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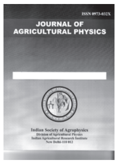

Research Article

Performance of Sensor-based Automatic Basin Irrigation System in Wheat Crop under Semi-arid Conditions

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ABSTRACT

The field experiment was conducted at the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi to enhance irrigation application efficiency through a soil moisture-based automatic basin irrigation system in wheat crops. Two irrigation basin plots of size 60×14 m were laid out adjacent to each other. One plot was irrigated through a soil moisture-based automatic irrigation system and the other was kept as manual control and irrigated manually as per the conventional farmer practice. The effects of manual control and sensor-based irrigation on different irrigation performance indices and water use efficiency were tested and evaluated. The overall application efficiency increased from 69.2% in the case of manual control irrigation to 88.0% in the sensor-based automated irrigation system. The overall water saving was 24.3% (water applied reduced from 298.0 mm in manual control irrigation to 225.5 mm in the sensor-based automated irrigation plot). The study also revealed that the irrigation water use efficiency (WUE) and water productivity (WP) were higher under sensor-based automated irrigation compared to manually controlled or conventional irrigation systems as evidenced by respective values of 1.94 and 1.48 kg m^{-3} for WUE and 38.4 and 29.2 ^{1} m^{-3} for WP. The current study confirms that the sensor-based automated basin irrigation system may provide a valuable tool for conserving water planning and irrigation scheduling for wheat which is extendable to other similar crops.

Key words: Basin irrigation, Irrigation performance indicators, Sensor-based, Wheat

Introduction

Water is a limited natural resource that needs to be used very wisely. Due to the large population water resources are under stress conditions. Nearly 70% of freshwater is consumed in the agriculture sector followed by industry and municipality (FAO, 2021). Irrigation is the highest water-consuming component of agriculture. Water consumption in irrigation was 688 billion cubic meters in 2010 and going to nearly double by 2050 (Jaganmohan, 2021). Water resources should efficiently be utilized for sustainable food production. As the pressurised irrigation techniques are very water-efficient and irrigation application efficiency goes up to 90% but

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it is not popular among small and marginal farmers due to their high initial cost involvement (Levidow *et al*., 2014). Surface irrigation is still popular among farmers due to its simplicity and low operation cost. However, poor irrigation efficiency (40-50%) and high labour requirements are the major challenges in surface irrigation (Jain *et al*., 2019). Basin irrigation is a type of surface irrigation in which water is ponded by the surrounding bunds. To overcome these challenges, we need to adopt real-time-based smart irrigation techniques. Many researchers have found that irrigation efficiency can be improved significantly by adopting automation in irrigation systems (Dassanayake *et al.,* 2009; Masseroni *et al*., 2018; Pramanik *et al*., 2022). Automatic systems for surface and furrow irrigation are found to be effective in improving application efficiency on maize, soybean, lucerne, pasture and cotton in Australia and North America (Koech *et al*., 2014; Gillies and Smith, 2015; Uddin *et al*., 2015).

Automation based on soil moisture sensor irrigation scheduling in drip irrigation systems has significantly improved irrigation efficiency (Sidhu *et al*., 2021). Automation refers to developing a system with the help of sensors, timers, motors and other software and hardware component so that the system can perform different tasks without or with minimal human intervention. An automated irrigation system helped to save water by up to 90% compared to the traditional method (Gutiérrez *et al.,* 2013). Each irrigation event's performance can be different even in the same field. Many hydraulic factors affect irrigation performance i.e. surface roughness, moisture content, cut-off and flow rates. This variability leads to over-irrigation and low irrigation application efficiency. Therefore, soil moisture-based real-time moisture status in the crop root zone will help to check over-irrigation. Many commercial low-cost soil moisture sensors (Gypsum block, tensiometer, capacitance-based) are available in the market which is compatible with an automatic system (Millan *et al*., 2019; Hardie, 2020; Vera *et al*., 2021). In view of the challenges in surface irrigation, an experiment was conducted to enhance irrigation application efficiency through a soil moisture-based automatic basin irrigation system in wheat crops.

