



Development of an IoT based weighing type micro-lysimeter for soilless cultivation

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Received: 30 January 2020; Accepted: 20 October 2020

ABSTRACT

In the present study, an attempt has been made to apply Internet of Things (IoT) for precise irrigation management. A weighing type micro-lysimeter based on IoT was developed to measure the amount of water consumed by the cucumber crop grown in soilless media under naturally ventilated greenhouse conditions at the Research Farm of Punjab Agricultural University, India. The developed system consisted of two components, i.e. hardware assembly and web-based application. The hardware assembly consists of load cells, a weight sensing module, i.e. HX711 module and a micro controller, i.e. arduino assembled in the control box of the weighing balance. A modular code was written in arduino to record the weight readings. The stored data in the microcontroller was sent to a web based application via wifi. The weight changes at the lysimeters due to irrigation, drainage and evapotranspiration were monitored in real time through an IoT platform, i.e. Thingspeak. Three lysimeters were placed at different locations to account for the slight variations in micro-climate within the greenhouse. The positive flux i.e. irrigation and negative flux, i.e. (leachate+ actual evapotranspiration (ET_c)) from the lysimeter were derived from the IoT platform. Irrigation and leachate from the lysimeter was also measured manually to verify the accuracy of the readings obtained from the IoT platform. The study showed that IoT based lysimeters presents a reliable and convenient way to measure ET_c as there was a good agreement ($R^2 > 0.98$) between irrigation component derived from IoT and actual irrigation applied.

Key words: Evapotranspiration, Greenhouse, IoT, Lysimeter, Soilless

Water has always been a limiting resource, both in terms of quantity and quality. Therefore, optimum irrigation is necessary, in terms of profitable agriculture to attain best level of production. As 80% of the available water is utilized in agriculture (Dhawan 2017), proper irrigation scheduling of the crops is required for efficient utilization of these scarce water resources. Calculations of irrigation scheduling are based on the estimations of crop water requirements (CWR). As 99% of the water used by the crop is in the form of evapotranspiration (ET) (Rana and Katerji 2000), it is important to measure ET accurately for all the crops.

There are many direct and indirect methods by which ET can be calculated or estimated but the use of lysimeters have long been considered as a standard method for actual measurement of ET and for validation of reference ET equations (Jensen 1974; Doorenbos and Pruitt 1977, Allen *et al.* 1989). A more detailed information on the use of lysimeters for ET can be found in Harrold (1966); Aboukhaled *et al.* (1982); Howell *et al.* (1985); Marek *et al.* (1988). Lysimeter is a device which essentially works

on the principle of soil-water-balance approach. The daily weight changes at the lysimeters are monitored regularly with the load cells or weighing balances to measure actual crop ET (Howell *et al.* 1985). Weighing lysimeters presents the most accurate data and ET can be determined accurately over periods as short as 30 min. (Allen *et al.* 2011). Lysimeters of many different designs, sizes, shapes, and measurement systems have been built over the years. Boast and Robertson (1982) introduced a new concept of micro-lysimeter and deviations were quantified with the traditional bigger lysimeters. Tyagi *et al.* (2000) used rectangular lysimeters for crops like rice, maize, sorghum, wheat, berseem and sunflower using water balance approach to compute the crop ET from the lysimeters. Abedi-Koupai *et al.* (2011) measured and modelled the water requirement for cucumber, tomato, and pepper using micro-lysimeter inside the greenhouse. The ET_c for cucumber crop was found to be 202 mm for a period of 3.5 months.

The concept of precise irrigation is already being used in agriculture to improve the water-use efficiency of the crops. Wireless Sensor Networks (WSN) are slowly being adopted to improve the efficiency in agriculture (Mendez *et al.* 2012; Liu *et al.* 2007). The WSN comprises various sensors that monitor physical and environmental conditions like temperature, relative humidity, solar radiation, soil

