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Study on the Influence of Water Storage Capacity of Aeolian Sandy Soil by Arsenic Sandstone: a Case Study in Mu Us Sandy Land in China

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Abstract. To analyze how the arsenic sandstone influence the water storage capacity of Aeolian sandy soil, experimental plots with different ratios of arsenic sandstone and Aeolian sandy soil were set in Mu Us sandy land in China, with spring maize planted one season per year, and the soil water of the depth 0-120 cm was monitored constantly during 2013-2015.The results conducted that, moderate arsenic sandstone could improve the water storage capacity of sandy soil from 100 mm of 2013 to over 200 mm of 2015, promoting the soil water to none deficiency state, strengthen the water storage capacity of soil, which was beneficial for the crops growth. Water storage capacity of soil layer below 40 cm was promoted most obviously, and the layers of 0-40 cm and 80-120 cm turned into more stable layers for water storage, which was helpful for the crop growth. Mixing the arsenic sandstone and Aeolian sandy soil with ratio 1:1, 1:2 and 1:5, with the addition of arsenic sandstone, the water storage capacity of the soil was enhanced, the soil water deficit degree decreased, the water storage variable coefficient increased.

1. Introduction

In the arid and semi-arid region of northwest China, because of less precipitation and limitation of irrigation, the ability to protect and store water of soil has become an important factor which influences water use efficiency in agricultural production, and adding the water retaining capacity and water conservation capacity of soil at the same time, it has decided fertilizer maintenance capacity of soil and affects the degree of water and soil erosion of the land. Thus, how to improve the ability to protect and store water of soil has the top priority in the local agricultural development [1, 2]. The main technical measures to improve the soil conservation and storage capacity currently include the application of super absorbent polymers [3, 4] and charcoal and other biomass ameliorants [5-7] as well as rational cultivation and so on [8]. All the technical measures above have been proved they can improve soil conservation and storage capacity at different degrees. However, due to higher cost in application, lower economic benefits and various reasons, the technical measures that can be really applied on a large scale in the land reclamation engineering are few. How to control the cost of application while improving economic benefits and researching the optimization technology about Aeolian sandy soil conservation and storage function with a better input-output ration have become an important demand of large-scale Aeolian sandy soil regulation project.

Since 2009, Han Jichang and others have used the peculiarity of complementary nature between arsenic sandstone and sand to compound them and form new "compound soil", which not only can improve the nature of Aeolian sandy soil through resource utilization of arsenic sandstone and form new effective land, but also greatly saves the engineering cost and is applied on a large scale in Mu Us Sandy Land [9, 10], which is always called "arsenic sandstone and sand compound soil technology". Research results have verified that the clay in arsenic sandstone can promote the transformation of texture of Aeolian sandy soil to sandy soil and loamy sand [11], increase the content of surface soil organic matter [12], effectively reduce the leaching phenomenon of nitrate nitrogen and ammonium nitrogen under the plough layer [13], promote the growth and development of crop and increase production [14]. Through laboratory test, She Xiaoyan and others have verified that a moderate amount of arsenic sandstone can effectively improve the water-holding capacity of Aeolian sandy soil [15], but this result has not been verified by field trials and also failed to analyze whether this effect can effectively eliminate the phenomenon that the soil water is deficient.

Based on arsenic sandstone in Yuyang Region, Shaanxi Province of northwest China and soil water observation of experimental plot as the basis and with the introduction of soil water storage capacity and soil water deficit degree index, this article systematically researches the influence of arsenic sandstone in different dosages on water storage characteristic of Aeolian sandy soil, which provide the basis of soil water for the large-scale application of arsenic sandstone and sand compound soil technology.

