Original Research Article

SPATIAL AND TEMPORAL DISTRIBUTION OF SOIL MOISTUREIN MAIZE USINGFREQUENCY DOMAIN REFLECTOMETRY SENSOR

ABSTRACT

Field experiment was conducted during *kharif* 2018, *rabi* 2018-19 and *kharif* 2019 at Department of Soil Water Engineering, Dr. NTR College of Agricultural Engineering, Bapatla, Andhra Pradesh to study the spatial and temporal distribution of soil moisture in maize using FDRsensor.The experiment was laid out in split plot design consisting of three irrigation levels (0.6 ETc (I_1), 0.8 ETc (I_2) and 1.0 ETc (I_3)) and four nitrogen levels consisting of fertigation levels (80% RDN (N_1), 100% RDN (N_2), 120% RDN (N_3) and Manual application (N_4) on sandy clay loam soil. Water requirement of the maize crop was calculated on the daily basis by using CROPWAT 8.0. Frequency Domain Reflectometry (FDR) Sensor was used to measure soil moisture data by installing 34 access tubes up to a depth of 100 cm with an interval of 10 cm from the soil surface and measured soil water content during crop period.Soil moisture was evaluated for 2.0lph emitter discharges at 3h after irrigation, 6h after irrigation, 24h after irrigation at emitter, 15 cm from emitter, 30 cm from emitter and 45 cm from emitter for soil moisture in the soil for arriving the best irrigation strategy. The soil water distribution under all drip irrigation treatments indicated that it was relatively high near the dripper and decreased as the distance from the dripper point increased.

Key words: Soil moisture distribution, FDR Sensor. Drip irrigation and Maize crop

1. INTRODUCTION

Irrigation is the most critical use of water in agriculture and a key tool in managing any crop production and should be used wisely. The main irrigation issue that needs to be addressed is finding ways to increase agricultural production while using less water, making irrigation efficiency crucial. Drip irrigation also known as trickle irrigation is one of the most efficient irrigation method of the available methods in the world. Water, nutrients and chemicals can be delivered at required place, required quantity and required time. The system consists of a network

of plastic pipes, drip laterals and emitters. In this system the water and nutrients can be released uniformly through emitters directly at the root zone of the plants. According to the crop requirement and crop stage, optimum soil moisture levels are maintained and quick response can be made to a variety of crop needs. When the water delivered through drip at rootzone of the plant, the moisture distributes spatially and temporally.

Spatial Distribution of Soil Moisture refers to the variation in soil moisture content across different locations or points within a given area. To assess the spatial distribution of soil moisture, we might use techniques like soil moisture sensors, remote sensing (e.g., satellite or aerial imagery), or geostatistical methods to create maps or charts that show moisture levels across the area of interest. Temporal Distribution of Soil Moisture relates to how soil moisture content changes over time. To assess the temporal distribution of soil moisture, we need to collect data over time using monitoring devices like soil moisture sensors or data loggers.

Analyzing this data helps us to understand the dynamics of soil moisture, such as how it responds to irrigation, rainfall, evaporation, and plant water uptake. Understanding the spatial and temporal distribution of soil moisture under drip irrigation during the crop period is crucial for efficient water management and optimizing crop yield. This can be achieved by identify the specific area where drip irrigation is employed and by installing soil moisture sensors at multiple locations within the study area.

2. MATERIAL AND METHODS

2.1 Location of the study area

The field experiment was conducted during *kharif* 2018, *rabi* 2018-19 and *kharif* 2019 under maize crop at the field irrigation laboratory, Department of Soil and Water Engineering, Dr. N. T. R. College of Agricultural Engineering, Bapatla, Bapatla district of Andhra Pradesh State, India. Geographically the experimental site is located at latitude of 16^0 N and longitude of 88^0 E with an altitude of 6 m above mean sea level.

Soil samples were collected at every 15 cm layers from land surface till the soil depth of 90 cm using soil augur to characterize the soil. The collected soil samples were analysed in laboratory for determining the physical properties of the soil such as Textural class,Hydraulic conductivity (cm/h), Bulk density (g/cm^3), Field capacity (% vol) and permanent wilting point (% vol). The results of the physical properties of the soil was presented in Table 1.

