Spatial Variability and Lateral Location of Soil Moisture Monitoring Points on Cotton Mulched Drip Irrigation Field

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Abstract：This experiment was conducted from April to September in 2009 in Baotou-lake Farm of Korla city, Xinjiang region, China. Two experiment schemes were designed for analyzing the spatial variability and lateral orientation of monitoring points for soil moisture. In scheme 1, 44 monitoring points were positioned with sampling depth of 0～60cm. In scheme 2, 20 monitoring points were placed with sampling depth of 0～80cm. Samples were taken in the whole cotton growing period before and after irrigation in both schemes. Statistical analyses including Q-Q test, descriptive statistics, t-test and geo-statistical analysis were performed to the soil moisture data. The results indicate that the increase of soil moisture can enhance their spatial variability. In drip-irrigated cotton cultivation, spatial variability of soil moisture resulted from the combination of several random variables and the structural factors such as climate, topography, soil form. Semi-variogram models belong to spherical model and the range of spherical model for soil moisture is about 9.40m～35.35m. The accuracy of the fitted model decreases as the soil moisture content increases. The monitoring points should be placed at the range of 0～0.475m from the drip tape and it is not suitable to place them at a farther place. It can be concluded that it is best to position the monitoring points at outward cotton row in consideration of management and soil

This Research is sponsored by following projects: the National Natural Fund Project on the Spatial Variability Mechanism of Soil Moisture and the Sensors' Layout Plan on Cotton Mulched Drip Irrigation（51060002）; High Technology Research and Development Program in Xinjiang Autonomous Region（200712111）; the National Technology Support Program for the 11th five-year Plan（2007BAD38B05）; the Key Discipline Construction Fund of Hydrology and Water Resources in Xinjiang.

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moisture monitoring. The outcome of this study can be used for the proper design and placement of monitoring points for soil moisture.

Key words：Cotton, Mulched drip irrigation, Soil moisture, Spatial variability, Monitoring point, Geo-statistics

1 Introduction

Xinjiang is not only one of the important cotton production bases but also it has the largest acreage of drip irrigated cotton area in China. In the last decades, Xinjiang has created a miracle of micro-irrigation development in the world. Until the year of 2009, drip irrigated cotton cultivation acreage in Xinjiang has reached about $9 \times 10^5 hm^2$ and the region has become the main area for research & development and application of drip irrigation advanced technology in China. With the promotion of drip irrigation, the technology development, automation and information management have become increasingly important. However, the implementation of irrigation decision-making on cotton still depends on the farmers' experience at present and it's still difficult to achieve accurate irrigation by the real-time monitoring information of soil moisture in field. In recent years, research of accurate drip irrigation on cotton has carried out in Xinjiang region to solve the key scientific problems such as the drip irrigation design theory and the methods for soil moisture monitoring system. However, these issues are extremely difficult to solve due to the unknown spatial variability of soil moisture. For the time being, drip irrigation system designers reduce the layout density of sensor randomly in order to reduce input costs. As a result, these practices affect the reliability of soil moisture information collection and accuracy. Thus the collection system of soil moisture has not yet really worked in decision-making on cotton drip irrigation.

Under drip irrigation, only soils near the root zone is moisturized, which is different to traditional surface irrigation. In addition to the influence of soil factor itself, there are many other factors that have significant impacts on the spatial variability of soil moisture, such as emitter flow, emitter spacing, drip tape uniformity and layout in field. After three years of experiment research, a database management system was established including soil moisture of cotton field, crop growth, irrigation water and social economy. The data measured by soil moisture sensors were transferred to Central Control Computer via the Remote Telemetry Control Unit (RTU) and the automatic evaluation of gathered data was processed through Central Control Computer by experts' system on cotton production and management. Practically, the solenoid valves will be opened or closed through RTU based on the orders issued by central control computer system. For details, see Fig.1.

There are many articles on the researches of spatial variability of soil moisture using statistical methods in literatures [2-10]. However, fewer scholars have done systematic study about method of setting soil moisture sensor in automatic monitoring system for growing cotton. In this study, we focused on this issue. The research results of this study could provide theoretical basis for the scientific design of soil moisture monitoring system and its high-level application in field to conduct study on the characteristics of spatial variability of soil moisture and reasonable layout method of soil moisture sensor. The outcomes from this study could also offer technical support for soil moisture automatic acquisition and processing information, accurate forecasting of soil moisture content, soil moisture intelligent diagnosis and real-time irrigation decision-making. It has important practical significance to realize precise irrigation and efficient use of water in agriculture in Xinjiang.

