from: J.A. Stone, B. D. Kay, & D.A. Angers(eds). 1991
Soil Structure Research in Eastern Canada. Proc.
of the Eastern Canada Soil Structure Workshop, Sept.
10-11, 1990. Guelph, Ontario

RAPID, INDIRECT ASSESSMENT OF SOIL STRUCTURE USING SMALL RING INFILTROMETERS

D.K. Cassel[1], H.M. van Es[2], and F. Agus[1]

[1] North Carolina State University, [2] Cornell University

ABSTRACT

Soil structure affects the infiltration process, the extent of which varies from soil to soil. The objectives of this paper are to describe a procedure for measuring sorptivity (S') to quantify soil structure of field soils, present sample data, and discuss advantages and disadvantages of the method. Single ring infiltrometers, 110 mm inside diameter and 230 mm long were driven 150 mm into the soil. An initial head of 70 mm of water was established and the falling head was recorded at prescribed times for 180 sec. Sorptivity was taken to be the slope of the plot of cumulative infiltration (mm) versus the square root of time for the first 100 to 120 sec. The S' data were transformed using the natural logs. The ln transformed S'(ln S') of a Typic Paleudult increased with clay content, but it was not possible to separate the effect of soil structure from soil texture. Differences in ln S' were found between trafficked and nontrafficked interrows and among management systems (both factors affect soils structure) for a Typic Rhodudult and a Typic Kanhapludult. The method is rapid, the equipment is inexpensive, and it requires little water, however, it is labor intensive and sorptivity is affected by the antecedent water content.

INTRODUCTION

In practice, it is difficult to precisely measure differences in soil structure imposed by different crops and management systems including various tillage operations. Sometimes changes in soil structure are visible to the human eye while at other times the changes are more subtle. One reason for the difficulty in measuring differences in soil structure is that it is often difficult to select the appropriate soil structural parameter or characteristic. In addition, because soil structure undergoes temporal changes caused by environmental conditions, as well as by crop and soil management practices, the timing of soil structure measurements in field soils is very important. Finally, the spatial variability associated with the measurement of many soil structural parameters is high, thus requiring a large number of measurements.

The choice of characteristic(s) to quantify soil structure is of ultimate importance. Kay (1990) indicated that the relative importance attached to a given structural characteristic is determined by the impact of that characteristic on the soil property or process that imposes the greatest limitation on the specific use of the soil. For many soils in the southeastern U.S., where mean annual rainfall ranges from 1000 mm to > 1500 mm, the greatest limitation to crop production is soil water. This is certainly true for sandy Coastal Plain soils which have less than 1% organic matter in the Ap horizon and exhibit weak soil structure at the surface. These properties result in high susceptibility to external forces (rainfall impact) which cause slumping and settling (Cassel 1983). Soil water is also the main factor limiting crop production for many Piedmont soils. These soils generally have less than 2% organic matter in the Ap horizon, typically contain non-expandible clays, and are prone to various degrees of surface crusting.

Previous research on many soils in the southeastern U.S. indicates that the pore size distribution is generally adequate to retain sufficient water for plant growth. Total rainfall is sufficient to support luxurious plant growth in most years. The main problem is inadequate infiltration. In some cases, less than half the rainfall infiltrates Piedmont soils. The infiltration process is affected directly by soil structure (pore size distribution, bulk density) of the thin layer of soil at the soil surface as well as by structure of the soil below the surface. Because water infiltration is so intimately related to soil structure, this process has often been used to assess the physical status (structural characteristics) of soils as affected by various soil management systems.

The use of small infiltration rings to estimate *in situ* sorptivity of field soils was initially proposed by Talsma (1969) and is briefly described in Methods of Soil Analysis (Green *et al.* 1986). Only a few studies using this method have been reported (Chong and Green 1979; van Es *et al.* 1988, 1991). The objectives of this paper are to (1) describe a procedure for estimating sorptivity of undisturbed field soil using small infiltration rings, (2) present examples of field measured sorptivity data for several sites, and (3) indicate advantages and disadvantages of using sorptivity to characterize soil structure.

