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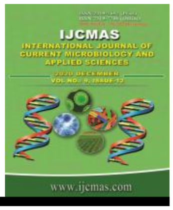

**Review Article**

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# Automation in Irrigation - A Review

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## ABSTRACT

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Impact of changing climate and growing population had created scarcity of water for agricultural purpose. Agriculture uses 85% of water for irrigation purpose only. In addition, the wastage of water has become the major problem in agriculture. The traditional irrigation methods causes various types of irrigation water losses *viz.*, seepage losses, erosion, water logging problems, deep percolation, salinization and runoff. So it is more important to improve the efficient use of irrigation water. In micro irrigation, the water loss due to percolation and evaporation is very less, so the water use efficiency of the crop becomes increased. Automation of irrigation is a promising approach in minimizing the wastage of irrigation loss and improving the efficiency of water use. Automation helps to irrigate only when there is acute requirement of water and deliver nutrients in controlled and precise manner which helps to save time, resource with increased efficiency and outcome of agriculture.

## Introduction

Efficient water management is a major concern in precision irrigation practices. There is a great need to modernize agricultural practices for better water productivity and resource conservation. The use of automated irrigation systems can provide water on a real-time basis at the root zone, based on the availability of soil water at the crop root zone, which also leads to saving of water (Ohja *et al.*, 2015). Automated irrigation systems allow for high-frequency irrigation, thus maintaining the soil water potential (SWP) relatively constant. Irrigation scheduling remains a reliable technique for applying the required amount of water at the appropriate time and automated irrigation systems based on crop water needs can maximize water use efficiency (Munoz *et al.*, 2003). Ganjeer (2019) studied on use of automated irrigation in comparison to manual irrigation in wheat by use of humidity controlled sensors and reported that maximum water use efficiency was obtained in sensor based irrigation and there was 15.85% water saving through sensor based irrigation. Jat *et al.*, (2019) studied on automation of micro-climate control through sensors and controllers under open-field and polyhouse culture, at irrigation levels of 80% or 100% of crop evapotranspiration and reported that programmable logic controller-based automation system worked well for micro-climate control leading to 93% and 53% higher yield and fruit weight, respectively in the polyhouse than open-field cultivation. Sathya *et al.,* (2016) proposed system develops an automated irrigation system in rice to direct the water flow in the paddy fields. This system uses water level sensors to identify the water level in the field and also the moisture sensors to identify the moisture level in the soil and change the flow of water to the next farm accordingly. It guarantees the efficient usage of water and also prevents the damage of crops due to overflow of water. With the use of these advanced technologies, some of the traditional techniques in the agriculture can be automated to increase the productivity and also the efficient usage of the resources.

## What is automation?

Automation of drip/micro irrigation system refers to operation of the system with no or minimum manual interventions.

Irrigation automation is well justified where a large area to be irrigated is divided into small segments called irrigation blocks and segments are irrigated in sequence to match the flow or water available from the water source (Rajakumar *et al.,* 2008).

## Specific features of automated irrigation system

It eliminates the manual opening and closing of valves.

It starts and stops pump exactly as and when required thus optimizing the energy requirement.

Irrigation system can be started at any desired time. One need not worry to visit farm during odd time (night). This is especially in Indian condition, where power supply is available for agricultural operation during night time.

Possibility to change frequency of irrigation and fertilizer application as per the crop need.

Use of water from different sources and increased water and fertilizer use efficiency (Rajakumar *et al.,* 2008).

## Types of automation

### Semi-automatic

Semi-automatic systems and controls require manual attention at each irrigation and are usually simpler and less costly than the fully automatic systems. Most semi-automated systems use mechanical or electronic timers to activate control structures at pre-determined times. The irrigator usually determines when to begin irrigation and its duration and manually resets or returns the devices to their original positions or moves them from one location to another before the next irrigation. The parts of given system may be automatic while other parts are semi-automatic or manually operated. Such systems require communication between the controller and system components located in the field.

### Fully automatic

Fully automatic systems normally operate without operator attention except for periodic inspections and routine maintenance. The irrigator may determine when and how long to irrigate and turn water into the system or start programmed controllers to initiate the automated functions. Fully automatic systems may use soil moisture sensors, such as tensiometers or electrical resistance blocks to activate electrical controls when soil water is depleted to predetermined levels. Irrigation duration may be controlled by programmed timers, soil moisture sensors or surface water sensors. Fully automatic systems require a water supply available on demand such as from wells or farm reservoirs. Most farm systems however do not have the flexibility required for complete automation.

## Types of controls

### Time based system

In time based system, time is the basis of irrigation. Time of operation is calculated according to volume of water required and the average flow rate of water. The duration of individual valves has to be fed in the controller along with system start-time, also the controller clock is to be set with the current day and time.

### Volume based system

In volume based system, the preset amount of water can be applied in the field segments by using automatic volume controlled metering valves. The major advantage of volume based irrigation system over time-based system is that is assures to deliver the preset amount of water irrespective of continuous availability of electricity, but time based system is comparatively cheaper and hence gaining more popularity than the volume based system.

### Open loop system

In an open loop system, the operator makes the decision on the amount of water that will be applied and when the irrigation event will occur. This information is programmed into the controller and the water is applied according to the desired schedule. Open loop control systems use either the irrigation duration or a specified applied volume for control purposes. Open loop control systems are typically low in cost and readily available from a variety of vendors. The drawback of open loop systems is their inability to respond automatically to changing conditions in the environment. In addition, they may require frequent resetting to achieve high levels of irrigation efficiency.

