GROUND PENETRATING RADAR (GPR) ANALYSIS OF SOIL MOISTURE WITHIN DIFFERENT LANDUSES IN AN AGRICULTURE LANDSCAPE, IN GEORGIA, US.

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Abstract. Soil moisture is a critical process in the water cycle and its assessment is of paramount importance to forecast changes in the water balance of a region. Ground Penetrating Radar (GPR) technology overcomes the limitations of point data by producing a tri-dimensional view of subsurface characteristics with a large economy of time, logistic, data processing and analysis. The purpose of this research is to study soil moisture under different land use/land covers (LULC) at the Little river watershed, near Tifton, Georgia collecting point data using a hand carried Theta probe (TP), and tri-dimensional data using a GPR equipment. Two sampling sites and six different land uses were analyzed in this project taking simultaneous samples with both instruments. Sub-surface tri-dimensional maps of 30x30m fields 1m depth were collected in three fields under different land use and vegetation cover. Transects of 30m and 1m depth were collected, one per field, for three additional fields under different land use and vegetation cover. Visualization tools and statistical analysis are used to compare subsurface profiles and soil moisture within and among land uses. Preliminary results showed that sub-surface soil in agriculture fields is highly stratified in patterns that can be the result of disturbance caused by agriculture equipment and practices and that affect the homogeneous distribution of soil moisture. These results are important to show a predominant role of ground disturbance in the soil moisture behavior.

INTRODUCTION

Soil moisture is a critical process in the water cycle and its assessment is of paramount importance to forecast changes in the water balance of a region (Salvucci et al. 2002). In agriculture production, soil moisture spatial variability can be responsible of unproductive crops and yield spatial variation, since soil moisture is required to make soluble the nutriments for the plant to absorb. To contribute to an efficient management of water in agriculture and in irrigated fields, large-scale, rapid data collection techniques of soil moisture are required considering the limited possibilities of conventional methods such as gravimetric, neutron scattering and capacitive sensors (Galagedara et al. 2005). These methods have logistical constrains in the processing and in the collection of a large number of samples needed to create an accurate representation of field conditions.

Ground Penetrating Radar (GPR) technology overcomes the limitations of point sampling techniques by producing a tri dimensional view of the subsurface soil characteristics with a large economy of time, logistic, data processing and analysis. Also, since environmental process linked to soil moisture, such plant-soil interaction, soil-atmosphere exchange are affected by deeper layers of the soil, GPR may advance the current knowledge of soil moisture studies and in the long round the understanding of the water cycle variations by producing a more accurate view of the sub-surface status than the one provided by point readings equipment (Weihermuller, et al. 2007)

Applications of Ground Penetrating Radar (GPR) technology in soil surveys has been an ongoing process in the United States since 1978. The tri-dimensional visualization of ground properties and the production of the ground two dimensional profiles have been useful in understanding the soil characteristics that define soil management, use and classification (Doolittle and Collins, 2007). This wealth of data is produced by the GPR sensor with high economy in field cost and increasing productivity (Doolittle and Collins, 1995). The study of soil moisture content using GPR technology is based in the attenuation of radar signal caused by changing in moisture conditions in the ground from dry to wet as well as the level of soil porosity. In this way, the GPR signal penetration is more effective under dry porous soils. Distinct radar reflections occur only with abrupt changes in soil properties including bulk density, texture or moisture. In this case, since water has more higher dielectric constant than soil or air, reflection of the electromagnetic waves in the soil depend on gradients in the soil moisture content (Friedli et al. 1998)

At the Little River Watershed (LRW) in the U.S. South Atlantic coastal plain near Tifton, Georgia, soil moisture experiments have been conducted since 2003 by the United States Department of Agriculture - Agriculture

Research Service - South East Watershed Research Lab (USDA-ARS-SEWRL; http://hydrolab.arsusda.gov/smex03/SMEX03v5.pdf; Bosch et al. 2007). A previous study using a hand carried Theta probe (Giraldo et al. 2008) showed that spatial and temporal differences in the soil moisture processes can be found within and among different land uses at the LRW. In this study point readings produced an assessment at 10cm depth, limited to understand sub-surface conditions of the soil water content. Studies have demonstrated that soils with less than 15% of clay content are favorable for deep penetration using GPR (Doolittle, et al. 2007), therefore, the sandy and relatively deep conditions of the soil at the LRW makes it suitable for this study. In this project we collected GPR subsurface views of the soil and Theta probe soil moisture data at the LRW aiming to compare GPR profiles and soil moisture under different landuse/land covers (LULC).

