3.5 MEASUREMENT OF NEAR−SURFACE SOIL MOISTURE WITH CONTINUALLY−CALIBRATED TDR INSTRUMENTS

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1. INTRODUCTION

Microwave radiometry can measure near−surface soil moisture, the water content of the first few centimeters of the soil (e.g. Wang et al., 1982). The sampling depth of a microwave radiometer is largely determined by its frequency and the density and structure of the vegetation canopy. At L−band (1.4 GHz), the sampling depth could be as high as 5 cm for bare soil, while at C−band (6.9 GHz), the sampling depth may be only 2 cm. As the amount of vegetation increases, the sampling depth shrinks.

In order to improve our understanding of the relationship between soil water content and terrain radiobrightness and quantitatively define near−surface soil moisture, the factors which determine this relationship must be measured accurately and at appropriate scales. In this paper we discuss the unique procedure used to make continuously−calibrated in situ measurements of soil water content on the plot−scale (an area on the order of 10^3 m^2).

2. PROBLEM STATEMENT

Continuous and accurate measurements of soil water content have been difficult to accomplish in the past. Buried time−domain reflectometry (TDR) instruments can monitor soil water content continuously but they must be calibrated to the specific soil. In situ calibration is problematic because it disturbs the soil and prohibits further measurements. Some researchers have attempted to calibrate TDR instruments by taking soil from a site to the laboratory and re−packing it into long cylinders. The soil water content can then be controlled to some degree but this method is troublesome because there is no way to be sure the natural soil bulk density and structure has been reproduced in the lab.

The scale of soil moisture measurements must also be taken into account. In plot−scale remote sensing experiments the near−surface soil moisture *inside the footprint of the microwave radiometer* is the quantity of interest. *This is not the same quantity measured by TDR instruments*. Not only are the sample volumes drastically different, but the volumes are also located in different places (see Figure 1).

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3. PROCEDURE

Our strategy was to link the soil water content inside the footprint of the radiometer to the soil water content measured by TDR instruments buried outside of the footprint.

A hand−held impedance probe (Theta Soil Moisture Probe, or ThetaProbe, type ML2x, Delta−T Devices) was used to periodically measure the mean, or *field average*, 0−6 cm soil water content of the entire experiment site. Twelve TDR probes (CS615 Water Content Reflectometers, Campbell Scientific) continuously measured soil water content in an area away from the footprint.

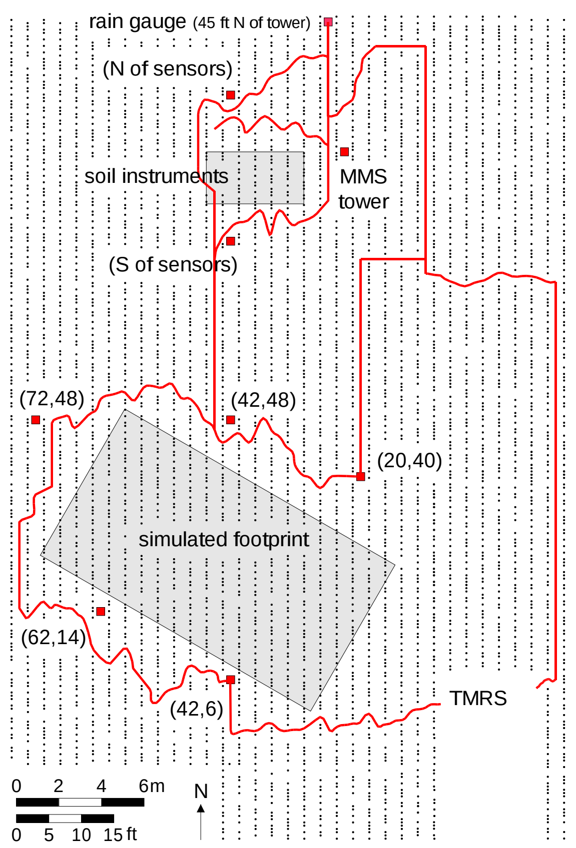

Figure 1: A microwave radiometer and buried TDR instruments sample different areas.

We compared the CS615s in situ to the field average 0−6 cm soil water content as measured by the ThetaProbe. ThetaProbe measurements were made periodically during the summer of 2001 both in the row (denoted as H areas) and between the rows (L areas) at seven locations within the experiment site. The experiment site was located in the middle of a unusually flat 400 m x 800 m corn field in Southeastern Michigan. The microwave radiometer footprint size was approximately 100 m^2. Each day the ThetaProbe was used ten randomly−placed measurements were made in H (in row) areas and ten more measurements in L (between the rows) areas at each location within an approximately 4 m^2 area surrounding each location. The entire sampling time for all locations took less than one hour. Measurements were made in the morning when soil moisture profiles are most uniform. This sampling procedure resulted in 10 x 7 = 70 daily 0−6 cm soil water contents for both H and L areas.

