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Variability and Modelling of Soil Moisture, Salt and Organic Matter Content in a Gravel-Sand Mulched Jujube Orchard

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ABSTRACT

Characterization of the variability of soil moisture, salt content and organic matter content (SOM) is of great significance in agricultural production management and sustainable soil utilization. We present a case study of the variability and modelling with the depth of soil moisture, salt and SOM in a gravel-sand mulched jujube orchard, using Geostatistics and Kriging interpolation. Soil moisture, salt and SOM were measured in 256 samples collected from a gravel-sand mulched jujube orchard in the 0-10, 10-20, 20-30 and 30-50 cm. Soil moisture, salt and SOM were more variable in the surface soil, due to several environmental factors, the coefficients of variation (CV) of soil were lower than 23%, indicating weak to moderate variation. The coefficient of variation of moisture and organic matter decreased with the depth and the salinity increased with the depth. There is a significant correlation between each soil layer, which decreases with the increase of the soil layer. The accuracy of the function model with depth as an independent variable and soil properties as a dependent variable is higher than 0.88. To master the relationship among soil depth, salinity, soil moisture and organic matter content can provide theoretical value for agricultural comprehensive management.

INTRODUCTION

Soil moisture, salt and organic matter content (SOM) are important components of soil. Soil moisture, salinity and SOM can provide a theoretical basis for soil dynamic change, ecological environment management and soil salinization. Under the background of global change, the problem of soil desertification, salinization and productivity decline caused by scarce precipitation and intense evaporation is increasingly serious. Characterizing soil moistures variability in space and time is critical to managing water resources, and optimize agricultural practices (Mascaro et al. 2019). The spatial distribution of soil salt can reflect the status and degree of soil salinization (Chervan et al. 2019). SOM is an important factor to characterize soil fertility and soil quality (Wright et al. 2005). Therefore, mastering the spatial pattern of soil moisture, salt and SOM is beneficial to the rational utilization of soil resources and the sustainable production of dryland crops (Liu et al. 2006, Ahmed et al. 2010).

Many scholars have studied soil moisture, salt and organic matter (referred to as SOM). Researches on soil moisture and salt mainly focus on the analysis of the spatial distribution (Hao et al. 2015, Yang et al. 2017). The relationship between different vegetation, soil quality or utilization type and soil moisture and salt (Selim et al. 2013, Zhang et al. 2018), and the coupling relationship between moisture and salt (Ding et al. 2015). Some studies on the spatial variation of moisture, salt and nutrients in surface soil have a certain rule, among which the spatial variation of soil salt is affected by structural factors (Gaston et al. 2001, Shen et al. 2015). Wang et al. (2012) collected soil samples to analyse the variation of soil moisture content and salinity with depth. Liu et al. (2011) found that SOM had a significant effect on soil moisture content under natural and air-dried conditions, which was beneficial to soil moisture retention. Moreover, Zhang et al. (2012) found that the spatial distribution of SOM was mainly affected by terrain indices, soil texture and soil genetic types.

The spatial variation of soil properties mainly includes the variation of the horizontal direction and vertical direction, the spatial variability of soil properties in different soils in the vertical direction and its main influencing factors are not the same. The effect and interaction of various processes in the soil profile can produce variable soils (Liu et al. 2014, Harguindeguy et al. 2018). Gravel and sand are commonly used as mulch in the semi-arid loessal regions of northwestern China to conserve the sporadic and limited rainfall for reliable crop production (Feng et al. 2018, Lü et al. 2013). Gravel-sand mulches on soil surfaces can improve soil conditions, conserve moisture, reduce the accumulation of surface salinity (Zhao et al. 2017b, Wang et al. 2011, Qiu et al. 2014), improve orchard survival and fruit production, solve land use, and improve the environment (Zhao et al. 2016). Soil moisture is used in hydrological models to determine infiltration and runoff rates at the local scale (Al Bitar et al. 2012). SOM is important in nutrient availability and often varies spatially due to its dependence on other soil attributes (Kosmas et al. 2000). In precision agriculture, information on spatial and temporal soil variability is essential to assist farmers in making agronomic decisions for farm management (Aliah Baharom et al. 2015).

However, most scholars focus on the spatial variation of single soil properties. There are few studies on the variability and modelling of soil moisture, salt and organic matter content in a gravel-sand mulched jujube orchard. The objectives of the study were (i) to obtain a more intuitive understanding of salinity, moisture, SOM by 3-D maps by Surfer12.0 and SEM; (ii) to analyse a function model with depth as independent variable and moisture, salinity, SOM as the dependent variable.

