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Spatio-temporal movement of water and nitrate under different dripper discharges in drip fertigation

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ABSTRACT

Fertigation is an advanced and efficient method of application of nutrients with irrigation water to the crop. Water and nutrient distribution in soil is one of the most important parameters to design efficient fertigation system. A field research was conducted to investigate the effect of dripper discharge at different system operating pressures on spatio-temporal soil moisture movement. The value of moisture contents varied significantly ($P<0.05$) under different operating pressures (0.5, 1.0 and 1.5 kg/cm^2) and at different locations below and away from the dripper. Highest values of soil moisture contents were observed below the drippers which decreased as the distance increased in both horizontal and vertical directions from the dripper. The values of moisture content in soil decreased as distance increase in both directions (horizontal and vertical) from the dripper. 9.4% and 14.3% higher values of soil moisture just below the dripper were observed with dripper discharges of 1.41 and 1.71 l/hr at 1.0 and 1.5 kg/cm^2 system operating pressures as compared to 0.94 l/hr dripper discharge at 0.5 kg/cm^2 system operating pressure. Wetting front extended up to 15, 20 and 26 cm horizontally and 30, 30 and 24 cm and extended vertically up to 0.94, 1.41 and 1.71 l/h dripper discharge at 0.5, 1.0 and 1.5 kg/cm^2 system operating pressure, respectively after 1 day of irrigation. Higher values of NO_3-N concentration in all soil depths were recorded at 1.5 kg/cm^2 operating pressure however lower values of NO_3-N concentration were recorded at 0.5 kg/cm^2 operating pressure 1 day after fertigation.

Key words: Drip irrigation, Dripper discharge, NO_3-N concentration, Soil water distribution, System operating pressure, Wetting front

Fertigation refers to application of fertilizers along with irrigation water in the vicinity of plants. In fertigation, fertilizers are injected with the help of injection devices such as fertilizer tank, fertigation pump and venturi and applied to the field through drip irrigation along with irrigation water. The fertilizer distribution uniformity and its availability to plant depends upon the selection and application of fertilizers, uniformity of water application and the flow characteristics of the drippers. In depth understanding of water and nutrients application rate and soil properties that affect the soil wetting zone developed around the crop root zone is important consideration for proper designing and management of drip irrigation system. Moisture and nutrients distribution pattern under a drip source is one of the basic requirements for efficient design of drip irrigation. Proper understanding of dripper type and injection devices used for fertigation in micro-irrigation systems is essential to improve nutrient distribution uniformity in a drip system (Kumar *et al.* 2014). The extent of soil wetted volume in drip irrigation system determines the optimal amount of water needed to wet the effective root zone. The amount of water and nutrients stored in the crop root zone can be estimated by the volume of wetted soil. Design parameters, such as percent of root zone to be wetted, spacing and location of drippers, application rates, frequency and amount of irrigation, etc. are governed by the moisture distribution patterns in the soil profile in drip irrigation which need to be thoroughly investigated. The depth of the wetted volume should coincide with the depth of the root system while its width is related to the spacing between drippers and drip laterals (Zur 1996). Water and nutrients movement in soil under drip irrigation is influenced by the type of soil and rate of water and nutrients application (Thabet *et al.* 2008). The exact wetted volume of the soil needs to be determined for providing the adequate amount of water and nutrients required by the crop (Al-Qinna *et al.* 2001, Kumar 2012). Wetting patterns and nitrogen distributions under fertigation from a surface point source are affected by several irrigation variables. Li *et al.* (2003) investigated the influences of emitter discharge rate, input nutrient concentration, and applied volume on water movement and nitrogen distribution and found that nitrate (NO_3^-) accumulated toward the boundary of the wetted volume for any combination of discharge rate. It is clear

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from this the nitrate is susceptible to movement out of the root zone by mismanagement of fertigation, thus leading to nitrate contamination of surface and ground water sources and soil.

It is clear from the above reviewed literature that information about water and nutrient movement in soil is the basic needs for better fertigation system design. Keeping this in view, the present investigation was carried out in 2010-2011 to study the water and nitrogen movement in soil under different drip discharges at different system operating pressures.

MATERIALS AND METHODS

A field experiment was conducted at the research farm of Water Technology Centre, Indian Agricultural Research Institute (IARI), New Delhi, India (Latitude $28^0$372 303 – $28^0$302 03 N, Longitude $77^0$882 453 –$77^0$812 243 E and AMSL 228.61 m). The soil samples were collected at 0.0-15.0, 15.0-30.0, 30.0-45.0, 45.0-60.0 cm soil depths below the soil surface. Soil of the experimental area was deep loam soil and comprising of 37.57% sand, 40.67% silt and 21.59% clay with an average bulk density, average field capacity and average saturated hydraulic conductivity of soil were 1.60 g/cm^3, 0.22 and 1.67 cm/h, respectively.