Half of the CS615s were buried at 1.5 cm and the other half at 4.5 cm below the surface. Assuming a CS615 samples a cylinder of soil approximately 3 cm in diameter, the instruments buried at 1.5 cm measured the 0 to 3 cm soil water content, while the ones buried at 4.5 cm measured the 3−6 cm soil water content. Averaging the appropriate CS615s together produced the same quantity of soil water content as measured by the ThetaProbe.

4. CALIBRATION OF THE IMPEDANCE PROBE

The ThetaProbe consists of four 6 cm rods. Three shield rods are arranged in a triangular pattern around the center signal rod. When inserted vertically into the ground, the rod array transmits an electrical signal. A standing wave is produced and the impedance of the soil (which is directly related to the volumetric water content) can then be measured. This is a frequency−domain measurement of soil moisture, as opposed to the more familiar TDR time−domain method in which the propagation time of a electrical pulse down and back the length of a TDR instrument is related to soil water content. The ThetaProbe samples a cylinder of soil approximately 6 cm long and 6 cm in diameter (Miller and Gaskin).

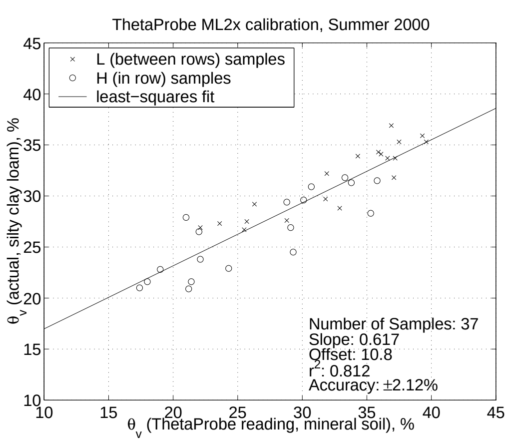

Figure 2: ThetaProbe calibration curve.

The ThetaProbe was calibrated during the summer of 2000 in a field one mile north of the field used during the summer of 2001. Both fields contain the same type of soil, a silty clay loam from the Lenawee series. Soil bulk densities were measured for both H areas (1.09 g cm^{-3}) and L areas (1.21 g cm^{-3}). As predicted by the manual, a soil−specific calibration accurate to within $\pm$2% was obtained (see Figure 2).

5. TDR MEASUREMENTS

A CS615 samples a cylindrical volume of soil approximately 30 cm long (the length of the transmission line) and approximately 3 cm in diameter (personal communication, Jim Bilskie, Campbell Scientific, Logan, UT). Soils with high amounts of organic matter, high clay contents, and high electrical conductivity often require soil−specific calibration. Soil−specific calibrations are expected to be accurate to within $\pm$2% (Campbell Scientific, 1996).

Three CS615s were inserted into the soil at 1.5 cm in H areas, three at 1.5 cm in L areas, three at 4.5 cm in H areas, and three at 4.5 cm in L areas. Only one CS615 was planted per row of corn to avoid mutual coupling and disruption of natural paths of water flow in the soil. Insertion at such shallow depths was possible because of the wetness of the soil at the time of burial. Care was taken to keep the transmission lines of the instruments level to the soil surface. The twelve CS615s were buried in the middle of May 2001 and then removed at the end of May so that the farmer could till the soil and apply chemicals (cultivate). The CS615s were then replanted in the middle of June.

The three CS615s planted at 1.5 cm in H areas were averaged together with the three CS615s planted at 4.5 cm in H areas to produce a quantity of soil moisture approximately equivalent to that measured by the ThetaProbe. The same was done for the L areas. Campbell Scientific supplies three different manufacture calibrations for soils with very low electrical conductivity, low conductivity, and high conductivity. A temperature correction is also suggested. Figures 3 through 6 show the ThetaProbe and CS615 measurements. The temperature correction was used in all of the CS615 measurements.

6. DISCUSSION

Because the soil was a silty clay loam, it was expected that the high conductivity calibration would perform the best. The manufacturer calibrations for very low and low soil conductivities were not consistent with the ThetaProbe measurements: the water content measured by the CS615s was always lower (except for the L area case before cultivation) than the ThetaProbe measurements but the difference was not consistent. On the other hand, the difference between the high conductivity CS615 measurement and the ThetaProbe was always 7 to 9% (except for the L area case before cultivation).

