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Soil Moisture Mechanism in Fixed Sand Dunes of Artemisia Ordosica Community in Mu Us Sandy Land

Liang Xianghan

Management Committee of Beijing Olympic Park Central Area, Beijing, 100101, China

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Abstract: In order to deeply analyze the factors that affect the change of soil moisture, this study carried out long terms and continuous monitoring of soil moisture at different depths of fixed sandy land of Artemisia ordosica community in Maousu sandy land from a large time scale and different levels of spatial scale, And observed the distribution of soil moisture at 0-200 cm layer during the study period, Redundancy analysis is used to analyze the factors (including meteorological, root and soil factors) that affect the soil water storage in each time period, identifying the redundant factors, and then comprising the main variables to calculate their contribution rate to the change of soil water storage The results showed that (1) RDA analysis was adapted in this study, and 13 factors affecting soil water storage were considered These environmental factors accounted for more than 85% of the change of soil water storage in the first two ranking axes, and the maximum value of EC index in the first two axes also exceeded 90% The interpretation results were satisfactory (2) After applying the previous selection and Monte Carlo replacement test, it can be included that only precision, precision interval, precision intensity, root biomass, and initial soil moisture can have a significant impact on soil moisture The top two environmental factors in various places, time periods and soil layers can provide more than 80% of RCC (3) After identifying redundant variables, although the number of environmental factors has decreased a lot, the degree of interpretation of environmental factors on soil water storage has not decreased significantly For the soil water layer with sharp change and active soil water layer in the non-growing season, root biomass and precision are the first two factors affecting the change of soil water storage; In the growing season, root biomass and initial soil water content are the first two factors that affect the change of soil water storage.

The northwest region of China has low precipitation, strong evapotranspiration, and low soil moisture, resulting in various arid and semi-arid landforms and landscapes, forming a desert ecosystem [1-3]. The formation and succession process of desert ecosystems are closely related to water, and water is one of the most active components in the system [4-6]. Precipitation, artificial irrigation, and condensed water all need to be converted into soil water through infiltration before they can be absorbed and utilized by plants. Soil water refers to the water content in the soil layer from the surface of the soil to the groundwater level above. It is an important component of water resources in desert ecosystems and serves as a bridge connecting precipitation, surface water, atmospheric water, and groundwater. In arid and semi-arid areas, soil moisture severely restricts plant growth and development, and land degradation is directly related to the decrease in soil moisture content. Therefore, research on soil moisture is of great significance for local vegetation restoration and reconstruction.

Artemisia ordosica is one of the most important constructive and dominant species in the Mu Us sandy land. 29.9% of the sand area is the Artemisia annua community, which is the largest area of local plant communities. Existing studies have shown that the natural succession process of Artemisia annua communities is characterized by mobile sandy land (pioneer species stage) - semi fixed sandy land (sparse stage) - fixed sandy land (built-up stage) - old fixed sandy land (degradation stage) - mobile sandy land. Scholars have made certain research progress on the influencing factors of soil moisture in Artemisia annua communities at different successional stages in Mu Us sandy land [7-11]. However, soil moisture is influenced by multiple factors, and current research mostly focuses on the study of a single factor, with very little research on the interaction of multiple factors; Although many scholars have conducted relevant research on the influencing factors of soil moisture before, there is currently almost no specialized research on the influencing factors of soil moisture in sandy areas. Therefore, this study conducted long-term and continuous monitoring of soil moisture content at different depths of the fixed sandy land of Artemisia annua community in Mu Us sandy land on a large time scale and different spatial scales. The distribution of soil moisture content in the 0-200cm layer during the study period was obtained, and redundant analysis was used to analyze the factors that affect soil water storage in each time period (including meteorological, root, and soil factors), removing redundant factors. Then decompose the main variables and calculate their contribution rate to changes in soil water storage.

1. Overview of the research area

Table 1: Basic Information of the Sample Land in the Study Area

Stage	Type	Characters in land surface and vegetation	Vegetation coverage (%)
Pioneer stage	Shifting sandy land	The sandy land is covered by sporadic Agriophyllum squarrosum, Psammochloa villosa, Artemisia sphaerocephala krasch and Artemisia Ordosica. The soil is loose with no crust and easy to be eroded.	5-20
Sparse stage	Semi-fixed sandy land	The sandy land is covered by Artemisia Ordosica, Artemisia sphaerocephala krasch and Leymus secalinus. The coverage of crust is about 10%-30%.	20-30
Build phase	Fixed sandy land	The sandy land is covered by Artemisia Ordosica,Suaeda glauca,Setaria viridis and Bassia dasyphylla,The coverage of crust is about 60%-80% with the thickness is 0.5~1.5cm.	30-50

