GPS-BASED REMOTE SENSING FOR SOIL MOISTURE MEASUREMENTS Ahmad Khalilian Charles Privette William Bridges Clemson University Clemson, SC

<u>Abstract</u>

Recently NASA has developed a GPS-based sensor technology which operates by recording the GPS signal reflected from the surface of earth. The measurements can be used to estimate the surface reflectivity (dielectric properties) of soil to estimate changes in soil moisture contents. Replicated tests were conducted during 2008 and 2011 to investigate the feasibility of utilizing the GPS-based technology for soil moisture measurements. The effects of soil texture, soil compaction, and ground cover on the GPS reflectivity were determined. The results showed that the space-based technology has a great potential for determining soil moisture contents. There were strong positive correlations between soil moisture and reflected signals at various soil depths; however, the relationship decreased as soil depth increased. Soil compaction, soil type, and ground cover, initially showed evidence of affecting the reflectivity, however additional analysis showed that the soil moisture content had the strongest relationship to reflectivity, and this relationship was basically consistent across soil compaction, soil type, and ground cover .

Introduction

Fields in Coastal Plains region have a high degree of variability in soil type and water holding capacity which affects irrigation management. One way to overcome problems associated with the field variability for improving irrigation management is to utilize a site-specific irrigation system. This system applies water to match the needs of individual management zones within a field, enhancing crop yields and significantly reducing water consumption, runoff, and nutrient leaching into ground water. A real-time and continuous soil moisture measurement at specific depths is essential for success of site-specific irrigation systems.

Many different soil-moisture sensors such as TDR, TDT, and multi-sensor capacitance probes have been suggested in literature (Mathur et al., 2002; Bellamy et al. 2009) for measuring volumetric soil water contents. However, these sensors either cannot be used for real-time soil moisture measurements or are very expensive. In addition, since these sensors measure soil moisture in discrete locations in a production field, significant number of sensors will be needed for site-specific irrigation management.

Many experiments have shown that microwave band frequencies in the range of 1-3 GHz can be used for soil moisture measurements. This frequency range is ideal for sensing soil moisture contents in a production field due to better penetration of vegetation at longer wavelengths (3 to 12 inches). The GPS constellation broadcasts a civilian-use carrier signal (L-band) at 1.575 GHz, an optimal frequency for soil moisture remote sensing.

Recently NASA has developed a GPS-based sensor technology which operates by recording the GPS signal reflected from the surface of earth (Masters et al., 2004; Katzberg, 2006). A modified GPS Delay Mapping Receiver (DMR) measures the direct Right-Hand-Circularly Polarized (RHCP) signal of a GPS satellite. It also simultaneously measures the delayed, earth-reflected, Left-Hand-Circularly Polarized (LHCP) GPS signal. These measurements can be used to estimate the surface reflectivity (dielectric properties) of soil to estimate changes in soil moisture contents.

Objectives

The objectives of this project were to: a) determine the feasibility of utilizing GPS-based technology for soil moisture measurements; and b) determine the effects of soil type, soil compaction, and ground cover on soil moisture reflectance values.

Materials and Methods

Replicated tests were conducted in 2008 at the Edisto Research and Educational Center near Blackville, South Carolina, on a typical Coastal Plains soil (Verina sandy loam). In 2011, tests were conducted on a six-acre field

with three different soil types: Faceville loamy sand, Fuquay sandy loam, and Lakeland sand. At the initiation of the tests, a commercially available soil electrical conductivity (EC) meter (Veris-3100) was used to identify variation in soil texture across the experimental field. The test fields then were divided into management zones based on soil EC and 50x25 ft rectangular plots were established in each zone (Figure 1).



Figure 1: Soil EC zones of the experimental fields, 2008 (left) and 2011 (right).

In 2008, the test field was equipped with a lateral variable-rate irrigation system that could be used for applying irrigation to the experimental plots. This allowed for creation of different soil moisture contents for testing of the DMR receiver. Three soil moisture contents: saturated soil, dry soil and an average condition were used in this test. These three conditions are synonymous with the three antecedent runoff conditions as used by the NRCS Curve Number Methodology. In 2011, tests were conducted on three different soil types (Figure 1) and a traveling gun was used to establish different soil moisture contents in the test plots. Three levels of ground cover were created by planting a cover crop (rye) at three seeding rates, six months prior to conducting field tests. The biomass in test plots averaged at 490, 2250, and 5136 lbs per acre. Different levels of soil compaction were achieved by driving a tractor over the test plots.

