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Site type classification for the shelter-forest ecological project along the Tarim Desert Highway

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Site types of the afforestation region of the shelter-forest ecological project along the Tarim Desert Highway were classified based on the natural conditions and windblown sand damages. The extremely severe environment, the irrigation with saline water, and large-scale linear project makes this classification of site types most unique and significant. It adopted a three-level classification system integrating the dominant factors and restrictive factors in regard to their impacts on plant survival and growth as well as on the protective property. Six site type districts were classified based on the medium-scale geomorphic unit, the windblown sand damages, and the major production facilities; 21 site type groups were obtained according to the small-scale geomorphic type, terrain, and wind regime; 36 site types were further classified based on the salt contents of the underground water and soil types. Especially, in this study, spatial distribution of the six site type districts along the desert highway is continuous, which is unique and different from that of most other classifications. In addition, the salt-stress tolerance threshold of the main afforestation plant species to underground water have been set to 8 g/L and 15 g/L according to selective breeding tests and the salinity spatial distribution of the underground water. Thus, the underground water with salinity lower than 8 g/L is defined as light saline water in this area.

Tarim Desert Highway, shelter-forest, site type classification, saline water, Xinjiang, afforestation

The Taklimakan Desert, located in the Tarim Basin in southern Xinjiang, also called “the sea of death”, was the largest desert in China with an area of 33.7×10^4 km^2. Its environment is very severe with a extremely dry and hot climate[1]. The Tarim Desert Highway is the first standard highway built in this desert. It is 562 km long, running across the Taklimakan Desert from the north at National Highway 314 in Luntai County to the south at National Highway 315 in Minfeng County[2].

The shelter-forest ecological project on the both sides of the Tarim Desert Highway is 436 km in length, but there are many potential sand damage zones along the highway due to intensive blown-sand activities. Constructions of this project started in 2004 and was completed in 2006. Since then, the windblown sand disasters to the highway has been effectively controlled. It ensured the long-term transportation of the highway.

Because of the large span of the region, the complexity of the landform types along the highway, and the difficulty of the afforestation, a reasonable division of site types for the shelter belt along the Tarim Desert

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Highway is the basis and the priority of the shelter-forest ecological project. At present, although there is not a uniform classification system for site types in large scale yet, there is a generally accepted system for classification of site types in medium and small scales; however it needs to be modified based on the selected factors and their spatial scales, as well as different nature conditions. The site types of this shelter belt had been pre-classified during the engineering design phase to meet the demands of this project[3,4]. After the completion of this project, accumulated research results should provide a better understanding of the characters of protection forest system and the natural conditions along the highway, so it is important to further classify the site types along the highway more accurately for the long-term maintenance and the renewal of this project.

With experimental study in past several years, we have studied the unique geomorphic conditions of this area, particularly its extremely severe climate and the underlaying surface conditions along the highway, as well as the forestation system irrigated with saline water and highways sand protection system. In this paper, we offer our insights and methods for the site type classification of the shelter belt along the Tarim Desert Highway, and hope to provide references for future construction of other similar ecological projects in desert.

1 Methods

1.1 Survey of the study region

The Tarim Desert Highway runs across the Taklimakan Desert from south to north between 82°—85°E and 37°—42°N. It belongs to the warm weather zone with an extremely dry weather[2, 5], which is characterized by very little precipitation, high evaporation, high yearly and daily temperature range, long sunshine duration, strong windblown sand activities. Its annual precipitation is 11—50 mm, and annual average wind speed is 2 m/s[5]. The elevation along the highway is lower in the north and higher in the south, varies very little with relative height lower than 80 m. The mobile sand covers more than 95% of the sand surface along the highway. There are very simple residential animal and plant species in small quantities along the highway.

The shelter belt along the Tarim Desert Highway was constructed on both sides of the highway from the K118+900 to K561+400, with a width of 72—78 m. The shelter belt is a large linear sand-control project. Three high stress-tolerant shrub species, *Tamarix*, *Calligonum*, and *Haloxylon*, have been planted and irrigated using an advanced drip irrigation technique.