2 Materials and methods

2.1 Experimental site

The study site is located in Baotou-lake Farm in China, East longitude 86°08′～86°26′, north latitude 41°45′～41°56′, which is some 30km away from Korla city. The irrigation condition is very good with Yongfeng Channel on the east and Kongque River on the west. The climate is dry and warm, the annual average temperature is 10.7℃, the annual average sunshine hours is 2886.8h, the annual average accumulated temperature is 4192.1℃, the average annual frost-free period is 132～181 days, the temperature difference between day and night is 12℃～17℃, the annual rainfall is about 103mm. It is abundant in sunshine with a long growing season, less rainfall in summer and less snow in winter.

The study was conducted on a 68-ha cotton field (Automatic Irrigation Demonstration Area on Cotton Mulched Drip Irrigation and the details of the control system are shown in Fig.1). The sources of irrigation network are well. Experimental site selected is at a spacing of 45m×54m and average drip tape space is 1.25m and emitter space is 0.30 m. Soil texture is sandy loam and soil bulk density is 1.45g/cm^3. The cultivation mode of cotton is four lines under a film with one drip tape placed in the center. The cotton growing direction is from east to west and cultivation mode is：25cm+45cm+ 25cm+40cm. The details are shown in Fig. 2.

2.2 Experimental schemes

Scheme 1: Analysis of spatial variability of soil moisture

As indicated in Fig. 3, the grid method was adopted in the layout of sampling points. Five rows of sampling points were designed along drip tape direction and row interval was 10 meters, space between consecutive points was 5 meters along submain direction. The experiment is divided into two stages. The first stage was from April 22nd to June 13th without any precipitation（winter irrigation was occurred at December 15th, 2008）and belonged to water shortage period； detailed experiment times are shown in Table 1、Table 2 and Table 3. The soil moisture was measured by drying and weighing method in three layers (0～20cm, 20～40cm and 40～60cm)

Scheme 2: Analysis of lateral orientation of soil moisture monitoring points

In 2009, a control area in one typical drip tape was selected. Four rows of sampling points were placed along vertical direction to drip tape. Row interval was 2 meters, each row has five sampling points and their locations were 0m,0.225m, 0.350m, 0.475m and 0.675m from drip tape respectively (namely located in drip tape, inward cotton row, in the center of two cotton rows, outward cotton row and at ditch between two neighboring membranes). The details are shown in Fig.3. Detailed sampling times are shown in Table 6. Soil moisture was measured by drying and weighing method in four layers (0～20cm, 20～40cm, 40～60cm and 60～80cm).

3 Methodology

The traditional and geo-statistical methods were utilized to analyze data in this study. Both methods have been used extensively in the literatures[1-10], readers are referred to above literatures for detailed description of the methods. In this study, a normal Q-Q test was performed and descriptive statistics were computed to the soil moisture data in scheme 1 using SPSS17.0 (Table 1, Table 2 and Table 3). Take the data of Jun 4, Aug 5, and Aug 10 for example, normal Q-Q tests were shown in Fig.4, Fig.5 and Fig 6；T test was performed to the soil moisture data in scheme 2 and the results are shown in Table 5. Geo-statistics analysis was performed to the soil moisture data in scheme 1 by GS+ software and results are shown in Table 4. The isogram of soil moisture for each depth was drawn by Kriging interpolation through Surfer 8.0 software. The details are shown in Fig.7.

