Comparing straw checkerboards paving methods in deserts of China with sustainability indicators

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Abstract. The straw checkerboard sand barrier (SCSB) is widely used to fix sand and prevent desertification in China. In this paper, two methods of straw checkerboard (SC) paving are compared using sustainability indicators: the traditional method employing workers using straw and shovel, and the mechanized method using straw and a sand fixing vehicle. The paper describes the processes of the two different paving methods. Data regarding these two different methods of SCSB paving were obtained from prior research experiments conducted by a sand-fixing vehicle prototype. The paper proceeds to use three sustainability indicators representing the three aspects of sustainable development. Using these indicators, data were compared to assess these two methods. The results show that the operational efficiency of the mechanized method is nearly 200 times higher than the traditional method, and that the total cost in the operational process can be reduced by about 7,200 Yuan (about 1,145 USD) per hectare. The completion cycle of the break-even point (164 hectares) is 52.5 days in mechanized method, which is about one tenth of the traditional method. This not only indicates a clear advantage of performance and cost-effectiveness for the mechanized process over the traditional method, but also shows that this mechanized process can contribute to sustainable development for the region greatly because the preliminary work on degraded land and soil restoration can be completed in a significantly shorter period and the health conditions of a large number of manual workers can be improved.

1. Introduction
As of 2014, desert covers 172 million hectares of land in China, accounting for 17.93% of the country’s total region. Desertification affects 920 counties and districts throughout the country, 93.95% of which is distributed in North and Northwest China [1]. In recent years, sandstorms caused by strong winds blowing over loose sand have become one of the most serious environmental problems in China. It does significant harm to the environment, transportation, communication, and infrastructures in the affected areas as well as the adjacent regions, undermining the government’s efforts to promote sustainable development of the country [2]. To alleviate these problems, scholars identified the key factors that produce sandstorms and suggested potential solutions to reduce the frequency and intensity of sandstorms, and to prevent further erosion and suspension of loose silt and sand [3].

Measures to combat desertification have been developed in many countries affected by deserts. These methods include biological, mechanical, and chemical methods. In China, many such measures have been experimented with and implemented to reverse desertification and alleviate its influence on the environment [4]. One such method, straw checkerboards sand barrier (SCSB) has been proven to be one
of the most successfully implemented sand stabilization methods [5-7]. There are two main methods to pave straw checkerboards (SC): the traditional method and the mechanized method. Traditionally, a SC is planted by manual labors using spades. Though a plate shaped shovel head specialized for paving SC has been designed to provide an easier way to press straw into sand [8], and a straw checkerboard reusing method was put forward to improve the utilization of materials [9], the paving efficiency of the traditional method remains low. An adult worker is reasonably estimated to complete about 100 to 200 m² SC in an eight-hour work day on average according to long-term observation (it is a wide range because the actual units of square meters of a worker’s accomplishment vary greatly in reality, determined by combined factors related to the individuals, the weather, and so forth). However, in China, the area affected by desertification is so large that the cost in terms of man hours of labor to pave SC would be enormous, while the cost to the laborers’ health is equally high. Not only is desert work physically demanding, but long-term exposure to large numbers of dust particles and strong UV radiation also significantly damages workers’ health [10-12]. More problematically, the SCSB can only last about 3 to 5 years as a result of the erosion caused by wind, sunlight and rain. This affects the desert improvement negatively because in most cases, SC paving is the first step in the long process of restoring degraded land and soil, followed by vegetation recovery. The SC paved to protect infrastructure such as highways, railways, and mining area etc. are particularly vulnerable, as those areas are not suitable for the survival of vegetation. The rate of SC deterioration and sand movement is so fast that manual labor alone cannot replace SC quickly enough to maintain their effectiveness. To overcome these difficulties, a mechanized method has been developed to pave SC.

Several research and development projects on the mechanized SC paving equipment’s functions have already been completed [13,14]. The first physical prototype of a SC paving robot has already been field-tested. The experimental data showed that in desert areas with gentle slopes, SC paving can be highly mechanized [15]. In order to further improve the equipment’s performance, a new generation of vehicles for stabilizing sand in surface has been manufactured through repeated optimization.

