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Development and integration of soil moisture sensor with drip system for precise irrigation scheduling through mobile phone

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Abstract: Soil moisture sensor is an instrument for quick measurements of soil moisture content in the crop root zone on real time basis. The main objective of this research was development and evaluation of an indigenous sensor for precise irrigation scheduling. The various parts of sensor developed were ceramic cup, acrylic pipe, level sensor, tee, reducer, gland, cork, and end cap. The designed system was successfully tested on okra crop and calibrated with frequency domain reflectometry (FDR) by three methods of irrigation, i.e. check basin, furrow and drip, respectively. The average depth of water depletion in modified tensiometer by these methods was 27 to 35 cm at 50% management allowable depletion (MAD) of field capacity. This depth was useful for the level sensor to be installed inside modified tensiometer for real time irrigation scheduling. The correlation coefficient (R^2) between soil moisture content obtained from the developed sensor and FDR was 0.963. Sensor network was integrated with global system for mobile communication (GSM), short message service (SMS) and drip head work to develop an automated irrigation system. This would enable farmers to effectively monitor and control water application in the field by sending command through SMS and receiving pumping status through the mobile phone.

Keywords: GSM, Irrigation, Mobile phone, Soil moisture sensor, SMS

INTRODUCTION

Water, a scarce natural resource, is fundamental to life, livelihood, food security and sustainable development. Agriculture consumes 70% of the fresh water globally (Goodwin and O'Connell, 2008; Dowgert, 2010). Presently, farmers manually irrigate their lands at regular intervals through surface irrigation. In spite of its wide use, the method is characterized by low irrigation efficiency resulting in over or under irrigation that leads to reduced crop yields (Adamala *et al.,* 2014). There is a great need to modernize agricultural practices for better water productivity and resource conservation. Sensor based automation irrigation system has potential of improving water use efficiency by maintaining constant soil moisture regime in crop root zone, thus solving problems associated with manual operated irrigation (Perea *et al.,* 2013). Efforts were made by many researchers on management of irrigation using soil moisture sensor such as tensiometer, which is used to measure matric potential. Switching tensiometer based on preset soil matric limit used as control system for irrigation scheduling (Meron *et al.,* 2001; Smajstrla and Locascio, 1996; Muoz-Carpena *et al.,* 2003; Dukes and Scholberg, 2005). It indicated that soil water is in equilibrium with water inside a porous ceramic cup of a tensiometer in which the pressure deficit is measured with vacuum gauge (Warrick, 2003). A correct estimation of the soil water potential in the tensiometer is dependent on many parameters i.e. soil type, soil temperature, and soil salinity etc. (Hanson *et al.,* 2000; Munoz-Carpena *et al.,* 2005). Automated irrigation controller interfaced with tensiometer and U-tube manometer to sense the soil matric potential was developed at Indian Institute of Technology (IIT), Kharagpur, India (Joshi *et al.,*1999). Automated valve for irrigation system was designed and developed to sense soil water tension through a modified manometer type tensiometer. This helped to control irrigation at predecided soil moisture tension as programmed by a timer (Luthra *et al.,*1997). In advanced agriculture, many instruments and methods i.e. tensiometers, watermarks, resistance blocks, gravimetric methods, granular matrix and enviroscan sensors have been used to monitor and measure soil moisture, which will continue to be widely applied in irrigation scheduling (Leib *et al.,* 2002; 2003; McCready *et al.,* 2009). A low cost tensiometer based irrigation system had been developed and reported that it had potential to improving agricultural productivity while maintaining soil moisture at optimum level (Pinmanee *et al.,* 2011). Wireless sensor array was developed for scheduling of irrigation at real time basis. The system's receiver was connected to computer and multiple sensor nodes in field. Sensor nodes measure soil moisture and soil temperature for irrigation scheduling and so represented the soil moisture variability in field (Vellidis *et al.*, 2008). Wireless Soil moisture sensors prevented moisture stress in the plant, reduced excessive water usage, saving man power, wiring and piping cost (Dursun *et al.,* 2011).

