RESEARCH ON WATER MOVEMENT PARAMETERS OF INFERIOR SOIL OF DIFFERENT SITE TYPES IN MINING AREAS

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Abstract. The present research aims to explore the difference in water movement parameters of inferior soils in different site types; the undisturbed soil, mine-accumulated soil and ecologically modified soil in Wujiata Mining Area, Yiqi, Erdos City, Inner Mongolia, were taken as the research objects. The soil texture, soil diffusivity and water characteristic curve were measured through laboratory tests, and the soil water characteristic curve model suitable for inferior soils in mining areas was selected, and the variation laws of soil hydrodynamic characteristics such as water retention characteristics, effective water content and water conductivity characteristics of inferior soils in different site types were discussed. The Van Genuchten (VG) model shows the best fitting effect on the soil water characteristic curve model of inferior soils of different site types in mining areas. Under the same pressure head, the water characteristic curves of different horizons of soil are quite different; under the condition of 0-7000 cm pressure head, the water-holding capacity of undisturbed soil, mine-accumulated soil and ecologically modified soil decreases with the increase of depth. The soil water characteristic curve changes greatly in the low-pressure head section (<1000 cm) and relatively gently in the middle and high-pressure head section (>1000 cm). The water-holding capacity of ecologically modified soil is obviously enhanced. Ecological restoration can improve the poor soil structure in the research area, optimize the soil structure, and control the soil erosion obviously.
Keywords: *inferior soil, soil water, water characteristic curve, unsaturated hydraulic conductivity*

Introduction

Soil water is an important part of water balance and water cycle, and the research on soil water movement and its law has always been highly attended in soil water research (Sun et al., 2021; Li and Song, 2020; Zhang and Wang, 2003). With the continuous integration and development of computer science and “3S” and other fields, the research direction of soil water has been further expanded. The traditional soil water research based on single-point infiltration process and indoor simulation has gradually changed into the improvement and coupling of soil water movement model. On the other hand, some scholars began to focus on numerical simulation at the scale of “watershed” and studied soil water movement by combining with “3S” technology (Li et al., 2015; Wei et al., 2015; Zhang and Wang, 2007). The hydrus-1d model and the RETC software are often used to determine the unsaturated water movement parameters of the soil (Ma et al., 2017) by means of capacitance and water content (Wang et al., 2021), to obtain the infiltration characteristics of the soil and to analyze the differences (Zhao et al., 2022; Dong et al., 2017) in the hydraulic characteristics of different soil layers (Hu et al., 2017; Gu et al., 2021). hydrus-1d models are often used to study the infiltration patterns of soil water (Pan et al., 2021) and to investigate the influence of soil hydraulic parameters on the long-range correlation of soil water under different climatic conditions (Li et al., 2022).

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The results show that soil structure and soil texture have an obvious influence on soil water movement. Excellent soil texture and soil structure are capable obviously promoting soil water movement, so many researchers have made researches on the topic, but the research on poor soil is rare. Soil in mining areas can be regarded as a typical representative of poor-quality soil because of the damage of soil structure during excavation. Research on the water movement and its law of inferior soil plays an important role in researching the ecological restoration of mining areas, and has a great influence on maintaining the structural and functional stability of ecosystems (Yadav and Kumar, 2017; Lehmann et al., 2018; Dong et al., 2018).

Aiming at the soil environmental problems caused by open-pit mining in Western Inner Mongolia, the present research plans to take undisturbed soil, mine-accumulated soil and ecologically modified soil in Wujiata mining area of Yiqi, Erdos City as the research objects, set up sample plots in soil areas with different site types, and take stratified sampling. By measuring the soil texture, soil diffusivity and water characteristic curve of inferior soil in different site types in the mining area, the change laws of soil hydrodynamic characteristics, such as water holding or retention characteristics, effective water content and hydraulic conductivity characteristics of inferior soils in different site types can be analyzed. Then, the physical and chemical properties of different soils and their correlation can be further studied, thereby finally concluding the change laws and response mechanisms of soil physical and chemical properties, which served as theoretical support and scientific basis for ecosystem restoration in mining areas.

Research methods and data sources

Overview of the research area

The research area is located in Wujiata Mining Area (39 15’ 16 “N, 110 05’ 56” E), Yiqi, Erdos City, Inner Mongolia. The research area is located in Mu Us Sandland, with fragile ecology, low annual average temperature of only 7.3 ℃, as well as low annual precipitation, ranging from 325 mm to 460 mm all the year round, as a semi-arid continental monsoon climate. It is located in the sandy land and has a long sunshine exposure time, with its high annual evaporation ranging from 2297.4 mm to 2838.7 mm, its annual average wind speed of 3.6 $m \cdot s^{-1}$. The terrain in the research area is complex, mainly hills and valleys. Due to the influence of geographical distribution, geomorphology and hydrogeological conditions, zonal soil and hidden soil are distributed in the research area, and aeolian sand accounts for about 70% of the research area, which is the main soil type.

