SPATIAL VARIABILITY OF SOIL PHYSICAL PROPERTIES AND VALIDATION OF GOSSYM ON SELECTED GROWTH PARAMETERS OF A COTTON CROP

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Abstract

Geostatistical concepts were used to evaluate the spatial variability of soil physical properties. A 400-acre cotton field was sampled on a 300 feet grid basis, taking 209 soil profiles at 3 depths. The spatial analysis of the soil texture, bulk density, water retension, and hydraulic conductivity data indicate high variability across the field. The semivariogram models show minimum nugget, sill and presence of spatial structure beyond its original sampling distance, except the saturated hydraulic conductivity with high nugget (109 cm day^{-1}), and high sill (390 cm day^{-1}) values. This large residual variation over small distances, could be due to wide sample spacing. To reduce the nugget effect a shorter grid sampling scale may be adopted for measurement of saturated hydraulic conductivity. The GOSSYM/COMAX-Cotton model was used on the same spatially variable sites to determine if the crop can be managed based on dominant soil types or could be managed site specifically. GOSSYM/COMAX was first run on selected 26 sites, consisting of 6 major soil series which represent 97% of the total soil series of the field. Then common soil series, physico-chemical properties were averaged to use as input in the model. The individual and averaged predictions were compared with each other and with the actual crop growth parameters and yield. The individual and averaged predictions for plant height, numbers of nodes, and yield were in good agreement. A significant correlation ($r = 0.87$) was found between individually predicted yields for soil series and actual yield.

Introduction

Site specific farming involves the use of state of the art technologies available for on and off farm. Among those technologies, one of the promising tools, is crop models. They predict the likely yield response to particular levels of inputs. The GOSSYM/COMAX-Cotton model is one such tool. GOSSYM/COMAX is the first crop simulation model which calculates specific cotton crop responses to soils, weather, and management practices (Whisler, et al., 1986). To run the model and test different soils, one has to provide the data on soil moisture rention curve, bulk density, texture, residual nitrogen, organic matter content, initial soil moisture content of the soil by 6 inch increments to a depth of 3 feet. One of the drawbacks in such models is that they don't take into account the soil spatial variability of the field but are programmed to predict the yield response for a particular soil scenario.

But soils are inherently variable due to geological and pedeological soil forming factors. Those factors interact with each other over spatial and temporal scales and are further modified, locally, by alluvial and erosion processes. Several researchers recorded changes in soil properties over a range of sampling distances. Burrough (1993) found most of the within field variation of bulk density and water content over 54 feet and of texture over 1500 feet. The classical statistical methods assume zero continuity and are based on random independent variables. While geostatistic takes the opposite approach, it assumes that the adjoining points are correlated spatially. This continuity is measured in terms of variogram analysis and is then used for estimations at unsampled points (Campbell, 1978). This implies that within a given distance or range of spatial dependence, differences in soil properties can be described as a function of their spatial separation. As a result, the nature of variability, identified by spatial studies of soil properties, depend largely on the scale of observation, the properties in question, and the methodology used to conduct the investigation (Wilding and Drees, 1983). Trangmar, et al., (1985) reported large variation of soil hydraulic conductivity over small distances in 0.741 acres plots relative to a 227 acres field and argued that it could be caused by local changes in particle size distribution and bulk density.

The objectives of this study were: (1) to evaluate the spatial variability of soil physical properties affecting cotton growth and (2) to use the GOSSYM/COMAX model to evaluate the response of spatially variable soils in a single field.

Methods and Materials

The study area was located at Hood's farm, Bolivar County, Mississippi (Mississippi Delta) in 1998. The parent material of the soil on the farm is dominantly alluvium, deposited by the Mississippi River and its tributaries. The sediments originated in the vast, diverse Mississippi drainage system, which comprises a large area of the United States. Consequently, the area represents diverse textural characteristics because of their heterogeneous origins and differential stages of weathering, and previous pedogenic development (Logan, 1916). The soils belong to the order Entisols, and 9 major soil series were identified in the field. The area of the field is about 400 acres.

The study was conducted in two parts. In the first part, geostatistical concepts were used to evaluate the spatial variability of soil physical properties, such as particle size

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distribution, bulk density, saturated hydraulic conductivity, and the moisture retention curve at 0.01, 0.1, 0.33, 0.67, 1.0, 5.0, and 15.0 bars. For this 209 soil profiles for an average of 3 horizons at variable depths, depending upon the location in the field, were collected. The profile cores were obtained to a depth of 3 feet on a 300 feet grid basis. Geoeas and GS^{+} software were used for prelimnary data exploration, and analysis of semivariograms. Kriging (universal) was performed based on their respective semivariograms and 2-d contour maps were generated for each variable at each depth for the whole field.

