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Design and computational simulation of insertion cutter head of self-propelled salix sand barricade transverse laying machine

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ABSTRACT

Due to global warming and drought, land desertification has become more serious all over the world, and desertification control has become the focus of global attention. Salix sand barriers as a desert wind and sand area engineering sand control mechanical sand barriers have been more widely used. For this reason, this paper analyzes the demand for sand willow sand barriers, starting from the causes of desertification research, and for the sand willow sand barriers laying method for in-depth analysis. Taking the research on the governance of salix sand barriers as the theoretical basis, the self-propelled salix sand barriers horizontal laying machine insertion cutter head is designed, in order to improve the efficiency of salix sand barriers laying and the survival rate of salix spike insertion. Through the test data, the driving force, resistance, and tractability parameters of the laying machine when traveling were theoretically calculated. And according to the different slip rate when the drive seeks to come up with the slip rate when the whole machine is actually working, and finally determine whether the tractor meets the requirements of the passability. Through simulation calculations, it can be seen that the cutterhead laying machine designed in this paper can overcome the resistance generated by acceleration and climbing in the application of sand willow sand barrier laying, and has good versatility in the desert environment.

Keywords: salix sand barriers, lateral laying machine, insertion cutterhead design, simulation calculation

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1. Introduction

China is one of the countries with the largest area of desertified land in the world, and the aggravation of desertification and the expansion of sandy land not only seriously constrain the development of agriculture, animal husbandry, and industry in sandy areas, but also constantly threaten the life and health of people in sandy areas [1-3]. In the long process of sand control, researchers have found that the combination of engineering sand control and biological sand control, laying sand willow sand barriers to fix the quicksand is one of the most effective methods to control the desert [4]. The main role of salix sand barriers is to increase the surface aerodynamic roughness, reduce the near-surface wind speed, block and intercept the transit wind and sand flow, so as to play the role of rapid fixation of quick sand flow [5-7].

The traditional sand barriers are mainly laid by manually implanting plants such as sandwillows into the dug-out trenches with tools to ensure that their root systems can be firmly rooted [8-9]. This method of making sand barriers is time-consuming, laborious and inefficient, and the cost of modern labor is greatly increased, making the cost of desert management is also increasing, resulting in a continuous reduction in the area that can be managed per unit of input [10-12].

In order to break the current predicament, scientific sand management has become the current consensus of the whole society. The in-depth development of China's ecological civilization construction, but also prompted the state in the desertification control science and technology innovation has new requirements, modern desert management must keep pace with the times, taking into account the scientific and efficient, etc., and strive to mechanization, intelligence, integration direction [13-14]. At present, the sand barrier laying represented by multifunctional three-dimensional sand fixing vehicle develops rapidly, and the performance of the equipment is constantly improved through continuous testing and improvement, which will surely play a greater role in the cause of China's sand control and prevention [15-16].

In this study, facing the problem of desertification against the limitations of sand willow sand barrier laying machine, the insertion cutter head of the laying machine was designed. The study firstly researched the causes of desertification, and conducted an in-depth study and comparison of the laying methods of salix sand barriers. Finally, the cutter head of the sand willow sand barrier laying machine was optimized and designed based on the flat laying type. The results of the application of the knife head designed in this paper in the self-propelled sand willow sand barrier lateral laying machine are verified through simulation calculation. The study shows that the knife head designed in this paper has good versatility in the application of laying machine and meets the demand of sand willow sand barrier laying.

2. Demand study for sand barriers spreaders for salicornia

Among the many environmental problems in the world today, desertification, as a major global environmental problem, has been plaguing the survival and development of human society, and desertification has become an economic and social problem faced by mankind, restricting sustainable socio-economic development.

2.1. Overview and causes of desertification

According to the United Nations Convention to Combat Desertification, "desertification" is defined as the degradation of land in arid and semi-arid areas caused by "wind-blown sand flow" caused by "climate variability and human activities". "Combating desertification" includes integrated land development for the realization of land based on these ecologically degraded lands. Desertification has caused immeasurable losses to the global social economy, and has brought great challenges to the development of human society and its own survival.

The issue of the causes of desertification has been one of the hot spots of desertification research. There are mainly three views:

1) It is believed that desertification is caused by climatic drought, and human activities have less influence.

2) Climate change is one of the causes of desertification, but the human factor occupies a dominant position in the formation process of desertification, and it is believed that desertification is the result of the irrational utilization of resources by human beings, and that man-made changes in the soil condition and the balance of water and heat of the earth's surface have led to the destruction of soil biopotential, and that climate change has only played a role in exacerbating the situation.

