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# Study on the water retention effect of compound soil of arsenic sandstone and sand under the condition of typical crop planting

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**Abstract.** Arsenic sandstone is the main reason of soil erosion in the Mu Us Sandy Land, simultaneously was proved to be a kind of good water retaining agent. In order to provide references for the utilization of water and soil resources and the prevention and control of desertification and soil erosion of the southern margin of Mu Us Sandy Land, on the basis of earlier studies the farmland experiments of compound soil with three ratios of 1:1, 1:2 and 1:5 between arsenic sandstone and sand under maize planting patterns were designed, whose experimental process was divided into six stages according to the crop growth status. The results showed that the soil moisture content was highest in the layer of 0~40cm where the compound soil mainly concentrated in, which was related to the potent water retention of arsenic sandstone and strong water permeability of undisturbed sandy soil. The variation coefficients in the soil of 1:1 and 1:2 were more stable and evenly distributed. The compound soil can effectively improve the soil water retention capacity, and prolong the storage time of soil water. Among them, water loss rate in soil of 1:1 and 1:2 were lower. The coefficient of variation also confirms that the water distributions of the two types of soil were more uniform and stable. Besides illustrating the effects of the soil amelioration measures on spatial and temporal variation of soil moisture content and the improvement of soil water regime, the study provides some references for the development and utilization of agriculture in Mu Us Sandy Land.

## 1. Introduction

Ecological environment has been widely considered as the basic condition of human survival and development. There are three main factors, including abundant loose gravel source, bare land surface and sand driving wind with high frequencies, which were regarded as the potential factors leading to desertification in arid and semi-arid area. As one of the four Chinese deserts, the Mu Us Sandy Land (MUSL) has huge mining potential; while sandy soil erosion and land desertification seriously restricted the sustainable development of the region. In order to make desertification in sandy land controlled and achieve economic benefits simultaneously, various integrative desertification control methods or models with farming and animal husbandry in consideration have been developed in recent years.

The early study of sandy land was mainly confined to the control of desertification and the protection of the ecological environment. In this period, the goal of sand control was often the pursuit of ecological effect, and the economic benefit was not taken into account. Therefore, the enthusiasm of



public to participate was not high, and the difficulty for large-scale ecological management and sustainable development were the two main problems existed [1-4]. Since the 80~90's in twentieth century, the research on sandy land gradually began to move towards integration and diversification, in order to seek a new sand control mode to be able to obtain the social, ecological and economic benefits. Desertification due to human activity and limited natural resource is the most serious problem on agricultural development in sandy land, which was highly concerned on account of its threats to human survival and social development [5, 6]. However, the sustainable development of any model requires the support of water in the sandy land. In various desertification control and development methods, water was known as the pivotal point. Hellden et al [7] pointed out that water resources were very important limiting factors in the growth of sandy land, and it was also an important cause of desertification.

In Mu Us Sandy Land, arsenic sandstone and sand are two kinds of main components, which are the major causes of soil erosion and land desertification relatively. Arsenic sandstone and sand on the physical properties are complementary. Han et al [8, 9] proposed that the arsenic sandstone and sand could be mixed into the soil by using permeability of sand and water holding characteristics of arsenic sandstone, in order to improve the sandy soil physical and chemical properties and the production capacity of soil. Wang et al [10, 11] studied the physicochemical properties of compounds of arsenic sandstone and sand at the ratios of 1:0.5, 1:2, 1:1, 1:2, 1:5 and 0:1 respectively, put forward that the compounds of 1:1, 1:2, and 1:5 has better water binding capacity and soil quality.

Based on the related research results of combination schemes of arsenic sandstone and sand, three kinds of compound soil (the ratio of 1:1, 1:2 and 1:5 of arsenic sandstone and sand) were taken as culture medium in the field experiment, with maize, which was the most important food crops for local people planted in it, to explore the water retention effect in different proportions of compound soil, and to provide reference for the development and utilization of agriculture in MUSL.