Sensor based wireless irrigation system had been demonstrated to address the challenges of higher productivity with greater resource-use efficiency by applying water as per the temporal and in-season variability, particularly in developed countries (Majone *et al.,* 2013). Research for developing a wireless irrigation system for adoption in open field conditions is lacking. The major constraint for adoption of this technology for addressing the spatial and temporal variability is small holdings in India (Sudha *et al.,* 2011). Due to limited availability of fresh water resources, saving of irrigation water is of paramount importance. Therefore, the focus of the present study was to develop an intelligent irrigation scheduling system which would enable the farmers to optimize the use of water and only irrigate where and when needed. Accordingly, one such indigenous automated irrigation system, was developed using sensor network, telecommunication technologies viz. GSM, SMS and a mobile phone, to control the water level in agricultural field remotely.

MATERIALS AND METHODS

Location and soil of experimental field: The study was conducted at the Precision Farming Development Centre of the Water Technology Centre, Indian Agricultural Research Institute (IARI), Pusa, New Delhi, India, which is located within 28°37'22" N and 28°39'00" N latitude and 77°8'45" E and 77°10'24" E longitude covering an area of about 475 ha at an average elevation of 230 m above mean sea level. The soil of the research farm is alluvial in origin and is sandy loam in texture.

Design approach of soil moisture sensor: The design and development of soil moisture sensor based on working principle of tensiometer is used to measure capillary tension of soil. The main limitation of the tensiometer is that it functions only from zero to about -0.8 bar, which represents small parts of the entire range of available water. But, the major problem faced by farmers regarding tensiometers are cost, limited availability and monitoring of vacuum gauge on regular basis (Munos-Carpena *et al.,* 2005; Thompson *et al.,* 2006). Hence, to overcome this problem, an effort was made to develop soil moisture sensor by modifying the tensiometer to measure the soil matric potential for all soil types.

The various parts of sensor developed includes ceramic cup, acrylic pipe, level sensor, tee, reducer, gland, cork, and end cap (Fig. 1). These components were selected because they are easily available, low cost, and simple to use.

Modified tensiometer consisted of porous ceramic cup connected with acrylic pipe via tee connected to end cap. The modified tensiometer was filled with distilled water and installed in the soil. Water flowed out into the soil from the tensiometer through the porous cup creating negative pressure within the tensiometer. When the negative pressure in the tensiometer becomes equal to the soil matric potential, the flow of water from tensiometer to soil stopped. The drop in water level in the tensiometer is measured by placing a meter scale along the length of acrylic pipe with the help of a transparent tape. Level sensors were inserted inside the acrylic pipe.

The level sensor was a conductive type using water as the conducting medium. The level sensor had three probes inserted at the bottom, middle and top levels on different MAD (Management Allowable Deficit) values: 25%, 35% and 50%. These probes sent information in the form of electromagnetic signals to the level controller to actuate and deactuate the irrigation pump through a timer and three different LED (light emitting diode) with different lights (pink, yellow, and red). These lights get illuminated on the basis of availability of moisture in the soil. The rate of rise and fall of water level depends on the soil moisture present in the root zone of the crop. The rise or fall of water level sensed by the level sensor changed the capacitance values to electromagnetic signals. These signals were interfaced with GSM receiver and controller to actuate and de-actuate irrigation pump and solenoid valve simultaneously. The GSM receiver sent coded text SMS to web based decision support system and pre-programmed SIM number of mobile phone for monitoring and control of water application remotely. Each modified tensiometer had a sensor code number e.g., 111, 110, 001; this code could be changed by the user.

Adjustment of level sensor: Level sensors had three probes at the mid, bottom and top level. These probes interfaced with three colors viz. pink, yellow, red light emit diode (LED). These LED lights showed the level of available moisture in the soil. Adjustment of level sensor in modified tensiometer was set as per crop and soil type. Level sensor was used for sensing the height of water level depletion with respect to the soil moisture content and interfaced with controller to control water application (Fig. 2). The sensors gave feed back to the electronic circuitry to actuate and de-actuate irrigation pump.

