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Moisture dynamics and water use efficiency as influenced by different methods and levels of irrigation for vegetable crop under salt-affected soils

■ SUBHAS BALAGANVI, P. BALAKRISHNAN, M.V. RANGHASWAMI AND D. TAMILMANI

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See end of the Paper for authors' affiliation

Correspondence to:

SUBHAS BALAGANVI
Department of Soil and Water Engineering, College of Agricultural Engineering, RAICHUR (KARNATAKA) INDIA
Email : subhasuasd@rediffmail.com

■ **ABSTRACT :** The study was conducted at the Agricultural Research Station, Gangavati, University of Agricultural Sciences, Gangavathi in northern Karnataka, India during *Rabi/*summer, 2007-08 and 2008-09 with beetroot (*Beta vulgaris)* as the test crop. Under the drip irrigation, the soil moisture content was the highest and maintained almost steadily near the field capacity throughout the cropping period at all distances away from the dripper. The maximum moisture content near the dripper was reduced to the extent of 15 and 19 per cent at a distance of 60 cm away horizontally and vertically downwards, respectively, from the dripper during 2007-08 in case of drip irrigation at 0.6 ET in salinity level-I, against16 and 20 per cent during 2008-09. The soil moisture content at particular distance from the point of application increased with increase in depth of applied water and it decreased with distance from the point of application (R^2= 0.83 to 0.92). The maximum water use efficiency of 6.74 and 6.23 kg m^{-3} was achieved in drip irrigation at 0.6 ET under salinity level-I and the lowest water use efficiency of 2.78 and 2.40 kg m^{-3} was recorded in drip irrigation at 1.4 ETin salinity level-III during 2007-08 and 2008-09, respectively. Among the surface irrigation levels, the highest water use efficiency of 4.25 kg m^{-3} at 1.0 ET and 3.32 kg m^{-3} in 0.8 ET was recorded in salinity level-I during 2007-08 and 2008-09, respectively.

■ **KEY WORDS :** Drip, Surface irrigation, Irrigation, Vegetable, Beetroot, Soil salinity, Moisture distribution, Water use efficiency

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Waterlogging and salinity are global phenomena that affect the agricultural economy considerably. The salt-affected soils are distributed in more than hundred countries especially in arid and semi-arid regions to the extent of about 95.5 M ha and it was estimated that the world as a whole is losing at least 3 ha of fertile land every minute due to salinisation/sodification (Siyal *et al*., 2002). Though India has made phenomenal irrigation development during the post-independence period, the performance of most of the major and medium irrigation projects is highly disappointing due to various factors. Particularly the twin menacing problems of waterlogging and salinity have become a major concern as they pose serious questions on capital investment and cause environmental problems. The salt-affected soils form sizable area in India and according to one estimate an area of 6.73 M ha has been salt-affected in the country (Sharma *et al.,* 2006). As per the future projection, an area of about 13 M ha is likely to be affected by these problems in the irrigation commands of India. This does not take into account the area under non-commands, coastal salinity and salinity in groundwater irrigated land with deep water table. Waterlogging, soil salinity and saline groundwater conditions at shallow depth in Haryana resulted in a potential annual loss of about US $ 37 M at 1998-'99 prices (Ambast *et al.*, 2007). About 42 per cent increase in area under waterlogging and soil salinity in southwest Punjab occurred over a 4-year period during 1997-2001. The state of Karnataka is no exception and considerable extent of command areas of various irrigation projects has been afflicted by the problems of waterlogging and salinity. According to guesstimates, 3.5 lakh ha area has been affected in the state; of which about 80,000 ha is in the Tungabhadra Irrigation Project (TBP) area accounting for nearly 22 per cent of the command area. The problems being dynamic in nature are developing at rapid pace. Unless, these problems are addressed and solutions are evolved for prevention of the same and reclamation/ management of the already affected areas, the performance of the projects and agriculture productivity and production would continue to pose serious concern.

The dynamic processes of waterlogging, salinisation and sodification in many irrigated command areas of the arid and semi-arid regions render the lands degraded, thereby causing decline in agricultural production. Accumulation of excess soluble salts as in case of saline soil influences crop production through changes in proportions of exchangeable anions, cations, the physical properties and the effects of osmotic and specific ion toxicity, etc. However, such saline soils can be managed to prolong field productivity with proper management of soil moisture, efficient irrigation systems, local drainage and the right choice of crops so that the adverse effect of salinity on crops can be minimised and hence the cropping intensity and yield would increase considerably and also the lands can be cultivated on sustainable basis. The recent advances in irrigation techniques involving efficient use of water through micro irrigation systems hold a key to arrest further increase in waterlogging and salinisation and also can improve the economy of the farmers especially in the tail-ends of commands through increased farm produce. With these issues in view, the present investigation was undertaken with beetroot (*Beta vulgaris)* to study the effect of different methods and levels of irrigation on moisture dynamics crop yield and water use efficiency.

■ METHODOLOGY

Experimental site :

The experiment to find out the effect of different levels and methods of irrigation on performance of beetroot was conducted at the salinity block of the Agricultural Research Station (ARS), Gangavathi, which is situated in the north-eastern dry zone *i.e.* zone-3 of region–II of Karnataka State, India and the location corresponds to 15°15’40” North latitude and 76°31’ 45” East longitude at an altitude of 419 m above the mean sea level. The site selected for the conduct of experiment was found to have wide range of soil salinity. Separate soil samples from 0-60 cm depth were taken to classify the experimental site into three salinity (EC, dS m^{-1}, 1:2.5 soil water extract) level blocks and divided accordingly. The soil of the experimental site was clay belonging to Noyyal series.