**Table 1.** The physical and chemical properties of soils.

Index		Arsenic sandstone	Sand	1:1	1:2	1:5
Texture		Sandy loam	Sand	Loamy soil	Sandy loam	Sandy loam
Volume weight of soil/(g·cm <sup>-3</sup> )		1.42~1.67	1.61	1.56	4.52	1.37
Capillary porosity/%		44.94	4.28	3.86	3.94	4.11
Compactness		Hard	Loose	Hard	Hard	Hard
Particle size proportion /%	sand particle ( ≥ 0.05~<0.2mm )	19.57	91.39	46.84	64.67	74.79
	powder particle ( ≥ 0.002~<0.05mm )	72.94	5.51	44.92	30.04	20.08
	clay particle ( <0.002mm )	7.49	3.10	8.24	5.29	5.13
Nutrient content/(g·kg <sup>-1</sup> )	Organic matter	3~5	1~3	2.26	2.61	2.97
	Total nitrogen	0.13	0.75	0.44	0.54	0.65
	Total phosphorus	0.38	0.63	0.50	0.55	0.59
	Total potassium	19.20	26.51	22.26	23.67	25.09
Water parameters	Field capacity/%	17.32	4.46	11.72	9.92	7.65
	wilting coefficient/%	8.96	1.29	6.53	5.06	3.30
	Saturated hydraulic conductivity (mm.min <sup>-1</sup> )	0.07	7.10	0.26	0.49	1.61
	Water stability aggregate content/(% (>0.25 mm))	32.30	18.13	29.58	26.32	22.54

## 2. Materials and methods

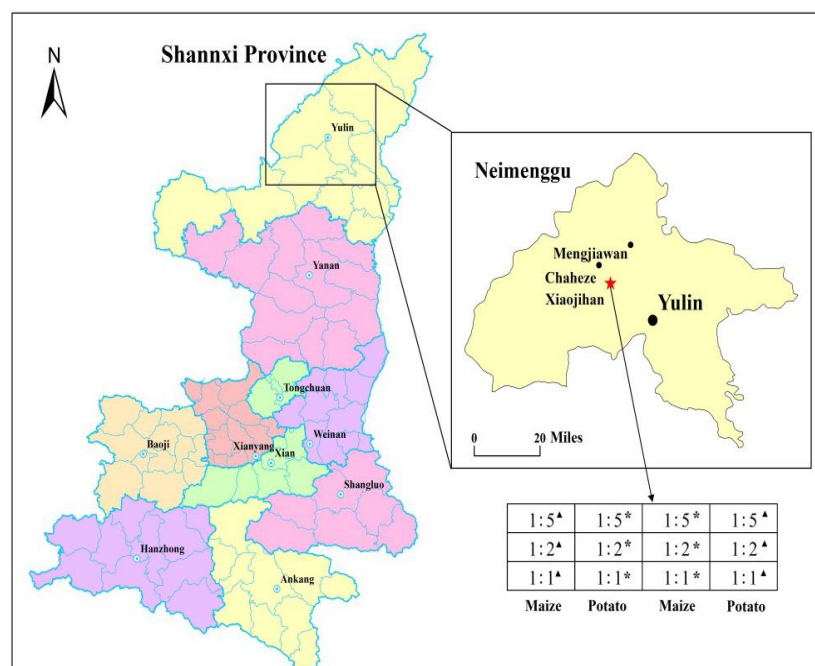
### 2.1. Study area

Yuyang District, which lies in the Middle North region of Yulin City in Shaanxi Province, is located in the southern margin of Mu Us Sandy Land. The experimental area belongs to Dajihan Village of Xiaojihan County in Yuyang District (E 109°29'50"-109°31'44, N 38°26'23"-38°27'02"), where is drought and lack of rain. The multi-year mean temperature is 6.0~8.5 °C and the average temperature in January is within 9.5~12 °C while 22~24 °C in July. The annual rainfall is 250 mm~440 mm, in which the amount of July, August and September accounts for 60~75% of the whole year. The intra-annual precipitation changes a lot, cause that the rainfall of rainy year is 2~4 times of dry year. Maximum daily rainfall amount is up to 100~200mm. Precipitation often appears in the form of a shower, which lasted a short time. As one of the most serious soil erosion areas in the upper and middle reaches of the Yellow River, Yuyang District has a large sediment concentration in surface runoff. Surrounded by lots of arsenic sandstone and sand [12], this region is a typical wind sand area. The physical and chemical properties of arsenic sandstone and sand are showed in table 1.

### 2.2. The experimental design

The main type of experimental area is aeolian sandy soil. The arsenic sandstone and sand was compounded in the ratio of 1:1, 1:2 and 1:5 (arsenic sandstone: sand), and the three types of soil were abbreviated to TC1, TC2, TC3 respectively. In addition, the original soil (total sand) was abbreviated to TS. Maize were chosen as the experimental crops for the reason that it was the most important grain crop for local people and were suitable to the local climate.

