TECHNICAL NOTES:
A COMPARISON OF TWO SATURATED HYDRAULIC CONDUCTIVITY MEASURING TECHNIQUES IN RELATION TO DRAIN INSTALLATION METHODS

M. S. Mirjat, R. S. Kanwar
STUDENT MEMBER ASAE MEMBER ASAE

ABSTRACT. *Saturated hydraulic conductivity (K_S) is an important parameter influencing subsurface drainage design and performance, and K_S can be affected by subsurface drain installation methods. K_S was measured at a field site at Nashua, Iowa, with 1.2-m (4-ft) deep drain lines installed with a trenchless plow and with a chain trencher at four depths [0 to 150, 150 to 450, 450 to 750, 750 to 1000 mm (0 to 6, 6 to 18, 18 to 30, 30 to 40 in.)] using the Guelph permeameter (in situ technique) and the constant head permeameter method (laboratory technique) on undisturbed soil cores which were removed from the field site. K_S values were 10 to 130 times greater for the constant head permeameter compared to the Guelph permeameter method and were significantly different at all depths for the two measurement methods. The laboratory technique yielded greater standard deviation values for all depths, whereas the coefficient of variation values were greater for the in situ technique. Drain line installation methods did not significantly affect K_S at the 0 to 150 and 150 to 450 mm (0 to 6 and 6 to 18 in.) depths; however, at the 450 to 750 and 750 to 1000 mm (18 to 30 and 30 to 40 in.) depths, the trencher installation method had K_S values two to three times greater than the trenchless installation method and these differences were significantly different. Subsurface drain line installation method can affect the K_S values particularly near the drain line depths; however, these affects did not affect drainage system performance 10 years after installation.* ***Keywords.*** *Hydraulic conductivity, Permeameters, Drain installation methods.*

The ability of a soil to transmit water is often characterized by its saturated hydraulic conductivity (K_S). The K_S value has an important application in areas ranging from the characterization of soil profile development and solute transport to the design of irrigation and drainage systems, septic systems, and many other industrial, environmental, and agricultural installations (Bouwer and Jackson, 1974; Mein and Larson, 1973). The K_S of soil is a function of both soil texture and structure (Topp and Sattlecker, 1983; Kanwar et al., 1989). Depositional layers and horizon development affect the horizontal component of K_S. Vertical dehydration, cracks, wormholes, and root channels affect values for vertical K_S (Bouma, 1982; Topp and Sattlecker, 1983; Wang et al., 1985; Kanwar et al., 1989; Mirjat 1992). Apart from these factors, the K_S values of soils near the drain may also be affected by the drain installation method (Kanwar et al., 1986).

The best choice of drain installation methods must optimize several interrelated factors, including accuracy, speed, simplicity, portability, manpower, capital costs, and others. With these criterion in mind, a study was conducted in 1991 to investigate the changes in K_S and bulk density values near subsurface drains installed either by a trenchless plow or a chain trencher. This article compares the performances of two techniques for measuring K_S. These techniques include *in-situ* measurements using Guelph permeameter and laboratory measurements using a constant head permeameter.

MATERIALS AND METHODS

SITE DESCRIPTION

The experimental site for this study was the Iowa State University's Northeast Research Center at Nashua, Iowa, in Floyd County. The study site, described in detail by Kanwar et al. (1986), is predominantly Kenyon loam soil in the Kenyon-Floyd-Clyde Soil Association. Kenyon soils are gently sloping and moderately well-drained, with a thick, dark, loamy surface layer and a high plant available water holding capacity.

SUBSURFACE DRAIN INSTALLATION

Corrugated plastic drains 102 mm (4 in.) in diameter were installed in the fall of 1979. A HOES trenchless drain plow [TITAN 623 model with a 228-mm (9 in.) flat blade and a 152-mm (6 in.) tubing guide box] and a HOES chain trencher [GIGANT 685 model with a 290-mm (11.4 in.) chain width and a 254-mm (10 in.) tubing box] were used to install the drain lines. All drains were installed without envelope material at a depth of 1.2 m (4 in.). One group of three drain lines spaced 24 m (79 ft) apart were installed with each installation method. Two experimental plots (one over a drain line installed by the trencher and the other over a drain line installed by the trenchless plow) were selected for this study during August of 1991. Both

Article has been reviewed and approved for publication by the Soil and Water Div. of ASAE.

Journal Paper No. J-14731 of the Iowa Agriculture and Home Economics Experiment Station, Ames. Project No. 2898. This research was partly supported by the USAID with funds provided from the Pakistan Participant Training Program.

