INTEGRATED TREE–SHRUB–GRASS VEGETATION RESTORATION IN SANDY RIPARIAN ZONES OF THE YARLUNG TSANGPO RIVER: TECHNIQUES AND ECOLOGICAL IMPLICATIONS

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Abstract. To advance the theory and practice of vegetation restoration on desertified lands, we conducted a field-based investigation in the sand-control experimental 'zone of Lirong Township', Milin County, situated in the middle reaches of the Yarlung Tsangpo River. Through a combination of long-term fixed-point observation and controlled field experiments, we examined the ecological impacts of integrating tree-shrub-grass species. We developed a composite planting model suited for sandy riparian zones and evaluated its performance. Results demonstrate that such vegetation assemblages effectively reduce wind speed, enhance relative humidity, and stabilize air, surface, and subsurface temperatures. Furthermore, the treatments improved soil water content and porosity while reducing bulk density and pH. Soil fertility metrics—including organic matter, total nitrogen, phosphorus, and potassium—also showed significant improvement, enhancing the land's productivity. Among the tested configurations, the assemblage of *Cupressus gigantea*, *Sophora moorcroftiana*, *Medicago sativa*, *Melilotus officinalis*, *Eragrostis nigra*, and *Astragalus adsurgens*, when paired with rainwater-collecting trays and geocell structures, proved optimal for ecological restoration in the riparian sandy soils of 'the central Yarlung Tsangpo basin'.
Keywords: *vegetation assemblage, configuration model, soil physicochemical properties, Milin County, Yarlung Tsangpo River*

Introduction

The Yarlung Tsangpo River, often referred to as the "Heavenly River," is the longest plateau river in China. In recent years, the region has faced increasing ecological stress due to global climate change and intensified human activities, resulting in wetland shrinkage, grassland degradation, and expanding desertification (Ma et al., 2021; Hou, 2021). The central reaches of the Yarlung Tsangpo River represent both the cultural and economic heart of Tibet and one of regions most severely affected by wind-driven desertification (Liu et al., 2019; Pan, 2007), with sandy land currently covering nearly 3000 hm^2. The primary driver of land desertification in this area is the seasonal exposure of river sediments caused by fluctuating precipitation. These exposed sediments, under the combined influence of strong solar radiation and frequent high winds, have led to widespread vegetation degradation across the middle and lower reaches (Luosang et al., 2022; Li et al., 2011). The expansion of aeolian sand activity has exacerbated ecological problems such as grassland degradation and biodiversity loss, and has also disrupted transportation infrastructure, thereby impacting the livelihoods and environmental quality of local communities. Urgent action is needed to address these issues.

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Considerable progress has been made in China battle against desertification. For example, Wang (2020) demonstrated that integrated treatments such as “sheep manure + fiber grid sand barriers + protected species” and “sheep manure + peat soil + protected species” significantly enhanced sand fixation and vegetation recovery in the headwaters of the Yellow River. Similarly, Jiang (2008) found that planting *Caragana microphylla* Lam. within straw grids in the Horqin Sandy Land effectively stabilized mobile dunes and improved soil and biodiversity. In the central Yarlung Tsangpo basin, researchers have also explored restoration strategies. Shen (2012) reported promising germination and survival rates for species such as *Corethrodendron scoparium* Fisch., *Calligonum mongolicum*, *Hedysarum mongolicum* and *Sophora moorcroftiana* in mobile sandy soils. Song and Bianba Zhuoma (2022) evaluated the ecological adaptability of forages and identified *Cichorium intybus* L., American ‘WL168HQ’ Alfalfa, *Agropyron elongatum*, and perennial *Lolium perenne* L. as high-biomass candidates. However, comprehensive studies on the ecological effects of mixed tree–shrub–grass vegetation assemblages for sandy land restoration in this region remain lacking.

The tree–shrub–grass planting model is widely recognized for its structural complexity and multifunctionality in ecological restoration. It serves as a robust system for water and soil conservation, capable of withstanding extreme environmental conditions (Bu et al., 2016). Both empirical knowledge and field trials confirm that biological measures—especially heterogeneous combinations of trees, shrubs, and grasses—are highly effective for stabilizing desertified land in the Yarlung Tsangpo River’s central basin (Song et al., 2022; Chang et al., 2014). Against this background, the present study focuses on the sandy land restoration trial zone in Lirong Township, Milin County. By investigating the establishment techniques and ecological outcomes of tree–shrub–grass assemblages, we aim to develop a practical and scientifically grounded restoration model. Our findings will support large-scale vegetation restoration and ecological reconstruction in the riparian sandy zones of the Yarlung Tsangpo River.

Materials and methods

Study area overview

This study was conducted in the region between Lirong Township and Wolong Town, within Milin County, located in the central reaches of the Yarlung Tsangpo River (*Fig. 1*). The study area (29°8′16″N, 93°45′26″E; elevation: 2973 m) is characterized by a semi-arid plateau temperate climate. The rainy season spans from June to September, while the dry season extends from October to May of the following year. The region receives an average annual precipitation of 698 mm, with an annual evaporation of 1964.4 mm. The mean annual temperature is 8.7°C, with the highest monthly average in July (29.5°C) and the lowest in January (–15°C). The annual effective accumulated temperature is 2791.8°C, total sunshine duration is 1669.6 h, the frost-free period lasts 153 days, and wind-blown sand events occur approximately 52 times per year (Zhan et al., 2022; Shen et al., 2009).

Experimental plots

Three experimental plots were established in the sand control demonstration area of Lirong Township: Treatment 1: A vegetation community composed of *Cupressus gigantea*, *Sophora moorcroftiana*, and a mix of herbaceous species, equipped with water-harvesting trays and geocell structures. Treatment 2: The same plant community

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configuration as Treatment 1 but without the use of water-harvesting trays and geocells. Control (CK): A bare sandy plot with no vegetation. All plots were rectangular and covered approximately 528 m² of mixed grassland or sandy soil.