The research area is located in Wushen Banner, Ordos City, Inner Mongolia Autonomous Region, which is the central area of Mu Us Sandy Land. The sand area of Mu Us Sandy Land is 41900 square kilometers, with coordinates of 37 ° 26.5 ′ -39 ° 21.5 ′ N and 107 ° 20.4 ′ -111 ° 30.3 ′ E, with an overall elevation between 1150 meters and 1350 meters. The research area is located west of the 400mm equal precipitation line in China and belongs to a temperate continental climate. The annual average precipitation fluctuates between 270-350mm, and the distribution is extremely uneven throughout the year. The highest precipitation occurs from July to September each year, accounting for more than 75% of the annual precipitation. The interannual distribution of precipitation is also extremely uneven, with the highest annual precipitation within 50 years being 548mm and the lowest being only 185mm, with a difference of nearly three times. The annual average temperature is 6.5 ℃, and the average temperature in January is -10.3 ℃, which is the lowest throughout the year; The average temperature in July was 21.4 ℃, which is the highest throughout the year. The study area has frequent wind and sand activities, and the surface soil is loose. Therefore, sandy vegetation and grassland vegetation dominated by natural vegetation. Perennial herbs and shrubs such as Artemisia *sphaerocephala krasch*, *Salix cheilophila*, and *Artemisia sphaerocephala krasch* are constructive and dominant species in the ecosystem, followed by first and second year herbs such as *Agriophyllum squarrosum. There are* not many species of tall shrubs and trees. Artemisia annua is the most important community building species in the region and is also the preferred species for planting and aerial seeding [12-14]. Table 1 summarizes the sand and vegetation types under different vegetation cover levels in the Mu Us sandy land.

2. Research Methods

Dig soil profiles from the selected sample plots in the research area, and then take soil samples in layers according to the layering standards of 0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm, 100-120cm, 120-160cm, and 160-200cm, totaling 8 layers. The volume of the soil sample collected is 100 ^{cm3}, and then the soil moisture content, soil bulk density, soil porosity, and soil mechanical composition are measured.

Within the selected monitoring points, the vegetation coverage of the monitoring points was first measured to be 52.9%. The second step is to select Artemisia annua and measure its height, crown width, and diameter. In 2017, the aboveground biomass and fresh weight of Artemisia annua were measured. Finally, the root distribution was investigated using root drills and root digging methods (Figure 3.2). Samples were taken from the main roots of Artemisia annua obtained by root digging method, and the fresh weight of underground biomass was measured. Three Artemisia annua plants were investigated using root digging method at each monitoring point, and six plants were investigated using root drilling method. The selected plants were relatively independent (with a distance of more than 1m from the surrounding plants), and the height and crown width of each plant were visually similar in advance to eliminate interference from Artemisia annua growth and plant age. The range of root extraction for both methods is 0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm, 100-120cm, 120-160cm, and 160-200cm, with a total of 8 layers. After drying to a constant weight in the laboratory, weigh the dry weight and divide the roots into 0-1mm (fine roots), 1-2mm (medium coarse roots), and larger than 2mm (coarse roots) according to their thickness. Study the distribution of root systems in each soil layer underground.

For the process of soil moisture dynamics and precipitation infiltration, there are multiple influencing factors, and these influencing factors also interact with each other, not acting solely on soil moisture. Based on this, redundancy analysis (RDA) can be used to select a few factors with strong explanatory power from multiple influencing factors.

CANOCO, as a mainstream software in ecological research, has multiple functions such as sorting, regression, and permutation, which can be used for principal component analysis, correspondence analysis, redundancy analysis, canonical correspondence analysis, etc. The ranking methods of CANOCO are divided into linear model (CCA) and unimodal model (RDA). The main functions of sorting are: ① analyzing community structure; ② Analyze the relationship between communities and environmental factors; ③ Test the hypothesis that when a factor undergoes significant changes, the response process of the community and other environmental factors; ④ Analyze the impact of different ecological experiments on community composition. The advantage of CANOCO is that once a sorting process is calculated, it can immediately generate relevant sorting graphs and explain the variation process and results of the independent and dependent variables. Therefore, CANOCO can effectively solve many problems in ecological research.

The analysis process of CANOCO is as follows: ① Create two Excel worksheets with environmental variables and biological factors as data, and then copy the data ranges of these two worksheets separately; ② Save the data table as two DAT files using CANOCO for Windows WcanoIMP; ③ Use CANOCO to read DAT files and select appropriate models for analysis; ④

Draw using CANODRAW. In a redundant sorting chart, the closer the absolute value of the arrow angle is to the horizontal, the greater the correlation between the two factors.

3. Result analysis

3.1 Root distribution characteristics

The underground biomass is 343.87g, most of which are concentrated in the 0-40cm soil layer. The relationship between vegetation coverage and root biomass is $y=^{e2}.134x+^{x2}-^{3}.8064x+298.03$. The root biomass decreases exponentially with the increase of soil depth. As vegetation coverage increases, the proportion of fine roots gradually increases, while the proportion of coarse and medium coarse roots gradually decreases. Fine roots, medium coarse roots, and coarse roots are evenly distributed in each soil layer, and there is no significant change in the percentage of biomass of the three root systems in each soil layer, which is close to the average level of the entire root distribution layer.

3.2 Soil Physical and Chemical Properties

The average soil bulk density within the sample plot is 1.57g/cm3, and the minimum soil bulk density occurs in the 0-40cm layer (root layer), which is 1.52g/cm3. The effect of plant root distribution on soil bulk density varies among different layers, but overall it is holistic and does not specifically target a particular layer of soil. The trend of soil bulk density variation between different soil layers in the same area is not significant; The soil porosity fluctuates between 38% -42%; Coarse sand generally does not appear in the root layer, while the content of medium sand and fine sand fluctuates between 70% and 80% in each soil layer.

