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Evolution Characteristics and Development Trends of Sand Barriers

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Abstract: Sand barriers are one of the main measures used to prevent desertification and have been widely used in desertification control. Here, we use bibliometric methods and content analysis to summarize sand barrier type, applications and research. Existing problems in research are pointed out and revolution characteristics and development trends of sand barriers are discussed. We conclude that three main driving factors have stimulated sand barrier study: demand, technology and development concept. Developing environmentally friendly technology and promoting industrialization of sand area economies are future directions for sand barrier research.

Key words: sand barrier; evolution characteristics; development trends

1 Introduction

The prevention and control of desertification has become a global research focus in environmental science and technology. A variety of mechanical materials or plant obstacles are used in sand barrier settings in order to control wind flow, speed and structure, erosion status, wind force and geomorphology (Zhu *et al*., 1998). Sand barriers are one of the main measures used to prevent and control wind engineering and sandy desertification (Sun, 2000). Sand barriers are classified into two categories: mechanical sand barriers and plant sand barriers. Mechanical sand barriers mostly use straw, clay, nylon netting and raw materials to increase sand surface roughness and promote sediment. Natural vegetation restoration requires a very long time if using mechanical sand barriers. Plant sand barriers (also known as biological sand barrier) are living plants and thus greatly reduce the vegetation recovery time. The cutting propagation of shrub branches as a sand barrier is one such example (Yuan, 1958).

Various factors need to be considered when selecting a sand barrier, including site conditions, material availability, economic cost and technology. Mechanical sand barriers are one of the main control measures (Chipil, 1995; Batchelor, 1967) mainly used at poor sites with more sand, strong winds and complex landforms where vegetation cannot grow. The effectiveness of mechanical sand barriers means they are also appropriately used at sites in good condition (Sun, 2000). In areas with good water conditions, plant sand barriers are commonly used. Plant sand barriers have the advantage of being low cost, rapid, of good stability and high ecological benefits. They not only improve the local ecological environment, reduce temperatures and reduce sandstorms, but also improve the ecological environment. It has always been the first choice in the treatment of sandy desertification.

Sand barrier research has a long history and has mainly focused on implantation. Research within China has a 30-year history and the number of case studies is large, but comparative, evaluation and technological studies are lacking. Here, according to information derived from various types of literature, we looked at the revolution characteristics and development trends of sand barrier research.

2 Data and methods

“Sand barrier” and “checkerboard barrier" were used as key

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words in Web of Science SCIE and CPCI databases; "sand barrier" was used in the CNKI database. 110 and 1877 articles were obtained respectively. Information obtained from books, research reports and networks was also included.

Bibliometric analysis and content analysis were used. Retrieved documents were managed with Endnote. Using the bibliometric analysis of keywords, sand barrier technologies were extracted and combined for content analysis. The time and location of sand barriers were listed in a table, and trends in sand barrier technology were analyzed.

3 Sand barrier research contents

3.1 Classification and nomination

Due to different classification systems and customs, various names appear in the sand barrier literature. The same sand barrier can have more than one name, and the same material can have a number of names (chemical composition, name of commodity, textile technology), thus causing confusion. Zhang *et al*. summarized decades of sand barrier research in China and identified ten categories, which are effective but require further discussion (Zhang *et al*., 2014). In order to establish a reasonable sand barrier classification, classification dimensions and levels should be clear and simple, and the names of sand barrier should be easy to remember, understand and extinguish. When establishing a sand barrier, setting principle, materials and setting mode are three primary factors, so the first dimension in classification can be principle, material and setting mode. Material can be divided into natural materials, semi-natural materials and non-natural materials. The setting mode can be divided according to spatial forms (Table 1).

According to this classification, nomination of sand barriers is solved, for example, a sand barrier can be named in accordance with the "setting principle + setting mode + material", in brief, in the form of "setting mode + material", which is easy to identify and remember, such as banded sand barrier and high vertical clay sand barrier.