Research methods

In this research, samples were collected and tested from three different site types: undisturbed soil, mine-accumulated soil and ecologically modified soil. The sampling period is 2018. The sampling point map is shown in *Figure 1*. The vegetation in the undisturbed soil sample plot is a mixed structure of natural grassland and artificial shrubs, and the artificial shrubs are distributed in intermittent strips, mainly *Salix psammophila* and *Caragana korshinskii*. After two years of natural recovery, the soil sample plot is covered with short-lived plants such as *Sarcophora*, associated *Corispermum declinatum*, etc. The vegetation coverage is less than 15%, the height is below 20 cm, and it is

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distributed in patches, and there is almost no vegetation in some sections. The soil is bare and wind erosion is extremely serious. Since 2011, the ecological soil sample plot has been transformed by adopting the biological control measures, which combine arbor, shrub and grass. Arbors and *Salix psammophila* grids have been planted on the slope of the dump to prevent wind and sand. Grass seeds, *Caragana korshinskii* and sea buckthorn (*Hippophae rhamnoides* L.) have been planted in the grids, and pine trees have been planted on both sides of the road to form a green area where twisted strips, sea buckthorn (*Hippophae rhamnoides* L.) and grasses are planted.

Figure 1. *The sampling point map*

The undisturbed soil sampling point is numbered as 1#, the mine-accumulated soil sampling point is numbered as 2#, and the ecologically modified soil sampling point is numbered as 3#. Each sampling point takes 30 cm as a horizon of soil, with 3 horizons in total. Three bags of samples are randomly collected from each soil horizon in each sampling point. During sampling, the ring knife method is applied to measure the dry bulk density of undisturbed soil, mine-accumulated soil and ecologically modified soil. The mechanical composition of soil is measured and analyzed by laser particle size analyzer, the soil water diffusivity is measured by horizontal soil column method, the semi-infinite horizontal soil column imbibition experiment, and the soil pressure head and water content are measured by pressure film method. In RETC software, Van Genuchten (VG) and Brooks & Corey (BC) models are used to fit the soil water characteristic curve. The expression formula of VG and BC models are:

(1) Van Genuchten (VG) model:

$$\theta(h) = \theta_{res} + \frac{\theta_{sat} - \theta_{res}}{\left(1 + |\alpha h|^{n}\right)^{\frac{n-1}{n}}} \quad \text{(Eq.1)}$$

where θ represents the water content, $cm^3 \cdot cm^{-3}$; θ_{res} represents the residual water content, $cm^3 \cdot cm^{-3}$; θ_{sat} represents saturated water content, $cm^3 \cdot cm^{-3}$; h represents the pressure head, cm; and α and n are empirical fitting parameters.

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(2) Brooks & Corey (BC) model:

$$\theta = \begin{cases} \theta_r + (\theta_s - \theta_r)(\alpha h)^{-m} & (\alpha h > 1) \\ \theta_s & (\alpha h \le 1) \end{cases} \quad \text{(Eq.2)}$$

where θ represents the water content, $cm^3 \cdot cm^{-3}$; θ_r represents the residual water content, $cm^3 \cdot cm^{-3}$; θ_s represents saturated water content, $cm^3 \cdot cm^{-3}$; h represents the pressure head, cm; and α and n are empirical fitting parameters.

Results and analysis

Soil texture

Because of the different site types of inferior soil, the bulk density of soil shows obvious differences in different soil horizons; but the bulk density of the same soil has little difference in different soil horizons. The dry bulk density of different horizons of undisturbed soil is as follows: 1.778 $g \cdot cm^{-3}$, 1.751 $g \cdot cm^{-3}$, 1.499 $g \cdot cm^{-3}$; the dry bulk density of different soil horizons of mine-accumulated soil is as follows: 1.747 $g \cdot cm^{-3}$, 1.563 $g \cdot cm^{-3}$, 1.468 $g \cdot cm^{-3}$; the dry bulk density of different soil horizons of ecologically modified soil is as follows: 1.602 $g \cdot cm^{-3}$, 1.665 $g \cdot cm^{-3}$, 1.578 $g \cdot cm^{-3}$; the average dry bulk density of each soil sample is as follows: 1.676 g/cm^{-3}, 1.593 g/cm^{-3} and 1.615 $g \cdot cm^{-3}$. It can be seen that the average bulk density of undisturbed soil in the mining area is higher than that of ecologically improved soil and mine-accumulated soil. Three kinds of dry bulk density all change with the change of soil horizon, and the general change laws of dry bulk density of each soil sample according to the depth of soil horizon are detailed as follows: 0 ~ 30 cm > 30 ~ 60 cm > 60 ~ 90 cm.

The content of soil particle size components measured by soil particle size experiment is shown in *Table 1,* and the soil texture is analyzed in combination with the classification map of American soil texture. It is obvious from *Table 1* that the three kinds of soil samples belong to sandy soil, and in terms of the content, grit > powder > cosmid.

