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Adaptive growth of *Tamarix taklamakanensis* root systems in response to wind action

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Root distribution and characteristics were investigated on a 70-year-old *Tamarix taklamakanensis* individual through uprooting. Rooting depth was restricted by water table, and root morphology adapted to resist the wind movement associated with shallow rooting. Root systems had more structural root mass and length on the leeward side than the windward side of the tree relative to the prevailing wind direction. Additional resistance to wind bending can occur as a result of increased thickening of the lower stem along the axis of the prevailing wind direction, and in *T. taklamakanensis*, this thickening is greater on the lee side of the stem. We conclude that increased root distribution and thickening of the lower stem on the leeward are an important strategy for *T. taklamakanensis* in response to wind action in the hinterland of Taklimakan Desert.

hinterland of desert, root distribution, stability, root mass

The primary functions of root systems of terrestrial plants are anchorage and acquisition and conduction of water and nutrients from soil[1]. The need for anchorage is in relation to three types of force. The plant must be able to resist the gravitational compression of its own mass, lateral forces due to wind, and vertical forces caused by grazing animals[2]. Resistance of forest trees to breakage or overturning in windy climates depends largely on structural modifications for mechanical strength. Plant growth responses to wind movement, termed thigmomorphogenesis by Jaffe, include changes in branch and foliar development, stem shape and mass[3]. In many tree species, leaf size, branch size and stem height are restricted by the mechanical action of the wind[4]. Additional resistance to wind bending can occur as a result of increased thickening of the lower stem along the axis of the prevailing wind direction[5], and in conifers, this thickening is greater on the lee side of the stem[6]. Development of stem shape is believed to maintain uniform stress over the stem surface during wind loading[7,8]. These above-ground developmental responses counteract increasing movement as the tree grows, and reduce the risk of stem breakage in high winds.

Uneven secondary thickening between root and stem, resulting in the development of supporting buttresses, may also reflect growth to equalize mechanical stress during wind loading[9]. Coutts[10] separated resistance to uprooting of shallow rooted trees into four components: resistance to bending of the leeward side ‘‘hinge’’ roots, anchorage of windward roots under tension, mass of the soil-root plate, and resistance of soil to breaking. The large tabular buttresses, characteristic of many tropical tree species, and the smaller more rounded buttresses, often observed on temperate trees, make a rigid

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connection between the stem and root system. Buttresses reduce bending and concentration of stress at the base of the tree[11]. These structures also increase the leverage required for overturning by moving the “hinge” point of the root system further from the base of the tree. Tree stability is improved by adaptive growth that increases the rigidity and size of the soil-root plate[12]. For example, shallow rooted Sitka spruce (*Picea sitchensis* (Bong.) Carr.) trees allocate more biomass to structural roots on their leeward side relative to the prevailing wind direction : a response that reduces bending in the soil-root plate and increases resistance to windthrow[13,14].

Trees continuously alter their morphology in response to changes in wind exposure. Wilson[15] found increases in growth ring width both in the lower stem and at the base of structural roots of *Pinus strobus* L. trees in response to increased wind movement after stand thinning. Urban et al.[16]. reported that, after removal of neighboring trees, there was an immediate increase in thickening of structural roots of *Picea glauca* (Moench) Voss*Tamarix taklamakanensis* M.T.Liu is endemic species in the hinterland of the Taklimakan Desert. Its adaptability to extreme environment causes the interests of many ecological researchers, but the concerned researches mainly concentrated in the general description of the ecological characteristics[17–19]. However, the adaptability of the *T. taklamakanensis* in windy environment is not reported. From the root distribution, this paper discusses adaptation in the strong windy environment in the hinterland Taklamakan Desert.

1 Materials and methods

1.1 Settings

The experiment was performed in the hinterland of Taklimakan Desert. It is located (83º40′E, 39º06′N) near the Tazhong station of Taklimakan Botanical Garden of Xinjiang Institute of Ecology and Geography, CAS (Figure 1). According to the data from Tazhong Meteorological Station and the Auto-Meteorological Station of the Botanical Garden, the mean annual precipitation is 36.6 mm. The relative humidity is 29.4% on average. The potential evapotranspiration rate is 3638.6 mm. The wind speed there is 2.5 m/s on average and the highest instantaneous speed is 24.0 m/s. Sandstorm often occurs. In a year, there are 60 days with heavy wind, they basically happen during April-August, the mean speed is 3.2 m/s. There are 74 days with floating dust, and 45 days with sand raised by the wind. In different physiognomy, soil has different features, mainly being the mobile wind sandy soil. The salinity content is 1.26—1.63 g/kg. In the underlayer of the soil, there is occasionally semi-clay of only 20—60 cm in thickness, amid the wind sandy soil. The sight on the ground is high mobile compound sand hill. The ground water is about 1.3 m.