3.2 Sand fixing principle

According to sand fixing principles, sand barriers can be divided into three types: fixation, accumulation and transportation. By blocking gas-solid interface effects, fixation sand barrier protect sand beds from erosion or reduce erosion, the most common type of application. Accumulation sand barriers increase sand flow resistance and reduce wind speed resulting in sand deposition. Transportation sand barriers

Table 1 Classification of sand barriers, basis and name

Classification basis				Name
Sand fixing principle				Sand fixation sand barrier
				Sand accumulation sand barrier
				Sand transportation sand barrier
Materials	Natural or not	Natural materials	Living materials	Living sand barrier (plants sand barrier): Salix, Salix gordejevii, Hedysarum mongolicum, artemisia, caragana, Salix microstachya, mountain bamboo, poplar and willow, Mongolia hedysarum, salsa, four Atriplex canescens, Xinjiang Calligonum, Achnatherum splendens, scoparium, Caragana, Kans, Amorpha fruticosa sand barrier.
			Non-living materials	Dead sand barrier (mechanical sand barrier): clay, gravel, stone slab, wheat straw, rice straw, reed stalk, cotton stalk, corn stalk, sunflower stalk, flax straw sand barrier
		Semi-natural materials		Coal gangue, old railroadtie, wattlesand barrier
		Non-natural materials (synthetic materials, chemical materials)		Polylactic acid fiber, polyester fiber, plastic, polyethylene, geotextile bags, nylon nets, cement, asphalt felt, polymer emulsion, palm pad, non-woven fabric, geogrid and soil coagulant, laminating sand bag obstacle sand barrier
Setting modes	Ground shape			Lattice sand barrier
				Banded sand barrier
				Other sand barrier
	Height			High vertical sand barrier
				Low vertical sand barrier
				Concealed sand barrier
	Porosity			Ventilated type sand barrier
				Sparse type sand barrier
				Compact type sand barrier
	Mobility			Fixed sand barrier
				Mobile sand barrier
	Spatial shape			Tiled type sand barrier
				Vertical type sand barrier

reduce sand movement resistance and prevent the occurrence of separation to promote or accelerate overall sand flow transportation. With progress in science and technology, applied observations and simulations of fluid mechanics theory, experimentation and observation equipment, sand flow in sand barrier in the new century, the sand barrier size, height, spacing and types of collocation were studied through field observation, wind tunnel simulation or experiments. A lot of work has been done on the principle of sand fixing, providing theoretical support to optimized setting, further promoting the development and utilization of sand barriers (Liu and Dong, 2003; Wang and Zheng, 2002; Qu *et al*., 2005; Wang, 2016; Dong *et al*., 2000; Arens *et al*., 2001).

3.3 Ecological benefits

It is generally believed that sand barriers change the movement state and intensity of wind sand flow, and achieve sand resistance or sand fixation. Its long-term role can significantly improve soil and adjust the local climate so that the sand surface is stable, conducive to vegetation restoration. There is no invalid sand barrier, but the utility size is different. Studies on the protective effect of different materials and methods for setting up sand barriers have been carried out. The less vertical Salix sand barrier and the less vertical straw-checker sand barrier are common mechanical sand barriers whose drawing materials are convenient and low cost, and setting is easy. Because of this, these sand barriers are widely used and usually cooperate with vegetation measures due to their good use in improving surface microclimates and soil quality. Cheng (Cheng, 2014) investigated the effects of sandbag sand barriers on traveling dune vegetation restoration and physicochemical properties of soils. Plant sand barriers and new environmentally friendly materials (such as poly lactic acid, PLA) sand barriers are particularly prominent. Yuan (2010) studied the effects of soil physical properties and protection benefits by PLA sand barriers, analyzing the effects of sand-fixed benefits, soil physical properties and vegetation while comparing the bare sand and straw barrier (the same specification as PLA sand barrier).

The rehabilitation and reconstruction of vegetation and soil in sandy regions is a core part and the ultimate goal of the prevention and control of desertification work. In plant sand barriers, *Salix gordejevii* sand barrier has a high degree of concern (Shi, 2008). The effect of different types of Salix sand barriers on wind erosion and sand fixation can reduce wind speeds, increase surface roughness, improve vegetation, improve soil physical properties, and help the formation of surface crusts.

A lot of research has focused on the effect of sand barriers on vegetation restoration, soil, seed bank and ecological environments (microclimate, environmental factors). Living sand barriers commonly improve vegetation, root systems and soil seed banks, aboveground biomass, coverage and species richness in the phytocommunity. The vegetation types, seed density in the soil seed bank, biomass, coverage and root system density increase year by year. Plants species, life forms and family genus structure have diversified. Influencers of sand barriers to micro-climates reduce wind velocity, elevate air temperature and air relative humidity and reduce the diurnal temperature range.