MATERIALS AND METHODS

Single ring infiltrometers (open ended cylinders) were constructed from steel electrical conduit (110 mm inside diameter and 115 mm outside diameter). The open ended cylinder was placed in a vertical position at the desired field location, a large block of wood was placed across the open ended top of the cylinder, and a series of impacts from a sledge hammer was used to drive the lower edge of the cylinder 150 mm into the soil. The base of each 230-mm long infiltrometer was bevelled to displace soil outward when it was forced into the soil. An alternative installation method is to use a hydraulic system to force the infiltrometer into the soil in one continuous process (van Es *et al.* 1988). Four layers of cheesecloth were placed on the soil surface inside the installed infiltrometer and a millimetre scale was securely attached to the inside wall of the infiltrometer. Water was transported to the measurement site in a plastic bucket. Water was poured into a beaker premarked at the level that would be equivalent to a 76-mm high head of water ponded on the surface of the contained soil. Water was poured from the beaker onto the cheesecloth within 1 to 2 seconds while simultaneously starting a pre-zeroed stopwatch. The level of water on the scale at 0 time was estimated and the water level was read and recorded at times t_i where i ranged from 1 to 14 (0, 5, 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 150 and 180 seconds). The antecedent water content was determined gravimetrically on a soil sample from the 0 to 150 mm depth taken 0.3 m from the infiltrometer.

The instantaneous, vertical infiltration rate under the ponded condition, v, can be estimated with the two-parameter Philip equation (Philip 1969)

$$v = 1/2\, S\, t^{-1/2} + A \qquad [1]$$

where S is sorptivity, A is a factor related to steady-state saturated hydraulic conductivity, and t is time. Integration of equation [1] yields

$$I = S\, t^{1/2} + At \qquad [2]$$

where I is cumulative infiltration. The first term on the right hand side of equation [2] dominates the "early time" in the infiltration process. For the sorptivity procedure proposed by Talsma (1969), this period was as long as 120 seconds, but the period was shorter for soils with large root channels and structural cracks. Sorptivity values are dependent upon the distribution, continuity, and configuration of soil pores; antecedent water content; and the head of water ponded above the soil surface. Because the falling pressure head varies with time, the sorptivity value measured in the field is not the true sorptivity value described by Philip (1969); hence the experimentally measured sorptivity values are denoted by S'.

The slope of the linear portion of the curve generated when I is plotted versus $t^{1/2}$ is equal to S'. A linear regression model given by

$$I_i = S't_i^{1/2} + B + E_i \qquad [3]$$

was developed for each set of infiltration measurements where B is the y-axis intercept and E_i is the error term. The R^2 value, where R is the correlation coefficient, was used to evaluate how well S' represented the experimental data in the linear portion of the curve. If $R^2 \geq 0.81$, the regression equation for S' was considered satisfactory, and this S' value was retained as the experimental value of S'. If $R^2 < 0.81$, the values of I for the larger values of t were sequentially deleted to remove the non-linear portion of the curve and the coefficients for the linear regression model recomputed. The computation ended when $R^2 \geq 0.81$.

For cases 2 and 3 discussed below, the S' data were transformed using ln (0.5 + S'). The residual distribution of the transformed data was normally distributed and had a stable variance. Analysis of variance was performed on the transformed data to evaluate soil structure as a function of the cropping system, the measurement position (defined later), and the cropping system by measurement position interaction effects. Means comparisons were done with Fisher's protected least significant difference (LSD).

