Spatio-temporal Variability Analysis of Soil Volumetric Moisture Content on the Field Scale

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Abstract. The objective of this study was to explore spatio-temporal variability characteristic of soil volumetric moisture content (SVMC) during wheat and maize rotation system. In the article, SVMC was determined by the Time Domain Reflectometry (TDR), a total of 104 soil moisture content data from sampling sites were collected from the surface layer (0–20cm) at the experiment field (117°3'55.74"E, 36°43'8.99"N) with the support of grid-sampling method, sample measurements were implemented on June 3rd and on September 24th, 2009. On each sampling point, we inserted vertically TDR probe to monitor soil moisture. Each moisture measurement was geo-referenced using a Differential Global Positioning System (DGPS). The statistical analysis results showed that the SVMC range from 2.65 to 4.65 covered approximately percent 67% of the total samplings on June 3rd, which indicated the important effects on the total statistical distribution. Approximately percent 76% of the total samplings range from 45.4 to 55.4 on September 24th. To analyze the temporal variability of SVMC, we developed the comparison analysis results also indicated that the spatial pattern of SVMC clarified the fundamental complicated factors of the spatial structures and the comprehensive factors, and the exogenous variable decreased the effects on the spatial variability of SVMC from percent 70.9% to 54.9%, the random factors dominated the spatial variability of SVMC. The spatial distribution map of SVMC by Kriging interpolation was better to help us precisely and well understand the spatial distribution pattern of the SVMC of wheat-maize rotation system on the field scale.

Keywords: TDR； Spatio-temporal variability； Soil volumetric moisture content

1 Introduction

Soil was inhomogeneous and continuous in nature, and its characteristics had the spatial structure. One of the challenges facing the adoption of precision agriculture (PA) technology was the identification of productivity-related variability of soil properties accurately and cost-effectively, the all-important work and base of precision agriculture was producing the spatial distribution map of soil property content. The study of soil volumetric moisture content (SVMC), as one of soil properties, was the heated debate of soil-crop system, and was also the key factor connection with crop growth system [1].Time domain reflectometry (TDR) was widely applied to measure soil electrical conductivity to infer SVMC. With a minimum of soil disturbance, TDR enabled to simultaneously estimate SVMC as well as electrical conductivity and was frequently applied as well in studies of solute transport in porous media[2]. Although SVMC was an important variable under soil-crop system framework,the spatio-temporal variability of SVMC had the less study from the correlation literatures, let alone analyze the SVMC variability on the field scale at home and abroad. The spatial variability of SVMC was developed from some reseachers[2], mainly with statistical analysis and geostatistics, which were used in many domains, but the spatio-temporal analysis of SVMC was seldom studied on the field scale in recent years. Temporal stability of SVMC was a reflection of the temporal persistence of spatial SVMC patterns. Grayson et al. Vachaud et al [3]. found that soil texture was responsible for an observed high degree of temporal stability. Kachanoski & de Jong expanded the definition of temporal stability and correlated scale dependency of the temporal stability of SVMC [4]. From the new perspective, developing the comprehensive influence of SVMC to the spatial distribution of SVMC was the other significant objective. The amount of spatial variability as well as the spatial distribution of SVMC can have a critical impact on the irrigation status and management measure on the field scale. The research also showed that a starting point to characterize the structure and heterogeneity of SVMC fields was an examination of the spatial structure. Therefore, the objective of this study was to evaluate the efficiency of spatial statistical analysis and spatial distribution of SVMC during two-cropping for wheat and maize in one year, moreover, and the study explored the comparative analysis of the structure factors and complicated association factors in temporal scale impact on SVMC [5].

2 Material and Methodology

2.1 TDR measurement principle and approaches

An overview of conceptual dielectric models for TDR application can be found in some literatures. TDR estimated the dielectric constant, in a soil matrix by measuring the propagation time of an electromagnetic wave (EM) sent from an EM pulse generator mounted on top of a coaxial cable, inserted into a soil matrix. EM waves propagate through the coaxial cable to the TDR probe, which was a rod made of stainless steel or brass. Part of the incident electromagnetic waves was reflected at the top of the probe because of the difference in impedance between cable and probe. The remainder of the wave propagated through the probe until it reached the end of the probe, where the wave was reflected. The round-trip time of the wave, from the beginning to the end of the probe was measured with an oscilloscope branched on the cable tester. For a homogeneous soil, volumetric water content is calculated by using a calibration curve. The curve was mathematically formulated in these literatures[6].

