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Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus

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12) Spatial variation in small scale of soil wetness evaluated by different methods

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Introduction

Soil water content θ in the field can be evaluated by direct or indirect methods. Among the direct - mostly destructive - procedures the gravimetric one is regarded as highly reliable and thus often preferred. Advantages of the direct determination are simplicity of principles and equipment. However, a major disadvantage is that the measurements can not be carried out *in situ* and that the sampling itself is destructive. In recent years Time Domain Reflectometry (TDR) became a widely used non-destructive method to evaluate θ. It is based on the determination of the dielectric constant of the soil ε by determination of the propagation velocity of electromagnetic waves. Its main disadvantage is the need of specific calibrations for some classes of soils and the high costs of the equipment. The characterization of the spatial variability of θ in the small scale may provide information that allow a better understanding of the deviations between values determined by different methods. The need of accurate measurements of θ for their use in calibrations of water balance models requires the knowledge of the spatial variability of θ as a essential factor for the choice of optimal methods and procedures.

Material and Methods

Evaluations of dielectric constants ε and samplings for the determination of θ and bulk density ρ, were carried out in four profiles of a Xanthic Ferralsol with high clay content (Latossolo Amarelo - Brazilian Classification) at the Experimental Station of Embrapa – Amazônia Ociental, in Manaus – AM - Brazil. The samples were taken near the soil surface (Profiles 1 and 3), in 0-5 and 5-10 cm of depth. Three undisturbed core samples and three disturbed auger samples were collected at each depth. The ε was determined in advance at six points with the probe inserted vertically and three points horizontally in each depth. In the subsurface (Profiles 2 and 4) disturbed samples were taken in 25-30 and 30-35cm, and undisturbed samples were collected in the depth of 27,5-32,5cm. For the determination of ε, a commercial device (EASY TEST®) with two transmission lines of 100 mm length, a diameter of 2 mm and a distance of 16 mm between the lines, was used. With the obtained ε – values the volumetric water contents were calculated with the empirical equations of Topp et al., (1980); Malicki et al, 1996 and Teixeira et al., 1997. The samples were weight and oven dried at 105° C for 48 hours. Analyses of variance were computed and means were compared by Tukey's test at the $p < 0,05$ level. The objective of this experiment was i) compare different methodologies and procedures for the determination θ near the soil surface and in the subsoil ii) compare the orientation of TDR probes in the soil.

Results and Discussion

Volume evaluated and probe orientation

A crucial question in comparing methods for determination of θ refers to the volume of the measurements in the soil. The estimation of the evaluated volume is relatively easy in direct method. In this study cylinders of $100cm^3$ were used. The disturbed samples were collected with a small soil auger ≈5cm that was inserted 10 cm deep, parallel to the surface of the soil. The sensitivity region of the TDR probes were assumed to resemble a cylinder that surrounds the transmission lines, concentrating the sensitivity in an area of ≈5cm with ≈11cm length (Figure 1). Thus, the evaluated volume of soil in all methods contained approximately the same volume, facilitating the comparison between the methods. In contrast to our assumption works of Baker & Lascano, 1989 and Zegelin et al., 1989, showed that the volume evaluated by the propagation of the electromagnetic waves presents an elliptic rather than a cylindrical form around the transmission lines, and a limited sensitivity extends much farther(Figures 2 and 3). However, the sensitivity of TDR in larger distances as well as the geometry of the transmission lines is still in discussion. The results presented in the Table 1 show that the TDR measurements with probes vertically and horizontally inserted were very similar for all empirical equation under study. However, larger transmission lines may exhibit results different from those due to larger integration volumes, and thus being more subject to the effects of the spatial gradients of θ, especially when installed vertically. The horizontal installation of transmission rods reduced the effect of the vertical gradients of θ considerably. However, this installation has the cost of the excavation and disturbance of the soil.