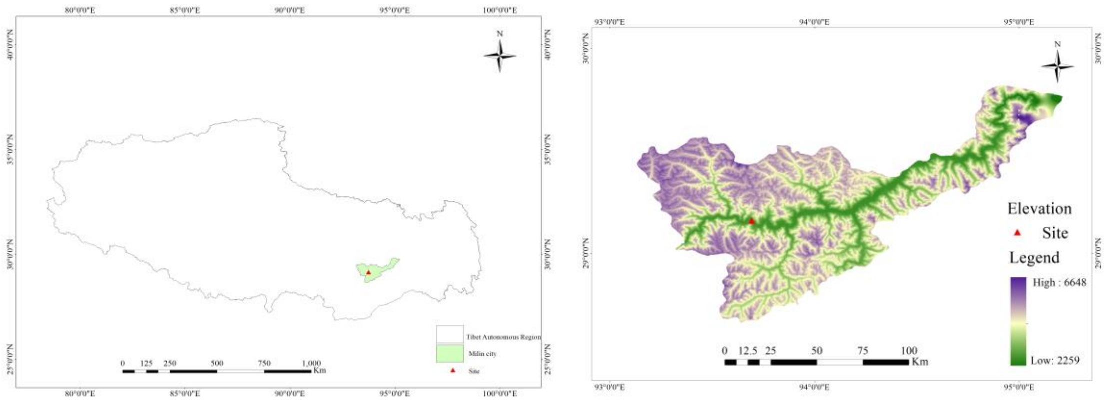

Figure 1. *Overview map of the study area*

In Treatment 1, grass species including *Medicago sativa*, *Melilotus officinalis*, *Eragrostis nigra*, and *Astragalus adsurgens* were sown using surface broadcasting techniques with soil coverage of 1-2 cm, and overlaid with eco-friendly non-woven fabric (18 ± 2 g/m²) to preserve soil temperature and moisture. The geocells used (HQ-100-330, black, 100 mm depth, 165 mm diameter) served to support herbaceous plant rooting, while rainwater-collecting trays (Tal-Ya, Israel) were applied to support the growth of *Cupressus gigantea* and *Sophora moorcroftiana*. The density of *Cupressus gigantea* was 70 individuals per acre, with a survival rate of 94%. The plants were spaced at 1.2 × 2.0 m intervals, and their heights ranged from 1.37 to 2.0 m. The crown widths varied from 0.91 to 1.44 m, while the breast-height diameters were between 2.5 and 3.7 cm, and the ground diameters were 3.9-5.1 cm. For *Sophora moorcroftiana*., the density was 90 individuals per acre, with a survival rate of 98%. These plants were spaced at 0.8 × 1.5 m intervals, with heights ranging from 0.81 to 1.20 m and crown widths from 0.72 to 0.80 m.

The grass plant community included Medicago sativa with an average height of 22.33 cm and a density of 52 plants per square meter, *Melilotus officinalis* with an average height of 63.20 cm and a density of 30 plants per square meter, *Eragrostis nigra* with an average height of 10.83 cm and a density of 106 plants per square meter, and *Astragalus adsurgens* with an average height of 16.00 cm and a density of 40 plants per square meter. The vegetation cover of the forage plants was 95%. All species were sown by broadcasting, followed by a soil cover of 1-2 cm and mulching with non-woven fabric to maintain soil temperature and moisture. In Treatment 2, the cultivation of forage plants (*Medicago sativa*, *Melilotus officinalis*, *Eragrostis nigra*, and *Astragalus adsurgens*), shrubs (*Sophora moorcroftiana*), and trees (*Cupressus gigantea*) was conducted without the use of environmentally friendly non-woven fabric (18 ± 2 g/m²), geocell structures (HQ-100-330/black, depth 100 mm, size 165 mm), or rainwater-collecting trays (Tal-Ya, Israel). The cultivation methods, densities, and spacings of the tree–shrub–grass planting model in the grassland were identical to those in Treatment 1. The survival rate of *Cupressus gigantea* was 61%, with plant heights ranging from 0.87 to 1.50 m, crown widths from 0.70 to 0.94 m, breast-height diameters from 1.9 to 2.7 cm, and ground diameters from 3.2 to 4.5 cm. For *Sophora moorcroftiana*, the survival rate was 73%,

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with plant heights ranging from 0.65 to 0.82 m and crown widths from 0.63 to 0.77 m. The grass community included *Medicago sativa* (average height 15.46 cm, density 44 plants/m²), *Melilotus officinalis* (average height 50.40 cm, density 21 plants/m²), *Eragrostis nigra* (average height 7.65 cm, density 79 plants/m²), and *Astragalus adsurgens* (average height 10.30 cm, density 19 plants/m²), with a vegetation cover of 56%. The control group was an open area with no vegetation cover.

Observation period

All vegetation was planted in April 2020. Five monitoring points were established within each plot. Microclimatic measurements were taken from July 25 to 30, 2022, with observations made every 2 h daily. Soil sampling was conducted on July 30, 2022.

Measurement methods

Microclimate monitoring

Air temperature, relative humidity, light intensity, wind speed, and subsurface temperature (at 5 cm depth) were recorded using a parallel observation method. Measurements were taken 80-100 cm above the ground using a digital thermometer-hygrometer (C20A, China), a light meter (RE-Y2061A, Zhejiang), and an anemometer (AR856, Guangdong).

Soil physical and chemical properties

Soil water content was determined via the drying method, using soil cores extracted from 0–50 cm depths (layered into 0-10, 10-20, 20-30, 30-40, and 40-50 cm intervals). In each treatment plot, three soil samples were collected per soil layer, resulting in a total of 45 samples, with each sample weighing 0.5 kg.

Determination of soil bulk weight and porosity: The bulk weight and porosity of the soil layers at depths of 0-10, 10-20, 20-30, 30-40 and 40-50 cm were determined by the ring knife-soaking method (ring knife volume of 100 cm^3) with three replications at each level. In each treatment plot, three soil samples were collected per soil layer, resulting in a total of 45 samples, with each sample weighing 0.5 kg.

$$Soil\ bulk\ density\ (pd) = \frac{M}{V} \quad \text{(Eq.1)}$$

$$Soil\ porosity = \left(1 - \frac{columetric\ weight}{relative\ density}\right) \times 100\% \quad \text{(Eq.2)}$$

where pd is the bulk density of a layer of soil (g/cm^3); M is the mass (g); V is the unit volume (cm^3) (Liu, 1982; Liu et al., 2023; Xu et al., 2020).