1.2 The principle and basis of site type classification

(i) The principle of site classification. Site classification is the foundation of forestation program and the prerequisite of implementing the forestation planning principle “right seedling for right land”, as well as the basis of proper utilization of the land resource and improvement of the quality of forestation. Classification of site types in a special region should consider multiple factors[6]; however, in arid area, the restricted factors are the main consideration[7]. The general principle for classification is to combine main factors at multiple levels based on scientific analysis; the other principle is the simplicity and practicability. Because site types classification eventually serves practical application, to achieve its scientific and practical goals, it should be simple, easy to understand and application[8,9].

(ii) Site type classification system. Site type classification is a system with multiple levels; each in turn is being controlled by its higher class. Research in this field has attracted much attention of many countries, and come into being many different classification methods in the world. Although a site classification system is still in its early discussion in China, a significant amount of work has been done by many scholars and experts, and a certain mutual agreement has been reached among them[6,7]. At present, there are two classification systems in China[10]: one was proposed by Zhan Zhaoning in the book “*China Forest Site Classification*” in 1989[11], the other was established by Zhang Wanru and Jiang Youxu in “*China Forest Site*” published in 1997[12]. Since the former has been more frequently used in the practice, it was also used as the site type classification system in this paper. This classification system has 6 levels: site area, site region, site subregion, site type district, site type group, and site type[11]. The first three levels, site area, site region, and site subregion, are at the higher levels of the system; the resulting areas, regions and subregions are also continuously distributed in space, similar to those classified by China forestry regional division system. On the other hand, the latter three levels, site type district, site type group, and site type, are discontinuous in the spatial distribution[9]. They are also more often used in site type classification for specific regions. Although the difference in the regional natural and social conditions determines the difference in site types and the different factors selected for site type classification, the basic components and their definitions are consistent among the various systems used in China.

1.3 Data source and collection

(i) Field survey. A comprehansive survey was carried out along the highway for the aeolian landform, the types and conditions windblown sand damages, the depth and quality of underground water, soil types, vegetation distribution and the land utilization.

(ii) Indoor analysis. Samples collected in the above field survey were analyzed by the standard methods for underground water quality (salt content, pH), salt content and fertility of the soil, etc.[13].

2 Site classification

2.1 Analysis of main site factors

(i) Climate. According to the data collected from the weather stations along the Tarim Desert Highway, the Tazhong area in the hinterland of the Taklimakan Desert has an annual precipitation of 10.7 mm, an annual evaporation of 3806.4 mm; its annual average temperature is 12.7℃, with the highest temperature in August at 43.2℃ and the lowest temperature in January at −19.3℃. It has an average of 2854.2 hours of sunlight, 6 days of strong winds, 74 days of floating dusts, and 45 days of sand blowing. The maximum depth of frozen ground in 50 years was 88 cm. There is a spatial and temporal difference in wind dynamics along the Tarim Desert Highway. Xiaotang, in the north part of the highway, mainly has winds with N, NNE, NE, ENE, E directions; Tazhong, in the middle part of highway, has the main wind directions of ENE, NE, E and NNE. In the south, the wind directions vary and are influenced by winds from NE, NW, and SW directions but its annual amount and frequency of sand-moving wind are significantly lower than those of Xiaotang and Tazhong. In the wind season from March to September, it has strong and prequent wind; however, from October to February, it has weaker and less frequent winds due to the high air pressure.

(ii) Landform. The elevation along the Tarim Desert Highway decreases from south to north with 450 m elevation variation. The aeolian landform along the highway has developed widely influenced by wind and the underlying geomorphy. The relative height of landform along the highway is high in the middle part and low at both ends. The scale of complex ridges (dunes) is 20—50 m in height with the maximal height 70 m and 1 km in width. The complex ridges are covered by a series of secondary dunes and dune chains, with the dune heights ranging from 3—10 m. The topography of interdunes located between two complex ridges is relatively smooth and open. The dunes in interdunes are mostly under 3 m high, and in a density about 60%. Dense dunes and dune chains with 3—5 m in height have developed in the transition regions between ridges and interdunes.

(iii) Underground water. Along the highway, there is little runoff. However, it is rich in underground water, with a volume of $1629\times10^8 m^3$[14]. The depth of groundwater table along the highway changes greatly in different landforms, about 5 m deep in interdunes and over 20 m on complex sand ridges. The major chemical component in the groundwater is $SO_4 \cdot Cl\text{-}Na$[1,2]. The salinity of groundwater ranges from 2.6 g/L to 30 g/L, with more than 15 g/L distributed in the north part between K119+800 (Xiaotang) and K176+000 (No. 1 well—No.15 well), 5 g/L in the middle part, and 5—10 g/L in the south part. This shows that all the groundwater along the highway is mostly saline water.

