

Study on Surface and Internal Humidity of Dunes in the Southwestern Margin of the Taklimakan Desert

Wei ZHANG, Liping CAO, Shengqing YU and Xiangling ZHOU¹

School of Physics and Electrical Engineering, Kashi University, Kashi 844006, China

Abstract. Greening on the edge of desert is an effective way to prevent and control desertification. This paper studies the humidity characteristics of sand samples collected from the surface and interior of dunes in the southwestern edge of the Taklimakan Desert, whose geographic coordinates are 39°43'37" – 39°43'41" N, 78°43'02" – 78°43'09" E. The humidity of sand samples at vertical depths under five different surface positions of windward slope bottom, windward slope middle, windward slope top, leeward slope middle and leeward slope bottom was studied. On the surface of the sand at different locations and at the same depth under the surface, the sand humidity is greater closer to the bottom of the slope, for both windward slope and leeward slope. The humidity gradient values on the surface and at different depths on different positions of the dunes are obtained. Finally, recommendations are provided for effective ways to prevent desertification in the desert edge of Kashgar.

Keywords. Desertification, Taklimakan Desert, moisture distribution characteristics

1. Introduction

The rapid growth of population in recent years has caused severe impact on the natural environment. Desertification is exacerbated by the lack of rainfall, the evaporation of water vapor at the edge of the desert, coupled with the unreasonable reclamation of wasteland in recent decades. Taklimakan Desert in Tarim Basin, Xinjiang, is the largest desert in China and a mobile desert [1]. Zhibao Dong et al. studied the aeolian landform of the Taklimakan Desert [2-7], and other scholars have extensively studied afforestation with drip irrigation at the desert edge in the middle and southeast of the Taklimakan Desert [8, 9]. The Kashgar region borders the southwestern edge of the Taklimakan Desert. The average annual precipitation is less than 50 mm, belonging to the arid area [10, 11]. The poplar forests along the Yerqiang River in the southwest of the Taklimakan Desert form a barrier between the desert and the oasis. In recent years, due to the lack of water, a part of the poplar forest has died. As a result, the quicksand of Taklimakan has accelerated its expansion to the oasis, and the desert has expanded to the oasis at an average rate of 4-10 meters per year. Sandstorms occur from time to time in Kashgar, which severely affect people's daily life. Desertification control, as an

¹ Corresponding Author, Xiangling ZHOU, School of Physics and Electrical Engineering, Kashi University, Kashi 844006, China; Email: 273243489@qq.com.

important measure for Xinjiang's economic development, is highly valued by all regions.

The key to control desertification is to fix sand. The mature sand fixation methods include engineering sand fixation and biological sand fixation. Plant sand fixation, a type of biological sand fixation, has some problems such as high cost, high labor intensity and low efficiency [12, 13], but it has long-term benefits for truly changing the ecological environment and achieving the goal of sand control and prevention. Hence, it has attracted increasing attention. Trees are planted at the edge of the desert to keep the desert from moving. For the most part, drip irrigation is used to replenish water for the plant roots. The humidity of plant root soil is one of the main factors affecting the speed and quality of plant growth and the survival rate of greening in the desert edge [14, 15].

Many Chinese scholars have studied the spatial and temporal characteristics of soil moisture for drip irrigation [16, 17]. Wang et al. studied the variation of soil moisture over time in shelterbelt under drip irrigation [18]. Du et al. studied the characteristics of root irrigation and water saving in Tarim Desert Highway shelterbelt [6]. Before artificial planting and greening, understanding the humidity distribution in the interior of sand dunes in natural environment can provide effective data for the selection of greening tree varieties and water supply measures in the desert edge. This paper studies the moisture distribution characteristics of barchan dunes under natural conditions in Bachu County, at the southwestern edge of the Taklimakan Desert, in September. The results can be helpful for artificial afforestation at the desert edge of Bachu County in the future, and provide basic information and technical support for afforestation at the dune edge and plant planting in the transition zone from desert to oasis.