Table 1 Physical properties of the experimental soil

Soil depth from surface (cm)	Textural class	Hydraulic conductivity (cm/h)	Bulk density (g/cm^3)	Field capacity (% vol)	Permanent wilting point (% vol)
0-15	Sandy clay loam	0.94	1.37	21.48	6.73
15-30	Sandy clay loam	0.50	1.57	27.17	9.12
30-45	Sandy clay	0.46	1.53	28.24	10.56
45-60	Sandy clay loam	0.96	1.63	27.69	10.92
60-75	Sandy clay loam	0.96	1.63	27.73	11.61
75-90	Sandy clay loam	0.95	1.67	26.62	10.75

2.2 Design and installation of drip irrigation system

A drip irrigation system was designed for the experiment under maize crop (Plate.1). Lateral lines of LLDPE (12 mm diameter) were taken out from the sub main line for the irrigation of the maize crop. The lateral lines were spaced at 1.2 m interval. Inline drip emitters with 2.0 lph rated discharge were placed on the lateral line at a spacing of 30 cm. Each plot has three laterals with a net plot size of 8.0 m × 3.6 m (28.8 m^2). A total of 36 plots were designed for the entire field area of 1350 m^2 (54 × 25 m).

Plate. 1 Design of drip irrigation system for maize crop

2.3 Design and installation of experiment

Field experiment was conducted with DEKALB DKC 8161 variety of hybrid maize under drip irrigation in split plot design consisting of three irrigation levels as main treatment and four fertigation levels as sub treatments with three replications during *kharif*2018, *rabi* 2018-19 and *kharif* 2019 at the Field irrigation lab, Dr. NTR College of Agricultural Engineering, Bapatla.Maize seed was sown in a paired row system as plant to plant and row to row spacings were 20 cm and 40 cm, respectively [(80 cm + 40 cm) × 20 cm]. The layout of the experiment was shown in Fig.1

Treatments are as follows:

Main plots: Irrigation levels (I)

I_1= 0.6 of the crop evapotranspiration
I_2= 0.8 of the crop evapotranspiration
I_3=1.0 of the crop evapotranspiration

Sub plots: Fertigation levels (N)

N_1= Drip fertigation with 80% of recommended dose of nitrogen (CF)
N_2= Drip fertigation with 100% of recommended dose of nitrogen (CF)
N_3= Drip fertigation with 120% of recommended dose of nitrogen (CF)
N_4= No drip fertigation (manual application) with 100% of recommended dose of nitrogen (CF)
(CF= Conventional Fertilizers)

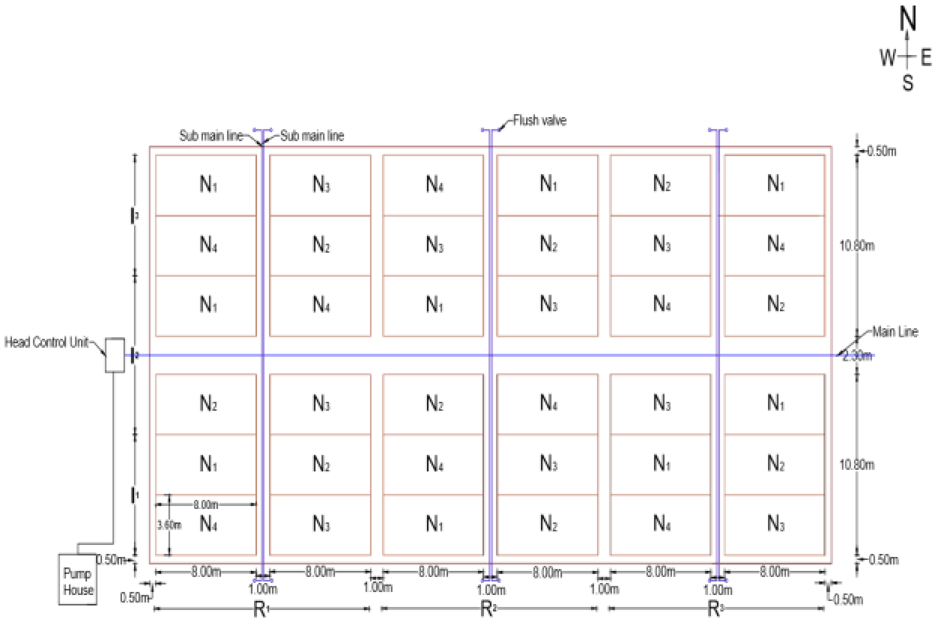


Fig.1 **Layout of the Experimental field**

2.4 FREQUENCY DOMAIN REFLECTOMETRY (FDR) SENSOR AND ITS CALIBRATION

2.4.1 Measurement of Soil Moisture Content

Soil moisture content was measured at every irrigation i.e., before starting of irrigation, immediately after irrigation, 3h after irrigation, 6h after irrigation and 24h after irrigation by using Diviner 2000 (Sentek). Diviner 2000 is a portable soil monitoring system. It comprises a data display unit and a portable probe. The portable probe measures soil moisture content at regular intervals of 10 cm down through the soil profile. Readings are taken through the wall of a PVC access tube. Data is collected from a network of access tubes installed in selected sites. When the probe is inserted into access tube that means an electrical field is applied. Then the soil around the electrodes (around the tube) forms the dielectric of the capacitor that completes the oscillating circuit. An access tube allows multiple sensors to take measurements at different depths. In one swipe and go action, Diviner 2000 records data from all levels in the soil profile to the depth of the probe i.e., 1.0 m. At a single depth level, the probe records moisture from a soil volume outside the access tube, which has a sphere of influence of 10 cm vertical height and 5-10 cm radial distance from the outer wall of the access tube.