1.2 Experimental designs

An adult buried shallow *Tamarix taklamakanensis* was arbitrarily selected in a relatively flat ground between sand dunes. From 0.5 m of selected plants, we dug soil sample every 20 cm in the vertical direction and measured the soil moisture content. All the plants roots were dug out by trenche method and root track method. The 1 m × 1 m grids were drawn with rope. To the east-west direction and the north-south direction through the plant, root distribution location was drawn by 100∶1 scale. In the center of plant root, the length of 2 m grid in the southeast, southwest, northwest and northeast directions extended outward to no roots. Root length and root fresh weight in the four directions were respectively measured. All the roots were collected back to the laboratory, baked at 80℃ to re-hang in the oven according to different sampling areas and then dry weight was measured.

2 Results

2.1 Distribution characteristics of root system

Spatial pattern of *T. taklamakanensis* root system is presented in Figure 1. It shows that the roots reach almost 30 m from east to west, and 20 m from north to south. They reach 140 cm in depth to touch the ground water, and the lateral roots are distributed at 70—90 cm.

With the basal stem as a center, the laterals spread 17 m, 13 m, 12 m and 8 m to west, east, south and north directions, respectively. It is clear that the *T. taklamakanensis* root system has a significant relationship with the water level underground, with the shallow rooting and widely lateral spread.

2.2 Distribution characteristics of root weight

The root distribution pattern of *T. taklamakanensis* shows directivity in horizontal dimension (Figure 1). It

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is mainly distributed in the southwest and southeast, less at northwest and northeast. As a result of this directional distribution (Figure 2), the weight of roots at the southwest is the highest, accounting for almost one half of the total weight (46.18%). But the weight of southeast and northwest takes up 37.21% and 13.51%, respectively. The lest weight exists at the northeast, only accounting for 3.1% of the total weight. This evidences that the root weight distribution pattern of *T. taklamakanensis* is significantly asymmetric.

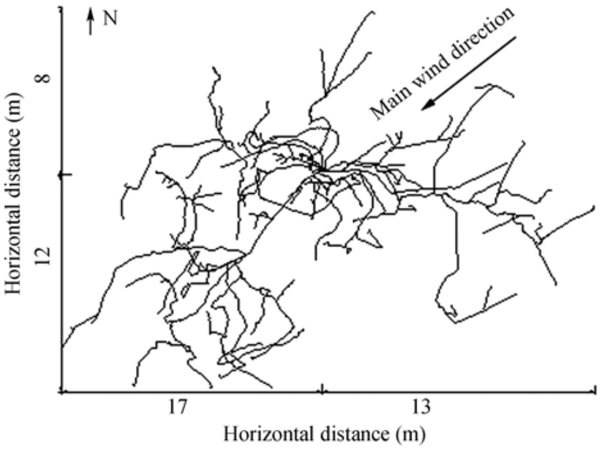

Figure 1 *T. taklamakanensis* root level of distribution.

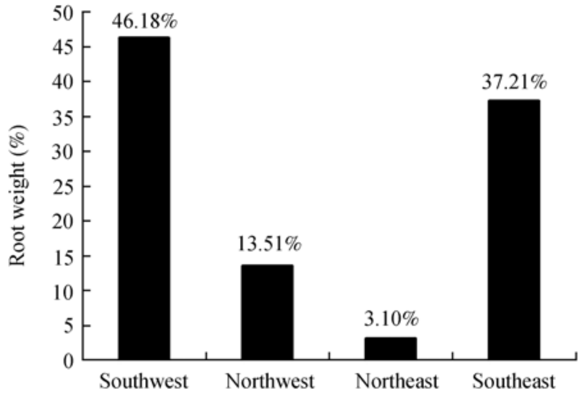

Figure 2 Ratios of root mass under different directions.

2.3 Distribution characteristics of root length

Figure 1 shows that the *T. taklamakanensis* has great lateral root. The total root length is estimated at about 399 m. Similar to the root weight distribution, the spatial distribution of root length is highly asymmetric too (Figure 3). But the numerical difference is small relative to the weight distribution. As presented in Figure 3, the root length at southeast is the highest and it accounts 40.10% of the total, and that at southeast and northwest it accounts for 30.83% and, 20.30%, respectively. The smallest part is at the northeast and it takes up 10% of the total length.