Outside of China, research on soil seed bank composition (Thompson, 1987; Guo *et al*., 1998), number dynamics (Ow and Chancellor, 1983), species composition (Johnston et al., 1969; Johnson and Anderson, 1986) and the relationship between vegetation (Thompson and Grime, 1979; O. Connor and Pickett, 1992) commenced in the 1930s. In the past three decades, research in China has emerged. Zhao *et al*. (2005) found that the parallel vertical reed barrier can effectively intercept plant seeds carried in wind sand flow. Li (2016) worked in Shapotou, described soil physical and chemical properties and biological crusts and found that sand barriers are conducive to the formation of biological crusts.

3.4 Other aspects

In order to improve the efficiency of setting sand barriers, research and development of mechanized operation methods have been developed but understudied in the literature (Zhang *et al*., 2014). The "grass grid paving robot" and "multifunctional joint sand fixing machine" and other kinds of mechanized equipment have achieved the popularization and demonstration effect in sandy land and Hailar sandy land (Shu and Liu, 2007). In order to extend the service life of the sand barrier, studies of the corrosion law (Na, 2010) and anti-corrosion measures of sand barrier materials (Song, 2011) have also been carried out.

Remaining challenges include material types without access conditions and standards which may cause environmental problems; missing evaluation index systems; and our understanding of protective effects, construction and combinations of sand barriers. It is necessary to explore the sustainable development of the organic combination of sand barrier construction and the sandy land economy in order to summarize the influence factors and development rules of sand barrier research.

4 Evolution characteristics and development trends of sand barrier research

Based on multiple types of literature, a chronology of sand barrier technology was extracted (Table 2). As early as 700 years ago, sand barriers were used to control coastal sand. Chinese sand barriers spread after 1949.

4.1 Development concept

In the early stage sand fixation is the basic purpose, many problems such as the follow-up action principle, influence and control benefits of different types of sand barriers have not attracted attention. With the concept of sustainable development and ecological civilization, sand barrier settings

Table 2 Evolution of sand barriers

Time	Kind of sand barrier	Location
Foreign countries		
1316	Coastal afforestation/sand Engineering/buried pine or reed sand barrier grid formation	Germany
1660	Coastal sandy land afforestation/sand barrier Engineering	Denmark
1709	Coastal sandy land afforestation/sand barrier Engineering	Hungary
1770	Coastal sandy land afforestation/sand barrier Engineering	Austria
1779	Coastal sand / sand barrier/vertical sand barrier	France
	Coastal sandy land afforestation/sand barrier	Poland
1826	Flat sand barrier/determinant sand barrier/a straw pressing type sand barrier	USA
1830	Straw checkerboard barrier	Egypt
1840	Half hidden sand barrier/straw checkerboard barrier	Soviet Union
1880	Shrub planting	Soviet Union
1904-1932	determinant sand barrier/a straw pressing type sand barrier	Soviet Union
after 1917	A variety of mechanical sand barriers, especially semi-hidden sand barrier	
1930's	High vertical plastic grid/cement sand barrier	West Asia and North Africa
1930's	Flat sand barrier	West Asia and North Africa
1930's	Living sand barrier	India
1940's	Engineering sand prevention technology/wind sand control	Soviet Union
1940's	Vertical or tiled sand barriers, and combined with sand fixing plants to establish live sand barrier	India
1940's	High vertical sand barrier	USA
1950's	Artificial forest dominated by pine	Soviet Union
1950's	The black forest of Haloxylon ammodendron pasture	Soviet Union
1950's	Shrub afforestation	USA
1953	Vertical sand barrier/live grass and shrub belt between the sand barrier	India
1953	Sediment transport engineering	Soviet Union
1953	Sand barrier and plant sand fixation(synthetic rubber)	Libya, Egypt, Yemen, Israel, Algeria, Australia, Tunisia, Saudi Arabia
China		
1750	Windbreak wall	Gansu Minqin
1942	Plant sand fixation	Shaanxi Jingbian
1951	Joe shrub (Robinia pseudoacacia + Amorpha fruticosa)	Western Hebei
1951	Firewood separated sand + sand barrier plant	Yulin
1949-1952	Artemisia Salix sand barrier	Yulin, Jingbian
1949-1955	Tall willow afforestation	Inner Mongolia Yikezhaomeng
1950's	Plant sand fixation	Liaoning Zhanggutai in Horqin Sandy Land
1950's	Combined with the "Qiao guan grass plant sand fixation, artificial sand barrier by comprehensive sand control method	Liaoning Zhanggutai
1956	Many kinds of sand barrier (especially straw checkboard)	Shapotou Ningxia experimental station
1950’s	Wheat straw semi-concealed sand barrier	Baotou Lanzhou Railway Shapotou section
1958	Salix gordejevii barrier	Western Liaoning
1961	Clay barrier	Minqin Oasis
1981	Gravel sand barrier/ high vertical sand barrier	Ningxia Shapotou
1980’s	Sandbag	Golmud Railway
1995	Plant grid sand barrier	Fuyu District in Songyuan, Jilin
1997	Coal gangue sand barrier	Maowusu sandland