Before using the diviner 2000, the sensor is normalized using a special normalization tube to set the air and water counts. This is necessary because each sensor responds slightly differently to air and water.

2.4.2 Calibration of the Frequency Domain Reflectometry (FDR) Sensor

Calibration of the FDR Sensors was done by comparing Scaled Frequency readings obtained from an access tube installed in the field with values of volumetric water content calculated gravimetrically from adjacent to the tube immediately. When these values were plotted on a graph, they form a relationship that was described by a mathematical equation.

2.4.3 Installation of Access Tubes

A total of 34 access tubes were installed in the experimental field for main and sub plots with different horizontal spacings from center of lateral pipe to a maximum of 45 cm distance at 15 cm interval. The total length of access tube is 1.5 m out of which 1.35 m was inserted below the ground and 15 cm height was left above the ground for identification. The installation of access tubes and moisture measurements are shown in Plate 2.

Plate 2 Installed access tubes and FDR sensor

2.5 Irrigation Application

Irrigations were applied as per the crop water requirement based on soil moisture condition of the field through drip. Water requirement of the maize crop was calculated on the basis of reference crop evapotranspiration (ET_0) on the daily basis by using Penman-Monteith's semi empirical formula (Smith, 1991). CROPWAT 8.0 which is Windows based computer program was used to estimate the crop water requirements and irrigation requirements from climate, soil, rain and crop parameter data. The crop evapotranspiration (ETc) was estimated by multiplying reference evapotranspiration (ET_0) with crop coefficient (K_c) based on crop growth stages i.e. $ETc = ET_0 \times K_c$. Therefore, maize crop period was divided into four growth stages namely, Vegetative state (6-30 days after sowing, DAS), Reproductive stage (31-60 DAS), Maturity stage (61-75 DAS) and harvest stage for all the seasons.

3. RESULTS AND DISCUSSION

Water was applied through drip irrigation in all the treatments immediately after six days of the sowing of maize crop. Before sowing, flood irrigation was given to all treatments for proper establishment of the crop. For I_1 treatment 0.6 of crop evapotranspiration (ETc), for I_2 treatment 0.8 of crop evapotranspiration (ETc) and for I_3 treatment 1.0 of crop evapotranspiration (ETc) was applied. Soil moisture distribution pattern was studied at 25 days after sowing, 50 days after sowing, 75 days after sowing and at harvest time during all the seasons. The soil moisture readings with Time Domain Reflectometry (TDR) probe at emitter and 15 cm from emitter were taken for I_1 treatment, for I_2 treatment the readings were taken at emitter, 15 cm from emitter and 30 cm from emitter and for I_3 treatment the soil moisture readings were taken at emitter, 15 cm from emitter, 30 cm from emitter and 45 cm from emitter. In all the treatments, soil moisture readings were taken before irrigation, immediately after irrigation, 3h after irrigation, 6h after irrigation and 24h after irrigation during *kharif* 2018,*rabi* 2018-19 and *kharif* 2019 and are shown through Fig. 2 to 5 respectively.

During *kharif* 2018, before irrigation at emitter on 25 days after sowing (Fig. 2) soil moisture distribution showed that the highest value of soil moisture occurred at 10-20 cm depth in treatments I_1, I_2 and I_3 are 18.61%, 24.09% and 27.10% respectively. Similarly at 15 cm from emitter, the highest value of soil moisture occurred at 10-20 cm depth in treatments I_1, I_2 and I_3 are 18.20%, 22.53% and 26.24% respectively. At 30 cm from emitter, the highest value of soil moisture occurred at 10-20 cm depth in treatments I_2 and I_3 are 16.76 % and 14.85% respectively. At 45 cm from emitter, the highest value of soil moisture occurred at 10-20 cm depth in treatment I_3 (11.36%). The results clearly indicated that, the highest moisture stored at 10-20 cm depth in all treatments and then decreased in the vertical plains before irrigation. The low value of soil moisture in the depth of 0-10 cm than 10- 20 cm depth in all treatments might be due to evaporation loss on surface of the soil.