Sustainable development is defined by the United Nations as development that is able “to meet the needs of the current generation without compromising the ability of future generations to meet their needs” [16]. Sustainability normally includes three aspects – economic, environmental, and social [17,18]. Sustainable development can be evaluated by Sustainability Assessment (SA), a process that aims to contribute to a better understanding of the meaning of sustainability. There are multiple frameworks for Sustainability Assessment Methods (SAM), including product-related assessment tools, indicators, indices, and integrated assessment methods. Among these, sustainability indicators have been determined to be the most useful assessment method suitable for different fields [19-21]. The extensive use of sustainability indicators is due to their following useful characteristics: easy summarization and the ability to focus and condense massively complex information to a series of valuable data capable of being managed. The results derived from the indicators simplify data comparison, allowing trends, hot-spots, and other informative insights to be more easily assessed [22,23]. Sustainability indicators developed by the United Nations are listed in the “Global indicator framework for the Sustainable Development Goals (SDGs) and targets of the 2030 Agenda for Sustainable Development” and are used in this paper.

In this paper, we focus on analyzing the positive impacts of a mechanized SC paving method on sustainable development. Our research question is: compared with the traditional method, is the mechanized method more advantageous than the traditional manual method to the economy, to the environment, and to the society in terms of sustainability?

2. Data and methods

2.1. Traditional (manual) straw checkerboards paving method

Straw checkerboards (SC) with the size of 1 m × 1 m has been shown to be the most effective for sand stabilization in most areas [7], so this size of checkerboard was used in this study. The process includes three steps [24], (i). On the soil surface, outline the straw’s grid by pressing a groove with a width of
about 1000 mm at 1000 mm of soil depth. (ii). Orderly lay the straw on the sand surface vertical with the marked line with enough thickness to ensure the sand resistance of the SC, pave to a width of about 1,000 mm band, ensuring that the middle point of the straw is coincident with the middle point of the mark line. (iii). Put the flat spade in the middle of the straw laid in step 2, press the spade heavily with the foot, and draw out the spade after two ends of straw are erected, then push the sand on both sides of the straw root to make the straw stand firmly.

In order to achieve the purpose of a windbreak and sand stabilization, the SC should meet the following criteria [25]: (i) the space between adjacent straw sand barriers should be 1000 mm (shown as figure 1(b)), range from 800 mm to 1000 mm is reasonable; (ii) the depth of SCSB beneath the sand surface (h in figure 1(a)) should range from 150 mm to 200 mm; (ii) the effective height (H in figure 1(a)) of SCSB should range from 150 mm to 200 mm.

![Figure 1](image1.png)

**Figure 1.** Characteristics of straw-checkerboard, (a) Plane structure; (b) Lateral section structure.

2.2. *Mechanized straw checkerboard paving method*

During the traditional SC paving process, the most time consuming and physically demanding steps for the workers are paving the straw with moderate thickness and then pressing the spade with their feet. Therefore, these two steps should be the first to be considered when proposing the mechanized paving method and designing the sand stabilization vehicle. The equipment should have the ability to pave mechanically, with low manual labor input and the flexibility to pave a variety of sizes.

To achieve the above purpose, a vehicle for sand stabilization was manufactured. We utilize a paving mechanism and a heavy-duty truck that has the ability to work in the special desert terrain using wheels as two main parts in the prototype, shown in figure 2. The tractor moves the paving mechanism and produces traction, while the paving mechanism paves the SC.

![Figure 2](image2.png)

**Figure 2.** Sand fixing vehicle.
The structure of the paving mechanism determines the process of the mechanical SC paving method. The paving mechanism consists of two parts: transverse paving mechanism and longitudinal paving mechanism (we define the vehicle’s moving direction as the longitudinal direction, and the direction perpendicular to the longitudinal direction as the transverse direction), as can be seen in figures 3(a) and 3(b).

When the sand fixing vehicle is working, in the longitudinal direction, straw is conveyed to the sand surface from the straw box (which stores a certain amount of straw) by an intermittent feeding mechanism. Then the transverse inserting tool inserts the straw into the sand to form the transverse straw sand barrier. In theory, adjacent straw sand barriers are spaced 1000 mm apart.

At the same time, in the longitudinal direction, the straw is conveyed and inserted into the sand continuously by a pressure wheel, paving a constant straw sand barrier. Together with the transverse straw sand barrier, the straw checkerboard sand barriers are formed, shown as figure 3(c).