METHODS

Study area. This research was conducted at the Little River Watershed (LRW) in the U.S. South Atlantic coastal plain near Tifton, Georgia, where an *in situ* network of 27 ground stations was established by the United States Department of Agriculture - Agriculture Research Service - South East Watershed Research Lab (USDA-ARS-SEWRL) in 2002 and 2003 to infer soil moisture and environmental variables at the landscape scale and to validate remote sensing data for environmental studies in the agriculture landscape of the southeastern United States (http://hydrolab.arsusda.gov/smex03/SMEX03v5.pdf).

The LRW is a highly heterogeneous landscape with the presence of more than 40 different soil types. The typical soil is a sandy loam with a sandy surface horizon and heavier textured subsoil, with low water holding capacities and fast superficial drainage. The landscape is a fragmented mosaic of fields and patches of different sizes classified in about 11 land uses randomly mixed within the landscape (Giraldo, et al. 2009). The landscape extends over a relatively flat terrain characterized by broad floodplains with poorly defined stream channels and gently sloping uplands varying from 1 to 5%. A detailed description of the environmental characteristics of the LRW, as well as, the in situ network of stations can be found in Bosch et al. (2004) and (2007).

Data collection. Two instruments were used in this experiment. A portable Theta capacitance probe (Dynamax Inc., ML2X Theta probe) that measures dielectric constant for the soil and convert it to volumetric soil moisture based upon a factory provided calibration equation. In the same study area that this research, the work of Bosch et al. (2006) showed that Theta probe readings present a relatively good agreement with gravimetric analysis of soil moisture, a conventional method to measure soil moisture. The second instrument used was a ground penetrating radar (GPR) SIR-3000 (TerraSIRch, Geophysical Survey Systems, Inc.) with a 0.4 GHertz antenna mounted in a three wheel chassis. Two sampling sites and six different land uses were analyzed in this project taking simultaneous samples with both instruments. The sites correspond to the areas where in situ soil moisture stations 32 and 63 of the USDA-ARS-SEWRL network are located.

Fields under turf cover, short grass and bare soil were sampled at site 63, while fields under short grass, fallow vegetation and mature orchard where sampled at site 32. At site 63, a 30 by 30m field was sampled for each land use using the GPR instrument creating a spatial distribute map of continuous readings collected at approximately 3 cm intervals in rows spaced every 25cm and 1m depth. At site 32, due to logistical limitations and difficulties in the accessibility of the fields, transects rather than surface maps were collected at each field. In this case three 30m long transects were obtained for each land use. At each site, the fields were sampled during the same day in April 2009 and to guarantee absence of dew in the ground cover, sampling was done between 11am and 4pm. Theta probe readings were systematically collected at locations every 5x5m until covering the entire field or the length of the transect. The location of each Theta probe sample was defined in metric grid and storaged in the database. Data from the GPR was downloaded and post processed using RADAN software (Geophysical Survey System, Inc.) which allows the creation of two dimensional visualizations of the sub-surface soil characteristics at different depths. Slides of the soil moisture were created every 5cm depth up to a meter and attention was given primary to slides 0, 5 and 10 corresponding to the first 10cm of the soil, depth at which Theta probe readings were collected.

Data analysis. Slides of the continuous readings and vertical profiles of the transects created in RADAN were then post processed in Surfer (GoldenSoftware Inc.) to color code areas according to soil variation. Also in Surfer, the data was converted into a three columns spreadsheet with *x*, *y* coordinates and *z* values corresponding to reflectance values. The spreadsheets were used to compare Theta probe and GPR readings using statistical analysis in SPSS (IBM SPSS Inc.) such as analysis of variance among and between fields, and correlation analysis between GPR and Theta probe data. Images created in Surfer were used in visualization analysis among and between fields. Using remote sensing image analysis software, GPR slides at 0, 5 and 10cm depths were analyzed estimating the spatial autocorrelation (SAC) of values within the field and statistical differences of SAC values among land uses for similar depths. In a similar way vertical profiles were compared among landuses for which transects data was collected.