3) The expansion of desertification is the result of the interaction between climate change and human activities. In terms of time, climate variation and the evolution of the natural environment are slow, but once human activities are involved in the process, they will stimulate and accelerate the process of desertification, thus causing greater environmental damage and qualitative metamorphosis in a short period of time.

The current situation of desertification in the world is shown in Table 1, and the desertified land in the world is mainly concentrated in the subtropical to temperate regions on both sides of the equator, in the northern hemisphere distributed in the N100-500, and in the southern hemisphere concentrated in the S100-500, and the east-west length is as long as 1.3 × 104km of arid desertification, which accounts for about 70% of the world's total area of desertification. One quarter of the global landmass and one billion people are affected by desertification, of which the degree of desertification in Africa and Australia is more than 50%, and the world is expanding at a rate of 5×104~7×104km2 per year, and the resulting economic loss is estimated to be 42.3 billion dollars per year. Desertification poses a serious threat to the living environment of all mankind and has become an obstacle to global economic development and social stability, making it imperative to combat it.

Table 1. The present situation of world desertification

Regional name	Land area	Semiarid region		Arid region		Particularly dry area		Total	
		Area	%	Area	%	Area	%	Area	%
North America	2128	235.2	11.05	149.02	7.00	42.55	2.00	426.77	20.05
Middle South America	1867.3	160.25	8.58	142.02	7.61	35.55	1.90	337.82	18.09
Africa	2979.7	545.72	18.31	732.55	24.58	452.75	15.19	1731.02	58.94
Asia	4236.5	635.51	15.00	804.95	19.00	127.13	3.00	1567.59	37.00
Australia	770.38	224.45	29.13	392.98	51.01	0	0	617.43	80.15
Europe	1003.21	75.22	7.50	20.11	2.00	0	0	95.33	9.50

2.2. Research on control of sand barriers based on salix sand barriers

Salix sand barriers are a kind of sand control measure widely used in northwest China. So far, different scholars have carried out a lot of research on salix sand barriers, mainly including laying methods and types, windbreak and sand fixation benefits, soil improvement, vegetation restoration, breakage and corrosion law, etc., and have achieved certain academic results. But there is little research on sand willow sand barriers laying machine, this paper will be comprehensive to the field of sand control and sand control scholars to introduce sand willow sand barriers sand control and sand control technology and the current progress of the research combing summary, which will be followed by the practical application of sand willow sand barriers to provide a certain theoretical basis for laying, but also for the paper's self-propelled sand willow sand barriers transverse laying machine inserted into the design of the cutter head for a certain amount of supplementation.

2.2.1. Influence of sand willow sand barriers on the effect of wind and sand stabilization. Frequent and violent wind and sand movement against important areas such as highways, railroads, power transmission tower foundations and farmland has long been an important environmental problem in arid and semi-arid areas. Sand barriers have been widely used as the primary measure for wind and sand control and afforestation in sandy areas. Scholars have done a lot of research work on the wind and sand control benefits of sand barriers, and the basic research idea is to analyze and explore the weakening effect of sand barriers on the near-surface wind speed and the interference effect on the wind and sand movement based on the perspectives of hydrodynamics, aerodynamics and wind and sand physics. Specifically, it includes the change of wind speed characteristics before and after the sand barriers, the change of relative wind speed characteristics within the barriers, the influence of the structure of wind and sand flow, the erosion characteristics of the surface and the change of roughness. The sand barrier laying form, sand barrier height, sand barrier porosity and other parameters are considered to be important parameters affecting the windproof performance of sand barriers.

For the hidden salix sand barriers laid in the form of square grid, the sand barrier specification is one of the main factors affecting its windproof and sand fixation effect. Square format sand barriers exposed height is certain, the protective effect will be paved with the increase in specifications and reduce, but small specifications of the sand barriers and can not be ignored its economic cost-effectiveness, combined with the protective benefits and economic cost-effectiveness, sand barriers are generally selected specifications for the 2m × 2m.

2.2.2. Impact of salix sand barriers on the effectiveness of vegetation restoration. The recovery of vegetation after the laying of sand barriers is a relatively slow process. Compared with the flowing sand dunes without sand barriers, the sand barriers changed the erosion condition of the ground surface, enhanced the soil resistance to erosion, and provided a relatively stable environment for the vegetation to settle on the flowing sand. At present, 2m×2m specifications of sand willow sand barriers are the most favorable for vegetation recovery, but the middle of the barriers is not conducive to seed retention and plant growth. The planting of Northern Salix in the low vertical Salix square barriers has higher growth indexes than that of wheatgrass square barriers. At the same time, through the reasonable setting of sand barriers and the setting of sand barriers in suitable parts, the expansion of quicksand can be better prevented and controlled, and the recovery process of natural vegetation can be promoted. Vegetation recovery was positively correlated with the number of years of laying, and the species diversity showed an overall upward trend with the increase of the number of years of laying sand barriers. At the same time, the number and density of plant species in the dune seed bank increased with the increase in the number of years of laying the barriers, and the smaller the specification of the sand barriers within a certain range, the greater the number and density of species in the soil seed bank under the same number of years of laying the sand barriers.