Table 1. *Composition of soil particles*

Soil sample	Soil horizon (cm)	Grit (%)	Powder particle (%)	Cosmid (%)
1#	0 ~ 30	95.73	3.97	0.30
	30 ~ 60	94.48	5.28	0.24
	60 ~ 90	95.62	4.17	0.21
2#	0 ~ 30	87.47	11.89	0.64
	30 ~ 60	86.33	13.07	0.60
	60 ~ 90	88.54	10.95	0.51
3#	0 ~ 30	95.72	4.11	0.17
	30 ~ 60	96.98	2.92	0.10
	60 ~ 90	98.29	1.61	0.10

The average particle composition of undisturbed soil is 95.28% grit, 4.47% powder and 0.25% cosmid; the average particle composition of mine-accumulated soil is 87.45%

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grit, 11.97% powder and 0.58% cosmid; the average particle composition of ecologically improved soil is 97.00% grit, 2.88% powder and 0.12% cosmid. Ecologically modified soil has the highest content of grit, followed by undisturbed soil, and finally mine-accumulated soil. With the increase of the depth, in ecological modified soil the particle composition of grit gradually increases, and the particle composition of powder and cosmid gradually decreases; in undisturbed soil and mine-mine-accumulated soil, the particle composition of grit decreases at first and then increases, while that of powder increases at first and then decreases, while that of cosmid decreases, like that of ecological modified soil, but when the particle composition of cosmid in ecological modified soil decreases to a certain value, it tends to become stable. Ecological restoration has improved the soil particle size and pore structure in the mining area, and the soil structure has undergone favorable changes, which have been significantly improved (Song et al., 2022).

Model fitting of soil moisture characteristic curve

The pressure film instrument method is used to measure the soil pressure head and water content in the mining area. Taking the water content θ as the ordinate and the pressure head h as the abscissa, the soil water characteristic curves of three soils at different depths of 0 ~ 30 cm, 30 ~ 60 cm and 60 ~ 90 cm are shown in *Figures 2, 3* and *4*.

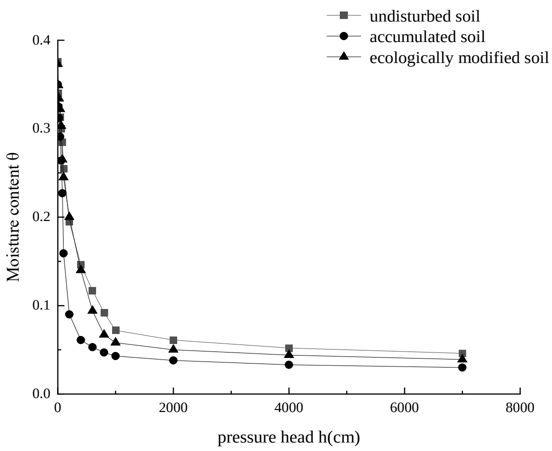

Figure 2. *0 ~ 30 cm soil moisture characteristic curve*

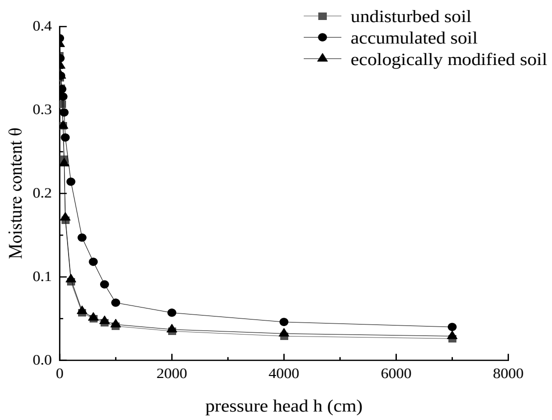

Figure 3. *30 ~ 60 cm soil moisture characteristic curve*

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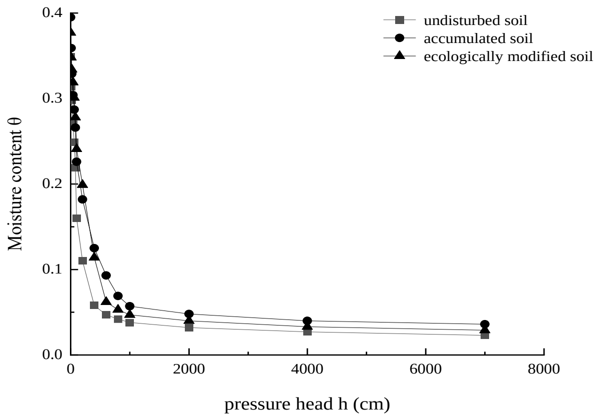

Figure 4. *60 ~ 90 cm soil moisture characteristic curve*

It is shown from *Figures 2-4*: with the increase of pressure head, the wet weight of soil gradually decreases, and the soil moisture content gradually decreases. The soil moisture content at the buried depth of 0 ~ 30 cm is higher than 30 ~ 60 cm and 60 ~ 90 cm. The minimum pressure head is 0 cm and the maximum pressure head is 7000 cm. Under different soil depths, the change of soil water content of undisturbed soil, mine-accumulated soil and ecological modified soil is the most obvious at the pressure head of 100 cm.