(iv) Soil. The soil types along the highway are very simple, and the main type is aeolian sandy soil showed in a weak soil formation. Other soil types cover smaller areas with a noncontinuous distribution[1]. The predominant soil type, mobile aeolian sandy soil, contains organic chemicals under 1‰, salt under 2‰, pH value about 9, water content under 0.5%; therefore, it is not suitable for plants. The immobile aeolian sandy soil scattered among the dunes contains 3‰ organic components and higher salt than mobile aeolian sandy soil. There are also takyr soil and saline soil scattered interdunes. There is no vegetation in takyr soil region, while a few plant species in saline soil region are distributed in interdunes, where has a higher underground water table, a 21.78‰—23.12‰ salinity in sand sheet on the ground surface, more than 65.18‰—151.26‰ in salt content in the salt-accumulating sheet below the sand sheet, and 2.67‰—24.15‰ salt below the salt-accumulating sheet.

(v) Native vegetation. The plant species in the native vegetation along the highway are simple and in small quantities, and predominantly mesophytes with intrazonality. According to the survey, in the hinterland of the Taklimakan Desert, there are 19 plant species which belong to 8 families, including *Calligonum* L., *Phragmites* Adns, *Hexinnia polydichotoma parviflora*, *Tamarix* L., and *Apocynum* L., etc. The plant species only exist in the low land with lower underground water table in interdunes distributed scatteredly in the vast of "sand sea".

2.2 The selections of the dominant and limiting factors

In general, the site type classification in a specific area should be done in consideration of multi-factors, particularly the landforms and soil types, in reference to the plant species, and finally it should be validated by the actual growing vegetation. Protection highway from windblown sand damage is the ultimate objective of the shelter-forest ecological project of the Tarim Desert Highway. To identify the dominant and limiting factors for afforestation, firstly, factors affecting plant growth, mainly including the quality of irrigation water, weather and soil should be considered. The most important one is the quality of underground water which determines plant survival, and the feasibility of the shelter-forest ecological project. Secondly, factors affecting the capacity of protection, such as landform, topography, wind regime (determining the type and intensity of windblown sand damages), soil, production facilities should be also considered, because they determine the scheme and structure of shelter belt. The shelter forest is irrigated using a precise drip irrigation technique, and the soil texture is homogeneous, then others factors, such as slope gradient, slope position, aspect, and elevation and so on, can be neglected.

2.3 Site classification system

(i) Classification factor assignment. According to effects of factors on the construction and protection capacity of shelter belt, all the dominant and limiting factors are assigned into four levels: (1) the middle-scale geomorphic unit, the windblown sand damages, and major production facilities, which all determine the overall layout of the shelter forest; (2) the small-scale geomorphic unit, the landform and wind regime, which determine the configuration and struction of the shelter belt; (3) underground water quality and meteorological factors, which determine the choice of plant species and the overall configuration of the shelter belt; and (4) soil conditions, which determine the choice of plant species and the configuration of shelter belt on plot. Despite its large span of more than 500 km from north to south, the Tarim Desert Highway is located in a region with a single climate type, which has little changes in meteorological factors and the physiognomy. Therefore, the three-level classification system was applied to the site type classification of afforestation along the Tarim Desert Highway. Site type districts were classified according to the factors in the first level, site type groups were classified according to the factors in the second level, and site types were classified according to the factors in the third and fourth levels.

