

Original Research Article

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Evaluation of Effectiveness of Nano Sensor (IITB) Based Irrigation System on Water Productivity and Yield of Maize (*Zea mays*)

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ABSTRACT

The growing water demand has raised serious concern to the future of irrigated agriculture in many parts of the country. Therefore, the knowledge of crop water demand is an important practical consideration to improve the water productivity in irrigation practices. The traditional irrigation systems provide unnecessary irrigation to one part of a field while leading to a lack of irrigation in other parts. Changing environmental conditions and shortage of water have led to the need for a system which efficiently manages irrigation of fields. Based with this background a field experiment was conducted at Water Technology Centre, PJTSAU, Hyderabad (India) to study the effectiveness of sensor based irrigation system on water productivity and yield of maize. The experiment was laid out in a split plot design replicated thrice with twelve treatments using DHM-117 as a test variety of maize. The results revealed that the amount of total water applied under drip irrigation through nano sensor (IITB) based readings was 322 mm against the surface furrow irrigation of 494 mm. Drip irrigation shown comparatively higher water productivity (1.96 kg m^{-3}) compared to surface furrow irrigation (1.15 kg m^{-3}) and among the schedules higher water productivity (1.53) was associated with nano sensor (IITB). Simultaneously, nano sensor (IITB) based irrigation system recorded the highest grains per plant (184.13 g), cob weight per plant (243.65 g) and grain yield (7.05 t ha^{-1}) of maize.

Keywords

Nano sensor based irrigation, Water productivity, Drip irrigation, Maize and yield

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Introduction

Water plays a crucial role in photosynthesis and plant nutrition. Agriculture is the major user of fresh water, consumes 70% of the fresh water *i.e.* 1,500 billion m^3 out of the 2,500 billion m^3 of water that is being used

each year (Shah and Das, 2012). One of the major problems in agriculture is non-optimal usage of water. It is estimated that 40% of the fresh-water used for agriculture in developing countries is lost, either by evaporation, spills, or absorption by the deeper layers of the soil, beyond the reach of plants roots (Shah and

Das, 2012). The problem of agricultural water management is today widely recognized as a major challenge that is often linked with development issues. Irrigation scheduling is important parameter to increase yield of a crop. Saving water in the agriculture sector through efficient irrigation scheduling is one way to reduce water consumption. Irrigation scheduling helps the grower to know when to irrigate, how to irrigate and how much to irrigate. The most often used laboratory method for soil water content measurement is based on drying of the sample and measurement of the resulting mass decrease to find out the gravimetric soil moisture. Although this method leads to very accurate results and requires standard laboratory equipment (oven and precise scale), it is very time consuming, as it lasts 24 hours (Gardner *et al* 1986).

In today's commercial agriculture, technology plays an important role in different sectors of farm management. Various methods and tools have been developed to determine when and how much irrigation water needs to be applied, this is true particularly in soil moisture sensor technologies which have proven to be efficient in helping growers to manage irrigation (Mohamed *et al.*, 2011). The agricultural sector faces the challenge to produce more food with less water by increasing crop water productivity (CWP) (Kijne *et al.*, 2003). Same production with the limited water resources, or a higher production from the same water resources, helps to improve the crop water productivity. Sensor based irrigation scheduling offers an opportunity for improving water productivity. It helps to save the water by applying only when it is required. Agricultural sustainability is a great challenge to produce more from the limited resources to feed the growing population. Water consumption by irrigation is more than other activities. So the challenges of food security and water

sustainability are closely linked. So, it is necessary to monitor the soil moisture *in situ* through sensor technologies as tools for irrigation scheduling for improving yield and to overcome the lacunas of gravimetric moisture measurement.

Reddy *et al.*, (2002) observed higher sugar beet yield (95 t ha⁻¹) when irrigation was scheduled based on watermark sensors (gypsum block) along with saving of 18 % water when compared to farmers practice. Chen *et al.*, (2009) and Simon *et al.*, (2013) concluded that the maize grain yield reduced with decreasing irrigation amounts and the maximum grain yield was obtained under fully irrigated treatment. Payero *et al.*, (2008) recorded as low as 28 % harvest index when plants are subjected to water stress after tasseling and maximum harvest index (61.77 %) was obtained with fully irrigated treatment. Karam *et al.*, (2003) revealed that water plays an important role in partitioning of the dry matter and application of optimum quantity of water results in better HI in maize crop. Based on with this background a field experiment was conducted at Water Technology Centre, PJTSAU, Hyderabad (India) to study the effectiveness of sensor based irrigation system on water productivity and yield of maize.