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moisture, etc and transmit that information to a base station to either control or monitor the factors which affect crop growth and yield. Various IoT platforms are now being used for crop monitoring and analysis, to optimise irrigation and for disease detection. The IoTs have recently been applied in many studies concerned with agriculture. Muangprathub *et al.* (2019) designed and developed a WSN based control system to analyse irrigation of agricultural crops and further applied knowledge discovery to optimize water requirement of the crops according to the season. Sarangi *et al.* (2016) proposed an agricultural support system based on IoT repository, i.e. Wisekar to implement a distributed Automated Crop-disease Advisory Service (ACAS) that guides the users about information on various crop diseases. Zamora-Izquierdo *et al.* (2019) designed, developed and evaluated an IoT based platform for irrigation requirements of tomato in soilless culture in a recirculation greenhouse based on edge and cloud computing. Kim *et al.* (2011) used a distributed WSN to develop a passive capillary wick type (PCAP) wireless lysimeter for web-based real-time monitoring of drained water and in-field weather data on the internet. He showed that WSN lysimeters offers a reliable and convenient way to measure drainage water volume and flux in the vadose zone as a good agreement was found between the estimated and measured discharge.

In the present study, an attempt has been made to extend the use of IoT for development of IoT based weighing-type lysimeters to measure the actual water consumed by the soilless crops under naturally-ventilated greenhouse conditions. The use of lysimeters for measurement of ET is prevalent for quite a long time, but literature pertinent to water consumed by the crops grown in soilless medium is very limited. The physiochemical properties of soilless medium are quite varied in comparison to soil, so the crops grown in soilless medium consumes water differently as compared to crops grown in soils.

MATERIALS AND METHODS

Development of the lysimeter

A weighing type micro-lysimeter based on automatic weighing monitoring system was developed to determine the water requirements of cucumber crop grown in pre-fabricated cocopeat slabs as soilless medium under naturally ventilated greenhouse conditions. Lysimeter had two major components, i.e. weighing platform and control unit with Liquid Crystal Display (LCD). The specifications of the weighing platform are given in Table 1.

The cocopeat slab was rectangular in shape. It has dimensions of 97.5 cm × 15.0 cm × 2.8 cm (0.0041 m³) when unsaturated but after saturating it the changed dimensions were recorded as 100 cm × 15 cm × 10 cm (0.015 m³).

The upper surface of the slab supported by the iron frame had 3 square openings of size 7.5 cm × 7.5 cm in which the transplanted seedlings were placed and these openings were spaced at 30 cm from center to center as shown in Fig 1. The slab was placed on the weighing

Table 1 Specifications of the precision weighing balance

Particular	Specifications
Company	Digitone Accurate Weighing Balance
Model No	DGT30
Platform dimensions	35 cm × 35 cm
Maximum Load	30 kg
Least count	5g

platform and the change in weight due to irrigation, leachate and evapotranspiration (ET_c) were recorded after every 5 min. The leachate term here refers to the amount of excess water drained from the slab after irrigation has been done.

An iron structure was built to support the creepers and train the plants vertically upwards such that the entire weight of the lysimetric assembly should remain focused on the load-cell itself. The dimensions of the iron structure are given in Table 2 and the base dimensions are represented in Fig 2. The base dimensions of the frame were made slightly larger than the surface area of the cocopeat slab to fully support the slab on the weighing balance. A wooden board 10mm thick having base dimensions similar to that of iron frame was placed beneath the iron-frame to prevent the frame from bending sideways. The spacing tray was placed inside the plastic trough and the leachate was collected in the plastic trough. Nylon strings tied with non-slipping loops were used to train the plants vertically upwards till the height of the frame, i.e. 1.8 m.

Design, overview and implementation of the micro-lysimeter

The present experiment aims for continuous weight

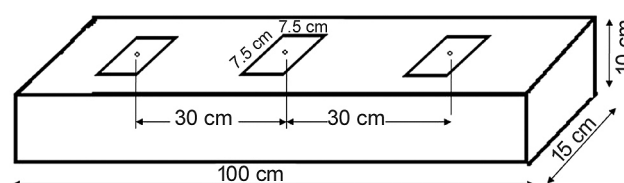


Fig 1 Detailed dimensions of the slab.

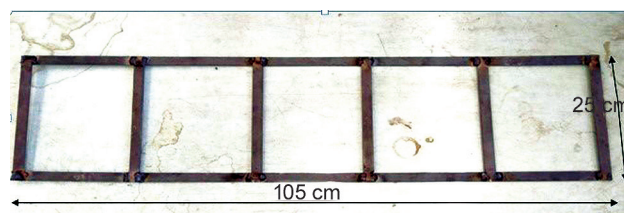


Fig 2 Base dimensions of the frame.