2. Natural Conditions in Research Area and Research Methods

2.1. Overview of the experimental area

The experimental area is located in Dajihan Village, Xiaojihan Township, Yuyang Region, Shaanxi Province, a place that is in south edge of Mu Us Desert, Northwest of China with the altitude of 1 206-1 215 m. This place belongs to the typical mid-temperate semi-arid continental monsoon climate zone with uneven distribution of annual precipitation in time and space and arid climate. The spring is windy and arid and the autumn is cool and moist. The annual average temperature is 8.1 ℃, and the accumulated temperature of ≥10℃ is 307.5 ℃, which lasts for 168 days. The annual average frost-free is 154 days; the annual average sunshine duration is 2879hours; the annual total radiation quantity is 6077.9 MJ/m^2. In the project area, the annual average precipitation is 400 mm, and the average total rainfall in growth period of corn (from May to September) is 324 mm, which account for more than 80% of annual precipitation.

In 2013, 2014 and 2015, the total annual precipitation in this area was respectively 552.4 mm, 552.4 mm and 310 mm, and among these, the total rainfall in growth period of corn respectively was 552.4 mm, 552.4 mm and 310 mm, namely, both in terms of total annual precipitation or total rainfall in growth period of corn, in the period of this study, 2013 was high flow year and 2014 and 2015 were normal flow years (Fig. 1).

2.2. Experimental setup

Study period was three consecutive years of growth period of spring corn: 2013, 2014 and 2015, and the experimental field started to plant from 2012 and is respectively equipped with three treatments with the ratio between arsenic sandstone and sand: 1:1, 1:2 and1:5, which were repeated in three plots. The basic properties of arsenic sandstone and sand in this study were shown in Table 1. The area of each plot was 5 m×12 m, and cover compound soil of different mixing ratios in 30-cm surface layer of the plot and the local raw sand was below 30 cm. In actual planting, because of years of mechanical ploughing, the soil of 30-40cm in the surface is also mixed with some of the compound soil, and the property is close to topsoil of 0-30cm. The experimental crop was spring corn 'Wanrui No. 5', which was planted respectively on April 22nd, 2013, May 8th, 2014 and May 8th, 2015 and harvested on September 15th, 2013, September 27th, 2014 and October 8th, 2015. Its planting spacing was uniformly set as 50 cm×33 cm. All the irrigation and fertilization treatments in plots were the same: base fertilizer diammonium phosphate: 335 kg/hm^2 before sowing, compound fertilizer (N-P_2O_5-K_2O=12%-19%-16%): 375 kg/hm^2, and 1 topdressing and urea: 375 kg/hm^2 during the elongation stage. The irrigation adopted sprinkler irrigation, and according to the local rainfall and water need of corn in growth period, confirming the irrigation amount. The total irrigation amount was 398.2 mm in 2013, 194.4 mm in 2014 and 145 mm in 2015. And the irrigation amount declined year by year.

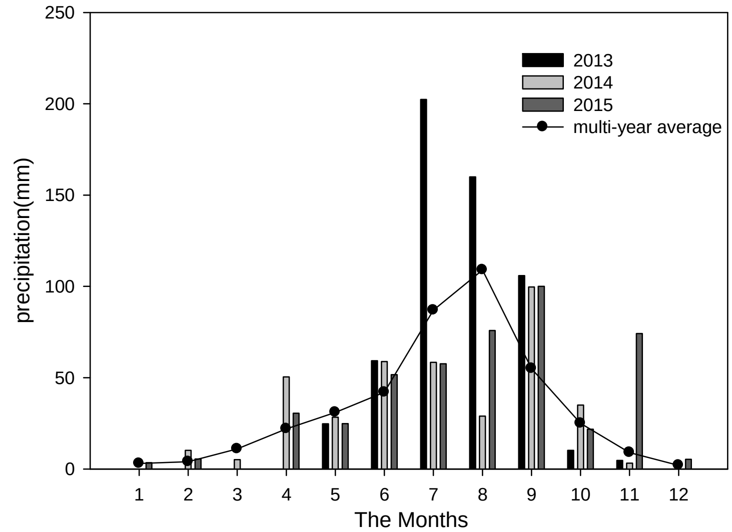

Figure 1. Precipitation in Yuyang District of China during 2013-2015

Table 1. Basic characteristics of Arsenic sandstone and sand

Physical properties		Arsenic sandstone	sand
Particle size proportion(%)	sand (≥0.05～＜2mm)	19.57	94.06
	silt (≥0.002～＜0.05mm)	72.94	3.21
	clay(＜0.002mm)	7.49	2.73
texture		silty loam	sandy soil