MATERIALS AND METHODS

Study Area

The study was conducted in a jujube orchard in Jingtai County near the Lanzhou University of Technology experimental station in the middle of the western portion of China's Gansu province on the east side of the Hexi corridor, at the junction of provinces of Gansu, Ningxia, and Inner Mongolia (Fig. 1). Brown desert soil and sierozem are the predominant soils in this area. The climate is intermediate between continental monsoon and non-monsoon regions, with a mean annual temperature of 8.2°C, fluctuating from -27.3 to 36.6°C from the winter to summer seasons. The mean annual precipitation is 185 mm, with a rainy season (accounting for approximately 61.4% of the annual rainfall) from July to September. The mean annual evaporation is 3038 mm, with annual average evaporation to precipitation ratio of 16.

Test Treatments

A total of 256 soil samples were collected at sampling points established every 4 m along two perpendicular transects of a randomly selected 32×32 m plot in a gravel-sand mulched jujube orchard (Fig. 2). The locations of the sampling points were determined using GPS. Each sample was a thorough mixture of core samples collected from the 0-10, 10-20,20-30, and 30-50 cm layers, named S1, S2, S3, and S4, respectively.

Research Methods

The electrical conductivity was measured using a conduc-

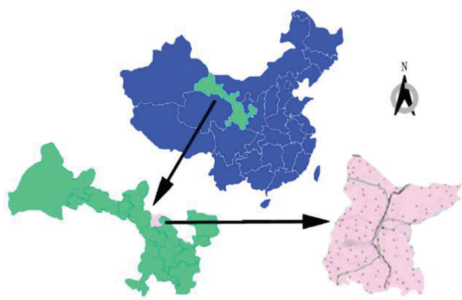


Fig. 1: Study area and the soil sampling locations in the study area situated in Gansu, China.

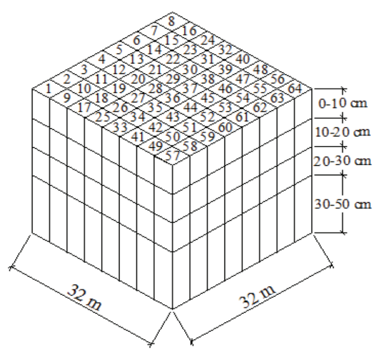


Fig. 2: Distribution of soil sampling points.

tivity meter (FG3-ELK, Mettler, Switzerland). The volume percentages of the particle-size classes were measured by a Mastersizer 2000 (Malvern Instruments, Malvern, England). Particles within the size range of 0.002 to 2.0 mm were categorized into 64 levels of increasing logarithmic intervals. The soil microcosm was analysed by SEM (s-4800, Hitachi, Japan) to obtain a more intuitive understanding of the PSDs. The determination of soil organic matter was carried out by potassium dichromate oxidation-external heating.

Data Analysis

The relationship between the conductivity and soil salinity was calculated as described by Yao et al. (2006).

$$y = 2.9995x - 0.2269 \quad \ldots(1)$$

Where, x is the conductivity (ms/cm) of the 5:1 moisture: soil solution and y is the salinity (g/kg), with a coefficient of determination (R^2) of 0.988. The above formula is applicable to soil samples with no measured ion composition (Wraith 2004).

$$CV = \frac{\sigma}{\bar{\theta}} = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\theta_i - \bar{\theta})^2}}{\bar{\theta}} \quad \ldots(2)$$

Where, s is the standard deviation, and CV is the coefficient of variation. Then θ_i is the soil moisture content of the i measuring point, and $\bar{\theta}$ is the average value of the soil moisture content of all the measuring points.

Fractal features can be described by the fractal dimension or fractal dimensionality of particle size. Soil D was calculated as described by (Tyler et al. 1990).

$$\frac{V(r < R_i^{'})}{V_T} = \left(\frac{R_i^{'}}{R_{max}}\right)^{3-D} \quad \ldots(3)$$

where r is size; R_i is the mean particle size of two sieved particle sizes, R_i and R_{i+1}; $V(r < R_i)$ is the accumulated mass of particles smaller than R_i; V_T is the mass sum of soils containing all particle sizes; R_{max} is the mean diameter of the largest particles; and 3-D is the slope of the linear regression line with $\log\frac{V(r < R_i^{'})}{V_T}$ and $\log\frac{R_i^{'}}{R_{max}}$ as the y- and x-axes variables, respectively. D was obtained by the logarithmic transformation of Eq. 3.