The parameters measured in the experiments on the mechanized SC paving method are in reasonable agreement with the SC technical criteria introduced in Section 2 (errors were caused by the vibration of the equipment and possibly the occasional imprecision of measurement). The depth of SC ranges from 165 mm to 240 mm, the height of SC ranges from 150 mm to 210 mm, the distance between two adjacent straw sand barriers ranges from 945 mm to 990 mm. According to the results, we conclude that the SC paved by the mechanical method on relatively flat terrain can achieve the sand stabilization effect.

2.3. Data collection

For the purpose of assessing the contribution of the mechanized SC paving method for sustainable development, a series of sustainability indicators were selected. We chose the traditional SC paving method, which has been successfully implemented by manual labor in China, as a baseline for comparison. The mechanized SC paving method with a sand stabilization vehicle was applied under comparable conditions. After, the data of the sustainability indicators of the two SC paving methods were assessed and compared.

In this paper, data for selected sustainability indicators by comparing experiments using both, manual and mechanical methods. The data are subsequently analyzed from the perspective of sustainable development. The key factor in the sustainability assessment process is to choose the most reasonable indicators related to sustainability [17, 26]. This is the first time that the sustainable effect of mechanized sand stabilizing procedure has been evaluated. The mechanized method will be compared to a baseline traditional manual method with three indicators, as shown in (table 1). Our selection of indicators and methods are listed below. (i) Government cash support: In China, SC is mainly paved for to protect agricultural land, communication facility and other infrastructures in desert areas, supported by government cash flow to assist development. Costs of a unit area determine the total area can be developed with the same total official flows. In this paper, both the costs of equipment and costs during the operation process are taken into consideration to calculate the official flows to a unit area of SC. For the mechanized method, this includes the costs of vehicle manufacturing, maintenance, diesel fuel, material, a driver and an assistant to the driver. As for the traditional method, it has been implemented...
in China for many years, the average costs of material and workers are based on the market prices. (ii) Frequency rates of non-fatal occupational injuries: Occupational health and safety ranked second and fifth respectively in social indicators for sustainable development [17]. The manpower employment (which is defined as the number of direct working hours needed to complete a hectare of SC (h/ha)) representing the physical labor volume of workers employed for SC paving, is related to the workers’ health. The manpower employments of the two methods are derived from their operational efficiency. (iii) The time involved to complete a selected unit area was evaluated in both procedures: The complete cycle of a unit area of SC indicates the beginning of the subsequent land and soil restoration. In most cases, only by combining sand stabilization with ecological restoration can the long-term effect on restoring degraded land. We take the break-even point of the two methods as an example, and compare the completion cycle of the two methods, and use the Green Cover Index [27] to evaluate the state of land recovery.

Table 1. Indicators for sustainability assessment.

| Category | Indicators                                      | Unit  | Data Collection       |
|----------|------------------------------------------------|-------|-----------------------|
| Economy  | Government cash to a unit area of SC          | Yuan/ha | Calculation          |
| Society  | Frequency rates of non-fatal occupational injuries |       | Interviewing/Literature |
| Environment | Degraded land and soil restoration | Day | Recording/Literature |

2.4. Experiment site
The experiment was carried out at the experimental site, an agricultural experimental station for sand stabilization in Heerhongde (located at N49°11′, E118°27′, figure 4), in the summer of 2010. This base belongs to Prairie Chenbarhu banner located at the northern part of the Hulun Buir Sandy Land, Inner Mongolia, China. This land is characterized by fixed and semi fixed dunes with a loose soil layer and low humus content, which keeps moving under wind action. Only sparse sand plants such as Corispermum hyssopifolium and Agriophyllum squarrosum grow on quicksand and flora species of sheep firewood, wheatgrass and caragana grow on fixed and semi-fixed sand dunes [28]. The weather in spring is dry and windy, in the winter it is very cold, in the summer and autumn there is a great temperature difference between day and night. The research site belongs to the continental monsoon climate zone with a semi-humid and semi-arid transitional climate where the annual average temperature is −2.5 to 0°C and the annual sunshine duration is 2900 to 3000 h. The annual precipitation ranges from 280 mm to 320 mm, and this precipitation mostly concentrated in summer and autumn. The annual evaporation ranges from 1400 mm to 1900 mm, which is five times more than the annual precipitation rate. Mean annual wind velocity ranges from 3.2 to 4 m/s [29].