Materials and Methods

The experiment was carried out at Water Technology Centre, College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad. The farm is situated at 17^o 19' 16.4" N latitude and 78^o 24' 43.7" E longitude and at an altitude of 542.6 m above mean sea level. The experiment was laid out in a split plot design replicated thrice with twelve treatments using DHM-117 as a test variety of maize. Treatment combination are detailed in table 1.

Surface furrow irrigation was imposed by creating small parallel channels along the field length in the direction of predominant slope. Water is applied to the top end of furrow and flows down under influence of gravity. Measured amount of water was applied through gated pipe depending upon the treatment.

The drip system consisted of a head control unit (including non return valve, air release valve, vacuum breaker, disc filter, fertigation unit, throttle valve, pressure gauge and water meter); water carrier system (including PVC main pipeline, PVC sub main pipeline, control valve, flush valve and other fittings) and water distribution system (including 16 mm lateral line with inline emitters, grommet, start connector, nipple and end cap).

The water source for irrigation was from an open well. The laterals of 16 mm diameter were laid at 1.2 m apart with spacing of 0.4 m distance between two inline emitters. The emitter discharge was 2.0 lph. Control valves were fixed separately to each treatment plot to facilitate controlling the water flow as per the treatments in the experiment.

In treatment S-1 to S-5, based on sensor triggered value irrigation was scheduled both in surface furrow irrigation and drip irrigation. The irrigation was rescheduled when the tension reached to 60-70 cbars in tensiometer, 40-50 centi bars in gypsum block, and when volumetric water content was registered as 20-25 % in profile probe, gravimetric moisture content of 14-15 % in nano sensor (IIT-B) and Red glow light indication in soil moisture indicator.

The number of cobs per plant, cob weight, grain weight per cob, number of grains per cob, grain yield, straw yield, harvest index and water productivity were recorded. The data obtained from the field experiment was

analysed statistically by applying the techniques of analysis of variance (Gomez and Gomez, 1984). The F values for treatments were compared with the table values. If the effects were significant, critical differences at the 5 % significance level were calculated for effecting comparison among the means. Data analytical package Web Agri Stat Package (WASP) ver 2.0 was used for data analysis.

Results and Discussion

The results of field evaluation of soil moisture sensors and irrigation methods on yield of *rabi* maize are detailed below.

Number of cobs plant⁻¹

The number of cobs plant⁻¹ in maize was not significantly affected by irrigation methods, as presented in Table 2. But under irrigation schedules it was found to be significant. The number of cobs plant⁻¹ among the sub treatments ranged between 1.05 and 1.23. Number of cobs is more in drip irrigated plot compared to surface furrow irrigation. While in surface furrow method of irrigation, less number of cobs plant⁻¹ recorded might be attributed to soil moisture stress experienced by the crop due to variations in amounts and frequency of irrigation water applied. Similar results were also reported by Kumar and Pandian (2010) and Sharan (2012). (Also mention about results of nano sensors)

Cob weight (g plant⁻¹)

The cob weight obtained was significantly high (244 g plant⁻¹) with drip irrigation method compared to surface furrow method of irrigation (196 g plant⁻¹) (Table 2). High frequency of irrigation scheduled under drip irrigation resulted in high cob weight compared to low frequencies of irrigation under surface furrow irrigation (Prasad and

Prasad, 1988). The cob weight of plant was significantly influenced by irrigation schedules and the highest cob weight (243.65 g plant⁻¹) was observed in nano sensors IITB, followed by gypsum block (239.20 g plant⁻¹) and differ significantly over rest of the irrigation schedules. The lowest cob weight (192.70 g plant⁻¹) was observed in irrigation scheduled by using tensiometer. Cob weight of maize was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules.

Grain weight (g plant⁻¹)

Significantly higher grain weight (184.6 g plant⁻¹) obtained with drip irrigation methods compared to surface furrow method of irrigation (143.7 g plant⁻¹). Significantly higher grain weight (193.57 g plant⁻¹) was observed with nano sensors-IITB based irrigation scheduling followed by gypsum block (184.13 g plant⁻¹) and differ over rest of the schedules. Whereas the lowest grain weight (132.15 g plant⁻¹) was observed in irrigation scheduled by using tensiometer (Table 2). Corn grown under conditions of water deficit in sensitive stages causes least grain weight per year (Cakir 2004). These results support the view that water stress at different growth stages affects grain weight per cob to a greater or lesser degree depending on the stage (Bajwa *et al.*, 1987; Roy and Tripathi, 1987). The per plant grain weight of maize was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules.