Table 2. Field irrigation amount during 2013-2015

Irrigation date of 2013	Irrigation amount(mm)	Irrigation date of 2014	Irrigation amount(mm)	Irrigation date of 2015	Irrigation amount(mm)
2013/5/21	55.6	/	/	/	/
2013/6/1	55.6	/	/	/	/
2013/6/16	55.6	/	/	2015/6/25	/
2013/7/1	55.6	2014/7/2	55.6	/	35
2013/7/15	55.6	2014/7/13	32.4	2015/7/7	/
2013/7/25	55.6	/	/	/	75
2013/8/15	55.6	2014/8/6	106.5	2015/8/13	35
Total irrigation amount	389.2	/	194.4	/	145

2.3. Measuring indexes and methods

After harvesting the corn of each plating season, cutting-ring method was used to hierarchically measure volume weight of compound soil in different ratios and field capacity. In the depth range of 0-40 cm, each 10 cm was a layer, and in the range of 40-120 cm, each 20 cm was a layer. Use CNC 100 water neutron probe to respectively measure the volumetric water content of field soil in different growth periods of spring corn, such as the stage before sowing, elongation stage, 12-leaf stage, tasseling stage, milk-ripe stage and mature stage, the measure depth was as the cutting-ring method. The weighted value of soil water content is the volumetric water content of soil in the depth of 0-120 cm.

The computational formula of soil water storage capacity is [16, 17]:

The computational formula of soil water storage capacity of each layer is:

$$Wi=\theta h \quad (1)$$

$$W=\Sigma Wi \quad (2)$$

In the formula, Wi is the soil water storage capacity of each layer, mm; W is the total soil water storage capacity, mm; θ is soil volumetric moisture content (%); h is the thickness of the soil layer with the value of 10 or 20 cm.

The computational formula of water deficit degree (WDD) is [18]:

$$DSW\ (\%) = (F-W)/\ F\times 100\% \quad (3)$$

In the formula, F is the soil water holding capacity, mm; W is the actual storage of soil, mm.

The formula for calculating the compensation degree of soil water (CSW) is:

$$CSW\ (\%) = (Wcm-Wcc)/\ (F-Wcc)\times 100\% \quad (4)$$

Among them, Wcm is the soil water storage capacity at the end of the growth period, and Wcc is the soil water storage capacity at the beginning of the growth period, and F is the field capacity.

2.4. Data statistics and analysis

Data were summarized through Excel 2007, and draw through Sigmaplot 10.0.

3. Result Analysis

3.1. Dynamic changes of soil water content during the growth period of corn

During the whole growth period of spring corn in 2015, soil water content of compound soil experimental field with 3 kinds of ratios was higher than 17% during the whole growth period of corn, which was significantly higher than that in 2013 and 2014 (Fig. 2). From 2013 to 2014, the soil water content of compound soil in the ratio of 1: 5 basically was the lowest in the three compound ratios, and the soil water content of compound soil in the ratio1:1 tended to be higher than the ratio of 1:2. Up to 2015, although the differences among the compound soil in three ratios reduced, in the measurement of July, 2015, soil water content of compound soil was still dramatically lower than the compound soil in other two ratios and its soil water retention was relatively poor. Correspondingly, in the calculation of soil water storage capacity in three consecutive years of different growth periods, the water storage capacity of compound soil in the ratio of 1:5 was the lowest in the three ratios at most of periods(Fig. 3).