RESULTS AND DISCUSSION

CASE 1. EROSION EFFECTS ON SORPTIVITY

Sorptivity was measured on three dates in 1986 at 290 locations in the nontrafficked interrow in a 2 ha field of Georgeville soil (clayey, kaolinitic, thermic, Typic Paleudult) planted to continuous corn, in the Piedmont of North Carolina. The colour of the soil surface varied in localized regions throughout the field. The redder regions (2.5 YR) were assumed to have had large amounts of top soil removed by past soil erosion and

thus, it was hypothesized, the redder areas would have slower infiltration rates (and therefore lower S' values) as compared to regions with hues greater than 2.5YR.

The underlying philosophy regarding the use of infiltration rings to characterize the soil in this field was that on any given day a high intensity rainfall event could soon saturate the soil surface, and runoff would be initiated at different times at different locations in the field. The infiltration rate at early time is affected by soil structure, crop cover, antecedent soil water content, and soil texture.

Sorptivity was calculated using data from 0 to 100 sec. Maps showing the distribution of S' throughout the field were generated using a two-dimensional sliding polynomial technique (Snyder *et al.* 1984). The mean, range, standard deviation, and CV for S' and antecedent soil water content in the 0 to 100 mm depth measured for three dates for the Georgeville soil are presented in Table 1. The S' values were more closely related to landscape position than they were to degree of past soil erosion, and contrary to our expectations, S' in general was greater for the redder soil (van Es *et al.* 1991). A map of S' for the field on June 5 is shown in Fig. 1. Field observations showed that soil structure "improved" as clay content increased and the soil became redder, but it was not possible to separate the effects of soil structure and soil texture on the measured sorptivity values.

CASE 2. SORPTIVITY IN SUSTAINABLE AGRICULTURE SYSTEMS

A long term experiment to evaluate various crop management systems for their sustainability and profitability in the Piedmont region in North Carolina began in 1985. The soils are Cecil and Appling gravelly sandy loam (Typic Kanhapludults) with 2 to 6% slope and moderate erosion. In 1989, S' was measured on three dates for the following four management systems: C(NT) - continuous corn (fallow over winter; chemical weed and insect control); CWS (C) - continuous corn-wheat-soybean rotation, corn planted in 1989; CWS(WS) - conventional corn-wheat-soybean rotation, soybean planted in 1989; and CWS(LI) low input corn-wheat-soybean rotation (no chemical fertilizer inputs, no cultivation). All treatments were replicated four times.

For the first date (29 March 1989), infiltration measurements were replicated four times in both the row (R) and the trafficked interrow (TI) position in each plot. Soil covers on the date of measurement were: C(NT), some weeds; CWS(C) some weeds; CWS(WS), winter wheat 12 cm high; and CWS(LI) crimson clover (a winter cover crop).

Sorptivity results ln(S' + 0.5) are presented in Table 2. Differences in the transformed S' data occurred among management systems in the TI, but not in the R position. No difference in water content in the 0-15 cm soil depth existed among cropping systems or positions.

On 25 May 1989, four replicated measurements of S' were made only in the row position (Table 2). Mean soil water content was 0.11 g/g with no differences among cropping systems. Again there were differences in transformed S'. Soil covers on this date were: C(NT) nearly bare, corn emerged; CWS(C) nearly bare, corn emerged; CWS(WS) wheat, > 60 cm tall; and CWS(LI) crimson clover.

On 2 August 1989, S' in each plot was measured at six equally spaced positions on two transects perpendicular to the row (Fig. 2). Data for the two TI positions were pooled as were the data for the two non-trafficked interrow (NTI) positions, and the two R positions. No difference in the 0.14 g/g water content existed with respect to management system or position. Sorptivity was not affected by cropping system when averaged across all positions (Table 3). When the systems were compared at a given position, however, differences in ln(S' + 0.5) were found at the R and NTI positions. No differences in ln(S'+ 0.5) occurred at position TI because all systems had been trafficked at this position during planting thereby decreasing sorptivity.