Material and Methods

Experimental site

A field experiment was carried out at the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi, India (28°37′55″ N latitude, 77°09′36″ E longitude and 230 m above mean sea level) during the growing season of *rabi* (from November to April) in 2020-21. The climate of the study area is semi-arid and sub-tropical (as per Koppen classification) with extremely hot summers and cold winters. June is the hottest month with 45°C mean daily maximum temperature, while January is the coldest month with 7°C mean daily minimum temperature. The average annual rainfall is about 703 mm of which 75-80% is received during monsoon periods of July to September. Pan evaporation varied between 1.0 to 8.6 mm day^{-1}. Variation of weather parameters during the experimental period recorded at the meteorological observatory adjacent to the experimental site is depicted in Fig. 1. The soil is yellowish to dark brown loam belongs to the major soil group of Indo-Gangetic alluvium, a hyperthermic family of Typic Haplustepts. The soil is slightly alkaline having pH (1:2.5 soil: water suspension) of 7.23 to 7.75 and electrical conductivity of 0.11 to 0.31 dSm^{-1} has soil depth of more than 1.20 m. The experimental site has field capacity of 35.8 % (v/v); permanent wilting point of 15.5% (v/v); and basic infiltration rate 6 mm h^{-1}. The basin irrigation layout (blocked end) was of the size of 60 × 14 m with a 0.0005 m/m slope.

Experiment details

Two irrigation basin plots of size 60×14 m with 0.0005 m/m slope were laid out adjacent to each other. One plot was irrigated through a soil moisture sensor-based automatic irrigation system (SBI) and another was kept as control and irrigated under manual control irrigation (MCI) as per the conventional farmer practice. Wheat (variety HD 3271) was sown in both plots on the second fortnight of November 2020 and harvested in the first fortnight of April 2021. Two capacitance-based soil moisture sensors were placed at 25% and 50% of field length at 37.5 cm (Sensor 1) and 15 cm (Sensor 2) soil depth,

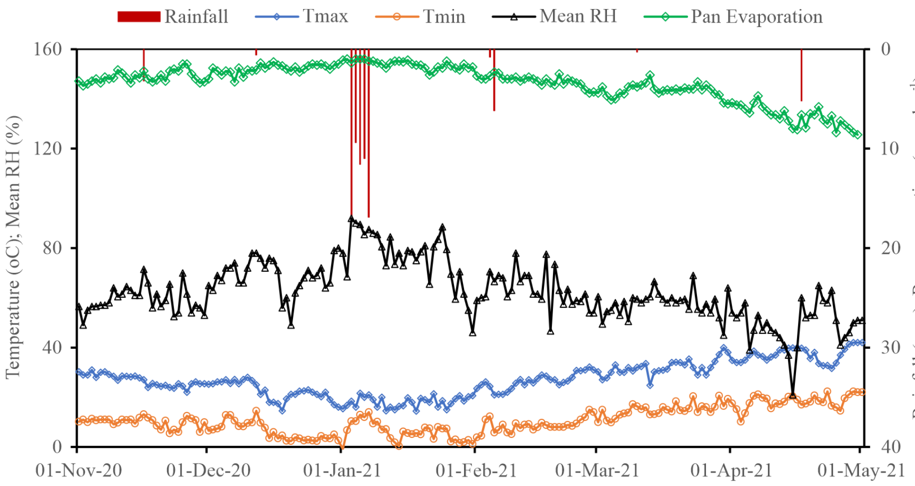

Fig. 1. Daily maximum, minimum temperature (°C), mean relative humidity (%), rainfall (mm) and daily pan evaporation (mm day^{-1}) during the *rabi* season 2020-21

respectively. The inlet of the field was equipped with a solar-powered automatic-check gate (Fig. 2) placed in a water supply channel to control the time and duration of flow. An ultrasonic flow meter Model Unidata 6526E) was placed at the inlet to measure the flow rate.

Automatic basin irrigation system

The automatic basin irrigation system consisted of a check gate, soil moisture sensor module, gateway and cloud server. The layout of the experimental plot and working of the wireless data transmission system

Fig. 2. Solar-operated automatic-check gate and soil moisture sensor installed in the field