(ii) Site type district classification. To control the sand hazard and ensure the traffic of the highway are the core objective of the shelter belt along the highway. Therefore, sand damage conditions along the desert highway are the basic data to collect. Our large-scale investigation and observation identified two dominant factors that affect windblown sand damages and cause the environment diversity. One is the difference in wind regime shown the driving power; the other is the difference geomorphology shown the underlying surface. The area along the Tarim Desert Highway from north to south can be divided into 5 site zones according to geomorphology: the complex transverse dune ridge zone on the Tarim River alluvial plain, the complex dome dune zone on the ancient lake plain at the northern part of the Tarim Basin, the central complound longitudinal dune ridge zone located in the center of the Tarim Basin, the complound longitudinal dune ridge zone in the downstream delta of the Yatongguz River[15], and the complex longitudinal dune zone at Minfeng upheaval in the downstream delta of the Niya River. On the other hand, the long-term wind power determines the characteristics of aeolian landforms along the highway which in turn influences the air flow near the ground surface. Therefore, considering the difference among the five site zones in regard to the differences in wind regime and the possibility or intensity of the windblown sand damages (including severe, moderate and light damages), the windblown sand disaster-pregnant environment can be generally divided into five site type districts, as shown in Table 1. Gas and oil pipelines were also found within 30 m at the west side of the Tarim Desert Highway, which is essential for the shelter belt. Based on all the above analyses, the area along the Tarim Desert High way was divided into six site type districts that are

Table 1 Classification of the site type district

Number	Name	Characteristics	Length (km)	Beginning and ending mileage
I	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain	Small topografic relief, widespread distributed river alluvial deposits; gentle highway transverse sections; strong windblown sand activity	65.1	K118+900－K174+000
II	The lightly damaged area of the complex dome-shaped dunes on the south of the Tarim River transition plain	Flat terrain, rich vegetation on interdunes; mostly low embankments or zero highway transverse sections; strong windblown sand activity	17.0	K174+000－K191+000
III	The north of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin (north of Tazhong), accompanying by oil/gas pipelines in the west	Significant topografic relief; large and high dunes on sand ridges and passing areas; strong windblown sand activity; oil/gas pipelines in the north	145.0	K191+000－K336+000
IV	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin (south of Tazhong)	High topografic relief, large dunes on sand ridges and passing areas, open and flat interdunes; strong windblown sand activity	94.3	K336+000－K430+300
V	The moderately damaged area of the complex longitudinal sand ridges in the downstream dry delta of the Yatonggus River	High topografic relief; ralatively large dunes on sand ridges and passing areas; open and flat interdunes; weak windblown sand activity	43.2	K430+300－K473+500
VI	The lightly damaged area of the complex sand ridges in the downstream delta of the Niya River and the Northern Minfeng Upheaval	High topografic relief; relatively large dunes on sand ridges and passing areas; high groundwater level; rich vegetation; weak windblown sand activity	87.9	K473+500－K561+400
Total			442.5	K118+900－K561+400

continuously distributed in space (Table 1).

(iii) Site type group classification. Site type groups, as the second level of the classification system, are the combinations of site types sharing similar site conditions and production potentials[9]. This classification depends on two types of factors: the small-scale landform factors, and the wind regime.

The desert highway passes through five types of dune zones. Although there are various sand ridges and compound dunes, small-scale landform can be divided into three regions: ridges or the passing area, transition region between ridges and the interdunes, and the interdunes. Our observation data showed that the type and intensity of the windblown sand damages in the three regions were different. When the Tarim Desert Highway passed through sand ridges covered with dense high and large dunes, the highway and its protective system suffered from severe wind erosion and sand burial of forward moving high dunes; when it passed through the interdunes covered with sparse low and small dunes, they suffered from sand deposition unloadded from wind-sand flow and sand burial of forward moving small dunes; when it passed through the transition region, they faced various types of possible windblown sand damages. Analysis about wind regime that cause these damages revealed that the wind directions in all sections along the Tarim Desert Highway are different. In the Xiaotang area in the north part of the highway, winds are mainly dominated by N, NNE, NE, ENE and E directions, and the resultant wind direction is NNE; in the Tazhong area in the hinterland of the highway, the wind directions are dominated by ENE, NE, E and NNE. For these two areas along the linear highway, the damagecausing winds share the wind direction of east. On the other hand, in the south area of the highway, wind directions vary, and are influenced greatly by winds from NE, NW, and SW; therefore, both sides of the highway are equally vulnerable to the sand damages. Based on these factors, 21 site type groups were divided along the Tarim Desert Highway, which are not continuously distributed in space (Table 2).

(iv) Site type classification. Site types along the Tarim Desert Highway were classified according to the third and fourth level factors in the classification system, the underground water quality and soil conditions, which are analyzed in both qualitative and quantitative methods.