2. Research Area and Research Methods

2.1. Overview of the Study Area

The research area is in Bachu County on the southwestern edge of the Taklimakan Desert. Bachu County has an average annual precipitation of about 50 mm and an average annual temperature of 11.8 °C, belonging to the temperate continental arid climate. The average rainfall was less than 5 mm in 2016, and the average temperature was 20.7 °C in September. The average maximum temperature was 27.1 °C, and the average minimum temperature was 14.3 °C in September. There was one rainfall on 2nd September, with short rainfall duration. The maximum rainfall was less than 3 mm, the minimum rainfall was 0.4 mm. The remaining 29 days were mostly sunny, with no continuous wind breeze.

2.2. Sample Collection and Analysis Method

The sampling site is in a sand dune in Bachu County, on the southwestern edge of the Taklimakan Desert. The geographical distribution of the dunes is in the range of 39°43'37"–39°43'41" N, 78°59'02"–78°59'09" E. The sampling time was September 24, 2016. In September, there was one rainfall in Bachu County, that is, on September 2, with an average rainfall of 2 mm. Thereafter, there was no rainfall or strong winds for 22 days prior to sampling. Under natural conditions, four crescent dunes at the junction of desert and oasis were selected for sample collection.

A section perpendicular to the ridgeline of each barchan dune at the sampling point is selected as shown in figure 1. The sections a, b, c, d and e are respectively represented as the bottom of the windward slope, the middle of the windward slope, the top of the windward slope, the middle of the leeward slope and the bottom of the leeward slope [4]. Samples were taken at 10 cm intervals on the surface of five different locations and at vertical depths below. Several sand samples were taken at depths of 0 cm, 10 cm, 20 cm, 30 cm and 40 cm, respectively. The collected samples were weighed in an electronic balance (model: AUY120, accuracy: 0.0001 g) to obtain the wet weight of sand W , and the dry weight W_0 was measured on the balance after the sand samples were dried by a thermostat. ρ is the percentage by weight of sand moisture, that is, the percentage (%) of the water weight in the sand to its dry sand weight [14]. The sand humidity at different locations can be calculated by the following formula:

$$\rho = \frac{w - w_0}{w} \times 100\%$$

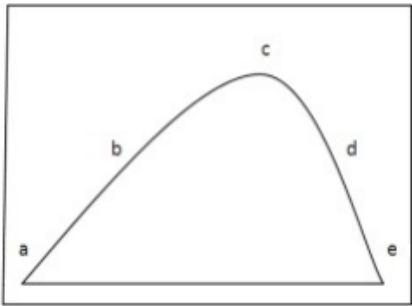


Figure 1. Five different sampling locations for the measurement of humidity.

3. Results and Discussion

3.1. Humidity Distribution Characteristics of the Surface and Interior of Sand Dunes in the Desert Margin in Bachu County

According to the humidity formula, the humidity data at five locations of the four dunes at different depths are shown in table 1.

For different barchan dunes, the distribution of humidity varied with depth at the same position of the dunes. In order to clearly observe the humidity conditions at the same location and at different depths on the sand surface and below, the data in the above table are compared in the form of line chart, as shown in figure 2.

3.1.1. Humidity Distribution Characteristics on the Surface and inside the Dune

Figure 2 shows the surface and internal humidity distribution of four different dunes at five locations: a-windward slope bottom, b-windward slope middle, c-windward slope top, d-leeward slope middle and e-leeward slope bottom. As can be seen from figure 2, the humidity distribution characteristics of the five positions in the interior of four different dunes are generally consistent. That is, the humidity of sand at different

depths at the same location gradually increases with the increase in depth. For the same depth of sand on and below the surface of different dunes, the humidity value of both windward slope and leeward slope increases gradually from the top of the slope to the bottom. Among the five positions of a dune, the general humidity distribution is that of greater humidity value at lower dune position and vice versa. The humidity on the surface and inside the dune is the largest at the bottom of the windward slope, followed by the bottom of the leeward slope, while the humidity at the top of the dune is the smallest. The variation trend of humidity in five locations of the four dunes is similar, but there are slight differences in different locations, likely due to the differences in the location of the dunes and the sampling time. The surface and internal humidity values at the same location of the dune have little difference when the depth is relatively shallow.