4 Results and discussion

4.1 Traditional statistical analysis of spatial variability for soil moisture on cotton mulched drip irrigation

Traditional statistical analysis[11-12] to the sample data of soil moisture in field were analyzed by SPSS

17.0 (only discuss it in two-dimensional plane), and the results are shown in Table 1, Table 2 and Table 3. As indicated from the Tables, in stage one, mean value, minimum value and maximum value of soil moisture in the whole experimental site decrease as time goes except some unusual value (the maximum of June 11th) which maybe attributed to the measurement error. However, the tendency of coefficient of variation Cv is opposite. Coefficient of variation Cv can express the dispersion degree of random variable. Generally speaking, when Cv≤0.1, it indicates weak variation； when 0.1< Cv <1.0, it indicates moderate variation； when Cv≥1.0, it indicates strong variation [13-14]. In stage one, Cv value vary in the range of 0.097～0.107, an approximate value is 0.1, thus it should belongs to weak variation； in stage two (including after irrigation and before irrigation), Cv value vary in the range of 0.104～0.173 and should belongs to moderate variation. This showed that the increase of soil moisture can enhance the spatial variability, namely, the spatial variability vary directly with soil moisture.

4.2 Geo-statistical analysis of spatial variability of soil moisture on cotton mulched drip irrigation

Wang et al. (2001) [15] suggested that the ratio of nugget variance to sill variance expressed as a percentage is an indication of the spatial dependence of the variable concerned. Cline et al. (1989) [16] and Cambardella et al.(1994) [17] stated that ratios between 25% and 75% represent moderate spatial dependence, those below 25% strong spatial dependence, and all others weak dependence (Qi Feng et al,2004)[18] when it was not suitable to do spatial forecast by interpolation.

According to Table 4, both in stage one and stage two, Nugget/ Sill variance of soil moisture in all three depths are between 25% and 75%,which represents moderate spatial dependence or autocorrelation. Thus this case of soil moisture spatial variability is resulted from the combination of several random variables and structural factors including climate, topography, and soil form and so on. From the coefficient of determination in Table 4, we can obtain that the best theory model is spherical model [18] for each stage. However, with the increment of soil moisture content, the accuracy of regression model has a tendency of decreasing. From Table 4, we can easily found that the range of spherical model is about 9.40m～35.35m, about the same value for placing monitoring points for soil moisture. However, fractal dimension did not show significant changing rule.

From the results of Geo-statistical analysis above, we obtained that it was suitable to do spatial interpolation in consideration of the moderate spatial dependence of soil moisture. So, the isogram [19-22] of soil moisture for each depth was obtained by Surfer 8.0, the details are shown in Fig.7. As indicated in

Fig.7, lines of the isogram are not too dense in all the three depth layers which indicate that the spatial correlation of soil moisture is strong while its variability is weak.

4.3 Lateral location research on monitoring points of soil moisture

The purpose of performing lateral location research of monitoring points on soil moisture is to obtain the best location of monitoring points by seeking the best vertical distance from monitoring points to the drip tape. This can improve the layout efficiency of monitoring points on soil moisture and their monitoring accuracy. The vertical profile of soils was divided into four layers, 0～20cm、20～40cm、40～60cm and 60～80cm. In order to perform t-test, the soil moisture data was divided into two Groups.Group 1 is composed from data of No.2~No.5 monitoring points observed from Jun 11, Jun 29, Aug 5 and Sep 3, and Group 2 is including the data of No.1 observed from Jun 11, Jun 29, Aug 5 and Sep 3 (monitoring points of No.1 are used to locate points in drip tape). A t-test to the data between Group 1 and Group 2 was performed to estimate its significance of soil moisture difference in vertical profile distribution and to determine the relative position between monitoring points and drip tape. The results are shown in Tab.5.

When $|t| \geq t_{\alpha/2}(n-1)$, the difference from the two data observed is significant； when $|t| < t_{\alpha/2}(n-1)$, there is no significant difference. As indicated in Tab.5, compared to No.1 point, there are significant differences in vertical profile 0~20cm soil moisture from No.2 point but 20～80cm；At 0～60cm vertical profile, there is no significant differences between No.3 and No.4 points. Compared to No.1 point, there is significant difference in No.5 point at 0～80cm. This research showed that: At top 0～60cm layer, there are no significant differences about soil moisture distribution among the points which are at 0.225m, 0.350m and 0.475m from the drip tape, respectively. However, there are significant differences between drip tape and at points 0.675m away from it. So, it is better to place the monitoring points at the range of 0～0.475m from drip tape while farther points from the drip tape is not suitable for placing monitoring points.