Weather and climate :

Daily climatological data during the study period were obtained from the meteorological station at the Agricultural Research Station, Gangavati. During the period of study (2007-’08), the maximum temperature of 34.9°C was recorded in the month of April, while the minimum temperature of 15.2°C occurred in the month of March, against the maximum temperature of 40.3°C in May and the minimum temperature of 16.8°C in February during 2008-09.

Treatment details :

The treatment consisted of three salinity levels in main plots and eight irrigation regimes in sub-plots as follows. The experiment was laid out in strip plot design with three replications.

Main plot: Salinity levels (Three) - S :

S_1 : Salinity level – I (EC = 1.3 dS m^{-1})
S_2 : Salinity level – II (EC = 2.7 dS m^{-1})
S_3 : Salinity level – III (EC = 4.3 dS m^{-1})

Sub-plots: Irrigation levels (Eight) - I :

I_1 : Drip irrigation at 0.6 ET
I_2 : Drip irrigation at 0.8 ET
I_3 : Drip irrigation at 1.0 ET
I_4 : Drip irrigation at 1.2 ET
I_5 : Drip irrigation at 1.4 ET
I_6 : Surface irrigation at 0.8 ET
I_7 : Surface irrigation at 1.0 ET
I_8 : Surface irrigation at 1.2 ET

Lay-out of drip irrigation system :

Irrigation water was pumped through 3 hp motor and conveyed to the main line of 75 mm OD PVC pipes after passing through sand and screen filters. From the main pipes, sub-mains of 63 mm OD PVC pipes were drawn. From the sub main, laterals of 12 mm LLDPE pipes were installed at an interval of 1.20 m. Each lateral was provided with individual tap control for imposing irrigation. Along the laterals, pressure compensating drippers of 4 Lph, were fixed at a spacing of 60 cm. One lateral was used for four rows of beetroot. Sub-mains and laterals were closed at the end with end cap. After installation, trial run was conducted to assess mean dripper discharge and uniformity co-efficient. During the irrigation period an average uniformity coefficient of 95 per cent was observed. This was taken into account for fixing the irrigation water application time.

Irrigation schedule :

Good quality water was used for irrigation (EC = 0.34 dS $m^{-1}$and pH = 7.64). Irrigation was scheduled based on climatological approachand the daily evapotranspiration (ET) rate of beetroot was estimated using the following equation

$$ET = Ep \times Kp \times Kc$$

where,

ET = evapotranspiration, mm
Ep = pan evaporation, mm
Kp = pan co-efficient
Kc = crop co-efficient.

Quantity of water required to be applied per day per plant for 100 per cent ET in case of drip irrigation was computed using the following equation.

$$Q = ET \times A \times B$$

where,

Q = quantity of water required per day per plant, L

A = gross area per plant, m^2

= plant to plant distance, m x row to row distance, m

B = amount of area covered with foliage fraction (100 per cent, Tiwari *et al.,* 2003).

From the above equation, irrigation water required to meet 100 per cent crop evapotranspiration (ET) was determined, followed by 0.6, 0.8, 1.2 and 1.4 ET values. Accordingly, the irrigation was given every 48 hours. The same quantity of water was applied for all the three salinity levels in both the methods under different levels of irrigation. For drip irrigation, one common irrigation of 60 mm was applied at sowing. Thereafter, irrigation through drip system was given at two days interval based on the estimated ET requirement of the crop. In case of surface irrigation one common irrigation depth of 60 mm at sowing and one life irrigation of 30 mm three days after sowing was applied before imposing the treatments.

Moisture dynamics :

In case of drip irrigation, the soil samples were collected at radial distances of 0, 15, 30, 45 and 60 cm from the emitters at 0-15, 15-30, 30-45 and 45-60 cm depths vertically downward from the surface. In surface irrigation, the soil samples were collected from 0-15, 15-30, 30-45 and 45-60 cm depths at every 48 hours interval during one rain free irrigation cycle and the soil moisture depletion pattern was studied. The moisture content was determined through gravimetric method.

Water use efficiency :

Water use efficiency (WUE) is the yield that can be produced from a given quantity of water. It was worked out by using the following formula and expressed as kg m^{-3}:

$$\text{WUE} = \frac{\text{Yield of crop, kg}}{\text{Total water used, m}^3}$$

■ RESULTS AND DISCUSSION

The results of relationship between moisture content, water applied and distance from the dripper (Table 1) and the soil moisture dynamics as influenced by drip irrigation at different ET levels (Fig. 1 to 5) revealed that, the moisture content was reduced to the extent of 15 and 19 per cent at a distance of 60 cm away horizontally and vertically downwards, respectively from the dripper during 2007-08 in drip irrigation at 0.6 ET at salinity level-I compared to moisture content near the dripper, against 16 and 20 per cent during 2008-09. Similar trend was observed with other drip irrigation levels in all the salinity levels. In general, irrespective of the salinity levels, the maximum moisture content was observed at the dripper point, which decreased gradually both laterally and vertically at all levels of irrigation.