Number of grains per cob

Significantly more number of grains per cob was noticed with drip irrigation method (485.00) compared to surface furrow method of irrigation (441.00) (Table 2). Yield components of maize like number of grains per cob, 100 grain weight were found higher

with drip irrigation scheduled at 1.0 Epan compared to surface method (Salah *et al.*, 2008; Asim *et al.*, 2011 and Sharan, 2012). The increase in number of grains per cob might be due to lower bareness of the cobs under high irrigation frequency regimes during growth period. The reduction in bareness of the cobs at higher irrigation level might be due to better pollination and consequent to better filling of cobs due to optimum moisture availability (Aulakh *et al.*, 2012). The number of grains per cob was not significantly influenced by the sensor based irrigation schedules and the highest number of grains per cob was observed by nano sensors IITB, followed by profile probe, gypsum block, soil moisture indicator, IW/CPE ratio. The lowest number of grains per cob was observed in irrigation scheduled by tensiometer. Yazar *et al.*, (1999) reported that number of grains per plant is moisture stress-dependent and concluded that number of grains per cob decrease is the primary effect of water deficit on corn grain yield. Setter *et al.*, (2001) evaluated the processes of kernel setting under a 5 days water stress and shading at the pre-pollination and early post-pollination stages, and determined that water deficit substantially increased ABA concentrations in all reproductive tissues of corn. They suggested that ABA may play a role in the loss of kernel set within apical regions of an ear in response to water deficit. The number of grains per cob of maize was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules.

Grain yield (t ha⁻¹)

The grain yield of maize was significantly influenced by irrigation methods and irrigation schedules. Significantly higher grain yield (6.30 t ha⁻¹) was obtained with drip irrigation compared to surface furrow irrigation plots (5.68 t ha⁻¹) (Table 3).

Table.1 Details of treatments

Main treatments: M₁ - Surface furrow irrigation and M₂ - Drip irrigation	
Sub treatments- Sensor based irrigation schedules (S)	Indicator value in the sensor to trigger the irrigation
S₁-Tensiometers (irrometer)	60-70 cbars
S₂-Granulated gypsum blocks (Water mark sensors)	40-50 cbars
S₃-Profile probe (Delta-T)	20-25% (moisture content volumetric)
S₄-Nano sensors (IITB)	14-15% (moisture content gravimetric)
S₅-Soil moisture indicator (ICAR)	Red LED glow
S₆-IW/CPE ratio or Epan	1.0

Table.2 Effect of irrigation methods and irrigation schedules on number of cobs plant⁻¹, number of grains per cob, cob weight and grain weight of maize during *rabi* 2017-18

Treatment	No. of cobs plant⁻¹	No. of grains per cob	Cob weight (g plant⁻¹)	Grain weight (g plant⁻¹)
Main plots :Irrigation methods (M)				
M ₁ –Surface furrow irrigation	1.16	441.0	196.0	143.70
M ₂ -Drip irrigation	1.19	485.0	244.0	184.60
SEm ±	0.03	13.12	8.61	6.85
CD (P = 0.05)	NS	36.74	25.12	20.55
Sub Plots: -Sensor based irrigation schedules (S)				
S ₁ -Tensiometers (irrometer)	1.05	424.3	192.7	132.15
S ₂ -Granulated gypsum blocks (Water mark sensors)	1.22	468.3	239.2	184.13
S ₃ -Profile probe (Delta-T)	1.21	477.3	221.3	169.48
S ₄ -Nano sensors (IITB)	1.23	503.8	243.6	193.57
S ₅ -Soil moisture indicator (ICAR)	1.16	467.9	212.4	155.39
S ₆ -IW/CPE ratio or Epan	1.17	435.0	210.4	150.19
SEm ±	0.04	25.21	5.63	7.91
CD (P = 0.05)	0.12	NS	16.63	23.33
Interaction				
S at same level of M				
SEm ±	0.06	35.6	7.9	11.18
CD (P = 0.05)	NS	NS	NS	NS
M at same or different level of S				
SEm ±	0.06	33.1	8.4	10.75
CD (P = 0.05)	NS	NS	NS	NS