5 Conclusions

Through the analysis of spatial variability of soil moisture and lateral orientation of soil moisture monitoring points, following conclusions can be made: (1) The increase of soil moisture can enhance their spatial variability. (2) In the drip irrigation system and cotton cultivation mode, spatial variability of soil moisture is resulted from the combination of several random variables and the structural factors including climate, topography, and soil form and so on. (3) Semi-variogram models belong to spherical model and the range of spherical model for soil moisture is about 9.40m～35.35m (4) With the increment of soil moisture content, the accuracy of regression models have a tendency of decreasing. (5) The monitoring points should be placed at the range of 0～0.475m from drip tape and it is not suitable to place them at a farther place. It is best to place them at outward cotton row in consideration of management and monitoring of soil moisture.

In this research, the range of spatial variability, field size and monitoring accuracy of soil moisture are considered in analysis of monitoring point lateral layout for soil moisture. The results from this research are helpful to guide the monitoring points' layout of soil moisture. As for how to place vertical direction monitoring points, it still needs a further study.

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Tab.1 Descriptive statistics of soil moisture content in Stage One

Sampling Time	Sample Number	Minimum	Maximum	Mean	Standard deviation	Variation coefficient	Skewness	Kurtosis
Apr 22	44	0.184	0.258	0.217	0.021	0.097	0.311	-0.961
May 15	44	0.174	0.256	0.209	0.021	0.100	0.583	-0.620
May 24	44	0.166	0.238	0.198	0.021	0.106	0.405	-0.915
Jun 4	44	0.156	0.233	0.198	0.021	0.106	-0.005	-0.990
Jun 11	44	0.141	0.235	0.187	0.020	0.107	-0.003	-0.029

Tab.2 Descriptive statistics of soil moisture before irrigation in Stage Two

Sampling Time	Sample Number	Minimum	Maximum	Mean	Standard deviation	Variation coefficient	Skewness	Kurtosis
Jun 29	44	0.101	0.225	0.168	0.029	0.173	0.017	-0.692
Jul 13	44	0.169	0.242	0.197	0.022	0.112	0.625	-0.835
Jul 24	44	0.140	0.256	0.183	0.025	0.137	1.039	0.923
Aug 5	44	0.138	0.257	0.189	0.026	0.138	0.518	-0.059
Aug 17	44	0.124	0.242	0.183	0.026	0.142	0.360	-0.128
Aug 27	44	0.185	0.291	0.222	0.023	0.104	0.626	0.216

Tab.3 Descriptive statistics of soil moisture after irrigation in Stage Two

Sampling Time	Sample Number	Minimum	Maximum	Mean	Standard deviation	Variation coefficient	Skewness	Kurtosis
Jun 17	44	0.185	0.287	0.237	0.025	0.105	0.434	-0.270
Jul 4	44	0.181	0.287	0.232	0.027	0.116	0.328	-0.514
Jul 15	44	0.190	0.319	0.258	0.029	0.112	0.300	-0.316
Jul 31	44	0.185	0.288	0.234	0.028	0.120	0.236	-0.919
Aug 10	44	0.158	0.289	0.223	0.031	0.139	-0.097	-0.535
Aug 20	44	0.177	0.287	0.229	0.027	0.118	-0.047	-0.397
Sep 3	44	0.197	0.299	0.236	0.026	0.110	0.826	-0.022

Tab. 4 Corresponding parameters of Semivariogram models and test parameters of regression models for soil moisture

	Depth cm	Theory Model	Nugget 10^4	Sill 10^4	Range A_0	Nugget/ Sill $C_0/(C_0+C)$	Decision R^2	Fractal Dimension D_0
Stage one	0～20	spherical	1.75	3.14	16.45	0.56	0.80	1.91
	20～40	spherical	1.80	3.14	19.27	0.57	0.49	1.95
	40～60	spherical	2.77	4.88	15.04	0.57	0.82	1.83
Before Irrigation in Stage two	0～20	spherical	1.05	3.59	9.40	0.29	0.73	1.91
	20～40	spherical	6.00	6.00	18.80	1.00	0.64	1.90
	40～60	spherical	5.40	11.59	11.75	0.47	0.38	1.92
After Irrigation in Stage two	0～20	spherical	5.50	9.33	21.92	0.59	0.70	1.82
	20～40	spherical	6.60	11.59	19.27	0.57	0.59	1.84
	40～60	spherical	4.00	12.99	35.35	0.31	0.30	1.98