3.2. Dynamic changes of soil water storage capacity

According to the computational analysis on soil water storage characteristics in different layers among the depth of 0-120 cm (Table 3, Fig.4), in the year of 2013 and 2014, the water storage of compound soil in different ratios was mainly the topsoil in 0-20 cm and 20-40 cm, and water storage capacity of each ratio in this layer accounted for 0-120 cm with the basic performance of ratio of total water storage: 1:1 < 1:2 < 1:5. With the increase of planting seasons, surface layer water storage capacity of compound soil in each ration increaseed, but the ratio of water storage decreased. The water storage capacity of middle layer (40-80 cm) and deep layer (80-120 cm) increased while the ratio of water storage also increased year by year. From the view of water storage capacity coefficient of variable (CV) in each layer, the variable coefficient in each layer of compound soil in the ratio of 1:5 trended to be higher than that of the other two ratios, and in the year of 2014 and 2015, the variable coefficients in each layer of each ration were basically higher than that of 2013. In 2013, the compound soil in each ratio was basically in layers of 0-20 cm and 100-120 cm, that was, the variable coefficient in the highest and deepest layer was highest with the largest variation between different growth periods. Among them, the variable coefficient of water storage capacity of compound soil with the ratio of 1:5 in the layer of 0-20 cm was 0.458 in 2013, which was 11.4 times of the coefficient of variation in the layer of 40-60 cm. But by the year of 2014 and 2015, the variable coefficient of compound soil of each ratio in the layer of 40-60 cm, 60-80 cm and 80-100 cm was obviously higher than that of other layers, becoming the layer with largest variation during different growth periods, and it could be recognized as soil water active layers.