### Closed loop system

This type of system requires feedback from one or more sensors. The operator develops a general control strategy. Once the general strategy is defined, the control system takes over and makes detailed decisions of when to apply water and how much water to apply. Irrigation decisions are made and actions are carried out based on data from sensors. In this type of system, the feedback and control of the system are done continuously. Closed loop controllers require data acquisition of environmental parameters (such as soil moisture, temperature, radiation, wind-speed, etc) as well as system parameters (pressure, flow, etc.).

### Real time feedback system

Real time feedback is the application if irrigation based on actual dynamic demand of the plant itself, plant root zone effectively reflecting all environmental factors acting upon the plant. Operating within controlled parameters, the plant itself determines the degree of irrigation required. Various sensors *viz.*, tensiometers, relative humidity sensors, rain sensors, temperature sensors, etc., control the irrigation scheduling. These sensors provide feedback to the controller to control its operation.

### Computer-based Irrigation Control System

A computer-based irrigation control system consists of a combination of hardware and software that acts as a supervisor with the purpose of managing irrigation and other related practices such as fertigation and maintenance.

### Automatic systems

In fully automated systems the human factor is eliminated and replaced by a computer specifically programmed to react appropriately to any changes in the parameters monitored by sensors. The automatic functions are activated by feedback from field units and corrections in the flow parameters by control of devices in the irrigation system until the desired performance level is attained.

### Sensor controlled micro irrigation

**Control by twin sensors** - One sensor is placed in the root zone and actuates the opening of water flow. The second sensor, located on the limit of the wetted zone, triggers the closing of water flow.

**Control by single sensor** - One sensor open and closes the water supply.

### Sensor

Sensor is defined as an element that senses a variation in input energy to produce a variation in another or same form of energy.

Different types of sensors used to monitor soil and plant parameters are as follows:

Electromagnetic sensors
Optical and Radiometric sensors
Mechanical sensors
Electrochemical sensors
Acoustic and Pneumatic sensors

### Electromagnetic sensors

Electrical conductivity is one sensor-based measurement that can provide an indirect indicator of important soil physical and chemical properties. Soil salinity, clay content, cation content, and temperature all affect EC (McNeill, 1992; Rhoades *et al.*, 1999).

Depending on the technique used, electromagnetic sensors can be divided into:

sensors for mapping electrical conductivity
sensors for mapping transient electromagnetic response
sensors which adjust various rate application in real-time

Measured soil EC has no direct effect on crop growth or yield. However, based on a measured soil data, a farmer can easily determine specific soil properties which may affect the crop yield.

| Sensors | Soil texture (clay, silt & sand) | SOM or total carbon content | Soil moisture content | Soil salinity | Soil bulk density | Depth varia-bility | Soil pH | Total N content | CEC | Other macro nutrient |
|---|---|---|---|---|---|---|---|---|---|---|
| **Electrical & Electro-magnetic** | x | x | x | x |  | x |  | x | x |  |
| **Optical and radiometric** | X | x | x |  |  |  | x | x | x |  |
| **Mechanical Acoustic& pneumatic** | X |  |  |  | X | x |  |  |  |  |
| **Electro-chemical** |  |  |  | x |  |  | x | x |  | x |

## Optical and radiometric sensors

Optical sensors measure the reflectance, absorption, or transmittance characteristics of the soil. They use light reflectance to measure soil organic matter, soil moisture, mineral composition, clay content, soil color, organic carbon, pH, and Cation Exchange Capacity. Sensors determine the soil's ability to reflect light in different parts of the electromagnetic spectrum. Changes in wave reflections may indicate changes in soil density or restrict soil layers. Optical sensors use the combination of four different wavelengths to measure certain soil characteristics; ultraviolet (100-400 nm), visible (400-700 nm), near-infrared (700-2500 nm) and mid-infrared (2500-25000 nm) wavelengths. Ultraviolet wavelengths are used in combination with visible spectra to determine inorganic minerals (iron oxide) in the soil. According to Baumgardner *et al.,* (1985), moisture, organic matter, particle size, iron oxides, mineral composition, soluble salts, parent material and other attributes affect soil reflectance.

Radiometric sensors use the gamma-ray spectrometer to measure the distribution of the intensity of gamma ($\gamma$) radiation versus the energy of each photon. There are two types of radiometric sensors; active and passive. Active $\gamma$-ray sensors use a radioactive source to emit photons of energy that can then be detected using a $\gamma$-ray, while passive sensors measure the energy of photons emitted from naturally occurring radioactive isotopes of the element from which they originate. Measured data is compared to the isotopes of potassium, uranium, and thorium in the soil, where the intensity of $\gamma$-ray is related to the elemental content in the soil.

## Mechanical sensors

Mechanical sensors are used to estimate soil mechanical resistance (compaction) as related to the variable level of compaction. These sensors use a mechanism that penetrates or cuts through the soil and records the force measured by strain gauges or load cells. When a sensor moves through the soil, it registers resistance forces arising from the cutting, breaking, and displacing of soil. Soil mechanical resistance is measured in a unit of pressure and represents the ratio of the force required to penetrate the soil medium to the frontal area of the tool engaged with the soil.