Table 1. The humidity distribution at different depths in the interior of four dunes in Bachu County.

Dune	Depth (d) (cm)	Windward slope Bottom (a)	Mid-windward Slope (b)	Windward slope Top (c)	Mid- leeward Slope (d)	Leeward slope Bottom (e)
Dune 1	0	0.25%	0.05%	0.02%	0.02%	0.05%
	10	0.70%	0.09%	0.03%	0.17%	0.69%
	20	1.64%	0.64%	1.10%	0.63%	2.75%
	30	2.28%	1.69%	1.43%	0.57%	2.54%
	40	3.48%	1.28%	2.10%	0.46%	2.99%
Dune 2	0	0.06%	0.08%	0.04%	0.06%	0.07%
	10	0.23%	0.11%	0.04%	0.26%	0.32%
	20	0.75%	0.49%	0.52%	0.55%	0.91%
	30	1.19%	1.99%	0.67%	0.75%	1.43%
	40	1.44%	1.81%	0.58%	2.10%	1.18%
Dune 3	0	0.11%	0.14%	0.03%	0.04%	0.05%
	10	0.81%	0.52%	0.45%	0.03%	1.14%
	20	1.89%	1.25%	0.56%	0.79%	2.11%
	30	3.27%	2.19%	1.07%	1.15%	2.88%
	40	2.79%	2.07%	0.87%	0.98%	2.60%
Dune 4	0	0.10%	0.11%	0.02%	0.05%	0.04%
	10	0.82%	0.71%	0.02%	0.07%	0.68%
	20	1.94%	1.30%	0.01%	0.41%	1.10%
	30	2.31%	1.68%	0.00%	0.48%	2.06%
	40	2.53%	1.91%	0.01%	0.54%	2.51%

3.1.2. Discussion on the Moisture Distribution Characteristics on the Surface and Inside the Dune

Dune 1 has no turning point. The reason may be that Dune 1 is close to the reservoir, and the humidity value increases with the increase in depth, so there is no turning point at 30 cm. Bachu County had only one rainfall in September, with an average rainfall of 2 mm on September. The moisture characteristics on the surface and inside the dune formed in September were analyzed. The reason for the maximum humidity value at the vertical depth of 30 cm might be related to the precipitation penetration distance on

September 2. In the case of continuous no rainfall and breeze, the sand particles on the surface of the dune migrate less, and only the surface evaporates easily, which tends to be dry. Inside the dune, the humidity is high at the vertical depth of 30 cm. The humidity at 40 cm is related to the original humidity and the height of the underground water table in Bachu County, so the value is large. One of the main reasons why the humidity of the leeward slope is less than that of the windward slope is that the bulk density of the leeward slope is less than that of the windward slope. Sand accumulates loosely and evaporates faster than on the windward slope, resulting in lower humidity value.

