Indian Journal of Agricultural Sciences **87** (5): 648–52, May 2017/Article

Development of decision support system based on crop water demand and soil moisture deficit for real time irrigation scheduling

JITENDRA KUMAR[1], NEELAM PATEL[2] and THAKUR BAHADUR SINGH RAJPUT[3]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received: 21 July 2016; Accepted: 25 October 2016

ABSTRACT

An automated irrigation system has a potential solution to control the site specific irrigation, is of benefits to producers can save water and improving water productivity. The study was conducted to develop a decision support system (DSS) and integrated with soil moisture sensor based on tensiometric principle, for real time irrigation scheduling either on time basis or soil moisture sensor basis. The designed system was successfully tested on potato crop under different methods of irrigation at Precision Farming Development Centre (PFDC), IARI, New Delhi, India. The reference evapotranspiration, water requirement of potato crop estimated from DSS was verified and tested with CROPWAT model, and approximately similar results were obtained. The crop evapotranspiration of potato crop was estimated 25.3 cm using DSS. The coefficient of determination (R^2) range was found 0.93-0.94, 0.82-0.91 between water level depletion in modified tensiometer and soil water suction measured by tensiometer, watermark at 20 cm, 30 cm soil depth respectively. The performance evaluation of developed system helped to control water application as per crop needs with its various functionality were found satisfactorily.

Key words: Decision support system, Irrigation scheduling, Soil moisture sensor, Tensiometer

India's food grain production was 252.02 million tonnes in 2014-15, and over 55% population depends directly on agriculture and it accounts for around 17.40% of Gross Domestic Product (GDP). Population of India has drastically increased from 361 million in 1951 to 1.3 billion in 2015 (GOI 2016). The country's per capita availability of water has decreased from 5177 cubic meter per annum in 1951 to 1554 cubic meters per annum in 2011 leading to a drastic reduction of 70 % in 60 years. The average irrigation efficiency of India is only 38% as water resources are very limited but demand of agricultural products' increase. In that situation, a farmer's goal is to always maximize farm profit with efficient use of input. However, There is a great need to modernize agricultural practices for better water productivity and resource conservation. Higher irrigation efficiency in the range of 75 to 95% can be achieved by adoption of precise application of water through sprinkler and drip irrigation, respectively (CWC 2011). A farm irrigation problem faced by farmer's, is to decide when to irrigate and how much to irrigate under different irrigation methods for different crop. This leads to need for development of a decision support system (DSS) based on information about weather, soil, crop, water quality and type of irrigation system. DSS improve decision process quality with faster and better data access and the evaluation of a large number of alternatives which help to increase on–farm productivity, efficiency, and water saving (Khadra and Lamaddalena 2010). Design and development of a decision support system to measure performance evaluation of micro irrigation system (Pedras *et al.* 2009). User friendly software namely as DRIPD was developed which could be used for the determination of different design parameters of a drip irrigation system for orchards and narrowly placed field crops. Based on drip capacity, total head loss, main sub-main, lateral pipe size and cost estimation of designed drip irrigation system were done (Rajput and Patel 2003). A decision support system was made for estimation of reference evapotranspiration using 22 different methods. This system computed ET_o and ET_c by FAO Penman Monteith Method and dual crop coefficients, respectively which help to develop irrigation schedules for sixty-six types of crop using soil and water balance approach. (Bandyopadhyay *et al.* 2012).

DSS based automatic irrigation system presently available in India are very limited and not adopted by most of the farmers. Most of these systems are imported and hence are not designed as per the need of marginal and small size farm applications. And some of this operation requires high technical skills. Therefore, The main objectives of develop DSS for automated irrigation to improving agricultural water productivity through continuous monitoring of soil moisture content and weather parameters.

[1]Ph D Research Scholar (e mail: jkagric@yahoo.com), Division of Agricultural Engineering, [2]Principal Scientist (e mail: np_wtc@yahoo.com), [3] Emeritus Scientist (e mail: tbsraj@yahoo.com), Water Technology Centre.

MATERIALS AND METHODS

The field experiment was conducted with potato crop at Precision Farming Development Centre, Water Technology Centre, IARI, New Delhi, India. The experimental site is located at 28°38'22" N, 77°10'24" E with an altitude of 228.61 m above mean sea level. Soil of the research farm represent a typical alluvial profile of Yamuna origin. As per USDA textural classification, major portion of the area belongs to sandy loam class. Average field capacity and permanent wilting point of soil were 27.8%, 10.2% respectively. Porosity in general is approximately 40% and its average hydraulic conductivity was 1.15 cm/h.

