Measurements and computational simulations of the effects of sand-fixing forest on the wind flow over two underlying surfaces

Sand-fixing forest and windbreak forest shelterbelt are widely distributed in the arid and semiarid desert region in the form of nets and fences. They are considered as one of the most remarkable instruments to improve the ecological environment by providing protection against wind erosion, controlling heat and moisture transfer, etc. Most of their protective effects are realized through altering airflow patterns (Huang, 2005; Li et al., 2007). However, most field observations were limited to the 0–10 m height range. It is known that the influence scope of sand-fixing forest and windbreak forest shelterbelt is generally several times of their height, but few observations of the forest effect were carried out to fully account for this sphere.

Through monitoring and simulating the mean wind velocity over complex underlying surface consisting of sand-fixing forest and windbreak forest shelterbelt, we aim to provide a general and convenient method to continuously and accurately clarify the flow field characteristics within a relatively extended vertical space and horizontal distance. The method should in turn offer theoretical guideline on how to set windbreaks for the optimal prevention of wind erosion in the most convenient way at the lowest cost.

1.Field experiment methods and data collection

We monitored the wind velocity at different levels during sandstorm processions at two 50 m high observation towers constructed inside and at the edge of the oasis, respectively.

2.Numerical simulation

The two-dimensional CFD model is 4300m long and 200 m height (figure 1)

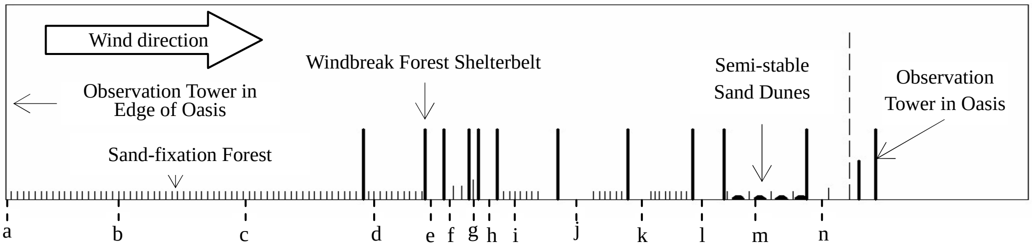

Fig 1 The sketch map of the computational domain and the locations of the study points a–n. The horizontal distance between each array of windbreak forest shelterbelt on this sketch map was reduced with certain scale. The distance from point a to point b and to point c is 500 and 1000 m respectively. Points d–n are located at the leeward of each windbreak forest shelterbelt at a distance of twice the height of the corresponding windbreak forest shelterbelt.

At the inlet boundary, the inflow velocity profile was defined by the UDF function of FLUENT. At the outlet boundary, the flow was assumed as a fully developed flow, and the outflow boundary condition was imposed. Because the top boundary was sufficiently away from the ground surface, the symmetrical boundary conditions were applied. At the ground boundary, a full-slip condition was used. Each array of sand-fixing forest or windbreak forest shelterbelt was simplified as idealized porous media with different height, thickness and permeability.

3. Result and discussion

3.1 Field experiment result

In the 0–50 m layer, the wind velocity increased with rising height at both sites. At the edge of oasis, the wind velocity of each sandstorm procession generally has a linear correlation with the logarithm of the height (Figure 2a). Inside the oasis, the wind profile of each sandstorm procession exhibited a characteristic curve, which was obviously different with that at the edge of oasis(Figure 2b).

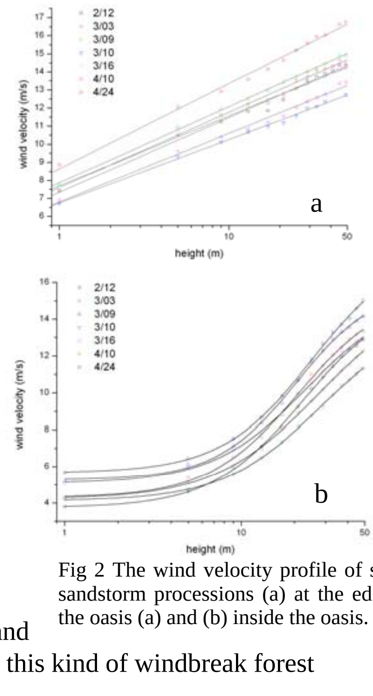

Fig 2 The wind velocity profile of seven sandstorm processions (a) at the edge of the oasis (a) and (b) inside the oasis.

3.2 The validation of numerical simulations and the simulation result

Figure 3 plots the observed and simulated wind profiles at the oasis edge and inside the oasis. It can be seen that the numerical simulation result is in satisfactory agreement with the field experiment data. The differences between the measured and the simulated wind velocities were all within 1.0 m s-1 at each altitude. Therefore, this numerical model can reasonably simulate the airflow on complex underlying surface.

3.3 Continuously wind field analysis

Figure 4 gives the wind profiles when the airflow progressed through different arrays of sand-fixing forest and windbreak forest shelterbelts. In general, with the addition of sand-fixing forest and windbreak forest shelterbelt arrays, the wind velocity gradually decreases, especially at higher altitude. Furthermore, we found that after several arrays of windbreak forest shelterbelt, the wind velocity at above 30 m became relatively constant and did not decrease with the further addition of shelterbelt array. We can infer that this kind of windbreak forest shelterbelt has windproof effect until above 30 m. Below 30 m, the wind velocity was dependent on the windbreak forest shelterbelt array spacing, the distance to the windward windbreak forest shelterbelt, and the existence of sand-fixing forest. The wind velocity was reduced where the array spacing was shorter, the distance was less (no less than twice the shelterbelt height, figure 5) and the sand-fixing forest existed (figure 6).