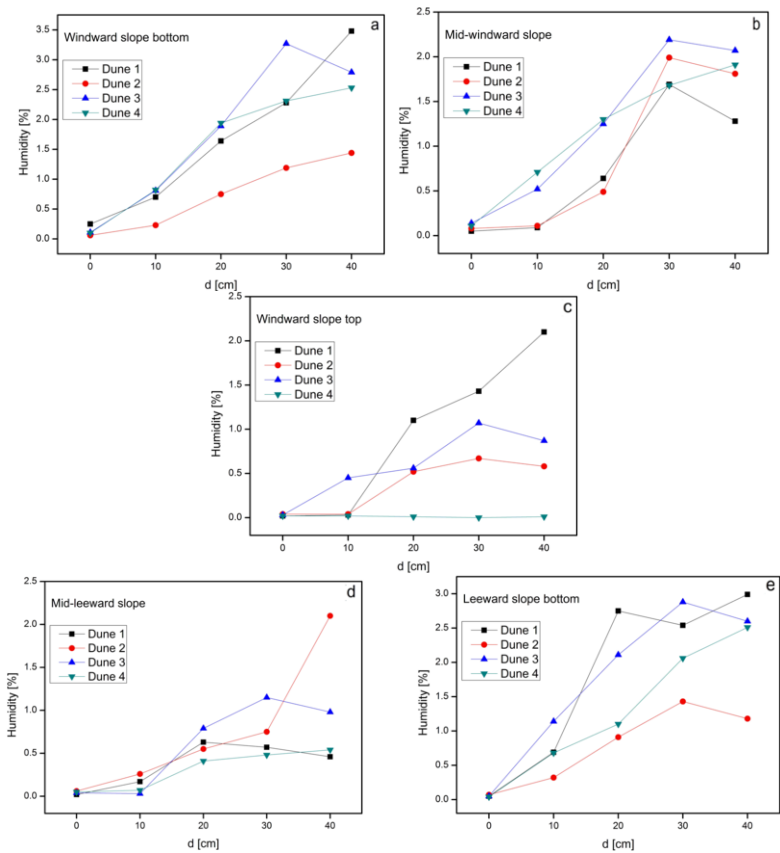


Figure 2. The humidity distribution of five dunes at different depths below the surface.

3.2. Surface and Internal Humidity Gradient of Sand Dunes at the Edge of the Desert in Bachu County

The average humidity of sand at different vertical depths on the surface and interior of dunes at the same location of the four dunes is presented in table 2. The humidity value of different depths is ρ , and the depth is d . Through fitting, the function graph of $\rho=ad+b$ is obtained, as shown in figure 3.

Table 2. Fitting values of humidity gradient inside sand surface at different locations and depths.

Depth (cm)	Windward slope bottom humidity	Mid-windward slope humidity	Windward slope top humidity	Mid-leeward slope humidity	Leeward slope bottom humidity
0	0.13%±0.01%	0.1%±0.01%	0.03%±0.00%	0.04%±0.00%	0.05%±0.00%
10	0.64%±0.06%	0.36%±0.08%	0.04%±0.00%	0.13%±0.08%	0.71%±0.08%
20	1.56%±0.14%	0.92%±0.12%	0.55%±0.010%	0.6%±0.01%	1.73%±0.15%
30	2.26%±0.15%	1.89%±0.20%	0.79%±0.04%	0.74%±0.12%	2.23%±0.18%
40	2.56%±0.16%	1.77%±0.24%	0.89%±0.06%	1.02%±0.15%	2.32%±0.21%

According to the fitting curve in figure 3, the moisture on the sand surface and inside the dune at different positions regularly changes with the vertical distance. The humidity value at the depth of 30 cm inside the dune is higher than the fitting line.

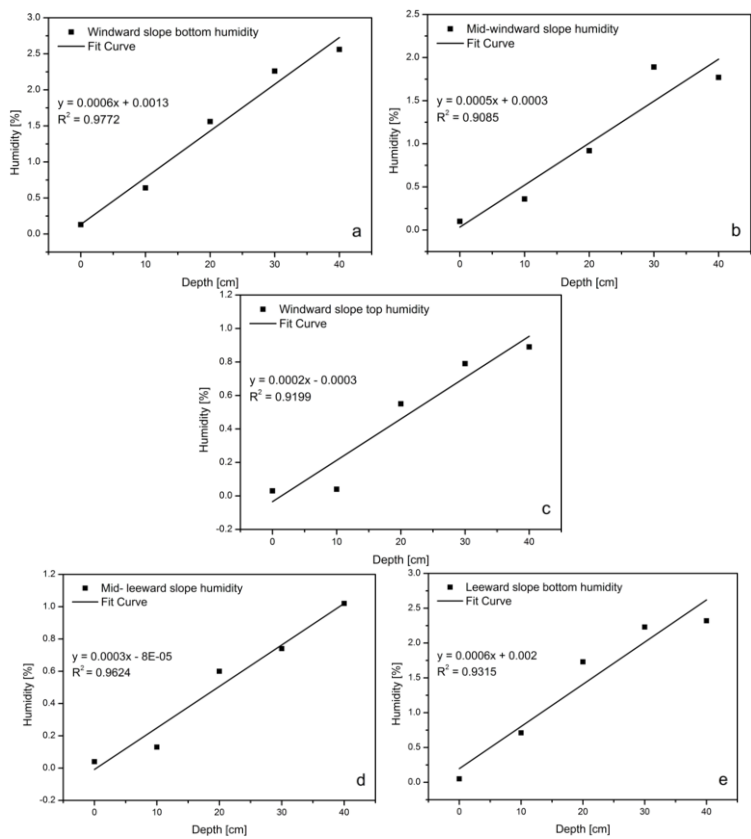


Figure 3. Fitting curve of humidity gradient in different positions of crescent dunes.