The climate of New Delhi, India is semi-arid and subtropical with hot and dry summers and cold winters and falls under the agro-climatic zone of "Trans-Gangetic Plains". May and June are hottest with maximum temperature ranging between 41°C and 46°C while temperature falls to its lowest during January with minimum temperature ranging between 4°C and 7°C. The mean open pan evaporation reaches as high as 12.88 mm and as low as 0.6 mm per day during the months of June and January, respectively. The required weather data (min. and max. temperature, rainfall, sunshine hours, wind speed, dew point etc.) for estimation of reference evapotranspiration was acquired in decision support system on real time basis from the weather station, installed at Precision Farming Development Centre (PFDC), Water Technology Center (WTC), IARI, New Delhi. Similar research works related to weather data used for irrigation management on real time basis were done by (Bandyopadhyay *et al.,* 2012).

Reference evapotranspiration (ET_o) expresses the evaporative index of the atmosphere at a specific location. It is independent of crop type, stage of development and management practices. The reference evapotranspiration had been calculated using FAQ Penman Montieth equation (Allen *et al.*1998) in the following form:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where, ET_o = Reference evapotranspiration [mm/day], R_n= Net radiation at crop surface [MJ/m^2/day], T= Mean daily air temperature at 2 m height [°C], Δ= Slope of vapour pressure curve [kPa/°C], u_2 = Wind speed at 2 m height [m s^{-1}], G= Soil heat flux density [MJ m^{-2} day $^{-1}$], γ = Psychrometric constant [kPa °C^{-1}], e_s - e_a= Saturation vapour pressure deficit [kPa].

Crop evapotranspiration (ET_c) is calculated by multiplying the reference crop evapotranspiration (ET_o) by crop coefficient (K_c). Kc varies with crop, climate, soil evaporation and crop growth stage (Allen *et al.* 1998).

Crop evapotranspiration (ET_c) is calculated as,

$$ET_c = K_c * ET_o$$

where, ET_c = Crop evapotranspiration [mm/day], K_c = Crop coefficient [dimensionless], ET_o = Reference crop evapotranspiration [mm/day].

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 of the crop root zone reached at critical point. In this research work, irrigation water were applied in potato crop at 30% MAD value based on physiological characteristics and its stage of growth (Michael 2008). Further, the measured quantity of irrigation was applied for a depth from the existing moisture level up to the field capacity. The quantity of irrigation water for each treatment was calculated based on the soil moisture content before irrigation and root zone depth of the plant using the Equation:

$$SMD = (\Theta_{FC} - \Theta_I) \times D \times Bd \times MAD$$

where, SMD: Soil moisture deficit (mm), Θ_{FC} : Soil moisture content at field capacity (%), Θ_I: Soil water content before irrigation (%), D: Depth of root development (mm), Bd: Bulk density of the particular soil layer (g cm^{-3}), MAD: Management allowable Depletion (%).

Producing optimal yield requires that the soil water content be maintained between an upper limit at which leaching becomes excessive and a lower point at which crops are stressed (Keller and Bliesner 1990). As water is removed from the soil through ET, there is a point below which the plant experiences increasing water stress. This point is known as the management allowable depletion (MAD). The typical MAD values considered as 33% for shallow-rooted, high value crops; 50% for medium-rooted, moderate value crops and 67% for deep-rooted, low value crops (Cuenca 1989). Selection of MAD value for different crop with respect to soil type, initially field capacity (FC), permanent wilting point (PWP), threshold soil moisture content (TSMC) must be determined. Threshold soil moisture content ascertains to what fraction of soil is allowed to dry before the next irrigation event. Threshold soil moisture content determined in this research work as:

$\Theta_{TSMC} = \Theta_{FC} - MAD(\Theta_{FC} - \Theta_{PWP})$ Where, all Θ values are dimensionless (L^3/L^3)

RESULTS AND DISCUSSION

Webpage of Decision Support System

The automated irrigation system consists of soil moisture sensor based on modified tensiometer, decision support system, GSM receiver, transmitter, water meter, solenoid valve and pump. The developed Decision support system (DSS) has potential to irrigate ten different plots with crops at Precision farming development centre field, WTC, IARI, New Delhi, India. Each plot has a modified tensiometer interfaced with, irrigation pump solenoid valve and receiver. The DSS was developed under ASP.NET programming language and different database, i.e. soil, weather, crop, and irrigation information were developed in Microsoft SQL server 2008. It is an easy and effective tool to develop web based applications for real time irrigation scheduling of agricultural crops. To start with, open Internet explorer and enter URL http://localhost/<project file name>/