The physical parameters of soil such as field capacity, bulk density etc. could not be altered much by management practices. Hence, applied water depth (X_1) and distance (X_2) from the point of application (dripper) were considered to develop empirical relationship between them and the soil moisture content. The boundary conditions for these equations were $4.9 \leq X_1 \leq 11.5$ and $0 \leq X_2 \leq 60$. It could be observed that soil moisture content at particular distance from the point of application increased with increase in depth of applied water and it decreased with distance from the point of application for any depth of water applied (R^2= 0.83 to 0.92).

In drip irrigation, the moisture content in the effective root zone depth was maintained within the range of 100 per cent of field capacity, which in turn maintained the soil moisture-air relationship in the effective root zone depth at an optimum level. The moisture content in the soil profiles under effective root zone of plant was found to be within the acceptable range of available moisture for the crop under drip irrigation. On the contrary, in case of surface irrigation the moisture content increased to field capacity moisture content immediately after the irrigation and then decreased during the ensuing period, with the least moisture content observed just before the next irrigation. The soil moisture was in the optimum range for only a small part of the irrigation interval. The moisture content in most of the crop root zone was around the field capacity 24 hours after irrigation, while it drastically dropped as the days progressed. The soil moisture content

Table 1 : Relationship between moisture movement and volume of water applied in drip irrigation

Sr. No.	Salinity levels	Vertical moisture movement	
1.	S_1	$Y= 30.75 + X_1 - 0.1 X_2$	$R^2 = 0.87$
2.	S_2	$Y= 40.73 + X_1 - 0.2 X_2$	$R^2 = 0.92$
3.	S_3	$Y= 42.95 + X_1 - 0.1 X_2$	$R^2 = 0.90$
		Horizontal moisture movement	
4.	S_1	$Y= 28.57 + X_1 - 0.1X_2$	$R^2 = 0.83$
5.	S_2	$Y= 37.16 + X_1 - 0.1X_2$	$R^2 = 0.88$
6.	S_3	$Y= 39.21 + X_1 - 0.1X_2$	$R^2 = 0.84$

Y- moisture content, per cent, X_1- water applied, mm ($4.9 \leq X_1 \leq 11.5$), X_2- distance, mm ($0 \leq X_2 \leq 60$)

