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Research on Spatial Variability Characteristics of Black Soil Unfrozen Water in Songnen Plain during Freezing-Thawing Period

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Abstract. To address the difficulties of the complexity and the quantitative description of spatial non-homogeneity in the process of freezing and thawing of soil moisture migration, taking the unfrozen water as the research object, and using geostatistics to study the spatial variability characteristics of unfrozen soil water in different freezing and thawing stages. The results show that different freezing and thawing stages of unfrozen soil water has good spatial structure and strong spatial correlation, and it has a strong spatial redistribution effect on soil moisture. The application of geostatistics provides a new train of thought for in-depth study on freezing-thawing process of soil moisture transport mechanism.

Keywords: Songnen Plain, black soil, soil unfrozen water, spatial variability

1 Introduction

Freezing and thawing of soil water movement, as an important part of the water cycle in nature, agriculture, water resources, environmental engineering, which occupies an extremely important position. To carry on an in-depth investigation into the variations of the freezing and thawing period soil moisture, master the laws of its motion, will not only help to promote the development of the theory of soil water dynamics, but also provide the theoretical basis for water resources accurately evaluation, efficient utilization of soil water, and a reasonable determination of farmland irrigation technical parameters, etc [1].

Study on the theory of soil water dynamics have made considerable progress, along with the changes of soil moisture from the morphology point of view to the energy state theory [2], the research methods also vary from the qualitative description [3-4] based on soil physics test to the quantitative research [5-6] based on the numerical simulation. However, dramatic phase transitions and spatial variability of soil moisture in the freezing thawing process, that lead to the existing methods in the analysis of soil moisture variation during freezing and thawing period insufficient.

Geostatistics is a theory, which study on the spatial variability of the properties of a system. The theory has been applied in the study on spatial variability of in unfreezing soil water [7].But it has fewer applications on the freezing and thawing soil moisture variation.

Therefore, in this paper, the methods of geostatistics were used to analysis the spatial variability of black unfrozen soil water in Songnen Plain in the freezing-thawing period, expecting to provide scientific basis for reasonable regulation and utilization of black soil water in Songnen Plain.

2 Materials and Methods

2.1 Study Area and Test Scheme

Field experiments were measured in a place of dry land in the city of Harbin, soil type is black soil. Harbin city is located in the southeast of Songnen Plain, has a temperate continental monsoon climate with its severe cold winter, dry and windy spring, has no perennial frozen soil layer, the annual average temperature is 3.6°C , the average January temperature is -20.3°C , the average frost free period is 141 days, the average annual precipitation is 523.3mm, the average annual snowfall is 63.1mm, the annual average frost depth is about 1.75m.

Field experiment treats the soil unfrozen water in freezing-thawing stages as the observation object, and uses TRIME-T3 time domain reflectometry to monitor soil unfrozen water during the soil thawing period of 2008 to 2009. In the same vertical profile every 2m buried 1 TDR probe, altogether 10 probes was buried, each TDR probe sets 8 measuring points, respectively 20cm, 40cm, 60cm, 80cm, 100cm, 140cm, 180cm, 220cm and 260cm.

2.2 Research Methods

Geostatistics is the most important method to study the spatial variability characteristics of soil. Since 1963, the famous French statistician Matheron G has put forward the concept of geostatistics [8], through decades of development, geostatistics has been widely applied in soil science, ecology, geology, hydrology, meteorology, environment and many other fields.

Since geostatistics methods and theory can not only keep the autocorrelation of space variables, but also can make the simulation value of measured point be equal to the measured value, it can use a few sampling point to simulate many unknown information and spatial distribution, which greatly reduced the field sampling and observed workload, enhanced visibility [9] of data analysis.

3 Results and Analysis

3.1 Semivariance Analysis

Based on the soil unfrozen water content observational data in different freezing-thawing stages, using the software of GS+ 7 for the semi variance analysis, as shown in Table 1.

Table 1. Semivariance analysis of soil unfrozen water content in different freezing-thawing stages

Date	Fitting model	Nugget	Sill	Nugget/Sill (%)	Range (m)	R^2
08-12-19	Sphere	0.228	1.323	17.2	14.41	0.827
09-01-10	Sphere	0.001	1.443	0.1	14.8	0.899
09-03-16	Sphere	0.001	1.41	0.1	14.2	0.876
09-03-27	Sphere	0.001	1.392	0.1	13.91	0.873
09-04-23	Sphere	0.216	1.081	20.0	9.82	0.737
09-05-19	Sphere	0.238	1.078	22.1	6.47	0.912

Results of the Semi variance analysis of soil unfrozen water content in different freezing-thawing stages in the experimental areas show that: soil unfrozen water content in different freezing-thawing stages has good spatial structure, their theoretical semivariogram models were all spherical model, as the same as the theoretical semivariogram models of unfrozen soil total water content in different freezing-thawing stages in previous research [10].The spatial structure of the soil moisture test area should adopt the spherical model to describe. Model fitting precision is lower than the total soil moisture content's, but still can meet the precision requirement. As is shown from the unfrozen soil water content Nugget/Sill in different freezing-thawing stages, the spatial correlation of most unfrozen soil water content is stronger than the corresponding position of the unfrozen soil water content [11].