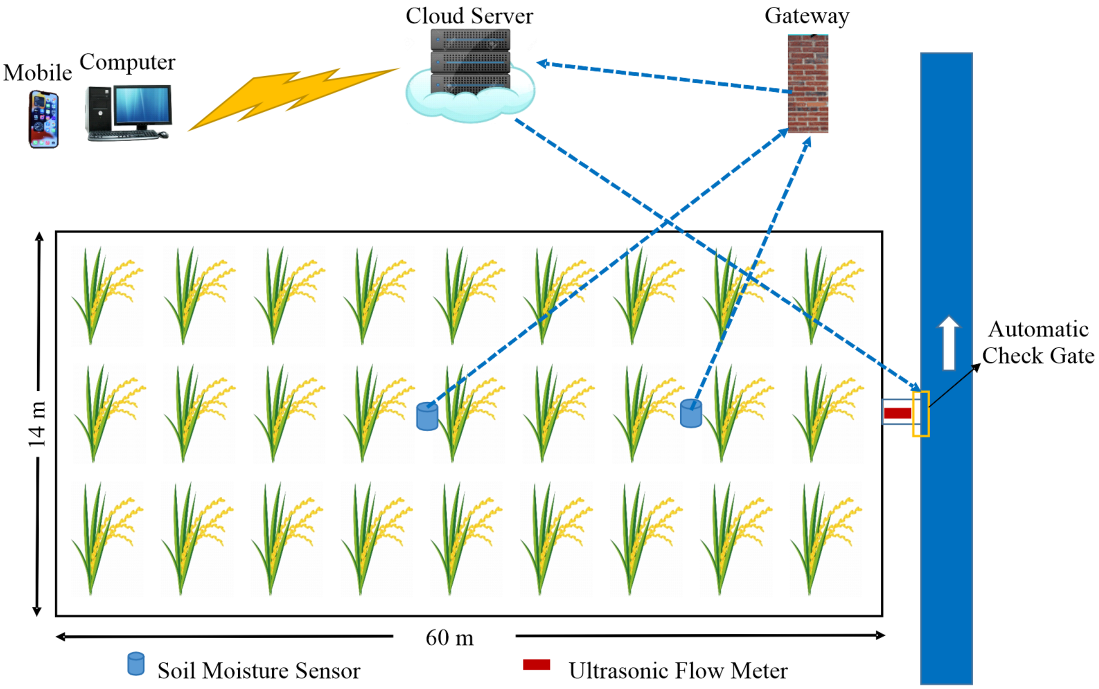

Fig. 3. Schematic diagram of the experimental field system

are schematically depicted in Fig. 3. Check gate was made up of an aluminium sheet (7.4 mm thickness) attached with a shaft which was operated by a 12-volt DC motor fixed on an iron frame. The gate was designed to open up to 30 cm from the ground. It was installed at the lined water channel to release water for a fixed time to the field. A solar-powered control unit with a 7 mAh battery was installed on top of the gate for operation. The control unit consists of a motor driver, GSM module, Arduino nano, ultrasonic sensor module and voltage converter. An ultrasonic sensor measured the closing and opening height of the gate. There was an optional switch in the control box to operate the gate manually. Gateway provides a passage to data coming from soil moisture sensors and sends it to the cloud server through the GSM module. The gateway was 100 m apart from the soil moisture sensors. Solar-powered capacitance-based soil moisture sensors were installed in the field to provide real-time soil moisture status. The soil moisture sensor module is comprised of a PVC pipe, a solar-powered circuit box and a capacitance-based soil moisture sensor. The circuit box contained a LoRa module, solar charger, microcontroller and Li-Ion battery. The cloud server functions as a virtual host which sends data to the control unit of the gate at a desirable time interval to open and close of gate according to predefined soil moisture values. Wireless communication was established between the soil moisture sensor and the check gate through the GSM module. Fig. 4 shows the operation of a soil moisture sensor-based automatic check-gate in the basin irrigation system.

Irrigation management

Irrigation events were managed by web or mobile-based Croplytics app developed by Agsmartic®. It consisted of irrigation configuration, soil moisture log and global positioning interface. The soil moisture data was stored at every 3-minute interval to the cloud server through the gateway. The time interval can be set by the user as per their requirement. Irrigation configuration allowed users to enter a value of soil moisture at which irrigation should start and stop. GPS location of sensors helped to identify the location of sensors in a large field. In this study, the check gate opened automatically and irrigation started whenever the soil moisture reached 50% soil moisture depletion [17.1% (v/v)] in sensor no. 2 installed at 50% field length and 15 cm soil depth. Irrigation cut-off by closing the check gate