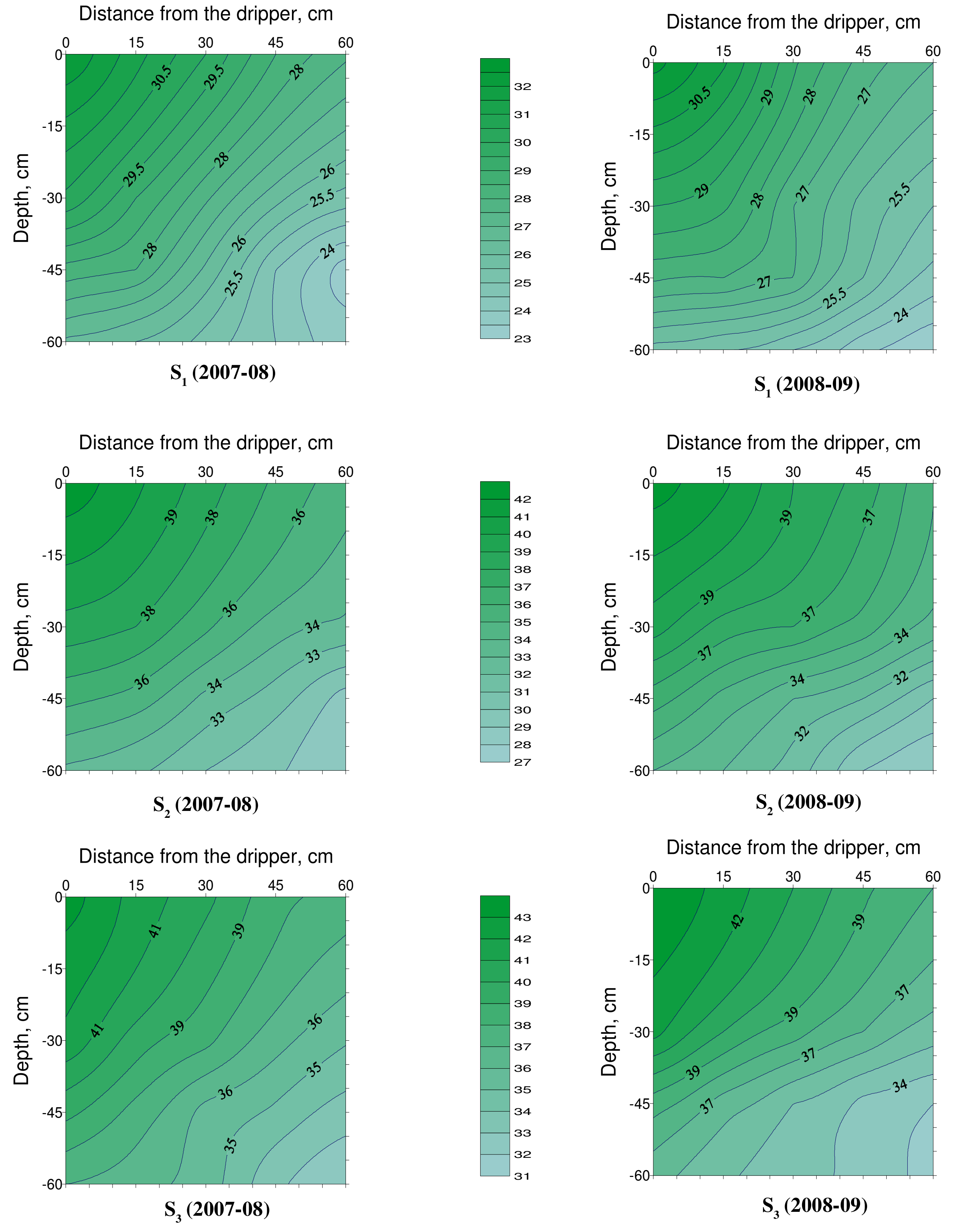

Fig. 1: Soil moisture dynamics as influenced by drip irrigation at 0.6 ET

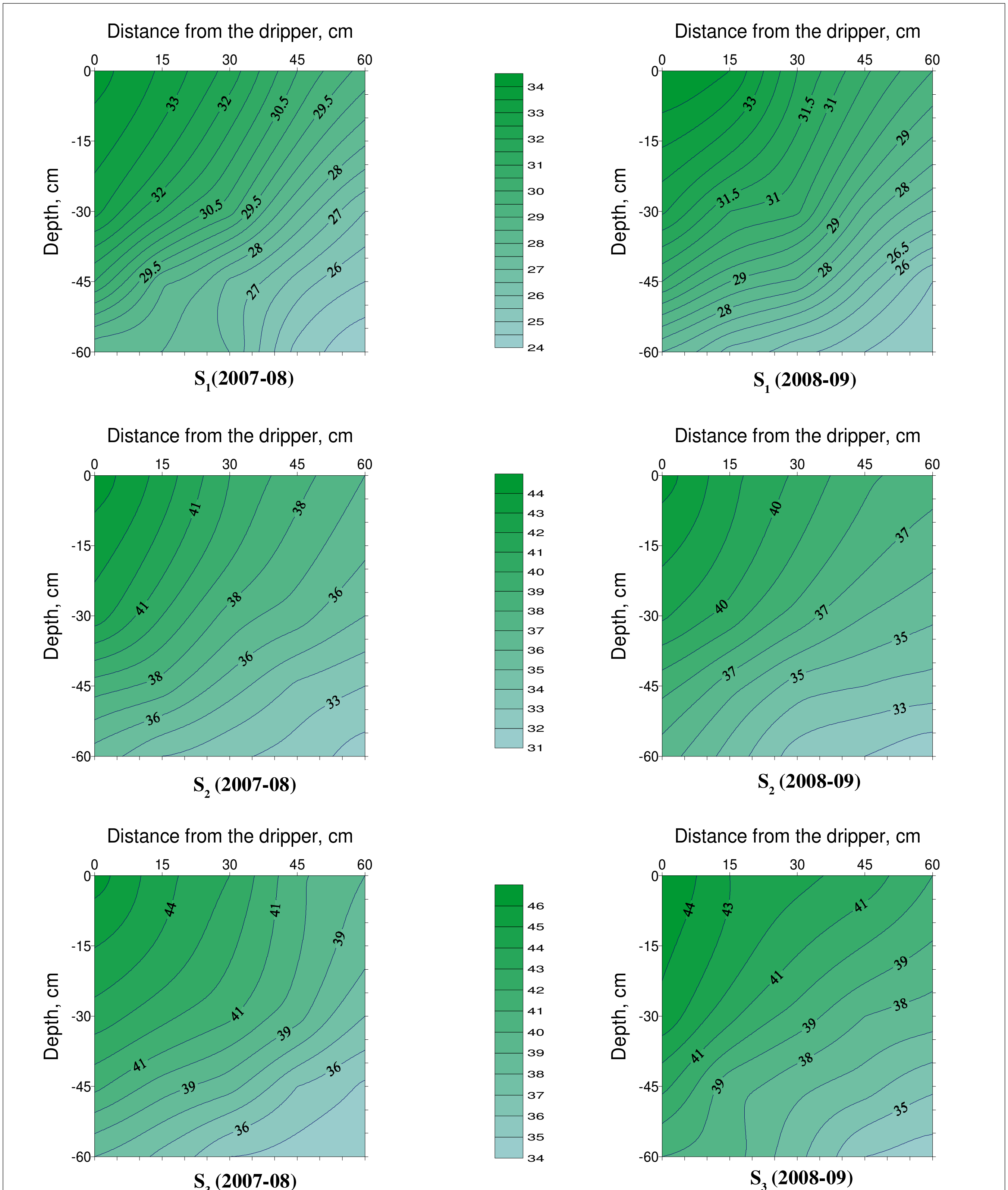

Fig. 2: Soil moisture dynamics as influenced by drip irrigation at 0.08 ET

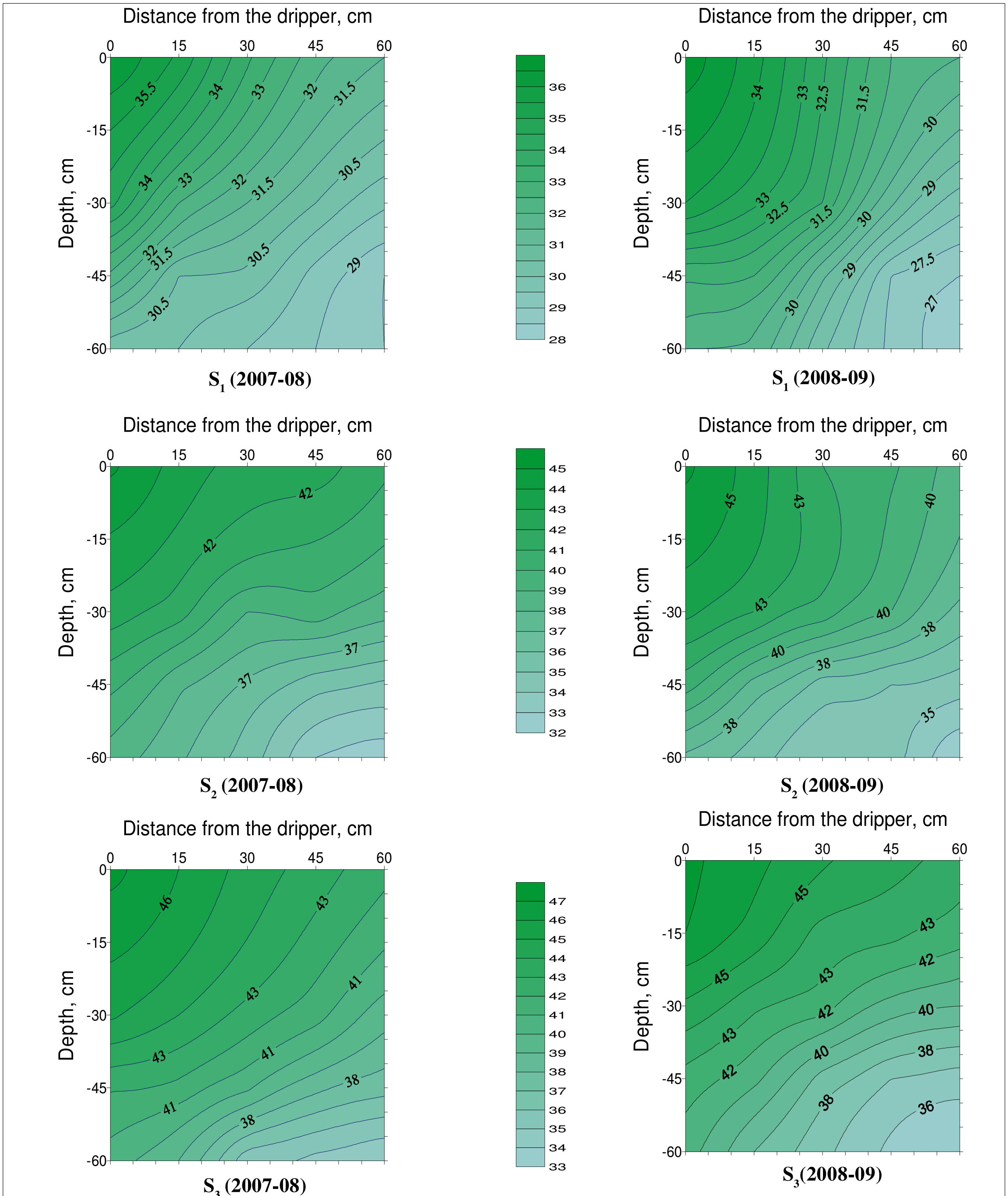

Fig. 3 : Soil moisture dynamics as influenced by drip irrigation at 1.0 ET

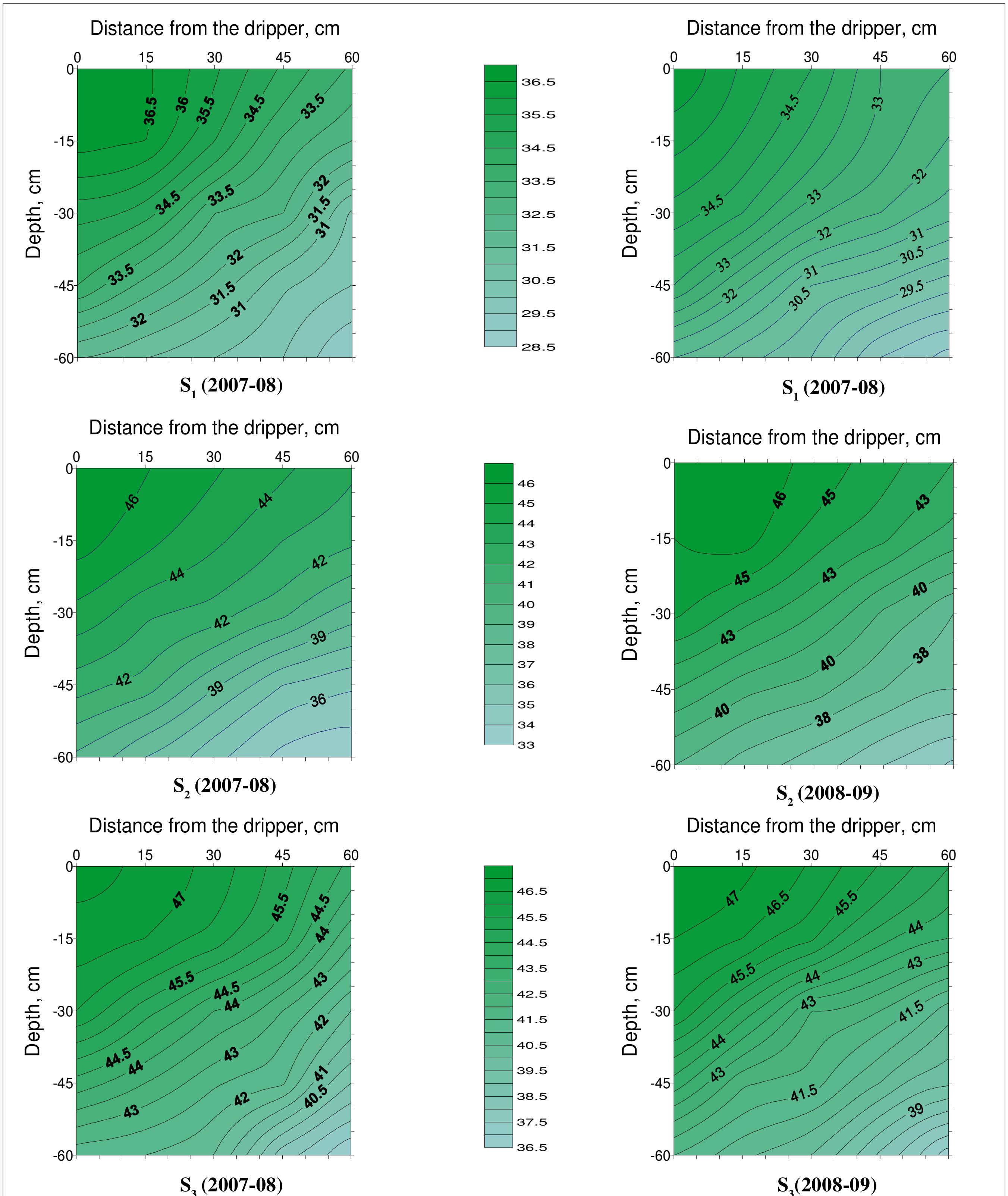

Fig. 4: Soil moisture dynamics as influenced by drip irrigation at 1.2 ET

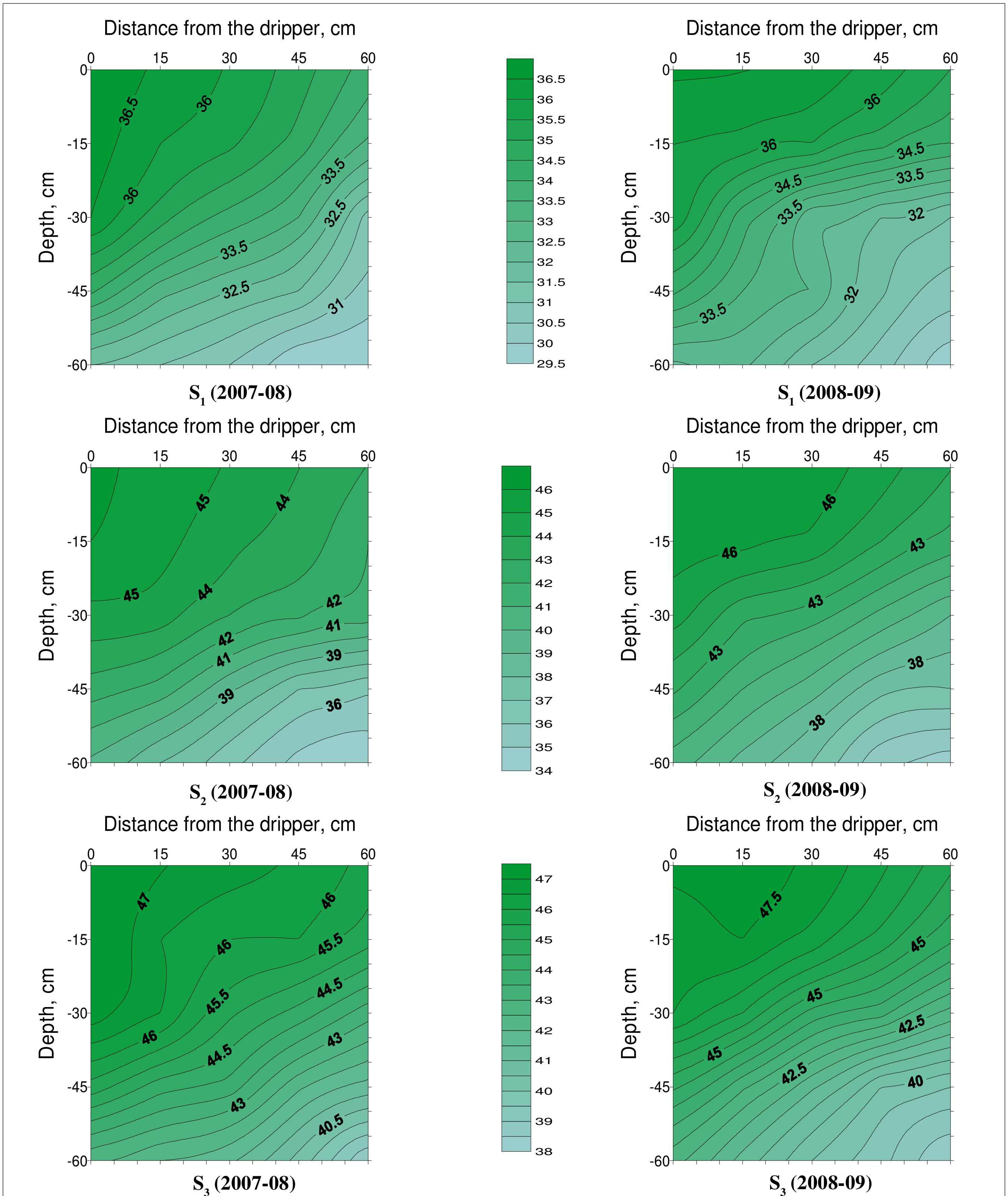

Fig. 5: Soil moisture dynamics as influenced by drip irrigation at 1.4 ET

observed in surface irrigation was comparable with that of drip irrigation treatments upto a period of 48 hours and thereafter there was a steady and steep decline in soil moisture content resulting in greater moisture stress to plants. These results corroborate the findings of Bresler *et al.* (1971), Bar-Yusef and Sheikhoslami (1976), Fulzele (1995), Shirahatti *et al.* (2001) and Rajak *et al.* (2006).

