

Statistical analysis of soil moisture at grassland in the Horqin Sand Land

S X Yao¹, C C Zhao^{1,2} and S Y Wang¹

¹Lanzhou City University, Lanzhou 730070, China

E-mail: zhao_chch1978@163.com

Abstract. Firstly, based on the observed data of soil moisture (SM) at grassland from May to September in 2009~2012, we analyzed the variation and statistical characteristics of SM from 0 to 150 cm in growing seasons (from May to September) at grassland of Horqin Sand Land by statistical analysis and the test method of normal distribution, and the normality of SM in different soil layer and different month were tested by Skewness, Kurtosis test method. Secondly, based on the SM of obeying normal distribution, we obtained the estimates and the confidence interval of the mean and variance for the normal distribution. The results indicated that: (1) The SM of grassland at the same soil layer and same month passed the hypothesis testing of normal distribution at the significance level of $\alpha = 0.1$, but the SM of grassland at different months did not pass this hypothesis testing; (2) The value of SM at grassland ranged from 2%~10%; The standard deviation of SM at grassland was 1~5; The variation coefficient of SM at grassland was between 0~1; (3) Influenced by precipitation, SM for grassland was higher in July, and significant different from other months in the growing season (from May to September); The estimates and confidence interval for the mean and variance of SM at grassland in July were significantly different from other months of the growing season; The variation of SM at grassland with month increased firstly and then decreased. (4) SM of grassland was lower at 0~10 cm and different from other soil layer; With the increasing of soil depth, SM of grassland presented a "adverse S" type.

1. Introduction

Soil moisture (SM) is the main source of plant water consumption, and has a significant impact on the physiological activities of plants [1]. Moreover, SM is not only an environmental factor sensitive to climate change, but also an important link of water cycle [2]. Therefore, the study of SM in soil-plant-atmosphere continuum (SPAC) is one of the hot topics of research in the current international academic circle [3]. However, for semi-arid sandy land, water is a key factor determining the structure and function of ecosystem in the region, and the changes in its hydrological cycle process are often a direct driving force for desertification and all other ecological problems in the region [3]. Therefore, the SM in semi-arid sandy land is an important parameter for the study of drought characteristics [4], and hence has become a hot spot of research on ecological environment and a basic scientific issue to be addressed first for the protection of ecological environment and vegetation restoration and reconstruction in sandy land [3]. At present, there have been some studies about SM of sandy land [5, 6], but there are few reports on the statistical analysis on the SM in grassland in Horqin Sand Land.

Horqin Sand Land is one of China's four major sandy lands. The ecological environment here is fragile, and SM is a key factor for its ecosystem stability, structure and normal functioning [7]. Due to



moisture restraints, the restoration of ecosystem in arid areas has become a worldwide problem [8]. Therefore, it is necessary to carry out statistical analysis on the SM in grassland, which was one of the main types of sandy land in the study area. With the help of the SM data on grassland by means of positioning and monitoring in 4 growing seasons from 2009 to 2012 of Naiman Station for Desertification Experiment and Research of the Chinese Ecosystem Research Network, in this paper, we used Skewness and kurtosis test method in statistics to analyze the normality of SM in the grassland, and obtained the mean value and point estimation of variance and the confidence interval at the confidence level of 0.95, aiming to provide a theoretical basis and guidance to improve the utilization rate of SM in grassland in this region.

2. Materials and methods

2.1. Study area description

The study area is located in the southern part of the the Horqin Sand Land in eastern Inner Mongolia, China (42°55' N, 120°42' E, 345 m a.s.l.). The Horqin Sand Land is one of four well-known sandy areas in northern China, which are generally thought to originate from sand and dust storms that occur frequently in the arid and semi-arid regions of northern China [9]. This area has a temperate continental semi-arid monsoonal climate. Annual precipitation is 366 mm. Mean annual potential pan-evaporation is approximately 1935 mm.

2.2. Soil properties of the site

Soil saturated hydraulic conductivity, bulk density and soil organic matter content were listed in table 1.

Table 1. Soil physical and chemical properties.