Table.3 Effect of irrigation methods and irrigation schedules on grain yield, straw yield and harvest index of maize during *rabi*, 2017-18

Treatment	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Harvest index (%)
Main plots :Irrigation methods (M)			
M ₁ -Surface furrow irrigation	5.68	11.16	33.4
M ₂ -Drip irrigation	6.30	12.22	34.2
SEm ±	0.19	0.35	0.19
CD (P = 0.05)	0.61	1.05	NS
Sub Plots: -Sensor based irrigation schedules (S)			
S ₁ -Tensiometers (irrometer)	5.21	10.84	32.72
S ₂ -Granulated gypsum blocks (Water mark sensors)	6.76	12.59	34.92
S ₃ -Profile probe (Delta-T)	5.92	11.23	33.81
S ₄ -Nano sensors (IITB)	7.05	12.95	35.43
S ₅ -Soil moisture indicator (ICAR)	5.46	11.31	32.57
S ₆ -IW/CPE ratio or Epan	5.52	11.23	32.29
SEm ±	0.13	0.24	0.73
CD (P = 0.05)	0.38	0.71	NS
Interaction			
S at same level of M			
SEm ±	0.18	0.34	1.03
CD (P = 0.05)	NS	NS	NS
M at same or different level of S			
SEm ±	0.19	0.36	0.96
CD (P = 0.05)	NS	NS	NS

Table.4 Irrigation, total water applied, effective rainfall and water productivity influenced by irrigation methods and irrigation schedules of maize during *rabi*, 2017-18

Treatment	Irrigation water applied (mm)	Total water applied (m ³)	Water Productivity (kg m ⁻³)
Main plots :Irrigation methods (M)			
M ₁ -Surface furrow irrigation	494	4940	1.15
M ₂ -Drip irrigation	322	3220	1.96
Sub Plots: -Sensor based irrigation schedules (S)			
S ₁ -Tensiometers (irrometer)	389	3890	1.34
S ₂ -Granulated gypsum blocks (Water mark sensors)	445	4450	1.52
S ₃ -Profile probe (Delta-T)	430	4300	1.38
S ₄ -Nano sensors (IITB)	460	4600	1.53
S ₅ -Soil moisture indicator (ICAR)	401	4010	1.36
S ₆ -IW/CPE ratio or Epan	366	3660	1.51

This finding is similar to that of Karimi *et al.*, (2006) who found that application of irrigation water through drip method in corn resulted in highest grain yield (3899 kg ha^{-1}). Ramulu *et al.*, (2010) clearly showed that the maize crop sown under paired row with drip at 1.2 m spacing resulted in significantly higher yield than the conventional surface irrigation method. Similar findings were also observed by Kumar *et al.*, (2006). Increase in grain yield under drip irrigation was mainly due to increased soil moisture status maintained in the upper 30 cm soil layer consequently higher plant relative water content and less negative leaf water potential (Viswanatha *et al.*, 2002).

Significantly highest grain yield (7.05 t ha^{-1}) was observed in nano sensor IIT-B based irrigation scheduling over rest of the irrigation schedules except gypsum block irrigation scheduling. 35.31 percent increase in grain yield was observed in nanosensor compared to the lowest treatment. This might be due to maintaining adequate soil moisture in the root zone depth throughout the crop growth period which facilitated in better uptake of water and nutrients having beneficial effect on growth *viz.*, plant height, leaf area and LAI which favoured more production and translocation of photosynthates to the sink there by high dry matter production and yield contributing factors *viz.*, number of cobs per plant, shelling percentage, cob weight, grain weight and test weight resulted in high grain yield. Similar findings also reported by Kumar *et al.*, (2001), Singh (2001), Hussaini *et al.*, (2002), Sanjeev *et al.*, (2006), Javaid *et al.*, (2009), Ramah *et al.*, (2009), Shinde *et al.*, (2009) and Hamidreza *et al.*, (2011). Whereas the grain yield realised with gypsum block (6.76 t ha^{-1}) based irrigation schedule was on par with yield obtained with nano sensor. The lowest grain yield (5.21 t ha^{-1}) obtained by tensiometer based irrigation scheduling. Reddy *et al.*, (2002) observed higher sugar beet yield (95 t ha^{-1}) when irrigation was

scheduled based on watermark sensors (gypsum block) along with saving of 18 % water when compared to farmers practice. Chen *et al.*, (2009) and Simon *et al.*, (2013) concluded that the maize grain yield reduced with decreasing irrigation amounts and the maximum grain yield was obtained under fully irrigated treatment. The grain yield of maize was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules.

