Site-Specific Characterization, Spatial Variability Analysis and Finite Element Modeling of Sub-soil compaction for Precision Farming Applications.

Soil compaction is one form of physical land degradation that declines soil productivity. The extent of compacted soil is estimated worldwide at 68 million hectares of land. Soil compaction is a process of soil particles rearrangement into a denser state, reducing the air-filled fraction of soil pores. With the increase in soil compactness, the permeability of soil to air and water decreases and the soil strength increases. The main causes of soil compaction are external loads from heavy machinery traffic and tillage. Animal trembling and natural reconsolidation forces can also cause soil compaction problem. Soils in the southeastern USA have a compacted root-restricting layer, commonly called soil hardpan, located below tillage depth (18-30 cm). The presence of the hardpan layer impedes root growth for the uptake of soil and nutrient reserves in the subsoil horizons in particular during drought periods. Researches have also indicated that the spatial distribution and depth of the root-restricting layer vary from field to field and also within field. Uniform depth sub-soiling, an expensive and energy intensive tillage, has been widely used annually or biannual to mechanically disturb the layer to improve the roots’ environment. Due to the field variability of the root-restricting layer, the tillage depth may be applied in parts of the field where soil compaction is not a problem or at a tillage depth that does not correspond with the depth of the root restricting layer. Variable depth/precision tillage applications may be an alterative sustainable soil compaction management approach that the tillage depth could be adjusted in real-time with detection of soil compaction or map based prescription tillage could be applied. Research studies have shown that variable depth tillage reduces tillage energy approximately 22% as compared to the conventional uniform depth tillage.

Soil compaction management where by tillage inputs are applied depending on the spatial location and depth of sub-soil compaction is generally called precision tillage. The success of precision tillage depends on the availability of economical, precise and accurate soil compaction sensing technology, field variability management, field positioning and application of tillage. The availability of GPS technology to a centimeter level accuracy may assist in field positioning of soil measurement and application of tillage. The main challenges for researches are the development of methods or procedures of soil compaction sensing technology, field variability management and real-time or map based prescription tillage.

The main goals of the PhD work were exploring the development of real-time soil compaction sensors, and finite element modeling and field spatial variability analysis of soil cone penetration for precision tillage. Experiments were conducted in soil bin, field based and computer simulation.

1). Soil bin Experiments.

Experiment was conducted at the National Soil Dynamics Laboratory in Auburn, AL to develop acoustic based soil compaction sensor for real-time or on-the-go characterization and application of sub-soiling. Acoustic sensor (microphone) was installed at the tip of a tillage shank (sub-soiler) that was mounted on instrumented vehicle. Soil hardpan was artificially installed in the soil bin using compression wheel at a predetermined depth. The experiment was conducted using split-plot design with main plot treatments of bulk density and sub-plot treatments of soil moisture. The acoustic sensor mounted shank was driven through the stratified soil layer. Measurements were taken for soil moisture using gravimetric method, soil cone penetration resistance using cone penetrometer and draft force using a dynamometer mounted on a soil bin vehicle. Signal processing was performed on the acoustic signal using Fast Fourier Transform (FFT) method in Matlab. Information containing frequency (~ 600 kHz) was found to be sensitive to the magnitude of the soil strength. After removing environmental noise using band-filtering techniques, the acoustic signal spectrums were compared with the cone index profiles. The results indicated that the acoustic signal pattern was similar to the cone index. The depth to the sub-soil compacted layer predicted from the acoustic sensor was close to the depth predicted using soil cone penetrometer.

2). Soil column and Soil Bin Experiment

Soil cone penetrometer, an ASABE standard instrument that measures a vertical insertion force of a cone into the soil, is a widely used soil compaction measurement tool. The influences of soil parameters, dynamics of soil reaction to cone penetration and soil-cone frictional properties on the cone penetration data may affect the cone penetrometer data interpretations in predicting the relative strength and depth of soil hardpan layer. Laboratory and field experimental studies were conducted to evaluate the tool in predicting the relative strength and depth of soil hardpan as influenced by soil moisture, bulk density and cone materials (Teflon, ASAE standard stainless steel and Teflon coated stainless steel). In the field study, very intense (10m x 10m sample grid) soil cone penetration measurements guided by RTK-based GPS for field positioning were taken in a 2 hectare area on Pacolet sandy loam soil in Auburn, AL. Algorithms were developed in Matlab to predict the relative strength and depth of soil hardpan. The spatial structures of the strength and depth of soil hardpan were determined using geo-statistical techniques in SAS. Contour maps for precision tillage were developed using Kridging interpolation technique in Surfer (software). The results showed that variogram parameters were affected on soil moisture that soil drying resulted an increase in sill and a decrease in range for the peak cone index (magnitude of soil hardpan). The effect of soil drying on depth to the hardpan was that the depth was found to be spatially uncorrelated. The hardpan was detected a shallower depth due to soil drying, however the differences were practically small that the tillage depth recommendation may not be affected.

3). Finite Element Modeling

A computer model using finite element method in ABAQUS, commercially available software, was also developed to investigate virtual axysimetric soil-cone penetration interaction. Finite element procedure was developed successfully to model surface contact problem of soil cone with frictional property using the master-slave contact algorithm in ABAQUS/Explicit for Norfolk sandy loam soil. The finite element model predicted soil hardpan depth shallower than cone penetrometer method. The soil stress and strain in finite element simulation of the soil cone penetration indicated that a zone of influence with a diameter nearly three times the cone was developed around the advancing cone.

The results indicated that cone penetrometer actually measures soil strength in the zone of influence suggesting interpretation of cone penetrometer data in stratified soil layer need to account such influence.