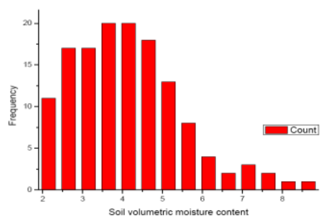
2.2 Data Acquisition of Soil Volumetric Moisture Content

SVMC was determined by TDR in the study. A total of 104 soil samplings about soil volumetric moisture content were collected from the surface layer (0–20cm) at the experiment field (117°3'55.74"E, 36°43'8.99"N) with the support of grid-sampling method, covering approximately 3 hm2, located on the north shore of Xiaoqing River in Shandong province, P.R. China. Explanatory variables included environmental spatial datasets such as land use, drainage class were put forward to analyze. On each sampling point, we inserted vertically a triple wire TDR probe to monitor soil moisture, each moisture measurement was geo-referenced using a Differential Global Positioning System (DGPS), five moisture measurements were made within a 1-m diameter circle. The average reading for each point was computed as SVMC datum point. Sample measurements were implemented before wheat harvest on June 3rd, maize harvest on September 24th, in the latter sampling, the more validation points, and "maize 958" of maize cultivars was planted in the study area. The Kriging algorithm combined with GIS was applied on drawing the distributing map of SVMC and it also offered the theoretical foundation for the connection between studying SVMC and enhancing yield[7].

3 Results and Analysis

3 .1 Statistical Characteristics of Soil Volumetric Moisture Content

The study explored the classical statistics analysis and developed the normality test of the variable based on Shapiro-wilk test in the normality of 0.05 incredile level. In general, Shapiro-Wilk normality test referred to the correlated documents. The classification of variance coefficient(C.V.), weak variation(C.V.<0.1), medieval variability (C.V.=0.1–1.0), strong variation(C.V.>1.0). Coefficient of variation of soil nutrients content, respectively.[8]C.V. of SVMC was 0.351, 0.105 in the two samplings, respectively, which belonged to the medieval variation, the mean value of the variable was 4.119, 50.739. In order to understand distribution characteristics of SVMC, we analyzed the frequency characteristics of the variable, the results referred to the Figure 1and Figure 2.



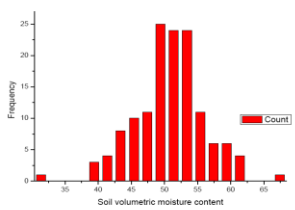


Figure 1 The frequency characteristics of SVMC on June 3rd **Figure** 2 The frequency characteristics of SVMC on September 24th

In the article, the study explored the frequency characteristics of SVMC on June 3rd and September 24th. The SVMC were divided into equal intervals ranging from low value to high value, the frequency statistics was developed for the variable, generally, sampling data falling on the interval boundary was considered of the high equal interval. As shown in Figure 1 and 2, the SVMC ranged from 2.65 to 4.65 covered approximately percent 67% of the total samplings on June 3rd, which indicated the important effects for the total statistical distribution. Approximately percent 76% of the total samplings ranged from 45.4 to 55.4 on September 24th, which responded to the whole statistical level. Normality distribution of the SVMC was the precondition of using interpolation to analyze SVMC feature, the normality was also developed in the study, the statistics characteristics of SVMC was illustrated about sampling data rather than the regional characteristics of the whole study area. Consequently, it is necessary to apply geostatistical methods together with GIS to solve this problem.