Based on the regionalized variables theory and intrinsic hypothesis, the semivariogram, $\gamma(h)$, was estimated by Pham (2016).

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(x_i + h) - Z(x_i)]^2 \quad \ldots(4)$$

Where, $N(h)$ is the number of pairs of observations. $Z(x_i)$ (and) $Z(x_i + h)$ separated by a distance h. Only isotropic semivariograms were considered (Wang et al. 2008).

$$N = \left(\frac{tS}{xd}\right)^2 \quad \ldots(5)$$

Where, N is the number of sampling points, t is the significance level corresponding to the distribution value (t-distribution table obtained by the investigation), S is the sample standard deviation, x is the mean model and d is the estimation accuracy.

Coefficient of determination (R^2) between the measured and predicted values was used to evaluate the performance of the regression models.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(o_i - \bar{o})(p_i - \bar{p})}{\left[\sum_{i=1}^{n}(o_i - \bar{o})^2\right]^{0.5}\left[\sum_{i=1}^{n}(p_i - \bar{p})^2\right]^{0.5}}\right]^2 \quad \ldots(6)$$

Where, O_i and P_i are measured and predicted values, respectively, $\bar{o}$ and $\bar{p}$ are the average measured and predicted values, respectively, and n is the number of observations in the validation data set.

RESULTS AND DISCUSSION

Analysis of Spatial Variation of Soil Moisture, Salt and SOM Content

A statistical analysis of soil moisture, salt and SOM content is provided in Table 1. With the deepening of soil depth, the CV of different soil properties is different. In this study, coefficients of variation (CV) ≤10% indicate weak spatial variability, 10%<CV<100% indicate moderate variability, and CV ≤100% indicate strong variability (Cambardella 1994). The CV of three soil factors were lower than 23%, indicating weak to moderate spatial variation. There are not only differences in soil moisture, salt and SOM content, but also differences in the degree of variation.

The variation of the soil moisture with the depth depends on the moment in which the soil sampling is done. Because it has rained a few days before, the soil moisture will surely be higher in the upper layers. The CV of moisture ranged from 11.07 to 22.34% and tended to increase with depth (Choi 2007). The significant differences in soil types, land use types, terrain indices may result in the variability of SOM. The CV of organic-matter contents ranged from 5.56 to 11.89% and tended to increase with depth. Average soil salinity increased with depth, the CV of salinity ranged from 8.68 to 18.59% and tended to decrease with depth. This result indicated that the vertical distribution of soil moisture, salt and SOM is not only restricted by soil texture, bulk density and other factors but also affected by environmental factors such as rainfall, evaporative land use type and vegetation (Brye 2010).

Spatial Distribution and SEM Observations of Soil Moisture, Salt and SOM Content

The author used surfer 12.0 to draw the spatial distribution,

Table 1: A statistical analysis of soil moisture, salt and SOM content

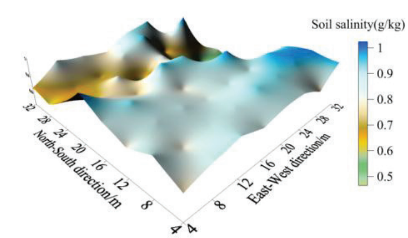
Depth (cm)	Soil properties	Maximum	Minimum	Mean	SD	Kurt	Skew	CV (%)
0-10	salinity (g/kg)	1.03	0.46	0.80	0.15	-0.47	-0.65	18.59
	moisture (g/kg)	11.60	7.60	9.81	1.09	-0.98	-0.31	11.07
	organic matter (g/kg)	5.75	4.25	4.95	0.27	0.89	0.22	5.56
10-20	salinity (g/kg)	1.12	0.55	0.88	0.14	-0.39	-0.72	15.90
	moisture (g/kg)	11.20	6.80	9.17	1.26	-1.10	-0.28	13.71
	organic matter (g/kg)	4.73	3.52	4.12	0.32	-0.78	-0.01	7.81
20-30	salinity (g/kg)	1.18	0.67	0.99	0.11	1.91	-1.39	10.77
	moisture (g/kg)	11.00	5.20	8.06	1.53	-0.91	-0.12	18.98
	organic matter (g/kg)	3.73	2.61	3.26	0.25	-0.37	-0.28	7.60
30-50	salinity (g/kg)	1.30	0.88	1.12	0.10	0.27	-0.50	8.68
	moisture (g/kg)	10.80	4.10	7.22	1.61	-0.40	0.01	22.34
	organic matter (g/kg)	3.61	2.41	2.86	0.34	-0.48	0.69	11.89

Note: SD standard deviation, CV coefficient of variation, Skew skewness, Kurt kurtosis.