3.3 Redundancy analysis

In RDA analysis, the environmental factors considered are precipitation (PR), precipitation intensity (RI), precipitation interval (PI), soil bulk density (SBD), soil particle size and porosity (SPS), root biomass (RB), soil temperature (ST), wind and wind speed (WPS), solar radiation (SR), soil organic matter content (SN), air humidity (AH), soil porosity (SP), and initial soil moisture content before precipitation (ISM) . For the sake of analysis, typical correlation coefficients are usually divided into five categories, namely 0-0.1 (uncorrelated), 0.1-0.3 (weakly correlated), 0.3-0.4 (moderately correlated), 0.4-0.5 (significantly correlated), and 0.5-1 (highly correlated). The relevant parameters of environmental factors mainly include eigenvalue (EV), cumulative variance percentage of soil water (AVP), and correlation coefficient (EC) between soil water and environmental factors. These three parameters can reflect the explanatory power of various environmental factors on changes in soil water storage. Table 2 shows the distribution of parameters in different soil layers within the three types of plots. From the table, it can be seen that in 8 different time periods, these environmental factors explained more than 85% of the changes in soil water storage within the first two sorting axes, indicating satisfactory explanatory results. The maximum value of EC index in the first two axes also exceeds 90%, and the EC value in the first axis is higher, indicating that environmental factors have a stronger role in the first axis.

Table 2: Parameter Statistics

Soil layer	time	time interval	Sort Axis	EV	AVP	EC
soil moisture Cataclysmic layer	2014	Growth season	1	0.7821	78.0482	0.9258
			2	0.3624	85.0783	0.5712
		Non growing	1	0.9539	96.5155	0.9946

		season	2	0.3313	97.9272	0.9913
	2015	Growth season	1	0.8128	82.0188	0.9187
			2	0.3614	89.6084	0.6699
		Non growing season	1	0.8226	81.5696	0.9304
			2	0.3105	93.4313	0.6593
	2016	Growth season	1	0.8614	85.0589	0.9469
			2	0.3351	89.4841	0.9846
		Non growing season	1	0.8956	89.1936	0.9774
			2	0.3169	89.9617	0.6765
	2017	Growth season	1	0.8599	84.3483	0.9342
			2	0.3394	90.1799	0.9986
		Non growing season	1	0.8925	88.2471	0.9758
			2	0.3171	89.6528	0.6781
soil moisture Active layer	2014	Growth season	1	0.8264	78.0943	0.9061
			2	0.3549	80.0679	0.5817
		Non growing season	1	0.9298	96.5079	0.972
			2	0.1124	98.0192	0.8243
	2015	Growth season	1	0.8998	82.0227	0.9289
			2	0.3829	83.551	0.7463
		Non growing season	1	0.7733	81.5645	0.9486
			2	0.3339	83.4351	0.7362
	2016	Growth season	1	0.7928	85.1563	0.9226
			2	0.3443	89.5385	0.9242
		Non growing season	1	0.8623	89.168	0.9552
			2	0.3981	89.9208	0.7604
	2017	Growth season	1	0.7738	84.2939	0.9085
			2	0.3365	90.1832	0.9833
		Non growing season	1	0.9301	88.3215	0.9909
			2	0.1067	89.6177	0.6455
soil moisture Stable layer	2014	Growth season	1	0.7251	78.139	0.9668
			2	0.3326	80.1755	0.5363
		Non growing season	1	0.9277	96.5919	0.9381
			2	0.3976	97.8866	0.9318
	2015	Growth season	1	0.7163	81.9213	0.8568
			2	0.3124	83.6365	0.7236
		Non growing season	1	0.7315	81.5175	0.9559
			2	0.3008	83.4869	0.6608
	2016	Growth season	1	0.8736	85.0099	0.9005
			2	0.3795	89.5559	0.9701
		Non growing season	1	0.8225	89.1834	0.9113
			2	0.3023	89.9363	0.7726
	2017	Growth season	1	0.8654	84.3989	0.8717
			2	0.3554	90.1635	0.9729
		Non growing season	1	0.8986	88.2737	0.9298
			2	0.2766	89.6301	0.5937

The results of redundancy analysis are shown in the ranking chart of soil moisture and environmental factors (Figure 2). The black line in the figure represents soil water storage capacity, the blue line represents environmental factors, and the cosine value of the angle between the blue and black lines is regular, indicating a positive correlation between soil water storage capacity and environmental factors. If it is negative, it indicates a negative correlation between soil water storage capacity and environmental factors; If the blue line is perpendicular to the black line, it indicates that there is no correlation between soil water storage and environmental factors. The closer the absolute value of the cosine value between the blue and black lines is to 1, the greater the impact of environmental factors on soil water storage; The closer the absolute value of the cosine value is to 0, the smaller the impact of environmental factors on soil water storage. The longer the length of the blue line, the stronger the explanatory power of environmental factors on soil water storage. In each graph, A represents a moderately humid period, B represents a moderate period, and C represents a moderately dry period; Layer A is the soil moisture dramatic layer, Layer B is the soil moisture active layer, and Layer C is the soil moisture stable layer. Through Figure 2, the key influencing factors affecting soil water storage changes in different time periods, locations, and soil layers can be summarized (Table 3). Combining Table 3 and Figure 2, it can be seen that for the non-growing season soil moisture dramatic layer (0-10cm) and active layer (10-120cm), root biomass and precipitation are the first two factors affecting soil water storage changes; During the growing season, root biomass and initial soil moisture content are the first two factors that affect changes in soil water storage capacity. In the stable soil moisture layer (120-200cm), the main factors affecting soil water storage during the growing season are precipitation and precipitation intensity, while the main factors affecting soil moisture during the non growing season are precipitation and precipitation interval.