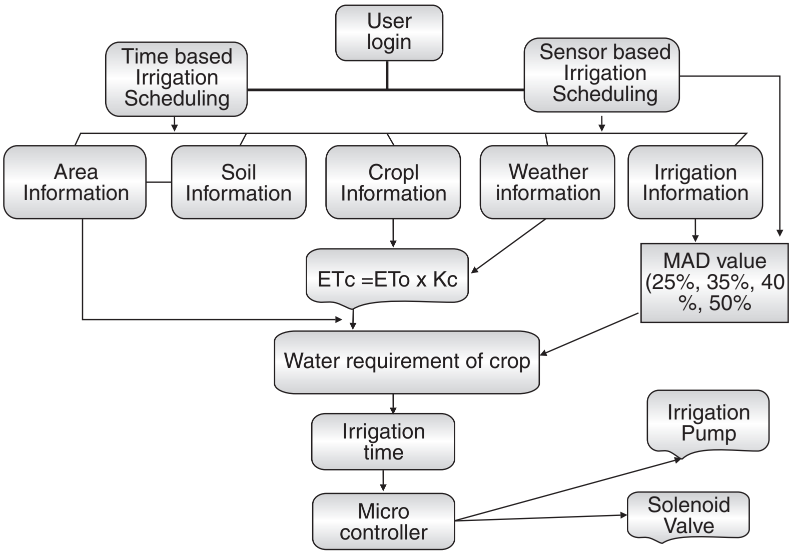


Fig 1 The algorithm flowchart of decision support system for automated irrigation

OFF command sent to controller via DSS to actuation-deactuation of irrigation pump. That programme would enable to develop future irrigation schedule for a specific crop.

In sensor based irrigation scheduling, same procedure were used as time based irrigation scheduling for calculation of irrigation requirement and pumping time. User fed input parameter as sensor code of installed soil moisture sensor at which plot irrigation to be done. User selects water application to crop at different management allowable depletion (30%, 35%, 50%) of total available water of soil. On that basis user set upper and lower limits of water level depletion in modified tensiometer which helps to control irrigation to specific plots. Irrigation programming schedule switch ON/OFF mode of irrigation when water level depletion is less than predefined lower limit, and more than the set upper limit or field capacity.

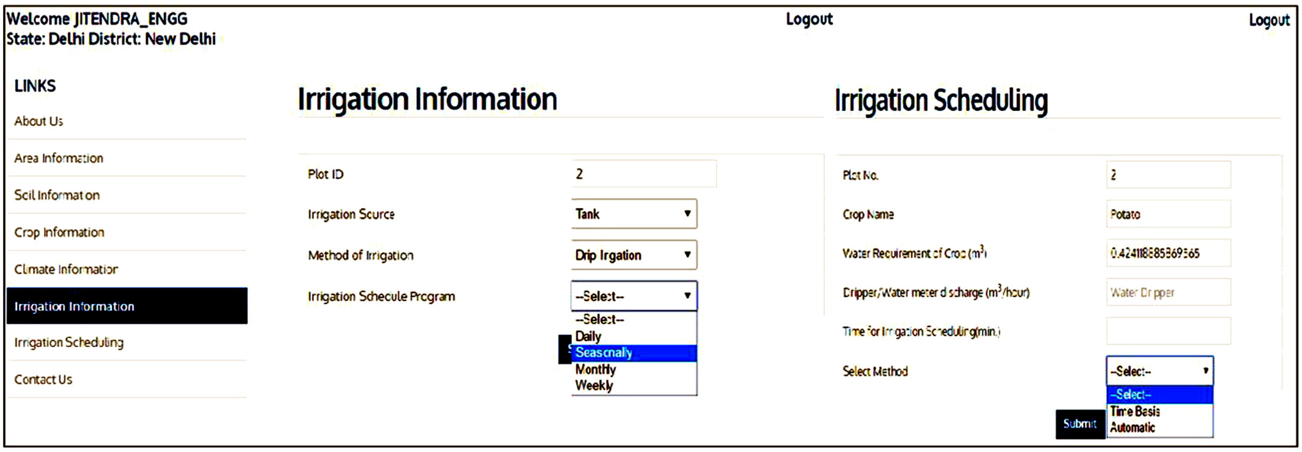
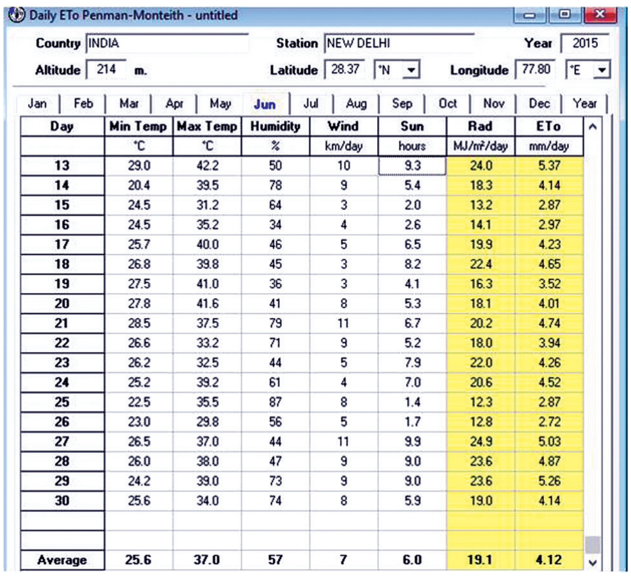