Straw yield (t ha^{-1})

Perusal of data indicates that straw yield of maize was significantly influenced by irrigation methods and irrigation schedules. Drip irrigated plots showed significantly higher straw yield (12.22 t ha^{-1}) when compared to surface irrigated plot (11.16 t ha^{-1}) (Table 3). This might be due to better vegetative growth, more dry matter production and biological yield produced under favoured soil moisture availability in drip irrigated plots (Sanjeev *et al.*, 2006). Irrigation schedules significantly influenced the straw yield. The highest straw yield (12.95 t ha^{-1}) was observed in nano sensors IIT-B based irrigation scheduling closely followed by gypsum block (12.59 t ha^{-1}) and differed significantly over rest of the schedule studied. Whereas, the lowest straw yield (10.84 t ha^{-1}) obtained by tensiometer based irrigation scheduling might be due to low leaf area index, leaf area and dry matter production which ultimately lead to lower straw yield (Qadir *et al.*, 1999). 19.46 percent increase in straw yield was observed in nano sensor compared to the lowest treatment. The straw yield was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules.

Harvest index (%)

The harvest index of maize was not significantly influenced by irrigation methods

and irrigation schedules. However, relatively high harvest index was observed in drip irrigated plot (34.2) compared to surface irrigated plot (33.4) (Table 3). Increasing moisture stress resulted in progressively less harvest index (Pandey *et al.*, 2000). Relatively high harvest index (35.43) was observed in nano sensor based irrigation scheduling followed by gypsum block (34.92), profile probe (33.81), soil moisture indicator (32.57), IW/CPE ratio (32.29) and lowest (32.72) was with tensiometer based irrigation scheduling. The harvest index was not significantly influenced by the interaction effect of irrigation methods and irrigation schedules. Payero *et al.*, (2008) recorded as low as 28 % harvest index when plants are subjected to water stress after tasseling and maximum harvest index (61.77 %) was obtained with fully irrigated treatment. Karam *et al.*, (2003) revealed that water plays an important role in partitioning of the dry matter and application of optimum quantity of water results in better HI in maize crop.

Water use studies

The data pertaining to amount of applied water on *rabi* maize was presented in table 4. The amount of total water applied under drip irrigation was 322 mm against the surface irrigation of 494 mm. The percent applied water saving in drip irrigation was 35%, over surface furrow irrigation. This result is in line with the findings of Anitha and Muthukrishnan (2011) that reduction in water consumption due to drip method of irrigation over the surface method of irrigation varied between 30 to 70 per cent and productivity gain in the range of 20 to 90 % for different crops. It might be due to effective utilization of water by crop in drip system as compared to conventional surface irrigation methods. Whereas, in sensor based irrigation scheduling an amount of 389, 445, 430, 460, 401 and 366 mm was used by tensiometer,

gypsum block, profile probe, nano sensor (IIT-B), soil moisture indicator and IW/CPE ratio respectively. Rainfall received during the crop growth period was nil.

Water productivity (WP)

A scrutiny of the data reveals that among irrigation methods, the drip irrigation recorded relatively higher WP (1.96 kg m⁻³) over surface furrow irrigated plots (1.15 kg m⁻³) (Table 4). Water productivity was three times more under drip irrigation than the furrow irrigation (Kadasiddappa *et al.*, 2015). The highest water productivity in drip irrigated treatments could be due to higher grain yield obtained coupled with lower water requirement (Fanish *et al.*, 2011). Similar results were reported by Kumar *et al.*, (2006) in cotton. Highest water productivity was associated with nano sensor (IITB) and gypsum block based irrigation schedules (1.53, 1.52 kg m⁻³ respectively)

It may be concluded that the amount of total water applied under drip irrigation was 322 mm against the surface furrow irrigation of 494 mm. Drip irrigation shown comparatively higher water productivity (1.96 kg m⁻³) compared to surface furrow irrigation (1.15 kg m⁻³) and among the schedules higher water productivity (1.53) was associated with nano sensor (IITB). Simultaneously, nano sensor (IITB) based irrigation system enhanced the highest grains per plant (184.13 g), cob weight per plant (243.65 g) and grain yield (7.05 t ha⁻¹) of maize.

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