## Electrochemical sensors

Electrochemical sensors are used to measure the most important soil characteristics for precision management; soil nutrient levels and pH. It's a great replacement for standard chemical soil analysis, which is expensive and takes more time to get the results. These sensors use an ion-selective electrode (ISE) or an ion-selective field effect transistor (ISFET) to measure the voltage between the sensing and reference part of the system related to the concentration of specific ions ($H^+$, $K^+$, $NO_3^-$). The soil sampling mechanism scoops a soil sample and brings it in contact with the electrode. After a stable reading is measured, the electrode is rinsed before the next reading.

## Acoustic and pneumatic sensors

Acoustic sensors are used to measure soil texture (sand, silt, clay) soil bulk density (compaction) and soil depth variability (depth of topsoil, depth to hardpan).

They work by measuring the change in noise level due to the interaction of a tool with soil particles. Pneumatic sensors measure soil-air permeability, which is the pressure required to force a given volume of air into the soil, at a certain depth. The measured data is compared to soil properties such as soil structure and compaction.

## Soil-plant water monitoring sensors

Different types of devices used to monitor soil-plant water status and to automate irrigation system are listed below:

a) Tensiometer
b) Resistance block
c) Gypsum block
d) Granular matrix sensor
e) TDR based soil moisture sensor
f) Infrared sensors for leaf air temperature
g) High frequency capacitance type soil moisture sensor.

## Effect of automated irrigation on crop growth

Majsztrik *et al.*, (2013 a,b) and Saavoss *et al.*, (2016) demonstrated that more timely irrigation decisions through the use of sensor networks in greenhouse production increased the yield and quality of snapdragon (cut-flowers) by 30% depending on season and cultivar.

Hong and Hsieh (2016) compared conventional timer control and soil moisture control method with the integrated control strategy in wireless irrigation that consisted of microcontroller, weather sensor, soil sensor and blue tooth module and reported that test group had higher performance in plant height, leaf number, fresh weight and dry weight (Table 1). Electricity and water usage also presents the ICS could save 90% of the electricity and water usage when compared to timer control method data for height of basil are mean ± SE of 23 plants.

Henderson Scott (2017) conducted experiment (Table 2) on improving Greenhouse Irrigation through a Sensor-based Automated Decision Support System using the sensors (GS3; Decagon Devices Inc., WA, USA) domain reflectometry sensors, which determine the growing substrate volumetric water content (VWC) by measuring the dielectric constant of the growth medium in bellflower and basil plants and reported the height of bellflower was 12.0 ± 0.3 and basil was 23.0 ± 0.5 which is higher than conventional methods.

According to Durga *et al.*, (2018), the result of irrigation scheduling in rabi maize the plant height was significantly influenced by irrigation methods and schedules (Table 3). Perusal of the data indicated that plant height increases progressively with the advancement of crop age to harvest. Among sensor based irrigation the highest plant height was observed in nano based sensor irrigation scheduling (228.7 cm at harvest).

Anand *et al.*, (2018) conducted an experiment on automation of irrigation in maize, rose plantation and chilly by incorporating additional microcontroller relay, solenoid valve, GSM systems (Table 4 & 5). In maize on day 8, 34.70 cm height and 0.79 cm of diameter in automation irrigation and 34.20 cm height of maize crop at 0.77 cm of diameter in without automation. In day 1, 14.50 cm height of rose plant at 0.79 cm diameters, same in both automation and without automation. In day 8, 14.75 cm height of rose plant at 0.85 cm of diameter in automation irrigation and 14.60 cm height of rose plant at 0.84 cm of diameter in without automation irrigation. Similarly with repeated process in chilly on day 8, height of chilly crop was 21.40 cm at 0.58 cm of diameter in automation irrigation and 21.30 cm height of chilly crop at 0.57cm of diameter in without automation.

Liu and Xu (2018) studied automatic irrigation control for soilless culture of lettuce and found that the average fresh weight (FW) per plant under intelligent irrigation are at least 16.60% and 11.37% higher than manual control irrigation at different growth stages in spring and summer (Table 6). This fact can be related to the low water holding capacity of substrate and also due to the intelligent irrigation method may detect and irrigate in real time and maintain the water content at root zone meeting the plant demand in comparison with the manual control irrigation method.

## Effect of automated irrigation on yield parameters

Munoz *et al.*, (2003) tested low-volume/high frequency soil moisture based drip irrigation system on tomato (Table 7) and reported that tensiometers at 15 cbar set point performed the best (up to 73% reduction in water use compared with commercial farm practice, and 50% with respect to the 100% recommended crop water needs treatment. Granular matrix sensors behaved erratically and did not improve water savings compared with the 100% recommended crop water needs treatment.

Parameshwar Shirgure (2012) stated that the research on automated irrigation in the Nagpur mandarin fruit yield was higher (30.91 tones/ha) with irrigation on alternate day 120 minutes three times, followed by irrigation scheduled with 90 minutes interval two times daily (30.11 tones/ha). Fruit weight (154.7 g), TSS (10.22 Brix) and juice percent (40.77%) was found with automatic irrigation at alternate day with 120 minute three times.

Anjali (2016) studied on solar power automated fertigation in cucumber with automated fertigation and manual fertigation application treatments and reported that automation fertigation system installed in polyhouse considered as best treatment and it gave the maximum value of yield parameters and yield (Table 8). Moreover, being fully operated with solar power, the system can be installed at remote and rural locations to achieve reduction in the cost of production and to enhance the yield.