Table 2 Specifications of the iron structure

Particular	Specifications
Width of the iron strip	1.90 cm
Thickness of the iron strip	2.54 mm
Base dimensions	105 cm × 25 cm
Height of the frame	1.8 m

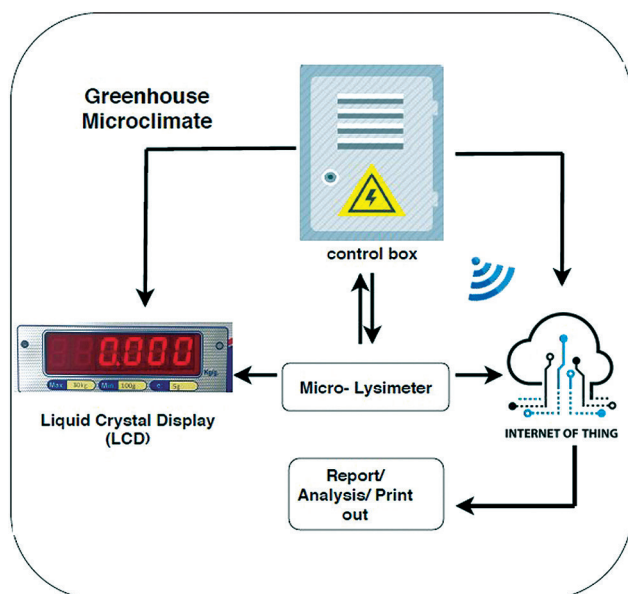


Fig 3 An overview of the system.

sensing through a micro-lysimeter and data monitoring mechanism using a cloud for web-based application. The greenhouse microclimate affects the weight changes at the lysimeter as shown in Fig 3.

The hardware assembly was installed inside the control box of the analytical weighing balance. The load cell used here consists of four strain gauges. The four wires coming out of the load cells are red for excitation+ (E+), black for excitation- (E-) or ground, white for Output+ (O+) and green for Output- (O-). The load-cells convert the weight placed on it into an electrical signal which is sensed by a weight sensing module, i.e. HX711 module. This module amplifies the electrical signal obtained from load cell (in mill volts) and converts the analog signal into a digital signal with inbuilt 24 bit A/D converter. It is a high-precision, low-cost front-end module that eases the communication between the load cell and microcontroller. The module specifications are given in Table 3.

This module was then connected to a microcontroller board, i.e. arduino uno. A modular code was written in arduino to record the weight readings every five minutes. For digital display of the weight reading, LCD (Liquid Crystal Display) was also connected to the arduino board. The arduino accesses the internet via wifi connection

Table 3 Specifications of HX711 Module

Particulars	Specifications
Data accuracy	24 bit (24 bit analog-to-digital converter chip)
Refresh frequency	10/80 Hz
Operation supply voltage range	4.8 ~ 5.5V
Operation supply Current	1.6mA
Operation temperature range	-20 ~ +85°C
Dimensions	36mm × 21mm × 4mm / 1.42" × 0.83" × 0.16"

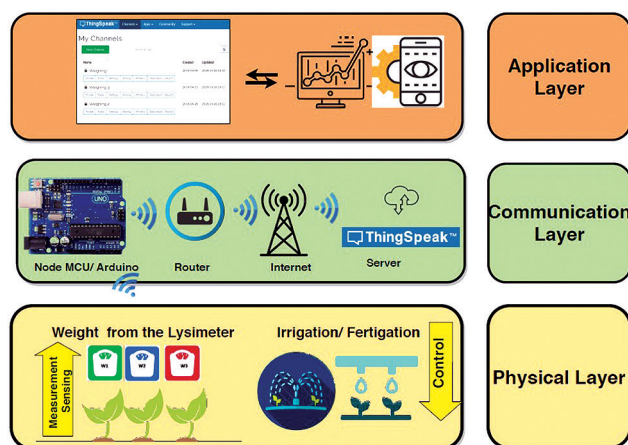


Fig 4 The architecture of the IoT system.

through ESP8266 module. A modem was installed inside the greenhouse for internet connectivity. The readings were stored on the IoT platform, i.e. Thingspeak platform. It is an open source IoT application that stores and retrieves data using the HTTP protocol via Internet. The specifications of the IoT platform are given in Table 4. Three different channels were created on the platform for the three lysimeters to record the weight readings in real time.