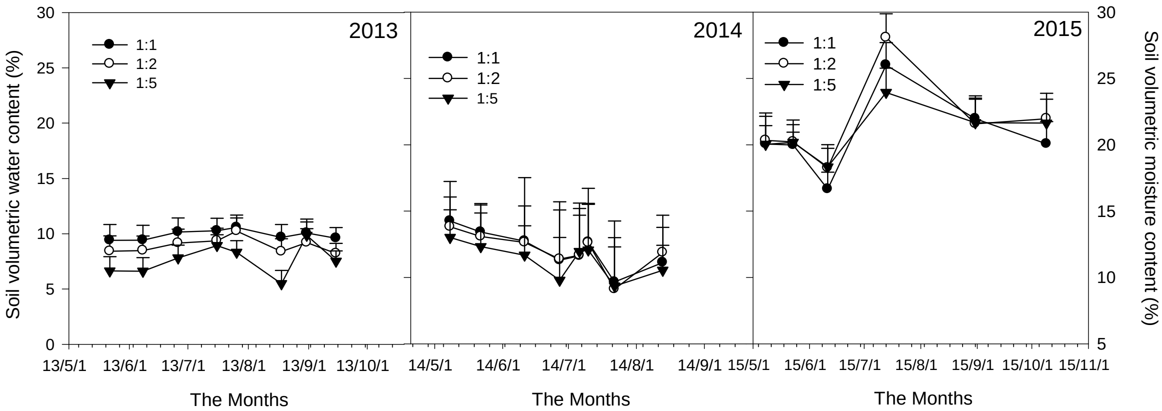

Figure 2. Dynamic change of soil volume water content in the depth of 0-120 cm

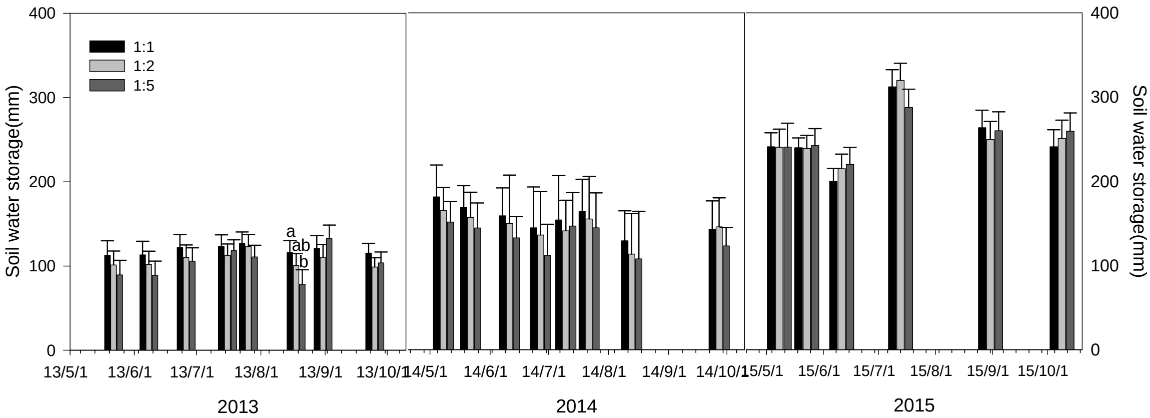

Figure 3. Total soil water storage in the depth of 0-120 cm

By 2015, compared with 2013 and 2014, soil water storage capacity of each layer in plot of compound soil in each ratio had been dramatically improved, probably because after several years of planting, while arsenic sandstone improved the soil texture of Aeolian sandy soil's surface layer (0-40 cm) and enhanced its protection and storage capacity, it also reduced the evapotranspiration of water in the subsoil. In addition, the increase of surface soil water storage capacity might enhance the absorption of crop's root system towards the surface soil water, thus reducing the absorption and utilization of deep soil water. However, the specific mechanism still needs further monitoring and analysis.

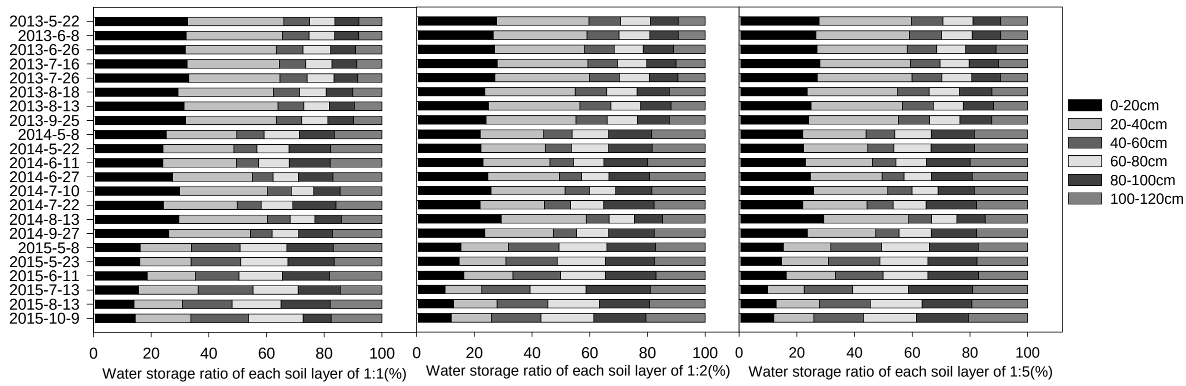

Figure 4. Soil water storage ratio of each layer in the depth of 0-120 cm during 2013-2015

Table 3. Water storage characteristics of different soil layers during 2013-2015

The mixed proportion	Soil depth (cm)	2013			2014			2015		
		average value (mm)	standard deviation (mm)	variable coefficient	average value (mm)	standard deviation (mm)	variable coefficient	average value (mm)	standard deviation (mm)	variable coefficient
1:1	0-20	37.9	2.4	0.064	40.8	3.4	0.083	39.4	4.9	0.124
	20-40	38.4	1.2	0.032	42	2.5	0.059	45.7	10.3	0.225
	40-60	10.8	0.6	0.059	12.5	2.3	0.185	44.1	9.7	0.22
	60-80	10.8	0.7	0.066	15.6	4	0.254	41.3	6.6	0.160
	80-100	10.2	0.5	0.050	19.2	4.8	0.252	37.2	8.3	0.224
	100-120	10.6	1.1	0.099	25.5	4	0.159	41.9	3.9	0.093
1:2	0-20	28.1	3.4	0.120	34.8	1.2	0.035	33.6	2.6	0.078
	20-40	34.1	3	0.089	34.8	1	0.03	38	2.1	0.054
	40-60	11.4	0.6	0.057	12.5	2.3	0.187	43.5	5.9	0.135
	60-80	11.1	0.8	0.069	15.8	3.8	0.242	44.3	9.8	0.221
	80-100	11.1	0.8	0.075	21.1	5	0.237	46.4	12.3	0.266
	100-120	11.5	1.3	0.118	26.4	4.3	0.164	46.7	8.7	0.187
1:5	0-20	34.9	16	0.458	28.6	2.9	0.102	35.7	2.5	0.069
	20-40	25.1	6.4	0.256	29.2	2.7	0.092	43.1	5.6	0.130
	40-60	10.3	0.4	0.040	13.7	2.2	0.16	42.8	6	0.140
	60-80	10.6	0.5	0.050	15.7	3.5	0.224	42.1	5	0.118
	80-100	10.8	0.6	0.059	19.4	4.8	0.245	43	4.4	0.103
	100-120	11.7	1.7	0.142	26.3	3.8	0.146	44.7	2.3	0.051