Fig 2 Irrigation information and irrigation scheduling webpage

Home.aspx. As the system executes, user fill registration form, feed input details and generates user id and password. As a result, welcome webpage would be on display on screen. On the graphical user interface webpage, user has an option to select sensor/time based irrigation scheduling. The flowchart of developed Decision support system and its working for automated irrigation is shown in Fig 1. User fed details of inputs required, i.e. net cropped area, soil type, crop type and stage, soil moisture deficit and sensor coded number of specific plot under different methods of irrigation.

In time based irrigation scheduling, user first selects own district, state, and feed input parameters, i.e. area dimension, crop soil type and irrigation information and on that basis output results as crop water requirement and pumping time is calculated (Fig 2). While execution time based irrigation schedule set checks the system, date and time, matches it with programming schedule of irrigation starting, stopping date and time. If result obtained were found in YES mode, alarm clock ON mode would be displayed on webpage. Therefore, as per instruction set in form of ON/


Daily ETo Penman-Monteith - untitled

Country INDIA Station NEW DELHI Year 2015
Altitude 214 m. Latitude 28.37 °N Longitude 77.80 °E

Jan | Feb | Mar | Apr | May | **Jun** | Jul | Aug | Sep | Oct | Nov | Dec | Year

Day	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
13	29.0	42.2	50	10	9.3	24.0	5.37
14	20.4	39.5	78	9	5.4	18.3	4.14
15	24.5	31.2	64	3	2.0	13.2	2.87
16	24.5	35.2	34	4	2.6	14.1	2.97
17	25.7	40.0	46	5	6.5	19.9	4.23
18	26.8	39.8	45	3	8.2	22.4	4.65
19	27.5	41.0	36	3	4.1	16.3	3.52
20	27.8	41.6	41	8	5.3	18.1	4.01
21	28.5	37.5	79	11	6.7	20.2	4.74
22	26.6	33.2	71	9	5.2	18.0	3.94
23	26.2	32.5	44	5	7.9	22.0	4.26
24	25.2	39.2	61	4	7.0	20.6	4.52
25	22.5	35.5	87	8	1.4	12.3	2.87
26	23.0	29.8	56	5	1.7	12.8	2.72
27	26.5	37.0	44	11	9.9	24.9	5.03
28	26.0	38.0	47	9	9.0	23.6	4.87
29	24.2	39.0	73	9	9.0	23.6	5.26
30	25.6	34.0	74	8	5.9	19.0	4.14
Average	**25.6**	**37.0**	**57**	**7**	**6.0**	**19.1**	**4.12**

Fig 3 Estimation of reference evapotranspiration on daily basis using CROPWAT model