The formal mechanism in the proposed system along with the system architecture is shown in the Fig 4. It consists of a physical layer, data communication layer and application layer. The physical layer is designed to collect data on weight changes from the lysimeters. The data communication layer shows the interaction between the arduino and the IoT platform and the storage of the data on the server. Finally, the application layer uses the accumulated data to monitor and control the irrigation requirements of the crop.

Field experimentation

The experiment was conducted inside a naturally ventilated greenhouse at the Research Farm of Department of Soil and Water Engineering, Punjab Agricultural University (PAU), Ludhiana. The site is located between a latitude of 30°56'N and longitude of 75° 52' E at an altitude of

Table 4 Specifications of the IoT platform

Particulars	Specifications
Website	thingspeak.com
Source	Open source IoT platform
Network	Internet or Local Area Network
Repository	github.com/iobridge/thingspeak
Written in	Ruby language (interpreted, high-level, general-purpose programming language, developed in mid-1990s)
Operating system	Cross-platform
Available in	English, Italian, Brazilian Portuguese
Type	API (Application Programming Interface)
License	GPL version 3 (GNU General Public License)

247 m above the mean sea level. The greenhouse was facilitated with ventilation from all four sides and the top. The ventilation from the sides was adjustable and the top ventilation was fixed. It was a double span greenhouse oriented in North-South direction having a floor area of about 560 m².

Soiless slabs containing cocopeat were used to grow cucumber inside the greenhouse. These slabs were laid in double vertical rows, i.e. 2 grow slabs were laid length wise side by side to form a double vertical row. Each plastic trough consisted of 40 slabs placed together and each slab had 3 plants. There were a total of 10 rows inside the greenhouse.

PBRK-4 variety of cucumber seeds was used to raise the nursery in conical cell trays. The nursery was raised in cocopeat medium in a poly house having a thickness of 200 µm and a shade net of height 1.80 m above the floor. The nursery was sown on March 15, 2018. The seedlings were transplanted in the cocopeat slabs 15 days after sowing (DAS). The cocopeat slabs were saturated with the nutrient solution for 24-hr via drip irrigation before transplanting in the lysimeters. The weight changes at the lysimeters were monitored for the entire crop duration over a period of 80 days.

A combination of both macro and micro-nutrients were supplied in a fixed proportion in soluble form for proper growth of the crop. The macro-nutrients applied were nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). The micronutrients include boron, iron, manganese, copper, zinc and molybdenum were applied in lesser quantities. The EC of the growing medium and pH of the nutrient solution were also monitored regularly. The plant height was measured weekly and the Leaf area index (LAI) values were measured at an interval of 15 days.

Site selection and installation of the lysimeter inside the greenhouse

The overall slope of the greenhouse is in North-South direction. The lysimeters were placed along the longitudinal diagonal of the greenhouse to account for minute variations in micro-climate at these locations inside the greenhouse and thus, give an average value of crop evapotranspiration (ET_c) from the three lysimeters. The surface beneath the lysimeters was levelled with the help of spirit level. A slope of 1% was given on the top of the balance for draining the excess water from the slab. The front view and side view