The total amount of water applied through drip irrigation was maximum in case of 1.4 ET (500.1 mm) followed by 1.2 ET (445.72 mm), 1.0 ET (391.2 mm), 0.8 ET (336.8 mm) and minimum for 0.6 ET (282.3 mm) during 2007-'08 including the effective rainfall of 29.5 mm. Similarly, during 2008-'09 the total amount of water applied through drip irrigation was highest in case of 1.4 ET (557.8 mm) followed by 1.2 ET (492.5 mm), 1.0 ET (427.1 mm), 0.8 ET (361.8 mm) and least for 0.6 ET (296.4 mm) which also included the effective rainfall of 40.3 mm. The total amount of water applied through surface irrigation was maximum in case of 1.2 ET (419.5 mm) followed by 1.0 ET (325.5 mm) and minimum in case of 0.8 ET (305.3 mm) during 2007-'08. Similarly, the amount of water applied through surface irrigation was highest in 1.2 ET (487.3 mm) followed by 1.0 ET (427.3 mm) and lowest for 0.8 ET (374.6) during 2008-09. All these included the effective rainfall of 95.3, 55.5, and 29.5 mm in 0.8, 1.0 and 1.2 ET in 2007-08 and 44.6, 37.3 and 37.3 mm under 0.8, 1.0 and 1.2 ET during 2008-09, respectively.