Sensor installation: The soil moisture sensor was installed in between two plant rows to monitor the variability in soil moisture in plants' root zone. Spatial variability was problematic when tensiometers were installed 30 cm from the drip irrigation emitters (Meron *et al.,* 2001). Tensiometer and granular matrix sensors were installed at depth deeper than 30 cm to prevent adverse effect of wetting and drying soil phase (Perea *et al.,* 2013). A hole in the soil profile using soil auger was made to the desired depth. Modified tensiometer was inserted in the pilot hole. Slurry of soil and water was filled into the pilot hole to ensure good hydraulic conductivity between soil and the porous cup. These sensors were installed at about one-fourth to one-third of the maximum root depth to schedule irrigation. The number of sensor depends on the field size, soil uniformity and cropping pattern, soil texture variability. The designed system was installed in the field for testing and evaluation (Fig. 3).

Working principle of GSM receiver: The probes of level sensor sent information in the form of electromagnetic signals interfaced with level controller and GSM receiver. The GSM receiver sent coded text SMS to pre-programmed SIM number of mobile phone for monitoring and control of water application remotely. As the level of water went up or down, it sent the SMS accordingly, operating on a 12V DC battery. A holding circuit had been interfaced with the output of the controller. As the timer operated, signal generated in the form of double pole double throw (DPDT) connected with master relay interface occurred single pole single throw relay that operated the pump and solenoid valve simultaneously (Fig. 4).

Table 1. Sensor response time for pumping system and solenoid valve.

S. N.	Response time (seconds)		
	Sensor 1	Sensor 2	Sensor 3
1	9	8	7
2	11	10	8
3	10	13	12
4	8	7	10
5	9	8	8
6	8	11	6
7	7	13	14
8	9	12	12
9	8	9	11
10	10	6	9
Average	9	10	10

RESULTS AND DISCUSSION

Design of the integrated system: The design approach used in remote control of automated irrigation system had the following steps (Casadesus *et al.,* 2012, Xiao *et al.,* 2013) which included the following steps: (i) design of soil moisture sensor, (ii) determining the installation point of level sensor in modified tensiometer to sense the height of water level depletion with respect to soil moisture content, and interfacing with controller to control water application (iii) sent a coded text message including command to the receiver, thus providing option to switched on/off a pump/valve remotely, when soil moisture content reaches some predefined threshold value (iv) development of user friendly automated irrigation system.

Evaluation of the designed system: The performance

Fig. 1. *Parts of developed sensor for soil moisture measurement.*

Fig. 2. *Level sensor and its working for sensed water level in modified tensiometer.*

Fig. 3. *Sensor (Modified tensiometer) installed in okra crop at PFDC Field.*

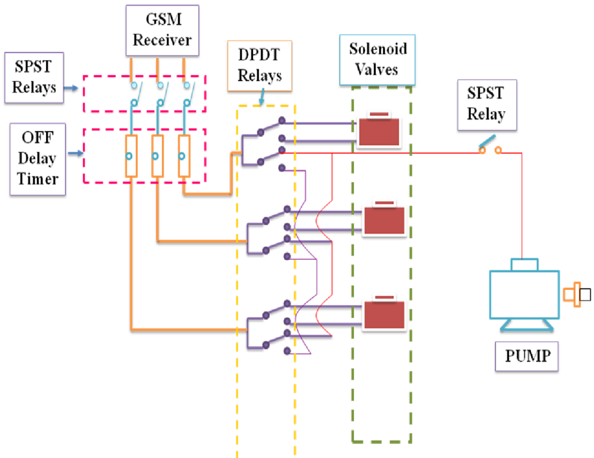

Fig. 4. *Line diagram of signal transformation of GSM receiver to pump.*

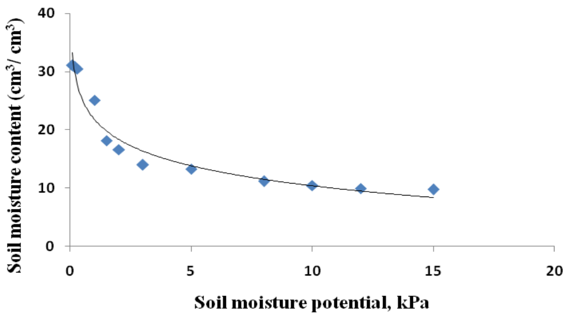

Fig. 5. *Soil Moisture Characteristic Curve indicating availability of moisture at different potential.*