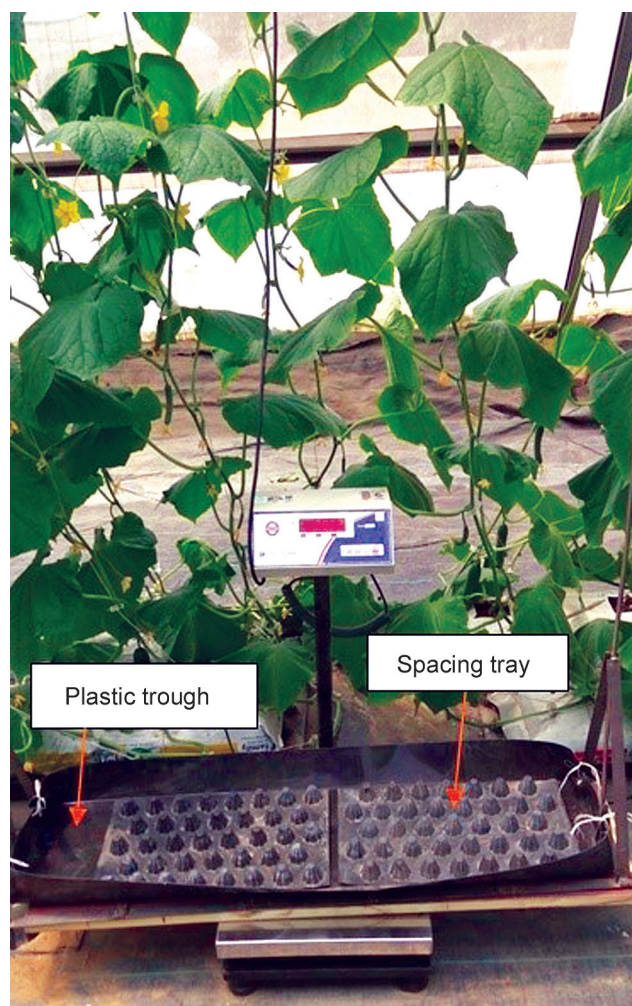


Fig 5a. Front view of the lysimeter



Fig 5b. Side view of the lysimeter

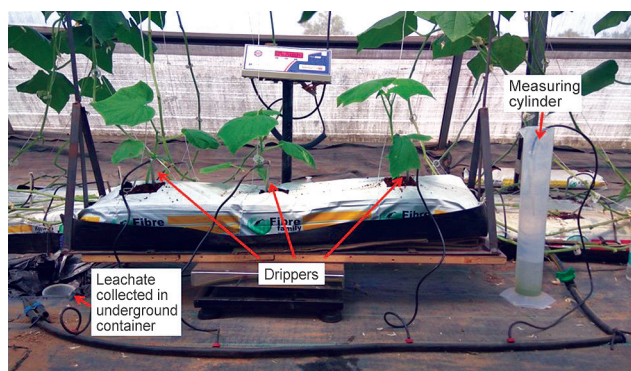


Fig 5c. Complete assembly showing the measuring cylinder and the drained water with the lysimeter

of the lysimeter are shown in Fig 5a and 5b respectively. The complete assembly of the lysimeter is as shown in the Fig 5c.

Measurement of actual evapotranspiration (ET_c)

The crop ET_c was measured directly by the daily weight changes occurring at the lysimeter. The irrigation was applied in a way that the leachate is not more than 30% of the applied irrigation. The irrigation was applied to the plant in lysimeters through drip emitters having discharge rate of 2 Litres (L)/Hour. Multiple irrigations of short durations were applied in a day starting from 1-2 irrigations per day in the initial stages of crop growth to 4-5 irrigations per day during later part of the crop growth period. The increase in weight of the lysimeter is indicative of the total irrigation applied, which was stored on the IoT platform. An extra dripper attached to the lateral was collected in a measuring cylinder. The irrigation applied in a day was measured manually to compare the actual irrigation readings with the ones stored at the IoT platform. Since three such drippers were irrigating a lysimeter, the discharge from a single emitter was multiplied with three to obtain the total amount of actual irrigation applied in a day. The excess water from the lysimeter was collected in the plastic trough. The excess water was drained in the plastic trough. The water from the trough was collected in a 2L beaker, placed below the ground surface, through a drain pipe connecting the trough and the beaker. These measurements were recorded for the entire crop season of 80 days. The ET_c from the lysimeters was calculated on a daily basis using the following equation.

$ET_c = \text{Irrigation water applied to the lysimeter} - \text{Leachate} \pm \text{Weight change at the lysimeter}$

$$\text{i.e. } ET_c = I - D \pm \Delta S \quad (1)$$

Here, the weight changes (in kg) were logged every 5 min but for the ease of calculations, values of ET were summed for the day to give daily values of ET_c . These weight changes, i.e. ΔS (in kg) were converted to equivalent depth of water (in mm) by dividing ΔS by the density of water (1 g/cm^3) and the surface area available to the plants of the lysimeter.