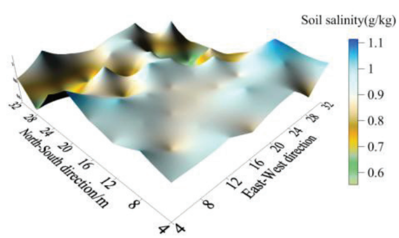
before kriging interpolation, the data for soil moisture, salinity and organic matter content soil salinity were transformed to a normal distribution. After interpolation, the measured data of soil can be converted into more data. The Kriging interpolation maps (Fig. 3) showed the horizontal and vertical distribution in each layer. Soil moisture at each layer showed irregularly distribution with peaks, which may be related to the topography in the sampling area, the result was consistent with Xing et al. (2015).

The distribution of salinity is irregular with peaks and valleys. With the increase of depth, the number of peaks decreases and the distribution is more uniform. The distribution of soil salt content in horizontal and vertical planes was highly consistent with those of soil water content (Li et al. 2018). Moisture, salinity and SOM were most variable in the 0-10 cm layer. The decrease in the number of peaks with the depth may have been due to the irrewwgular surface topography in the orchard. The distributions were significantly affected by the terrain, rainfall, evaporation and cultivation, human factors, tended to gradually stabilize with depth (Zhao et al. 2017c).

SEM has helped the intuitive observation of the texture distribution of soil and the change rule of pore space



(a)



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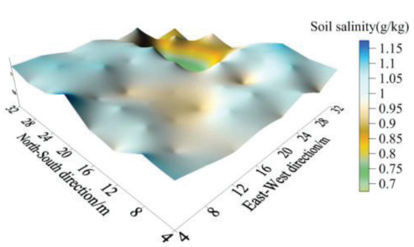

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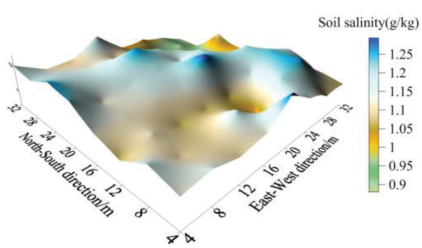

