African Journal of Agricultural Research Vol. 4 (1), pp. 049-054, January 2009
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2009 Academic Journals

Full Length Research Paper

Effect of applied water and discharge rate on wetted soil volume in loam or clay-loam soil from an irrigated trickle source

Bilal Acar[1]*, Ramazan Topak[1] and Fariz Mikailsoy[2]

[1]Department of Farm Buildings and Irrigation, Faculty of Agriculture, University of Selçuk, Konya-Turkey.
[2]Department of Soil Science, Faculty of Agriculture, University of Selçuk, Konya-Turkey.

Accepted 23 December, 2008

This study was designated to determine the effect of different applied water by use of different emitter discharges on the wetting patterns of a loam or clay-loam soil under trickle source. Irrigation water was applied when the soil water depletion of 30 and 50% from available water capacity of soil in 0 - 90 depth. The discharge rates of 2 and 4 L h^{-1} was selected in irrigation treatments. The parameters affected the wetted soil volume of vertical wetting front advance Z_f, lateral wetting front advance within the soil profile R_s or at the surface R_f, were researched. The Z_f and R_s varied 43 to 58 cm and 54 to 60 cm, respectively. Different emitter discharges had no significant effects on Z_f, R_s and R_f. Different water applications had significant effect on Z_f but, had no significant effects on R_s or R_f. The highest wetted soil volume was obtained as 122681.6 cm^3 irrigation at 50% depletion from the available water capacity of soil from by 4 L h^{-1} emitter discharge use. The results showed that higher application rate favors the both vertical and lateral direction of water.

Key words: Trickle, irrigation, wetting front, wetted volume.

INTRODUCTION

Trickle irrigation is one of the most efficient methods and the system usually makes use of saving water supply in order to apply precise amount of water to the root zone. It is planned to deliver frequent light applications of water to wet only portions of the soil (Al-Qinna and Abu-Awwad, 2001). In order to preserve water resources and to improve its use efficiency, trickle irrigation is considered as a good way to achieve that. Trickle irrigation allows a large degree of water saving, enabling accurate application of irrigation amounts according to crop water requirements. Under optimum management, trickle irrigation systems will reduce the water losses caused by evaporation and by deep percolation (Tanji and Hanson, 1990). On the other hand, the use of this technique is relatively recent and little information is known about the movement of the water in soil profile under field condition. Therefore, the size of the wetted soil volume under emitters is an important field characteristic in trickle irrigation system design (Revol et al., 1991). In trickle irrigation, frequency and application rate determine the soil water content, and as a result root distribution and patterns of plant water uptake (Coelho and Or, 1999; Assouline et al., 2002). The wetted soil volume under an emitter can be determined the purpose of estimating the available soil water as the product of percent wetted area and depth of rooting. The dimensions of this and the percenttage of the wetted area depend on the emitter discharge, spacing and soil properties (Keller and Karmeli, 1974; Goldberg et al., 1976; Assouline, 2002). The boundaries of the wetted soil volume are reasonably well defined and are surrounded by drier soil (Zur, 1996; Wooding, 1968). Mitchell and Lembke (1981) reported that increase emitter discharge reduced lateral and increase the vertical movement of water under silt-clay-loam soil. Clark et al. (1993) reported that lateral movement of water varied

*Corresponding author. E-mail: biacar@selcuk.edu.tr.
Tel.: +90332 2232851; Fax: +90332 2410108.

Table 1. Particles size distribution and water holding capacity of experimental soil.

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Bulk density (g cm^{-3})	$ø_{fc}$ (%)	$ø_{pwp}$ (%)	AWC (mm 30 cm^{-1})
0 – 30	21.4	46.6	32.2	1.33	34.15	20.60	40.65
30 – 60	32.4	35.4	32.2	1.36	31.21	21.66	28.65
60 – 90	30.4	40.4	29.2	1.29	32.33	19.81	37.53

$ø_{fc}$: Volumetric water content at the field capacity, %;
$ø_{pwp}$: Volumetric water content at the permanent wilting point, %;
AWC: Water holding capacity of the soil, mm 30 cm^{-1}.

Table 2. Irrigation water properties used in treatments.