The soil moisture content was more at 0-10 cm depth immediately after irrigation, 3h after irrigation and 6h after irrigation in all treatments at emitter, 15 cm from emitter, 30 cm from emitter and 45 cm from emitter respectively. The soil moisture at 24h after irrigation shows that highest moisture was observed at 10-20 cm depth in almost all treatments. Overall, soil moisture is maintained in the soil depth range of 10 – 40 cm and decreased in the vertical plane after the 40 cm soil depth.

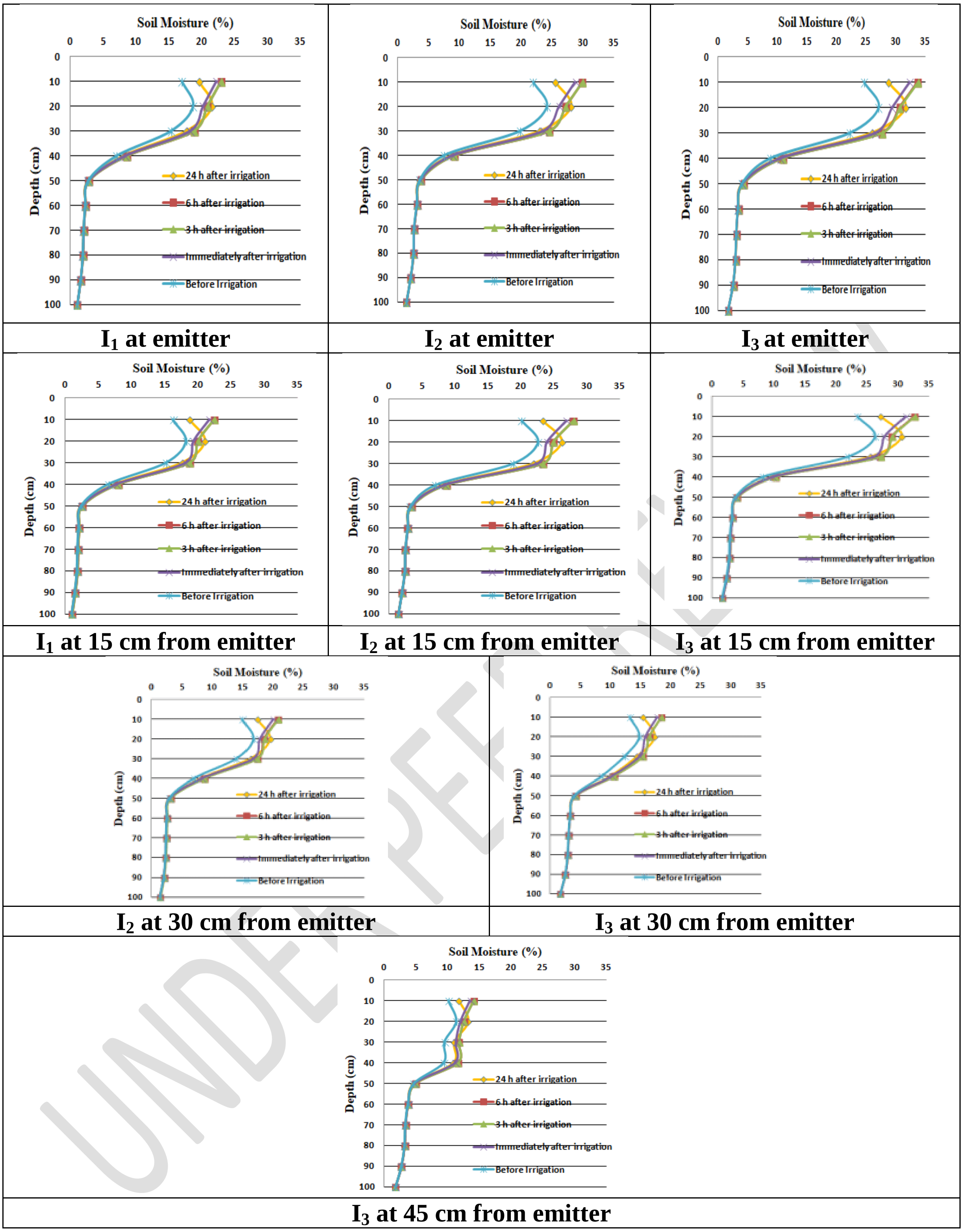


Fig. 2 Soil moisture distribution at 25 days after sowing during kharif 2018

Soil moisture distribution, before irrigation at emitter on 50 days after sowing (Fig. 3) shown that the highest value of soil moisture occurred at 30-40 cm depth in treatments I_1, I_2 and I_3 are 18.30 %, 20.51 % and 21.06% respectively. Similarly, at 15 cm from emitter the highest value of soil moisture occurred at 30-40 cm depth in treatments I_1, I_2 and I_3 are 18.06 %, 20.10 % and 20.18 % respectively. At 30 cm from emitter, the highest value of soil moisture occurred in the same depth of 30-40 cm in treatments I_2 and I_3 are 19.21 % and 20.36 % respectively. At 45 cm from emitter, the highest value of soil moisture occurred at 10-20 cm depth in treatment I_3 is 16.23%. The results clearly showed that, before irrigation the highest moisture stored at 30-40 cm depth in all treatments and then decreased in the vertical plane.