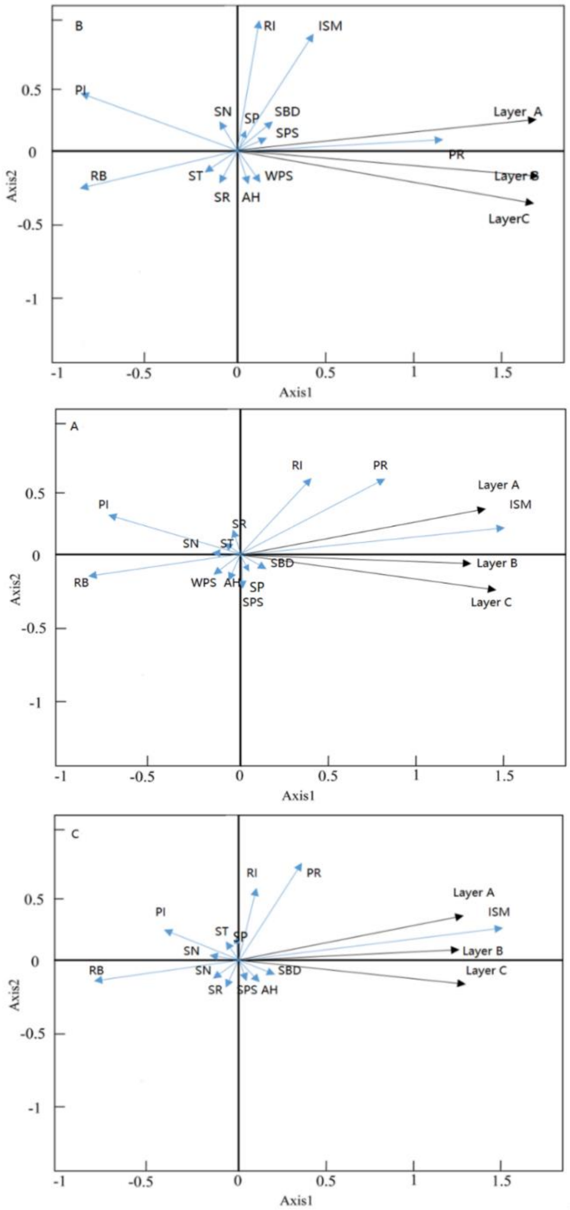

Figure 1: Redundancy Analysis Sorting Chart

After analyzing the ranking chart of soil moisture and environmental factors, the main factors affecting soil moisture changes were extracted using antecedent selection and Monte Carlo permutation test. The general hypothesis testing method uses a known specific hypothesis as the null hypothesis, while the Monte Carlo permutation test uses its own generated distribution as the null hypothesis. The purpose of such hypothesis testing is to test the constrained ranking model and determine its significance. When the structures between the samples are the same or similar, the position of the samples will not have a significant impact on the final inspection result. Here, the F-value is used to test the significance of the regression model. If there is autocorrelation in the position of the sample, it is not possible to swap the positions of the sample casually. In this case, CANOCO can use the rotation method to solve this problem, connecting the head and tail of the sample to form a cylinder. When the sample rotates, the ratio of the sample to the environmental factor can be changed. This constrained sorting method is similar to multiple regression, which often measures the percentage that the explanatory variable in the response variable can explain. Not all explanatory variables can explain changes in response variables, and some of them will be filtered out. Here, CANOCO's Monte Carlo permutation test can be applied to evaluate the explanatory power of various environmental factors on soil moisture changes. Firstly, each environmental factor is analyzed as an independent variable, and the most explanatory environmental factor is marked as a covariate. Then, other environmental factors are analyzed as the only main variable. If the Monte Carlo permutation test rejects the null hypothesis (in which case the null hypothesis is that the environmental factor cannot explain changes in soil water storage), this environmental factor is selected into the model.

Table 4 shows the distribution of the results of the antecedent selection and Monte Carlo permutation test at different time periods, which also confirms the conclusion of Table 3. Generally speaking, when conducting Monte Carlo permutation tests, factors with expansion coefficients greater than 20 and factors with p-values greater than 0.05 should be excluded. In this analysis, the expansion factors are all less than 20, so there is no need to exclude them. In addition, from Table 4, it can be seen that the only factors that can truly affect soil moisture are precipitation, precipitation interval, precipitation intensity, root biomass, and initial soil moisture content. The top two environmental factors in various locations, time periods, and soil layers can provide over 80% RCR (relative contribution rate), and all environmental factors listed in this study can provide over 90% RCR. The contribution of soil bulk density, soil particle size, and soil porosity to soil moisture changes is not significant, while the effects of humidity, temperature, soil organic matter, wind speed, and wind speed on soil moisture can be ignored. From this, it can be seen that the application of antecedent selection and Monte Carlo permutation test can effectively separate environmental factors with high explanatory power and eliminate redundant variables with weak explanatory power. This has important basis for the quantitative separation of environmental factor contributions in the following text.