Irrigation Water Class	EC (µmhos cm^{-1})	pH	Cations, meq L^{-1}			Anions, meq L^{-1}		
			Ca^{++} Mg^{++}	Na^{+}	K^{+}	HCO_3^-	SO_4^{-2}	Cl^-
C_3- S_1	967	7.40	10.40	0.55	-	2.8	6.62	1.13

15.5 - 20 cm by use of 1.5 - 1.9 L h^{-1} emitter discharge in sandy soil conditions. Gençoğlan and Yazar (1998) studied the effects of different irrigation water applications on lateral wetting front advance under clay soil condition and measured between 45 and 60 cm. Schwartzman and Zur (1986) studied the geometry of wetted soil volume under trickle irrigation and developed a series of empirical equations relating the width and depth of the wetted soil volume to emitter discharge, saturated hydraulic conductivity of the soil and volume of water in wetted soil volume. The few studies have been cited in the literature about determination of wetted soil volume under field condition.

The objective of the present research, therefore, was to study the effect of applied water by using different emitter discharges on the wetted soil volume at the end of irrigation under field conditions.

MATERIALS AND METHODS

The investigations were carried out during the summer period of 2001 in the Karaman province located in Middle Anatolia Region of Turkey. The research site was 36° - 37° north latitude and 32° - 34° east longitude with an elevation of 1033 m above sea level. The region experiences almost arid climate with extremely hot during summer and cold during winters. According to the long term climate records, the mean average temperature, relative humidity and wind speed during the study year were 11.8℃, 61% and 2.4 m s^{-1}, respectively. Annual rainfall and evaporation were recorded as 333.6 and 1334 mm, respectively (Anonymous, 2008). The percentage of clay, silt and sand with some physical properties of the experimental soil is given in Table 1. The total soil available water capacity, AWC, was 106.83 mm 90 cm^{-1}.

The in- line trickle tube used for irrigation was (GR type Eurodrip U.S.A., Inc.) consisting of 50 m long PE distribution lines, 16 mm in diameter, 0.75 cm drip away, each delivering 2 L h^{-1} and 4 L h^{-1} of irrigation capacity at 100 kPa pressure. For proper determination of wetting parameters, or testing the individual emitter, some emitters were closed. Trickle irrigation lines were 5 m apart, equally spaced in the plant rows. The trickle system had the control unit with a fertilizer tank (100 L), a disk filter, control valves and a water flow meter.

In research, irrigation water is taken from deep wells with 80 m in depth and 60 m^3 h^{-1} capacity. The properties of irrigation water are given in Table 2 and it was C_3S_1 class (Anonymous, 1954). Although irrigation water is third class in terms of the salinity hazard, there was not observed any signs of salt in soil profile.

In order to evaluate the wetted soil volume, two irrigation water levels were applied (depletion of 30 and 50% of available soil water capacity of the soil in 0 – 90 cm soil depth) by use of two discharge rates of 2 and 4 L h^{-1} in the experiment. The parameters affected the wetted soil volume of vertical wetting front advance Z_f and lateral wetting front advance within the soil profile R_s with on the surface R_f, were researched. The Z_f and R_s were determined by measuring the soil moisture content by gravimetric method after the day of irrigation. The soil samples were taken from 0 - 30 cm, 30 - 60 cm and 60 - 90 cm depth by the 10 cm increments from the emitter point up to 80 cm away by use of in small diameter auger. The boundaries of the wetted soil volume were the volume of wetted soil that was above the field capacity of soil (Gençoğlan and Yazar, 1998). The parameters of the lateral wetting front advance on the surface (R_f) were measured by use of graded steel measure. Like a previously graph (Hammami, 2001; Iusheng et al., 2004) was used (Figure 1) to determine the wetting patterns under emitters from a surface point source.

The shape of the wetted soil volume is like truncated ellipsoid. The equation of ellipsoid for origin (o-h), radius of a and b can be written as follow;

$$\frac{x^2}{a^2} + \frac{(z+h)^2}{b^2} = 1 \qquad (1)$$

The x value in equation 1 for calculation of volume of cut ellipsoid that refers to the wetted soil volume obtained from area in Figure 1 by rotating the 360° on the o-z axis, can be written as;

$$x = \varphi(z) = \pm \frac{a}{b}\sqrt{b^2 - (z+h)^2} \qquad (2)$$

The volume limited by rotating surface can be as follow;

Table 3. Vertical wetting front advance (Z_f) within soil profile for different applied water and emitter rate.