Twelve experimental plots with dry compounds of arsenic sandstone and sand at the ratios of 1:1, 1:2 and 1:5 respectively were divided into two groups (figure 1). Each plot was set up as 12m × 5m. Compound soils of different mixing ratios were covered to the surface of each plot to the depth of 40 cm, under that was the local original sand. Before planting, the field is fertilized with diammonium phosphate (DAP) of 335 kg/ha and compound fertilizer (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O=12-19-16) of 375 kg/ha, then with a rotary tiller the compound soil and fertilizers were mixed uniformly within surface layer of 15 cm. The same fertilization measures were used to deal with 6 residential areas.



**Figure 1.** The position of the study area and the distribution of monitoring points.

Neutron moisture meter (CNC100B) was used as experimental measuring instrument in one of the groups of experimental plots, and the other group was processed by oven-drying method as a comparison. The data measured by the neutron moisture meter will be verified and corrected by oven-drying method. In the following study, the data measured by neutron moisture meter was analyzed and calculated in the results. Six moisture content measuring tubes (marked by \*) were installed in the experimental area in different proportions of compound soil. During the experiment, neutron moisture meter was used to detect the soil moisture content of 9 soil layers (0, 10, 20, 40, 60, 80, 100, 120, 130 cm). The arrangement of the measuring tubes was shown in figure 1:

Before starting the experiment, the whole growth period of the crops were divided into 6 stages according to the growth status of crop. The sowing date was May 9th, 2016, and the harvest date was September 17th and 18th. The entire crop growth period was taken as research time. Refer to the existing research results, combined with the local crop cropping system, the growth stages of maize were divided as table 2.

**Table 2.** Division of corn growth stages.

Crop	Period (d)	Germination stage	Seeding stage	Jointing stage	Heading stage	Filling stage	Mature stage
Maize	130	10	30	35	20	20	15
Growth status		Sowing- Emergence	Emergence- Jointing	Jointing- Heading	Heading- Filling	Filling- Ripening	Ripening- Harvest
Date	5.09- 9.17	5.09-5.18	5.19-6.18	6.19-7.24	7.25-8.14	8.15-9.04	9.04-9.18

### 2.3. The irrigation scheduling

Sprinkler irrigation has significant water saving effect, whose water utilization rate could reach 80%. In order to save water, sprinkler irrigation was used for irrigation in this study. According to the "Quota of agriculture water use (Shaanxi provincial standard DB 61/T 943-2014)" in the Northern Shaanxi area along the Great Wall wind beach area (including Jingbian, Hengshan, Dingbian, Yulin, Shenmu, Fugu), the irrigation schedule for maize was shown in table 3. In this study, all the crops were irrigated with a uniform irrigation schedule.

**Table 3.** Irrigation schedule for Maize under sprinkler irrigation.

Crop	Growth stages	Irrigation (m <sup>3</sup> /mu)	quota	Quota (m <sup>3</sup> /mu)	times
Maize	Germination stage	290		28	1
	Seeding stage			28	1
	Jointing stage			28	2
	Heading stage			30	3
	Filling stage			24	2
	Mature stage			20	2