CASE 3. SORPTIVITY OF CLAYEY SOILS AFFECTED BY SOIL MANAGEMENT

Sorptivity of Hiwassee clay loam (Typic Rhodudults) was measured at the end of the 1989 growing season, but before harvest, of the fourth consecutive silage crop in as many years. Management systems replicated four times were all combinations of two levels of tillage (no till, double discing) and three water (irrigation) levels. Four replicated measurements of sorptivity were made at the R, TI and NTI positions.

Data in Table 4 indicate differences in transformed S' among positions within a given treatment and among treatments for a given position. Infiltration data over a 120-sec long period were used.

DISCUSSION

ADVANTAGES AND DISADVANTAGES

The use of small infiltration rings to assess soil structure has both advantages and disadvantages. The method is rapid, allowing a large number of measurements to be

taken in a single day, thus minimizing temporal variability. One person can collect data for 10 to 12 infiltration events per hour if the rings are previously driven into the soil and the rings are spaced no more than 20 m apart. The equipment required is inexpensive, light weight, and easy to transport. Less than 1 litre of water is required per measurement.

Disadvantages of the method include the necessity of using a large labour crew if a large number of measurements are needed. Eight persons working one 8 hour day were required to obtain the 290 measurements for the erosion study in case 1. Proper reading of the water level in the infiltrometer as a function of time requires an individual to be on his knees or lying prone on the soil, and the task requires extreme concentration. When soils are in the dryer water content range, the task of driving cylinders into the soil becomes difficult and the likelihood of disturbing the structure of the soil surface increases. Because S' is affected by antecedent soil water content, water content must be measured for each sorptivity measurement.

Determination of sorptivity based on a falling water head leads to an error in the true sorptivity value. An alternative approach to using the falling head discussed in this paper is to use a constant head permeameter (Clothier and White 1981) or an unconfined disk permeameter which rests on a porous material, usually sand, poured on top of the undisturbed soil surface (Perroux and White 1988). The disk permeameter allows one to measure both sorptivity and unsaturated hydraulic conductivity at negative pressure heads, but the minimum time required per measurement increases to 10 min and often longer.

ALTERNATIVE ANALYSIS

An alternative method for analyzing the data from the small infiltrometers in lieu of computing sorptivity values is to use a variable which is equal to the mm of cumulative water infiltrated at an arbitrary time, e.g. 120 sec. Table 5 shows the mm of water infiltrated into Hiwassee soil after 120 sec. Comparison of data in Tables 4 and 5 indicates that the variable ln(S'+ 0.5) had greater power in detecting differences among treatments.

REFERENCES

Cassel, D.K. 1983. Spatial and temporal variability in soil physical properties following tillage of Norfolk loamy sand. Soil Sci. Soc. Am. J. **47**: 196-201.

Clothier, B.E., and White, I. 1981. Measurement of sorptivity and soil water diffusivity in the field. Soil Sci. Soc. Am. J. **45**: 241-245.

Chong, S.K., and Green, R.E. 1979. Application of field-measured sorptivity for simplified infiltration prediction. p. 88-96. *In* Proc. Symposium on Hydrologic Transport Modelling. ASAE Pub. 4-80. New Orleans, LA, 10-11 December. American Society of Agricultural Engineers.

Green, R.E., Ahuja, L.R., and Chong, S.K. 1986. pp. 771-798. Hydraulic conductivity, diffusivity, and sorptivity of unsaturated soils: field methods. *In* Methods of Soil Analysis, Part 1 - Physical and Mineralogical Methods, Second Edition. Klute, A. (ed.). American Society of Agronomy. Madison, WI.

Kay, B.D. 1990. Rates of change of soil structure under different cropping systems. *In* Stewart, B.A. (ed.). Advances in Soil Science **12**: 1-52. Springer Verlag, New York.

Perroux, K.M., and White, I. 1988. Designs for disc permeameters. Soil Sci. Soc. Am. J. **51**: 1205-1215.