3. Design of insertion cutterheads for self-propelled salix sand barrier transverse spreaders

The previous paper has discussed the current situation of the causes of desertification and the prevention and control of sand willow sand barriers, but how to extend the service life cycle of sand barriers is urgently needed. For this reason, this paper designs a self-propelled sand willow sand barriers lateral laying machine inserting cutter head to improve the survival rate and efficiency of sand willow sand barriers laying.

3.1. Comparison of laying methods of sand barriers for salix sand barriers

The laying method of salix sand barriers is an important factor affecting the effect of sand prevention, therefore, this paper analyzes the laying method of salix sand barriers combined with the actual situation of the test area. The test area is located in the northwest of Ordos Plateau Hangjin Banner in the Kubuzi Desert hinterland of the Seven Star Lake scenic area, the geographical coordinates are located in the east longitude 105 ° ~ 109 ° north latitude 39 ° ~ 40 °. Windy and sandy, flowing dunes account for about 60%. The dunes are 10~60m high, and the morphology is dominated by dune chains and lattice dunes. The average annual wind speed is 3~4m/s, the number of windy days is 27~33 days, and the number of sandstorm days is 27~57 days.

Five lengths of willow spikes of 110, 120, 130, 140 and 150 cm were planted in the low vertical and flat sand willow sand barriers respectively, and eight replications were set up for each spike length, while sand willow was planted on the flowing dune as a control test.

Comparison of survival rate is shown in Table 2. In this paper, the spikes of salix that did not die completely but the growth trend was not optimistic were defined as salix that tended to die and did not enter into the number of survival. By comparison, it was found that the flat-laying sand willow sand barriers > flowing sand dunes > low vertical sand willow sand barriers. The survival rate of planted willows in the paved sand willow sand barriers was the greatest at 75%. The survival rate of willow planting in the mobile dune flush was intermediate with a value of 62.5%, and the survival rate of the low vertical sand willow sand barrier was the smallest with 52.5%. Analysis of variance (ANOVA) of the survival rates of willow planting in the two sand barriers and the flowing dune wash showed that the difference in the survival rates of willow planting under the three silvicultural site conditions was not significant ($p = 0.46$). However, the survival rate of the flat-laying type is actually higher, so the design of the insertion cutter head of the self-propelled sand willow sand barriers in this paper is also based on the flat-laying method.

Table 2. Survival comparison

Laying mode	N	Live quantity	The number of deaths	The number of possible deaths	Survival rate (%)
Flat type	80	60	7	13	75.0
Low vertical	80	42	15	23	52.5
Flow dune	80	50	10	20	62.5

3.2. Design of insertion cutterheads for transverse spreaders

The existing laying machine takes a heavy truck as a carrier, sets up a storage bin and a laying device at the rear, and installs a pressure wheel to insert the sand willow spike into the sand, and this equipment has high laying efficiency, but the production cost and the use cost are high, and there are also some limitations. Its limitations are specifically manifested in the existing laying machine can only lay longitudinal sand barriers, in the need to change the direction, not only time-consuming and laborious, but also in the device laying horizontal sand barriers, may destroy the original has been laid sand barriers, resulting in the effect of the sand barriers are not stable, windproof sand effect is not strong, and can not achieve the effect of the restoration of the desert ecosystem. In addition, the existing paving machine has horizontal and vertical paving program at the same time, although it can improve efficiency, but this program ignores the sand barriers must have the “weaving”, horizontal and vertical intersection is the program's largest stress point, if the same time, the intersection of the sand barriers will reduce the paving, or even because of overlap caused by the lack of weaving! Intersections. Because the size of the laying of a wide variety of styles, the shape of the sand also varies from the topography of the sand, such a fixed cross distance will greatly reduce the applicability of the device.

Aiming at the defects and problems of the above existing devices, and combining with the trend of automation and lightweight of modern sand management machinery, this paper improves and designs a paver insertion cutter head, and the structure of the insertion cutter head of the self-propelled transverse paver designed in this paper is as shown in Fig. 1. The improved cutter head structure can better solve the sand barrier longitudinal laying problem, while using the direction of the different shovel plate to solve the sand barrier laying a variety of conditions, reduce the working time and labor force, so that the sand willow sand barrier laying is more reasonable, but also to enhance the use of the cutter head of the service life of the cutter head, the efficiency can be reached to the maximum.