Soil layer (cm)	Soil saturated hydraulic conductivity (mm/ d)	Bulk density (g/cm ³)	Organic matter content (%)
0~10	403.2	1.51	3.20
10~30	376.4	1.43	2.74
30~60	275.7	1.41	3.43
60~90	201.4	1.34	3.36
90~120	171.3	1.31	3.31
120~150	132.6	1.27	3.43
Mean	260.1	1.38	3.25

2.3. Methods

CNC100 (Beijing) neutron moisture meter was employed for determination of SM. Three neutron moisture meters at the depth of 2 m were buried at an equal interval on each sample land for regular observation of SM at the depth of 0~150 cm in grassland. Every 10 cm constituted a new soil layer. From early May to the end of September every year, SM was determined once every 10d without rain, and one more time after each rainfall for 4 consecutive years (2009-2012), and the determination was repeated three times every time. The measurement values of the 3 neutron moisture meters were calibrated by the traditional drying method to calculate the average moisture for analysis.

“Skewness and Kurtosis test method” in statistics was employed for normality test of SM [10]. The basic idea is as follows: If the population X is a normal variable, assume that X_i is a sample from the population X , and propose the testing hypothesis that H_0 : X is a normal population, let

$$\sigma_1 = \sqrt{\frac{6(n-2)}{(n+1)(n+3)}}; \sigma_2 = \sqrt{\frac{24(n-2)(n-3)}{(n+1)^2(n+3)(n+5)}},$$

$$U_1 = G_1 / \sigma_1; U_2 = (G_2 - \mu_2) / \sigma_1; \mu_2 = 3 - 6 / (n + 1).$$

If H_0 is true, and n is sufficiently large, the observed values of $|U_1| = |G_1 / \sigma_1|$ and $|U_2| = |G_2 - \mu_2 / \sigma_2|$ should not be too large, that is, $|u_1| = |g_1 / \sigma_1|$ and $|u_2| = |g_2 - \mu_2 / \sigma_2|$ should be smaller. Where, g_i is the observed value of G_i , $i = 1, 2$.

In addition, when n is sufficiently large,

$$G_1 \sim N(0, \frac{6(n-2)}{(n+1)(n+3)}), G_2 \sim N(3 - \frac{6}{n+1}, \frac{24(n-2)(n-3)}{(n+1)^2(n+3)(n+5)}).$$

Where $G_1 = B_3 / B_2^{3/2}$ and $G_2 = B_4 / B_2^2$ were the third-order origin moment and the fourth-order origin moment of the moment estimators for X , respectively [10].

Data processing was completed by using 2003 software. Normality test and parameter estimation of SM as well as analysis on the differences of SM at different months and at different soil layers were all completed using SPSS 17.0 statistical analysis software [11].

3. Results

“Skewness and kurtosis test method” was used for testing of 0~150 cm SM in grassland on Horqin Sand Land between May and September during 2009-2012. The results showed that SM at the same soil layer in the same month passed the normal distribution test with significance level $\alpha = 0.1$, while the SM at the same soil layer in different months failed to pass the normality test.

Let \bar{X} and S^2 was the unbiased estimated value of sample mean value (μ) and sample variance (σ^2), respectively. The confidence interval of \bar{X} and S^2 at the confidence levels of 0.95 obtained from SM which have passed normality test in grassland was shown in table 2.

As shown in table 2, the range of the unbiased estimated value of sample mean value in grassland was 2%~10%, mainly concentrated within 5%~8%, accounting for 76.7%. Due to the heaviest precipitation in July in the study area [12], and given the fact that the main source of SM in the region is recharge from precipitation [13], the SM in July is significantly higher than that in other months. The confidence interval of μ was mainly between 2% and 10%.

From table 2 we also seen that both the sample mean value and the sample variance estimated value of SM in grassland in July were greater than those in other months, and the confidence interval significantly shifted to the right compared with other months. The statistical characteristics of SM in grassland (table 2) showed, the standard deviation of SM in grassland of different depths in different months was basically 1~5; the coefficients of variation were 0~1, that was, it was belonged to the moderate variability. In addition, the unbiased estimated of σ^2 in grassland was 1~29, and the confidence interval of σ^2 was mainly between 1 and 47. The range of the confidence interval of σ^2 was wider than μ .