Depletion from AWC, (%)	Emitter discharges (L h^{-1})	Vertical wetting front advance, Z_f (cm)
30	4 L h^{-1}	55
50		58
30	2 L h^{-1}	43
50		46

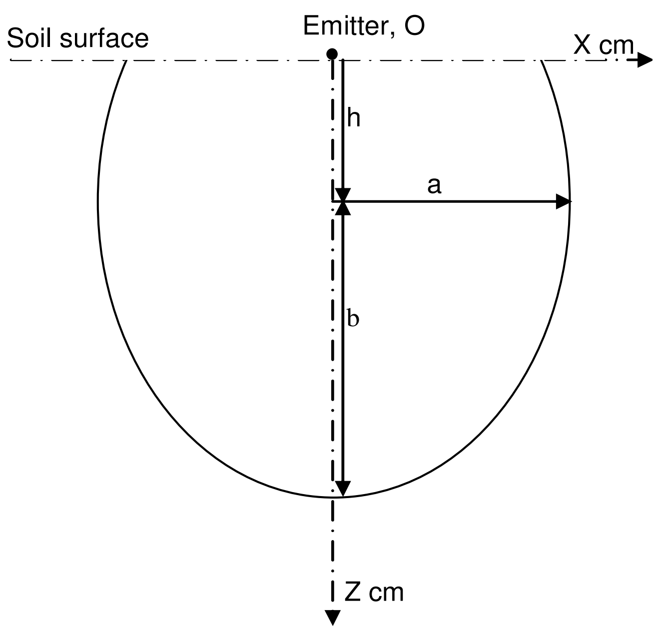

Figure 1. Schematic description of the wetted soil volume parameters.

$$V_{oz} = \pi \int_{-b-h}^{0} \varphi^2(z)dz \quad (3)$$

By solving the definite integral equation given above, following formula can be first derived for calculation of cut ellipsoid volume;

$$V_{oz} = \frac{a^2\pi}{3b^2}(b+h)\left(2b^2 - h^2 + hb\right) \quad (4)$$

where; V_{oz} - wetted soil volume (cm^3), a- ½ of the maximal lateral wetting front advance (cm), b- depth between maximal lateral wetting front advance and vertical wetting front advance (cm) and h- depth between maximal lateral front advance and soil surface level (cm).
Analysis of variance of evaluated characteristics was done and means compared by the Tukey probability test (5%).

RESULTS AND DISCUSSION

The wetting patterns are characterized by the depth of wetting front advance (Z_f) under the point source (emitter) and the lateral wetting front advance within the soil profile (R_s). The variables are mainly influenced by the applied water amounts and the application rate.

Vertical wetting front advance (Z_f)

The vertical wetting front advance data are given in Table 3. The deepest point of wetting front advance located at 55 and 58 cm under the treatment of 30 and 50% water content depletion from the AWC by emitter discharges of 4 L h^{-1}, respectively, whereas they were measured at 43 and 46 cm under same water applications for discharge rate of 2 L h^{-1}. The highest Z_f was obtained as 58 cm from the emitter discharge of 4 L h^{-1}. Thabet and Zayani (2008) have also similar results that Z_f was 52.5 cm for emitter discharge of 4 L h^{-1} under loam-sand soil conditions. The higher the applied water and emitter discharges the more the vertical wetting front advance that was in agreement with the previous observation (Mostaghami et al., 1981).

Lateral wetting front advance within soil profile (R_s)

Lateral wetting front advances or maximal widths in soil profile are presented in Table 4. In examine the Table, 4 L h^{-1} emitter discharge resulted in horizontal extent of 56 and 60 cm under different water applications. These were measured as 54 and 57 cm for 2 L h^{-1} emitter discharges. Increase the emitter discharge from 2 to 4 L h^{-1} resulted in small amount of increase in lateral wetting front in soil profile. Gençoğlan and Yazar (1998) also reported similar findings. In trickle system design, due the slight differences both treatments can be selected. In arid regions, small discharge might be recommended for greater land irrigation in one set.