The drip irrigation system was installed in a field plot of 21 m × 100 m. The drip system has one hydro cyclone filter (flow rate 27 m^3/h, 75 mm size), one sand media filter (flow rate 25 m^3/h, 50 mm size, silica sand 0.7 mm) with back ûush mechanism. The field was divided into three equal size sub-plots. Each sub-plot has 3 drip lines connected through a valve tree. Drip lines were connected with sub-mains (PVC pipes of 40 mm diameter) and sub-mains lines were connected with main lines (PVC pipes of 60 mm diameter). Flush manifolds were connected at the lower end of each block.

Field experiment was designed to determine the water and nitrogen movement in soil with various dripper discharges under different system operating pressures. The thin-walled drip line (Azud line, 16 mm diameter with 30 cm dripper spacing and dripper discharge 1.4 l/h) was used for the experiment. The drip irrigation system was operated at three operating pressures (0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2). The discharge rates of the dripper at different system operating pressure were determined by collecting the volume of water in the catch cans for a particular duration. A relationship was developed between discharge and pressure of the selected drippers.

Water and nitrogen movement in the soil were observed on all system operating pressures. The drip irrigation system was operated continuously for one hour duration at all the system pressures (0.5, 1.0 and 1.5 kg/cm^2) without crop. The soil samples were collected through the pipe auger to observe water movement in the soil. The soil samples were collected in both horizontal (0, 15, 30 cm) and vertical (0-15, 15-30, 30-45 and 45-60 cm) direction across the dripper, 1.0 hour, 1 day, 3 day and 7 days after the operation of the system.

The wetting front was recognized by the colour difference of the wetted and surrounding soils. The horizontal and vertical wetting distances on the wetted face were recorded by ordinary meter scale. Soil moisture content was estimated by gravimetric method.

Urea fertilizer was used and fertilizer solution was prepared by dissolving the urea in the irrigation water based on the solubility of urea fertilizer. The fertilizer solution was injected through venturi injector. A bucket containing fertilizer solution was placed near the venturi injector and suction tube of venturi was placed in the bucket to allow suction of fertilizer solution from the bucket. The soil samples were collected at 7.5 cm (0.0–15.0 cm), 22.5 cm (15.0–30.0 cm), 37.5 cm (30.0–45.0 cm), 52.5 cm (45.0-60.0 cm) soil depths below the dripper and 15 and 30 cm away from the dripper, respectively. The soil samples were also collected at 1 day, 3 days and 7 days after fertigation.

The collected soil samples were stored in the deep refrigerator. The fresh samples were analyzed for nitrate-nitrogen. The nitrate-nitrogen was estimated with the help of Gerhardt nitrogen distillation unit (Vapodest VAP-20) by the method of Rao and Reddy (2009).

RESULTS AND DISCUSSION

Discharge versus pressure relation

A relationship was developed between discharge and pressure of the selected drippers. Fig 1 shows the discharge and pressure relationship of the selected emitters. The data collected during the experiment fitted to a conventional power function that takes the form of equation 1.

$$q = kP^x \quad (1)$$

where, q, emitter discharge (l/h); P, system operating pressure (kg/cm^2); x , emitter discharge exponent; and k , a regression coefficient.

The values of k and x are 1.2178 and 0.1818, respectively. By substituting these values, equation 1 can be written as:

$$q = 1.2178\ P^{0.1818} \quad (2)$$

The above power function regression for the tested emitter had exponent values of 0.1818 with R^2=0.8981. The

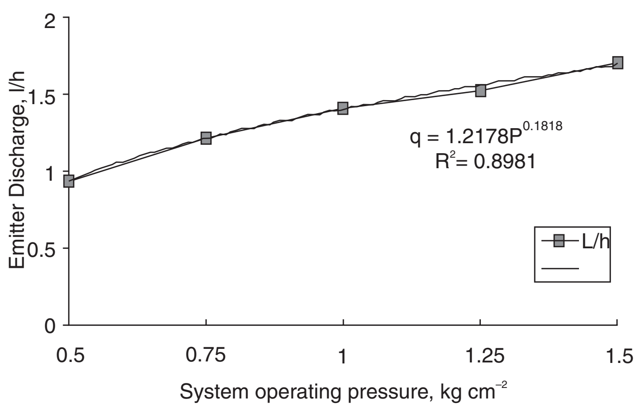

Fig 1 Emitter discharge and system operating pressure relationship

Table 1 Manufactures discharge rate at different operating pressures

Operating pressure, bar	0.25	0.50	0.75	1.00	1.25	1.50
Discharge (l/h)	0.6	0.9	1.2	1.4	1.6	1.7

measured discharges at the nominal pressure (1 kg/cm^2) for the tested emitter were almost same to the reported manufacturer values. Manufacturer's emitter discharge at different system operating pressures is summarized in Table 1.