Sandra *et al.*, (2019) conducted automatic irrigation experiments in plum tree and found that in 2017 and 2018, the treatments gave a higher yield than the C treatment (Table 9). These differences were due to the higher number of fruits per tree in the RDI and A treatments, though the differences were only significant in 2017 between the C and A treatments. In 2018 although A showed some tendency towards higher productions, the differences with RDI did not become significant.

Ganjeer (2019) studied on soil moisture sensor based automated gravity fed drip irrigation (Table 10). Sensor is calibrated in such a way that system starts automatically when soil moisture deplete by 50% till replenish 80% of field capacity and reported that maximum water use efficiency was obtained in sensor based irrigation 73.4 kg $ha^{-1}$ $mm^{-1}$ and the minimum water use efficiency was obtained in control irrigation 57.13 kg $ha^{-1}$ $mm^{-1}$ and there was 15.85% water saving through sensor based irrigation. The maximum yield 19500 kg $ha^{-1}$ was recorded in sensor based irrigation when compared to control irrigation 16875 kg $ha^{-1}$.

## Effect of automated irrigation in water use efficiency (wue)

Kumar (2017) conducted experiment to test the performance evaluation of indigenously developed automated system on vegetable crops under different methods of irrigation and reported that water productivity increased under automated drip irrigation system (Table 11). The water saving range was 39.6 – 48.6% using automated drip irrigation over manual control check basin irrigation.

Guerbaou *et al.*, (2013) developed a PC-based automated system to manage the drip irrigation/fertigation (Table 12). A graphical interface was developed using lab view to manage and monitor irrigation and fertigation and the results reported that computer based drip irrigation used 5670 $m^3$ /ha over 7000 $m^3$ /ha by drip and reduced water consumption by 20 to 30%.

**Table.1** Comparison of physical properties for test group and check group of lettuce

| | **First week** | | **Second week** | |
|---|---|---|---|---|
| **Parameters** | **Test group (WIS)** | **Check group** | **Test group (WIS)** | **Check group** |
| **Height (cm)** | 16.5±1.2* | 15.9±0.7 | 23.5±1.1 | 22.4±1.2 |
| **Leaves no.** | 6.8±0.6 | 6.5±0.5 | 7.2±0.5 | 6.9±0.4 |
| **Fresh wt. (g)** | NA | NA | 17.8±3.3 | 15.5± 3.4 |
| **Dry wt. (g)** | NA | NA | 0.81±0.14 | 0.7± 0.17 |

* means±std. dev

**Table.2** Growth attributes of bellflower and basil plants determined at the end of the respective production cycles

| **Growth attributes** | **Bellflower z**<br>**Mean ± SE** | **Basil y**<br>**Mean ± SE** |
|---|---|---|
| **Shoot Fresh Mass (g/plant)** | 54.2 ± 1.9 | 43.2 ± 0.9 |
| **Shoot Dry Mass (g/plant)** | 6.5 ± 0.2 | 3.87 ± 0.1 |
| **Height (cm)** | 12.0 ± 0.3 | 23.0 ± 0.5 |
| **Growth Index** | 25.2 ± 1.2 | 42.0 ± 1.4 |

zData for height of bellflower are mean ± standard error (SE) of 30 plants.
yData for height of basil are mean ± SE of 23 plants.

**Table.3** Sensor based irrigation schedules

| **TREATMENT** | **30 DAS** | **60 DAS** | **90 DAS** | **HARVEST** |
|---|---|---|---|---|
| **S1-Tensiometer (irrometer)** | 40.3 | 108.2 | 179.4 | 193.3 |
| **S2-Granulated gypsum blocks (Watermark sensors)** | 44.0 | 147.1 | 208.8 | 217.6 |
| **S3-Profile probe (Delta-T)** | 42.7 | 139.0 | 196.6 | 213.5 |
| **S4-Nanosensors (IITB)** | 45.2 | 150.4 | 224.9 | 228.7 |
| **S5-Soil moisture indicator (ICAR)** | 41.9 | 130.7 | 193.5 | 199.2 |
| **S6-IW/CPE ratio or Epan** | 41.8 | 133.9 | 187.4 | 195.8 |
| **SEm+_** | 1.2 | 6.6 | 8.7 | 6.8 |
| **CD (P = 0.05)** | NS | 19.5 | 25.8 | 20 |

**Table.4** Automation of irrigation in maize

| Maize crop | | | | |
|---|---|---|---|---|
| **Day** | **With automation** | | **Without automation** | |
| | **Height (cm)** | **Diameter (cm)** | **Height (cm)** | **Diameter (cm)** |
| **1** | 34.00 | 1.75 | 34.00 | **1.75** |
| **2** | 34.20 | 1.76 | 34.00 | **1.75** |
| **3** | 34.20 | 1.76 | 34.00 | **1.75** |
| **4** | 34.50 | 1.77 | 34.10 | **1.76** |
| **5** | 34.50 | 1.78 | 34.10 | **1.76** |
| **6** | 34.50 | 1.78 | 34.10 | **1.76** |
| **7** | 34.60 | 1.78 | 34.10 | **1.76** |
| **8** | **34.70** | **1.79** | **34.20** | **1.77** |