Continued

Time	Kind of sand barrier	Location
China		
1997	Banded scoparium sand barrier	Jinji mining area in Yulin, Shaanxi
1999	Hedysarum fruticosum sand barrier	Inner Mongolia Bahrain Right Banner in Horqin Sandy Land
1999	Reed barrier	Mongolia Bahrain Right Banner
2002	Nylon mesh/plastic warp knitted mesh/polyester covered wire mesh	Coastal dune
2003	Plastic barrier	Minqin, Gansu
2003	Banded vertical reed barrier	Chen Barag Banner, Inner Mongolia
2004	Salix sand barrier/soil coagulant sand barrier	Yijinhuoluo Banner, Inner Mongolia
2006	High vertical reinforced concrete sand barrier	K1054 and K1064 department in Beijing-Lhasa highway
2007	Geogrid barrier (polypropylene sheet)	Wind tunnel simulation
2007	PLA sand barrier	Inner Mongolia Alashan jartai town
2008	Sand bag barrier	Xilinuole Meng 207 State Road, Inner Mongolia

need to simultaneously consider temporary and permanent benefits for ecology and the economy so as to establish a sustainable development pattern.

4.2 Demand-driven research

Practical research began in sandy coast desert control. These sand barriers were established to fulfill the demands of national economies, such as protection of farmlands, railways, highways and oil fields. From 1316 to 1953, many European coastal counties, such as Germany, Denmark, France and Poland built sand barriers on coastal sand dunes to protect farmlands; in India and the Soviet Union it was to protect railways; and in West Asia and North Africa it was to protect oil fields (Yu, 2014). After exploration and improvement, the overall situation of desertification was prevented by treatment; sand damage no longer existed and exploration of sand barrier mechanisms was no longer a focus of research outside China.

After the 1950s, key areas for sand barriers were transferred to China. After the early boom in the 1950s real attention was gained in the 1980s and theory and practice stimulated each other, jointly promoting research and practice in Chinese. This has especially been the case since 1997 with the rise in knowledge innovation. Chinese researchers used the theory to carry out a lot of work in sand protection and theoretical progression. Search results retrieved in the Web of Science SCIE and CPCI databases indicate that sand barrier/checkerboard applied research focused on the sedimentary record of coastal dune sand barriers in the inversion of the climate with no intersection with sand barriers in desert sand control in research conducted outside China. While In the CNKI database more than 1800 articles were located, including sand barrier setting type (classification, the use of materials, naming), set technology, protective benefits (windbreak and its mechanism, improve soil properties and the growth of vegetation restoration, microclimate improvement), anti-corrosion research (damage mechanism and measures) and other related aspects of a comprehensive and in-depth, practice and demonstration effect. Countries other than Chinese have strong scientific research strengths and have also solved sand disaster prevention and control technology, even if China is designated by the United Nations as a global teacher of desertification control technology. Only the contradiction between resources, environmental problems and China's population can explain this rapid increase in China: even in desert areas with fragile ecological environments a large human population is present and desertification control is critical to ecological environmental protection *and* human survival.