3.2 Geostatistical Characteristics of Soil Volumetric Moisture Content

Kriging Interpolation was the most common interpolation method in geostatistics. It was the method of optimized and precise estimation of partial variables in unobserved locations with application of original data and configuration of semi-variance function. The involved variables of semivariogram and the parameters of estimation accuracy provided the basic description of Kriging prediction, these variables and parameters was introduced in the other documents [8]. Such as nugget, sill, range, ME(Mean standardized error),ASE(Average standard error),RMSE(Root-mean-square error),MSE(Mean standard error) and RMSSE(Root-mean-square standardized error). The degree of spatial autocorrelation was described by the ratio of nugget and sill, the ratio of nugget and sill of soil volumetric moisture content was 0.709, 0.549 in the study, respectively. Results showed there was the medium spatial autocorrelation of SVMC. During the semivariogram model, the anisotropic change of SVMC was considered of 4.8 angel direction on June 3rd, good-fitness model was exponential model for the two times samplings of SVMC. From the Kriging results, for the sampling on June 3rd, ME equalled -0.020, RMSE equalled3.844, ASE equalled 3.812, MSE equalled -0.007, RMSSE equalled1.009. For the sampling on September 24th, ME equalled -0.018, RMSE equalled 1.359, ASE equalled 1.298, MSE equalled-0.028, RMSSE equalled 1.047. The prediction results from the two times sampling responded to the simulation accuracy. The evident change was presented in nugget, sill and range parameter of semivariaogram model of SVMC, the ratio of nugget and sill of SVMC indicated that the random factors had an impact on the spatial variability of SVMC for the two times samplings, 70.9% and 54.9% of the total spatial variability, on June 3rd, the spatial results emphasized the rainfall and irrigation stochastic factors, but the samplings on Sep.24th, the exogenous variable decreased the effects on the spatial variability of SVMC from percent 70.9% to 54.9%, the random factors dominated the spatial variability of SVMC. The Kriging algorithm combined with GIS was applied on drawing the distributing map of SVMC of different crops harvest stages and it also offered the theoretical foundation for the connection between studying SVMC and enhancing the yield. This study provided a systematic approach for estimating changes of SVMC at the regional scale. As shown in Figure 3 and Figure4, we concluded that the Kriging algorithm provided a practical spatial statistical tool for prediction and simulation of categorical soil moisture variable. For the two samplings (wheat harvest on June 3, maize harvest on September 24th, 2009), the comparison analysis results indicated that the spatial pattern of SVMC and also clarified the fundamental complicated factors of the spatial structures and the comprehensive factors from time-scale analysis.

The continued distribution of SVMC responded to the random factors and structure factors. The comparative results showed that the sensitivity of soil moisture holding-capacity which restricted the soil moisture content in the results. The high content regions of spatial surface on June 3rd located in the in the upper right corner, the spatial surface on September 24th measurement regions basically inherited the surface on June 3rd, the dominant factors were verified by the comparative analysis of the two times moisture content spatial distribution. Under the sensitivity, involvement of exogenous variable (such as stochastic rainfall factor, irrigation factor), SVMC in the surface layer can be resulted into change, but from a more stable changes, the distribution of high-value and low-value regions of SVMC were in touch with soil moisture-holding capacity. So the continued distribution of SVMC not only provided the foundation of the dynamic monitoring of the total distribution of soil water status, but also was the important part of soil water monitoring system.

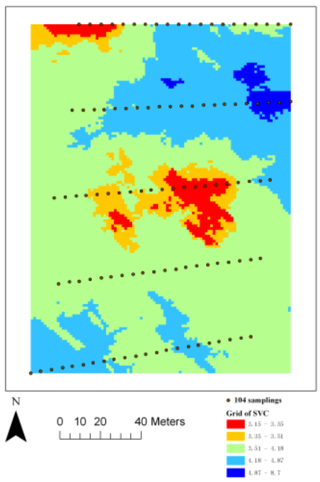


Figure 3. the spatial variability of SVMC on June 3rd

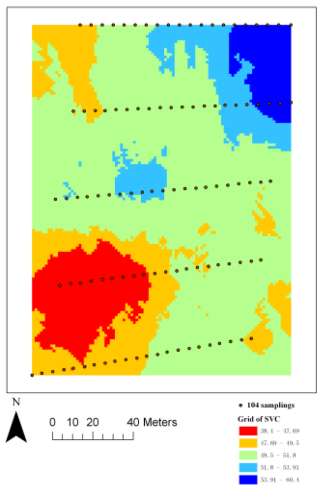


Figure 4. the spatial variability of SVMC on Sep. 24th

4 Conclusions and Discussion

With the support of classical statistics, analysis results of 104 topsoil soil samplings indicated that the average content of SVMC, frequency analysis results showed that the SVMC ranged from 2.65 to 4.65 covered approximately percent 67% of the total samplings on June 3rd, approximately percent 76% of the total samplings ranged from 45.4 to 55.4 on September 24th, which responded to the whole statistical level. We concluded that the Kriging algorithm provided a practical spatial statistical tool for prediction and simulation of categorical soil moisture variable. For the twice samplings, the comparison analysis results showed that the spatial pattern of SVMC and also clarified the fundamental complicated factors of the spatial structures and the comprehensive factors from time-scale analysis. Making a better spatial distribution map of SVMC was of significance in promptly adjusting precise agriculture management like fertilization and irrigation, especially, the comparative study of the spatial variability of SVMC, which also offered the theoretical foundation for dynamic monitoring the connection between SVMC and the other variable, for example, crop yield. The spatial distribution map of SVMC by Kriging interpolation was better to help researchers precisely and well understand the spatial distribution of the SVMC located in the farmland of wheat-maize rotation system.

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