The soil moisture content was more at 30-40 cm depth immediately after irrigation, 3h after irrigation and 6h after irrigation in all treatments at emitter, 15 cm from emitter and 30 cm from emitter respectively. The soil moisture content in the top surface layers (10 cm – 30 cm) is extracted by crop since it is in vegetative stage at 50 days. At 45 cm from emitter, it was more in the soil depth of 10-20 cm immediately after irrigation, 3h after irrigation and 6h after irrigation and 24h after irrigation. Overall, soil moisture is maintained in the soil depth range of 10 – 40 cm and decreased in the vertical plane after 40 cm soil depth.

The same trend was observed at 75 days after sowing and at harvest (Fig. 4 and 5). Field capacity of various layers of the soil of experimental site was in the range of 21.48-28.24%. From literature, it was found that for maize crop grown in sandy clay loam soil (Fahad *et al*., 2014), water content in the root zone has to be maintained in the range of 20-40 %. This indicated that even 24 hr after irrigation, favorable soil moisture is maintained in the root zone of maize crop.

Overall, soil moisture content was relatively higher in upper profiles and near the emitters in all the three irrigation levels after irrigation. Water content in all soil layers (0-100 cm) decreased as the distance from emitter increased in the horizontal direction. Similar results were reported by Kaul (1979), Hayens (1990), Chakarbordy (1997), Mishra (2001), Ajdary (2007) and Tawutchaisamongdee (2018).