Measurement of soil chemical properties

pH was measured using a soil-to-water ratio of 1:2.5 with a pH meter (Lu, 2000). Total nitrogen, phosphorus, and potassium were measured following standard protocols. Organic matter content was determined using the potassium dichromate oxidation method. We collected soil samples from the 0–25 cm depth using a soil auger, with five sampling points established in each treatment plot. One soil sample was taken per sampling point, resulting in a total of 15 samples, each weighing 0.5 kg.

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Data analysis

Data were statistically analyzed using Excel 2022 software. Significant comparisons for temperature, humidity, illuminance, and wind speed among different treatments were conducted using the ANOVA procedure in SPSS 22.0, followed by Tukey's HSD test for post hoc analysis. Similarly, significant comparisons for fourteen factors—maximum temperature, minimum temperature, daily temperature range, surface maximum temperature, surface minimum temperature, surface daily temperature range, subsurface maximum temperature, subsurface minimum temperature, subsurface daily temperature range, total nitrogen, total phosphorus, total potassium, soil organic matter, and pH—were also conducted using the ANOVA procedure in SPSS 22.0, followed by Tukey's HSD test. All data were checked for normal distribution and homogeneity of variance before analysis. Graphs were created using Origin 9.0.

Results

Effects of vegetation assemblages on microclimate: air temperature, humidity, light intensity, and wind speed

Significant differences were observed in microclimatic conditions—namely air temperature, relative humidity, light intensity, and wind speed—across the three treatments (*Table 1*). At 14:00, the highest recorded air temperatures were 31.15°C, 31.80°C, and 37.55°C for Treatments 1, 2, and the control, respectively. Compared to the control, Treatment 1 showed significantly higher air humidity at 08:00, 10:00, 14:00, 16:00, and 18:00 ($P < 0.05$). At all measured time points (08:00, 10:00, 12:00, 14:00, 16:00, 18:00, and 20:00), light intensity in Treatment 2 was significantly lower than in the control ($P < 0.05$), while at 10:00, 12:00, 14:00, and 16:00, light intensity in Treatment 1 was significantly lower than in Treatment 2 ($P < 0.05$), indicating enhanced shading from denser vegetation cover. Air wind speeds in Treatments 1 and 2 were significantly lower than the control at 08:00, 16:00, and 18:00 ($P < 0.05$). At 10:00 and 14:00, wind speed in Treatment 1 was significantly lower than the control ($P < 0.05$); at 12:00, wind speed in Treatment 2 was significantly reduced, with Treatment 1 showing significantly lower wind speed than Treatment 2 ($P < 0.05$).

Surface microclimatic patterns mirrored those of the air (*Table 2*). At 14:00, the surface temperature peaked at 27.65°C, 28.90°C, and 44.50°C in Treatments 1, 2, and the control, respectively. Compared to the control, Treatment 1 showed a significant decrease in surface temperature at 12:00 ($P < 0.05$), and both Treatment 1 and 2 showed reductions at 14:00 ($P < 0.05$). Treatment 1 also had significantly higher surface humidity at multiple time points (08:00, 12:00, 16:00, and 18:00). Surface light intensity in Treatment 2 was significantly lower than in the control at most time points, while Treatment 1 showed significantly lower values than Treatment 2 ($P < 0.05$). Wind speed measurements followed a similar trend, with both vegetated treatments reducing wind speed significantly compared to the control.

Subsurface temperature measurements at 5 cm depth revealed a similar temporal pattern to surface and air temperatures (*Table 3*), showing a general increase followed by a rise and fall during the day. Peak subsurface temperatures at 14:00 were 25.70°C, 27.15°C, and 34.10°C in Treatments 1, 2, and the control, respectively, with Treatment 1 significantly lower than the control ($P < 0.05$).

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***Table 1.** Plant community air temperature, humidity, light level and wind speed test results*

Time	Treatment 1				Treatment 2				Control (CK)			
	Temperature °C	Humidity %	Light level lx	Wind speed m/s	Temperature °C	Humidity %	Light level lx	Wind speed m/s	Temperature °C	Humidity %	Light level lx	Wind speed m/s
06:00	14.90 ±1.55a	61.00 ±4.71a	9.50 ±2.11a	1.50 ±0.42a	15.55 ±1.02a	55.00 ±5.19a	9.50 ±2.30a	2.20 ±0.41a	16.65 ±2.07a	43.00 ±4.16a	14.50 ±0.92a	2.25 ±0.59a
08:00	16.20 ±1.70a	58.00 ±5.92a	2660 ±77.29b	0.95 ±0.28b	16.20 ±1.21a	50.00 ±3.95ab	3695 ±89.71b	0.95 ±0.14b	16.65 ±1.78a	37.00 ±5.31b	7565 ±90.02a	1.60 ±0.32a
10:00	20.95 ±0.72a	53.00 ±3.83a	9270 ±80.41c	0.85 ±0.19b	21.30 ±1.37a	41.00 ±6.04ab	19700 ±79.36b	1.10 ±0.25ab	21.90 ±2.04a	29.00 ±4.92b	98900 ±88.93a	1.40 ±0.24a
12:00	26.15 ±0.24a	39.00 ±4.33a	10000 ±69.67c	0.80 ±0.20c	26.65 ±2.09a	34.00 ±3.96a	28300 ±59.92b	1.50 ±0.42b	30.30 ±2.13a	28.00 ±2.04a	167950 ±97.61a	2.35 ±029a
14:00	30.90 ±1.31a	32.00 ±4.09a	14700 ±49.81c	2.00 ±0.73b	31.80 ±1.77a	28.00 ±1.99ab	73250 ±99.33b	2.95 ±0.33ab	37.55 ±2.15a	21.00 ±3.09b	211000 ±104.21a	3.65 ±0.71a
16:00	29.10 ±2.03a	34.00 ±3.72a	30200 ±90.06c	2.60 ±0.57b	29.85 ±2.24a	29.00 ±4.01ab	72600 ±57.59b	3.00 ±0.29b	31.85 ±1.95a	21.00 ±4.07b	132150 ±67.84a	4.70 ±0.27a
18:00	25.20 ±1.15a	40.00 ±5.39a	25100 ±88.63b	1.80 ±0.71b	26.15 ±2.05a	34.00 ±4.61ab	37400 ±74.38b	2.10 ±0.35b	27.90 ±2.31a	24.00 ±3.94b	118200 ±121.45a	4.05 ±0.39a
20:00	22.20 ±2.54a	48.00 ±6.02a	10800 ±60.94b	2.45 ±0.70a	21.60 ±1.33a	44.00 ±3.95a	15575 ±90.21b	2.80 ±0.19a	21.00 ±2.05a	35.00 ±4.03a	47580 ±77.95a	3.30 ±0.44a