The different levels of salinity had marked influence on tuber yield during both the years. The highest tuber yield of 22.685 t ha^{-1} in drip irrigation at 1.2 ET and the lowest tuber yield of 6.103 t ha^{-1} in surface irrigation at 0.8 ET were registered, respectively in salinity levels-I and III during 2007-08 (Table 2). During 2008-09, the maximum tuber yield of 22.248 t ha^{-1} in drip irrigation at 1.2 ET under salinity level-I and the lowest of 5.725 t ha^{-1} in salinity level-III were recorded (Table 3).

The highest water use efficiency of 6.74 kg m^{-3} and the lowest of 4.36 kg m^{-3} in drip irrigation levels at 0.6 and 1.4 ET were recorded during 2007-'08 in salinity level-I, respectively (Table 2). Similarly, the maximum water use efficiency of 6.23 kg m^{-3} and the least of 3.81 kg m^{-3} were obtained in drip irrigation treatments at 0.6 and 1.4 ET under salinity level-I during 2008-09 (Table 3). Among the surface irrigation levels the maximum water use efficiency of 4.25 kg m^{-3} in 2007-08 at 1.0 ET and 3.32

Table 2: Effect of different methods and levels of irrigation on total water used and water use efficiency during 2007-08

Treatments	Yield (kg ha^{-1})	Water applied (mm)	Effective rainfall (mm)	Total water used (mm)	WUE (kg m^{-3})
