CWC 2015). The promotion of these new and state-of-art technologies is important for enhancing agricultural productivity in the country (Marazky *et al.* 2011, Hussain *et al.* 2013, Ojha *et al.* 2015). Therefore, the increased efforts are required in the direction of precision irrigation water management. Sensor based automated irrigation system provides an effective and non-destructive alternative for achieving the target of precise and real time irrigation scheduling which enhances the water productivity in the field along with the continuous coverage over a larger area (Dursan and Semih 2011, Majone *et al.* 2013). Sensor based irrigation system facilitates aggregation of data on the soil and plant conditions which in conjunction with decision support advisories and control systems applies real time irrigation based on crop needs. The existing micro irrigation technology is further needed to be improvised in order to facilitate the real time monitoring, and to eradicate the human labour associated with it during manual operation. This can be done by automated irrigation system. Therefore, an attempt was made to develop an indigenous automated irrigation system for real time irrigation management and its effectiveness was evaluated in the broccoli (*Brassica oleracea* var. *italica*) crop.

The field and laboratory experiments were conducted during 2013-14 and 2014-15 at Precision Farming

Development Center (PFDC), Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi (latitudes of 28°37'22"N and 38°39'05"N and longitudes of 77°8'45" E and 77°10'24"E at an average elevation of 228.61 m amsl) in order to develop and evaluate the performance of automated system in broccoli crop. The climate of Delhi is categorized as semi-arid sub-tropical with hot and dry summer and cold winter which falls under the agro-climate zone of "Trans-Gangetic Plains" in the Agro-eco-region-IV (Ajdaury *et al.* 2007).

Design of field experiments: A field plot of 21 m × 21 m was used for conducting the field experiment. A buffer strip of one meter was maintained for separating the plots from one another. The whole plot was divided into six sub-plots and dimension of each sub-plot was 10.0 m × 6.0 m. The experiment was laid out in the split plot design with three replications and irrigation methods, *i.e.* check basin, furrow and drip irrigation. The sub-plot treatments were irrigated through manually controlled and sensor based automated irrigation system. The water meter was installed at each sub-plot to measure the volume of water applied per irrigation.

Irrigation scheduling: Irrigation scheduling is the process of deciding the period and quantity of irrigation water during the crop growth under different irrigation methods (Allen *et al.* 1998). Its main objective is to apply irrigation at the right period and in right amount. Irrigation amount is determined in terms of gross irrigation requirement and pumping time per application, while irrigation time is based on depletion of soil moisture content in the crop root zone reached at critical point (Ramadan *et al.* 2006).

Water productivity (WP): Water productivity is indicated by the yield per unit of water used during the crop growth. It can be improved through judicious management of irrigation (Passioura 2006). The water productivity is estimated using the data generated from the field experiment or through sensor-based irrigation scheduling at different matric potential or soil water suction under different scenario of irrigation water management. In this research work, irrigation water productivity and crop water productivity

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of broccoli crop was calculated under different methods of irrigation, *i.e.* check-basin, furrow, drip irrigation each under manual and automated control system. The water productivity calculated as;

$$\text{Crop water productivity (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Crop evapotranspiration (m}^3\text{/ha)}} \quad (1)$$

In crop production, irrigation water productivity defined as the ratio of crop yield to the depth applied in the field (Ali and Talukder 2008).

$$\text{Irrigation water productivity (kg/m}^3\text{)} = \frac{\text{Crop yield (kg/ha)}}{\text{Water used to produce yield (m}^3\text{/ha)}} \quad (2)$$

Design approaches of Indigenous Automated Irrigation System: The automated irrigation system having modified tensiometer was based on soil moisture sensor, decision support system, level sensor, level controller, GSM receiver, transmitter, solenoid valve, water meter and pump. Earlier efforts have not been made in this direction of using tensiometer to sense drop in water column by using capacitance sensors. Sensing of water column level also showed the availability of soil moisture content and placement of capacitance sensors inside the tensiometer could be an alternative option for irrigation scheduling on real time basis. The developed modified tensiometer was calibrated with gravimetric method and compared with FDR, tensiometer, watermark, simultaneously, under different methods of irrigation. The average depth of water column range was found to be 29–35 cm, at 50% management allowable depletion (MAD) of available water in broccoli crop under different irrigation methods, *viz.* check basin, furrow and drip irrigation. This range was useful for level sensor to be installed inside modified tensiometer for real time irrigation scheduling. Based on similar concept, a Decision Support System (DSS) was developed to process the user information and to provide input to the integrated sensor network for irrigation scheduling either on time basis or/ on soil moisture sensor basis.

The weather station and soil moisture sensor were interfaced with decision support system via wireless communication. This helped to estimate water requirement, pumping time and control water application as per crop needs under different irrigation methods, *viz.* border, check basin, and drip, respectively. The automated irrigation system developed in the present research work would ensure economic use of most precious input in agriculture, *i.e.* water. Farmers can decide the time and amount of water to be applied for achieving desired target crop yield using sensor-based irrigation system. Farmers can also operate the irrigation system using mobile phones through sending sensor

code command in the form of SMS to the controller. The small and marginal farmers can use this system for efficient irrigation scheduling which can guide them towards more judicious use of irrigation water for achieving higher crop water productivity.

