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Quantifying In-season Soil Moisture Dynamics under Long-term Tillage Management

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RATIONALE

Agronomic practices that minimize or eliminate tillage and conserve soil-protective crop residue have fostered higher yields, farm income, and reduced the environmental cost of cropping moderate to highly erodible soils. The principal reason cited for this is more efficient capture, utilization, and profile storage of available moisture.

Moisture storage in the soil profile depends on inherent soil and geophysical properties but may exhibit continuous change over time and space. Until recently, soil moisture dynamics could only be approximated by periodic gravimetric sampling or use of the neutron probe. Consequently, information about the impact of tillage practices on soil moisture dynamics has been constrained by lack of safe, cost-effective, and adaptive methods to measure profile moisture over extended temporal and spatial domains. A relatively new technology, the multi-depth capacitance probe, overcomes these limitations.

OBJECTIVES

- Describe the general operating principles of capacitance probes and their application to profile moisture monitoring in cropping systems.
- Evaluate the performance of the Delta-T multi-depth PR2/6 probe.
- Examine soybean yield in relation to in-season accumulation, storage, and depletion of profile moisture.

OUR APPROACH

We used two, long-term tillage trials, both on fine, kaolinitic, thermic Typic Kanhapludults, established in 1984 at the Upper Piedmont Research Station, Reidsville, NC. Both experiments are randomized complete blocks repeated four times and have maintained controlled traffic patterns.

In one trial, polycarbonate access tubes 100 cm long × 2.8 cm in diameter were installed in the plant row on 20 May 2008 in selected treatments: no-tillage; in-row subsoiling; full-width tillage via disking, chisel, moldboard, and chisel + disking. In the other trial the treatments were no-tillage, disking, and alternating no-tillage with disking. Volumetric moisture content was monitored with a Dynamax PR2/6 (Delta-T Devices Ltd., Cambridge, UK; Dynamax, Houston, TX) multi-depth capacitance probe 10-, 20-, 30-, 40-, 60-, and 100-cm deep beneath soybean on a weekly basis beginning 13 June; a bi-weekly schedule was adopted November through the end of December.

Soybean (Pioneer AG4903 Group IV RR) was planted on 08 May using a 2-row KMC no-till planter calibrated to deliver ~312,500 seeds ha^{-1} on 96 cm rows. Soil tests from 2006 showed high to very-high P and K index levels following annual corn fertilization with 45 kg ha^{-1} P_2O_5 and 134 kg ha^{-1} K_2O so no fertilizer was applied. NCSU recommendations were used for weed control. No supplemental irrigation was provided. Soybeans were machine harvested in November from the interior two 15.2 m long rows in each plot and grain yield and moisture content determined.

The PR2/6 data logger stores data as volumetric moisture (m^3 m^{-3}) and voltage readings that are downloaded to Microsoft Excel in comma separated value (.csv) format. The .csv files are then converted via Excel VBA macros to a rectangular data frame that can be processed for graphical or statistical analysis.

Long-term tillage plots on a Wedowee sandy clay loam, Reidsville, NC. Note the change in soil color across systems, which are randomly ordered.

Right: Aerial image of the Upper Piedmont Research Station and surrounding area showing 2-ft contours and local soil map units. The area has sloping topography typical of the North Carolina Piedmont region where erosion and runoff are ever-present concerns. The Wedowee tillage plots (red bulls' eye) are oriented NW-SE. Cropping is roughly across the contour on a ~ 5% slope.

Early post-emergence view of soybean in two adjacent tillage plots on a Pacolet sandy loam. Reidsville, NC.

Right: Aerial image of the Upper Piedmont Research Station and surrounding area showing 2-ft contours and local soil map units. The Pacolet trial site (red bulls' eye) is situated on the upper shoulder of a ridge tilting slightly to the west.

DYNAMAX PR2/6 CAPACITANCE PROBE

Capacitance probes utilize the soil's capacitive properties to estimate the apparent dielectric constant, or permittivity, of the soil mineral-water-air matrix, which is mainly a function of moisture content.

$$C = \varepsilon_r g \varepsilon_0$$

- In principle, the capacitance C (in farads) of two electrodes is equal to the product of the relative permittivity ε_r (dielectric property of a medium), the free-space permittivity ε_0 (a constant), and g a constant defined by the geometry of the electrodes.

$$\varepsilon_r^{\alpha} = \sum_i V_i \varepsilon_i^{\alpha}$$

- The variable ε_r may be modeled as a mixture of permittivity components where V_i = the volume fraction mineral-air-water components, ε_i = relative permittivity of the i_{th} soil component, and α , an empirical geometric component, typically ½.