4.3 Technology driven

Materials for sand barriers were initially obtained from nature and were raw and traditional, such as sand, gravel, firewood and clay. With progress in technology, high-technology materials appeared, some of which were harmful to the environment. Recently, high-tech environmentally friendly materials were discovered. Traditional sand barrier materials still play a great role in preventing quicksand, but the source of raw materials and transportation conditions limit their utility and they are suitable for specific areas only. With the development of material science, a large number of new sand control materials have emerged, such as soil coagulating agent, laminated sand bag, nylon net, plastic warp knitted mesh, and polyester covered wire mesh. Wheat straw, clay, plastic net and nylon net sand barriers have achieved good benefits in some sand desert areas, however, through long-term practice, the application of these sand barriers has some limitations. Salix, wheat straw and firewood have other perishable or susceptible to wind erosion characteristics such as maintenance. Straw sand barriers lose function in 3–5 years and they are very difficult to reset on the spot. Clay sand barriers are a kind of sand fixing sand barrier with no ventilation structure. They have good performance in fixing sand dunes. It is only suitable for the place where

there are rich clay layers. Plastic mesh, nylon mesh and other new materials contain a variety of chemical components, secondary pollution may occur (caused by and after losing the protection function of the residual fragments), the material easily age, the material and setup costs are high and applications limited.

Therefore, it is urgent to find new sand barrier materials that are simple and easy to operate, with good sand fixing effects and of low cost.

4.3.1 Re-excavation of low cost raw materials

Fence-style cotton haulm is a new and low cost raw material. Comparative analysis of its sand fixing effectiveness found that the fence-style cotton haulm protective benefits are significant, and its setting is scientific and reliable. This material may replace sand dune-fixing materials like nylon nets and plastic nets. It has rich raw materials, is of low cost and is easy to construct. There is no environmental pollution and it can be used in mechanical desert control.

4.3.2 New high-technology materials

PLA is a fiber extracted from cereal crops, so it is a kind of completely biodegradable material. Its production and utility produces no pollution, and is widely used in industrial, agricultural, forestry, health care and other fields. PLA material has a high temperature resistance, is light and is easy to transport. Sand barriers built with PLA are simple, and have a long life and protective effect.

4.3.3 Anti-corrosion technology

Sand barrier material anti-corrosion technologies extend the utilization time of sand barriers and reduce costs. Research has focused on external forces responsible for corrosion (such as wind, sand burial, erosion of bacteria, fungi, actinomycetes and soil microorganisms) and the nature of the material itself. Sand barrier protection measures, such as improved sand barrier design and anti-corrosion measures (e.g. preservatives that deal with sand barrier materials) were implemented to enhance corrosion resistance.

4.3.4 Theory, observation, monitoring and experimental techniques

Early in the initial use of the sand barrier prevention of coastal sand disasters, there were no theoretical or experimental conditions to support sand barriers. Progress in science and technology, fluid mechanics theory, sand flow, sand barrier size, height, spacing, different types of collocation used by field experiments, wind tunnel simulation, configuration and optimization have all benefited our understanding of wind sand. In addition to monitoring and evaluation methods, 3S technology is playing a more important role in the monitoring of desertification and restoration of vegetation after the construction of sand barriers.

Progress in science and technology has played and will play a huge role in providing theoretical support, finding more materials, and monitoring desertification to successively solve barrier settings, materials and benefits.

5 Conclusions

As a major measure of sand control engineering, sand barriers are widely used because of advantages in simplicity, efficiency, diversity and cost. Sand barrier classification, sand fixing principles and simulations, ecological effects of sand barrier, sand barrier mechanization and sand barrier anti-corrosion measures have been a strong focus in research in this area.

Problems remain for sand barrier research: sand barrier material types, access conditions and standards and a sand protection benefit evaluation index system. Sustainable development methods and factors influencing the development of sand barrier research require further work.

The evolution of sand barrier technology is driven by three factors: the concept of development, social and economic development, ands science and technology. Development trends in sand barrier technology include: (1) developing more ecological environmentaly friendly technologies; (2) developing new sand barrier materials that are easy to set, have good sand fixing, are low cost and easy to obtain; (3) strengthening comparative studies of different sand barriers across material, construction technology, cost and utilization time; and (4) integrating the development of the sand industry in sand barrier research.

References

Arens S, A Baas, J Van, *et al*. 2001. Influence of reed stem density of fore-dune development. *Earth Surface Processes and Landforms*, 26: 1161–1176.

Batchelor G K. 1967. *An Introduction to fluid dynamics*. Cambridge University Press: 409–413.

Cheng C. 2014. Effects of sandbag sand barrier on traveling dune's vegetation restoration and physicochemical properties of soil. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)

Chipil W S. 1995. The physics of wind erosion and its control. *Advances in Agronomy*, 15: 211–302.