Different lowercase letters in the same row indicate that the difference of the same index between different treatments is significant (P < 0.05), the same as *Table 2, Table 3* and *Table 5*

***Table 2.** Plant community surface temperature, humidity, illumination and wind speed test results*

Time	Treatment 1				Treatment 2				Control (CK)			
	Temperature °C	Humidity %	Light level lx	Wind speed m/s	Temperature °C	Humidity %	Light level lx	Wind speed m/s	Temperature °C	Humidity %	Light level lx	Wind speed m/s
06:00	15.60 ±2.94a	69.00 ±10.02a	2.00 ±0.57c	0.40 ±0.09	15.60 ±2.33a	60.00 ±5.92a	5.50 ±0.81b	0.85 ±0.22b	15.50 ±1.22a	48.00 ±3.92a	9.00 ±1.65a	1.30 ±0.32a
08:00	16.60 ±1.73a	64.00 ±7.92a	895 ±17.89c	0.40 ±0.17b	16.95 ±1.92a	55.00 ±9.04ab	1430 ±40.42b	0.50 ±0.19b	15.75 ±0.95a	42.005.0 4b	6360 ±50.43a	1.05 ±0.41a
10:00	19.55 ±2.43a	59.00 ±5.74a	5155 ±40.86c	0.40 ±0.06b	21.00 ±1.09a	46.00 ±10.20ab	10615 ±50.99b	0.55 ±0.22b	24.85 ±1.76a	30.00 ±5.21c	82300 ±79.52a	0.90 ±0.29a
12:00	24.60 ±1.82b	44.00 ±5.03a	6000 ±39.77c	0.40 ±1.20b	27.15 ±1.81ab	40.00 ±5.33ab	15050 ±97.48b	0.50 ±0.18b	37.20 ±2.34a	27.00 ±2.94b	145450 ±113.25a	1.40 ±0.62a
14:00	27.65 ±2.09b	38.00 ±3.90a	8650 ±50.24c	0.40 ±0.09c	28.90 ±1.93b	33.00 ±4.62ab	30900 ±104.51b	0.95 ±0.09b	44.50 ±2.51a	25.00 ±2.12b	176650 ±99.49a	2.85 ±0.33a
16:00	27.40 ±1.07a	40.00 ±6.03a	11200 ±70.92c	0.60 ±0.11c	28.00 ±2.03a	33.00 ±3.07ab	25200 ±85.93b	1.00 ±0.31b	39.25 ±2.09a	25.00 ±1.89b	111700 ±103.37a	3.15 ±0.71a
18:00	24.10 ±2.20a	46.00 ±3.61a	10300 ±97.01c	0.25 ±0.14c	25.55 ±1.35a	39.00 ±2.97ab	16650 ±90.05b	0.80 ±0.08b	30.95 ±1.93a	29.00 ±3.66b	65850 ±95.43a	2.95 ±0.25a
20:00	23.55 ±2.12a	54.00 ±4.11a	6002 ±66.75b	0.20 ±0.05b	22.80 ±1.55a	50.006.0 2a.	7175 ±87.09b	0.30 ±0.03b	21.70 ±2.04a	39.00 ±3.17a	17395 ±86.49a	2.10 ±0.36a

Diurnal variation of air, surface, and subsurface temperatures

Both Treatments 1 and 2 exhibited lower air, surface, and subsurface temperatures compared to the control group (*Table 4; Fig. 2*). Temperature variations throughout the day

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followed an "S-shaped" curve. Maximum surface temperatures in Treatments 1 and 2 were significantly lower than in the control ($P < 0.05$), as were maximum subsurface temperatures in Treatment 1. Additionally, the diurnal temperature range in air, surface, and subsurface layers was significantly narrower in Treatment 1 than in the control ($P < 0.05$), indicating that vegetation cover effectively moderated temperature extremes. Daily minimum temperatures for all plots occurred at 04:00, while maximum temperatures were recorded at 14:00. At 04:00, the lowest air, surface, and subsurface temperatures for Treatment 1 were 14.40°C, 14.75°C, and 16.00°C, respectively; for Treatment 2, these were 14.20°C, 14.55°C, and 16.00°C; and for the control, 13.70°C, 13.30°C, and 15.00°C.

Table 3. *Test results of below-ground (-5 cm) temperature (℃) of plant communities*

Time	Treatment 1	Treatment 2	Control（CK）
06:00	16.00 ± 1.54a	16.00 ± 1.91a	15.50 ± 2.04a
08:00	17.00 ± 0.96a	17.00 ± 1.07a	16.00 ± 0.85a
10:00	19.00 ± 1.15a	20.00 ± 1.62a	21.00 ± 1.73a
12:00	23.00 ± 2.33a	23.65 ± 1.95a	26.15 ± 1.42a
14:00	25.70 ± 2.19b	27.15 ± 2.36ab	38.10 ± 1.90a
16:00	25.05 ± 1.84a	26.95 ± 1.58a	28.55 ± 2.03a
18:00	23.35 ± 1.25a	24.00 ± 1.77a	26.35 ± 1.00a
20:00	20.00 ± 0.92a	20.00 ± 0.81a	20.35 ± 0.64a

Table 4. *Test results of air, surface and subsurface temperatures of plant communities—daily averages*