RESULTS

The post-processing of field data and the creation of numerical and visual datasets has been a very slow and demanding process. The enormous amount of data is still under post processing and therefore most of the statistical analyses are not ready yet. Slides created for some of the landuses have showed a high level of spatial variation in readings at the field level for the three depths. Figure 1, corresponding to a 5cm depth slide of bare soil, shows parallel areas of lighter color of about 1m wide organized in rows following the *y* axis. These areas spaced about every two meters correspond to marks let by the activity of past agriculture equipment, despite high superficial homogeneity of the terrain.

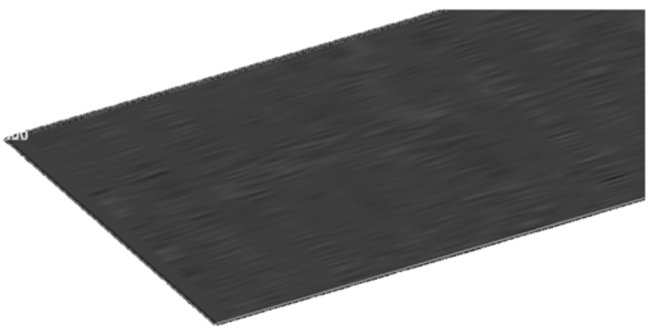

Figure 1. A 10 x10 section of a 5cm depth slide for a bare agriculture field.

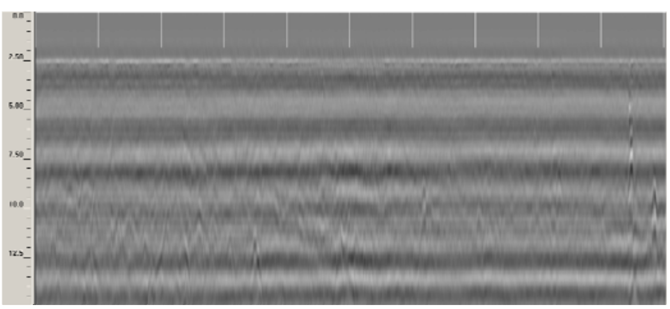

Figure 2. A vertical profile of a GPR transect collected over bare soil terrain.

The transect shown in Figure 2, presents very well define horizontal layers of about 5cm thick or less and parallel to the terrain surface. These layers particularly present below the 7.5 cm mark are homogeneous and relatively continuous suggesting similar areas where soil moisture conditions have homogeneous value that may differ from conditions in adjacent layers. These layers suggest a not homogeneous soil moisture process within the tri-dimensional 30x30m field, highly stratified and affected by previous disturbance suffered by the terrain. Regarding the regional assessment of soil moisture conditions using point data heterogeneous subsurface terrain is particularly important since over/under estimation of the soil moisture behavior can occur depending on the location of the soil moisture sensor. Regarding the effects in soil moisture of land use, these observations suggest that vegetation cover in the terrain is limited in defining the initiation water infiltration process and its lost due to root intake, and that after water has reached a level below the root system the soil physical characteristics and its level of disturbance are what define moisture content and time of retention. In cases where soil is bare, the disturbance in soil physical structure defines the heterogeneous behavior of water infiltration process and soil moisture content.

CONCLUSIONS

The preliminary results of this project although un-conclusive showed that soil moisture within agriculture fields is highly stratified in both the horizontal as well as in the vertical dimension and affected by the disturbance caused in the ground. In the horizontal profile soil moisture was organized in continuous rows according to the tracks of agriculture equipment. In the vertical profile soil was seen as organized in horizontal layers affecting soil moisture infiltration process. These results are important to demonstrate that the role of vegetation cover in the soil moisture behavior is limited to the superficial process of infiltration in the upper layer of the ground and that it is the soil physical properties and the level of ground disturbance the largest causing of the soil moisture heterogeneity at the field level. A limitation of this study is the lack of repetitions of the GPR over a extended period of time for each of the land uses that provides soil profiles under different moisture conditions. This should be considered for further studies (Friedli et al. 1998).

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