Spatio-temporal distribution of soil moisture

The soil samples were collected at 0, 15 and 30 cm away from the dripper and different depths (15 cm interval, up to 60 cm) below the dripper under different system operating pressures after 1 h, 1, 3 and 7 days of irrigation for spatio-temporal soil moisture distribution. The soil wetting pattern was characterized by the radial distance of the wetting front and the depth from the emitting source.

Spatial distribution of soil moisture

The spatial soil moisture distribution after 1 hr duration under different system operating pressures were measured. The spatial distribution of soil moisture was significantly ($P<0.05$) different at different locations in horizontal and vertical directions from the dripper 1 h after the irrigation. However, it was not significantly ($P<0.05$) different at different locations 3 and 7 days after irrigation. The highest value of soil moisture content was observed below the dripper (a saturated condition) which decreased as the distance increased from the dripper. Maximum (25.4%) value of moisture content was observed near the dripper with 1.71 l/h dripper discharge at operating pressure of 1.5 kg/cm^2 while minimum value (20.9%) of soil moisture content was observed below the dripper with 0.94 l/h dripper discharge at system operating pressure of 0.5 kg/cm^2. The wetting fronts resulting from higher system operating pressures (higher discharge rate of drippers) were more in the horizontal direction, i.e. the lateral movement of water was comparatively higher than that of low operating pressures. The wetting front extended up to 15 cm vertically at 0.5 kg/cm^2 system operating pressure however at 1.5 kg/cm^2 system operating pressure it reached up to 20 cm horizontally after one hour. It was observed that the moisture continent below the dripper at system operating pressure of 1.0 kg/cm^2 and 1.5 kg/cm^2 were 9.4% and 14.3% higher respectively as compared to 0.5 kg/cm^2 system operating pressure.

Temporal distribution of soil moisture

The temporal distribution of soil moisture below 15 and 30 cm away from the dripper after 1, 3 and 7 days at different locations away from the dripper under different system operating pressures are presented in Fig 2.

It is clear from Fig 2, that highest value of moisture content was observed below the drippers after 1 hour at all operating pressures. Soil moisture moved in the soil 1 day after irrigation and higher values of soil moisture contents were observed at 15-30 cm soil depth. The higher values of soil moisture were present at upper soil layer (15-30 cm soil depth) at higher dripper discharges even after 3 days after irrigation. However, almost similar values of soil moisture were recorded in all the soil layers 7 days after irrigation.

The wetting front extended up to 15 cm horizontally and 30 cm vertically with 0.94 l/h dripper discharge at 0.5 kg/cm^2 system operating pressure whereas, it extended up to about 20 cm horizontally and about 30 cm vertically at with 1.41 l/h dripper discharge at 1.0 kg/cm^2 operating pressure after 1 day of irrigation. However, it reached to about 24 cm vertically and 26 cm horizontally with 1.71 l/h dripper discharge at 1.5 kg/cm^2 operating pressure after 1 day of irrigation. Similar trends of wetted fronts were reflected from the observations taken after 3 days of irrigation.

At higher discharge rates, horizontal distances of water front were relatively larger as compared to vertical distances which may be attributed to less resistance to water flow in horizontal direction as compared to the vertical and negligible gravity forces for horizontal flow of water. Similar results were reported in other studies of Ah Koon *et al*. (1990), Li *et al*. (2004) and Badr and Taalab (2007). Ah Koon *et al*. (1990) and Badr and Taalab (2007) investigated the effect of drip discharge rate on the soil water distribution in soil and reported that increasing in the discharge rate of dripper resulted in an increased lateral movement of water and a decrease in wetted soil depth.

Spatio-temporal distribution of NO_3-N in soil

NO_3-N distribution throughout the soil profile varied in both horizontal and vertical directions. The soil samples were collected 7.5 (0-15 cm), 22.5 (15-30 cm), 37.5 (30-45 cm) and 52.5 (45-60 cm) cm soil depths below at 0, 15 and 30 cm away from the dripper to study the movement and distribution of nutrients in soil profile. The samples were collected 1 day, 3 days and 7 days after the fertigation event. Spatio-temporal distribution of nutrients in soil is presented in Fig 3.