3.3. Dynamic changes of water deficit degree and storage compensation degree

According to dynamic changes of compound soil water deficit degree in three different kinds of ratio in 2013-2015 (Fig.5, Fig.6, Fig.7), there was no regular difference in water deficit degree of each ratio, but along with the increase of planting years, water deficit degree of each ratio was significantly reduced and the soil storage capacity dramatically improved, and until 2015, it all turned into negative value, that was, the soil was not in water deficit condition since then. According to the layers, in 2014, the soil layers of 0-40 cm and 80-120 cm in each ratio had entered into a condition without deficit, and the soil layer of 40-80 cm did not break away from the water deficit condition until 2015, namely, the improvement of the water deficit condition in this layer was slowest. In view of soil water storage deficit compensation degree (Fig. 8), the compensation degree of compound soil in the ratio of 1:5 was lowest and the ration of 1:2 was highest, but there was no prominent regular change among different years.

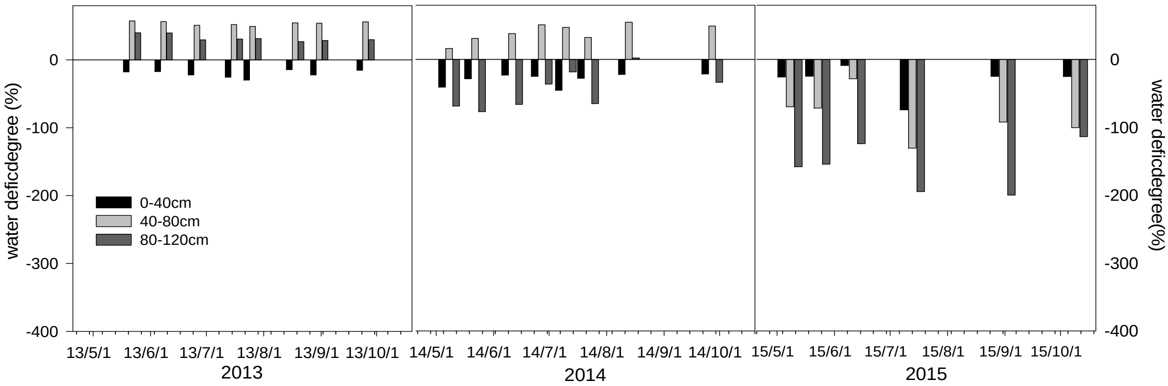

Figure 5. Water deficit degree dynamics change of arsenic sandstone and sandy soil with ratio 1:1