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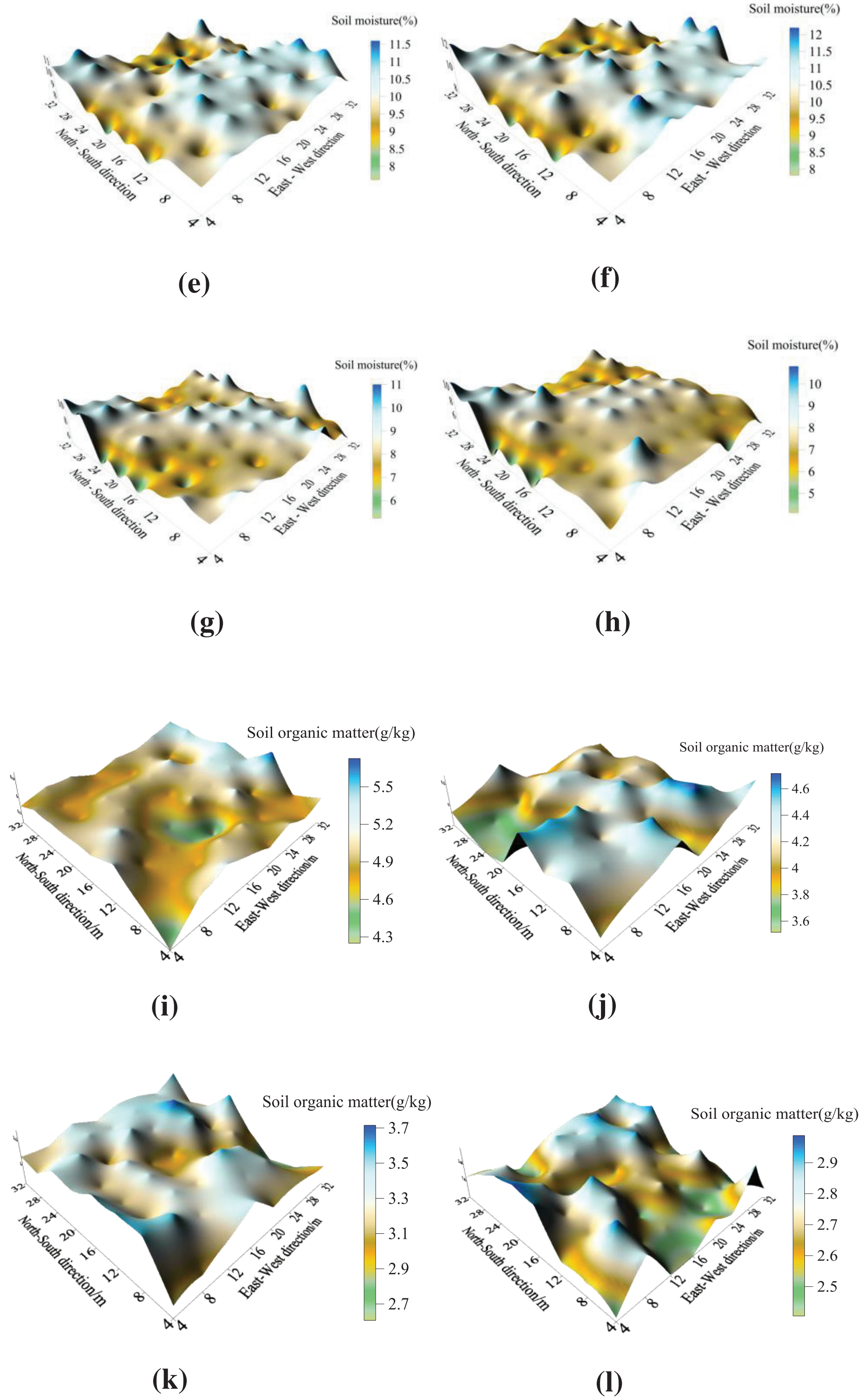

Fig. 3: Spatial distribution of soil salinity, moisture and organic matter content in 0-50 cm layers. (a) salinity: 0-10 cm; (b) salinity: 10-20 cm; (c) salinity: 20-30 cm; (d) salinity: 30-50 cm; (e) moisture: 0-10 cm; (f) moisture: 10-20 cm; (g) moisture: 20-30 cm; (h) moisture: 30-50 cm; (i) organic matter: 0-10 cm; (j) organic matter: 10-20 cm; (k) organic matter: 20-30 cm; (l) organic matter: 30-50 cm.

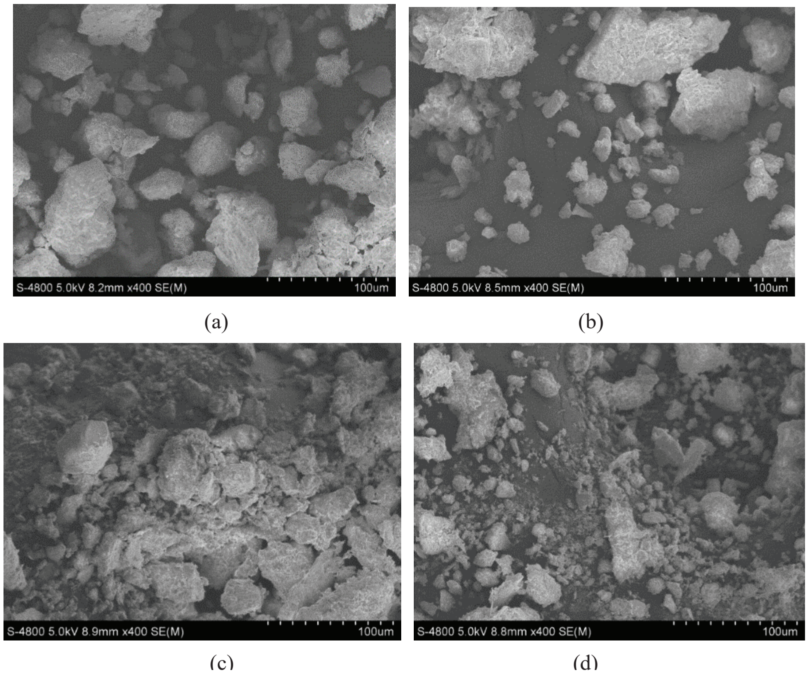

Fig. 4: Scanning electron micrograph of soil particle-size distribution in each layer. (a) S1; (b) S2; (c) S3; (d) S4.