Figure 4. Experiment site.
The geography of the experimental base for wind and sand stabilization in Heerhongde is characterized by sand dunes alternating with gently undulating inter lowlands. It is object free, without stones and shrub stumps. Our SC paving experiment was conducted by the sand fixing vehicle prototype at the speed of 0.5 m/s (or 1.8 km/h, approximately), the distance between two adjacent straw sand barriers was set at 1000 mm. The straw used in the experiment was sorted and ranged from 600 mm to 750 mm in length. We measured the parameters of SC randomly with measurement tools, including tape, steel ruler and stopwatch, to test if the mechanical paving method fulfilled the SC paving criteria. Using this data, we were able to calculate the practical work efficiency of the sand fixing vehicle.

3. Results and discussion

3.1. Results

With a satisfactory SC paving effect, operation efficiency plays an important role in the following results and analysis of sustainability indicators. In this study, operation efficiency was considered as the area of SC paved in an hour (m²/h). The data for the two methods is given in table 2. The SC paving experiment was carried out under the condition of keeping sand fixing vehicle moving at a constant speed of 0.5 m/s (or 1.8 km/h, approximately). At this speed, the vehicle paves 3 m² SC every 2s (because the transverse inserting tool is designed as 3 m in width and the longitudinal inserting tool includes three pressure wheels with 1,000 mm spacing), thus the theoretical operation efficiency is 5400 m²/h. But in practice, 1 hectare SC can be completed in about 2.6 hours. Because the sand fixing vehicle needs to stop to resupply straw material, and occasionally the straw feeding mechanism may be stuck and require maintenance. Thus, about an average of 3,900 m² SC can be paved in 1 hour, namely the machine’s actual efficiency is 3,900 m²/h. Note that two workers are required for the operation of the sand fixing vehicle, a driver controls the truck and another worker completes the rest of the work. In the traditional method, an adult worker can complete about 100 – 200 m² SC in eight hours at an efficiency of 12.5 – 25 m²/h.

Table 2. Operations of two methods.

|                         | Traditional Method | Mechanized Method |
|-------------------------|--------------------|-------------------|
| Completed area (m²)     | 100 ~ 200          | 10,000            |
| Work hours(hr)          | 8                  | 2.6               |
| Efficiency (m²/h)       | 12.5 ~ 25          | 3,900             |
| Work speed(m/s)         | /                  | 0.5               |
| Number of driver        | 0                  | 1                 |
| Number of labor         | 1                  | 1                 |
| Size of checkerboard (m)| 1 × 1              | 1 × 1             |
| Tool                    | Spade              | Sand fixing vehicle |

Government cash flows to a unit area of SC (as of 2017): In a regional project such as restoration of deserts, the government funds were assigned to cover costs incurred are funneled to cover costs incurred by many collaborating units over many years. The SC paving project is a small portion of this large effort and by reducing the cost of the project, we can effectively reduce the government cash support. Before commencing operations, the straw preparations are the same in both the traditional and the mechanized methods. Therefore, the costs of preparation can be omitted in our calculation. Here, we take 1 hectare SC as the study area in order to estimate the government cash flow needed to accomplish the unit area with both, manual and mechanical methods to a unit area of two methods.