According to the horizontal time span comparison, the spatial correlation of the initial freezing period (December 19, 2008) and the melt season (April 23 and May 19, 2009) is relatively weak. Soil has strong spatial correlation in stable freezing period. Effect of freezing process on soil unfrozen water content spatial correlation was in contrast to the situation in soil water content.

Investigation of the range of soil unfrozen water content: range of soil unfrozen water content in every freezing stages of the freezing period (before April 23, 2009) was about 14m,the range of melting period decreased by 50%.It shows that the freezing-thawing processes also have impact on the spatial correlation distance of unfrozen soil water content, but relatively small.

3.2 Analysis of Spatial Variation Characteristics

Using the Geostatistical Analyst module in ArcGIS 9 Software to carry on the spatial local estimation of the unfrozen soil water content in different freezing-thawing stages and to map the spatial distribution, as shown in Fig.1.The left side data in the spatial distribution of the unfrozen soil water content in different stages in Fig.1 represents

the depth of the measuring points, the unit is cm; the upper marks represents each TDR probe.

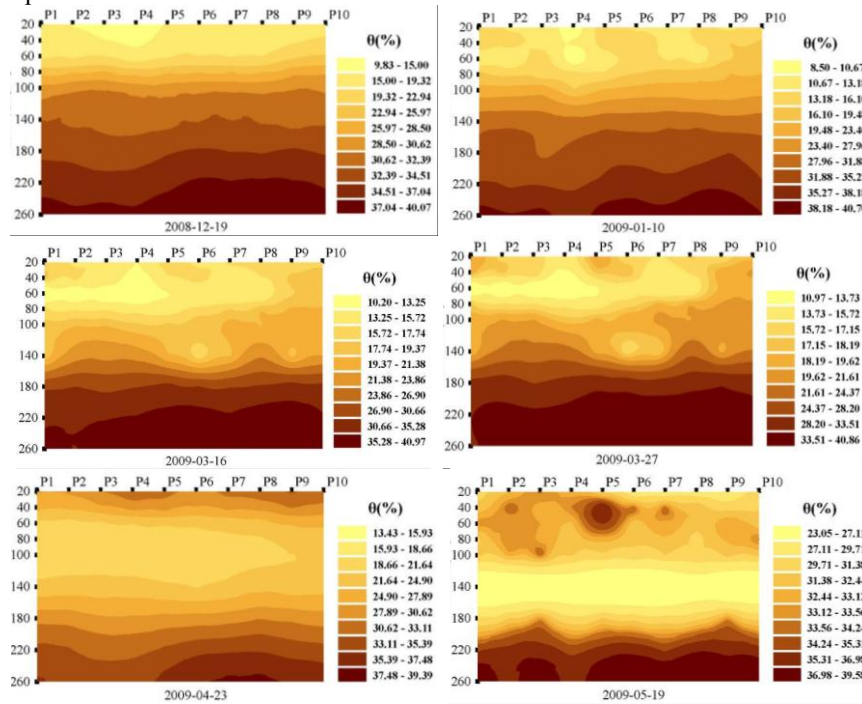


Fig.1. Spatial distribution maps of soil unfrozen water content in different freezing-thawing stages

From Fig.1 we can see, in the process of freezing-thawing stages, the two dimensional spatial distribution of the unfrozen soil water content in the profile has certain regularity. The unfrozen soil water content and soil the negative temperature has an extremely close relationship [12-13]. In December 19, 2008, the soil belongs to the initial freezing period, freezing depth is 65cm, the equivalent zone of soil unfrozen water content present banded rules, it shows that the phase change process of water plays an important role in the redistribution of soil moisture. For the part above 60cm measuring point in the freezing layer and the part below 100cm measuring point in the unfrozen layer, the banded equivalent zone of soil unfrozen water content is wide, that is to say soil unfrozen water in these region changes little in the vertical direction. However, the equivalent zone of soil unfrozen water content at the measuring points between 60cm and 100cm is narrow, it changes heavily in the vertical direction. Because of the existence of soil freezing front, the unfrozen soil water below the location of the freezing front migrate to the frozen zone, this phenomenon dovetails the fact of the freezing depth of 65cm.