In the formula $\rho = ad + b$, $a = \partial \rho / \partial d$ is the humidity gradient, and b represents the change rate of humidity with depth. R^2 represents the fit degree; the greater the R^2 value, the better the fit. Table 3 shows the parameter values of humidity gradient fitting graph at five positions of the dune. It can be seen from table 3 that the humidity gradient values at the bottom of the windward slope and the leeward slope of the dune are the largest, both of which are 0.0006/cm. The humidity gradient at the top is the

minimum (0.0002/cm). The humidity gradient in the middle of the windward slope is 0.0005/cm, slightly larger than the humidity gradient in the middle of the leeward slope (0.0003/cm). It can be seen from the data that the humidity is high at the bottom of the windward slope and the leeward slope, suggesting that plants should be planted at the bottom. When planting plants for desert edge greening, sand dunes should be bulldozed, which would help moisturize the roots of plants.

Table 3. Fitting values of humidity gradient inside sand surface at different locations and depths.

	Windward slope bottom	Mid-windward slope humidity	Windward slope top	Mid- leeward slope	Leeward slope bottom
a (cm ⁻¹)	0.0006	0.0005	0.0002	0.0003	0.0006
b	0.0013	0.0003	-0.0003	-0.0000	0.0002
R ²	0.9772	0.9085	0.9199	0.9624	0.9315

4. Conclusion

In this paper, the surface and internal humidity of the sand collected from five locations of the barchan dune in Bachu, at the southwestern edge of the Taklimakan Desert, under natural environment in September were analyzed, and the following conclusions were drawn:

(1) The moisture percentage value of sand increases with the depth at the same location of the surface and interior of dunes. However, there is a turning point at a depth of 30 cm, and the humidity values decrease at depths greater than 30 cm. The dunes on the edge of the desert also indirectly reflect that when the average daily rainfall in Bachu County is 5 mm in September, the penetration depth of rainwater is 30 cm after 20 days of natural dunes.

(2) The sand humidity values on the surface and interior at the same depth at different locations were compared. For both the windward slope or the leeward slope, the closer the sand is to the top of the slope, the smaller the humidity values on the surface and interior of the sand. Conversely, the closer the sand is to the bottom, the greater the humidity values on the surface and interior of the sand. The water distribution on the leeward slope surface and interior of natural dunes is greater than that on the windward slope surface and interior.

(3) Surface and internal humidity gradients at different locations of dunes are different. The maximum humidity gradient on the windward slope and the bottom of the leeward slope is 0.0006/cm, the minimum humidity gradient on the top of the dune is 0.0002/cm, and that in the middle of the windward slope is 0.0005/cm, which is slightly higher than that in the middle of the leeward slope (0.0003/cm).

(4) Below the surface depth of 30cm, there is a wide range of humidity values at each location of the dune. Therefore, the roots of plants planted in dunes should be selected to survive easily in this range. The top of the dune is not suitable for planting greenery. If it is to be greened, the top of the dune should be bulldozed as much as possible.

Thus, studying the humidity change characteristics inside the dune surface provides effective data for planting trees on the edge of the desert, and allows comparison of the drip irrigation afforestation research on the edge of the desert on both sides of the highway in the central Taklimakan Desert. There are still many factors to be considered in the study of desert greening on the edge of oasis, such as the

temperature around the plant and the measures of sand-fixation and soil-fixation, which need to be paid more attention and studied in the future.

Acknowledgments

This work was partly supported by the Natural Science Foundation of Xinjiang Uygur Autonomous Region of China (No.2021D01A19) and National Natural Science Foundation of China (No. 11464022).