evaluation of developed sensor was tested on okra crop under an experimental plot of 21 m x 21 m at Precision farming development Centre (PFDC), Water Technology Center, Indian Agricultural Research Institute, New Delhi, India. Soil moisture characteristic curve of experimental soil at various matric potential was determined by pressure plate apparatus (Fig. 5). The developed system was calibrated with frequency domain reflectometry (FDR) under three methods of irrigation, viz., check basin, furrow and drip, respectively (Fig. 6). The performance of soil moisture sensor system was related to soil water content (McCready *et al.*, 2009; Zotarelli *et al.*, 2009; Cardenas-Lailhacar and Dukes, 2010). The system performance was enhanced by microcontroller. Circuit design complexity and cost is reduced and moreover it is easy to upgrade (Al Smadi, 2011). Water level depletion in modified tensiometer in check basin irrigation was initially less but it was more after 48 hrs of irrigation as compared to furrow and drip irrigation. The reason might be that percolation losses were more due to gravity force. The average depth of water depletion in modified tensiometer in all the three methods was 27 to 35 cm at 50% management allowable depletion (MAD) of field capacity. This depth was useful for the level sensor to be installed inside modified tensiometer for real time irrigation scheduling. The Coefficient of Determination (R^2) was found to be 0.963. Many researchers have reported that the relationship between tensiometer and gravimetric method for soil moisture measurement had correlation coefficient (R^2) range from 0.96 – 0.98 (Thompson *et al.,* 2006; Marazky *et al.,* 2011).

Transfer of information: These sensors collected information of available soil moisture in the field and sent information in the form of electromagnetic signal to the level controller for lighting the light emit diode (three different colour pink, yellow, red). These light that were visible to users could help to understand soil moisture availability in the crop root zone. This data was sent to user on mobile phone. The user could then view this information and can decide irrigation by switch on/off the irrigation pump. Transfer of information was most important factor for collecting information regarding the status of soil moisture available for crop. GSM and SMS tech-

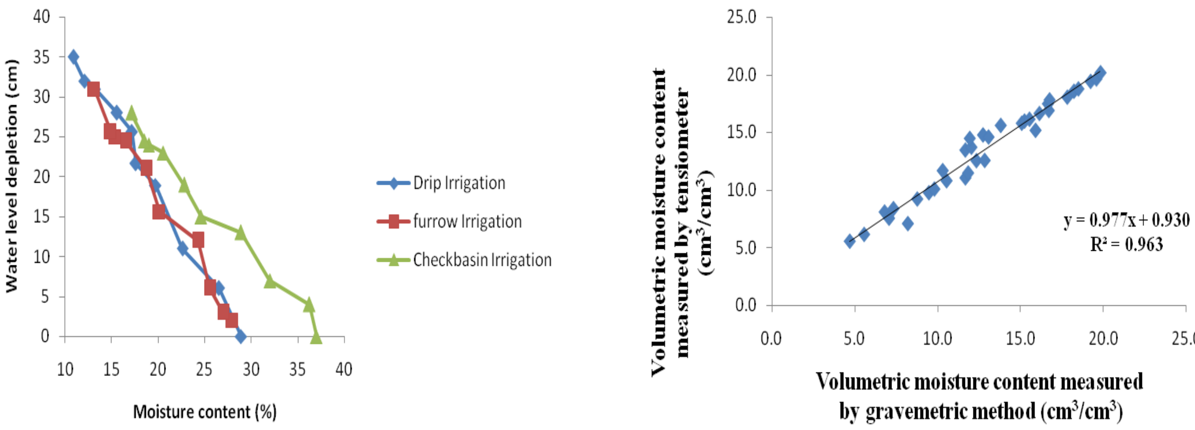

Fig. 6. *Performance evaluation of developed sensor under different methods of Irrigation.*