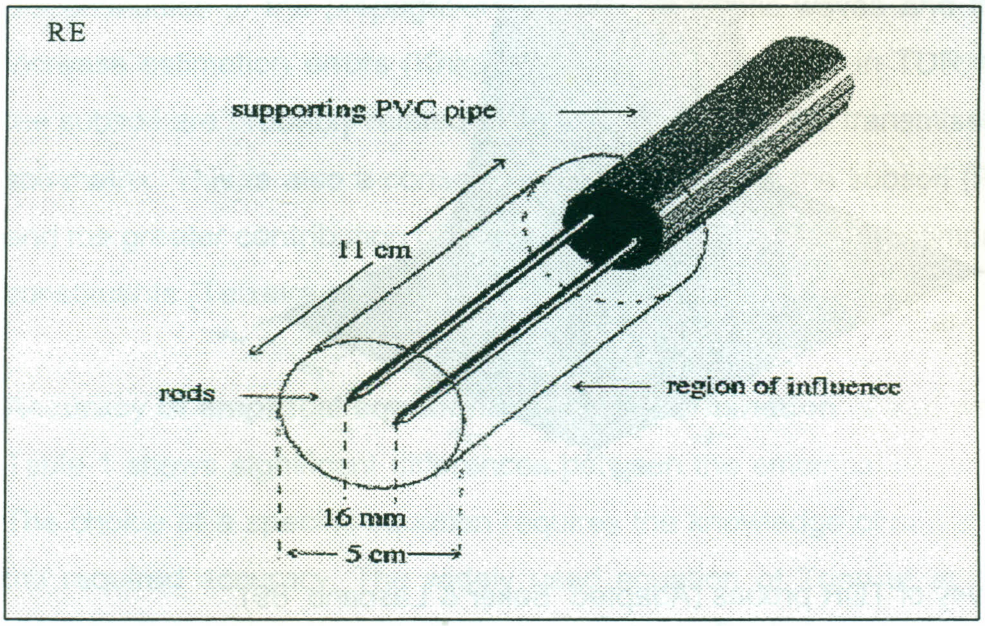

Figure 1 – Geometric characteristics and sensitivity volume of Easy Test – TDR probe (Adapted Easy Test ,s.d.)

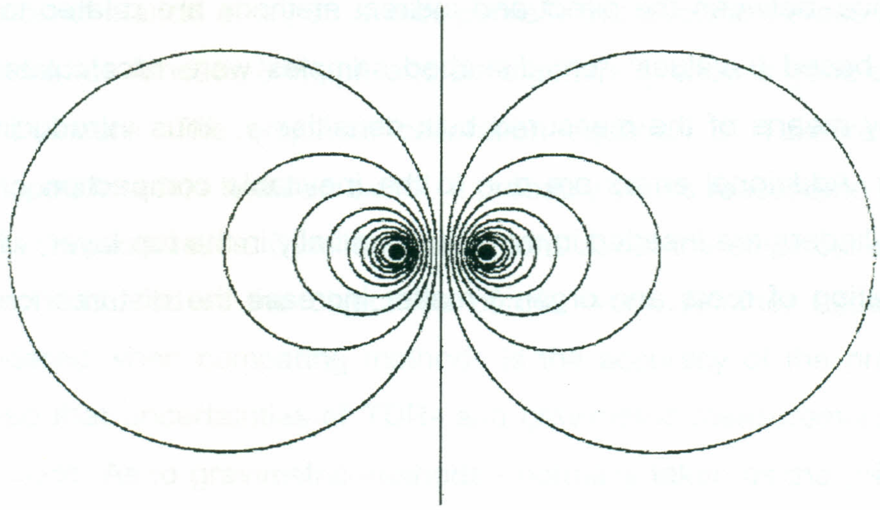

Figure 2 – Dimensionless electric field distribution normal to the direction of probe insertion for two-wire probe (Zegelin et al., 1989).

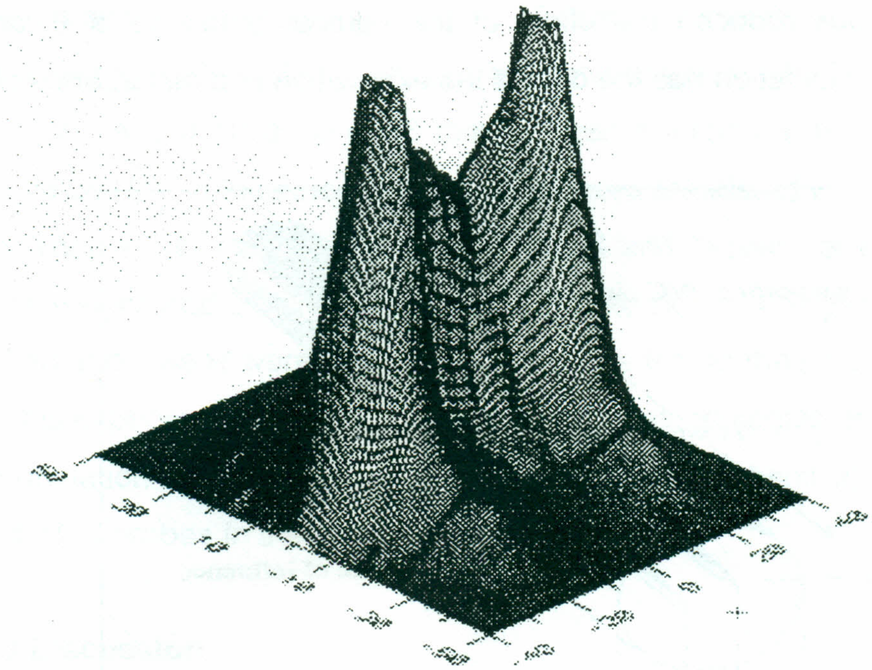

Figure 3 – Sensitivity of TDR probes (Adapted Baker & Lascano, 89).

Topsoil and subsoil measurements

The greater difference between the direct and indirect methods are related to the fact that the mass based θ–values from disturbed samples were recalculated to volumetric values by means of the measured bulk densities ρ, thus introducing a new source of error. Additional errors are due to the inevitable compaction of the sample, when the cylinders are inserted in the soil, especially in the top layer, where the larger concentration of roots and organic matter increase the disturbances of sampling procedure.