Spatial and temporal movement of NO_3-N

Depth wise distribution of NO_3-N concentration in the soil profile varied significantly under different system operating pressures (Fig 3). Higher values of NO_3-N concentration in all soil depths i.e. 7.5, 22.5, 37.5 and 52.7 cm were recorded as 107.0, 87.7, 22.3 and 19.6 mg/kg, respectively at 1.5 kg/cm^2 operating pressure however lower values of NO_3-N concentration (80.7, 51.8, 22.1 and 19.4 mg/kg, respectively) were recorded at 0.5 kg/cm^2 operating pressure 1 day after fertigation.

The highly mobile nitrate ion moves with the soil water and tends to accumulate at the border of the wetted soil volume. NO_3-N movement and distribution in soil was measured under all the operating pressures 1, 3 and 7 days after fertigation event and is presented in Fig 3.

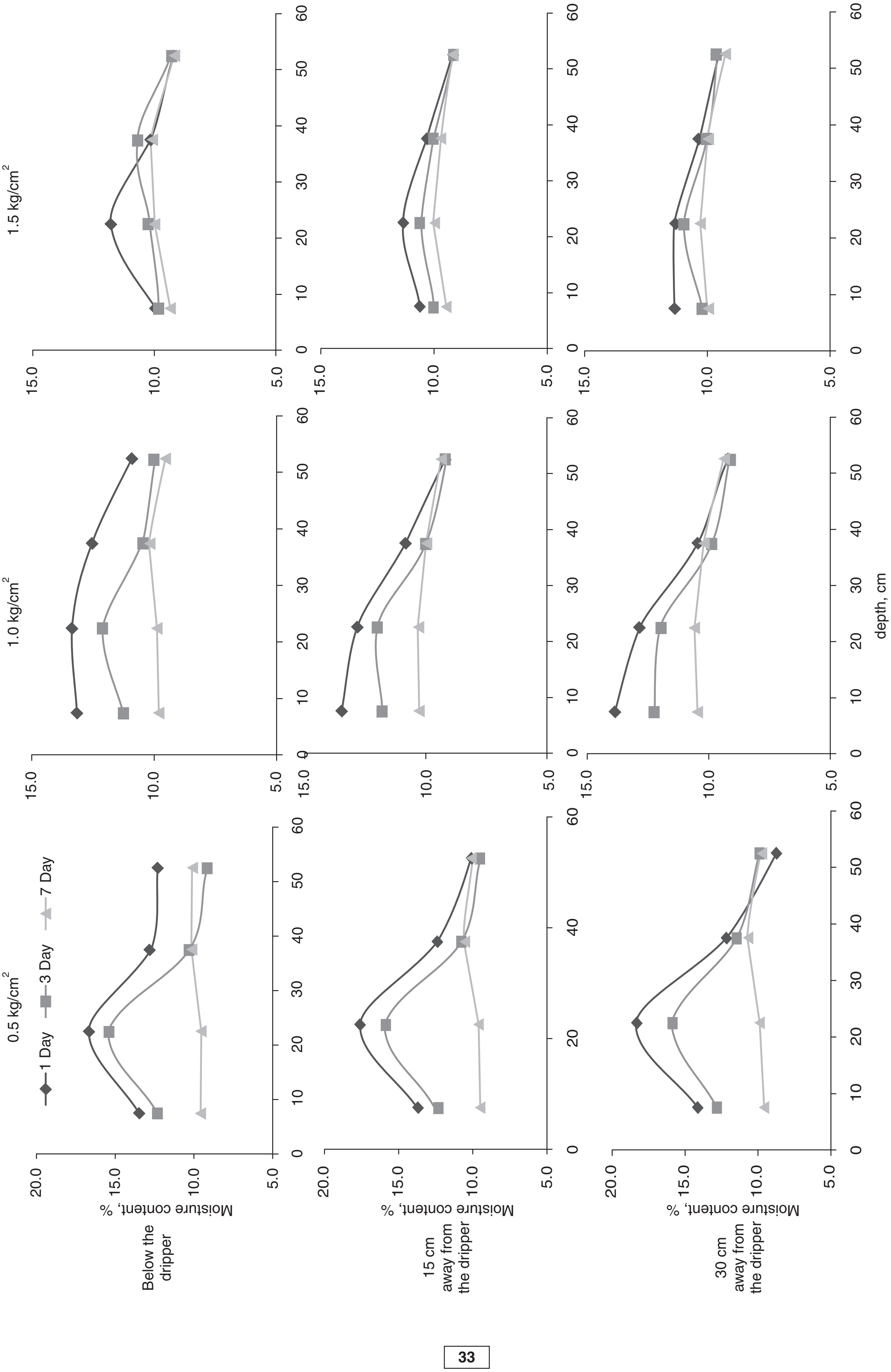

Fig 2 Temporal distribution of soil moisture distribution 1, 3 and 7 days after drip irrigation at different locations away from the dripper with different dripper discharges at 0.5, 1.0 and 1.5 kg/cm^2 system operating pressures