Treatment	Temperature indicators								
	Maximum temperature (℃)	Minimum temperature (℃)	Diurnal temperature range (℃)	Surface maximum temperature (℃)	Surface minimum temperature (℃)	Surface diurnal temperature range (℃)	Underground maximum temperature (℃)	Underground minimum temperature (℃)	Below-ground diurnal temperature range (℃)
Treatment 1	30.90 ±1.75a	14.40 ±1.09a	16.75 ±1.87b	27.65 ±1.96b	14.75 ±1.36a	12.90 ±0.92b	25.70 ±2.33b	16.00 ±1.52a	9.70 ±0.87b
Treatment 2	31.80 ±2.03a	14.20 ±2.11a	17.50 ±2.42ab	28.90 ±2.54b	14.45 ±1.19a	14.35 ±1.05b	27.15 ±1.94ab	16.00 ±1.63a	11.50 ±1.81b
Control (CK)	37.55 ±1.82a	13.70 ±1.27a	23.25 ±2.06a	44.50 ±2.62a	13.30 ±1.23a	31.20 ±2.49a	38.10 ±2.48a	15.00 ±2.26a	19.10 ±2.35a

Different lowercase letters in the same column indicate significant differences between treatments ($P < 0.05$). *Table 6* is the same

Effects of vegetation assemblages on soil physical properties

As soil depth increased, soil water content and total porosity in Treatments 1 and 2 initially rose and then declined, while bulk density showed the opposite trend—decreasing and then increasing. In contrast, the control group exhibited a gradual increase in soil water content and porosity with depth and a corresponding decrease in bulk density (*Table 5*). In the 0–40 cm soil profile, Treatment 1 had significantly higher water content than the control ($P < 0.05$). The 20–30 cm layer recorded the highest water content

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(5.56% for Treatment 1, 4.14% for Treatment 2), the greatest total porosity (43.35% and 41.3%, respectively), and the lowest bulk density (1.11 g/cm³ and 1.25 g/cm³). From 20–50 cm, total porosity in Treatment 1 was significantly higher than in the control ($P < 0.05$), indicating enhanced soil structural development under vegetative cover.

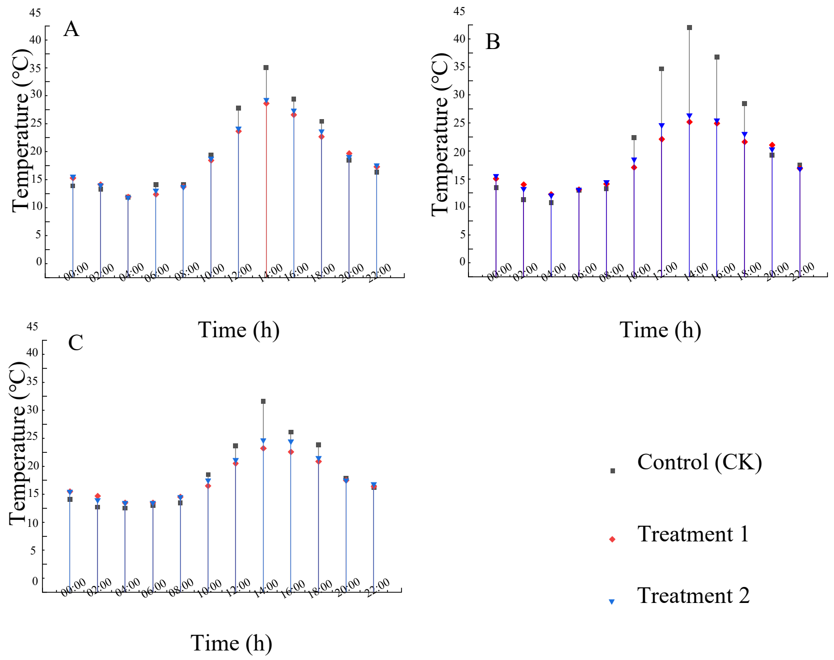

Figure 2. *Daily variation of air, surface and subsurface temperatures in plant communities. A air temperature; B surface temperature; C subsurface temperature*

Table 5. *Soil physical property test results*

Sampling depth (cm)	Treatment 1			Treatment 2			Control (CK)		
	Moisture content (%)	Capacity (g/cm³)	Total porosity (%)	Moisture content (%)	Capacity (g/cm³)	Total porosity (%)	Moisture content (%)	Capacity (g/cm³)	Total porosity (%)
0~10	4.04 ±1.16a	1.23 ±0.26a	32.16 ±5.39a	2.92 ±0.72ab	1.42 ±0.39a	38.81 ±4.73a	2.34 ±0.97b	1.52 ±0.44a	36.50 ±8.04a
10~20	4.61 ±1.72a	1.22 ±0.37a	41.45 ±6.03a	3.22 ±0.94ab	1.38 ±0.27a	40.82 ±5.17a	2.68 ±0.11b	1.40 ±0.37a	34.99 ±5.92a
20~30	5.56 ±1.07a	1.11 ±0.09a	43.35 ±7.21a	4.14 ±1.13ab	1.25 ±0.31a	41.30 ±5.29ab	3.16 ±0.74b	1.35 ±0.29a	27.51 ±4.55b
30~40	5.31 ±0.96a	1.14 ±0.25a	35.20 ±5.54a	3.90 ±0.95ab	1.28 ±0.26a	33.14 ±4.93ab	3.33 ±0.85b	1.31 ±0.32a	23.32 ±6.03b
40~50	4.97 ±1.14a	1.18 ±0.23a	31.82 ±4.07a	3.74 ±0.68a	1.28 ±0.32a	28.12 ±3.66ab	3.58 ±1.01a	1.29 ±0.39a	20.89 ±4.33b

Effects of vegetation assemblages on soil chemical properties

Marked differences in soil chemical characteristics were observed across treatments (*Table 6*). Both Treatments 1 and 2 exhibited significantly higher total nitrogen and organic matter contents compared to the control ($P < 0.05$), with Treatment 1

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outperforming Treatment 2 ($P < 0.05$), suggesting enhanced soil fertility under improved vegetation structure. Treatment 1 also showed significantly greater total phosphorus content than the control ($P < 0.05$), although no significant differences were observed in total potassium levels among treatments. Soil pH was highest in the control group (7.9), followed by Treatment 2 (7.3), and lowest in Treatment 1 (6.8). Compared to the control, soil pH in Treatments 1 and 2 decreased by 13.92% and 7.6%, respectively, indicating a substantial acidifying effect associated with vegetation recovery.