The overall change trend of soil water characteristic curve is basically the same, and three different types of inferior soils are all in “L” shape at the same depth. The water content θ decreases with the increase of the pressure head. 1000 cm pressure head is an obvious milestone. Before the pressure head reaches this milestone, the water content θ decreases obviously, and the curve shows a rapid downward trend. After that, the change is relatively gentle, and the curve begins to show a horizontal trend. Separately, in the same depth soil horizon, obvious differences can be observed in the water characteristic curves of different kinds of site soils. When the pressure head is the same (for example, 2000 cm at the depth of 0 ~ 30 cm), the water content of undisturbed soil, mine-accumulated soil and ecologically modified soil are 0.038, 0.061 and 0.05 respectively. The soil water characteristic curve changes greatly in the low-pressure head section (<1000 cm) and relatively gently in the middle and high-pressure head section (>1000 cm).

It can be clearly seen from the figure that the ecological restoration has an impact on the soil water characteristic curve, and it moves up as a whole compared with the soil water characteristic curve of mine-accumulated soil. In another word, under the same soil water suction, the soil moisture content of ecologically modified soil is larger than that of mine-accumulated soil and less than that of undisturbed soil. The main reason is that, after ecological restoration, the soil pore structure is improved, the soil porosity is reduced, and the water retention is enhanced. Compared with the original soil, there is still a gap, but the overall improvement has been obvious.

Soil water characteristic curve reflects the relationship between soil water and potential energy, and fully shows the dynamic characteristics of soil water, so it can be called an important basis for researching and analyzing soil water (Su et al., 2018; Fredlund, 2019; Lu et al., 2014). Soil structure, texture and other factors have great influence on soil water, so it is often necessary to combine these factors when analyzing

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soil water characteristic curve (Lu and Likos, 2006). Under the same pressure head, the water content of mine-accumulated soil decreases rapidly. Combined with the soil texture, it can be clearly shown that the mine-accumulated soil has a high content of powder particles. In this case, compared with the other two kinds of soils, there are more macropores in the overall structure, which leads to this situation. In the low-pressure head section (<1000 cm), the part of the curve shows a steep and straight trend. With the increase of pressure head, the curve trend changes gently, and the overall change trend is obvious.

In RETC software, Van Genuchten (VG) model and Brooks & Corey (BC) model are used to fit the soil water characteristic curves for three site types.

It is shown from *Table 2* that the R^2 of each soil sample at different soil depths is larger, reaching above 0.99, with a high degree of fitting. It shows that Van Genuchten (VG) model can simulate the soil water characteristic curves of three site types. The residual water content θ_{sat} of all soil samples decreases with the depth, except for the depth of 30 ~ 60 cm in ecologically modified soil, with the most drastic decrease from the depth of 30 ~ 60 cm to the depth of 60 ~ 90 cm, and the minimum residual water content θ_{sat} of mine-accumulated soil at the depth of 60 ~ 90 cm is only 0.0001. Compared with the undisturbed soil, the saturated water content (θ_{sat}) of the mine-accumulated soil and the ecologically modified soil shows a rising trend, and the residual water content θ_{sat} of the mine-accumulated soil at the depth of 60 ~ 90 cm is the largest, 0.36702.

Table 2. *Fitting parameters of Van Genuchten (VG) model*

Soil sample	Soil horizon (cm)	θ_{res}	θ_{sat}	α	n	R^2
1#	0 ~ 30	0.03645	0.33211	0.01402	2.56173	0.99384
	30 ~ 60	0.03334	0.34623	0.01337	2.61185	0.99394
	60 ~ 90	0.02089	0.32776	0.01647	2.03820	0.99267
2#	0 ~ 30	0.02060	0.35582	0.01351	1.53046	0.99284
	30 ~ 60	0.01168	0.36702	0.01118	1.64694	0.99448
	60 ~ 90	0.00001	0.37531	0.01954	1.55163	0.99192
3#	0 ~ 30	0.01533	0.35756	0.01235	1.70200	0.99225
	30 ~ 60	0.03478	0.36187	0..01448	2.51940	0.99596
	60 ~ 90	0.01285	0.35464	0.01069	1.86914	0.99092