RESULTS AND DISCUSSION

The proposed lysimeters were designed to apply IoT technology in the field of agriculture. The weight changes in the lysimeters as a result of irrigation, drainage and ET from a fixed mass of growing medium were stored and monitored on IoT platform. The Fig 6a shows an example web page of the IoT platform Thingspeak giving channel information about the three lysimeters installed at different locations within the greenhouse. The data on weight change from the lysimeters was logged in a csv format which was exported to the laptop. The csv file was converted to excel file to extract the relevant information as shown in Fig 6b.

Computation of actual crop evapotranspiration (ET_c)

The positive flux, i.e. irrigation and the negative flux, i.e. ($\text{Leachate} + ET_c$) of the lysimeter were derived from the readings stored at the IoT platform. The ΔS value was calculated as the difference between the lysimeter weight at one day interval. The leachate values were taken from daily observations. The ET_c of the crop was calculated according to the Equation (1). The total crop growth period of 80 days was divided according to the stages of crop development, i.e. initial, development, mid-season and end season and the amount of irrigation, leachate and ET_c values obtained during the different stages are given in Table 5. And the individual components are discussed in the following subheads.

Irrigation

The total amount of irrigation water applied was more or less similar for all the three lysimeters, i.e. 288.01, 287.15 and 290.24 litres of water were applied during 80 days of crop growth period to lysimeter 1, 2 and 3 respectively. It can be said that the initial water requirements of the plants in lysimeters is quite low as the crop cover is less

Table 5 Amount of irrigation and drained water in different lysimeters

Crop stage	Duration (Days)	Lysimeter 1			Lysimeter 2			Lysimeter 3		
		Irrigation (L)	Leachate (L)	ET_c (mm)	Irrigation (L)	Leachate (L)	ET_c (mm)	Irrigation (L)	Leachate (L)	ET_c (mm)
Initial	10	7.73	2.29	9.92	7.93	2.02	11.11	8.47	2.06	12.73
Development	20	50.23	8.81	70.22	50.24	7.24	73.87	49.46	7.29	71.25
Mid-season	40	201.45	40.31	274.13	200.38	38.41	275.5	203.11	35.48	285.17
End-season	10	28.6	5.05	43.63	28.6	5.24	43.22	29.2	4.12	46.56
Total	80	288.01	56.46	397.9	287.15	54.35	403.7	290.24	48.95	415.71

and the water requirement increases as the plant enters the development stage. The amount of water applied is highest in the mid-season because of increase in biomass, crop cover and yielding of fruits during this stage. Nearing the end of the growth period, less amount of water was applied as the plant stopped yielding the fruits.

The irrigation component is the only positive flux in the lysimeter. In order to evaluate the accuracy of the readings stored at the IoT platform, the actual irrigation measured in the measuring cylinder on daily basis was compared with the irrigation component derived from the IoT platform. The Mean Absolute Error (MAE) was found to be 0.22 and the Root Mean Square Error (RMSE) was 0.28. An $R^2 > 0.98$ between the actual irrigation and the IoT readings was obtained for all the three lysimeters as shown in Fig 7. It was observed that the readings stored on the IoT generally underestimate the irrigation component slightly. This may be due to fact that the total irrigation applied in a day was calculated from IoT platform by adding the increase in weight recorded at the time of irrigation, however, during this period itself there may be some drainage too, which slightly reduces the recorded irrigation value. A straight line was also fitted into the data points and a corrected function for IoT readings of irrigation was developed given by

$$y = 1.031x + 0.115$$

where, y = Actual Irrigation x = Irrigation obtained through IoT platform.

This corrected function for actual irrigation can be feed into the IoT platform for improving the value of IoT based irrigation for the next season.

Leachate

The total leachate from the 3 lysimeters during total crop growth period was 56.46, 52.92 and 48.95 litres respectively. It was observed that the location of the lysimeters inside the greenhouse affects the amount of water consumed by the crop. Since, lysimeter 3 was placed on the outward side of

the last row, where direct radiation was encountered between 8:00 to 11:00 AM, it consumed more amount of water as compared to the other two lysimeters; thereby giving least leachate. Lysimeter 2 also gave less drainage than lysimeter 1 as it was placed in the centre of the greenhouse just below the meeting point of the two shade nets. It resulted in slightly higher ET_c as there was a gap between the shade nets. During the end stage of the crop growth, the amount of drained water was negligible since less water was supplied as crop stopped yielding fruits.