**Table.5** Automation of irrigation in rose plantation and chilly

| **Rose plantation** | | | | | **Chilly crop** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Day** | **With automation** | | **Without automation** | | **Day** | **With automation** | | **Without automation** | |
| | Height (cm) | Diameter (cm) | Height (cm) | Diameter (cm) | | Height (cm) | Diameter (cm) | Height (cm) | **Diameter (cm)** |
| **1** | 14.50 | 0.79 | 14.50 | 0.79 | 1 | 21.00 | 0.54 | 21.00 | **0.54** |
| **2** | 14.50 | 0.80 | 14.50 | 0.79 | 2 | 21.10 | 0.54 | 21.00 | **0.54** |
| **3** | 14.55 | 0.81 | 14.55 | 0.79 | 3 | 21.10 | 0.55 | 21.00 | **0.54** |
| **4** | 14.60 | 0.82 | 14.60 | 0.80 | 4 | 21.30 | 0.55 | 21.10 | **0.55** |
| **5** | 14.61 | 0.82 | 14.61 | 0.81 | 5 | 21.30 | 0.56 | 21.10 | **0.55** |
| **6** | 14.65 | 0.83 | 14.65 | 0.82 | 6 | 21.30 | 0.56 | 21.20 | **0.56** |
| **7** | 14.70 | 0.84 | 14.70 | 0.83 | 7 | 21.40 | 0.57 | 21.20 | **0.56** |
| **8** | **14.75** | **0.85** | **14.75** | **0.84** | **8** | **21.40** | **0.58** | **21.30** | **0.57** |

**Table.6** Automatic irrigation control for soilless culture of lettuce

| **Irrigation Methods** | **FW in Spring/g** | | | | | **FW in Summer/g** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **7day** | **14 day** | **21day** | **28 day** | **35day** | **7 day** | **14 day** | **21 day** | **28 day** | **35 day** |
| **Intelligent irrigation** | 3.15 a | 10.14 a | 31.65 a | 92.21 a | 211.20 a | 1.78 a | 6.57 a | 20.96 a | 85.08 a | **178.52 a** |
| **Manual control irrigation** | **2.06 b** | **7.12 b** | **18.63 b** | **76.18 b** | **181.13 b** | **1.37 b** | **5.21 b** | **16.30 b** | **63.71 b** | **160.38 b** |

Letters indicate statistical significance at α = 0.05 level within “a” and “b”

**Table.7** Water applied and yield comparison with respect to the commercial field in automatic based drip irrigation in tomato

| Treatment | Water applied (mm) | Yield (kg/ha) |
|---|---|---|
| **T-10 cbar** | 112 | $36602^{a,b}$ |
| **T-15 cbar** | 91 | $39096^{a}$ |
| **WM-10 cbar** | 182 | $40584^{a}$ |
| **WM-15 cbar** | 172 | $40889^{a}$ |
| **Time – 100%** | 185 | $40638^{a}$ |
| **Time – 150%** | 262 | $28153^{b}$ |
| **Farmer Control** | 335 | $45243^{a}$ |

$^{a,b,c}$ Different letters depict statistically different means at $P \leq 0.05$

**Table.8** Influence of solar powered automated and non automated fertigation system on yield parameters of cucumber

| Treatment | No. of fruits/plants | Length of the cucumber fruit (cm) | Total yield (t/ha) |
|---|---|---|---|
| **T1 – Fertigation with developed system** | 29.12 | 21.35 | 23.86 |
| **T2 – Manual application in polyhouse** | 10.50 | 20.70 | 7.71 |
| **T3 – Manual application in open field** | 7.25 | 17.27 | 3.63 |
| **SEd** | 2.26 | 0.77 | 1.16 |
| **CD (P=0.05)** | 5.38 | 1.62 | 2.24 |

**Table.9** Automatic irrigation experiments in plum tree

| Yield | Treatment | 2017 | 2018 |
|---|---|---|---|
| **Yield (kg/ha)** | C | 4076 ± 414.82 | 14491 ± 1090.55 |
| | RDI | 6229 ± 587.07 | 16448 ± 1538.96 |
| | A | 7228 ± 818.03 | 19908 ± 1447.29 |
| | Significance | * | * |
| **Number of fruit/trees** | C | 130 ± 14.31 | 404 ± 29.08 |
| | RDI | 203 ± 19.21 | 456 ± 50.78 |
| | A | 237 ± 27.50 | 485 ± 34.86 |
| | Significance | * | NS |

* Indicates significant differences according to Duncan's multiple range test (p = 0.05); NS indicates not significant

**Table.10** Yield in soil moisture based automated gravity fed drip irrigation system for cabbage

| Treatments | Yield (kg/ha) |
|---|---|
| **Control irrigation** | 16875 |
| **Sensor based** | 19500 |

**Table.11** Water saving in okra under automated irrigation for 1 ha area

| Treatment | Water Saved over check basin irrigation |
|---|---|
| **Check basin irrigation** | …… |
| **Furrow irrigation** | 17.43 |
| **Drip irrigation** | 36.21 |
| **Automated check basin** | 13.61 |
| **Automated furrow** | 28.00 |
| **Automated drip irrigation** | 45.64 |

**Table.12** Recommended daily doses in the irrigation of the tomato under greenhouse by PC based irrigation

| Period | Dose (L/plant/day) | Dose (L/plant/period) |
|---|---|---|
| **August-sep** | 2 | 2 x 60 =120 |
| **Oct - Nov** | 1.5 | 1.5 x 60= 90 |
| **Dec - Feb** | 0.5 | 0.5 x 90 = 45 |
| **Mar - April** | 1 | 1 x 60 = 60 |
| **Total** | | **5670$^3$/ha** |