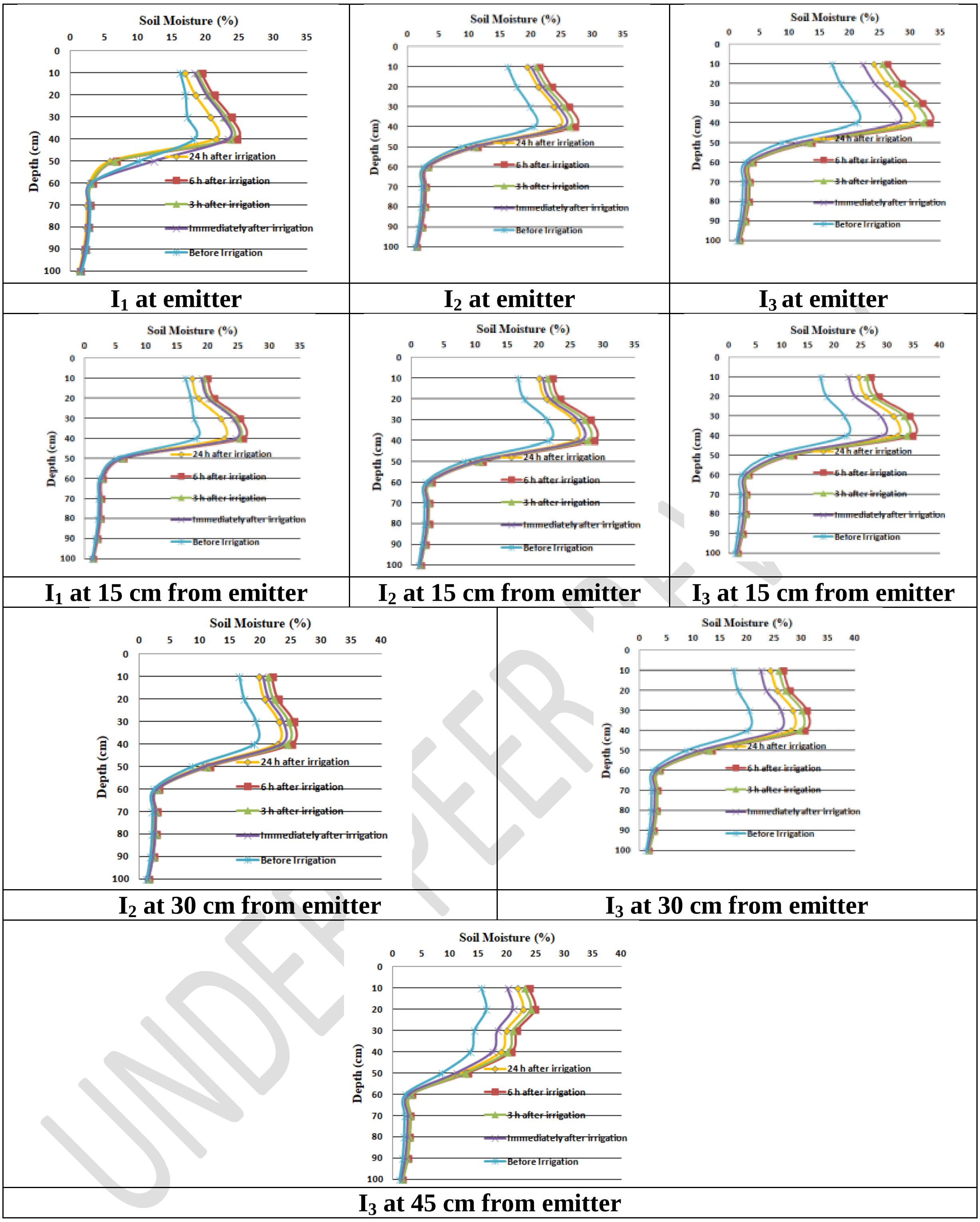


Fig. 3 Soil moisture distribution at 50 days after sowing during kharif 2018