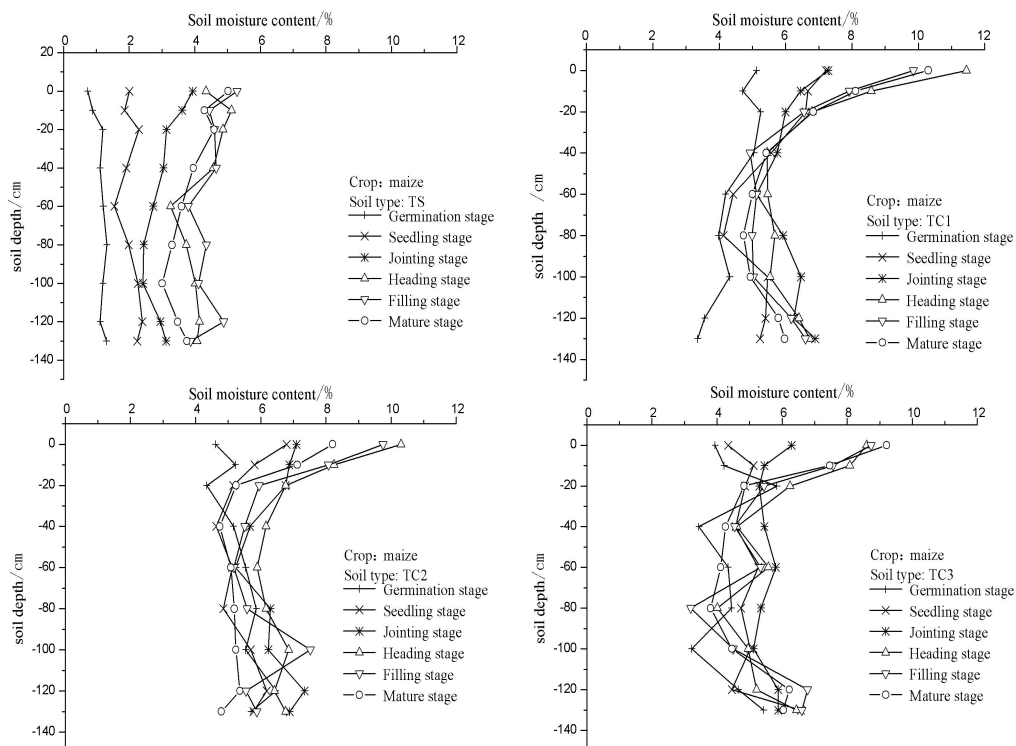
## 3. Results and discussion

### 3.1. Dynamic changes of soil moisture in the vertical soil profile

In the early stage of crop growth, the water content was less than that of late stages, as shown in figure 2 which illustrates the dynamic changes of soil moisture in the vertical soil profile. As the upper soil was easily affected by the weather conditions, the average water content of each soil layer decreased gradually with the increase of soil depth. Soil moisture in the 1:2 compounds was the highest and the most stable one, showing a better integrity and continuity of water, as well as the distribution at



different growth stages was relatively uniform, followed by 1:5. The moisture within the layer of 0-40 cm of all the three proportions have always been in a higher state, which was associated with that compound soil of arsenic sandstone and sand were mainly stored within the depth of 40 cm. This showed that the arsenic sandstone effectively increased the water holding characteristics of soil water retention and the dynamic distribution of soil moisture was influenced by soil texture. Influenced by distribution of soils of different textures, all the three kinds of compound soil showed the same characteristics: soil moisture was highest in the 0~40 cm layer, at lower value in the layer of 40~80 cm, and increased gradually in the depth of 80~130 cm under the influence of infiltration effect and groundwater. Inflection point appeared at the depth of 100 cm in the soil of compound ratio of 1:1 and 1:5, while it appeared in the 1:2 compounds at the depth of 80 cm inflection point with minor changes.



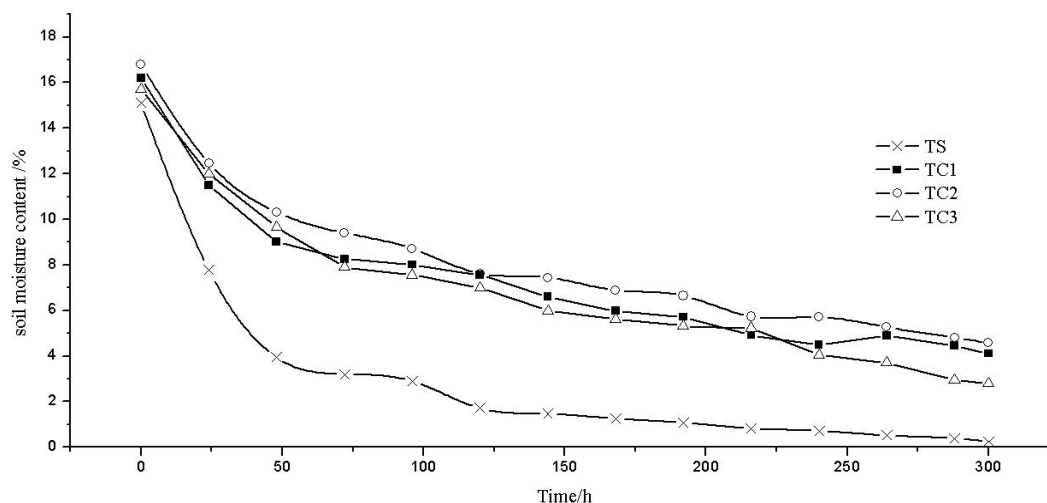
**Figure 2.** Dynamic changes of soil moisture in the vertical soil profile.