Lateral wetting front advance on soil surface (R_f)

Table 5 shows the lateral wetting front advance on the soil surface. According to such Table, R_f was slightly higher in great discharge (4 L h^{-1}) than small discharge (2 L h^{-1}) for 50% of the AWC water application. The highest R_f value was measured at 32 cm from 50% of the AWC water application and discharge rate of 4 L h^{-1}, and the

Table 4. Lateral wetting front advance ($R_s = 2a$) within soil profile for different applied water and emitter rate.

Depletion from AWC, (%)	Emitter discharges (L h^{-1})	Lateral wetting front advance, R_s (cm)
30	4 L h^{-1}	56
50		60
30	2 L h^{-1}	54
50		57

Table 5. Lateral wetting front advance (R_f) on soil surface for different applied water and emitter rate.

Depletion from AWC, (%)	Emitter discharges (L h^{-1})	Lateral wetting front, R_f (cm)
30	4 L h^{-1}	30.5
50		32.0
30	2 L h^{-1}	29.4
50		31.0

Table 6. Effect of emitter discharges on soil wetting patterns.

Emitter discharge, L h^{-1}	Z_f (cm)	R_s (cm)	R_f (cm)
2	49±7.04a	55±3.35a	29.95±1.71a
4	52±6.81a	58±2.53a	31.50±1.76a
$LSD_{0.05}$	ns	ns	ns

ns- not significant; s- significant
Average in the same column followed by the same letter did not differ by Tukey test (5%).

lowest one was at 29.4 cm from 30% of the AWC water application with discharge rate of 2 L h^{-1}. This lateral wetting front is attributed to the capillary predominance effect for small discharge at the opposite of gravity effect which is more important with great discharge. Gupta et al. (1995) reported that wetting front advance was 40 cm for clay loam soil and this was higher than our study result. The difference might be resulted from the soil characterristics of experimental soil.

Statistical evaluation of experimental results

The individual effects of different emitter discharges and water applications on Z_f, R_s and R_f are presented in Table 6 and 7.

According to the Table 6, increase of emitter discharges from 2 to 4 L h^{-1} had no significant effect on Z_f, R_s, and R_f. The differences were found not significant for measured all parameters. Under these conditions, 2 L h^{-1} emitter discharge was seen more suitable for increasing the irrigated areas with same amount of water supply.

As seen from the Table 7 that the different water applications had only significant effect on vertical wetting front advance ($P < 0.05$). Increase the applied water resulted in increase in vertical wetting front advance. The mean Z_f values were 44.50 and 56.50 cm for 30 and 50% of AWC water applications, respectively. The differences between R_s and R_f were not found significant.

Wetted soil volume (V_{oz})

The wetted soil volume under an emitter can be determined for the purpose of estimating the available soil water. The mean wetted soil volumes as influenced by the different applied water and emitter discharges were calculated and presented in Table 8 and Figure 2. The differences in wetted soil volume within each applied water and emitter discharges were not very large: 101317.3 - 122681.6 cm^3 and 73812.43 - 86053.47 cm^3 for 4 and 2 L h^{-1}, respectively. In general, V_{oz} was higher in 4 L h^{-1} than 2 L h^{-1} emitter discharge and the highest was computed at 122681.6 cm^3 under 50% depletion of soil water content from the AWC with 4 L h^{-1} emitter discharge. Increase applied water and the emitter discharge the more the wetted soil volume. Under this experimental condition, designers may use the small emitter discharges in areas of limited water resources supply. However, higher emitter discharge might be recommended only in areas where the water supply is sufficient. Our

Table 7. Effect of applied water on soil wetting patterns.

Depletion from AWC of soil, %	Z_f (cm)	R_s (cm)	R_f (cm)
30	44.50±2.07a	55±1.79a	30.20±2.0a
50	56.50±3.27b	58±3.79a	31.25±2.16a
$LSD_{0.05}$	s	ns	ns

ns- not significant; s- significant
Average in the same column followed by the same letter did not differ by Tukey test (5%).