I_1 S_1	19023	252.8	29.5	282.3	6.74
I_1 S_2	16528	252.8	29.5	282.3	5.85
I_1 S_3	11204	252.8	29.5	282.3	3.97
I_2 S_1	20255	307.3	29.5	336.8	6.01
I_2 S_2	17581	307.3	29.5	336.8	5.22
I_2 S_3	12307	307.3	29.5	336.8	3.65
I_3 S_1	21470	361.7	29.5	391.2	5.49
I_3 S_2	18796	361.7	29.5	391.2	4.80
I_3 S_3	13665	361.7	29.5	391.2	3.49
I_4 S_1	22685	416.2	29.5	445.7	5.09
I_4 S_2	20417	416.2	29.5	445.7	4.58
I_4 S_3	15193	416.2	29.5	445.7	3.41
I_5 S_1	21794	470.6	29.5	500.1	4.36
I_5 S_2	19120	470.6	29.5	500.1	3.82
I_5 S_3	13920	470.6	29.5	500.1	2.78
I_6 S_1	12789	210.0	95.3	305.3	4.19
I_6 S_2	11053	210.0	95.3	305.3	3.62
I_6 S_3	6103	210.0	95.3	305.3	2.00
I_7 S_1	13831	270.0	55.5	325.5	4.25
I_7 S_2	12095	270.0	55.5	325.5	3.72
I_7 S_3	7184	270.0	55.5	325.5	2.21
I_8 S_1	14757	390.0	29.5	419.5	3.52
I_8 S_2	13194	390.0	29.5	419.5	3.15
I_8 S_3	8642	390.0	29.5	419.5	2.06

kg m^{-3} in 2008-09 in case of 0.8 ET was recorded, whereas the minimum water use efficiency of 3.52 kg m^{-3} during 2007-08 and 2.98 kg m^{-3} in 2008-09 was obtained at 1.2 ET in salinity level-I.