**Table.13** Effects of the AIS and CIS on wheat and tomato water use efficiency during the growing season

| Irrigation treatment | Wheat | | Tomato | |
|---|---|---|---|---|
| | WUE (kg/m$^3$ | IWUE (kg/m$^3$) | WUE (kg/m$^3$ | IWUE (kg/m$^3$) |
| **AIS (2013-14)** | 1.27 | 1.12 | 7.5 | 6.56 |
| **CIS (2013-14)** | 1.13 | 1.06 | 5.72 | 4.7 |
| | | | | |
| **AIS (2014-15)** | 1.64 | 1.37 | 7.15 | 6.32 |
| **CIS (2014-15)** | 1.47 | 1.21 | 5.33 | 4.3 |

**Table.14** Automatic irrigation control for soilless culture of lettuce

| | Irrigation/ m3 | Drainage/ m3 | FW/kg | IWUE/kg m3 | Irrigation/ m3 | Drainage/ m3 | FW/kg | IWUE/kg m3 |
|---|---|---|---|---|---|---|---|---|
| **Intelligent irrigation** | 6.18 a | 0.53 A | 12.67 a | 2.05 a | 7.48 A | 0.736 A | 10.71 a | **1.43 A** |
| **Manual control irrigation** | **8.89 b** | **2.21 B** | **10.87 b** | **1.22 b** | **13.33 B** | **3.59 B** | **9.62 b** | **0.72 B** |

Letters indicate statistical significance at α = 0.05 level within “a” and “b”

**Table.15** Estimated amount of water for different irrigation techniques in paddy cultivation

| Stages of growth | Manual – flood irrigation (mm) | Drip irrigation (mm) | Smart drip irrigation method (mm) |
|---|---|---|---|
| **Field preparation** | 200–300 | 200–300 | 200–300 |
| **Planting** | 400– 450 | 300–400 | 300–350 |
| **Flowering** | 400– 450 | 100–200 | 100–150 |
| **Maturity** | 100–150 | 50–100 | 10–25 |
| **Total span (100%)** | 1100–1350 | 650–1000 | 610– 825 |
| **Average** | 1225 | 825 | 717.5 |
| **Percentage utilization of water** | | | |
| **With respect to flood irrigation** | 100 | 67.35 | 58.57 |
| **With respect to drip irrigation** | 148.8 | 100 | 86.97 |
| **With respect to Smart drip irrigation** | 170.73 | 114.98 | 100 |

**Table.16** Cost and economics in okra under automated irrigation for 1 ha

| Treatment | Cost of Production (Rs/ha) | Crop Yield (t/ha) | Gross income Rs/ha) | Net Returns Rs/ha) | BC ratio |
|---|---|---|---|---|---|
| **Check basin irrigation** | 55648 | 6.7 | 88140 | 32492 | 1.58 |
| **Furrow irrigation** | 58850 | 9.73 | 126490 | 67640 | 2.15 |
| **Drip irrigation** | 72345 | 16.6 | 215800 | 143455 | 2.98 |
| **Automated check basin** | 69050 | 9.63 | 125190 | 56140 | 1.81 |
| **Automated furrow** | 72350 | 13.68 | 177840 | 105490 | 2.46 |
| **Automated drip irrigation** | 85550 | 23.63 | 307190 | 221640 | 3.59 |