### 3.2. Variation of soil moisture content over time

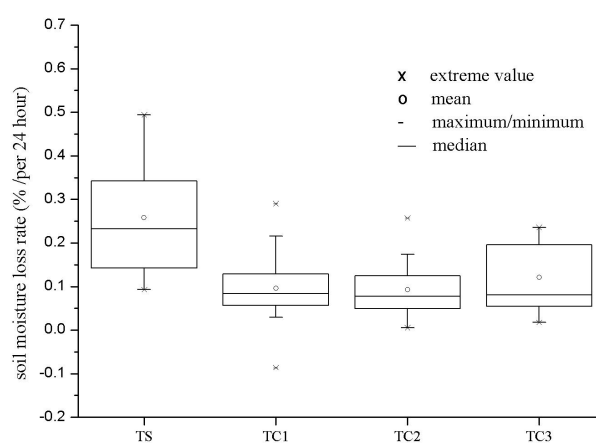
Heading stage of maize is a critical period to determine the growth status and the yield of maize. Taking the Heading stage as a typical period to study the variations of soil moisture content over time, different types of soil within the soil layers of 40 cm were stratified sampled and measured every 24 hrs, and the change of soil moisture content with time in 300 h was observed. No rainfall was occurred in the period, and soil has not been supplied by other water supplies, namely all losses are evaporation losses and crop root absorption. The results showed that the soil moisture content of different types of soil has a high consistency with time, showing a trend of rapid decline over time, especially in the former 75 h. Soil moisture content of TS was less than 3% after 75 h, showing a poor water retention performance, which could not provide and maintain the water needed for crop growth for long-term. The loss of water within 72 h accounted for 78.8% (TS), 49% (TC1), 44% (TC2), and 49.7% (TC3) (figure 3). The amount of water loss decreased gradually over time, as well as the loss rate.

Soil moisture loss rate was the moisture dropped in per 24 hour. The moisture content that dropped every 24 hours within 300 hours were shown by Box-plot (figure 4), which illustrated that the upper and lower range of TC1 and TC2 were significantly less than TS and TC3, showing that the decline process of moisture content was more stable. The median line of TC1, TC2, TC3 were adjacent (TC3

was larger slightly), while that of TS was significantly higher than the other three, indicating that the rate of TS was fastest significantly. Compared with TS, it showed that the compound soil can effectively improve the soil water retention capacity, and prolong the storage time of soil water, in which the ratio of 1:1 and 1:2 had the best performance. “x” stands for extreme values, and in view of this point, the data of TC2 were much more centralized and better than TC1.



**Figure 3.** Changes of soil moisture of four types of soil over time.



**Figure 4.** Soil moisture loss rate of four types of soil.

### 3.3. Variation characteristics of soil moisture in different layers

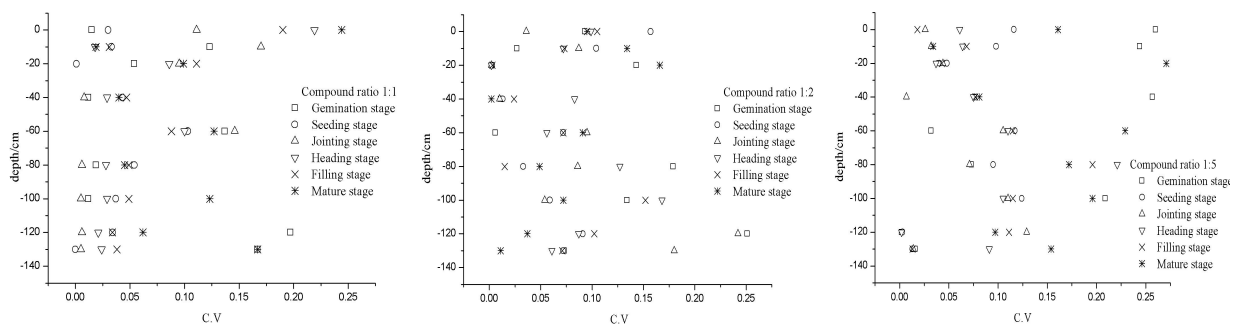
The coefficient of variation characterizes the stability of water in the soil. Previous analysis has shown that the compound soil has better water retention than total sand; therefore the TS were no longer discussed here. In order to explore variation characteristics of soil moisture content in different soil depths, the compound soil of same depth and growth stages were analyzed by the degree of dispersion, using the variation coefficient method to measure the variation of the observed values. The data of three types of soil were calculated in the same way. The calculation formula of coefficient of variation [13] (C.V) is:

$$C.V = \frac{S}{x} \quad (1)$$

Among them,  $S$  stands for the standard deviation of a certain layer of soil during certain growing

period,  $\bar{x}$  stands for the average value.

The value of the coefficient of variation represents the degree of dispersion of the measured value, and the calculated results are shown in figure 5. The variation coefficient  $C.V. \geq 0.15$  was used as the criterion for judging the degree of dispersion. As can be seen from figure 5, the coefficient of variation which were higher than 0.15 mostly concentrated in the deep layer of 0~40 cm and 100~130 cm. In the three ratios of compound soil, the highest value was 0.244 of the layer of 0~10 cm in the mature stage, 0.251 of the layer of 120 cm in the germination stage and 0.271 of the layer of 20 cm in the mature stage respectively. The main reason was that since the beginning of middle and late growing stages, the leaf area of maize increased, which caused the decrease of sunlight on surface of soil, and then evaporation reduced. Owing to the groundwater in Yuyang area is shallow (only 1.2 m~2.9 m in average) [14, 15], the layer of 100~130 cm was affected by the groundwater more strongly. And the growth of maize root is more vigorous, especially in Yulin which belongs to the arid area, thus roots of maize could grow to about 1m underground. The maximum mean value of the coefficient of variation all concentrated in the layer of 20~40 cm in the three kinds of soil (0.0298, 0.0238 and 0.0424 respectively), which represents that the soil moisture in the layer of 40cm was the most stable one with less fluctuations.



**Figure 5.** Variation coefficient of soil moisture in different soil layers.

### 3.4. Crop yield of maize in compound soil

From the overall point of view, crop yield planted in the TC1 and TC2 were higher, while it in the TC3 was low (table 4). Among them, the output of maize in 1:2 compounds soil was the highest. This may be related to that the soil moisture under rate of 1:1 and 1:2 was the higher and more stable, and the soil moisture distribution were relatively uniform. Grain output is closely related to grain security. From the point of view of production, maize is more suitable for planting in TC2.

**Table 4.** Crop yield of maize in four types of soil.

Soil Type	Crop yield (t/ha)
TS	5.74
TC1	8.25
TC2	8.96
TC3	7.5

## 4. Conclusions

Through the measurement and analysis of soil moisture content in different depths, the dynamic variation characteristics were studied under maize planting patterns in compounds of arsenic sandstone and sand with ratios of 1:1, 1:2 and 1:5 in the southern margin of MUSL. Affected by the soil texture, the surface layer of 0~40 cm depth was a higher water content area, where the compounds primarily concentrated in, layer of 40~80 cm belonged to the lower value area, and the soil moisture content in



the layer of 80-130 cm increased with the increase of depth, from which it can be seen that the vertical distribution curve showed a "C" type. Relatively, the soil moisture content of corn planting patterns under the ratio of 1:2 compounds of arsenic sandstone and sand was higher and more stable, and evenly distributed.

Under the same tillage and irrigation system, the water content of the compound soil was obviously higher than that of the whole sand. Soil moisture content will decrease with time, while the rate of water loss of compounds were relatively flat, indicating that compound soil can effectively improve the soil water retention capacity, and prolong the storage time of soil water. Among them, water loss rate of TC1 and TC2 were lower. The coefficient of variation also confirms that the water distributions of TC1 and TC2 soil were more uniform and stable.

It can be concluded that incorporation of arsenic sandstone and sand significantly enhances the soil water retention effect and water holding capacity, and the compound soil has a positive effect on crops growth. Besides illustrating the effects of the soil amelioration measures on spatial and temporal variation of soil moisture content and the improvement of soil water regime, the study provides some references for the development and utilization of agriculture in MUSL. This new mode of sand land agriculture development could greatly improve the ecological environment in MUSL, and bring more income for local farmers, which was a sustainable comprehensive development mode of sandy land.

### Acknowledgments

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