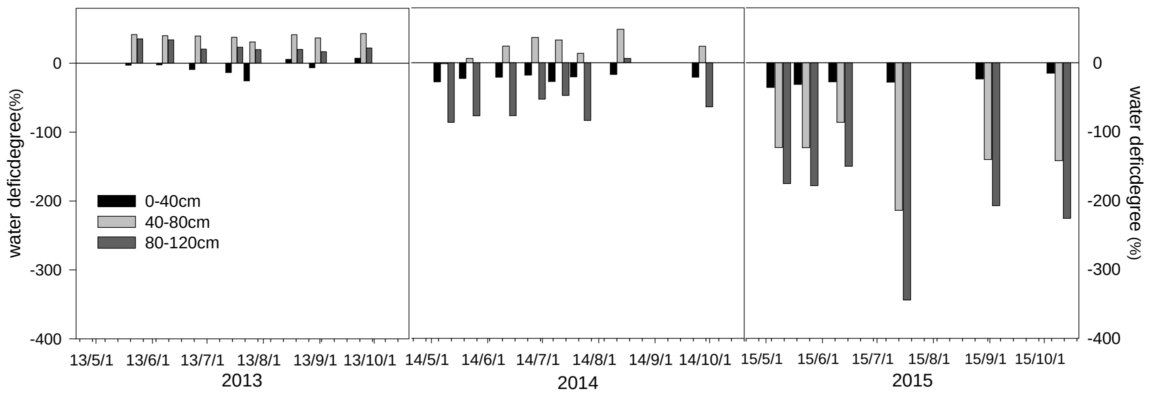

Figure 6. Water deficit degree dynamics change of arsenic sandstone and sandy soil with ratio 1:2

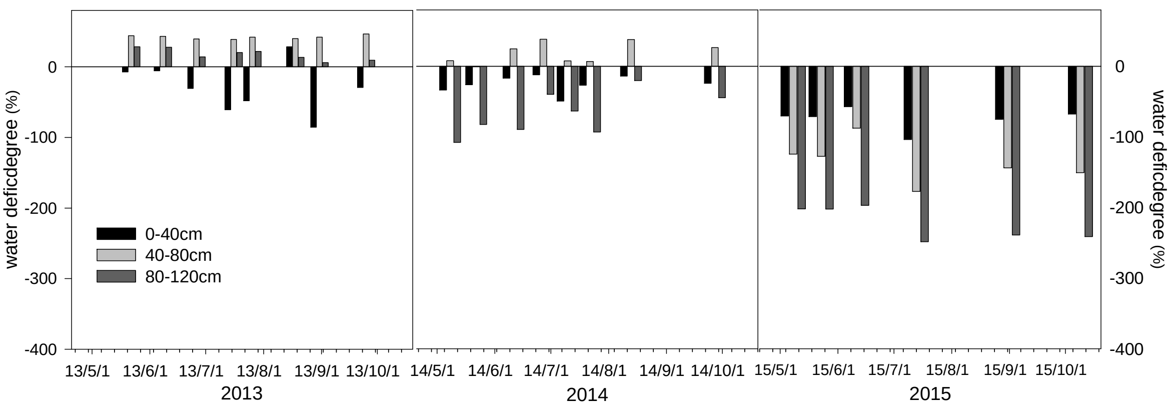

Figure 7. Water deficit degree dynamics change of arsenic sandstone and sandy soil with ratio 1:5