Change in storage

The ΔS represent the constant storage component of the lysimeter. In the later part of the crop growth, the weight reduces drastically in all the three lysimeters. This is because towards the end of development stage, the crop growth becomes stagnant and the applied irrigation was reduced, so the lysimeter compensates the water requirement from the stored water. In general, negative values of ΔS signify the amount of water used by the crop when the irrigation component was not sufficient enough to meet the crop ET_c . Positive values of ΔS suggests an addition to the constant storage when extra water is applied. When the applied irrigation is more than the CWR, the lysimeter stores a part of it for future needs in later period. All the three lysimeters show a similar trend with respect to the change in the weight of the lysimeter.

Actual evapotranspiration (ET_c)

The total amount of actual evapotranspiration was 397.9 mm, 403.7 mm and 415.717 mm from lysimeter 1, 2 and 3 respectively. The average ET_c values during initial phase of crop development ranges from 0.66- 1.54 mm/day, rises up to 6.74 mm/day during the development phase, the values become constant during the mid-season and ranges between 5.71- 7.78 mm/day and again decreases to 3.15mm/day during senescence. The ET_c is lesser during the initial stage of crop development. After about 10-15 days, the ET_c values start increasing gradually with the development of the crop and

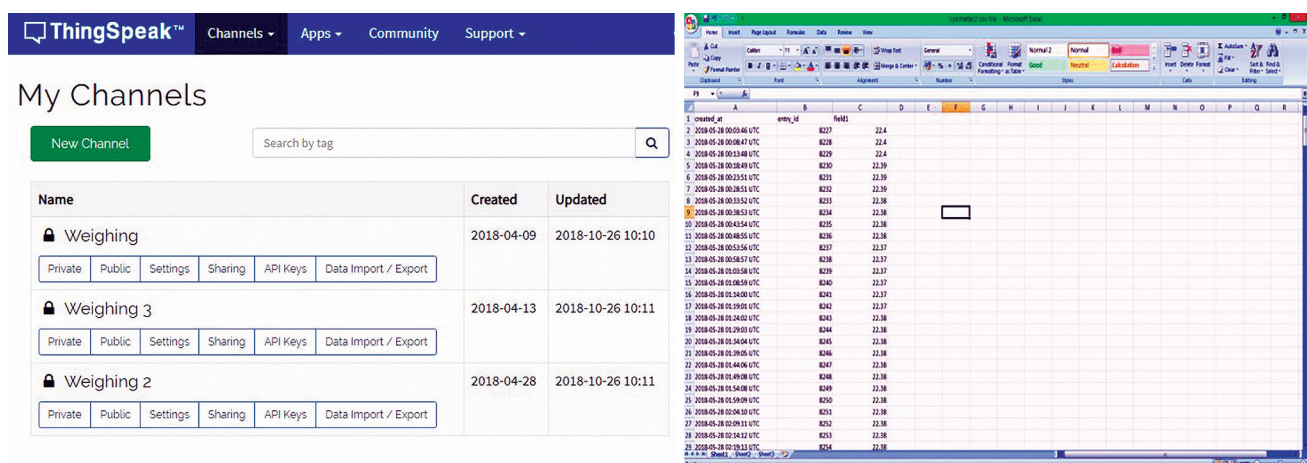


Fig 6 a. An example web page of the IoT platform giving channel information on all the three lysimeters. b. Sample CSV file downloaded from the IoT platform on weight information from the lysimeter.