Dong Z, D Fryrear, and S Gao. 2000. Modeling the roughness effect of blown-sand-controlling stand vegetation in wind tunnel. *Journal of Desert Research*. 20(3): 260–263. (in Chinese)

Guo Q F, P W Rundel, and D W Goodall. 1998. Horizontal and vertical distribution of desert seed banks patterns causes and implications. *Journal of Arid Environment*, 38: 465–478.

Johnson R G, and R C Anderson. 1986. The seed bank of a tall-grass prairie in Illinois. *American Midland Naturalist*, 115: 1223–1230.

Johnston A, S Smoliak, and P W Stringer. 1969. Viable seed population in prairie top soils. *canadian journal of plant science*, 49: 75–82.

Li X, H Zhou, X Wang, *et al*. 2016. Ecological restoration and recovery in arid desert regions of China: A review for 60-year research progress of Shapotou desert research and experiment station, Chinese Academy of Sciences. *Journal of Desert Research*. 36(2): 247–264. (in Chinese)

Liu X, Z Dong, and X Wang. 2003. Aerodynamic roughness of fixed sandy beds. *Journal of Desert Research*. 23(2): 111–116. (in Chinese)

Na Q. 2010. Study On *Salix Psammophila* checkerboard corrosion rule and soil corrosive factors. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)

O.Connor T G, and G A Pickett. 1992. The influence of grazing on seed

production and seed bank of some African savanna grasslands. *Journal of Applied Ecology*, 29: 247–260.
Ow CD, and R J Chancellor. 1983. Factors affecting the viable seed content of soils beneath low land pastures. *Journal of Applied Ecology*, 20: 915–922.
Qu J, Y Ling, R Zu, *et al*. 2005. Study on comprehensive sand protecting efficiency of semi-buried checherboard sand barriers. *Journal of Desert Research*. 25(3): 329–335. (in Chinese)
Shi X. 2008. Study on wind control effect and surface breadcrust physico-chemical properties of *Salix gordejevii* barrier. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)
Shu Q, and J Liu. 2007. The overall design of the windbreak and sand fixation checkerboard Paving Robot. *Transactions of The Chinese Society of Agricultural Machinery*, 38(6): 219–221. (in Chinese)
Song Z. 2011. Study on chemical anticorrosive effect of *Salix Psammophila* checkerboard. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)
Sun B. 2000. *Desertification control engineering*. Beijing: Chinese Forestry Pres: 144–202. (in Chinese)
Thompson K, and J P Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. *Journal of Ecology*, 67: 893–921.
Thompson K. 1987. Seeds and seed banks. *New Phytologist*, 106: 23–48.
Wang Y. 2016. Effect of checkerboard barrier on wind erosion characteristics around the electric transmission line tower base. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)
Wang Z, and X Zheng. 2002. A simple model for calculating measurements of straw checherboard barriers. *Journal of Desert Research*. 22(3): 229–232. (in Chinese)
Yu Y, G Gao, J Wang, *et al*. 2014. Sand control technologies of sandbag barriers. Beijing: Science Press. (in Chinese)
Yuan L. 2010. Study of effects of soil physical properties and protection benefits by PLA san barrier. *Inner Mongolia Agricultural University master degree thesis*. (in Chinese)
Yuan S (Japan). 1958. *Coastal sand afforestation*. Beijing: China Forestry Press. (in Chinese)
Zhang L, D Zhou, and Y Gao. 2014. Review of sand barrier desertification combat in China. Journal of inner Mongolia Normal University (natural science edition), 43(3): 363–369. (in Chinese)
Zhao T, Z Cao, C Zheng, *et al*. 2005. Parallel sand barrier on vegetation and soil seed bank in the seriously desertified grassland. *Journal of forestry university*. 27(2): 34–37. (in Chinese)
Zhu Z, X Zhao, and Y Ling. 1998. *Sand control engineering*. Beijing China. Environmental Science Press: 1–3, 96–116. (in Chinese)

沙障技术演化特点及发展趋势

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摘 要：沙障是风蚀工程治沙的主要措施之一，已在荒漠化防治领域广泛应用。采用文献计量和内容分析法，对国内外沙障应用以来在沙障类型、研究内容等方面的工作进行简要归纳和总结，指出了沙障研究中存在的问题，详细论述了沙障研究规律及发展趋势，认为科技、需求和发展理念是沙障研究的三大驱动因素，发展环境友好的生态技术，促进沙区经济产业化是沙障研究的方向。

关键词：沙障；演化特点；发展趋势