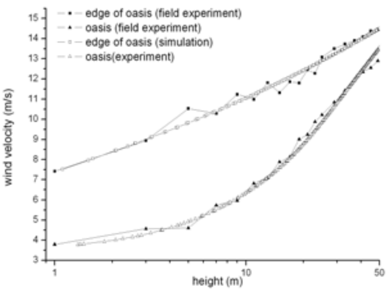

Fig 3 Comparison of the observed and simulated wind velocity profile of the sandstorm procession on February 12.

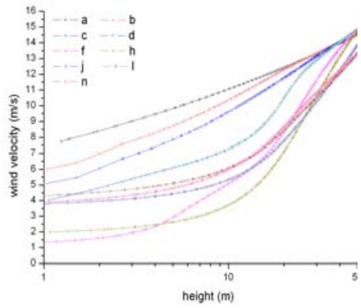

Fig 4 Simulated wind velocity profiles at points a–n.

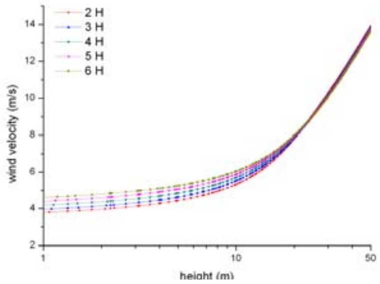

Fig 5 Simulated wind velocity profiles at five points located at different distances (from 2H to 6H) behind the first array of the windbreak forest shelterbelt. H is the windbreak forest height.

3.4 Turbulent kinetic energy analysis

From points b to i, the turbulent kinetic energy gradually increased with the addition of sand-fixing forest and windbreak forest shelterbelts arrays(Figure 7). The turbulent kinetic energy of these points all had an obvious peak value and decreased quickly afterwards. The height of the peak value in the sand-fixing forest is increased with the addition of sand-fixing forest arrays and fixed around the height of 20 m between the windbreak forest shelterbelt. In contrast, from points k to n, the turbulent kinetic energy profiles also had peak values, but the profiles of these points are much more similar and changed little when extra shelterbelt array was added. Figure 8 showed that the turbulent kinetic energy in the 0–50 m range at points d and i was remarkably increased by the sand-fixing forest, whereas little difference was observed at point j. We can thus conclude that the existence of sand-fixing forest between two arrays of windbreak forest shelterbelt will obviously affect the airflow between the shelterbelt.

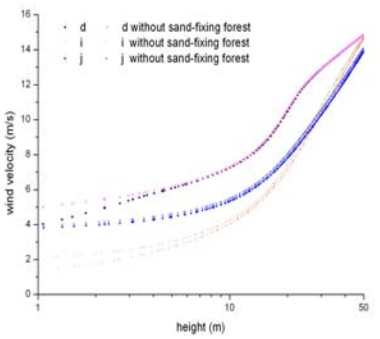

Fig 6 Comparison of the simulated wind velocity at three points with and without sand-fixing forest.

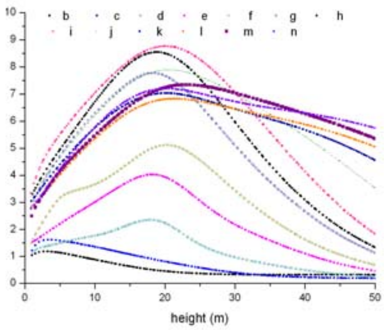

Fig 7 Comparison of the wind velocity profile simulation results with sand-fixing forest exist or not at three points.

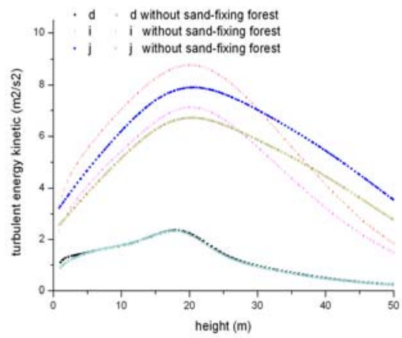

Fig 8 Comparison of the turbulent kinetic energy at three points with and without sand-fixing forest.

4. Conclusion

The underlying surface can significantly change the wind profile. The height of the shelterbelt, addition of shelterbelt array, array space, and exiting of sand-fixing forest among the shelterbelts nor not all influenced the wind velocity remarkable. the shorter array space, the fewer distance, and existence sand-fixing forest, the lower wind velocity.

The profiles of the turbulent kinetic energy at all sites had obviously peak values. The height of the peak value in the sand-fixing forest increased with the addition of sand-fixing forest arrays, and the height of the peak value was fixed around 20 m in the windbreak forest shelterbelt. The sand-fixing forest magnified the turbulent kinetic energy.

References

Huang C.H., Lee C.I, Tsai C.J. (2005). Reduction of particle reentrainment using porous fence in front of dust samples, J. Environ. Eng. 131, 1644-1648.

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