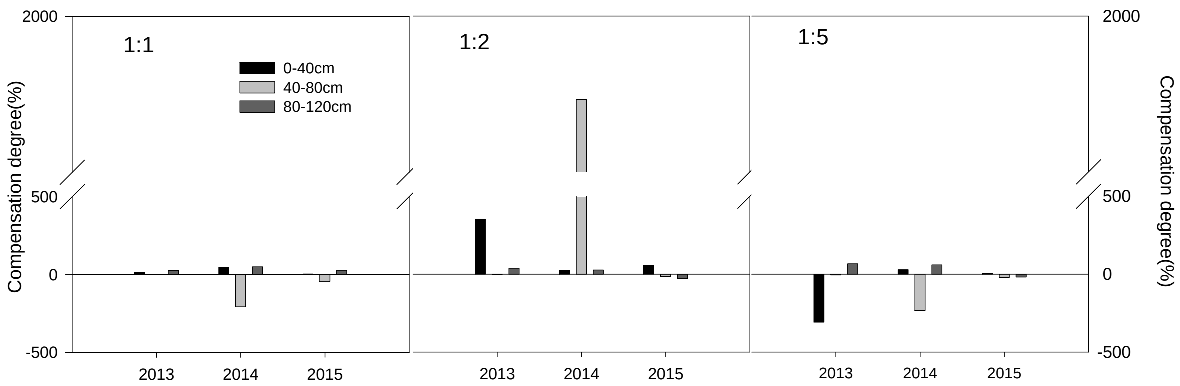

Figure 8. Soil water storage deficit compensation degree during 2013-2015

4. Discussion and Conclusion

Soil water is the primary limiting factor of agricultural development and vegetation construction on Loess Plateau and is affected by atmospheric precipitation and soil texture [18]. It is generally believed that under the same climatic conditions, the lower the content of physical clay in soil is, the less the soil water storage is [19]. The average content of sand particles in Aeolian sandy soil reaches up to 95%, the lowest content of clay particles is less than 1% [11], soil particle lacks of good cementation, water protection and conservation capacity is rather weak, and soil water storage capacity is particular small. Thus, it severely limits plant growth and affects the agricultural development and vegetation recovery negatively. As a kind of concomitant substance with Aeolian sandy soil in Mu Us sandy land, the content of arsenic sandstone's silt particles reaches up to 58% and its clay particles content can reach 7.6% [11]. By mixing with Aeolian sandy soil in a certain proportion, it can effectively improve the texture of Aeolian sandy soil. The improvement of particle composition will promote the benign development of physical and chemical properties of soil.

In this study, with mixing the arsenic sandstone and sand in the ratio of 1:1, 1:2 and 1:5, water storage capacity showed a trend of increase along with the increase of planting years. As the ratio of arsenic sandstone reached higher, its storage capacity was better and water storage content was higher (Fig. 2, Fig. 3). This is mainly due to the clay and silt particles content increase of compound soil with the ratio of the arsenic sandstone increase, the cementation of soil enhanced, soil water storage capacity enhanced correspondingly and soil water loss rate reduced [20]. At the same time, along with the increase of the planting years and the joint effects of application of organic fertilizer as well as crop's straw returning, organic content of soil had improved and soil storage capacity continued to improve [12, 21, 22]. Meanwhile, it might be one of reasons that lead to decreased differences in water storage capacity of compound soil in different ratios, along with the increase of planting years and even lead to the decreased differences in crop yield of compound soil in different ratios in the future.

The water storage variable coefficient of each soli payer of compound soil in the ratio of 1:5 tended to be higher than that of 1:1 and 1:2, and the main reasons were lower ratio of arsenic sandstone, lower soil clay particles content and relatively weaker protection and storage capacity, thus, the water lost more easily [20]. However, in terms of soil water deficit degree, the trend of the three ratios was basically consistent, and the difference among them was not obvious. With the increase of planting seasons, relatively reasonable seasonal cultivation, application of organic fertilizer and other farming measures had gradually improved organic content of compound soil, and while increasing soil water storage capacity, it also had improved the deficit condition of soil water, but there was no obvious variation trend about water storage compensation degree among different years (Fig.5, Fig.6, Fig.7). The water storage deficit compensation degree of compound soil in the ratio of 1:2 was a remarkable tendency that was higher than that of the other two ratios, namely although there was no obvious difference about soil deficit degree among various ratios, with the combination of soil water storage capacity and water absorbing capacity and other various factors, the compensation degree in the ratio of 1:2 has significant advantages, and the specific reasons still remains to be further researched.

In conclusion, the addition of suitable amount of arsenic sandstone can effectively improve the soil water storage capacity of Aeolian sandy soil, and after many years of planting, it gradually adjusts soil water to the condition without deficit, remarkably improves soil water storage capacity and satisfies the demands of crop growth. As the ratio of arsenic sandstone to sand increases between 1:1 and 1:5, its improvement on water storage characteristic of Aeolian sandy soil shows the increasing trend which is not significant. In this study, due to arid climate of Mu Us sandy land and special nature character of Aeolian sandy soil, Aeolian sandy soil without improvement is particular difficult for crop cultivation, so the study fails to take it as a contrast, and in the future, it should be given further verification.

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