- When direct-current voltage (via 9V battery) is applied to the PR2/6 probe, it creates a fixed-frequency (100 MHz) radio signal…

…which is applied to pairs of stainless-steel ring electrodes located at nodes along the length of the probe...

…which propagate an electromagnetic field extending about 100 mm into the soil. The field passes easily through the access tube wall, but less easily through air voids.

- The relative permittivity of a medium is governed by the tendency of the molecules to polarize, or orient atomic charge, within an electromagnetic field. Free water is highly polar, consequently ε_r dominates the permittivity of the soil mineral-air-water matrix.

- The water content-dependent permittivity of the soil system influences the applied electromagnetic field. The resulting change in oscillation frequency and amplitude leads to a measured voltage drop, which can be related to water content.

$$\sqrt{\varepsilon_r} \sim V_{out}$$

- The profile probe uses a polynomial function suitable for 'normal' mineral soils (e.g., non-extreme texture) to compute volumetric moisture θ_v from V_{out} .

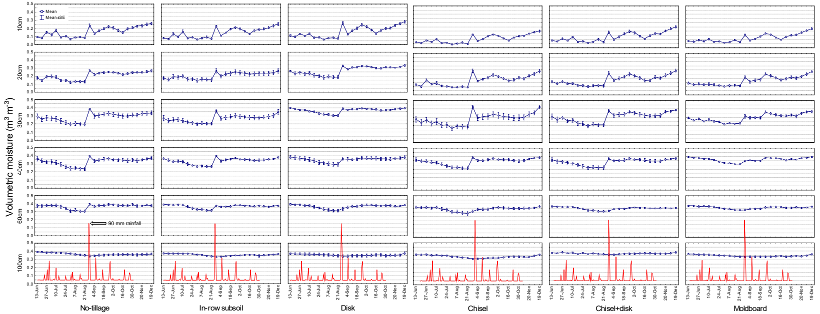
To install PR2/6 access tubes, a slotted metal probe is first driven into the ground. Guide plate ensures directional alignment of the probe's cavity and access tube.

After clearing the cavity, the access tube is Installed. Cavity walls must be void-free and maintain intimate soil-tube contact for accurate moisture readings.

To take readings, the PR2/6 probe is inserted Into the access tube.

Three moisture readings are taken at each of six depths by rotating the probe 120° from a fixed reference point.

2008 profile volumetric moisture June-December, Wedowee sandy clay loam



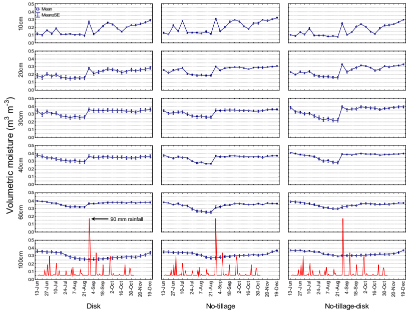
YEAR 1 RESULTS

In 2008, we logged over 15,000 moisture measurements. Our end goal is modeling the dynamic behavior of profile moisture in tillage systems over multiple cropping seasons to quantify the interrelationships of crop yield, profile moisture, and soil physical properties. Following are some insights we gained from the 2008 campaign.

- Profile volumetric moisture content from June-December in a Wedowee and Pacolet sandy loam soil show moisture peaks associated with high rainfall events diminishing with depth. (see above and right)
- Fluctuations in profile moisture associated with high rainfall events decreased as tillage intensity increased on the Wedowee plots. On the Pacolet plots, there is less variation in between-treatment peaks associated with rainfall, but also sharply depleted profile (0-100 cm) H_20.
- Variability in PR2/6 probe readings differed as a function of tillage and depth (not shown), an important observation which requires further investigation.
- Soybean grain yield was positively related to in-season accumulation of profile volumetric moisture in the Wedowee soil whereas higher soybean yields depleted that reservoir in the Pacolet soil. (see Table below)

Trial	Tillage System	Yield	Profile Δ H_2O
		(kg ha^{-1})	(mm)
Wedowee	No-tillage	1314	+36
	In-row subsoil	1085	+37
	Spring chisel	1133	+33
	Spring disk	1252	+32
	Spring chisel+disk	714	+27
	Spring moldboard+disk	709	+29
Pacolet	No-tillage	1711	+18
	Disk	1719	+19
	Alternating no-tillage-disk	1236	+26

2008 Profile volumetric moisture June-December, Pacolet sandy loam



FUTURE WORK

- Moisture monitoring will continue in 2009.
- More information is needed about the geophysical environment surrounding the PR2/6 access tubes and beneath.
- Use non-invasive geophysical methods to characterize spatial variability of Ap and subsurface horizons in the tillage plots.
- Are crop yields more sensitive to Ap horizon management or limited by inherent subsurface physical properties? What is the effective rooting depth of corn and soybean in the tillage plots?