Table 3: The first two environmental factors affecting soil water storage capacity

time	**time interval**	**Soil layer**		
		Cataclysmic layer	**Active layer**	**Stable layer**
2014	Growth season	RB ISM	RB ISM	PR RI
	Non growing season	RB PR	RB PR	PR ISM
2015	Growth season	RB ISM	RB ISM	PR PI
	Non growing season	RB PR	RB PR	PR ISM
2016	Growth season	RB ISM	RB ISM	PR PI
	Non growing	RB PR	RB PR	PR ISM

	season			
2017	Growth season	RB ISM	RB ISM	PR PI
	Non growing season	RB PR	RB PR	PR ISM

Table 4: Previous Selection and Monte Carlo Test Results

Soil layer	**environmental factor**	**2014 Growth Season**			**2014 non growing season**			**2015 Growth Season**			**2015 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
soil moisture Cataclysmic layer	PR	0.0619	0.492	3.86	0.0019	73.37	48.49	0.076	1.655	1.66	0.0023	78.44	33.89
	RI	0.067	0.539	3.22	0.0694	1.602	3.55	0.0937	0.227	3.39	0.0622	0.499	1.22
	PI	0.0909	0.191	3.8	0.0944	0.416	1.69	0.0814	0.998	1.29	0.0775	1.837	2.23
	SBD	0.074	0.978	1.74	0.0668	0.818	1.17	0.0847	1.893	2.4	0.0965	1.749	3.63
	SPS	0.0709	1.036	1.98	0.0642	1.803	1.88	0.0809	0.438	2.16	0.0737	1.088	2.51
	RB	0.007	8.26	46.41	0.0023	34.55	36.46	0.0092	47.78	41.24	0.0076	62.47	41.98
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0073	66.26	37.01	0.0895	1.744	3.82	0.0058	74.71	45.23	0.0682	1.879	1.79
	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	98.02	-	-	97.06	-	-	97.37	-	-	87.25
		2016 Growth Season			**2016 non growing season**			**2017 Growth Season**			**2017 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
	PR	0.0723	0.223	2.12	0.0073	62.72	42.25	0.0914	0.867	2.89	0.0035	79.91	38.72
	RI	0.0948	1.35	2.81	0.0851	0.298	3.05	0.0993	0.649	1.84	0.0713	0.628	2.86
	PI	0.0668	0.942	3.38	0.0923	0.831	2.7	0.064	1.657	3.2	0.0926	0.266	1.34
	SBD	0.0857	1.84	2.13	0.0914	0.73	1.01	0.0891	0.964	2.93	0.0646	0.958	3.78
	SPS	0.0741	1.248	3.27	0.0812	1.217	1.19	0.0777	0.835	1.79	0.077	1.449	1.2
	RB	0.0085	61.63	47.77	0.0065	66.94	41.42	0.0089	38.91	48.22	0.0042	25.99	44.36
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0034	73.86	35.96	0.0607	0.159	2.7	0.0048	43.44	38.02	0.064	0.807	3.92
	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	97.44	-	-	94.32	-	-	98.89	-	-	96.18
Soil layer	**environmental factor**	**2014 Growth Season**			**2014 non growing season**			**2015 Growth Season**			**2015 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
soil moisture Active layer	PR	0.0704	1.78	1.81	0.0041	67.85	36.84	0.0705	1.216	2.62	0.0040	47.65	46.83
	RI	0.0822	1.35	2.99	0.0676	0.366	1.65	0.0685	0.738	1.75	0.0950	1.869	2.28
	PI	0.0951	1.741	2.1	0.0698	0.406	3.38	0.0697	1.144	1.9	0.0666	1.653	1.7
	SBD	0.0741	0.474	3.07	0.0983	0.599	3.73	0.0966	0.788	3.52	0.0936	0.204	1.01
	SPS	0.0704	1.317	3.58	0.0689	1.102	1.52	0.0962	0.678	2.65	0.0990	1.144	2.63
	RB	0.0093	76.46	41.35	0.0091	63.68	39.86	0.0018	65.87	39.7	0.0064	56.93	41.48
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0037	26.57	43.41	0.0694	0.273	3.64	0.0086	54.45	40.3	0.0830	0.701	3.39