Table 6. *Results of soil chemical properties testing of plant communities*

Treatment	Chemical indicators				
	Total N (g/kg)	**Total P (g/kg)**	**Total K (g/kg)**	**Organic matter (g/kg)**	**pH value**
Treatment 1	0.34 ± 0.10a	0.62 ± 0.13a	20.64 ± 3.02a	5.86 ± 0.92a	6.80 ± 0.41a
Treatment 2	0.23 ± 0.07b	0.49 ± 0.09ab	20.16 ± 2.84a	3.63 ± 0.74b	7.30 ± 0.53a
Control (CK)	0.12 ± 0.05c	0.46 ± 0.05b	20.05 ± 2.07a	2.25 ± 0.68c	7.90 ± 0.56a

Discussion

Microclimatic modulation by vegetation assemblages

Riparian zones are recognized as ecologically sensitive interfaces where vegetation restoration presents significant challenges (Li et al., 2011). The selection and spatial arrangement of plant species must align with local ecological adaptability and biogeographic principles to ensure restoration success. Our previous research identified a suite of tree, shrub, and herbaceous species with high ecological suitability for the central Yarlung Tsangpo region. Building on this, the present study demonstrates that, at 14:00, surface temperatures in both Treatments 1 and 2 were significantly lower than in the control group ($P < 0.05$). This supports the hypothesis that vegetation, via transpiration and canopy shading, can buffer against extreme surface temperatures—findings consistent with previous studies (Deng et al., 2023). Subsurface temperatures were similarly moderated, indicating that increased vegetation coverage can influence deeper soil thermal regimes.

Significant reductions in light intensity were recorded across vegetated plots at all observation times (08:00, 10:00, 12:00, 14:00, 16:00, 18:00 and 20:00), attributed to increased canopy density and shading effects. Notably, Treatment 1 consistently exhibited lower light intensities than Treatment 2 ($P < 0.05$), confirming denser plant coverage and a more developed vertical structure. These findings parallel earlier work on vegetation-induced light attenuation (Liu et al., 2008). Wind is a critical driver of aeolian processes and strongly influences vegetation dynamics (Zhang et al., 2006; Sun et al., 2019). Our study found that vegetated treatments significantly reduced both surface and air wind speeds compared to the control, particularly in Treatment 1. This indicates the potential of woody–shrubby–herbaceous systems to mitigate wind erosion and stabilize sandy substrates—echoing prior research conducted in similar desert environments (Wu et al., 2013). Microclimate stabilization was further reflected in increased humidity across vegetated plots. At multiple time points (08:00, 10:00, 14:00, 16:00 and 18:00), both air and surface humidity levels were significantly higher in Treatment 1 ($P < 0.05$). This may result from reduced wind-driven evaporation and the ability of dense vegetation to retain transpired and soil-emitted moisture (Leck and Brock, 2010; Moran et al., 1994).

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The diurnal temperature range (DTR) of air, surface, and subsurface temperatures, defined as the difference between the maximum and minimum temperatures within a day, is an important indicator of climate change (Hansen et al., 1995; Ru et al., 2018). Vegetation cover not only affects surface and subsurface temperatures but also significantly influences the DTR of air, surface, and subsurface temperatures. In this study, the DTR of air in Treatment 1 was significantly lower than that in the control group ($P < 0.05$). The maximum surface temperature in both Treatment 1 and Treatment 2 was significantly lower than that in the control group ($P < 0.05$), and the DTR of surface and subsurface temperatures in these treatments was also significantly lower than that in the control group ($P < 0.05$). These findings indicate that tree–shrub–grass plant communities have the capacity to stabilize regional temperatures and prevent the occurrence of extreme temperatures. This effect may be attributed to the ground cover provided by the vegetation, which shields the soil from direct sunlight during the day and reduces temperature drops caused by wind at night. Additionally, the reduction in wind speed is also an important factor influencing the DTR of air, surface, and subsurface temperatures.

Improvement of soil physical and chemical properties

Soil total porosity, bulk density, and moisture content are key indicators of soil physical properties (Wang et al., 2023; Liu et al., 2023; Genga et al., 2022). In this study, in the 20–50 cm soil layer, the total porosity of soil in Treatment 1 was significantly higher than that in the control group ($P < 0.05$). This indicates that the root systems of tree–shrub–grass plants can improve soil aggregate structure, which is of great physical significance for accelerating the soil formation process of sandy soils in desertified areas. The reason may be that the dead branches and leaves of tree–shrub–grass plants mix with the sandy soil, providing necessary nutrients for microbial activity. Meanwhile, with the increase of dead branches and leaves, microbes become more active, thereby increasing soil porosity. This is similar to the findings of Yang (2022) on the impact of straw returning duration on the physical properties of the plow layer soil. In this study, in the 20–30 cm soil layer, the total porosity of soil in Treatment 1 and Treatment 2 reached the maximum, while the soil bulk density reached the minimum. The reason may be that the root systems of the tree–shrub–grass plant community are concentrated in this soil layer. In the 0–40 cm soil layer, the soil moisture content in Treatment 1 was significantly higher than that in the control group ($P < 0.05$). This indicates that the root systems of the tree–shrub–grass plant community under Treatment 1 have a strong water retention capacity. The reason may be the increase in soil total porosity and the decrease in bulk density.

The improvement of soil physicochemical properties and the promotion of microbial activity accelerated the decomposition of returned materials, thereby increasing soil nutrient content and enzyme activity (Chen et al., 2018; Gou, 2019; Zhou et al., 2021). In this study, the total nitrogen and organic matter content of the soil in Treatment 1 and Treatment 2 were significantly higher than those in the control group ($P < 0.05$). This indicates that tree–shrub–grass plants have the ability to enrich soil fertility, which is of great ecological significance for reducing the amount of fertilizer applied to sandy lands and improving their productivity. This is consistent with the findings of Wei (2023) on the effects of mixed sowing of *Medicago ruthenica* and *Agropyron cristatum* on soil nutrient content and enzyme activity in grasslands. Moreover, compared with Treatment 2, the total nitrogen and organic matter content of the soil in Treatment 1 were significantly higher ($P < 0.05$), indicating that Treatment 1 has a greater capacity to enrich soil fertility than Treatment 2.