In salinity level-II, the highest water use efficiency of 5.85 kg m^{-3} under drip irrigation at 0.6 ET against of 3.82 kg m^{-3} in the drip irrigation at 1.4 ET was recorded during 2007-08 (Table 2). Among the surface irrigation levels, the maximum water use efficiency of 3.72 kg m^{-3} in case of 1.0 ET and the least of 3.15 kg m^{-3} at 1.2 ET was achieved during 2007-08. Similarly, during 2008-09 the highest water use efficiency of 5.32 kg m^{-3} under drip irrigation at 0.6 ET and the minimum of 3.34 kg m^{-3} in the drip irrigation at 1.4 ET was recorded. While in surface irrigation the highest water use efficiency of 2.85 kg m^{-3} in 0.8 ET and the least of 2.62 kg m^{-3} at 1.2 ET was obtained (Table 3).

Similarly, in salinity level-III, the highest water use efficiency of 3.97 kg m^{-3} in drip irrigation at 0.6 ET and the lowest of 2.78 kg m^{-3} in 1.4 ET was achieved during 2007-08 (Table 2). However, among surface irrigation levels, the maximum water use efficiency of 2.21 kg m^{-3} in 1.0 ET and the minimum of 2.0 kg m^{-3} in 0.8 ET was recorded during 2007-08. In 2008-09, among the drip irrigation levels, the highest water use efficiency of 3.52 kg m^{-3} at 0.6 ET and the least of 2.40 kg m^{-3} at 1.4 ET was noticed. Similarly, the highest water use efficiency of 1.69 kg m^{-3} was recorded in 1.2 ET, as against the least of 1.53 kg m^{-3} in 0.8 ET under surface irrigation in salinity level-III (Table 3).

The maximum water use efficiency was obtained in drip irrigation than surface irrigation. The yield was higher and the water applied was less in drip irrigation compared to surface irrigation, due to which higher water use efficiency was achieved in case of drip irrigation over surface irrigation. Similar findings were also reported by Chowdegowda and Jangandi (1995), Balasubrahmanya *et al.* (2001) and Tiwari *et al.* (2003). Among the drip irrigated treatments, the water use efficiency was the highest in case of 0.6 ET and the lowest in case of 1.4 ET. While, among the different salinity levels, the maximum water use efficiency was achieved in salinity level-I and minimum in salinity level-III. This might be due to higher tuber yield realised in salinity level-I than salinity level-III due to less stress comparatively.

Table 3 : Effect of different methods and levels of irrigation on total water used and water use efficiency during 2008-09

Treatments	Yield (kg ha^{-1})	Water applied (mm)	Effective rainfall (mm)	Total water used (mm)	WUE (kg m^{-3})
I_1 S_1	18472	256.1	40.3	296.4	6.23
I_1 S_2	15766	256.1	40.3	296.4	5.32
I_1 S_3	10423	256.1	40.3	296.4	3.52
I_2 S_1	19769	321.5	40.3	361.8	5.46
I_2 S_2	17030	321.5	40.3	361.8	4.71
I_2 S_3	11696	321.5	40.3	361.8	3.23
I_3 S_1	21016	386.8	40.3	427.1	4.92
I_3 S_2	18310	386.8	40.3	427.1	4.29
I_3 S_3	13122	386.8	40.3	427.1	3.07
I_4 S_1	22248	452.2	40.3	492.5	4.52
I_4 S_2	19914	452.2	40.3	492.5	4.04
I_4 S_3	14565	452.2	40.3	492.5	2.96
I_5 S_1	21276	517.5	40.3	557.8	3.81
I_5 S_2	18634	517.5	40.3	557.8	3.34
I_5 S_3	13394	517.5	40.3	557.8	2.40
I_6 S_1	12419	330.0	44.6	374.6	3.32
I_6 S_2	10660	330.0	44.6	374.6	2.85
I_6 S_3	5725	330.0	44.6	374.6	1.53
I_7 S_1	13345	390.0	37.3	427.3	3.12
I_7 S_2	11701	390.0	37.3	427.3	2.74
I_7 S_3	68164	390.0	37.3	427.3	1.60
I_8 S_1	14537	450.0	37.3	487.3	2.98
I_8 S_2	12766	450.0	37.3	487.3	2.62
I_8 S_3	8221	450.0	37.3	487.3	1.69

With the foregone discussions, it may be concluded that, adoption of drip irrigation for hybrid beetroot is a viable proposition for cultivation in salt-affected soils to achieve greater yield and water saving benefits as compared to surface irrigation.

Authors' affiliations:

P. BALAKRISHNAN, College of Agricultural Engineering, University of Agricultural Sciences, RAICHUR (KARNATAKA) INDIA

M.V. RANGHASWAMI AND D. TAMILMANI, Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, (T.N.A.U.) COIMBATORE (T.N.) INDIA

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