Philip, J.R. 1969. Theory of infiltration. Adv. Hydrosci. **5**: 215-296.

Snyder, W.M., Bruce, R.R, Harper, L.A., and Thomas, A.W. 1984. Two-dimensional sliding polynomials. Univ. of Georgia Coll. Agric Expt Station Research Bull. 320.

Talsma, T. 1969. In situ measurement of sorptivity. Austr. J. Soil Res. **7**: 277-284.

van Es, H.M., Bruce, R.R., and Cassel, D.K. 1988. pp. 369-376. Evaluating infiltration variability of eroded fields. *In:* Fok, Y-S. (ed.). Infiltration principles and practices. Water Resource Research Center, Univ. Hawaii, Honolulu, Hawaii.

van Es, H.M., D.K. Cassel and R.B. Daniels. 1991. Infiltration variability and correlations with surface soil properties for an eroded Hapludult (accepted for publication in Soil Sci. Soc. Am. J.).

Table 1. Mean, range and coefficient of variation for sorptivity (S') and antecedent soil water content in a 2 ha field of Georgeville soil on three dates.

	Sorptivity			Antecedent soil water content		
Date	Mean†	Range	CV	Mean	Range	CV
		mm sec$^{-½}$	%		m^{-3}	%
5 June	5.2	1.2-20.5	62	0.05	0.01-0.13	57
16 July	5.3	0.5-27.0	67	0.09	0.02-0.18	37
8 Sept	4.1	0.2-17.7	69	0.29	0.17-0.42	20

† Geometric mean for sorptivity, arithmetic mean for antecedent soil water

Table 2. Ln (0.5 + S') as affected by management system and measurement position on 29 March, and cropping system on 25 May 1989.

Cropping System	29 March			25 May
	R	TI	R vs. TI	R
		mm sec$^{-1/2}$		mm sec$^{-1/2}$
C(NT)[‡]	0.682a[†]	0.352b	*	0.967a
CWS(C)	0.663a	0.603ab	ns	0.664b
CWS(WS)	0.942a	0.313b	**	0.088a
CWS(LI)	0.891a	0.874a	ns	1.119a

† Entries in a given column followed by the same letter are not different at the P = 0.05 level by Fisher's LSD.

‡ C(NT=corn, no till; CWS (C) = corn-wheat soybean rotation, corn crop; CWS (WS) = wheat soybean part of corn-wheat-soybean rotation; CWS(LI) = corn-wheat soybean rotation, low input; R = row, TI = trafficked interrow.

Table 3. Ln (0.5 + S') as affected by management system and measurement position on 2 August 1989.

Crop System	Position			System Means
	R	NTI	TI	
	mm sec$^{-1/2}$			
C(NT)[‡]	1.164a,p[†]	1.071a,p	0.450a,q	0.895a
CWS(C)	0.554b,p	0.731b,p	0.456a,p	0.580a
CWS(WS)	0.974a,p	0.387c,q	0.576a,q	0.646a
CWS(LI)	1.104a,p	1.112a,p	0.615a,q	0.944a
Position means	0.949 p	0.825 p	0.524 q	

† Entities in a given column followed by the same letter (a,b,c) and entries in a given row followed by the same letter (p,q) are not different at the P = 0.05 level by Fisher's LSD.

‡ C(NT = corn, no till; CWS(C) = corn=wheat soybean rotation, corn crop; CWS(WS) = wheat soybean part of corn-wheat-soybean rotation; CWS(LI) = corn-wheat soybean rotation, low input; R = row, TI = trafficked interrow

Table 4. Ln (0.5 + S') of Hiwassee soil on 12 Sept. 1989 as affected by tillage and irrigation management.