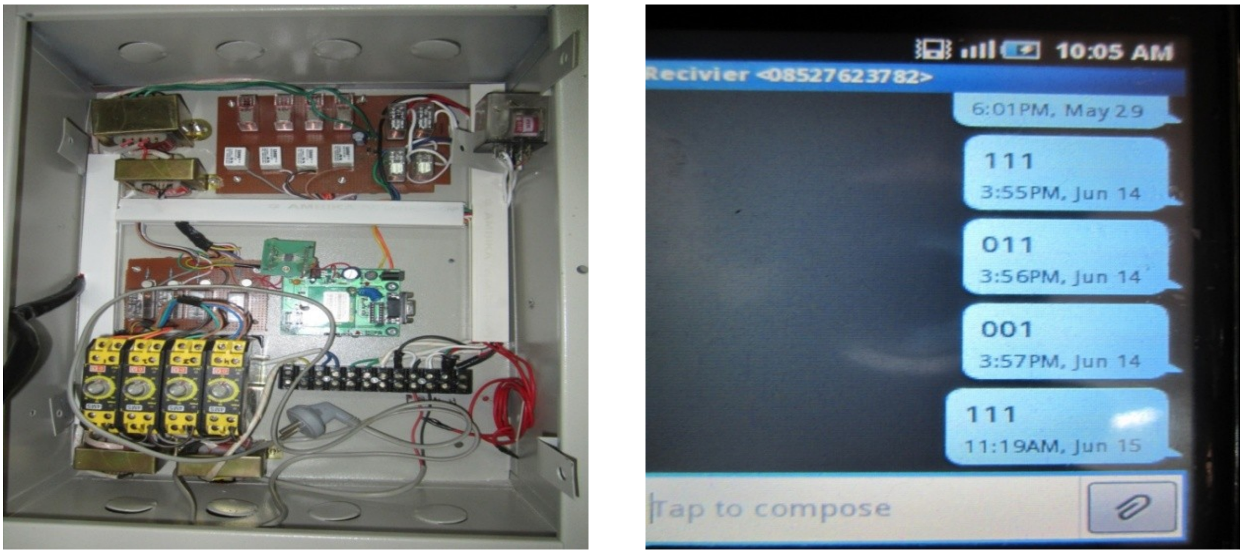

Fig. 7. *Set up of receiver, transmitter, level controller and SMS of mobile phone display.*

nologies were used to transfer the data from sensors to transmitter. Once the transmitter received the data from all the sensor nodes, it developed a database to organize the data and then an SMS would be triggered and sent via GSM modem through the cellular network to the user's mobile phone. GSM technology had wide range of coverage and provided advantages of being fast. The SMS technology provides an efficient information delivery service to the user's mobile phone. Short message service (SMS) as an alternative option for improving water use efficiency, based on irrigation informatics (Car *et al.,* 2007; 2012).

Sensitivity of the developed soil moisture sensor: Sensitivity of the developed soil moisture sensor using modified tensiometer was checked by two methods 1) by sending SMS using mobile phone 2) by modified tensiometer installed in the okra field. The sensitivity of the soil moisture sensor having modified tensiometer was checked after integration with drip head work of different methods of irrigation i.e. drip, furrow and check basin. In this experiment three modified tensiometers were used, and each modified tensiometer had individual sensor code no. (eg.111, 110, 001),which could be changed by the user (Fig.7). Time taken by the pump to switch ON was estimated by sending the message to the receiver SIM near the pump. This process was repeated several times to estimate the average time required by the pump to start. The message to the different sensors using a single receiver was achieved by sent the sensor code number (eg.111, 110, 001,) to the receiver. The time required by the pump to start after receiving the SMS from mobile were noted down and similar such trials were carried out to estimate the average starting time of the pump. A total of ten trials were carried out and the average starting time of pump was 9, 10 and 10 seconds for drip, furrow and check basin irrigation, respectively (Table 1).