It can be shown from *Table 3* that R^2 of fitting parameters of Brooks & Corey (BC) model is all up to 0.97, which is less than Van Genuchten (VG) model, but it can also simulate soil moisture characteristic curve well. The residual water content (θres) is obviously different from Van Genuchten (VG) model, and it is 0.00001 for multi-horizon soil. There is little difference in saturated water content. Compared with undisturbed soil, the saturated water content (θsat) of mine-accumulated soil and ecologically modified soil shows a rising trend. The value α is the reciprocal of soil water suction value at the inflection point when the water characteristic curve is close to saturation. The larger the value α is, the worse the soil water holding capacity is. It is shown from the parameters fitted by the two models, α of the ecologically modified soil at the depth of 0 ~ 30 cm and 60 ~ 90 cm is less than that of the mine-accumulated soil, and the water holding capacity is better, but the depth of 30 ~ 60 cm is the opposite. m and n are shape coefficients, reflecting the bending degree of the fitted curve. Compared

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with the undisturbed soil, the other two soils show a downward trend, and the mine-accumulated soil is less than the other two soils at different depths. On the whole, the Van Genuchten (VG) model shows a better fitting effect on soil water characteristic curves of three site types in mining areas.

Table 3. *Fitting parameters of the Brooks & Corey (BC) model*

Soil sample	Soil horizon (cm)	θ_{res}	θ_{sat}	α	m	R^2
1#	0 ~ 30	0.03076	0.31950	0.01972	1.08333	0.98884
	30 ~ 60	0.00884	0.34333	0.02613	0.70469	0.98261
	60 ~ 90	0.00001	0.32033	0.02921	0.59970	0.98261
2#	0 ~ 30	0.00001	0.34667	0.02538	0.39795	0.97830
	30 ~ 60	0.00001	0.35350	0.01901	0.46268	0.98403
	60 ~ 90	0.00001	0.36100	0.03006	0.44907	0.97842
3#	0 ~ 30	0.00001	0.35200	0.02450	0.44706	0.98019
	30 ~ 60	0.01372	0.35767	0.02692	0.73615	0.98718
	60 ~ 90	0.00001	0.34450	0.01906	0.57468	0.98008

Soil diffusivity

It is shown from the measured data that the soil water diffusivity decreases with the decrease of water content. Further comparative analysis of soil samples concludes the relationship between soil diffusivity $D(\theta)$ and water content θ in three different sites, as shown in *Figures 5*, *6* and *7*.

It can be clearly shown from the figure that the soil curves of each site type have a good exponential relationship. Obviously, the diffusivity is proportional to the water content θ, but when it reaches a critical value at a certain point, the critical values of different soil types at different depths are different. When it exceeds this critical value, the diffusivity begins to show a downward trend. The soil diffusivity $D(\theta)$ and water content of the same site type are significantly different at different depths ($p < 0.05$). The difference between curves of different site soils at the same depth is also very obvious.

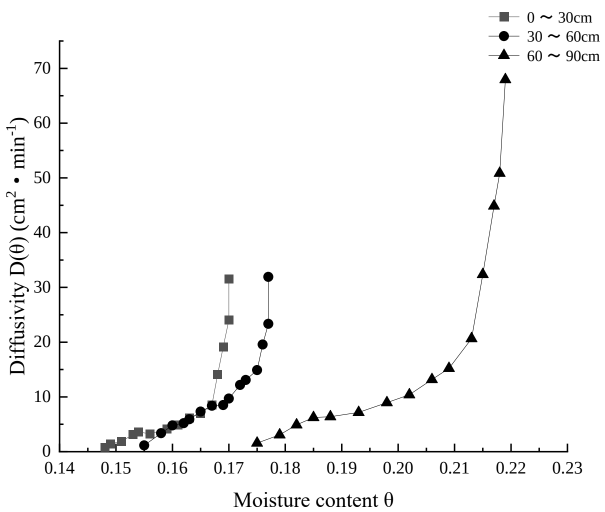

Figure 5. *The relationship between soil water diffusion rate D (θ) and θ at different depths of undisturbed soil*

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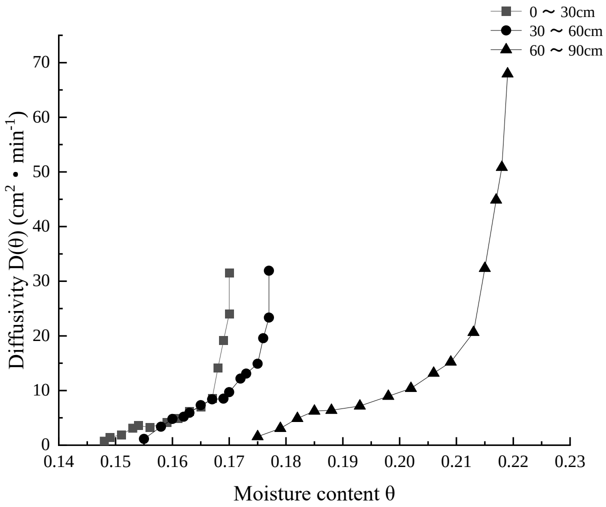

Figure 6. *The relationship between soil water diffusion rate D (θ) and θ at different depths of mine-accumulated soil*