Based on the same principle, the freezing depth is about 100cm in January 10, 2009, 160cm in March 16, 2009, and in March 27, 2009 the freezing depth reached the maximum 162cm, in the adjacent soil layer below measuring points for 100cm and the soil layer between 140cm to 180cm between the unfrozen water content

dramatic changes in the vertical direction, which were associated with the development of freezing depth or the depth of the freezing front, that's to say that the drastic change in the vertical direction of soil unfrozen water content in each frozen stages was caused by soil freezing. Therefore, the location of the freezing soil can be inferred according to the spatial distribution chart of the soil unfrozen water content in the freezing period. The unfrozen soil water content in freezing period showed a trend of increasing gradually from top to bottom. At the same time, notably in the freezing period of soil, for the frozen layer, the spatial distribution of the unfrozen water content presents regularly banded structure as the same as in the initial freezing period. It shows that when the soil is frozen, the unfrozen water content decreases rapidly, and continues to decline with the temperature's further reducing, but the freezing effect on the movement of the unfrozen water in frozen layer is small, the possible reasons to this question mainly are the atmospheric environmental conditions, the boundary of micro topography and the spatial variability of the soil water conductivity characteristics.

For the soil thawing period, the soil began to melt from two directions [14-15], while the soil unfrozen water content also increased from two directions. The spatial distribution situation of the soil unfrozen water content in the whole soil profile in April 23 and May 19, 2009 were shown in Fig.1. Frozen soil region is the low value area of unfrozen water content in soil, such as the measuring point between 40cm to 140cm in April 23, 2009 and the measuring point between 100cm to 140cm in May 19, 2009. At the same time, according to the spatial distribution of soil unfrozen water content in soil thawing period melting position between the upper and lower soil layer could be roughly inferred. For the soil surface in melting period, the initial melting period was the main driving force for migration of the unfrozen soil water content. Thus, the distribution of the soil surface unfrozen water content was regularly banded, and so was the situation in initial soil melting period. The soil unfrozen water content showed strong spatial variability after the surface soil began to thaw for a period of time. This is because in this period soil unfrozen water content is mainly affected by the different position of soil evaporation and the spatial variability of the water conductivity characteristics [16]. The lower soil also melted, but was less affected by external factors, so the unfrozen water content showed no spatial variability characteristics.

In order to analyze the severity that the different soil unfrozen water content vary with time in soil freezing-thawing period, spatial distribution maps of soil unfrozen water content coefficient of variation were drawn, as shown in Fig.2.

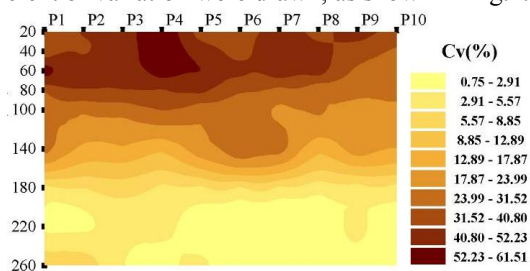


Fig.2. Spatial distribution map of coefficients of variation of soil unfrozen water content in freezing-thawing period

We can see from Fig.2, during the whole freezing-thawing period, coefficient of variation of the upper layer of the soil unfrozen water content is large, the lower layer of the soil unfrozen water content on the contrary. This is due to the upper layer of the soil unfrozen water content is not only the influence of the freezing-thawing effect, but also restricted by other factors. The coefficient of variation of bottom soil unfrozen water content is very small, below 5.57%. The phase change of the soil moisture in freezing period did not occur in this part of soil layer, so there were many other factors that bring about the slight variation of its soil unfrozen water content with time changes.

4 Conclusions

Different stages of freezing and thawing soil not frozen water content has good spatial structure and strong spatial correlation, but has relatively small influence on the spatial correlation distance of the soil unfrozen water content. In the whole process of freezing-thawing, the severe variation of soil water content in vertical direction happened in the position of soil freezing front. The spatial distribution of soil unfrozen water content was mainly influenced by the effect of freezing-thawing in the initial freezing-thawing period, and was influenced by the environment and the variability of the soil itself in the late period of freezing-thawing period.

Using geostatistical theory and method is a good way to analyze different stages of freezing-thawing soil spatial variation features of unfrozen water content, also can visually depict the spatial distribution state's variation of soil unfrozen water content in different freezing-thawing period, at the same time, it can infer the freezing-thawing position and the variability of the whole soil profile according to the spatial distribution of the unfrozen soil water content in the freezing-thawing period, so as to provides a new thought and method for further research on soil moisture migration mechanism of Songnen plain's black soil region at the freezing-thawing period.

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