Why is the L area before cultivation case different? Here the discrepancy between the high conductivity CS615 calibration and the ThetaProbe measurements are approximately 1 to 3% instead of 7 to 9%. ThetaProbe 0−6 cm soil water content in L areas was ~17% too low if the relationship between CS615 measurements and ThetaProbe measurements observed for the other cases is correct. Since soil bulk densities were only measured *after* cultivation we hypothesize that when the farmer cultivated the field the bulk density of the L areas between the rows changed significantly. After the farmer cultivated and loosened the soil, the bulk density in the L areas decreased. Hence the ThetaProbe is measuring too low before cultivation. Increasing the L area bulk density of 1.21 g cm^{-3} measured after cultivation by ~17% to ~1.4 g cm^{-3} would account for the observed discrepancies.

7. CONCLUSION

Simply adding 8% to the temperature−corrected high conductivity calibration for the CS615 was sufficient for a field average soil−specific calibration for the entire experiment period.

8. REFERENCES

Campbell Scientific, 1996: CS615 water content reflectometer instruction manual version 8221−07 revision 10/96.

Miller, J. D. and G. J. Gaskin: ThetaProbe ML2x: Principles of operation and applications, MLURI Technical Note (2nd ed).

Wang, J. R., T. J. Schmugge, W. I. Gould, W. S. Glazar, and J. E. Fuchs, 1982: A multi−frequency radiometric measurement of soil moisture content over bare and vegetated fields, *Geophysical Research Letters*, 9, 416−419.

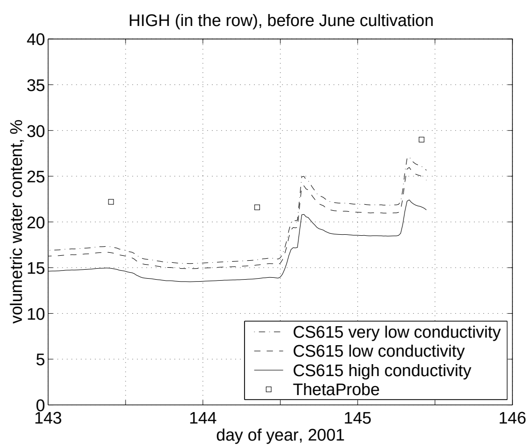

Figure 3: ThetaProbe and CS615 comparison in H areas (in the row) before cultivation.

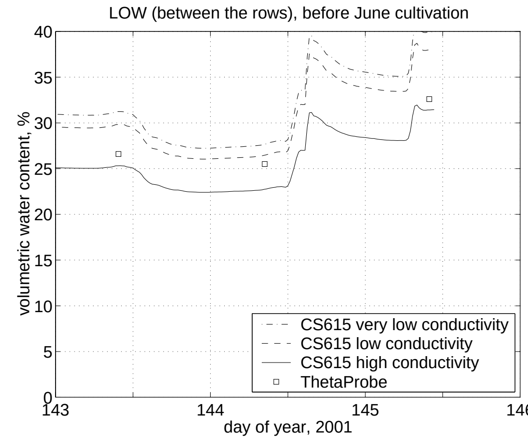

Figure 4: ThetaProbe and CS615 comparison in L areas (in the row) before cultivation.

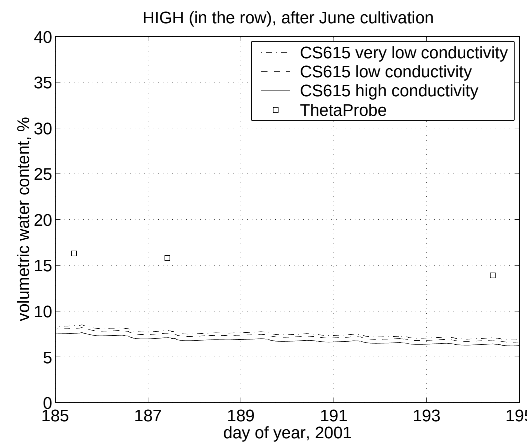

Figure 5: ThetaProbe and CS615 comparison in H areas after cultivation.

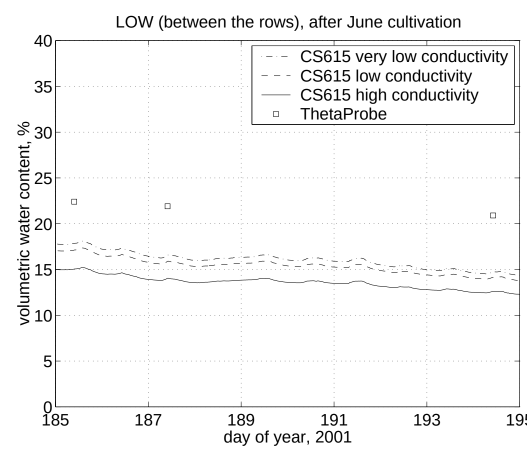

Figure 6: ThetaProbe and CS615 comparison in L areas after cultivation.