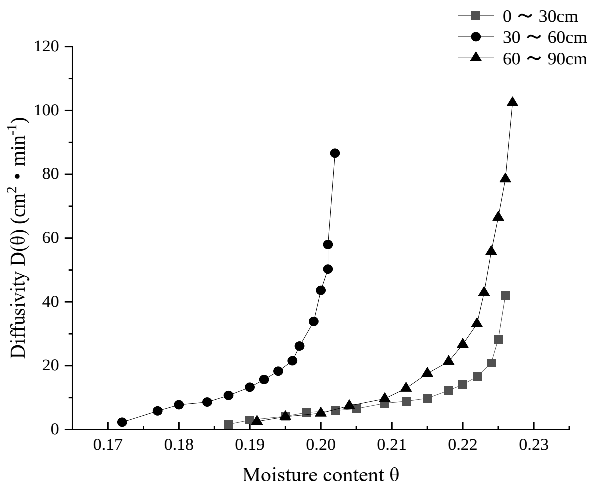

Figure 7. *The relationship between water diffusion rate D (θ) and θ in different depths of ecologically modified soil*

Comparing the soils of three site types, it is obvious that: The maximum diffusivity of the deposited soil is 268.957 $cm^2 \cdot min^{-1}$ at the depth of 30 ~ 60 cm. Among the three soils, the undisturbed soil has the smallest diffusivity, and the diffusivity of each horizon of soil is less than 70 $cm^2 \cdot min^{-1}$, and that at the depth of 0 ~ 60 cm is less than 32 $cm^2 \cdot min^{-1}$. Compared with the mine-accumulated soil, the diffusion rate of the ecologically improved soil at the depth of 30 ~ 60 cm decreased to 86.579 $cm^2 \cdot min^{-1}$, with a decrease rate of 67%, after ecological restoration measures combining arbor, shrub and grass are taken.

Firstly, it is analyzed from the perspective of soil physical properties. Soil can affect the diffusivity through its surface soil solid particles and capillary pores, and different soil texture will have different effects on diffusivity (He and Wang, 2019; Carrick et al., 2011; Laio et al., 2009; Laio, 2006; Kawamoto et al., 2006). The adsorption of soil is directly proportional to its surface area. When the θ increment is the same, the water in

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sandy soil spreads faster because of matrix suction, while cohesive soil does the opposite. Secondly, the more and larger the pores in the soil, the more obvious the effect of promoting the diffusion of water is. When θ decreases, the force applied changes from capillary force to adsorption force, and the water in the soil also changes from capillary water to bound water. At the same time, the binding force on the surface of soil particles increases, which is unfavorable to the diffusion of water. On the contrary, when θ increases, the number of water-filled capillaries in soil increases, and the pores become larger, which further promotes the diffusion of water.

The relationship between diffusivity $D(\theta)$ and water content θ in each soil horizon is established by using exponential equation and measured data, and the curve fitting is performed according to the data of diffusivity $D(\theta)$ and water content θ. The fitting results are shown in *Table 4*.

Table 4. *Diffusion rate fitting results*

Soil sample	Soil horizon (cm)	Fitting formula	R^2
1#	0 ~ 30	$D(\theta)$ = 1E - 08$e^{70.282\theta}$	0.9266
	30 ~ 60	$D(\theta)$ = 1E - 07$e^{62.127\theta}$	0.9185
	60 ~ 90	$D(\theta)$ = 2E - 05$e^{44.876\theta}$	0.9319
2#	0 ~ 30	$D(\theta)$ = 1E - 04$e^{39.748\theta}$	0.9275
	30 ~ 60	$D(\theta)$ = 4E - 05$e^{43.234\theta}$	0.9272
	60 ~ 90	$D(\theta)$ = 3E - 06$e^{45.719\theta}$	0.9613
3#	0 ~ 30	$D(\theta)$ = 1E - 05$e^{39.729\theta}$	0.9451
	30 ~ 60	$D(\theta)$ = 1E - 07$e^{59.589\theta}$	0.9479
	60 ~ 90	$D(\theta)$ = 3E - 08$e^{59.583\theta}$	0.9627

Generally, the diffusivity is affected by soil water content, bulk density, particle composition, porosity and other factors. Under a certain dry bulk density, the more cosmid content, the greater capillary porosity, the faster diffusion rate and the less water content. Similarly, under a certain cosmid content, the larger the dry bulk density, the larger the capillary porosity, the faster the diffusion rate and the less the water content.

Discussion

In arid and semi-arid areas, soil water is often the most important limiting factor that can affect ecology. The structural and functional stability of the ecosystem is closely related to it. Mining in the mining area will cause the destruction of soil structure, and change in the soil structure, porosity and moisture content. With the changes of these factors, the water movement will also change, thereby causing serious damage to surface water and underground water system. The research results of Lv Jingjie et al. show that the soil moisture content in the mine-accumulated soil area decreases. Compared with the other two site types, the drastic spatial variation worsens the living environment of the surface vegetation and seriously damages the surface landscape (Ma et al., 2013; Zhang et al., 2009; Lv et al., 2005).