	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	98.31	-	-	90.62	-	-	92.44	-	-	99.32
		2016 Growth Season			**2016 non growing season**			**2017 Growth Season**			**2017 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
	PR	0.0608	1.042	2.56	0.0088	35.6	43.22	0.0752	1.099	2.26	0.0066	30.11	38.27
	RI	0.0983	0.589	3.95	0.0629	1.312	2.67	0.0703	1.713	2.99	0.0845	0.672	2.07
	PI	0.0926	1.791	1.87	0.0617	1.024	2.7	0.0823	0.971	2.03	0.0612	1.914	1.97
	SBD	0.0653	1.318	2.88	0.0835	0.611	3.61	0.0887	1.125	1.15	0.0954	1.179	2.2
	SPS	0.0748	0.596	3.99	0.0871	0.324	3.48	0.0723	1.354	1.08	0.0831	1.201	3.75
	RB	0.0027	62.54	39.47	0.0013	65.89	37.68	0.0056	13.22	40.91	0.0055	46	44.72
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0031	16.36	42.12	0.0752	0.658	1.87	0.0029	51.53	40.44	0.0997	0.878	1.28
	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	96.84	-	-	95.23	-	-	90.86	-	-	94.26
Soil layer	**environmental factor**	**2014 Growth Season**			**2014 non growing season**			**2015 Growth Season**			**2015 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
soil moisture Stable layer	PR	0.0028	74.43	35.11	0.0017	33.6	30.64	0.0041	22.14	32.84	0.0068	25.66	32.84
	RI	0.0019	50.51	36.16	0.0934	0.837	1.82	0.0034	15.88	39.35	0.0602	0.314	2.58
	PI	0.0899	1.527	3.23	0.0059	55.06	41.86	0.0678	1.622	2.78	0.0070	10.6	40.84
	SBD	0.0888	1.572	3.53	0.0965	0.842	2.8	0.0689	0.39	2.03	0.0890	1.469	2.99
	SPS	0.0955	0.348	1.84	0.0948	1.09	1.06	0.0647	1.773	3.58	0.0900	0.932	3.3
	RB	0.0691	1.634	3.51	0.0733	1.97	1.51	0.0780	1.368	1.54	0.0651	0.288	1.4
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0629	1.196	1.44	0.0825	0.614	1.3	0.0880	1.756	3.16	0.0766	0.212	1.69
	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	84.82	-	-	80.99	-	-	85.28	-	-	85.64
		2016 Growth Season			**2016 non growing season**			**2017 Growth Season**			**2017 non growing season**		
		P	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**	**P**	**F**	**RCR**
	PR	0.0018	15.41	34.72	0.0055	46.39	31.2	0.0085	67.89	42.14	0.0025	56.01	51.1
	RI	0.0052	32.29	42.32	0.0680	1.789	1.59	0.0019	67.33	43.63	0.0845	0.107	2.05
	PI	0.0639	1.047	1.34	0.0080	53.55	39.99	0.0941	0.224	2.77	0.0054	62.42	32.8
	SBD	0.0966	1.049	1.81	0.0629	0.265	2.98	0.0793	0.248	2.44	0.0703	1.273	2.92
	SPS	0.0882	0.871	3.53	0.0880	0.272	3.83	0.0643	1.645	2.1	0.0931	0.7	1.11
	RB	0.0859	1.809	1.93	0.0827	1.7	1.5	0.0759	1.648	3.57	0.0841	0.194	1.44
	ST	-	-	-	-	-	-	-	-	-	-	-	-
	WPS	-	-	-	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-	-	-	-
	SN	-	-	-	-	-	-	-	-	-	-	-	-
	AH	-	-	-	-	-	-	-	-	-	-	-	-
	ISM	0.0852	0.784	3.98	0.0927	0.3	1.74	0.0785	1.19	2.78	0.0967	0.789	3.7
	SP	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	89.63	-	-	82.83	-	-	99.43	-	-	95.12

Table 5 shows the main parameters of three types of plots after removing redundant variables. From the table, it can be seen that after removing redundant variables, although the number of environmental factors has decreased significantly, the explanatory power of environmental factors on soil water storage has not significantly decreased.

Table 5: Parameter statistics after removing redundant variables

Soil layer	**time**	**time interval**	**Sort Axis**	**Before removing redundant variables**			**After removing redundant variables**		
				EV	**AVP**	**EC**	**EV**	**AVP**	**EC**
soil moisture Cataclysmic layer	2014	Growth season	1	0.7821	78.0482	0.9258	0.6929	77.9780	0.9081
			2	0.3624	85.0783	0.5712	0.2952	85.0185	0.5582
		Non growing season	1	0.9539	96.5155	0.9946	0.8803	96.4330	0.9329
			2	0.3313	97.9272	0.9913	0.2950	97.9026	0.9152
	2015	Growth season	1	0.8128	82.0188	0.9187	0.7302	81.9749	0.8602
			2	0.3614	89.6084	0.6699	0.2864	89.5526	0.6002
		Non growing season	1	0.8226	81.5696	0.9304	0.7703	81.5400	0.9183
			2	0.3105	93.4313	0.6593	0.2194	93.3641	0.5765
	2016	Growth season	1	0.8614	85.0589	0.9469	0.7893	85.0308	0.8675
			2	0.3351	89.4841	0.9846	0.2836	89.4130	0.9159
		Non growing season	1	0.8956	89.1936	0.9774	0.8467	89.1377	0.9593
			2	0.3169	89.9617	0.6765	0.2438	89.9468	0.6074
	2017	Growth season	1	0.8599	84.3483	0.9342	0.7675	84.2691	0.8348
			2	0.3394	90.1799	0.9986	0.2688	90.1684	0.9171
		Non growing season	1	0.8925	88.2471	0.9758	0.8191	88.1718	0.8961
			2	0.3171	89.6528	0.6781	0.3049	89.5772	0.6015
soil moisture Active layer	2014	Growth season	1	0.8264	78.0943	0.9061	0.7587	78.0108	0.8082
			2	0.3549	80.0679	0.5817	0.2870	79.9958	0.5536
		Non growing season	1	0.9298	96.5079	0.972	0.8631	96.4121	0.9537
			2	0.1124	98.0192	0.8243	0.0965	98.0079	0.8068
	2015	Growth season	1	0.8998	82.0227	0.9289	0.8104	81.9432	0.8514
			2	0.3829	83.551	0.7463	0.2856	83.4556	0.6845
		Non growing season	1	0.7733	81.5645	0.9486	0.7336	81.5238	0.9314
			2	0.3339	83.4351	0.7362	0.2734	83.3821	0.6421
	2016	Growth season	1	0.7928	85.1563	0.9226	0.7281	85.1376	0.8674
			2	0.3443	89.5385	0.9242	0.2464	89.5124	0.8627
		Non growing season	1	0.8623	89.168	0.9552	0.8313	89.0975	0.8836
			2	0.3981	89.9208	0.7604	0.3148	89.8620	0.6907
	2017	Growth season	1	0.7738	84.2939	0.9085	0.7281	84.2721	0.8906
			2	0.3365	90.1832	0.9833	0.2863	90.1017	0.9521
		Non growing season	1	0.9301	88.3215	0.9909	0.8367	88.2373	0.9641
			2	0.1067	89.6177	0.6455	0.0257	89.5968	0.6244
soil moisture Stable layer	2014	Growth season	1	0.7251	78.139	0.9668	0.6634	78.1084	0.8974
			2	0.3326	80.1755	0.5363	0.3125	80.1528	0.4601
		Non growing season	1	0.9277	96.5919	0.9381	0.9167	96.5350	0.8541
			2	0.3976	97.8866	0.9318	0.3204	97.8598	0.8552
	2015	Growth season	1	0.7163	81.9213	0.8568	0.6214	81.8788	0.8168
			2	0.3124	83.6365	0.7236	0.2532	83.5736	0.6846
		Non growing	1	0.7315	81.5175	0.9559	0.6844	81.4370	0.8837
			2	0.3008	83.4869	0.6608	0.2316	83.4376	0.6373