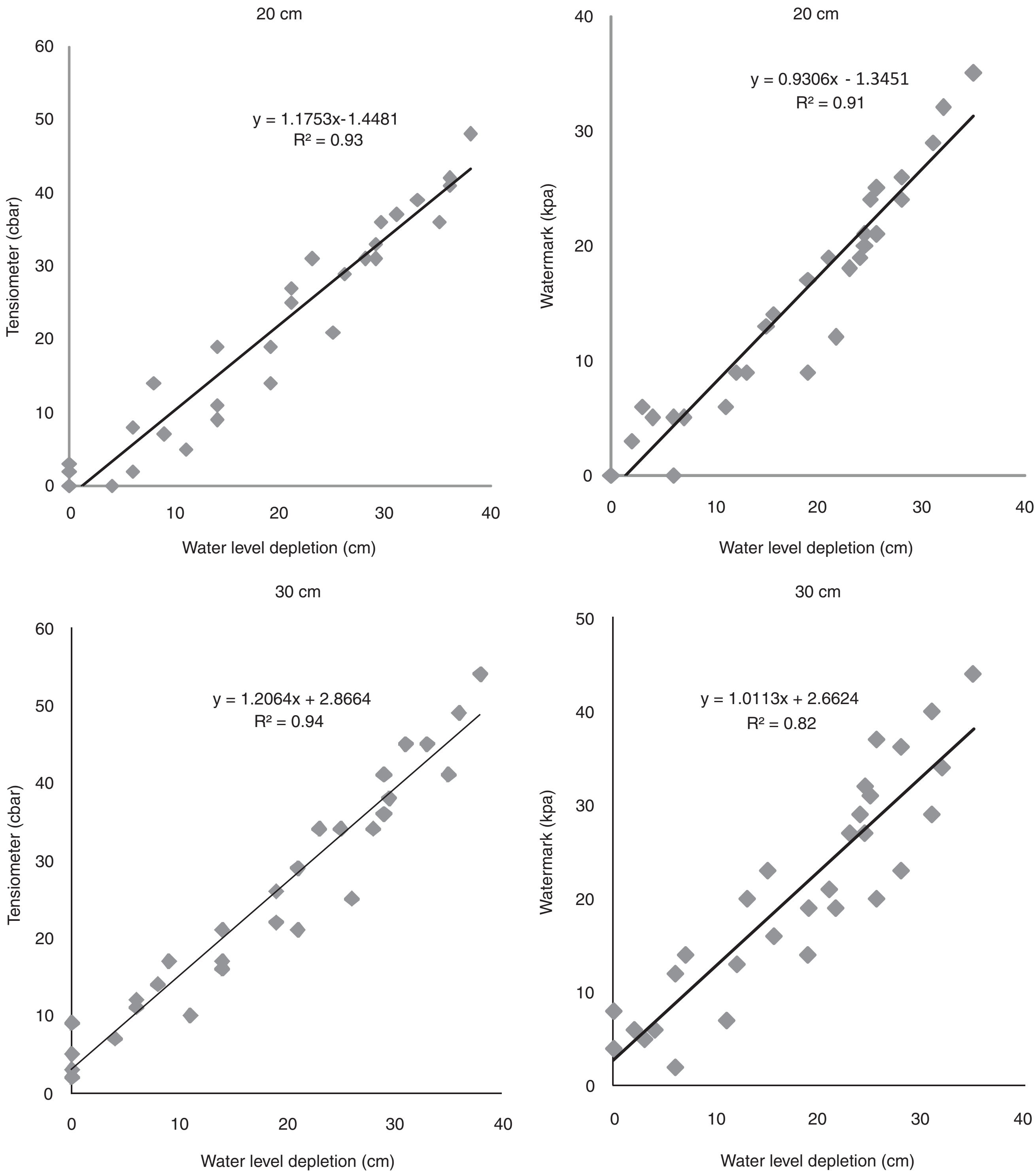


Fig 4 Relationship between water level depletion and soil water suction in potato crop under different methods of irrigation at 20 cm, and 30 cm soil depth

Verification and testing of Decision support system with CROPWAT model

CROPWAT model is extensively tested, widely accepted and also recommended by FAO, for estimation of Irrigation requirement and irrigation scheduling of different crop. The meteorological data was taken from Agromet Observatory, Division of Agricultural Physics, IARI, New Delhi. CROPWAT ver. 8.0 model used weather data and employs the modified penman-monteith approach used to estimate reference evapotranspiration on a daily basis. The general soil properties of the experimental field were used in CROPWAT model. Based on the details of soil characteristics, total available water was taken 135 mm/m depth of soil. Infiltration rate was measured using double ring infiltrometer and the basic rate was 10 mm/hr. Initial soil moisture was assumed to be at 50 percent of total available water. The irrigation requirement of potato crop and reference evapotranspiration data obtained from developed DSS was verified, tested with CROPWAT model. The reference evapotranspiration value estimated on daily basis were obtained 4.59, 4.52 mm using DSS and CROPWAT model (Fig 3). The total quantity of irrigation water needs to fulfilled crop evapotranspiration of potato crop was estimated 25.3 cm. Although, the performance of DSS was found satisfactorily and similar result obtained, when compared with other model.