Conclusion

The soil moisture sensor was successfully designed, assembled and tested in the field plot of okra crop irrigated through check basin, furrow and drip irrigation at the preset position of the level sensor. The developed system calibrated with frequency domain reflectometry, and the correlation coefficient (R^2) was found to be 0.963. The height of water level depletion in modified tensiometer was sensed by level sensor with respect to variation of soil moisture content. The performance of level sensor was checked on different MAD (Management Allowable Deficit) values: 25%, 35% and 50% of soil moisture content, and determined installation point of level sensor in modified tesniometer. Water level depletion in modified tensiometer in check basin irrigation was initially less but it was more after 48 hrs of irrigation as compared to furrow and drip irrigation. Sensor network integrated with GSM, SMS had potential to develop fully automated system for precise irrigation scheduling. Thus, interpolation over an area for spatial decision making needs to be tapped for making agriculture attractive in future. The design is still in its prototype stage. However, more testing of the system must be done to quantify the water and labor saving.

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REFERENCES

Adamala, S., Raghuwanshi, N.S. and Mishra, A. (2014). Development of surface irrigation systems design and evaluation software. *Computer and Electronics in Agriculture,* 100: 100-109

AL-Smadi, T.A. (2011). Low cost smart sensor design. *American Journal of Engineering and Applied Sciences*, 4(1): 162-168

Car, N.J., Moore, G., Christen, E.W., Hornbuckle, J.W. and Bartlett, C. (2007). Tool for improving water use efficiency: irrigation informatics implemented via SMS. International Congress on Modeling and Simulation, and Modeling and Simulation Society of Australia and New Zealand. Pp 135-141, University of Melbourne, Victoria. ISBN: 978-0-9758400-4-7

Car, N.J., Christen, E.W., Hornbuckle, J.W. and Moore, G.A. (2012). Using a mobile phone short messaging service (SMS) for irrigation scheduling in Australia – farmers' participation and utility evaluation. *Computer and Electronics in Agriculture,* 84: 132-143

Cardenas-Lailhacar, B. and Dukes, M.D. (2010). Precision of soil moisture sensor irrigation controllers under field conditions. *Agricultural Water Management,* 97: 666-672

Casadesus, J., Mata, M., Marsal, J. and Girona, J. (2012). A general algorithm for automated scheduling of drip irrigation in tree crops. *Computer and Electronics in Agriculture,* 83: 11-20

Dowgert, M.F. (2010). The impact of irrigated agriculture on a stable food supply. In: Proceedings of the 22nd Annual Central Plains Irrigation Conference, Kearney, NE.

Dukes, D.M. (2003). Automatic soil moisture-based drip irrigation for improving tomato production. *Proceedings of The Florida State Horticultural Society,* 116: 80-85

Dukes, D.M. and Scholberg, J.M. (2005). Soil moisture controlled subsurface drip irrigation on sandy soils. *Applied Engineering in Agriculture,* 21(1): 89-101

Dursun, M. and Semih, O. (2011). A wireless application of drip irrigation automation supported by soil moisture sensors. *Scientific Research and Essays,* 6: 1573-1582

Goodwin, I. and O'Connell, M.G. (2008). The future of irrigated production horticulture- world and Australian perspective. *Acta Horitculturae,* 792: 449-458

Hanson, B.R., Orloff, S. and Peters, D. (2000). Monitoring soil moisture helps refine irrigation management. California Agriculture, 54: 38-42

Joshi, A., Tiwari, K.N. and Banerjee, S. (1999). Automated irrigation controller patent application no. 6/Cal/99 dated 04-1-1999, Indian Institute of Technology, Kharagpur, India.