		season							
	2016	Growth season	1	0.8736	85.0099	0.9005	0.7747	84.9393	0.8081
			2	0.3795	89.5559	0.9701	0.2916	89.4763	0.9290
		Non growing season	1	0.8225	89.1834	0.9113	0.7732	89.1415	0.8151
			2	0.3023	89.9363	0.7726	0.2236	89.9211	0.7260
	2017	Growth season	1	0.8654	84.3989	0.8717	0.8024	84.3352	0.7976
			2	0.3554	90.1635	0.9729	0.3107	90.1290	0.9495
		Non growing season	1	0.8986	88.2737	0.9298	0.8391	88.2556	0.8923
			2	0.2766	89.6301	0.5937	0.1854	89.5958	0.5114

The explanation of environmental factors on soil water storage can be divided into conditional explanation and marginal explanation, and these two explanations have some overlap. The concept of quantitative separation of variables can be introduced through variance decomposition. Generally, in practical research, two or more sets of explanatory variables are quantified, or they are quantified as separate or overlapping explanatory variables of two or more environmental variables. The most commonly used method is to quantify them as separate and overlapping explanatory variables between time and space. Assuming the simplest condition, analyze the process of explanatory quantity decomposition using two (or two sets) environmental variables as examples. In Figure 3, w represents the part that cannot be explained by these two environmental variables, x represents the part that is explained solely by the first environmental variable, y represents the part that is explained solely by the second environmental variable, and z represents the part that can be explained jointly by these two environmental variables. When y is ignored, the part that can be explained by the first environmental variable is x+z. x. The quantities of y, z, and w can be obtained through partial constraint analysis. When using variable decomposition, the first environmental variable can be used as the main variable and the second as the covariate to obtain x; Then use the second variable as the main variable and the first variable as the covariate to obtain y; Subtract x and y from the explanatory variables when both variables are used as the main variables to obtain z. When z is negative, it indicates that two sets of variables can have interactive effects, and their explanatory power is greater than the sum of individual explanatory power.

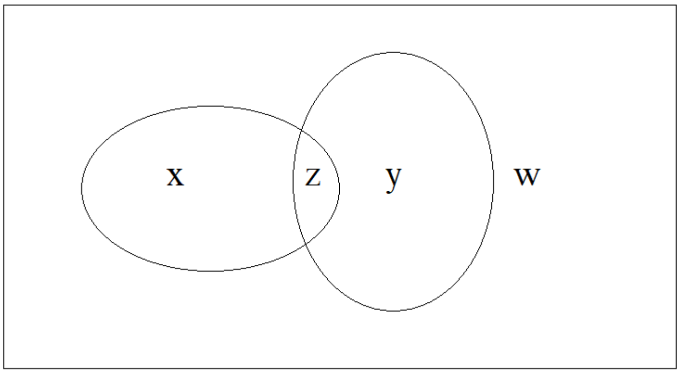

Figure 2: Variable Separation of Environmental Factors

When using CANOCO for redundancy analysis, the required matrices are soil moisture matrix, precipitation matrix, precipitation intensity matrix, root biomass matrix, precipitation interval matrix, and initial soil moisture matrix before precipitation. Then, the individual interpretation and overlapping interpretation of each factor are calculated. Finally, MATLAB is used to map, and the basic idea of mapping is as follows:

Using Figure 3 as a template to create a directional separation result map of environmental factors, the directional separation results of environmental factors can be obtained for different soil layers and time periods. The various indicators are shown in Table 6. From the table, it can be seen that within the soil moisture dramatic layer, root biomass contributed the most to soil moisture changes during the growing seasons of abundant and flat water years, far exceeding other indicators. However, during the growing season of 2015, the contribution rates of root biomass and initial soil moisture were relatively small, which was due to the precipitation year pattern. However, different situations occurred in the active and stable soil moisture layers. The contribution rates of root biomass and initial soil moisture content were higher in both wet and dry years, due to different precipitation year types and infiltration depths. From the table, it can also be seen that there are basically no significant differences in the contribution rates of precipitation, root biomass, precipitation intensity, and precipitation interval to soil moisture variation in various soil layers during non growing seasons.