Water productivity of broccoli crop under different irrigation methods: Water productivity expressed the relationship between crop yield to the per unit amount of water used during the crop growth. In this research work, the irrigation water productivity (IWP) and crop water productivity (CWP) of broccoli crop calculated under different methods of irrigation, *i.e.* check-basin, furrow, drip irrigation under manual and automated control system is presented in Fig 1. Interactive effect of automated and manual control irrigation system on broccoli crop under different methods of irrigation revealed that the irrigation methods combination exhibited higher values of IWP (9.7 and 6.3 kg/m³) and CWP (10.6 and 8.5 kg/m³) and their values were significantly higher than other treatments. Manual and automated controlled check basin irrigation system had lower IWP (2.5 and 4.2 kg/m³) and CWP (5.0 and 7.3 kg/m³) than all other methods (Fig 1). These results are in agreement with the results of Karam *et al.* (2002), Kadayifci *et al.* (2004) and Miggiaccio *et al.* (2015).

IWP and CWP obtained under automated drip irrigation system were highest, and were lowest under manual control-based check basin irrigation system. Similarly, in sensor based automated irrigation methods, maximum irrigation water productivity (9.7 kg/m³) and crop water productivity (10.6 kg/m³) were recorded under drip irrigation. Sensor network based automated drip irrigation system continuously maintained wetting of active root zone on real time basis whenever plant required. Therefore, it resulted into maximum crop water productivity (CWP) and irrigation water productivity (IWP) that helped in saving irrigation water.

Water saving and benefit-cost ratio under different irrigation methods: The highest and lowest benefit cost

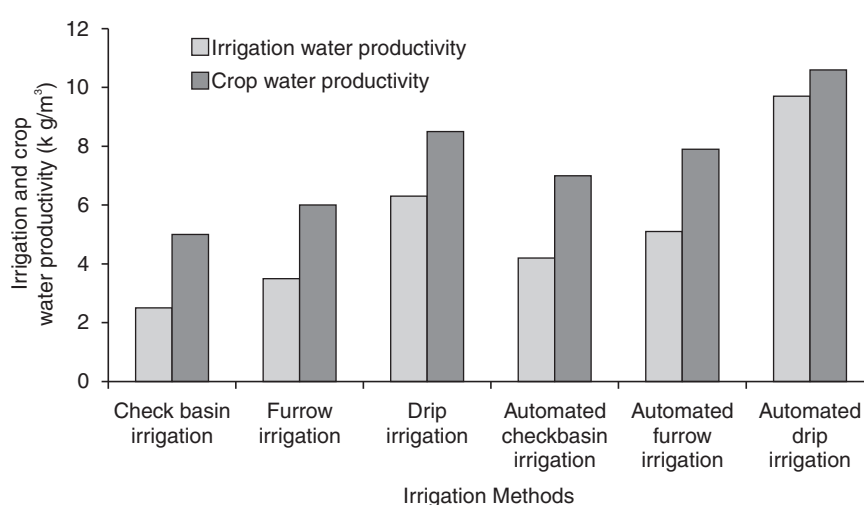


Fig 1 Irrigation and crop water productivity estimated under different methods of irrigation in broccoli crop.

ratio (3.24 and 2.50) were obtained for automated drip irrigation and manual check basin, respectively. The water saving was obtained 44.75% using automated drip irrigation over manually controlled check basin irrigation in broccoli crop. The highest benefit cost ratio (BCR), and water saving obtained by automated drip irrigation is followed by manual control drip irrigation system in all the treatments. This study was carried out to develop an indigenous automated irrigation system for irrigation scheduling on real time basis. This system helped to estimate crop water requirement and pumping time under different methods of irrigation, and controlled water application as per crop needs. The significant findings of this study would serve as a guideline for water requirement and irrigation scheduling decisions of broccoli crop for obtaining higher irrigation and crop water productivity.

SUMMARY

The present study was attempted to develop an automated irrigation system for real-time irrigation management using soil moisture sensor, decision support system, level sensor, level controller, GSM receiver, transmitter, solenoid valve, water meter and pump. The performance of developed automated irrigation system was evaluated under different methods of irrigation in broccoli crop. The field experiment in Broccoli crop was conducted (2013-14 and 2014-15) in split plot design with three irrigation methods, i.e. check-basin, furrow and drip irrigation as main plot treatments, and irrigation control methods, i.e. automated and manually-controlled as sub-plot treatments. Water saving, water productivity and cost economics of developed system were calculated and compared under different studied irrigation methods. It was found in the present study that the sensor based automated drip irrigation system resulted in highest irrigation water productivity (9.7 kg/m^3) and crop water productivity (10.6 kg/m^3) as compared to all other treatments. Similarly, the highest benefit-cost ratio (3.24) and water saving was obtained under the sensor based automated drip irrigation system. Therefore, the developed indigenous sensor based automated drip irrigation system can be used for efficient irrigation management in the broccoli crop.

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