Treatment	Position R	Position T	Position NTI	Means
	---------- mm sec $^{-½}$ ----------			
CN1‡	0.505a,q†	0.447a,q	1.244a,p	0.732a
CN2	0.155b,p	0.018b,p	0.492b,p	0.276b
NT1	0.291b,q	-0.272c,r	0.577b,p	0.199b
NT2	0.091b,q	-0.552d,r	0.332b,p	-0.043c
Position means	0.261q	-0.049r	0.662p	0.291

† Entries in a given column followed by the same letter (a,b,c) and entries in a given row followed by the same letter are not different at the P = 0.05 level by Fisher's LSD.

‡ CN1 = double disk, dryland; CN2 = double disk, irrigated; NT1 - no till, dryland; NT2 - no till, irrigated; R = row, T = trafficked interrow, NTI = nontrafficked interrow.

Table 5. Cumulative infiltration into Hiwassee soil after 120 sec as affected by tillage and irrigation management measured on 12 Sept., 1989.

Treatment	Position R	Position T	Position NTI	Means
	---------- mm ----------			
CN1‡	14a,q†	14a,q	35a,p	21a
CN2	9a,p	11,ap	16b,p	12b
NT1	10a,q	3b,r	15b,p	9b,c
NT2	9a,q	4b,r	12b,p	8c
Position means	10,p,q	8q	19p	13
C.V.(%)	60	81	60	64

† Entries in a given column followed by the same letter (a,b,c) and entries in a given row followed by the same letter are not different at the P = 0.05 level by Fisher's LSD.

‡ CN1 = double disk, dryland; CN2 = double disk, irrigated; NT1 - no till, dryland; NT2 = no till, irrigated; R = row, T = trafficked interrow, NTI = nontrafficked interrow

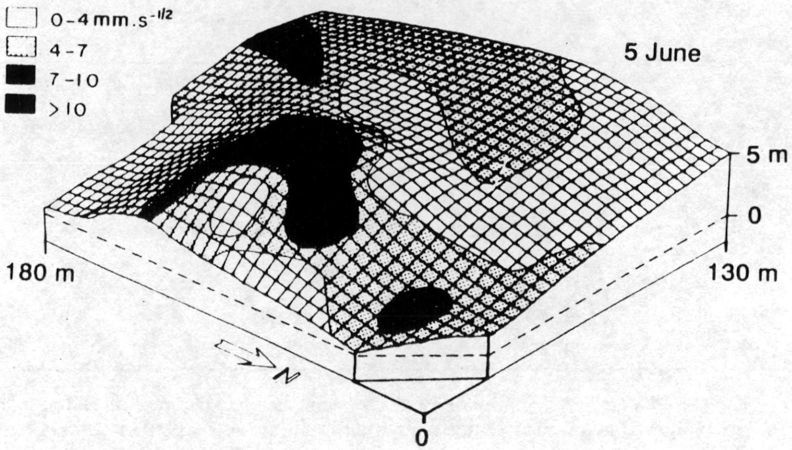

Figure 1. Sorptivity distribution in a 2 ha field of Georgeville soil on 5 June 1986.

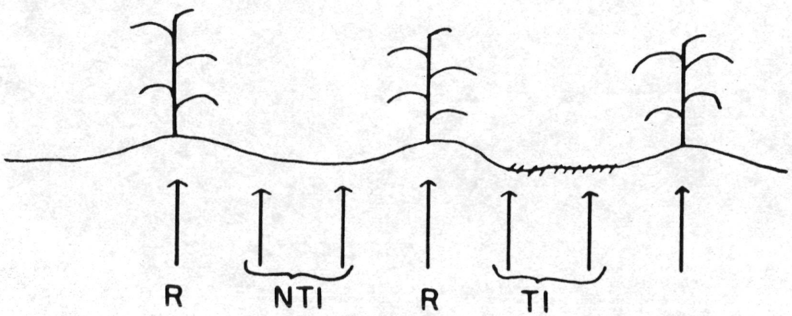

Figure 2. Furrow cross section showing the row (R), trafficked interrrow (TI) and non trafficked interrow (NTI) position.