Leib, B.G., Hattendorf, M., Elliott, T. and Mattews, G. (2002). Adoption and adaptation of scientific irrigation scheduling: Trend from Washington, USA as of 1998. *Agricultural water management,* 55, pp 105-120

Leib, B.G., Matthews, J.D. and Gary, R. (2003). Field evaluation and performance comparison of soil moisture sensors. *Journal of Soil Science*. 168: 396-408

Luthra, S.K., Kaledhonkar, M.J., Singh O.P. and Tyagi, N.K. (1997). Design and development of an auto-irrigation system. *Agricultural Water Management,* 33: 169-181

Majone, B., Viani, F., Filippi, E., Bellin, A., Massa, A., Toller, G., Robol, F. and Salucci, M. (2013). Wireless sensor network deployement for monitoring soil moisture dynamics at the field scale. *Procedia Environmental Sciences*, 19 : 426-435

Marazky, M.S.A.E., Mohammad, F.D. and Al-Ghobari, H.M. (2011). Evaluation of soil moisture sensors under intelligent irrigation systems for economical in arid regions. *American Journal of Agricultural and Biological Sciences*, 6(2): 287-300

McCready, M.S., Dukes, M.D., and Miller, G.L. (2009). Water conservation potential of intelligent irrigation controllers on St. Augustinegrass. *Agricultural water management,* 96, pp 1623-1632

Meron, M., Hallel, R., Bravdo, R. and Wallach, R. (2001). Tensiometer actuated automatic micro irrigation of apples. *Acta Horitculturae.* 562: 63-69

Munoz-Carpena, R., Bryan, H., Klassen, W., Dispenza, T.T. and Dukes, M.D. (2003). Evaluation of an automatic soil moisture-based drip irrigation system for row tomatoes. Proceedings of the ASABE Annual International Meeting, July 27-30. Las Vegas, Nevada, USA.

Munoz-Carpena, R., Dukes, M.D., Yuncong. C.Li. and Klassen, W. (2005). Field comparision of tensiometer and granular matrix sensor automatic drip irrigation on tomato. *HortTechnology*, 15: 584-590

Perea, H., Enciso, J., Jifon, J., Nelson, S. and Fernandez, C. (2013). On farm performance of tensiometer and granular matrix soil moisture sensors in irrigated light, medium, and heavy textured soils. *Subtropical Plant Science*, 65:1-7

Pinmanee, S., Spreer, W., Spohrer, K., Ongprasert, S. and Muller, J. (2011). Development of a low-cost Tensiometer driven irrigation control unit and evaluation of its suitability for irrigation of lychee trees in the uplands of Northern Thailand in a participatory approach. *Journal of Horticulture and Foresty,* 3: 226-230

Smajstrla, A.G. and Locascio, S.J. (1996). Tensiometer-controlled, drip irrigation scheduling of tomato. *Applied Engineering in Agriculture,* 12(3): 315-319

Sudha, M.N., Valarmathi, M.L. and Babu, A.S. (2011). Energy efficient data transmission in automatic irrigation system using wireless sensor networks. *Computer and Electronics in Agriculture,* 78: 215-221

Thompson, R.B., Gallardo, M., Aguera, T. and Valdez, M.D. (2006). Evaluation of the watermark sensor for use with drip irrigated vegetable crops. *Irrigation Science*, 24: 185–202

Vellidis, G., Tucker, M., Perry, C., Kvein, C. and Bednarz, C. (2008). A real-time wireless smart sensor array for scheduling irrigation. *Computers and Electronics in Agriculture*, 61(1): 44-50

Warrick, A. W. (2003). Soil water dynamics. Oxford Univ. Press, New York, 416 p.

Xiao, D., Feng, J., Wang, N., Luo, X. and Hu, Y. (2013). Integrated soil moisture and water depth sensor for paddy fields. *Computer and Electronics in Agriculture,* 98: 214-221

Zotarelli, L., Scholberg, J.M., Dukes, M.D., Munoz-Carpena, R. and Icerman, J. (2009). Tomato yield, biomass accumulation, root distribution and irrigation water use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. *Agricultural Water Management,* 96: 23-34