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The soil pH value, which serves as an indicator of soil acidity or alkalinity, can alter the distribution and transformation of soil nutrients through its effects on the physical, chemical, and biological properties of soil (Xu et al., 2015; Mueller et al., 2012). In this study, the control group had the highest soil pH value (7.9), while the soil pH values in Treatment 1 and Treatment 2 were reduced by 13.92% and 7.6% respectively compared with the control group. This suggests that the pH value of sandy soil is alkaline, and the tree–shrub–grass plants have reduced the pH value of sandy soil. The reason may be that the absorption by tree–shrub–grass plants and the leaching effect of precipitation have led to the consumption of base cations by plants (Zhang et al., 2021).

Conclusions

The vegetative assemblage comprising *Cupressus gigantea*, *Sophora moorcroftiana*, *Medicago sativa*, *Melilotus officinalis*, *Eragrostis nigra*, and *Astragalus adsurgens*, structured in a stratified the tree–shrub–grass configuration and supported by cultivation facilities (geocell structures and rainwater-collecting trays), formed a synergistic system in which species coexisted harmoniously, promoting ecological stability and functional integration. The tree–shrub–grass planting model composite ecosystem significantly improved microclimatic conditions—reducing wind speed, increasing relative humidity, and stabilizing air, surface, and subsurface temperatures. Concurrently, it enhanced soil physical and chemical properties by lowering bulk density and pH while increasing porosity, water content, and concentrations of organic matter, total nitrogen, total phosphorus, and total potassium. The integrated configuration mode of the tree–shrub–grass combination of *Cupressus gigantea*, *Sophora moorcroftiana*, *Medicago sativa*, *Melilotus officinalis*, *Eragrostis nigra*, and *Astragalus adsurgens*, combined with rainwater-collecting trays and geocell structures, can achieve comprehensive restoration of the environment, soil, and ecology. This approach is conducive to rebuilding a favorable ecological environment in the riparian sandy lands of the middle reaches of the Yarlung Tsangpo River and to realizing the sustainable use of water and soil resources.

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REFERENCES

[1] Bu, F. Q., Du, S. J., Fang, L. M., Liu, Q. Q., Cheng, H. (2016): Progress of research on combining arbor-irrigation-grass to manage wind-sanding of land in the north of China. – Journal of Anhui Agri. Sci. 44(3): 48-49, 54.

[2] Chang, X. X., Chen, H. S., Li, Z. G., Zhang, H. P. (2014): Species diversity of ecological restoration plant communities in typical desert areas of the Brahmaputra River Basin in Tibet. – Journal of Desert Research 41(6): 187-194.

[3] Chen, D. D., Li, Q., Chen, X., He, C. F., Zhao, X. C., Xu, S. X., Zhao. L. (2018): Response of soil microbial biomass C and N, C metabolism characteristics of microbes to grass-

legume mixtures of annual artificial grassland in Sanjiangyuan Region. – Acta Agrestia Sinica 26(5): 1064-1070.
[4] Deng, Y. C., Ji, D. D., Liu, Y. J., Meng, Y. (2023): Effects of vegetation cover change on surface temperature in Tianxingzhou of Wuhan. – Journal of Green Science and Technology 25(6): 53-57.
[5] Genga, Y. P., Zhou, S., Yang, K., Wang, Y., Yang, S. W., Liu, G., Yang, T. Y., Zha, D., Wang, Z. G. (2022): Effects of plateau pika disturbance on plant community and soil physical property of alpine meadow in northwest Sichuan. – Grassland and Turf 42(1): 38-48.
[6] Gou, W. L. (2019): Study on Productive Features of Annual Grass-Legume Community in the Western Sichuan Plain. – Gansu Agricultural University, Lanzhou.
[7] Hansen, J., Sato. M., Ruedy, R. (1995): Long-term changes of the diurnal temperature cycle: implications about mechanisms of global climate change. – Atmospheric Research 37(1): 175-209.
[8] Hou, W. (2021): A preliminary study on the selection and configuration of plants for ecological restoration in the middle reaches of the Yarlung Tsangpo River. – Xizang Science and Technology (9): 40-44.
[9] Jiang, D. M., Cao, C. Y., Li, X. H., Zhou, C. L., Li, M. (2008): Vegetation restoration and its effects on soil improvement in Horqin sandy land. – Ecology and Environment 3: 1135-1139.
[10] Leck, M. A., Brock, M. A. (2010): Ecological and evolutionary trends in wetlands: Evidence from seeds and seed banks in New South Wales, Australia and New Jersey, USA. – Plant Species Biology 15(2): 97-112.
[11] Li, H. D., Shen, W. S., Fang, Y., Yan, S. G., Zhang, H., Zhao, W. (2011): Point pattern analysis of several psammophyte populations in the riparian ecotone in the middle reaches of Yarlung Zangbo River of Tibet, China. – Chinese Journal of Plant Ecology 35(8): 834-843.
[12] Li, Y. X., Fang, J. P. (2011): Analysis on dynamic changes of land desertification in the middle reaches of Yarlung Zangbo River. – Guizhou Agricultural Sciences 39(12): 71-74.
[13] Liu, H., Ma, J., Liu, Z. W., Liu, Z. Y. (2008): Study on ecological effect of plant communities. – Journal of Shanxi Agricultural Sciences (7): 81-85.
[14] Liu, M., Zhao, C., Fan, H., Yin, W., Fan, Z. L., Hu, F. L., Sun, Y. B. (2023): Effects of long-term intercropping and no-tillage on soil physical properties and crop yield. – Chinese Agricultural Science Bulletin 39(2): 28-35.
[15] Liu, X. Y. (1982): Soil Physics and Soil Improvement Research Method. – Shanghai Scientific & Technical Publishers, Shanghai.
[16] Liu, Y., Wang, Y. S., Shen, T. (2019): Spatial distribution and formation mechanism of aeolian sand in the middle reaches of the Yar-lung Zangbo River. – Journal of Mountain Science 16(9): 1987-2000.
[17] Lu, R. K. (2000): Soil Agrochemical Analytical Methods. – China Agricultural Science and Technology Press, Beijing.
[18] Luosang, Q. J., Yan, M., Ma, P. F., Za, D., Ge, D., Zhang, Z. C. (2022): Study on the sand transport quantities on the different landscapes in the middle area of Yarlung Zangbo River. – Journal of Desert Research 42(2): 6-13.
[19] Ma, P. F., Zhang, Z. C., Lunzhu, Q. P., Gao, J. J., Dai, R., Ci, W., Pan, K. J. (2021): Analysis on the sand transport wind power conditions and suggestions on the sand disaster preventions in the middle reaches of Yarlung Zangbo River, China. – Journal of Desert Research 41(1): 10-18.
[20] Moran, M. S., Clarke, T. R., Inoue, Y., Vidal, A. (1994): Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index. – Remote sensing of environment 49(3): 246-263.
[21] Mueller, K. E., Eissenstat, M. D., Hobbie, S. E., Oleksyn, J., Jagodzinski, A. M., Reich, P. B., Chadwick, O. A., Chorover, J. (2012): Tree species effects on coupled cycles of carbon,