Tab.5 Significance test for soil moisture between soil monitoring points before irrigation

Scheme	0-20cm		20-40cm		40-60cm		60-80cm	
	t	$t_{\alpha/2}{}^{(n-1)}$	t	$t_{\alpha/2}{}^{(n-1)}$	t	$t_{\alpha/2}{}^{(n-1)}$	t	$t_{\alpha/2}{}^{(n-1)}$
No.1～No.2	0.625	0.576	-0.340	0.756	-0.132	0.903	-0.307	0.779
No.1～No.3	-0.131	0.904	0.121	0.911	0.395	0.719	-0.692	0.539
No.1～No.4	0.264	0.809	-0.333	0.761	-0.441	0.689	2.810	0.067
No.1～No.5	0.918	0.426	-0.612	0.584	-1.614	0.205	0.609	0.586

Tab.6 Irrigation time and Irrigation requirement at different periods

Period of growth	Irrigation requirement (m^3/hm^2)	Time	
		Before irrigation	After irrigation
Seedling stage	300	Jun 11	Jun 13
Budding period	300	Jun 29	Jul 1
Flowering stage	300	Aug 5	Aug 7
Boll opening stage	300	Sep 3	Sep 4

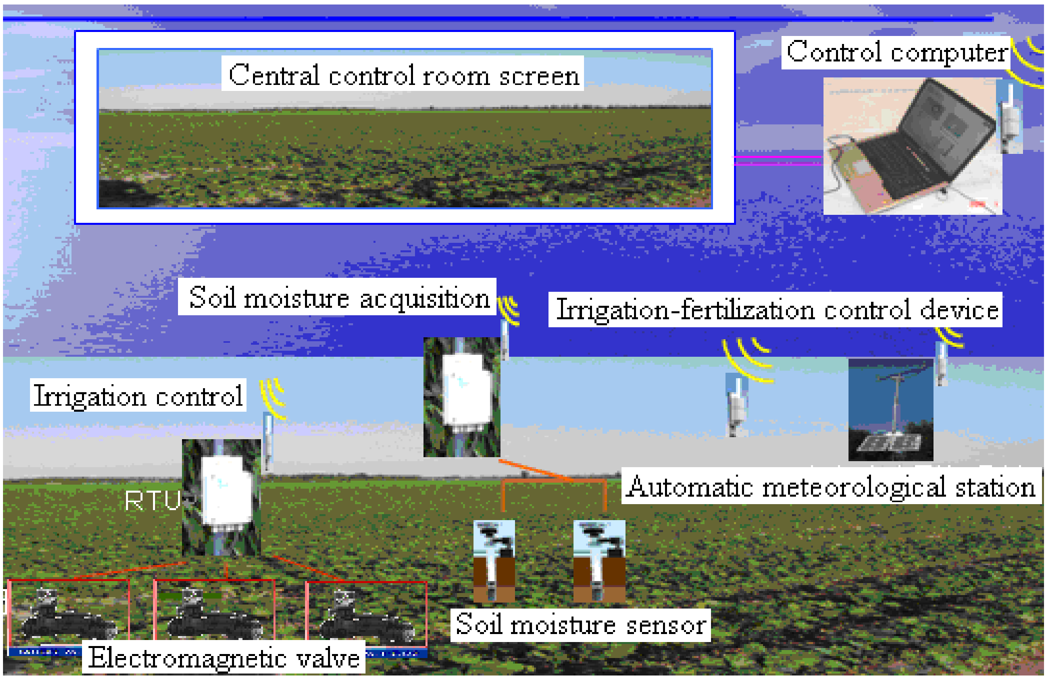


Fig. 1 Automatic control system in drip irrigation demonstration

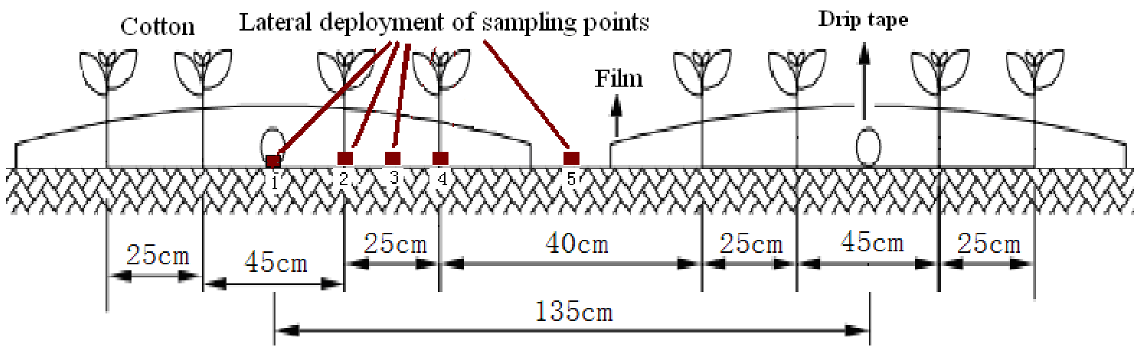


Fig. 2 Cotton cultivated pattern and layout of sampling points

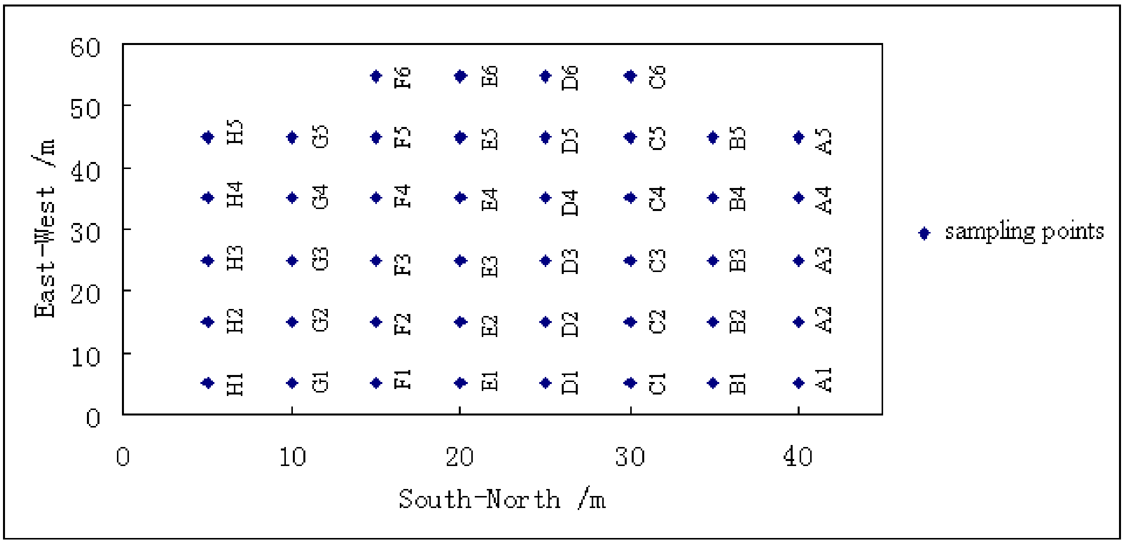
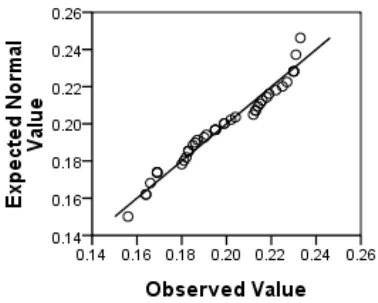
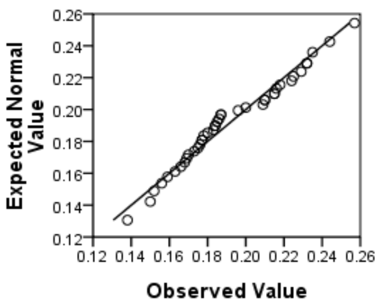


Fig.3 Distribution of sampling points for soil moisture





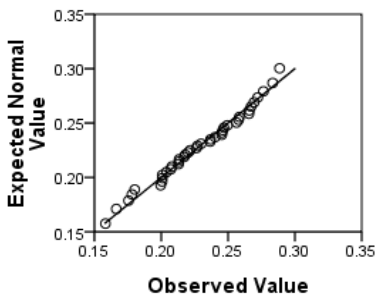


Fig.4 Normal Q-Q plot of June 4th Fig.5 Normal Q-Q plot of August 5th Fig.6.Normal Q-Q plot of August 8th