**Fig.1** Automatic irrigation system in paddy using WSN (Redirection of water in farm)

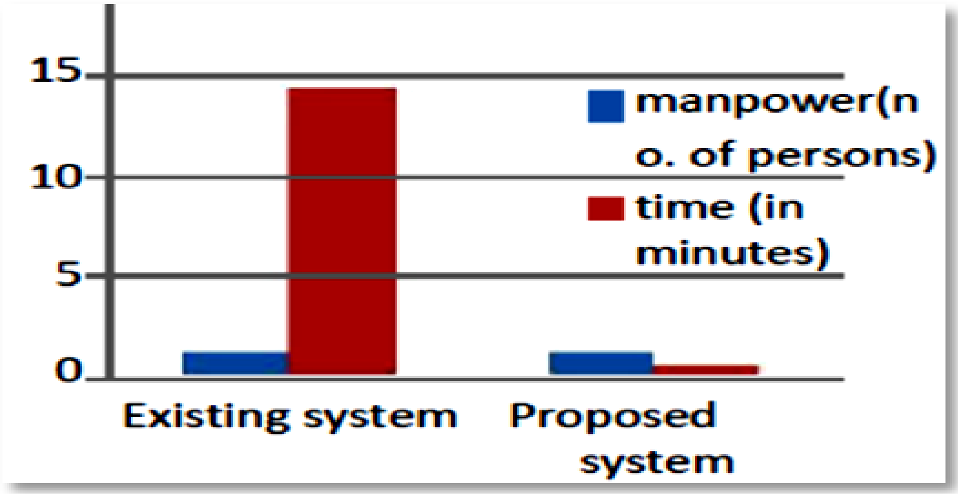


**Fig.2** Automated sensor-based control technology in strawberry

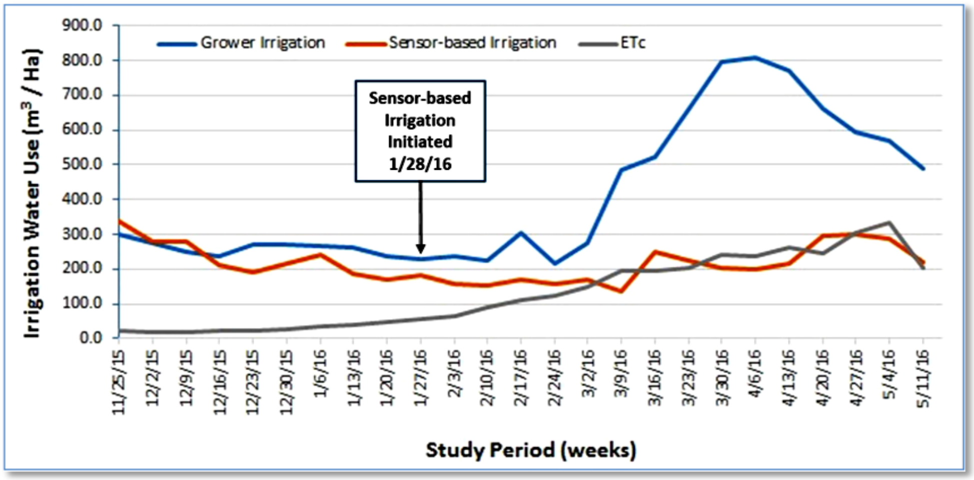
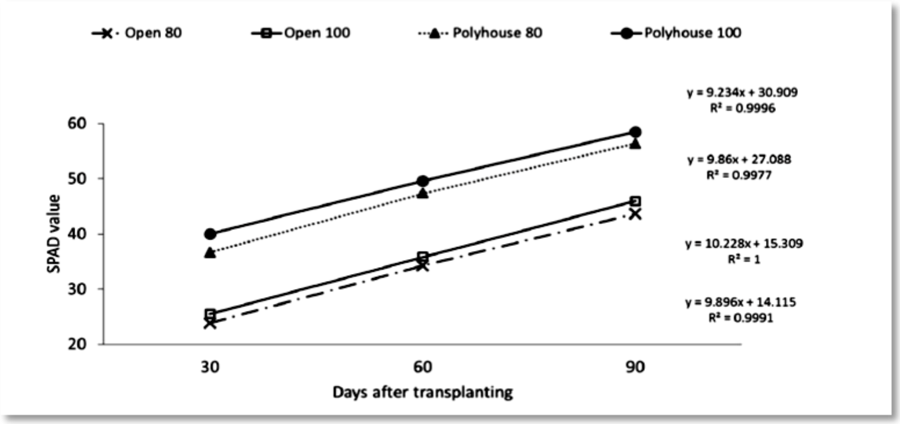


**Fig.3** Variation in SPAD value as affected by the growing environment × irrigation level × different days after transplanting interaction in capsicum



Sathya *et al.,* (2016) proposed system develops an automated irrigation system in rice to direct the water flow in the paddy fields (Fig 1). This system uses water level sensors to identify the water level in the field and also the moisture sensors to identify the moisture level in the soil and change the flow of water to the next farm accordingly. The system automatically irrigates the field through the entrance valve when the water level is lower than the threshold level and also according to the moisture of the soil. The entrance valve closes after the water level reaches the threshold level and also the GSM modem sends SMS about the time taken to fill the farm with water to the farmer. In the existing system the farmer has to direct the water towards the desired farm manually. Farmer needs to go directly to the field to direct the water to the next farm. Farmers have to monitor the water level continuously to direct the flow of water. The proposed system guarantees the efficient usage of water and also prevents the damage of crops due to overflow of water.

Guery *et al.,* (2016) studied on automated sensor-based control technology in strawberry (Fig 2). Soil moisture was monitored with loggers which are connected with sensors at 10 and 20 cm below the root zone depth. Sensor controlled irrigation was initiated when volumetric moisture content decreases below the set point 19% and reported that during the 15 weeks of the study (January 27-May 11, 2016), pulse-irrigation applied 7,618 $m^3$ $ha^{-1}$ of irrigation water in 2-5 pulses $day^{-1}$, compared to3,141 $m^3$ $ha^{-1}$ applied with sensor based control (58.8 % less water).

Al-Ghobari *et al.,* (2017) studied the effect of controllers using drip and sprinkler irrigation systems in tomato and wheat for two successive seasons and reported that the water use efficiency (WUE) and irrigation water use efficiency (IWUE) were typically higher in the AIS than in the conventional irrigation control system (CIS) (Table 13). Under the AIS treatment, the WUE and IWUE values were 1.64 and 1.37 kg $m^{-3}$ for wheat, and 7.50 and 6.50 kg $m^{-3}$ for tomato; under the CIS treatment the values were 1.47 and 1.21 kg $m^{-3}$ for wheat and 5.72 and 4.70 kg $m^{-3}$ for tomato, respectively. Therefore, the AIS provided significant advantages in both water savings by utilizing upto 27% in wheat and 26% in tomato less water than the CIS, and simultaneously generating higher total yields. The automated irrigation system technique may be a valuable tool for conserving water and scheduling irrigation for wheat and tomato crops, and may be extendable to other similar agricultural crops.

Liu and Xu (2018) studied automatic irrigation control for soilless culture of lettuce (Table 14) and found that the intelligent irrigation reduce the irrigation amount, drainage amount and increase the IWUE compared to the manual control irrigation, the IWUE of intelligent irrigation is 68.03% and 98.61% higher than manual control irrigation in spring and summer, respectively.