The underground water quality along the Tarim Desert Highway is generally very low, which directly determines the selection of tree species of the shelter belt. Because increasing salinity leads to reduction in the amount of optional tree species, suitable plant adaption thresholds of groundwater salinity must be chosen to classify the appropriate tree species. Saline water irrigation tests showed that salinity of 7－10 g/L and 15 g/L are the two threshold values that restrain the survival and growth of some psammophytes, respectively[16]. Along the Tarim Desert Highway, there

Table 2 Classification of site type group

Site type district	Site type group	Wind direction	Landform type	Sand dune height (m)	Sand dune density (%)
I	I1	Obvious prevailing wind direction	Interdunes	≤1	≤60
	I2		Transition regions between ridges and interdunes	1－3	60－100
	I3		Large sand ridges	≥3	80－100
II	II1	Obvious prevailing wind direction	Interdunes	≤1	≤20
	II2		Transition regions between ridges and interdunes	1－3	20－80
III	III1	Obvious prevailing wind direction	Large regions between ridges	≤3	≤60
	III2		Transition regions between ridges and interdunes	3－5	60－100
	III3		Large sand ridges	≥5	80－100
IV	IV1	Obvious prevailing wind direction	Interdunes	≤3	≤60
	IV2		Transition regions between ridges and interdunes	3－5	60－100
	IV3		Large sand ridges	≥5	80－100
	IV4	Multi-directions	Interdunes	≤3	≤60
	IV5		Large sand ridges	≥5	80－100
V	V1	Obvious prevailing wind direction	Interdunes	≤3	≤60
	V2		Transition regions between ridges and interdunes	3－5	60－100
	V3		Large sand ridges	≥5	80－100
VI	VI1	Obvious prevailing wind direction	Interdunes	≤1	≤60
	VI2		Transition regions between ridges and interdunes	1－3	60－100
	VI3		Large sand ridges	≥3	80－100
	VI4	Multi-directions	Large sand ridges	≥3	80－100
	VI5		Desert marginal zones	≤1	≤60

are 108 water supply wells for irrigation, 10 of which are distributed in the north part with greater than 15 g/L salinity, 12 at the two ends with salinity of 8－15 g/L, 86 wells in the central part with salinity ranging from 2.6 g/L to 8 g/L, making up for 80% of all wells. So, three underground water quality types, which are the light saline water (L) of less than 8 g/L salinity, the medium saline water (M) of salinity from 8 g/L to 15 g/L, and high saline water (H) of greater than 15 g/L salinity, can be used as the main indexes to classify site types. There are three soil types, mobile aeolian sandy soil, takyr soil, and solonchak soil along the highway. The mobile aeolian sandy soil accounts for 95% of the entire area, and takyr soil and solonchak soil are only in scattered distribution in interdunes, mostly distributed in samll patches, except one small continuous area in the north. Because they are difficult to be classified properly, and have little effects on the configuration of the shelter belt, takyr soil and solonchak soil can be neglected.

According to the above analysis, the afforestation area along the Tarim Desert Highway can be classified into 36 site types (Table 3), and divided into 208 segments (not shown).

3 Discussions

(1) A three-level site classification system for the shelter belt along the Tarim Desert Highway has integrated various dominant factors that affect the survival, growth and protection capacity of the shelter belt. It has also reflected highway's damage conditions resulted from windblown sand; therefore, it has provided a basis for the design, construction and management of the shelter belt of desert highway. It must be pointed out that the region along the Tarim Desert Highway belongs to non-suitable forestation area, the worst site in terms of suitability for afforestation, in the Three-North Shelter Forest Project in North China. In general, the improvement of desert vegetation in such non-suitable area should be realized mainly by the protection of current existing plants[7]. Therefore, its site type classification must be carried out with a great deal of experimentation, especially for plant specie introduction and the afforestation test.