As an index of basic physical properties of soil, soil bulk density can significantly affect soil water permeability, air permeability, water holding capacity and solute transport. The soil bulk density of different soil horizons of mine-accumulated soil is

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less than that of undisturbed soil and ecologically modified soil. With the stability of soil subsidence, the soil bulk density difference with other two site types tends to decrease. Mining subsidence in mining area significantly affects the physical characteristics of surface soil. It is considered that subsidence causes the migration of fine-grained materials on soil slopes, resulting in sandy phenomenon, among which soil water content is the most affected factor. Relevant research shows that many factors affect the characteristic curve of soil water, among which porosity, bulk density, texture and human activities are regarded as the major affecting factors. There is a good positive correlation between unsaturated soil diffusivity and water content θ, and the former can increase with the increase of θ. The water content θ is greatly influenced by soil texture, bulk density and other factors, and then has different effects on diffusivity.

After two years' natural recovery, the mine-accumulated soil in Wujiata mining area has been covered by short-lived plants such as *Chenopodium album*, *Chenopodium glabra*, *Salsola salsa*, and *Salsola collina*. The vegetation coverage is less than 15%, and the height is below 20 cm. the plants are distributed in patches, and there is almost no vegetation in some sections. At present, it is still in the quicksand vegetation structure dominated by pioneer plants. After seven years of ecological restoration, the vegetation structure of the modified soil sample plot is close to the original soil, and the soil erosion is basically controlled. However, it has not reached the level of undisturbed soil landform vegetation, it still needs longer time to recover.

Conclusions

In this paper, the undisturbed soil, mine-accumulated soil and ecologically modified soil in Wujiata mining area, Yiqi, Erdos City, Inner Mongolia are selected as three inferior soils with different site types. All three soils are sandy.

With the increase of the depth of the three inferior soils, the relative content of cosmid in the soil structure decreases, and the bulk density also decreases. Van Genuchten (VG) model shows the best effect on simulating the water characteristic curve of inferior soil in different site types in the mining area. The soil moisture characteristic curves of three different soils in different depth horizons show the same trend as a whole, and all of them show a good "L" shape. When the inferior soil is pressurized, the water content is inversely proportional to it, and then decreases. Under the condition of 0-7000 cm pressure head, the water content θ of undisturbed soil, mine-mine-accumulated soil and ecologically modified soil decreases with the increase of depth, or the water holding capacity is inversely related to the depth. The soil water characteristic curve changes greatly in the low-pressure head section (<1000 cm) and relatively gently in the middle and high-pressure head section (>1000 cm). The water-holding capacity of the ecologically modified soil is enhanced. Ecological restoration is capable of improving the inferior soil structure in the research area, and optimizing the overall structure obviously; making the vegetation structure close to the original soil vegetation, enhancing the ability to regulate water, and controlling the soil erosion basically.

REFERENCES

[1] Carrick, S., Buchan, G., Almond, P., Smith, N. (2011): Atypical early-time infiltration into a structured soil near field capacity: The dynamic interplay between sorptivity, hydrophobicity, and air encapsulation. – Geoderma 160(3-4): 579-89.

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DOI: http://dx.doi.org/10.15666/aeer/2005_45254537