By significant test (table 2), we found that there were significant differences ($P < 0.05$) between SM in July and other months at the same soil layer, and SM at 0~10 cm, 10~30 cm and 30~60 cm were significantly different from each other.

By further analysis the variation of SM in grassland with month and soil layer (figure 1) we discovered that, influenced by precipitation, the SM at different soil layers was highest in July (figure 1(a)). After analysing the various SMs with soil layer (figure 1(b)), we found that SM at 0~10 cm was the lowest, and with increasing of soil depth, SM increased firstly, and decreased after then, and increased finally.

Table 2. Statistical characteristics, unbiased estimated and confidence interval at 0.95 levels of μ (%) and σ^2 of SM at grassland.

Soil layers/ (cm)	Month	Unbiased estimated of	Unbiased μ estimated of	Confidence interval of μ	Confidence interval of σ^2	Statistical Characteristics of SM	
		\bar{X}	S^2			SD	CV
0 ~ 10	5	3.64 ^{ab}	5.17	(2.93, 4.34)	(3.50, 8.41)	2.25	0.62
	6	3.86 ^{ab}	5.97	(3.13, 4.59)	(4.09, 9.53)	2.42	0.63
	7	5.47 ^a	25.67	(4.08, 6.86)	(18.10, 40.20)	5.02	0.92
	8	3.27 ^b	10.50	(2.41, 4.14)	(7.47, 16.20)	3.21	0.98
	9	2.71 ^b	2.38	(2.16, 3.26)	(1.54, 4.17)	1.52	0.56
	Mean	3.79 ^C	9.94	(2.94, 4.64)	(6.94, 15.70)	2.88	0.74
10 ~ 30	5	7.27 ^{ab}	20.01	(5.88, 8.67)	(13.50, 32.50)	4.42	0.61
	6	7.25 ^{ab}	8.47	(6.38, 8.13)	(5.81, 13.50)	2.88	0.40
	7	9.69 ^a	23.99	(8.35, 10.0)	(16.90, 37.60)	4.85	0.50
	8	6.58 ^b	10.74	(5.70, 7.45)	(7.64, 16.60)	3.25	0.49
	9	5.61 ^b	2.54	(5.05, 6.18)	(1.64, 4.45)	1.57	0.28
	Mean	7.28 ^B	13.15	(6.27, 8.09)	(9.10, 20.93)	3.39	0.46
30 ~ 60	5	7.87 ^{ab}	29.04	(6.19, 9.55)	(19.70, 47.20)	5.32	0.68
	6	7.62 ^{ab}	17.09	(6.38, 8.87)	(11.70, 27.30)	4.09	0.54
	7	9.5 ^a	17.97	(8.41, 10.70)	(12.70, 28.10)	4.20	0.44
	8	6.24 ^b	4.21	(5.70, 6.79)	(3.00, 6.50)	2.03	0.33
	9	6.68 ^b	7.19	(5.73, 7.63)	(4.65, 12.60)	2.64	0.40
	Mean	7.60 ^A	15.10	(6.48, 8.71)	(10.35, 24.34)	3.66	0.48
60 ~ 90	5	5.63 ^b	3.67	(5.03, 6.23)	(2.49, 5.97)	1.89	0.34
	6	5.59 ^b	2.20	(5.14, 6.04)	(1.51, 3.52)	1.47	0.26
	7	8.07 ^a	13.04	(7.08, 9.06)	(9.19, 20.40)	3.58	0.44
	8	6.01 ^b	5.80	(5.37, 6.65)	(4.13, 8.96)	2.39	0.40
	9	6.80 ^{ab}	9.12	(5.73, 7.87)	(5.90, 16.00)	2.97	0.44
	Mean	6.42 ^{AB}	6.77	(5.67, 6.70)	(4.64, 10.97)	2.46	0.38
90 ~ 120	~5	5.77 ^b	3.26	(5.21, 6.33)	(2.21, 5.30)	1.78	0.31
	6	5.58 ^b	2.16	(5.13, 6.02)	(1.48, 3.45)	1.45	0.26
	7	7.30 ^a	10.02	(6.43, 8.17)	(7.06, 15.70)	3.13	0.43
	8	5.88 ^b	4.63	(5.31, 6.45)	(3.30, 7.15)	2.13	0.36
	9	6.82 ^{ab}	8.61	(5.78, 7.86)	(5.57, 15.10)	2.89	0.42
	Mean	6.27 ^B	5.74	(5.57, 7.00)	(3.92, 9.34)	2.28	0.36
120 ~ 150	5	6.82 ^{ab}	4.34	(6.17, 7.46)	(2.94, 7.06)	2.06	0.30
	6	6.56 ^b	2.87	(6.05, 7.07)	(1.97, 4.58)	1.68	0.26
	7	7.87 ^a	9.67	(7.01, 8.72)	(6.82, 15.20)	3.08	0.39
	8	6.08 ^b	1.61	(5.75, 6.42)	(1.15, 2.49)	1.26	0.21
	9	7.44 ^{ab}	7.76	(6.45, 8.43)	(5.02, 13.60)	2.74	0.37
	Mean	6.95 ^B	5.25	(6.29, 7.62)	(3.58, 8.59)	2.16	0.31