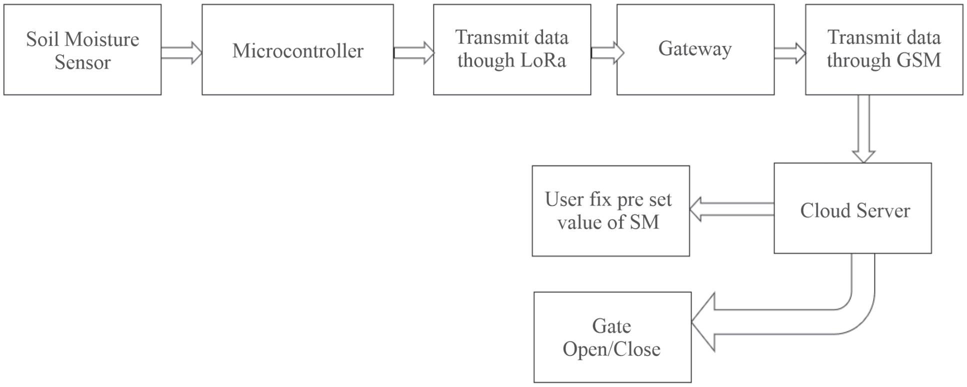

Fig. 4. Block diagram of automatic basin irrigation system

automatically as the soil moisture reached 90% of field capacity at soil moisture sensor no.1 placed at 37.5 cm depth and 25% field length. In control plots, irrigation was scheduled as the soil moisture depletion reached 50% depletion and cut-off when the whole field was well ponded with water. The GSM-enabled system helped to access and control the system from anywhere.

Measurement

To evaluate the irrigation performance under manual control and sensor-based irrigation plot treatment, the following indicators were calculated and compared.

Irrigation application efficiency (E_a; Bos, 1997) is the ratio of the quantity of water stored in the root zone of the crops to the quantity of water delivered into the field. Total water applied during each event was measured using an ultrasonic flow meter installed in the channel just after the gate. Irrigation application efficiency is given by Eq. 1

$$E_a = \frac{V_s}{V_a} \times 100$$ (Burt *et al*., 2000) …(1)

Where V_s is the amount of water stored in the root zone and V_a is the volume of applied irrigation. Three soil moisture sensors were placed at 7.5 cm, 22.5 cm and 37.5 cm soil depth representing three soil layers of 0-15 cm, 15-30 cm and 30-45 cm, respectively. V_s was calculated before each irrigation using the formula $V_s = \sum_{i=1}^{3} \theta_i \times \rho_i \times Z_i$ where θ_i is gravimetric water content before irrigation, ρ_i is the bulk density and Z_i is the depth of soil layer in cm for ith layer (Ranjan *et al*., 2017).

Distribution uniformity (DU) is a measure of how uniformly water is applied to the target area. The low quarter DU (DU_{lq}) is a measure of the average of the lowest quarter of samples, divided by the average of all samples. The higher the DU_{lq}, the better the coverage of the area measured. The soil samples were collected after each irrigation event from a 10 m × 4.5 m grid to determine the distribution uniformity. DU_{lq} was calculated using Eq. 2

$$DU_{lq} = \frac{Average\ \ of\ the\ lowest\ \ 1/4}{Average\ \ of\ all} \times 100$$ (Merrian and Keller, 1978) …(2)

Water requirement efficiency (WRE) is intended to measure the degree to which the field has been under-irrigated. The value of this parameter is always 100% when the entire field has been fully irrigated. WRE was calculated by Eq. 3.

$$WRE = \frac{Average\ \ depth\ of\ root\ zone\ storage}{Average\ \ depth\ of\ potential\ \ storage} \times 100$$ (Walker and Skogerboe, 1987) …(3)

Irrigation water use efficiency (WUE) and water productivity (WP) were calculated using Eqs. 4 and 5, respectively.

$$WUE = \frac{Y}{WU}$$ (Michael, 1978) …(4)

$$WP = \frac{Agricultural\ \ benefits}{Water\ \ use} = \frac{Y \times MSP}{WU}$$ (Cook *et al*., 2006) …(5)

Where Y is the grain yield (kg ha^{-1}), MSP is the minimum support price of the crop (₹ kg^{-1}).