The authors are **Mohammad Saffar Mirjat**, USAID Fellow, and **Ramesheshar S. Kanwar**, Professor, Dept. of Agricultural and Biosystem Engineering, Iowa State University, Ames.

experimental plots consisted of a 1 × 3 m (3.28 × 9.84 ft) area centered over the drain line. The plots were divided into three rows 450 mm (18 in.) apart, with the middle row located exactly over the drain line, and the other two rows located at a distance of 450 mm (18 in.) on either side and parallel to the drain line. Three locations along each row [1.4 m (4.6 ft) apart] were used to take in-field readings for K_s measurements at depths of 0 to 150, 150 to 450, 450 to 750, and 750 to 1000 mm (0 to 6, 6 to 18, 18 to 30, and 30 to 40 in.) at each location.

Saturated Hydraulic Conductivity (K_S) Measurements

K_s values of the soil were measured in-situ with the Guelph permeameter (Reynolds and Elrick, 1986; Reynolds et al., 1983). In the laboratory, K_s values were measured on undisturbed soil cores using a constant head permeameter (Klute and Dirksen, 1986). A brief description of each method and a detailed description of the procedures used are given below.

Guelph permeameter and procedure description: The Guelph permeameter is basically an "in-hole" Mariotte bottle constructed from concentric, transparent acrylic tubes where an air-inlet (inner) tube provides the air supply, a reservoir (outer) tube allows measurement of flow from the permeameter, and an outlet (outer) tube provides a conduit to carry water to the bottom of the hole. The construction and procedures are described in detail by Reynolds et al. (1983) and Reynolds and Elrick (1986), therefore, only the details peculiar to this work are given here.

Three Guelph permeameters were used simultaneously to collect data on K_s at three locations across rows. For each measurement, a 60-mm (2.4-in.) diameter hole was prepared with an auger. The permeameter was centered over the hole and lowered so the tip entered the hole bed without disturbing the sides or the bottom. The permeameter was filled with water, and adjusted until a 50 mm (2 in.) water head was established in the hole. The rate of fall of water level in the reservoir was recorded every 2 min until steady state was reached. The rate of fall over time was calculated by finding the difference between two readings and dividing by 2 min. The measurement procedures were repeated with a 100 mm (4 in.) water head in the hole.

Laboratory method (constant head permeameter) and procedure description: K_s was measured in undisturbed cores using a constant head permeameter. In this method, water passes through a saturated soil column of uniform cross-section. A constant head above the soil column is maintained. The amount of water passing through the column is collected until steady-state flow has been reached. Three soil cores (75 mm diameter × 75 mm long (3 in. × 3 in.) near each hole prepared for *in-situ* measurement were taken to determine K_s in the laboratory. A total of 27 soil cores were collected for each of the four depths studied at each experimental plot. Soil cores were collected in cylindrical metal containers that served as retainers for the soil K_s determination. In the laboratory, one end of each sample was covered with cheese cloth held by a rubber band and placed in a tray with the cloth-covered end facing down. The tray was filled with water to a depth just below the top of the samples. Undisturbed samples were allowed to soak in water until completely saturated. Once saturated, a piece of filter paper was placed on top of each core. Samples were shifted to an air-tight chamber of the constant head permeameter where standard procedures as explained by Klute and Dirksen (1986) were followed to complete the measurements. Soil particle size and bulk density were also determined using standard methods.

Results and Discussion

Guelph permeameter (*in-situ*) and constant head permeameter (laboratory) techniques were statistically compared within each experimental plot on the basis of mean K_s, range (R), standard deviation (SD), and coefficient of variation (CV) of the K_s values. The K_s, R, SD, and CV values for the two techniques for the two experimental plots are given in table 1. At all depths, K_s-values for the laboratory method were 10 to 130 times greater than those determined *in-situ*. The differences in mean K_s values for all depths were significant at the 0.05 probability level between the two measuring techniques. There could be several possible explanations for these differences in K_s measurement techniques. The primary reason is the difference between the two K_s measuring techniques themselves. The Guelph permeameter does not measure either the vertical or horizontal K_s separately but some combination of horizontal and vertical components of K_s (Reynolds and Elrick, 1986), whereas, the laboratory method measures only the vertical component of K_s. The other reason is presence of macropores (cracks, wormholes, wall effects, etc.). Many of the cores tested in the laboratory had visible root and wormholes [about 2 to 10 mm (0.08 to 0.4 in.) in diameter]. Some of these holes ran through the entire soil core which must have caused pipe flow. Also, the short length of the laboratory cores

Table 1. Saturated hydraulic conductivity (K_s), range (R), standard deviation (SD), and coefficient of variance (CV) at two selected plots over trenched drains as determined by two measuring techniques