Barkunan *et al.,* (2019) proposes an automation of drip irrigation in which the Smartphone initially captures soil image, calculates its wetness level and transmits the data onto the microcontroller through GMS module intermittently (Table 15). The microcontroller decides the irrigation and sends the status of the field to the farmer's mobile phone. The system is tested for paddy field for over a period of three months. It is observed from the experimental setup, that it saves nearly 41.5% and 13% of water compared to the conventional flood and drip irrigation methods respectively.

## Effect of automated irrigation on photosynthesis and spad value

Boutraa *et al.,* (2011) studied on two different water irrigation regimes, 80% and 40% of the field capacity which are controlled using humidity sensors connected to a micro-controller that detects the water quantity and compensates for water loss in the soil and the results showed that at 40% water treatment, the photosynthesis rate declined significantly ($p < 0.05$) in plants irrigated manually, while in plants irrigated by the automatic system had no decline, and this was observed even at 1500 µmol quanta of photosynthesis active radiation (PAR). Higher photosynthetic rate is the indication of high biomass production and higher yield.

Jat *et al.,* (2019) studied on automation of micro-climate control through sensors and controllers under open-field and polyhouse culture, at irrigation levels of 80% or 100% of crop evapotranspiration in capsicum (Fig 3) and reported that programmable logic controller-based automation system worked well for micro-climate control leading to 93% and 53% higher yield and fruit weight, respectively in the polyhouse than open-field cultivation. The SPAD value increased with increase in plant growth up to 90 DAT in all treatments. At 90 DAT, maximum SPAD value (58.5) was in the polyhouse due to the 100% ETc treatment.

The SPAD value was lower in open field compared to the polyhouse for corresponding DAT. Optimum micro-climatic conditions inside the polyhouse led to better growth and might have resulted in higher chlorophyll content. Similarly, higher soil moisture availability in the 100% ETc treatment might have resulted in better water and nutrient uptake.

## Economics of automated irrigation

Kumar (2017) conducted experiment to test the performance evaluation of indigenously developed automated system on vegetable crops under different methods of irrigation and reported that water productivity increased under automated drip irrigation system (Table 16). The results revealed that the higher net income and maximum BCR registered under automated drip irrigation.

## Merits and demerits of automated irrigation

### Merits

An automated micro irrigation system increases crop yield, save water and energy and labour costs as compared with the manual system. The automated irrigation system starts watering just at the predetermined level of moisture content and stops irrigation as the desired soil moisture content or field capacity is attained. The system accounts for effective rainfall to schedule irrigation, eliminates the need to visit the farm frequently and ensures optimum soil water condition in the root zone. This prevents leaching of minerals and nutrients vital for the plant's healthy growth and eliminates the long term ill-effects of over irrigation that leads to development of the salinity. The system is useful for both arid and humid areas where unpredictable and unevenly distributed rainfall disrupts a fixed irrigation schedule. This system also facilitates high frequency and low volume irrigation.

**Reduced labour:** As the irrigator is not required to constantly monitor the progress of irrigation, the irrigator is available to perform other tasks uninterrupted.

**Improved life style:** The irrigator is not required to constantly check the progress of water down the bays being irrigated. The irrigator is able to be away from the farm, relax with the family and sleep during night.

**More timely irrigation:** Irrigators with automation are more inclined to irrigate when the plants need water, not when it suits the irrigator.

**Assists in the management of higher flow rates:** Many irrigators are looking to increase the irrigation flow rates they receive through installing bigger channels and bay outlets. Such flow rates generally require an increase in labour as the time taken to irrigate a bay is reduced thus requiring more frequent change over. Automation allows for these higher flows to be managed without an increase in the amount of labour.

**More accurate cut-off:** Automation of the irrigation system allows cut-off of water at the appropriate point in the bay. This is usually more accurate than manual checking because mistakes can occur if the operator is too late or too early in making a change of water flow.

**Reduced runoff of water and nutrients:** Automation can help keep fertiliser on farm by effectively reducing runoff from the farm. Retaining fertiliser on farm has both economic and environmental benefits.

**Reduced costs for vehicles used for irrigation:** As the irrigator is not required to constantly check progress of irrigation, motor bikes, four wheelers and other vehicles are used less. This reduces the running costs of these vehicles and they require less frequent replacement.

### Demerits

**Cost:** There are costs in purchasing, installing and maintaining automatic equipment.

**Reliability:** Can the irrigator trust an automatic system to work correctly every time. Sometimes failure will occur. Often these failures are because of human error in setting and maintaining the systems. A reuse system is good insurance to collect any excess runoff when failures occur.

**Increased channel maintenance:** There is a need to increase maintenance of channels and equipment to ensure the system works correctly. Channels should be fenced to protect the automatic units from stock damage.

In conclusion the automation results in higher production, increased productivity, better quality, improved safety, shorter workweeks for labour. Automated systems typically perform the irrigation process with less variability than human workers, resulting in greater control and consistency. Also, increased process control makes more efficient use of irrigation water, resulting in less water consumption or high water use efficiency. Automated irrigation systems (AIS) can save man power, reduce use of natural resources, dependency on rainfall can be avoided, improve quality and production efficiently, mix the fertilizers in the required ratio for the crops and feed it through the irrigation lines and also maintains the soil moisture content at optimum levels, thereby helping the farmers to increase their yield.

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