The rainfall data were received from the meteorological observatory situated at the Research Farm, IARI, New Delhi. The effective rainfall was computed using the USDA approach:

$$P_e = \frac{P_t}{125(125-0.2P_t)} \text{ when } P_t < 250 \text{ mm} \qquad \ldots(6)$$

$$P_e = 125 + 0.1P_t \text{ when } P_t > 250 \text{ mm} \qquad \ldots(7)$$

Where, P_e= monthly effective rainfall (mm) and P_t = monthly total rainfall (mm).

The WU is the total water used for crop production (m^3 ha^{-1}) and it was computed as the sum of water applied through irrigation and estimated effective rainfall.

The results of all the parameters evaluated were measured and analysed using MS office excel. The mean values under the manual control irrigation and sensor-based irrigation system were compared within groups using the two-tailed paired t-test. A two-tailed p-value less than 0.05 was considered to be statistically significant.

Results and Discussion

Irrigation efficiency

A total of four irrigations were applied matching with the critical growth stages of wheat at crown root initiation (CRI), booting, flowering and milking stages after 18, 66, 92 and 110 days after sowing (DAS), respectively. During each irrigation event, the system automatically opens and closes the check gate according to the pre-set value. Solar power successfully operated the system during the crop growing season. Water applied, irrigation application efficiency, lower-quarter distribution uniformity and water requirement efficiency of various irrigation events at four critical growth stages of wheat are given in Table 1. The results of the study showed that water-saving varied from 17.3 to 30.3 % at different growth stages. The overall water saving was 24.3% (water applied reduced from 298.0 mm in MCI to 225.5 mm in the SBI plot). Our result was corroborated by the findings of several researchers worldwide (Dassanayake *et al.,* 2009; Ganjeer, 2019) who reported that automation in irrigation projects using an intelligent irrigation controller and wireless sensor network could save water up to 38% over conventional irrigation control methodologies. The irrigation application efficiency under the automated SBI plot was higher (ranging between 85.7-90.1%) than the MCI system (varied between 67.1-72.4%) at all four growth stages of wheat. The overall application efficiency increased from 69.2% in the case of manual control irrigation to 88% in the automated irrigation system. The increase in application efficiency might be because of the reduction in deep percolation by keeping the soil moisture within the head reach (Sacks *et al*., 2009). Different case studies in which these systems are adopted for wheat, barley, canola and maize crops also demonstrated that the application of automatic systems leads to a reduction of the time spent by the farmer for irrigation (Koech *et al*., 2014) and to an increase in water application efficiency (Smith *et al*., 2016). The low-quarter distribution uniformities were very good in both MCI and SBI systems. However, this performance indicator was slightly better under the MCI system at the initial (i.e., CRI) and later (i.e. milking) growth stages. The water applied reduced from 64.3 mm under MCI to 50.6 mm under SBI at the booting stage but, the distribution uniformity remained the same. This indicates the applied water was uniformly distributed in the whole plot under SBI even under lower irrigation. Similar trends were also observed under other growth stages. The lower water applied under the SBI system reflected lower WRE at different growth stages except for CRI. Ascough and Kiker (2002) reported that different sprinkler systems exhibited high uniformity and generally had high application efficiencies with some exceptions. In addition to irrigation applied to the wheat, the crop received 82.0 mm of rainfall in eleven rainfall events during the growing season. The total volume of water applied to the crop under SBI and MCI systems were 2970 and 3690 m^3 ha^{-1} respectively. These results indicate that the total volume of water used under sensor-based automated irrigation systems was 19.5% less compared to conventional irrigation.

Grain yield, water use efficiency and water productivity of wheat

The effect of automated and conventional irrigation systems on wheat grain yield, water use efficiency and water productivity has been presented

Table 1. Water applied and irrigation performance indicators under manual control irrigation and sensor-based automatic irrigation treatments at different critical growth stages of wheat

Days after sowing (DAS)	Growth stage	Water applied (mm)		Irrigation application efficiency (%)		Distribution uniformity (DU_{lq})		Water requirement efficiency (%)	
		MCI	SBI	MCI	SBI	MCI	SBI	MCI	SBI
18	Crown root initiation	105.0	73.3	67.1	85.7	0.92	0.89	100	100
66	Booting	64.3	50.6	71.3	89.2	0.90	0.90	100	95.2
92	Flowering	66.2	50.0	70.0	90.1	0.88	0.89	97.5	96.4
110	Milking	62.5	51.7	72.4	87.3	0.92	0.88	98.2	92.8
	Overall	298.0	225.5	69.2	88.0				