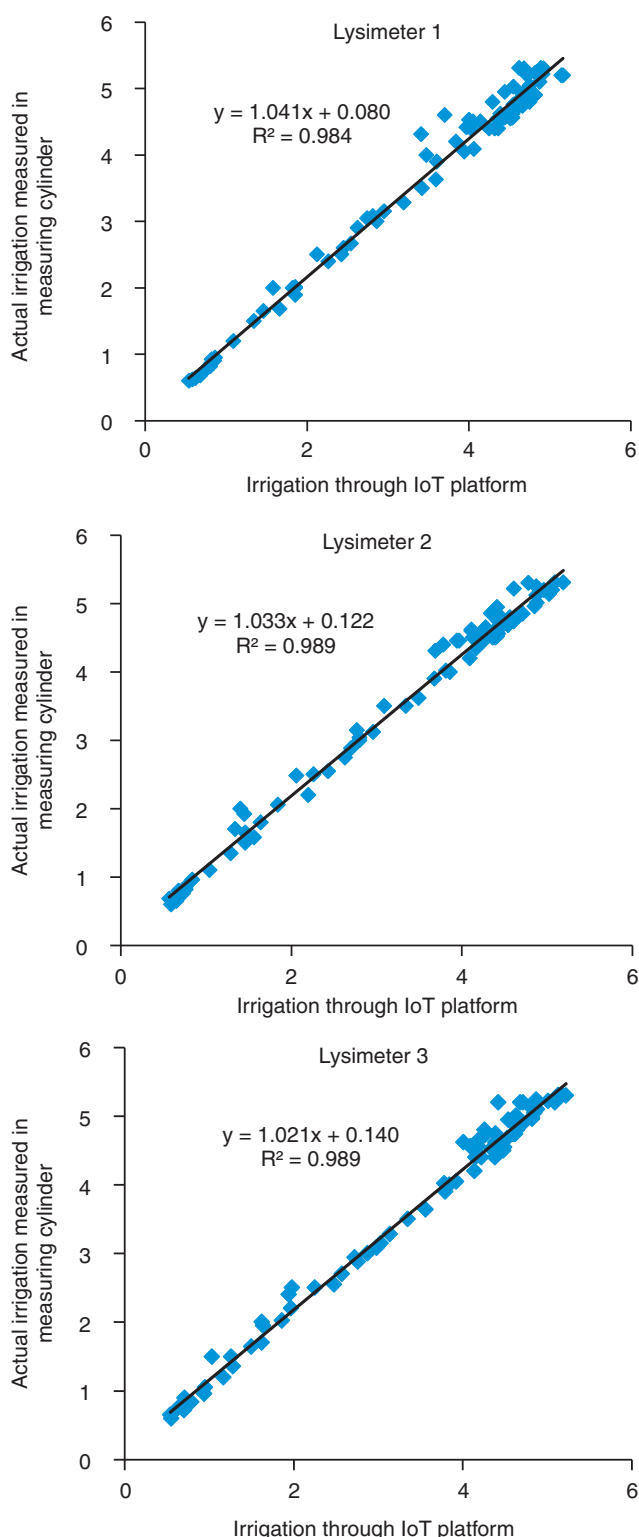


Fig 7 Graphs indicating strong linear relationship between the actual irrigation and irrigation from the IoT platform.

rise in temperature. Again, towards the end of crop growth, ET_c values decreases when the crop growth becomes stagnant.

Conclusions

The IoT was applied in agriculture for precise irrigation management. To quantify the amount of water consumed

by a crop in soilless medium under naturally-ventilated conditions, a weighing type micro-lysimeter based on IoT was developed. The developed system comprises of two components, i.e. hardware assembly and a web based application. The weight changes at the lysimeters due to irrigation, drainage and evapotranspiration were monitored in real time through the web based application, i.e. Thingspeak for the entire crop growth duration of 80 days. Three such lysimeters were placed at different locations to account for the slight variations in micro-climate at these locations within the greenhouse. The positive flux, i.e. irrigation and negative flux, i.e. (leachate+ actual evapotranspiration (ET_c)) from the lysimeter were derived from the IoT platform. Irrigation given to and the leachate from the lysimeter was also recorded on a daily to compare with the readings stored at the IoT platform. A correlation value of $R^2 > 0.98$ between the observed values of irrigation from the actual reading and the readings from the IoT platform shows that the lysimeters presents a reliable and convenient way for quantification of water consumed by the crop. The study shows that these lysimeters can be used in future for finding water requirements of other soilless crops.

ACKNOWLEDGEMENT

The authors are thankful to National Committee on Plasticulture Applications in Horticulture (NCPAH), New Delhi, India for the financial support needed during the course of the study.

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