(2) Site type district is the highest classification unit used in this study. In general, the distribution of site type districts is discontinuous in space[9,10]. However, the site type districts classified by our site classification system are continuous, which is characteristically different from other systems. This can be explained by the facts that the shelter belt was constructed along a straight, linear highway without many turns and variations in geomorphology or repetitive landforms, although the highway itself is quite long and spans a large space. Site type

Table 3 Classification of site type

Site type district	Site type group		Site type	Range of underground water salinity (g/L)
I	I1	I1L1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, a light salinity water, and the aeolian sandy soil	≤8
		I1L2	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, a light salinity water, and the chapped soil	≤8
		I1m1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, a medium salinity water, and the aeolian sandy soil	8—15
		I1m2	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, medium salinity water, and the chapped soil	8—15
		I1h1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, the high salinity water, and the aeolian sandy soil	≥15
		I1h2	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, interdunes, the high salinity water, and the chapped soil	≥15
	I2	I2L1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, transition regions between ridges and interdunes, light salinity water, and the aeolian sandy soil	≤8
		I2m1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, transition regions between ridges and interdunes, the medium salinity water, and the aeolian sandy soil	8—15
		I2h1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, transition regions between ridges and interdunes, the high salinity water, and the aeolian sandy soil	≥15
	I3	I3L1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, large sand ridges, light salinity water, and the aeolian sandy soil	≤8
		I3m1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, large sand ridges, medium salinity water, and the aeolian sandy soil	8—15
		I3h1	The heavily damaged area of the complex transverse sand ridges on the Tarim River alluvial accumulation plain, characterized by predominant wind direction, large sand ridges, the high salinity water and the aeolian sandy soil	≥15
II	II1	II1m3	The lightly damaged area of the complex dome-shaped dunes on the south of the Tarim River transition plain, characterized by predominant wind direction, interdunes, the medium salinity water, and the solonchak soil	8—15
	II2	II2L1	The lightly damaged area of the complex dome-shaped dunes on the south of the Tarim River transition plain, characterized by predominant wind direction, the transition regions between ridges and interdunes, the light salinity water, and the aeolian sandy soil	≤8
		II2m1	The lightly damaged area of the complex dome-shaped dunes on the south of the Tarim River transition plain, characterized by predominant wind direction, the transition regions between ridges and interdunes, a middle salinity water and the aeolian sandy soil	8—15
III	III1	III1L1	The north of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, interdunes, the light salinity water, and the aeolian sandy soil	≤8
	III2	III2L1	The north of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, the transition regions between ridges and interdunes, the light salinity water, and the aeolian sandy soil	≤8
	III3	III3L1	The north of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, the large sand ridges, the light salinity water, and the aeolian sandy soil	≤8
IV	IV1	IV1L1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, interdunes, the light salinity water, and the aeolian sandy soil	≤8
	IV2	IV2L1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, the transition regions between ridges and interdunes, the light salinity water, and the aeolian sandy soil	≤8
	IV3	IV3L1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, the large regions between ridges, the light salinity water, and the aeolian sandy soil	≤8
		IV3m1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by predominant wind direction, the large sand ridges, medium salinity water, and the aeolian sandy soil	8—15
	IV4	IV4L1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by the multi-wind-directions, interdunes, the light salinity water, and the aeolian sandy soil	≤8
	IV5	IV5L1	The south of the heavily damaged area of the large complex longitudinal sand ridges in the hinterland of the Tarim Basin, characterized by the multi-wind-directions, the large regions between ridges, the light salinity water, and the aeolian sandy soil	≤8

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V	V1	V1L1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, interdunes, the light salinity water, and the aeolian sandy soil	≤8
		V1m1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, interdunes, the medium salinity water, and the aeolian sandy soil	8—15
	V2	V2L1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, the transition regions between ridges and interdunes, the light salinity water, and the aeolian sandy soil	≤8
		V2m1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, the transition regions between ridges and interdunes, the middle salinity water, and the aeolian sandy soil	8—15
	V3	V3L1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, the large sand ridges, the light salinity water, and the aeolian sandy soil	≤8
		V3m1	The moderately damaged area of the complex longitudinal sand ridges in the downstream delta of Yatonggus River, characterized by predominant wind direction, the large sand ridges, the medium salinity water, and the aeolian sandy soil	8—15
VI	VI1	VI1L1	The lightly damaged area of the complex sand ridges in the downstream delta of Niya River and the Northern Minfeng Upheaval, characterized by predominant wind direction, interdunes, the light salinity water, and the aeolian sandy soil	≤8
	VI2	VI2L1	The lightly damaged area of the complex sand ridges in the downstream delta of Niya River and the Northern Minfeng Upheaval, characterized by predominant wind direction, transition regions between ridges and interdunes, light salinity water, and the aeolian sandy soil	≤8
	VI3	VI3L1	The lightly damaged area of the complex sand ridges in the downstream delta of Niya River and the Northern Minfeng Upheaval, characterized by predominant wind direction, large sand ridges, light salinity water, and the aeolian sandy soil	≤8
		VI3m1	The lightly damaged area of the complex sand ridges in the downstream delta of Niya River and the Northern Minfeng Upheaval, characterized by predominant wind direction; large sand ridges, middle salinity water, and the aeolian sandy soil	8—15
	VI4	VI4L1	The lightly damaged area of the complex sand ridges in the downstream delta of Niya River and the Northern Minfeng Upheaval, characterized by multi-wind-directions, large sand ridges, light salinity water, and the aeolian sandy soil	≤8
	VI5	VI5L3	The lightly damaged area of the complex sand ridges in thedownstream delta of Niya River and the Northern Minfeng Upheaval, characterized by multi-wind-directions, desert marginal zones, light salinity water, and the solonchak soil	≤8