Table 8. Parameters for calculation of wetted soil volume (V_{oz}) for different applied water and emitter rate

Depletion from AWC (%)	Emitter discharges (L h^{-1})	a(cm)	b(cm)	h(cm)	Wetted volume, V_{oz} (cm^3)
30		28	35	20	101317.3
50	4 L h^{-1}	30	37	21	122681.6
30		27	29	14	73812.43
50	2 L h^{-1}	28.5	29.5	15.5	86053.47

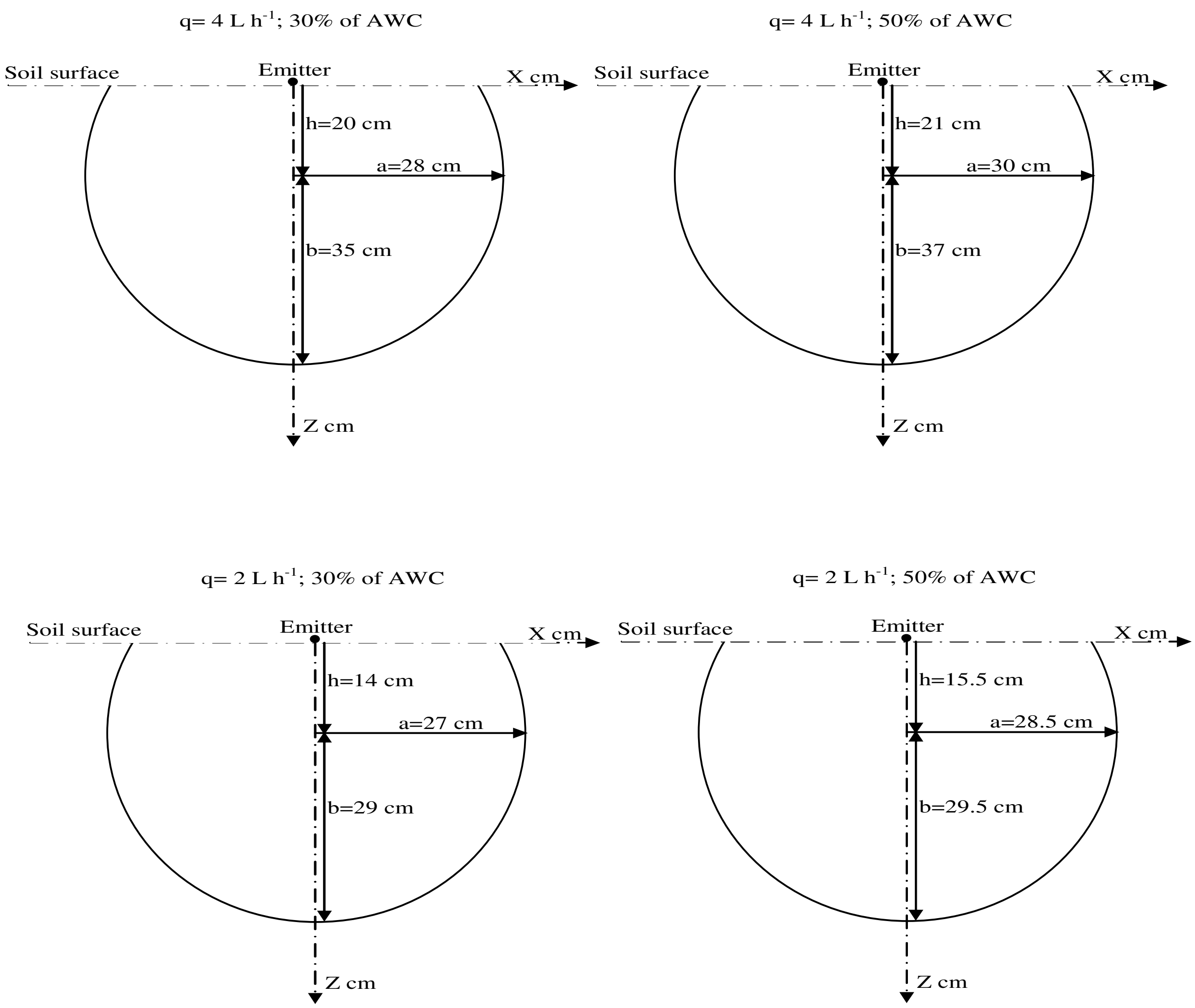

Figure 2. Wetting patterns under different applied water and emitter discharges.

ficient. Our calculation formula yielded similar results by Thabet and Zayani (2008). The results of this experiment will be very useful for trickle irrigation design especially selection of lateral and emitter spacing.