In the SC paving project, operational cost accounts for the major proportion, which includes the cost of materials, tools, and labors. In the traditional method, 1 hectare SC needs five to six metric tons of straw [30]. The average price of straw is 600 Yuan/ton in 2017, so the official flows to straw for 1 hectare SC is around 3,000 to 3,600 Yuan (about 454 to 545 USD). As for the government cash support for labor, we calculate with an estimated average efficiency of 20 m²/h (it takes 500 hours to finish 1
hectare), one worker costs on average 15 Yuan/h, hence the total government cash support per worker would be 7,500 Yuan/ha (about 1,165 USD). With the help of straw feeding mechanism in sand fixing vehicle, the straw is relatively evenly spread on sand surface, requiring 4.25 to 4.5 metric tons per hectare which cost 2,550 ~ 2,700 Yuan (about 395 ~ 420 USD). 1 hectare of SC can be completed in 2.6 hours with the efficiency of 3,900 m²/h, the assistant’s cost is 25 Yuan/h, and the driver’s hourly wage is an average of 60 Yuan/h. The government support for labor is 221 Yuan/ha (about 35 USD). The theoretical diesel fuel consumption of 2.6 hours is about 148L according to power rating (249 KW) and the minimum fuel consumption at full load (≤192 g/kW.h) of the engine WD615.95C, and the density of diesel fuel (0.84 g/ml), thus the government support to fuel (average price of diesel fuel is 5.77 yuan/L in Sep, 2017) is about 854 yuan (135 USD). As for the price of sand fixing vehicle, we can reasonably estimate the production price instead of providing the accurate purchase price because the preliminary research, design and manufacturing of prototypes was a process of continuous optimization that incurred extra costs that might be recuperated by the sales of patents in the long run. In addition, this process was subsidized by the government in the forms of research grants, which might be difficult to justify to include in the final retail prices. To make relatively reasonable price estimation, we consider only the costs of parts in the paving mechanism manufacturing and the price of the heavy-duty truck (about 350,000 yuan), on these bases, the price of a sand fixing vehicle is estimated at about 900,000 yuan (142,100 USD). Clearly, the cost of production of a single prototype is far higher than that of mass production. Therefore, if the sand fixing vehicle is in mass production, its price may be drastically reduced. The maintenance cost of the sand fixing vehicle (with a life cycle of 10 years, which is the mandatory retirement standard for heavy duty vehicles in China) is estimated to be about 300,000 yuan based on its components’ prices.

As can be seen in table 3, to complete 1 hectare SC, the total government cash support to labor employment and material is 11,100 yuan (about 1,743 USD) in traditional method and 3,775 yuan (about 598 USD) in mechanized method. After considering the mechanized method’s costs of one-time purchase and ongoing maintenance of the vehicle, the break-even point for the two different methods is 164 hectares (1.64 km²), when the total official flows of two methods is only a few thousand yuan in difference.

Frequently rates of non-fatal occupational injuries: The amount of worker’s exposure to occupational environment can be estimated using the operational efficiency discussed earlier. The manpower employment of the traditional method is 500 hours/ha and that of mechanized method is about 5.2 hours/ha considering one driver and one assistant. The mechanized method can prevent more workers suffering from physical harms, such as dehydration, ultraviolet radiation and high levels of fine particulate matter (e.g. PM2.5 and PM10) [31], which can be analyzed.

Restore degraded land and soil: As mentioned earlier, degraded land and soil restoration process is affected by SCBC’s paving operation cycle. In theory, to complete 164 hectares (the break-even point) SC, about 420 hours are needed by the mechanized method. The completion cycle is 52.5 days calculated on the basis of an 8-hour work day, with a driver and an assistant. In comparison, 82,000 hours are needed for the traditional method, the completion cycle is 5,125 days with two workers. In other words, the traditional method can complete the same work using the same number of days as the mechanized

| Category         | Traditional Method (yuan/ha) | Mechanized Method (yuan/ha) |
|------------------|-------------------------------|-----------------------------|
| Worker/Assistant| 7,500                         | 65                          |
| Materials        | 3,000–3,600                   | 2,550–2,700                 |
| Driver           | /                             | 156                         |
| Fuel             | /                             | 854                         |
| Vehicle          | /                             | 900,000                     |
| Maintence        | /                             | 300,000                     |
| Total for 164 ha | 1,233,000–1,233,600           | 1,214,200–1,214,350         |
method, as long as about 390 workers are employed to do the work.

3.2. Discussion

It is reasonable to conclude that at the working speed at 0.5 m/s (1.8 km/h approximately), the operational efficiency of the mechanized method using a sand fixing vehicle is nearly 200 times more productive than that of the traditional method. The most important aspect brought about by the mechanized method’s higher efficiency is the reduction of government subsidies to a unit area’s development assistance. The result indicates that paving 164 hectare of SC is the break-even point of the two methods. If more SC were paved, the official flows to a unit area (1 hectare) saved by the mechanized method are more than 7,200 Yuan/ha (about 1,145 USD), which is multiplied with the number of hectares involved. This reduction is particularly important for this region because agriculture is the fundamental way of living for the poor and vulnerable groups in these rural and remote areas. Arable land is the foundation for agricultural production, food supply and therefore farmers’ income. Large area of agricultural land is affected by moving sand in China, forcing the government to invest billions to protect the existing arable land and reform the desertification land for agriculture. Similarly, grassland used for livestock husbandry around the desert is also seriously affected. The grassland resources are indispensable to the livestock husbandry, which is a traditional trade in the region. Therefore, protection and utilization of grassland are the fundamental measures to sustain livestock husbandry and achieve stable and high yield, to raise the income level of herdsmen, and to promote the comprehensive economic development in the pastoral area. The mechanized method helps to pave larger area of SC with a reduced government cash flows, which has a positive impact on protecting local infrastructures and increasing the area of land that can be engaged in agricultural production. In other words, this method can complete an equal area of SC with less money. Taking the “13th Five-Year Project” of China as an example, the government planned to improve 100 thousand km² of sandy land during this period [1]. Calculating with the saving cost (7200yuan per hectare) after the break-even point (1.64 km²), about 72 billion yuan (11.45 billion USD) can be saved if mechanical method were applied in this project. The saving investment could be possibly redirected to develop other facilities in rural area. This helps fulfill the requirements of the SDGs because it helps to enhance agricultural productive capacity and improve the local economic sustainable development in developing countries.