Manual control irrigation (MCI); Sensor-based irrigation (SBI)

Table 2. Yield, water productivity and water use efficiency of wheat under automated irrigation system and conventional system

Irrigation treatment	Yield (q ha^{-1})	Water use efficiency (kg m^{-3})	Water productivity* (₹ m^{-3})
Manual control irrigation (MCI)	54.5	1.48	29.2
Sensor-based irrigation (SBI)	57.7	1.94	38.4
p-value#	0.023	0.018	0.018

*For calculation of water productivity, the rate of wheat is taken as ₹ 1975 per quintal, the minimum support price of wheat (2021) by GoI, India

#p-value was calculated using paired t-tests

in Table 2. The results revealed that the WUE and WP were higher under automated irrigation (SBI) compared to conventional irrigation (MCI) i.e. 1.94 and 1.48 kg m^{-3} for WUE and 38.4 and 29.2 ₹ m^{-3} for WP of SBI and MCI, respectively. The wheat crop yield also increased by 3.2 qha^{-1} under the SBI system over the MCI system. These results indicated that the water was more effectively used under the SBI system than the MCI system. Our results are in agreement with those reported by Al-Ghobari *et al.* (2013), who found that water use efficiency under intelligent irrigation systems was higher (1.37 kg m^{-3}) compared to that under irrigation control system (1.21 kg m^{-3}) of wheat in arid regions of Saudi Arabia. Similarly, Koech *et al.* (2014) and Uddin *et al.* (2018) tested a real-time optimisation system for furrow irrigation in a cotton field in Australia and demonstrated potential for an improvement in WUE and a reduction in labour and energy requirement.

Cost of the System

The approximate cost of an automated irrigation system was ₹ 12720. The cost of an automated irrigation system comprising four modules, a check gate with the controller, solar charging module, gateway and soil moisture sensor are presented in Table 3.

Table 3. Cost of different components of automated irrigation system

S. No.	Component	Cost (₹)
1.	Check gate with controller	5270
2.	Solar charging module	1800
3.	Gateway	3090
4.	Soil moisture sensor	2560
	Total cost (₹)	12720

Conclusions

The results showed that implementing a sensor-based automatic irrigation system proved to be an easy flexible practical tool to schedule irrigation for higher irrigation efficiency. The result indicated that 24.3% of irrigation water was saved under SBI compared to the conventional MCI system. The SBI system resulted in a greater yield than MCI. Also, the results indicated that the values of WUE and WP were higher under SBI than the MCI system. This technology may provide a valuable tool for conserving water planning and irrigation scheduling for wheat, which is extendable to other similar crops. Furthermore, the irrigated area could also be increased to some extent with the saved water when shifting from manual control to a sensor-based irrigation system.

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References

Al-Ghobari, H.M., Mohammad, F.S. and El Marazky, M.S.A. 2013. Effect of intelligent irrigation on water use efficiency of wheat crop in arid region. *The Journal of Animal and Plant Sciences* **23**: 1691-1699.

Ascough, G.W. and Kiker, G.A. 2002. The effect of irrigation uniformity on irrigation water requirements. *Water SA* **28**: 235-241.

Bos, M.G. 1997. Performance indicators for irrigation and drainage. *Irrigation and Drainage Systems* **11**: 119-137.

Burt, C.M., Clemmens, A.J., Solomon, K.H., Bliesner, R.D., Hardy, L.A. and Howell, T.A. 2000. Irrigation performance measures: efficiency and uniformity. *Irrigation and Drainage* **123**: 423-442.

Cook, S., Gichuki, F. and Turral, H. 2006. Water productivity: Estimation at plot, farm, and basin scale. Basin Focal Project Working Paper No. 2. Challenge Program on Water and Food, Colombo.

Dassanayake, D., Dassanayake, K., Malano, H., Dunn, M., Douglas, P. and Langford L. 2010. Water saving through smarter irrigation in Australian dairy farming: use of intelligent irrigation controller and wireless sensor network. 18th World IMaCS/MODSIM congress, Cairns, Australia, 13-17 July 2010.

FAO. 2021. AQUASTAT - FAO's Global Information System on Water and Agriculture http://www.fao.org/aquastat/en/overview/methodology/water-use (2021) (Accessed on July 11, 2021).