References

- [1] Li B, Dong G, Ding T, Jin J, Jin H and Gao S 1990 Some problems on wind-drift sand geomorphy in east Taklimakan Desert *Chinese Science Bulletin* **35** (23) 1815-1818.
- [2] Zhao J, Zhang C, Dong Z, Shao T and Li E 2011 Particle size composition and formation of the mega-dune in the Badain Jaran Desert *Journal of Geological* **85** (8) 1389-1398.
- [3] Pang Y, Qu J, Niu Q, Zhang K, Xie S and An Z 2017 Grain size characters of dune surface in sediment in the crescent spring scenic spot, Dunhuang *Arid Zone Research* **34** (3) 701-701.
- [4] Yu S, Abdolmikit, Zhou X and Huang X 2013 Grain size characteristics of different parts of the crescent dunes in Karakum Desert *China Journal of Desert Research* **33** (6) 1629-1635.
- [5] Qian Y, Zhou X and Wu Z 2000 Study on the grain size's characteristics of the sand materials in the junggar basin *Arid Zone Research* **17** (2) 34-41.
- [6] Zhang K, Qu J, Niu Q, An Z, Jing Z and Zhang W 2015 Near-surface aeolian sand paths and intensity around the crescent moon spring, Dunhuang *China Journal of Desert Research* **35** (3) 521-525.
- [7] Zhang Z, Dong Z, Zhao A, Han L, Qian W and Luo W 2007 Characteristics of aeolian sand activity in desert areas: A case study of aeolian sand observation field of Chinese Academy of Sciences *Arid Zone Research* **24** (4) 550-555.
- [8] Ding X, Zhou Z, Xu X, Lei J, Lu J, Ma X and Feng X 2015 Three-dimensional temporal and spatial dynamics of soil water for artificial vegetation in the center of Taklimakan desert under saline water drip-irrigation *Chinese Journal of Applied Ecology* **26** (9) 2600-2608.
- [9] Li F, Wang X, Lin J and Li N 2013 Effect of drip irrigation with brackish water with different salinities on soil alkali-hydrolyzable nitrogen content rhizosphere of zizphus jujube jujuba trees *Arid Zone Research* **30** (3) 424-429.
- [10] Zhang W, Yang S and Zhou X 2016 Analysis on the sandstorm weather changing characteristics and the climatic influence factors in Kashgar area *Journal of Arid Land Resources and Environment* **30** (6) 95-101.
- [11] Zhou X, Yu S, Mijiti A and Liu A 2013 Characteristics of blow sands environment in Buguli Desert *Arid Land Geography* **36** (5) 795-800.
- [12] Wen X 2015 Influence of sand fixation chemicals on biodiversities of plants and microorganisms on degraded sands *Chinese Agricultural Science Bulletin* **31** (22) 1-6.
- [13] Yang R, Zhao C, Wang X and Tang Y 2015 Research progress of stability of sand-binding plant communities *Journal of Central South University of Forestry & Technology* **35** (11) 128-134.
- [14] Chen X, Guo J, Dong Z, Li H, Li J and Wang H 2015 Effects of different land use types on fractal characteristics of soil in Ulan Buh *Journal of Arid Land Resources and Environment* **29** (11) 169-173.
- [15] Liu X, Zhang T, Zhao H, He Y, Yun J and Li Y 2006 Influence of dry sand bed thickness on soil moisture evaporation in mobile dune *Arid Land Geography* **29** (04) 523-526.
- [16] Xi H, Feng Q, Si J, Chang Z, Su Y and Guo R 2011 Spatiotemporal characteristics of soil Ejina oasis *Journal of Desert Research* **31** (1) 68-75.
- [17] Ding X, Zhou Z, Xu X, Lei J, Lu J, Ma X and Feng X 2015 Three-dimensional temporal and spatial dynamics of soil water for the artificial vegetation in the center of Taklimakan desert under saline water drip-irrigation *Chinese Journal of Applied Ecology* **26** (9) 2600-2608.
- [18] Zhang J, Xu X, Lei J and Li S 2010 Effects of salt crust on soilevaporation condition with saline-water drip-irrigation in extreme and region *Transaction of the CSAE* **26** (9) 34-39.