Another equally important aspect is that the higher efficiency is related to the social sustainable development from a view of decreasing frequency rates of non-fatal occupational injuries. Non-fatal injuries of short-term labor working in harmful environment such as mining, construction [32] and deserts (including labors paving SC) have not received enough attention. Extreme heat, drastic temperature fluctuation, rapid evaporation and strong reflection of sunlight characterize the desert environment. The maximum temperature of some deserts can reach 45℃, the perceived temperature is often even higher. Desert environment affects physical labor’s health in various ways. Wilk et al. reported body weight losses of 0.65% following a 3-hour activity (intermittently at 35±1℃, 45-50% relative humidity) when individuals were allowed water ad libitum, accompanied by the loss of a large number of electrolytes. Another investigation made in warm environment (30℃ dry bulb, 50% relative humidity) showed that when the individuals are dehydrated by 2% of their body weight, their physical performance will be impaired and a decrease by 30% of work capacity will occur when they are dehydrated by more than 5% of their body weight. If they bear high and sustained sweat rates of more than 1 L/hour, that is body weight loss of 1 Kg/hour, subsequent rapid body weight losses are possible in protective clothing [33]. Investigation carried out in simulated desert conditions showed that the water loss following prolonged exercise is up to 11 liters per day. The water loss is not shared by the whole body equally: the blood serum is the main source, which causes a decrease of the circulating blood volume, bringing server influences [33]. Secondly, it has been proven that there is a strong correlation between ultraviolet (UV) light and the risk of both non-melanoma skin cancer and malignant melanoma [10,34]. An investigation reported that erythemal radiant exposure of 65% outdoor workers exceeded 1000 J/m² (10 SED), corresponding to MED with adaptation for skin phototypes III and IV, based on which the occupational risk estimation are high [35,36]. It is reported that the annual total amount of
UV in the Taklimakan Desert reaches 305.64 MJ/(m²•A). May to August is a period of greater intensity of UV, and the cumulative value of UV for these 4 months accounted for 46.67% of the total annual UV. The maximum monthly average daily amount of UV is 1.23 MJ/m² in July, and the average annual amount is 0.84 MJ/m² [37]. Workers in desert from May to August suitable for SC paving are exposed to higher UV radiation. What’s more, dust storm is a frequent phenomenon in sandy sites. PM2.5 and PM10 originating from the dust contain various pollutants and biological components, some of which have been shown to be positively related to increased mortality and hospitalizations of the people who have been exposed to airborne particles [10, 38, 39], causing respiratory disorders.

Labor for SC paving in traditional method bear a long-term exposure to the extreme hot and dry environment, intensive UV radiation and air-borne particles, resulting in harmful effects that may only reveal themselves years after exposure. This increases the frequency rates of non-fatal occupational injuries. Furthermore, these contract labors are usually employed from rural regions near the working site, including many women, who are largely uneducated and lack the legal knowledge to protect themselves from occupational injuries with these contracts. In these often tight-knit rural communities, once these workers are chronically injured in the desert occupational environment, they and their family will suffer enormous pressure, which restricts the sustainable development of local society. “Protect labor rights and promote safe and secure working environments for all workers, especially women and precarious employment” is suggested in SDGs [31]. The sand fixing vehicle is a method to reduce physical labor required for SC paving. And its higher efficiency reduces the length of exposure for the workers to the unhealthy occupational environment, helping to decrease the local people’s frequency rates of non-fatal occupational injuries, coinciding with the SDGs.