Conclusion

Different irrigation water amounts were applied by use of two emitter discharges for determination of wetted soil volume under field conditions. The boundaries of the wetted soil volume were the volume of wetted soil that was above the field capacity of soil. Statistical analysis indicated that use of different emitter discharges had no significant effects on vertical wetting front advance, lateral wetting front advance within the soil profile and at the surface. Different water applications had significant effect on only vertical wetting front advance but had no significant effects on lateral wetting front advance within the soil profile and at the surface. The results showed that both vertical, lateral wetting front advances and wetted volume increased under higher emitter discharges. The study results will be very beneficial for trickle irrigation design especially selection of lateral and emitter spacing and consequently application time.

REFERENCES

Al-Qinna MI, Abu-Awwad AM (2001). Wetting patterns under trickle source in arid soils with surface crust. J. Agric. Engng. Res. 80(3): 301-305.

Anonymous (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook, No: 60, p.160, USA.

Anonymous (2008). Government Meteorological Station, Konya (in Turkish).

Assouline S (2002). The effects of microdrip and conventional drip irrigation on water distribution and uptake. Soil Sci. Soc. Am. J, 66: 1630-1636.

Assouline S, Cohen S, Meerbach D, Harodi T, Rosner M (2002). Microdrip irrigation of field crops: Effect on yield, water uptake, and drainage in sweet corn. Soil Sci. Soc. Am. J, 66: 228-235.

Clark CA, Sranley FS, Zazueta FS (1993). Qualitative sensing of water movement from a point-source emitter on a sandy soil. Transactions of ASAE, 9 (3): 299-303.

Coelho EF, Or D (1999). Root distribution and water uptake patterns of corn under surface and subsurface drip irrigation. Plant Soil, 206: 123-136.

Gençoğlan C, Yazar A (1998). Determination of emitter spacing based on the amount of water applied and trickle discharge rates. Tr. J. Agric. Forestry, 22: 43-50.

Goldberg D, Gornat B, Rimon D (1976). Drip Irrigation: Principles Design and Agriculture Practices. Drip Irrigation Scientific Publication; Kafar Shumar Yahu p. 296, Israel.

Gupta RK, Rudra RP Dickinson WT, Lamm FR (1995). Proceedings of the 5 th inter. Microirrigation congress, Orlondo, Florida (2-6 April) p. 628.

Hammami M (2001). Nouvelle approache pour determiner le volume du sol humidite par un goutteur. These de Doctorate d' Etat en Sciences Physics, Universite de Tunis, p. 214.

Iusheng L, Zhang J, Rao M (2004). Wetting patterns and nitrogen distributions as affected by fertigation strategies from a surface point source. Agricultural Water Management, 67: 89-104.

Keller J, Karmeli D (1974). Trickle irrigation design parameters. Transactions of ASAE, 17: 678-684.

Mitchell JK, Lembke WD (1981). Effect of discharge rate on distribution of moisture in heavy soil from a irrigated trickle source. ASAE Paper no: 81, p.2081.

Mostaghami S, Mitchell KJ, Lembke WD (1981). Effect of discharge rate on distribution of moisture in heavy soils irrigated from a trickle source. Trans. ASAE, 25: 2081-2085.

Revol PH, Clothier BE, Vachaud G, Thony JL (1991). Predicting the field characteristics of trickle irrigation. Soil Technology. 4:125-134.

Schwartzman M, Zur B (1986). Emitter spacing and geometry of wetted soil volume. J Irrig Drainage Enginr ASCE 112: 242-253.

Tanji KK, Hanson BR (1990). Drainage and return flow in relation to irrigation management. In: BA Stewart, DR Nelson (Eds.), Irrigation of agricultural crops. Agronomy monograph no. 30, ASAE, Madison, WI.1057.

Thabet M, Zayani K (2008). Wetting patterns under trickle source in a loamy sand soil of South Tunisia. American-Eurasian J. Agric. Environ. Sci., 3(1): 38-42.

Wooding RA. (1968). Steady infiltration from a shallow circular pond. Water Res. Res. 4:1259-1273.

Zur B (1996). Wetted soil volume as a design objective in trickle irrigation. Irrig. Sci. 16:101-105.