In order to collect the reflected GPS signals from the plots, the DMR receiver was mounted on a 30-ft boom with a zenith RHCP antenna viewing the sky and a nadir LHCP antenna viewing the ground. The boom was equipped with a three-point-hitch attachment system for mounting on a tractor (Figure 2).



Figure 2: The GPS reflectometer mounted on the platform of a 30-ft tower.

To accurately take soils samples from each plot based on the exact location where the reflected GPS signal bounced from the ground; the DMR receiver was set-up over a blank plot and allowed to collect both direct and reflected GPS signals over time. This raw data was then processed with a predicted reflected path algorithm to show the actual GPS locations from where the reflected signal originated (Figure 3). Based on these reflected paths, the exact location of the DMR receiver could be mapped in all test plots allowing the reflected arc path to cross over the center portion of the plots. These predicted arc paths were then mapped in their corresponding plots in the field (Figure 3).



Figure 3: Reflected GPS arc paths based on location of the DMR reflectometer (left) and predicted path location in test plots (right).

Geo-referenced soil samples were taken from each plot, immediately following data collection with the DMR receiver. The soil cores were divided into 2-in increments to determine moisture contents at different soil depths. In addition, soil compaction data were collected at different depths using a GPS-based penetrometer system. Soil compaction values were calculated from the measured force required pushing a 0.5-in² base area, 30-degree cone into the soil. Surface vegetation density (ground cover) was determined by removing the above ground biomass from a 3 ft by 3 ft area in each plot. The samples were oven dried (using standard procedures) to determine dry matter. After all data (reflectance, soil moisture, cover crop, and compaction) were taken, the post-processed reflectivity data was compared to the soil moisture profiles to develop correlation with depth. Correlations between the GPS reflectivity, soil moisture, soil compaction, surface vegetation density, and soil types were determined using the software developed by NASA and Statistical Analysis System (SAS).

Results and Discussion

Figure 4 shows the relationship of soil moisture content and GPS reflectivity for the 2008 test. A strong correlation between the GPS reflectivity measurements and soil moisture content was detected. The GPS reflectivity increased as the soil moisture contents increased which indicates that the space-based technology has a great potential for measuring soil moisture contents. Careful analysis of the test data also indicated that the sensitivity of L-Band signal (1.575 GHz) to soil moisture contents changed with sampling depth (i.e., the strength of the relationship as measured by the coefficient of determination (R^2) decreased as the sampling depth increased).

Figure 5 shows the consistency of the relationship between the GPS reflectivity and soil moisture contents across soil compaction and cover crop for the 2011 tests. For each level of soil compaction and cover crop, there was a strong positive correlation between soil moisture contents and GPS reflectivity; and the slopes of the regression lines for the levels were not significantly different. Combining the data, a strong correlation ($R^2 = 0.785$) was obtained between soil moisture contents and the GPS reflectivity. Again, the sensitivity of L-band signals to soil moisture contents decreased as the sampling depth increased.



Figure 4: Effects of soil moisture contents on GPS reflectivity - 2008.



Figure 5: Effects of soil moisture contents on GPS reflectivity as affected by soil compaction and ground cover (2011).

Figure 6 shows the consistency of the relationship across three different soil types (Faceville, Fuquay, and Lakeland) on GPS reflectivity. The sand contents of these soil types were 78, 85, and 90%, respectively. In each soil type there was strong positive correlation between the GPS reflectivity and soil moisture content; and the slopes of the regression lines for the soil types were not significantly different.

Regression analysis of combined data correlating the GPS reflectivity to soil compaction resulted in a coefficient determination of (R^2) less than 0.1. Similar results were obtained when correlating the GPS reflectivity data to ground cover biomass. These results indicate that these two parameters had no significant effects on the GPS reflectivity.



Figure 6: Effects of soil type on GPS reflectivity (2011).

Summary

There were strong correlations between the GPS reflectivity measurements and soil moisture contents. The GPS reflectivity increased as the soil moisture contents increased. The relationship was strongest the first two inches of soil moisture, as measured by the coefficient of determination (R^2); and the relationship strength decreased as the sampling depth increased. Soil compaction, soil type, and ground cover, initially showed a relationship with reflectivity, however additional analysis showed that the only significant parameter affecting the GPS reflectivity was soil moisture contents.

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Disclaimer

Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available.

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