Note: Different letters for average values indicate significant differences at $P < 0.05$.

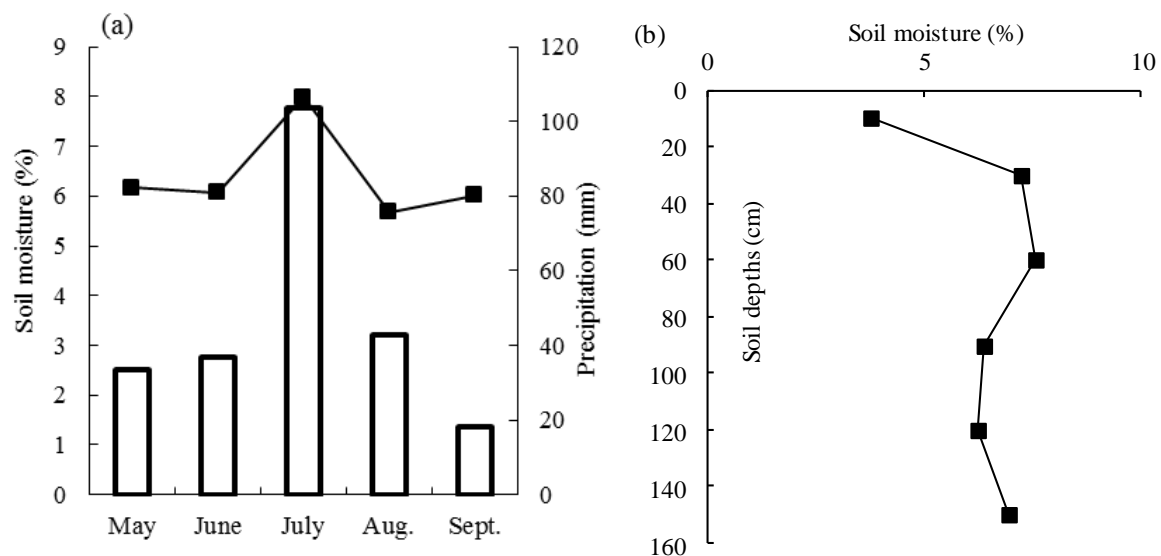


Figure 1. Variation of SM along with (a) month, (b) soil depth at grassland.

4. Conclusions

- The average values of SM in grassland vary within the range of 2%~10%; SM in grassland on Horqin Sandy Land at the same soil layer and same month obeys normal distribution;
- SM in grassland in July is significantly higher than that in other months, and significantly different from other months, and the confidence interval of SM in July shows a trend of significantly rightward shifting; From May to September every year, SM shows an “increasing firstly, and then decreasing” trend, and peaks in July;
- SM in grassland at the depth of 0~10cm is considerably lower than other soil layers, and significantly different from other soil layers; SM in grassland shows an “increased firstly, then decreased and eventually increased again” trend with changes in soil depth.

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