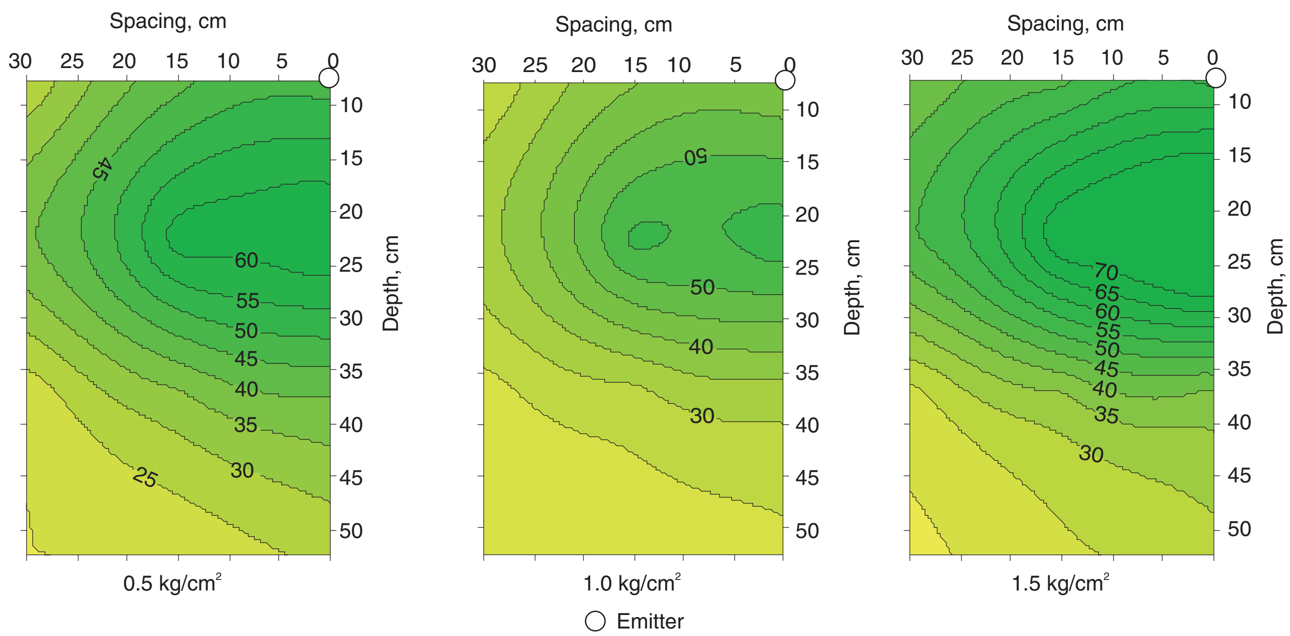

Fig 3 NO_3-N distribution 7 days after irrigation at 0.5, 1.0 and 1.5 kg/cm^2 system operating pressures

As the water front extends in both horizontal and vertical directions after 3 days of fertigation, NO_3-N concentration also increased away from the dripper and below the dripper. It was observed that NO_3-N reached up to about 23, 26, 28 cm horizontally at operating pressure of 0.5, 1.0 and 1.5 kg.cm^{-2} respectively whereas the vertical movement was same (about 34 cm) at all above operating pressures. A perusal of the Fig 3 reveals that similar pattern of NO_3-N distribution were reflected from the observations taken after 7 days of fertigation.

The effect of dripper discharge at different system operating pressures on spatio-temporal water and nutrient movement was investigated and found that higher values of moisture content were present just below the dripper. However, it decreased as distance increase in both directions (horizontal and vertical) from the dripper. The value of moisture contents varied significantly ($P<0.05$) under different operating pressures (0.5, 1.0 and 1.5 kg/cm^2) and at different locations below and away from the dripper. NO_3-N, concentration significantly ($P<0.05$) varied at different locations below and away from the drip at 0.5 and 1.0 kg/cm^2 operating pressures, however, it did not vary significantly at 1.5 kg/cm^2 operating pressure.

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