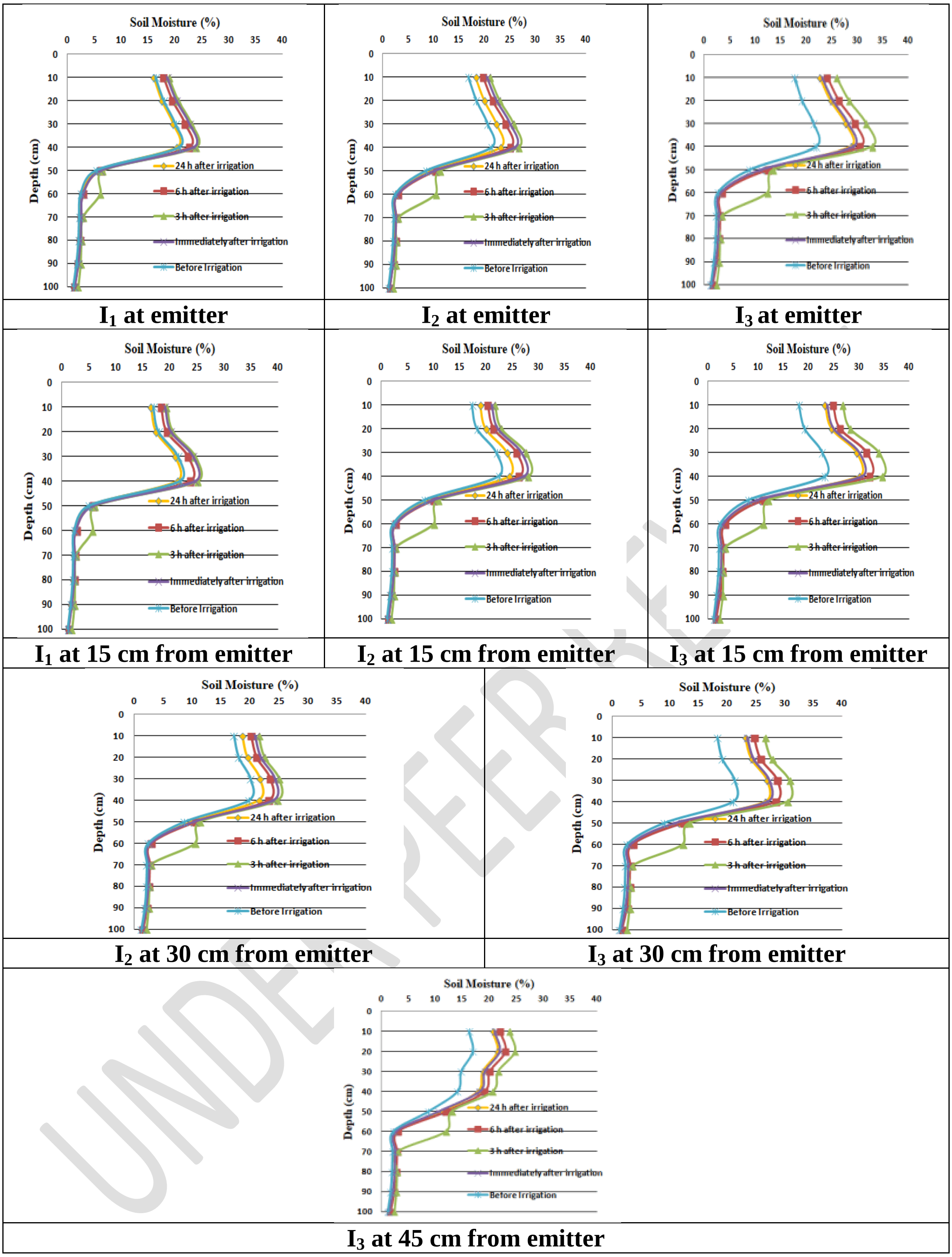
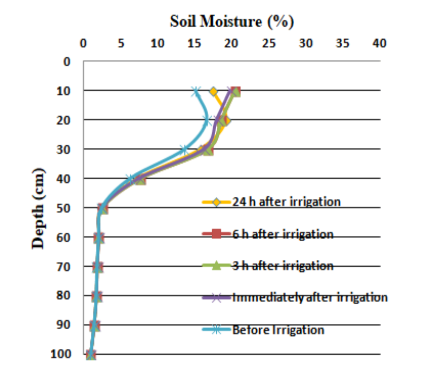
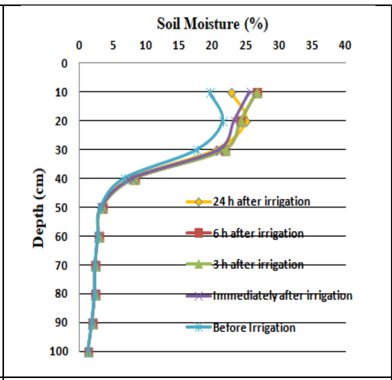