Depth from Soil Surface	Method	N	Mean K_s* (mm/h)	Range (mm/h)	SD (mm/h)	CV (%)
			Trench Method			
0-150 mm	*In-situ*	9	17.0^a	2.8- 30.3	9.7	57.1
	Lab	27	66.2^b	26.7-106.0	25.3	38.2
150-450 mm	*In-situ*	9	10.1^a	4.9- 28.5	7.4	73.3
	Lab	27	57.6^b	26.7- 89.5	19.0	33.0
450-750 mm	*In-situ*	9	16.2^a	0.5- 62.2	13.2	81.5
	Lab	27	86.3^b	23.4-112.0	28.7	33.3
750-1000 mm	*In-situ*	9	13.2^a	0.1- 39.1	17.4	131.8
	Lab	27	97.9^b	20.0-160.0	32.7	33.4
			Trenchless Method			
0-150 mm	*In-situ*	9	11.2^a	4.1- 39.6	11.1	99.1
	Lab	27	63.6^b	21.4- 98.4	26.3	41.4
150-450 mm	*In-situ*	9	8.4^a	0.3- 31.8	9.6	114.3
	Lab	27	49.4^b	12.8- 98.6	21.4	43.3
450-750 mm	*In-situ*	9	5.5^a	0.2- 22.8	6.9	125.5
	Lab	27	41.4^b	0.6- 88.0	20.2	48.8
750-1000 mm	*In-situ*	9	0.9^a	0.1- 2.5	0.8	88.9
	Lab	27	40.2^b	10.4- 85.5	26.7	66.4

* Means followed by same letter are not significantly different at 5% probability level for that depth.

compared to the flow domain of the Guelph permeameter could be an important factor causing differences between the field and laboratory methods. These findings are in agreement with those of Kanwar et al. (1989); they found K_s values 10 to 800 times greater for the laboratory method than for the Guelph, and velocity permeameter methods.

The R, SD, and CV for two K_s measurement techniques are given in table 1 for the two experimental plots. The laboratory technique yielded greater SD values compared to the *in situ* technique for all depths, whereas, the CV values were greater for the *in situ* technique. In general, greater CV variation is an indicative of poor estimates under that measuring technique, but generalization is of course not always true. As pointed out by Lee et al. (1985), the higher CV values do not mean that a poor estimate of K_s is obtained, but rather that considerable inherent variation exists within the measuring techniques. By the same token, lower CV values do not necessarily mean that corresponding K_s values are more accurately obtained, they may simply mean that the measurement technique is sampling only a subset of the entire population of K_s values. The CV values, therefore, include variation resulting from both the populations being measured and the measurement technique itself (Warrick and Nielsen, 1980). Generally, the high CV values (table 1) indicate that a relatively large number of measurements are required to obtain a reliable estimate of K_s by means of any measuring technique.

Regardless of measuring techniques, it is seen that a different pattern of difference in the mean K_s values was found for the two installation methods (table 2). The K_s values increased with depth in the plot over the trenched drains, whereas the opposite trends in the mean K_s values were observed with increasing depth in the plot over trenchless drains. The K_s values at 0 to 150 mm and 150 to 450 mm (0 to 6 and 6 to 18 in.) were not significantly different for the installation methods. The trench method, however, resulted in roughly one to three times greater K_s values than the trenchless method at the 450 to 750 mm and 750 to 1000 mm (18 to 30 and 30 to 40 in.) depths. These differences were significant at the 5% level of significance using standard analysis of variance procedures. The differences in K_s values at 450 to 750 mm and 750 to 1000 mm (18 to 30 and 30 to 40 in.) depths might be due to the installation methods. During the installation process, the soil's physical properties are usually altered. For example, a trencher machine removes the clayey subsoil and trenches are usually back filled with more permeable topsoil, thus greater K_s values can be anticipated. Lateral compaction and smearing of the clayey subsoil often accompanies trenchless plow installations which might contribute to lower K_s values. Mirjat and Kanwar (1992) observed differences in soil physical properties for the two installation methods. High clay contents were observed where the drains were installed by the trenchless method. Although soil physical and hydraulic characteristics near the drain appeared to be affected by installation method, overall drainage system performance, (in terms of total outflow and field water table depths) was not affected by installation method 10 years after installation (Mirjat and Kanwar, 1992).