Soil characteristics

The tendency of the data to show smaller vertical gradients in the subsoil horizon (2 e 4) is obviously correlated with the fact that the gradients of the underlying physical properties of the soil decrease considerably with increasing depth due to the reduced biological activity. Values of ρ in the subsoil layers increase with depth (data not shown). Further, higher contents of organic matter can cause an underestimation of ε as indicated in previous work of Topp et al. (1980) and reconfirmed by works of Herkelrath et al. (1991). Later, works of Malicki, et al., 1996; Roth et al., 1992; Roth et al., 1990; Dirksen & Dasberg, 1993, Teixeira et al., 1998 showed significant effects of ρ on ε. The presence of macropores can cause discontinuities in the propagation of electromagnetic waves and thus considerably increase estimation errors (Knight, 1992). Smaller errors in TDR measurements in the subsoil are probably related to a better contact of the transmission lines with the soil matrix. This is also a consequence of higher θ in the subsoil (Profiles 2 and 4), and the greater contribution of water to the dielectric constant compared to other soil constituents (Teixeira et al., 1998 and Roth et al., 1990).

Accuracy of empirical equations for the determination of soil wetness

Table 1 shows significant differences between the empirical equations under study. The choice of a specific equation requires the knowledge of soil characteristics and the required accuracy. The widely used equation of Topp et al., 1980 was found valid for mineral soils with low clay content. Deviations in soils with high clay contents are caused by the monomolecular layer of water, which induces a dielectric behavior of the water molecules different from free water (Bohl & Roth, 1994). The equation of Malicki et al., 96 avoids partially this specific surface problem because it is a bivariate function $\theta=f(\varepsilon,\rho)$, and soils generally show a good correlation between ρ and texture. The empirical calibration equation of Teixeira et al., 1997 was developed in a fine textured oxisol. It probably yields reasonable results in soils with similar characteristics. Detailed discussions about the empirical calibration equation are not included in the objectives of this work. Another aspect that has to be considered when comparing methods is the accuracy of the procedure. Literature showed that uncertainties of TDR- and gravimetric measurements are of the same magnitude. As to gravimetric methods - normally taken as the „true“ value of θ - the principal sources of errors are: the sampling scheme; uncertainties in the equilibrium time when drying the sample; the presence of colloidal material, that show high capacity of retention of water even when exposed to high temperatures; the presence of organic material that can oxidize and or volatize; difficulties in maintaining a constant temperature in the oven; the precision of the used balance; and especially errors in the determination of ρ (Gardner, 1986; Blake & Hartage, 1986). The knowledge of principles and limitations of each method are the essential for the choice of methods and procedures. The small scale variability of θ can cause erroneous estimates, which can be partially compensated by increasing the number of measurements as well as a vertically stratified sampling design, especially near the surface. However, for many problems, the improvement may be small compared to the uncertainties and errors introduced by the use of a single average and thus ignoring the spatial distribution as a whole - especially when dealing with transport problems.

Table 1 – Soil wetness (θ) measured with direct and indirect methods.

Profile	Depth.	Volume	**Direct Method**		**Indirect Method** Time Domain Reflectometry (TDR)					
			Disturbed Samples	Undisturbed Samples	Probe orientation in Soil					
					Horizontal	**Vertical**	Horizontal	**Vertical**	Horizontal	Vertical
					Teixeira et al., 97		Malicki et al.,96		Topp et al.,80	
	cm	cm^3	θ (m^3 m^{-3})							
1	0-5	≈100	0,2773b	0,4080a	0,2873b	+	0,3037b	+	0,2466b	+
1	5-10	≈100	0,3680a	0,3726a	0,3414a	+	0,3612[a]	+	0,3026a	+
Mean	0-10	≈200	0,3226ab	0,3903a	0,3143ab	0,3341ab	0,332ab	0,3554ac	0,2746b	0,2988bc
3	0-5	≈100	0,2760bc	0,3297a	0,3091ac	+	0,3252[a]	+	0,2716bc	+
3	5-10	≈100	0,3297a	0,3280a	0,3546a	+	0,3730[a]	+	0,3186a	+
Mean	0-10	≈200	0,3079b	0,3288b	0,3318b	0,3318b	0,3490[a]	0,3376b	0,2950b	0,2842b
2	25-30	≈100	0,3682cd	0,3927§b	0,4251a	+	0,4306[a]	+	0,3837bd	+
2	30-35	≈100	0,3730c	0,3927§b	0,4334a	+	0,4388[a]	+	0,3906b	+
Mean	25-35	≈200	0,3706b	0,3927b	0,4292a	0,4209a	0,4347[a]	0,4271a	0,3871b	0,3801b
4	25-30	≈100	0,3375d	0,3911§bc	0,4097ac	+	0,4238[a]	+	0,3701bcd	+
4	30-35	≈100	0,3416c	0,3911§b	0,4202a	+	0,4342[a]	+	0,3794b	+
Mean	25-35	≈200	0,3395e	0,3911bcd	0,4149ad	0,4205ac	0,4290[a]	0,4346a	0,3748b	0,3796b

(§) One sampling for both depths collected between 27,5-32,5cm.

(a) Values within lines followed by the same letter are not different by Tukey p< 0,05.

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