Performance evaluation and integration of DSS with modified tensiometer

The modified tensiometer used to measuring the soil water content instead of matric potential using simple calibrated curve for all soil types, and interfaced with DSS (Decision support system) through Internet and GSM (Global system for mobile communication) module. The performance of modified tensiometer was calibrated with tensiometer and watermark sensor under different methods of irrigation, viz. check basin, furrow and drip irrigation. A decision support system for improving water productivity in surface methods of irrigation, i.e. furrow, basin and border irrigation (Jose *et al*. 2009). A field plot of 21 m × 21 m was used for conducting the field experiments on potato crop to test the designed system. A total of six each modified tensiometer, tensiometer, watermark sensor were installed up to a depth of 20 cm, 30 cm in the field to measure the soil moisture content.

The coefficient of determination (R^2) range was found 0.93-0.94, 0.91-0.82 between water level depletion in modified tensiometer and soil water suction measured by tensiometer, watermark at 20 cm, 30 cm soil depth respectively (Fig 4). The water level depletion range was found 30-37 cm, 18-22 cm at 50%, and 30% MAD value in potato crop under different methods of irrigation at 20 cm, 30 cm soil depth respectively. This water level depletion depth taken as reference threshold point for switch ON the irrigation system in potato crop. Soil water suction range was found approx 30-35 centibar, 40-45 kPa at 30 cm depth less than compared to 40-50 centibar, 45-52 kPa at 20 cm depth, measured by tensiometer and watermark respectively (Fig 4). It might be due to dominant role of gravity force, moisture content at 30 cm depth was slightly more than 20 cm depth, therefore suction range less at the same depth. Initially moisture content in check basin was more followed by furrow and drip irrigation because water application in check basin method was more compared to furrow and drip irrigation.

ACKNOWLEDGEMENTS

First author wishes to acknowledge the support and guidance given by faculty of Division of Agricultural Engineering, and Post Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, India for providing the fellowship and facilities for undertaking this research under the Ph D programme.

REFERENCES

Allen R G, Pereira L S, Raes D and Smith M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements. FAO irrigation and drainage paper no. 56, Rome, Italy.

Bandyopadhyay A, Bhadra A, Swarnakar R K, Raghuwanshi N S and Singh R. 2012. Estimation of reference evapotranspiration using a user-friendly decision support system: DSS_ET. *Agricultural and Forest Meteorology* **155**: 19–29.

Central Water Commission (CWC). 2011. Water Resources at a Glance, New Delhi. (Available at: http://www.cwc.nic.in).

Cuenca R H. 1989. *Irrigation System Design-An Engineering Approach,* p 552 Prentice-Hall, Inc., Englewood, Cliffs, NJ, USA.

GOI. 2016. *A Reference Annual*. Ministry of Information and Broadcasting, Government of India. Publications Division, New Delhi, pp 83–107.

Jose J, Goncalves M and Pereria L S. 2009. Web based decision support system for developed surface irrigation design. *Journal of Irrigation and Drainage Engineering* **135**: 343-53.

Keller J and Blienser R D. 1990. *Sprinkler and Trickle Irrigation*, pp 19-95. Van Nostrand Reinhold, New York.

Khadra R and Lamaddalena N. 2010. Development of a decision support system for irrigation system analysis. *Water Resource Management* **24**(12): 3 279–97.

Kim Y and Evans R G. 2009. Software design for wireless sensor-based site-specific irrigation. *Computers and Electronics in Agriculture* **66**: 159–65.

Michael A M. 2008. *Irrigation Theory and Practices*, pp 448-584. Kalyani Publishers Ludhiana.

Pedras C M G, Pereira L S and Goncalves J M. 2009. MIRRIG: A decision support system for design and evaluation of micro-irrigation systems. *Agricultural Water Management* **96**(4): 691–01.

Rajput T B S and Patel N. 2003. User's Guide for –DRIPD- A software for designing drip irrigation system. TB-ICN: 2003 WTC, IARI, New Delhi.