Table 2: The correlation analysis of soil moisture, salt and SOM content in different soil layers.

	depth/cm	0-10	10-20	20-30	30-50
salinity	0-10	1			
	10-20	0.928**	1		
	20-30	0.584**	0.649	1	
	30-50	0.307*	0.299*	0.568**	1
moisture	0-10	1			
	10-20	0.782**	1		
	20-30	0.593**	0.610**	1	
	30-50	0.566**	0.520**	0.667**	1
organic matter	0-10	1			
	10-20	0.518**	1		
	20-30	-0.645*	0.567**	1	
	30-50	-0.412	0.504*	0.639**	1

Note: * Correlation is significant at 0.05 level; ** Correlation is significant at 0.01 level.

(Markgraf et al. 2007). Fig. 4 can be seen that soil texture changes with depth, the texture is uneven at 0-10cm, but uniform within 10-50cm. It can be seen that there are several large particles in S1, mainly due to the gravel-sand mulch on the surface. The gravel-sand mulch had gradually degenerated due to natural or artificial damage, so the interface between the soil and gravel was indistinct, with an uneven texture and large particle size sand in S2. Particle sizes were homogeneous in S3-S4. The development degree of macropores decreases with the increase of soil depth. Therefore, the larger the soil bulk density, the smaller the soil moisture content, the smaller the salt immersion range and the higher the soil salt content.

Correlation Analysis of Different Soil Properties

To describe the soil moisture, salt and SOM and the correlation with soil layers accurately, analysed by SPSS, the correlation was significant when the absolute value of the correlation coefficient was high. There is a significant

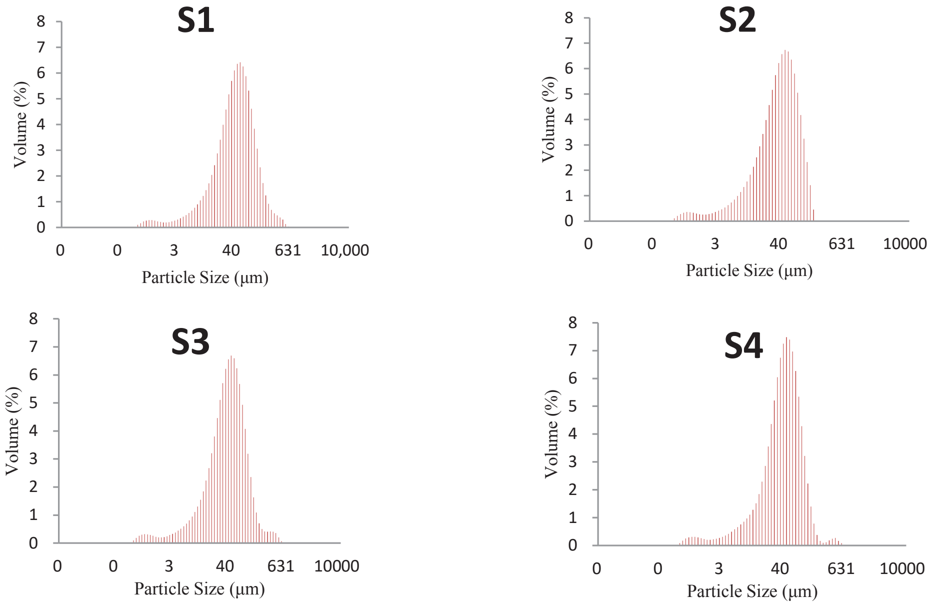

Fig. 5: Frequency distribution of volume content of the soil particles of the various layers.

correlation between the soil layers, and decreased with the increase of soil interval, from the correlation analysis of soil moisture, salt and SOM content in different soil layers (Table 2). The correlation of each soil properties was different, the correlation coefficients were 0.928 to 0.568 for salinity and 0.782 to 0.566 for moisture, respectively, which decreased with depth. The correlation coefficient between the 20-30 cm was the highest, followed by 10-20 cm and 30-50 cm for organic matter.