Table 2. Analysis of variance to compare the two installation methods according to saturated hydraulic conductivity K_s, mm/h results

Parameter		Trench Mean	Trench SD	Trenchless Mean	Trenchless SD	F	Pr > F
		***In-situ* Measurements**					
Depth	0-150 mm	17.0	9.7	11.2	11.2	1.37	0.2592
	150-450 mm	10.1	7.4	8.4	9.6	0.17	0.6829
	450-750 mm	16.2	13.2	5.5	6.9	4.65	0.0466*
	750-1000 mm	13.2	17.4	0.9	0.8	4.53	0.0492*
		Laboratory Measurements					
Depth	0-150 mm	66.2	25.3	63.6	26.3	0.15	0.6996
	150-450 mm	57.6	19.0	49.4	21.4	2.22	0.1419
	450-750 mm	86.3	28.7	41.4	20.2	44.24	0.0001*
	750-1000 mm	97.9	32.7	40.2	26.7	56.74	0.0001*

* Means are significantly different at 0.05 level.

CONCLUSIONS

Experiments were conducted to compare two saturated hydraulic conductivity (K_s) measuring techniques. The measurements were made in two plots selected over two subsurface drain installation methods (trenchless plow and chain trencher). Two measuring techniques, Guelph permeameter (*in-situ*) and constant head permeameter (laboratory), were used to determine the K_s values at four different depths. This study resulted in the following conclusions:

- K_s values determined by the laboratory technique were 10 to 130 greater than those measured *in-situ* using the Guelph permeameter. The differences in mean K_s values for all depth were significant at the 0.05 probability level between two measuring techniques.
- The laboratory technique yielded greater SD values than those calculated with *in situ* data for all depths, whereas, opposite trends in CV values were observed between two measuring techniques.
- The K_s values at 0 to 150 mm and 150 to 450 mm (0 to 6 in. and 6 to 18 in.) depths were not significantly different between installation methods. However, K_s values at 450 to 750 mm and 750 to 1000 mm (18 to 30 in. and 30 to 40 in.) depths were about two to three times greater for drains installed with a trencher than those for drains installed with a trenchless plow. At the lower depths, the K_s values near the drain were significantly different at the 0.05 probability level between the two drain installation methods.

REFERENCES

Bouma, J. 1982. Measuring the hydraulic conductivity of soil horizons with continuous macropores. *Soil Sci. Soc. Am. J.* 46:438-441.

Bouwer, H., and R. D. Jackson. 1974. Determining soil properties. In *Drainage for Agriculture*, ed. J. van Schifgaarde. Madison, WI: Am. Soc. Agron. Agronomy 17:611-672.

Kanwar, R. S., H. A. Rizvi, M. Ahmed, R. Horton and S. J. Marley. 1989. Measurement of field-saturated hydraulic conductivity by using Guelph permeameter. *Transactions of the ASAE* 32(6):1885-1890.

Kanwar, R. S., T. S. Colvin and S. W. Melvin. 1986. Comparison of trenchless drain plow and trench methods of drainage installations. *Transactions of the ASAE* 29(2):456-461.

Klute, A. and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: Laboratory methods. *Methods of Soil Analysis*, Part 1, 687-734. Agronomy Monograph No. 9, 2nd Ed.

Lee, D. M., W. D. Reynolds, D. E. Elrick and B. E. Clothier. 1985. A comparison of three field methods for measuring saturated hydraulic conductivity. *Can. J. Soil Sci.* 65:563-573.

Mein, R. G., and C. L. Larson. 1973. Modelling infiltration during a steady rain. *Water Resource Res.* 9:384-397.

Mirjat, M. S. 1992. Hydraulic evaluation of subsurface drain installation methods and their impact on water quality. Unpublished M.S. thesis, Iowa State University, Ames.

Mirjat, M. S. and R. S. Kanwar. 1992. Evaluation of subsurface drain installation methods using water table and drain outflow data. *Transactions of the ASAE* 35(5):1483-1488.

Reynolds, W. D. and D. E. Elrick. 1986. A method for simultaneous *in situ* measurement in the vadoze zone of field-saturated hydraulic conductivity, sorptivity and the conductivity-pressure head relationship. *Ground Water Monit. Rev.* 6:84-95.

Reynolds, W. D., D. E. Elrick and G. C. Topp. 1983. A reexamination of the constant head well permeameter method for measuring saturated hydraulic conductivity above the water table. *Soil Sci.* 136:250-268.

Topp, G. C. and S. Sattlecker. 1983. A rapid measurement of horizontal and vertical components of saturated hydraulic conductivity. ASAE Paper No. 79-2515. St. Joseph, MI: ASAE.

Wang, C., J. A. McKeague and K. D. Switzer-House. 1985. Saturated hydraulic conductivity as an indicator of structural degradation in clayey soils of Ottawa area, Canada. *Soil & Tillage Res.* 5:19-31.

Warrick, A. W. and D. R. Nielsen. 1980. Spatial variability of soil physical properties in the field. In *Application of Soil Physics*, ed. D. Hillel, 319-344. Toronto, Ontario: Academic Press.