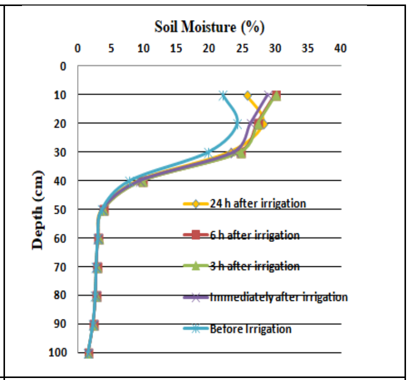
Fig. 4 Soil moisture distribution at 75 days after sowing during kharif 2018



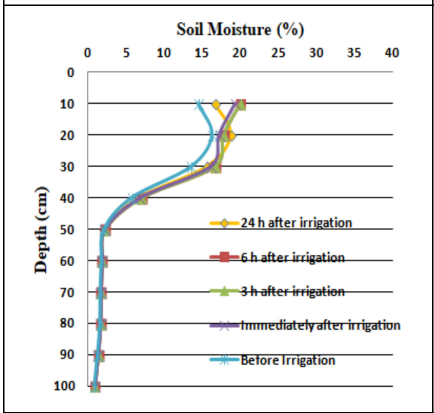
I_1 at emitter



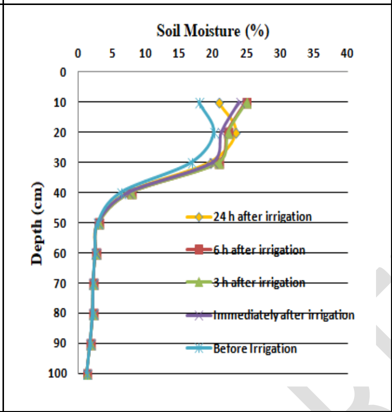
I_2 at emitter



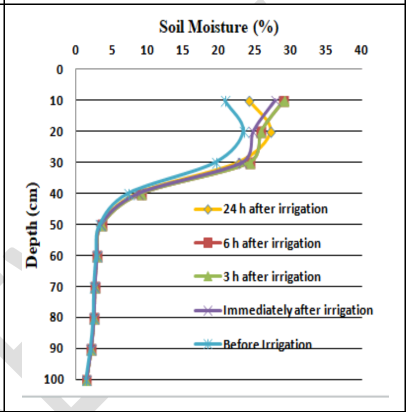
I_3 at emitter



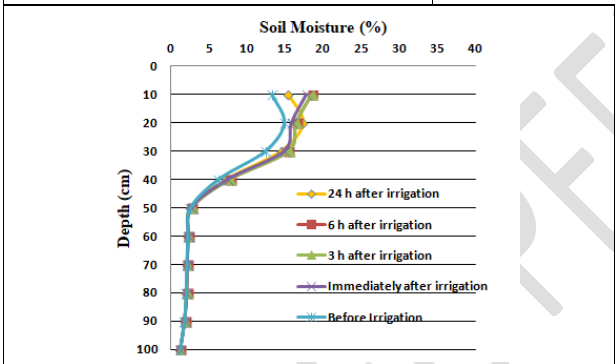
I_1 at 15 cm from emitter



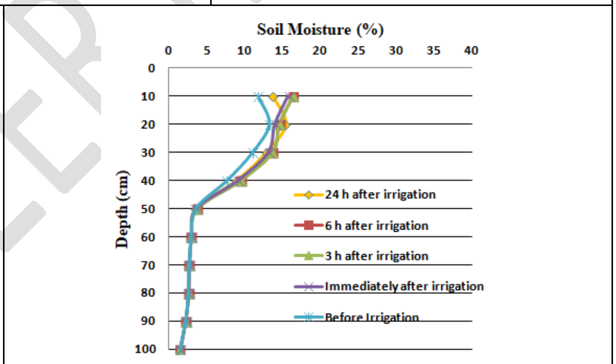
I_2 at 15 cm from emitter



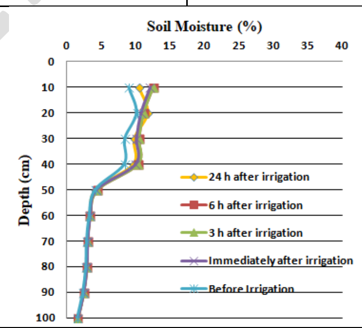
I_3 at 15 cm from emitter



I_2 at 30 cm from emitter



I_3 at 30 cm from emitter



I_3 at 45 cm from emitter

Fig. 5 Soil moisture distribution at harvest during kharif 2018

During the season *rabi* 2018-19, overall soil moisture content was relatively higher in top 0-10 cm depth and this is maintained up to 30 cm depth and then decreased trend in vertical plane was observed before irrigation, immediately after irrigation, 3h after irrigation, 6h after irrigation and 24h after irrigation in all treatments.

Soil moisture distribution at 25 days after sowing before irrigation during *rabi* 2018-19 at emitter reveals that the highest value of soil moisture occurred at 0-10 cm depth in treatments I_1, I_2 and I_3 are 12.24%, 16.63% and 17.15% respectively. Similarly at 15 cm from emitter also occurred the highest value of soil moisture at 0-10 cm depth in treatments I_1, I_2 and I_3 are 11.96%, 15.55% and 16.60% respectively. At 30 cm from emitter reveals that the highest value of soil moisture occurred at 0-10 cm depth in treatments I_2 and I_3 are 11.57 % and 9.39% respectively. At 45 cm from emitter recorded the highest value of soil moisture at 0-10 cm depth in treatment I_3 is 7.19%. The results clearly showed that, before irrigation the highest moisture stored at 0-10 cm depth in all treatments and then decreased the soil moisture in the vertical plane. The high value of soil moisture in all treatments in the depth of 0-10 cm might be due to low temperatures in the month of December.

The similar trend was observed immediately after irrigation, 3h after irrigation 6h after irrigation and 24h after irrigation in all treatments at emitter, 15 cm from emitter, 30 cm from emitter and 45 cm from emitter respectively. Overall, soil moisture is maintained in the depth range of 10 – 40 cm and decreased in the vertical plane. The same trend was observed at 50 days after sowing, 75 days after sowing and at harvest.

During the season *kharif* 2019, overall soil moisture content was relatively higher in top 0-20 cm depth and this is maintained up to 40 cm depth and then decreased trend in vertical plane was observed before irrigation, immediately after irrigation, 3h after irrigation, 6h after irrigation and in 24h after irrigation in all treatments. The moisture distribution pattern was same as *kharif* 2018.

In all the seasons the soil moisture content was found to be higher in the plots treated with 1.0 ETc, which was higher than the field capacity of the soil after irrigation. Though the crops treated with 0.8 ETc experienced moisture content below field capacity after 6h of irrigation, however the moisture content was maintained at 80 per cent of field capacity, the roots tend to absorb more water and nutrients to satisfy the crop need, which might have resulted in comparable yield to 1.0 ETc. The hydraulic conductivity of the field soil is normal which indicates that the soil is a well drained soil and this might be the reason that the crops have not faced water stagnation or water stress throughout its growth period. The soil water distribution under all drip fertigation treatments indicated that it was relatively high near the dripper and decreased as the distance from the dripper point increased. This finding was in concurrence with the findings of Chakraborty *et al*. (1999).

4. CONCLUSION

- Soil water content attained field capacity in upper layers 3h after irrigation and maintained well upto 6h and dropped slightly below the field capacity at 24h and even upto 48h before irrigation around 20% of SWC is existing. There was no percolation below the active root zone. Therefore, Irrigation scheduling with emitter discharge of 2.0 lph on alternate day is appropriate for maize crop in sandy clay loam soil.
- There is not much variation in soil water content at emitter and 15 cm from emitter. Hence, emitter to emitter spacing of 30 cm is suitable for irrigation in sandy clay loam soil.

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