In the second part of the study, GOSSYM was used to determine if a cotton crop can be managed based on dominant soil types or could be managed site specifically. For that purpose 26 profiles were selected, for plant mapping, which represented 97% of the soil series of the field. A 20 inch plant row length plot was laidout at each site which was comprised of 5 to 10 plants depending upon the location in the field. Each plant in the plot was mapped throughout the growing season of the crop. At the end of the growing season yield was recorded by a GPS equipped cotton picker. GOSSYM was first run for each plot using their respective individual hydology files. Then common soil series hydology files were averaged and GOSSYM was run using the average soil series hydrology files. The individual and averaged predictions were compared to the actual crop growth parameters and yield.

Results and Discussion

Soil Spatial Variability

Generally the field under study was highly variable in terms of soil physical properties. Sand content ranged from 0.27 to 91 %, clay content ranged from 0.63 to 53 %, soil bulk density ranged from 0.8 to 1.5 g cm^{-3}, and saturated hydraulic conductivity ranged from 0.03 to 154 cm day^{-1}.On the average the higher clay content (27%), bulk density (1.4 g cm^{-1}) were found in the B_1 horizon accompanied by low sand content (11 %) and low hydraulic conductivity (1.5 cm day^{-1}) for most of the soil series of the field, suggesting a compacted subsurface soil layer.

The cumulative frequency distribution of the 209 measured values for each varible for 3 depths were approximately, normally distributed except for saturated hydraulic conductivity which were negatively skewed. Hydraulic conductivity data was log-normaly tansformed and then back transformed after kriging. The spatial structure of each data set was isotropic in nature, and hence it was assumed that the semivariogram depended soley on the magnitude of measured values and not its direction.

The spatial analysis of the soil texture, bulk density, water retension, and hydraulic conductivity data indicates high variability across the field. The semivariogram models shows minimum nugget, sill and presence of spatial structure beyond its original sampling distance, except the saturated hydraulic conductivity with high nugget and sill values, suggesting a large residual variation over small distances, which could be a function of depth and wide sampling spacing. To reduce the nugget effect a shorter grid sampling scale may be adopted for future sampling.

Since all soil physical properties exhibited spatial structure, analysis was extended to kriged values for unsampled locations in the field. Contour maps illustrated positional similarities between particle size distribution, bulk density, hydraulic conductivity and moisture retension at different potentials at variable soil depths. Abrupt changes from high to low or low to high were eliminated from kriged maps by the smoothing effects of kriging. High sand (30 to 60 %), hydraulic conductivity (15 to > 100 cm day^{-1}) and with low volumetric water content at 0.3 bar (16 to 24 cc/cc) were observed at the western part of the field extending from NW to SW along the field boundries. The soil is mainly comprised of the Robinsonville soil series (sandy loam soils). High clay (14 to > 50 %), low hydraulic conductivity (1.5 to 14 cm day^{-1}) and high volumetric water content at 0.3 bar (26 to > 40 cc/cc) were observed in the eastern part of the field especially in the natural drainage ways and low lying areas. That part of the field is mainly comprised of Commerce and Souva soil series (silt loam to silty clay loam). The above positional similarities between different soil physical properties suggest a differential irrigation scheme would be advantageous, since the whole field is uniformaly irrigated by a central pivot system.

Crop Modeling

Comparisons between observed and GOSSYM predicted outputs were made for plant height, number of nodes and yield. GOSSYM was first run on individual 26 sites, consisting of 6 major soil series. The observed and predicted values for plant height and number of nodes were in good agreement for most of the 26 sites, except GOSSYM over predicted plant height 5 to 10 inches at early growing stages for the Souva soil series. Then common soil series, of 26 sites, physical properties were averaged and GOSSYM was run based on soil series. The comparison improved in terms of plant height and numbers of nodes. The model under predicted from 0.07 (0.3 % relative error) to 4.0 inches (19.9 % relative error) for Commerce silt loam, Commerce loam, and Commerce silt. The model over predicted from 1.5 (7.6% relative error) to 6.5 inches (23.7% relative error) for Robinsonville sandy loam, Robinsonville loam and Souva soil series. A significant correlation (r=0.87, p=0.001) was found between GOSSYM predicted and actual yield. Highest actual yield (2.46 bales/acre) was recorded for the Commerce silt loam while the lowest (1.30 bales/acre) was recorded for Souva soil series.

Conclusion

The field was highly variable in terms of soil physical properties, which was obeserved in terms of crop growth and yield. This suggests fine tuning of water application, based on dominanat soil series. The high bulk density of subsoil associated with poor crop growth, especially in the west side of the field indicates the presence of a hard pan, and suggests subsoiling and leveling. The high nugget effect in saturated hydraulic conductivity suggests erratic variation at small distances that could be due to large sample spacing (300 feet). Crop parameter predictions were improved by GOSSYM based on common soil series groupings over individual variable sites.

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