Based on the above analysis results, it can be seen that the contribution rates of different environmental factors to soil moisture production are all above 80% in each time period. This indicates that the environmental factors selected in this study meet the actual needs in both quantity and quality. The conclusions drawn from this study on soil moisture dynamics and its influencing factors can provide scientific basis for the rational allocation, restoration, and reconstruction of vegetation in semi-arid sandy areas.

There is a mutual influence between vegetation and soil moisture. On the one hand, the establishment of sand fixing vegetation has changed soil properties, especially soil water holding and retention capacity, but at the same time, it has also caused an increase in evapotranspiration in the region. Therefore, the soil moisture content will show a certain downward trend with the establishment of sand fixing vegetation; On the other hand, the high or low soil moisture content also affects the physiological activity of vegetation, further affecting the density of vegetation communities. When soil moisture cannot meet the demand for evapotranspiration, vegetation will develop poorly, and even wither, die, and other phenomena may occur. Numerous studies have shown that the cyclic succession process of the Artemisia annua community is driven by soil moisture, and if vegetation density is not artificially controlled during vegetation restoration, this succession process will still occur in the community. From the perspective of ecological benefits and sustainable development, maintaining the long-term stability of the Artemisia annua community is more conducive to achieving a balance of ecological benefits, landscape benefits, and economic benefits. The results of path analysis and redundancy analysis indicate that the other factors affecting soil moisture are uncontrollable, and only root biomass and vegetation density can be artificially controlled. By substituting the correlation between root biomass and vegetation coverage into the analysis, it can be seen that in order to maintain soil water balance in the Mu Us sandy land, the root biomass should not exceed 335.46g, corresponding to a vegetation coverage of 68.4%. Currently, based on the vegetation coverage of fixed sandy land, it is not possible to maintain soil moisture balance in a year of water deficit. Therefore, the vegetation coverage within fixed sandy land should be appropriately reduced.

Table 6: Contribution of Main Control Factors to Soil Moisture Variation

Soil layer	time	time interval	Main control factor	index			
				X	Y	Z	W
Soil moisture dramatic layer	2014	Growth season	RB ISM	0.4613	0.2996	0.1839	0.0552
		Non growing season	RB PR	0.4793	0.3049	0.1898	0.026
	2015	Growth season	RB ISM	0.3231	0.2125	0.1525	0.3119
		Non growing season	RB PR	0.3882	0.3386	0.1875	0.0857
	2016	Growth season	RB ISM	0.4646	0.3665	0.1683	0.0006
		Non growing season	RB PR	0.3761	0.3509	0.177	0.096
	2017	Growth season	RB ISM	0.4556	0.3244	0.1518	0.0682

		Non growing season	RB PR	0.383	0.379	0.1899	0.0481
Soil moisture active layer	2014	Growth season	RB ISM	0.4275	0.3684	0.1629	0.0412
		Non growing season	RB PR	0.3271	0.3696	0.1613	0.142
	2015	Growth season	RB ISM	0.4953	0.3345	0.1651	0.0051
		Non growing season	RB PR	0.3899	0.3358	0.1871	0.0872
	2016	Growth season	RB ISM	0.3588	0.2011	0.1633	0.2768
		Non growing season	RB PR	0.3889	0.2601	0.1907	0.1603
	2017	Growth season	RB ISM	0.3831	0.3891	0.1746	0.0532
		Non growing season	RB PR	0.3676	0.2221	0.1793	0.231
Soil moisture stable layer	2014	Growth season	PR RI	0.4517	0.2137	0.1994	0.1352
		Non growing season	PR PI	0.3291	0.3917	0.1968	0.0824
	2015	Growth season	PR RI	0.4746	0.2982	0.1503	0.0769
		Non growing season	PR PI	0.3254	0.3471	0.1882	0.1393
	2016	Growth season	PR RI	0.4247	0.2753	0.1794	0.1206
		Non growing season	PR PI	0.3613	0.2296	0.1622	0.2469
	2017	Growth season	PR RI	0.3501	0.3505	0.1596	0.1398
		Non growing season	PR PI	0.3689	0.2298	0.169	0.2323

4. Conclusion

(1) This study used RDA analysis and considered 13 factors that affect soil water storage. These environmental factors explained more than 85% of the changes in soil water storage within the first two ranking axes. The maximum value of EC index in the first two axes also exceeded 90%, and the explanatory results were satisfactory.

(2) After applying the previous selection and Monte Carlo permutation test, it can be concluded that the only factors that can significantly affect soil moisture are precipitation, precipitation interval, precipitation intensity, root biomass, and initial soil moisture content. The top two environmental factors in various locations, time periods, and soil layers can provide over 80% of RCR.

(3) After removing redundant variables, although the number of environmental factors decreased significantly, the explanatory power of environmental factors on soil water storage did not show a significant decrease. For the non growing season soil moisture dramatic layer and soil moisture active layer, root biomass and precipitation are the first two factors affecting soil water storage changes; During the growing season, root biomass and initial soil moisture content are the first two factors that affect changes in soil water storage capacity.

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