[2] Dong, Y. Y., Hu, S. J., Zhao, C. Y., Zhu, H., Wang, D. D., Ding, Z. Y. (2017): One-dimensional horizontal infiltration test for determining permeability coefficient of aeolian sandy soil in interdune at the southern edge of Gurbantünggüt Desert. – Arid Land Ceography 40(04): 729-736.
[3] Dong, S. Y., Guo, Y., Yu, X. (2018): Method for quick prediction of hydraulic conductivity and soil-water retention of unsaturated soils. – Transportation Research Record 2672(52): 108-17.
[4] Fredlund, D. G. (2019): State of practice for use of the soil-water characteristic curve (SWCC) in geotechnical engineering. – Canadian Geotechnical Journal 56(8): 1059-69.
[5] Gu, J. Y., Yang, B. G., Wei, Y. J., Cai, C. F. (2021): Analysis on the difference of soil hydraulic properties in different soil layers of Benggang. – Journal of Soil and Water Conservation 35(2): 61-67.
[6] He, D., Wang, E. L. (2019): On the relation between soil water holding capacity and dryland crop productivity. – Geoderma 353(11-24).
[7] Hu, C. W., Wang, H., Liu, C., Yuan, H., Li, Y. Y. (2017): Difference analysis of hydraulic characteristics of typical soils in South China. – Journal of Soil and Water Conservation 31(2): 97-102.
[8] Kawamoto, K., Moldrup, P., Ferre, T. P. A., Tuller, M., Jacobsen, O. H., Komatsu, T. (2006): Linking the Gardner and Campbell models for water retention and hydraulic conductivity in near-saturated soil. – Soil Science 171(8): 573-84.
[9] Laio, F. (2006): A vertically extended stochastic model of soil moisture in the root zone. – Water Resources Research 420(2): 10.
[10] Laio, F., Tamea, S., Ridolfi, L., D'Odorico, P., Rodriguez-Iturbe, I. (2009): Ecohydrology of groundwater-dependent ecosystems: 1. Stochastic water table dynamics. – Water Resources Research 45(5): 207.
[11] Lehmann, P., Merlin, O., Gentine, P., Or, D. (2018): Soil texture effects on surface resistance to bare-soil evaporation. – Geophysical Research Letters 45(19): 10398-405.
[12] Li, Y., Song, W. F. (2020): Advances in numerical simulation of soil moisture movement. – Subtropical Soil and Water Conservation 32(2): 26-31.
[13] Li, C. M., Yang, Y. G., Qin, Z. D., Zou, S. B., Li, J. C. (2015): Simulation and prediction on variations of groundwater in mining area based on FEFLOW and GIS. – Arid Land Geography 38(2): 359-367.
[14] Li, L., Wu, D. D., Wang, T. J., Di, C. L. (2022): Effects of soil hydraulic parameters on long-range correlation of soil moisture based on numerical simulation. – Journal of Soil and Water Conservation 36(1): 80-85 + 94.
[15] Lu, N., Likos, W. J. (2006): Suction stress characteristic curve for unsaturated soil. – Journal of Geotechnical and Geoenvironmental Engineering 132(2): 131-42.
[16] Lu, N., Kaya, M., Godt, J. W. (2014): Interrelations among the soil-water retention, hydraulic conductivity, and suction-stress characteristic curves. – Journal of Geotechnical and Geoenvironmental Engineering 140(5): 10.
[17] Lv, J. J., Hu, C. Y., He, X. (2005): Studied on the influences of coal mining collapse on the soil water dynamics of fixed dune. – Journal of Arid Land Resources and Environment S1: 152-156.
[18] Ma, Y. B., Gao, Y., Zhang, Y., Zhang, L. W., Huang, Y. R. (2013): Infuence of collapse and cracks of rolling loess area because of coal mining to the soil moisture of slope surface. – Soil and Water Conservation in China (11): 54-57 + 79.
[19] Ma, M. H., Zhang, S. H., Wang, H. X., Yang, H. C., Li, Q. (2017): Parameters of unsaturated soil moisture movement: a case study of red soil in Kunming. – Journal of Beijing Normal University (Natural Science) 53(1): 38-42.
[20] Pan, Z. H., Li, P., Xiao, T. (2021): The law of water infiltration in loess based on numerical simulation. – Journal of Northwest University (Natural Science Edition) 51(3): 470-484.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_45254537

[21] Song, L., Li, J. H., Zhou, T., Fredlund, D. G. (2017): Experimental study on unsaturated hydraulic properties of vegetated soil. – Ecological Engineering 103(207-16）.
[22] Su, S., Yang, Y. G., Huang, L. (2018): Dynamic characteristics of soil water in different sites during ecological restoration in mining area. – Bulletin of Soil and Water Conservation 38(01): 18-23.
[23] Sun, F. H., Xiao, B., Li, S. L., Wang, F. F. (2021): Effects of moss-dominated biocrusts on surface soil-water movement parameters in the Chinese Loess Plateau. – Transactions of the Chinese Society of Agricultural Engineering 37(14): 79-88.
[24] Wang, J. K., Guo, Y. F., Qi, W., Yao, Y. F., Wang, H. (2021): Horizontal infiltration characteristics and applicable models of Pisha sandstone soil in Inner Mongolia. – Journal of Inner Mongolia Agricultural University (Natural Science Edition) 42(5): 46-52.
[25] Wei, G. X., Wang. D. J., Wang. G., Li. C. B., Zhu, F., Xu, T. (2007): Application of GIS technique and FEFLOW to numerical simulation of groundwater system in Jiuquan East Basin. – Journal of Lanzhou University (Natural Sciences) 6: 1-6.
[26] Yadav, R. R., Kumar, L. K. (2017): One-dimensional spatially dependent solute transport in semi-infinite porous media: an analytical solution. – International Journal of Engineering, Science and Technology 9(4): 20-27.
[27] Zhang, C., Wang, H. X. (2003): A brief review of advances in soil water research. – Agricultural Research in the Arid Areas 4: 117-120 + 125.
[28] Zhang, X., Wang, J., Liu, C. Y. (2009): Influences of coal mining subsidence on soil water loss and its mechanisms. – Journal of Anhui Agricultural Sciences 37(11): 5058-5062.
[29] Zhao, W., Zhao, J., Wei, Z. M., Yin, C. Y., Liu, H., Zhu, B. (2022): Effect of aeolian sandy soil improved by gasification slag on soil water physical properties. – Research of Soil and Water Conservation 29(02): 64-69.

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