Moisture, salinity, SOM analysis has improved with remote sensing technology and developed by applying the remote-sensing optical method, which can provide timely, accurate and efficient information for salinization, agricultural production (Finn et al. 2011, Farifteh et al. 2006, Anne et al. 2014). The monitoring accuracy, however, is higher for surface soil than for subsoil. Thus, an effective method that can accurately evaluate and predict the moisture, salinity, SOM of deeper soil from routinely available surface-soil data can be developed in our future work, which would save human and material resources (Zhao et al. 2017b).

The soil particles were classified as clay (0-0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2 mm) (Pieri et al. 2006). The frequency curve of soil particle size distribution can directly reflect the distribution of particle size, and the uniform and smooth curve indicates the uniform volume distribution of particle size fraction. As shown in Fig. 5, the curve distribution of S1 was relatively uniform, and the volume of sand particles is large. The particles in S2 are finer (e.g. < 0.1mm), where the powder has a high volume fraction. Most particles in other layers were mainly distributed between 0.002 and 0.05mm.

Fractal dimension (D) of soil particle size calculated from Eq.1 and Fig. 5 for each layer, D varied between 2.54 and 2.82. From the results of the correlation analysis of each variable in Table 3, there was a significant correlation between the different parameters. The D was negatively correlated with moisture content and positively correlated with organic matter content and salinity. Therefore, D can be used to some extent as a quantitative indicator of the status of soil moisture and salt in the gravel-mulched field

Table 3: Correlations analysis of different soil properties.

	D	salinity	moisture	organic matter
D	1			
salinity	0.327	1		
moisture	-0.356	-0.996**	1	
organic matter	-0.242	-0.97*	0.983*	1

Notes: D, fractal dimension; *Correlation is significant at 0.05 level; **Correlation is significant at 0.01 level.

Table 4: Modelling with depth and the measured value of each soil characteristics.

Soil properties	Equation	R^2
salinity	$y = 0.745x^{0.008}$	0.979
moisture	$y = 10.969-0.117x + 0.001x^2$	0.882
organic	$y = 6.25-0.141x + 0.018x^2$	0.924

Notes: R^2 is the coefficient of determination. Units of x, y are %.

(Zhao et al. 2017a). From the soil in Table 3, we find that moisture and salt are highly correlated. This is different from the correlation between soil moisture and salt in the wetland studied by Xu et al. (2013). It may be affected by climate, distance from moisture area and soil type.

Soil Moisture, Salt, SOM and its Relationship with Soil Depth

Measured values of soil moisture, salinity and organic matter content were changeable in different depths. To find out the values of them more conveniently and efficiently, the author analysed the function model with depth as the independent variable and soil properties as the dependent variable and selected the best model of each soil properties (Table 4). Soil moisture, SOM all fitted to the quadratic equation, the salinity fitted to the exponential equation, and the R^2 were all higher than 0.88 in a gravel-sand mulched jujube orchard, which indicated the result of the fitting were precision.

Although moisture, salinity and SOM can be measured by experiments, soil sampling and laboratory analysis are time-consuming, labour intensive and expensive (Corwin et al. 2016). Our current research can directly calculate the values of moisture, salinity and SOM at different depths through the model, and the accuracy is high. Therefore, it can increase agricultural output value and reduce salinization. We plan to study the precision effects of the terrain on moisture and salinity and the effect of SOM where jujube is planted with sand mulching in further.

CONCLUSION

The soil of a gravel-sand mulched jujube orchard was analysed by Geostatistics and Kriging interpolation. The CV of soil was lower than 23%, indicating weak to moderate spatial variation. The CV of salinity tended to decrease with depth, the CVs of moisture and organic-matter contents increased with depth. Kriging interpolation was performed by Surfer software and three-dimensional spatial distribution map of soil moisture, salt and organic matter content was drawn. The soil microstructure was scanned by SEM. The change of moisture, salinity and SOM in the 0-10cm layer was the largest, and the number of peaks decreases with depth. There is a significant correlation between soil layers, and decreased with the increase of soil interval, from the correlation analysis of moisture, organic matter content, salinity. D was correlated negatively with moisture, organic matter content, and positively with salinity. The author analysed a function model with depth as a variable, the R^2 were all higher than 0.88.

This study has contributed to our understanding of the variability of soil moisture, salinity and organic matter content in a gravel-sand mulched jujube orchard. The results can be effectively applied to ecological hydrology to prevent soil salinization and improve agricultural production value.

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