classification must serve for the production purpose, this classification is very easy to understand and also practical, since it is in the favor of the design, construction and management of the shelter belt. In addition, oil and gas pipelines, an integral part of production facility, have been considered in our site type district classification. Oil and gas pipelines accompanied by the highway are always a part of the construction plan of the shelter belt, since they require pre-treatment against rust, and reservation of the operation area; they affect the structure and configuration of the entire shelter forest. At the same time, these pipelines can be divided relatively easily by their spatial distribution.

(3) Site type group is the core of the site classification system based on the small-scale landforms and wind regime that reflect the conditions of windblown sand damages. The shelter belt along the Tarim Desert Highway is a typical windbreak and sand-fixing forest. Windblown sand hazard control is the ultimate purpose of the shelter belt construction. Thus, this site type group classification based on the severity of sand damages are in agreement with the principle of “heavier protection against more severe damage, lighter protection against lighter damages, and all protective measures should be set based on the severity of the potential damages” to achieve the maximal protection against windblown sand.

(4) Site type is the basic unit of the site classification system[7] based on the underground water salinity. Underground water along the Tarim Desert Highway is extremely low in quality, and varies greatly among the regions. Underground water quality is the most important limiting factor affecting plant’s survival and growth, and determining plant specie selection in each region. Two threshold values of 8 g/L and 15 g/L were obtained from saline water irrigation tests as maximal salinity levels for the survival and growth of most psammophytes along the highway. It must be pointed out that the threshold value of underground water salinity is relative to the salt tolerance of plant species. At present, saline water irrigation tests of inland region are focused on

light saline water of less than 10 g/L salinity, and on plant species with salt tolerance much weaker than those in the desert[17−21]. In general, water with salinity between 2—3 g/L or between 2—5 g/L is considered as light saltine water[22−25]. However, in this study, for halophytes with high economic values, or arbor and shrub species with ecological benefits, due to their wider range of saline water usage, the threshold value of light salinity water has been set at 8 g/L. This was for the convenience of our site type classification, although unique, it may not be applied to a more general scale.

4 Conclusion

Site type classification for afforestation regions is the foundation and the early stage work of all forest engineering projects. The shelter forest ecological project along the Tarim Desert Highway is a very large-scale and unique project, because it was conducted in an extremely droughty desert area using saline water irrigation. From construction to maintenance, it is largely dependent on human proper management, therefore it can be regarded as an authentic artificial forest. This shelter forest ecological project is not very commonly seen in the world, and the scientific and systemic classification in the Taklimakan Desert is initial. Site types were first established by the two-level site type classification system before the project implementation[3, 4], and then they have been re-classified in this study. This re-classification has combined our experience in both management and afforestation construction, and used the most common classification system in China, and integrated the dominant and limiting factors. Due to the subjective nature of this work, the site type classification system and the results still need to be validated by future practice.

The extremely harsh conditions in the afforestation region along the Tarim Desert Highway, and the uniquely authentic artificial forest construction made this work most significant, and added reference values for the construction of similar shelter belts in other desert areas. However, it is expected that differences in climates, vegetation, landforms, and groundwater quality among different desert areas will result in different selections for all relevant factors and plant adaptation threshold values to groundwater in their site type classification for afforestation.

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