Ganjeer, P. 2019. Performance evaluation of developed soil moisture based automated drip irrigation system for cabbage, *Ph.D Thesis*, Indira Gandhi Krishi Vishwavidyalaya, Raipur.

Gillies, M.H. and Smith, R.J. 2015. SISCO: Surface irrigation calibration and optimisation. *Irrigation Science* **33**: 339-355.

Gutiérrez, J., Villa-Medina, J.F., Nieto-Garibay, A. and Porta-Gándara M.A. 2013. Automated irrigation system using a wireless sensor network and GPRS module. *IEEE Transactions on Instrumentation and Measurement* **63**: 166-176.

Hardie, M. 2020. Review of novel and emerging proximal soil moisture sensors for use in agriculture. *Sensors* **20**: 6934.

Jaganmohan, M. 2021. Water demand in India in 2010-2050 by sector. https://www.statista.com/statistics/1111839/india-water-demand-by-sector/ (Accessed on July 11, 2021) (2021).

Jain, R., Kishore, P. and Singh, D.K. 2019. Irrigation in India: Status, challenges and options. *Journal of Soil and Water Conservation* **18**: 354-363.

Koech, R., Smith, R. and Gillies, M. 2014. A real-time optimisation system for automation of furrow irrigation. *Irrigation Science* **32**: 319-327.

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M. and Scardigno, A. 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Agricultural Water Management* **146**: 84-94.

Masseroni, D., Moller, P., Tyrell, R., Romani, M., Lasagna, A., Sali, G., Facchi, A. and Gandolfi, C.

2018. Evaluating performances of the first automatic system for paddy irrigation in Europe. *Agricultural Water Management* **201**: 58-69.

Merrian, J.L. and Keller, J. 1978. Farm irrigation system evaluation, 3rd Ed., Agricultural and Irrigation Engineering Department, Utah State University, Logan, Utah, USA.

Michael, A. 1978. Irrigation and theory practice. Vikas Pub. House Pvt. Ltd., New Delhi, India.

Millán, S., Casadesús, J., Campillo, C., Moñino, M.J. and Prieto, M.H. 2019. Using soil moisture sensors for automated irrigation scheduling in a plum crop. *Water* **11**: 2061.

Pramanik, M., Khanna M., Singh M, Singh D.K., Sudhishri S, Bhatia A. and Ranjan R. 2022. Automation of soil moisture sensor-based basin irrigation system. *Smart Agricultural Technology* **2**: 1-10 100032 https://doi.org/10.1016/j.atech.2021.100032

Ranjan, R., Sahoo, R.N., Chopra, U.K., Pramanik, M., Singh, A.K. and Pradhan, S. 2017. Assessment of water status in wheat (*Triticum aestivum* L.) using ground based hyperspectral reflectance. *Proceedings of the National Academy of Sciences, India, Section B: Biological Sciences* **87**: 377–388.

Sacks, W.J., Cook, B.I. and Buenning, N. 2009. Effects of global irrigation on the near-surface climate. *Climate Dynamics* **33**: 159-175.

Sidhu, R.K., Kumar, R., Rana, P.S. and Jat, M.L. 2021. Automation in drip irrigation for enhancing water use efficiency in cereal systems of South Asia: Status and prospects, Ed: Donald L. Sparks, *Advances in Agronomy*, Academic Press, **167**: 247-300.

Smith, R.J., Uddin, J.M., Gillies, M.H., Moller, P. and Clurey, K. 2016. Evaluating the performance of automated bay irrigation. *Irrigation Science* **34**: 175-185.

Uddin, J., Smith, R.J., Gillies, M.H., Moller, P. and Robson, D. 2018. Smart automated furrow irrigation of cotton. *Journal of Irrigation and Drainage Engineering* **144**: 04018005-1.

Vera, J., Conejero, W., Mira-García, A.B., Conesa, M.R. and Ruiz-Sánchez, M.C. 2021. Towards irrigation automation based on dielectric soil sensors. *Journal of Horticultural Science and Biotechnology* **96(6)**: 696-707.

Walker, W.R. and Skogerboe, G.V. 1987. Surface Irrigation: Theory and practice. Prentice-Hall Inc. Englewood Cliffs, NJ, USA.

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