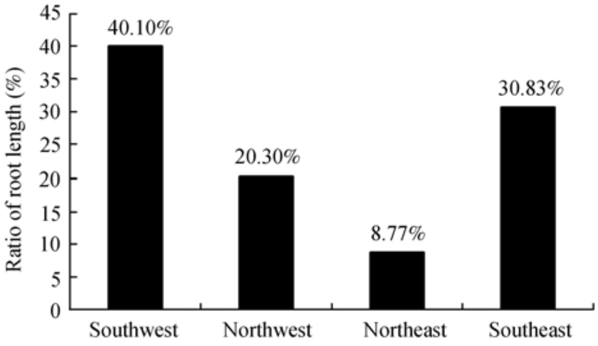

Figure 3 Ratios of root length at different directions.

2.4 Characteristics of tree-ring

In order to determine tree-ring growth characteristics of *T. taklamakanensis*, we saw the basal stem to observe the tree-ring at the transverse section. The tree-ring pattern exhibits a clear dark brown curve. From this pattern, we can see that the *T. taklamakanensis* has an eccentric growth trend, with the complete tree-ring presented within the 15-year region. Out of this region, there are two growth areas, with the pith at the northwest. Thus the entire section shows a “heart” shape.

3 Analyses and discussion

The shallow-rooted trees have little anchorage from downward roots. Consequently, stability depends largely on the rigidity of the soil-root plate. Soil under a flexible soil-root plate will be disturbed when subjecting to a smaller force compared with soil under a rigid plate of the same area. This experiment shows that *T. taklamakanensis* has shallow top root distribution which is quite different from the early result considering that *Tamarix.* spp is deep-rooted system[20]. However, they have one common property-they both reached the ground water. The main factor is that rooting depth was restricted by a water table[19]. Compared to the downward roots, the lateral roots stretch a long distance which is in concordance with Yang’s result[21]. *T. taklamakanensis* allocates more biomass to construct roots at leeward side relative to the prevailing wind direction. It is a response to reduce bending in the soil-root plate and increase resistance to wind-throw. This distribution is exactly similar with *Sitka spruce*[13,14]. In contrast to previous studies in angiosperm species where buttresses were larger on the windward side of the tree and appearing to function for strength in tension. We found greater buttress development at the leeward side, implying that, structures of gymnosperms species have developed to act as compression. The different roles of buttresses are reflected in the shape of the root[22, 23]. This result is in concordance with Bruce[24] who has confirmed on 46-year-old *Sitka spruce.*

The allocation of biomass among roots would be expected to have a large effect on tree stability[25]. Root biomass of *T.taklamakanensis* shows the extremely uneven distribution pattern and the weight also shows the asymmetry characteristic (Figure 2), this conclusion is in agreemet with Bruce[23]. If root biomass is clustered asymmetrically in the root plate, trees may be overturned easily The evenness of biomass distribution within the structural root system is related to genotype and competition between roots for nutrients in their early development stage[26]; however, in our study, trees were all unrelated individuals grown from seed, and there was no evidence of uneven nutrition around trees on this site. The allocation of assimilation within root systems is also influenced by wind action, and Stokes et al.[27] found increased growth of roots on both the leeward and windward sides of young trees. In view of morphology, the *T. taklamakanensis* is generated by the seed germination in this study. At the same time, nutrients are even around it. This explains that tree disk of the *T. taklamakanensis* is not eccentric in the age of 15, and the young *T. taklamakanensis* has a complete tree disk, which is in concordance with Xiao's work on *Tamarix ramosissima*[28].

In larger trees, Nicoll et al. showed that the center of mass of the root system was clustered down-slope, and away from the prevailing wind direction[14]. In our study, root mass was clustered upslope and away from the prevailing wind direction, implying that the response to wind loading is the important factor, and that trees allocate greater resources to develop roots on the leeward side of the tree.

Out of the 15-years-old area in the tree disc, growth ring of *T.taklamakanensis* has the apparent eccentricity marked by the significantly increased thickness of leeward side. Xiao pointed out this phenomenon is caused by the pressure from above-ground stretching[28], but it also has a close relationship with prevailing wind. The results of this study are comparable to those of Robertson who reported an increase in thickening on the leeward side of stems of coniferous trees[29]. We conclude, therefore,that *T. taklamakanensis* reacts to wind loading by increasing growth on parts of the roots and stems in compression.

4 Conclusion

The plants show the various mechanical adaptations of root system in order to adapt the windy habitats. *T. taklamakanensis* increases rigidity and length of roots to move the hinge point away from the body, like increasing the length of lever arm resulting in increasing the resistance to overturning. We conclude that, because of the wind, shallow ground water and extremely arid hinterland of Taklamakan Desert, the vertical root of *T. taklamakanensis* is restricted. As a result, it increases the thickness of stems on the leeward side and the length of lateral root in order to prevent plants from overturning. Thus thickened stems on the leeward side and uneven allocation of root system are strategies for *T. taklamakanensis* to accommodate to the windy habitats in the hinterland of Taklimakan Desert.

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