The SDGs suggested that governments should implement resilient agricultural practices to help maintain ecosystems, strengthen capacity for adaption to extreme weather and drought and progressively improve land and soil quality [31]. SC combined with ecological restoration works well for these objectives. A great deal of research shows the SCSB has a positive link with sand stabilization, its contribution is to increase the sand surface roughness and reduce the wind speed, forming a stable aeolian environment where plant seeds can sprout and take root while water, soil organic carbon, and fine particle contents can accumulate to facilitate vegetation survival [40, 41]. The most common degraded land and soil restoration method is to sow seeds and plant native vegetation suitable for survival in the desert with the SC. With the succession of plants, the land surface will form a biological soil crust. Gradually, the area will form a complex ecosystem with other species moving into the area, achieving ecological restoration [42, 43]. However, the ecological recovery process requires a long period in the desert environment due to the extreme climate and water shortage. The crust is still in the initial stage and the soil nutrient content remains low even after 3 to 5 years [41]. Even in the Shapotou desert, one of the most successful sites in China using SCSB to fix sand and restore degraded land, the highest coverage of artificial vegetation planted there is a scant 40% even after 8 to 9 years of recovery [44].

![Figure 5. Vegetation change. (a) Original; (b) 1 year later; (c) 3 year later.](image)

Specific to our program, the status of degraded land and soil restoration after 3 years is shown in figure 5(c). Note that the original proportion of bare sand land in figure 5(a) is 62% with an annual
vegetation coverage of 18%. The reason bare sand was not 100% and vegetation cover was not 0% is because the experiment base is not a total desert, it is the grassland eroded by wind and buried by sand in recent years. In other words, it is a semi-sandy and semi-arid area. The rate of moisture here is relatively higher than desert condition, bringing good results for land and soil restoration. The green cover index results show that soil wind erosion was reduced by 60%, the most obvious decrease of all. The other indicator (the proportion of bare sand to vegetated area) fell by almost 50% too. The proportion of annual vegetation coverage in our demonstrative plot continuously rose from 18% to 58% over the course of 3 years.

Since SC pavement is the preliminary step, its completion cycle plays a decisive role for subsequent vegetation restoration. Paving equal area of SC with the same number of labors, the completion cycle of the traditional method is nearly 100 times longer than that of the mechanized method. Due to the arid climate, the period suitable for SC paving in most desert areas is from late spring to early autumn. The mechanized method has a definite advantage in shortening the SC paving cycle to start the degraded land and soil restoration much sooner. This is especially beneficial in the areas with the most urgent need to restore land and recover green cover, helping local environmental sustainable development. In the past, large area of SC was paved by traditional method to restore degraded land and protect agricultural land, mining area, transportation and other infrastructures in China, contributing to the sustainable development of agriculture and animal husbandry in rural desert region. Due to the rapid rate of sand expansion and SC degradation, the mechanized method is developed to improve the operation efficiency and protect the manual workers’ health. In addition, the restored land and recovered green belt is conducive to decrease the mean levels of finest particles, which is related to reduce mortality rate attributed to ambient air pollution.

4. Conclusion
The SDGs highlight that combating desertification, and halting and reversing land degradation and halting biodiversity loss are significant parts to achieve global sustainable development. Straw checkerboard sand barrier is one of the most effective methods to resist desertification. Both the traditional method and the mechanized method are used for SC paving, conducive to sustainable development. In comparison, the mechanized method can reduce the government cash support to development assistance, decrease frequency rates of non-fatal occupational injuries and greatly shorten the operation cycle, which helps to largely reduce the time involved in restoring degraded land. To achieve the UN’s SDGs and targets of the 2030 Agenda, we suggested that the local governments should organize these sand-fixing operations as a collective effort, and reasonable tax incentives and/or subsidies to be established by the central government to encourage the mechanized method since desertification negatively affects cities outside of the desert regions as well.

Sand fixation and afforest the desert area are essential parts of Chinese government’s sustainable development policies [16]. This paper should be of great importance to the decision-makers as it provides an evaluation of the mechanized method relative to the baseline manual method in terms of sustainability. These results will help them determine whether the sand fixing vehicle should be implemented to further the sustainable development objectives of halting further desertification and facilitating revegetation in the region.

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