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DOI: http://dx.doi.org/10.15666/aeer/2401_925938

nitrogen, and acidity in mineral soils at a common garden experiment. – Biogeochemistry 111(1): 601-614.
[22] Pan, H. X. (2007): Strengthen desertification combating of Yajiang Basin to promote ecological barrier of Tibetan Plateau. – Forestry Economics (8): 34-36.
[23] Ru, C., Duan, S. B., Jiang, X. G., Leng, P., Gao, M. F., Huo, H. Y., Li, Z. L. (2018): A method for surface soil moisture estimation based on the DTR-FVC space. – Journal of University of Chinese Academy of Sciences 35(6): 771-781.
[24] Shen, W. S., Li, H. D., Zhang, T., Zhou, C. X., Yan, S. G., Yuan, L. (2009): Feasibility analysis of fly seeding on high cold wind sandy land in Tibet. – Journal of Ecology and Rural Environment 25(1): 106-111.
[25] Shen, W. S., Li, H. D., Lin, N. F., Zhang, T., Yuan, L., Sun, M., Sun, J., Ji, D. (2012): Screening trial for the suitable plant species growing on sand dunes in the alpine valley and its recovery status in the Yarlung Zangbo River basin of Tibet, China. – Acta Ecologica Sinica 32(17): 5609-5618.
[26] Song, G. Y., Bianba, Z. M. (2022): Test on forage introduction adaptability on desertification land in the middle of the Yarlung Zangbo River Basin. – Modern Agricultural Science and Technology 815(9): 171-174.
[27] Sun, S. S., Liu, X. P., Wei, S. L., Zhang, T. H., He, Y. H., Cheli, M. G., Lu, P., Wang, M. M. (2019): Response of plant seedling growth to the changes in precipitation and wind velocity in Horqin Sandy Land. – Arid Zone Research 36(4): 870-877.
[28] Wang, H. L., Wu, Q. Z., Lan, W. M., Chen, X. L., Ke, Q., Wang, Z. Y., Wei, Z. M., Chen, L. J., Wu, L. C., Cao, J. D. (2023): Dynamics of understory vegetation and soil physical properties in Eucalyptus plantations of different generations. – Journal of Central South University of Forestry & Technology 43(2): 1-9.
[29] Wang, Q., Tang, J. N., Li, Y. K., Jin, H. X., Yuan, H. B., Yang, X. M. (2020): Key techniques for controlling mobile dunes and grassland restoration in a desertified grassland of Gannan: take the first bending of the Yellow River as an example. – Pratacultural Science 37(9): 1719-1728.
[30] Wei, K. T., Yu, X. J., Bai, M. M., Ma, K. K., Liu, Y. F., Zhang, X. M. (2023): Effect of mixed sowing ratio on soil nutrient content and enzyme activity of Medicago ruthenica-Bromus inermis mixed grassland in Longzhong Loess Plateau. – Chinese Journal of Grassland 45(02): 56-66.
[31] Wu, W. Y., Zhang, D. S., Tian, L. H., Zhao, C., Jia, F. F. (2013): Variable characteristics of wind profile of the artificial sand dune in sandy land around the Qinghai Lake. – Research of Soil and Water Conservation 20(6): 162-167.
[32] Xu, J. P., Li, J. H., Wei, Y. J., Zhang, G. H., Yang, B. G., Cai, C. F. (2020): Fractal characteristics of particle composition for soils developed from different parent materials. – Acta Pedologica Sinica 57(5): 1197-1205.
[33] Xu, K. J., Shi, L. L., Wang, Y. F., Li, M., Sun, F. L., Liu, Y. D., Xi, Y. J. (2015): Effect of the pH value on switchgrass seedling growth and development in hydroponics. – Acta Ecologica Sinica 35(23): 7690-7698.
[34] Yang, X. Z., Ge, X. L., Liu, J., Fan, X. Y., Zheng, W., Zhang, R. F. (2022): Effects of straw returning years on soil physical properties of topsoil under maize shallow buried and drip irrigation. – Journal of Inner Mongolia Minzu University 37(4): 295-300.
[35] Zhan, Q. Q., Zhao, W., Yang, M. J., Fu, H., Li, X. J., Xiong, D. H. (2022): Identification of sandy land in the midstream of the Yarlung Zangbo River. – Journal of Geo-information Science 24(2): 391-404.
[36] Zhang, J. J., Liu, J. C., Yan, C., Wang, Y. X., Liu, K., Shi, X. R., Yuan, Z. Y. (2021): Effects of soil pH on soil carbon, nitrogen, and phosphorus ecological stoichiometry in three types of steppe. – Acta Prataculturae Sinica 30(02): 69-81.
[37] Zhang, K. Q., Qu, J. J., Dong, Z. B., Zu, R. P., Fang, H. Y. (2006): Effect of wind speed fluctuation on sand transport rate. – Journal of Desert Research 26(3): 336-340.

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DOI: http://dx.doi.org/10.15666/aeer/2401_925938

[38] Zhou, J. J., Baima, G. W., Wei, W., De, K. J. (2021): The effects of grass-legume mixing farming on forage nutritional quality and soil nutrient in alpine zone of Tibet. – Agricultural Research in the Arid Areas 39(2): 143-149.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_925938