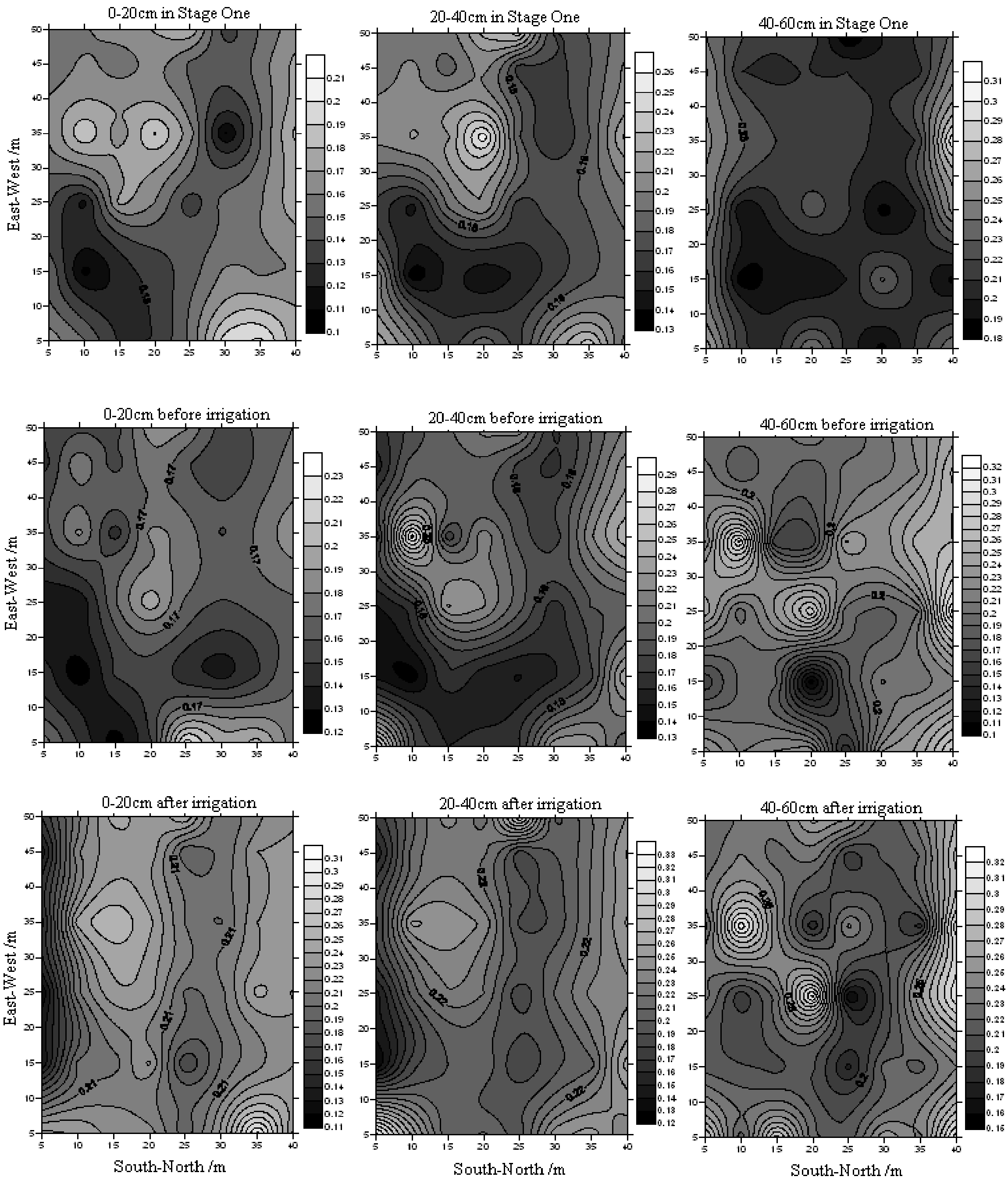


Fig.7 Isogram of soil moisture at three depths in June 4th、August 5th and July 31st