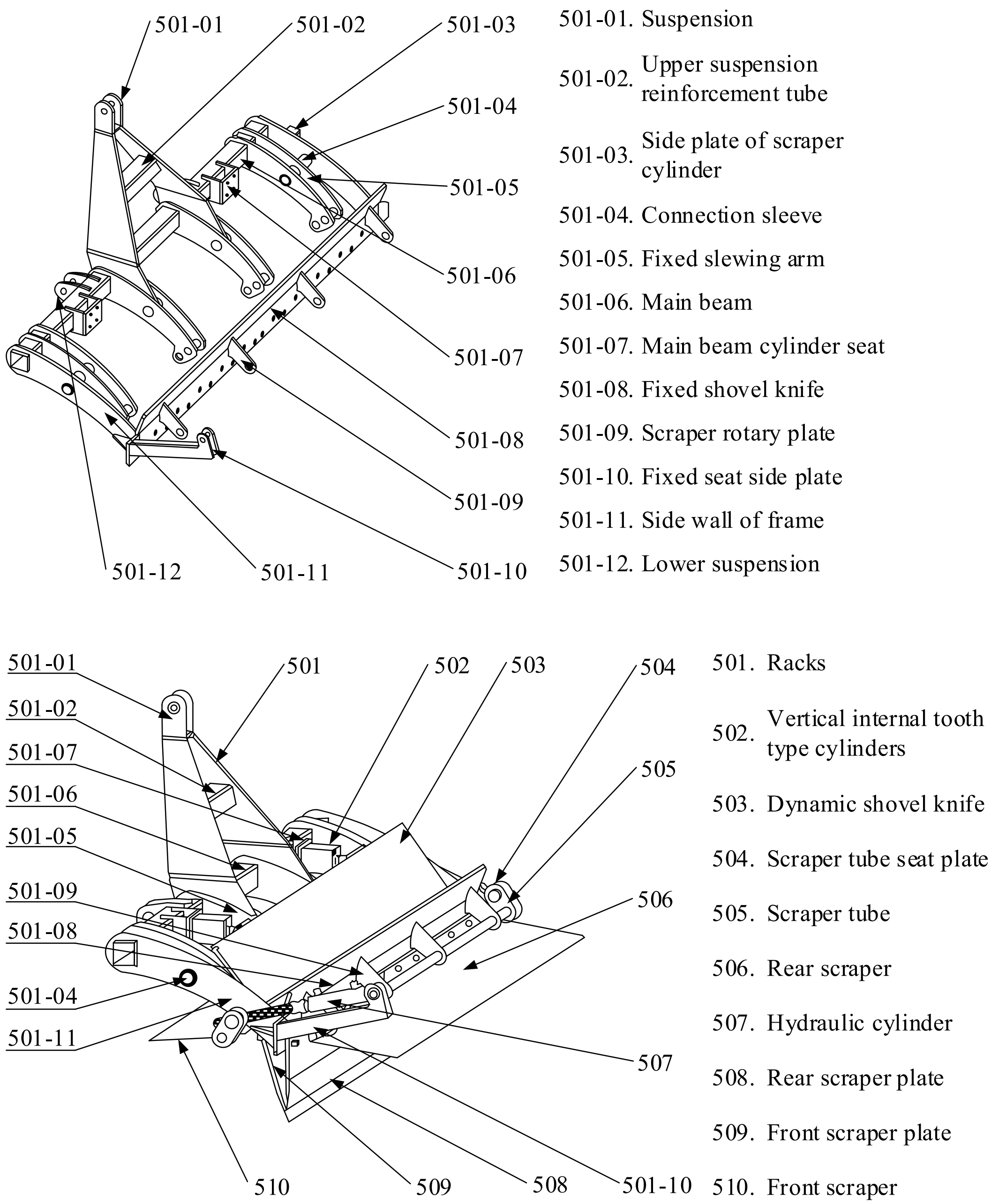

Fig. 1. The self-walking horizontal laying machine is inserted into the knife head

4. Simulation experiments on sand barriers laying machines for salicornia

4.1. Verification of key components of salix sand barriers laying machines

In the design process of the paver, its roller and cutter head are the main force components, so they need to be calibrated and analyzed. The motion state of the cam is an important factor in calculating the recoil force, which needs to take into account the incidence angle, speed and direction of the cutterhead relative to the desert. Generally speaking, if the contact area between the cutter head and the desert is small, its recoil force will also be smaller. And if the speed is too fast or the direction is not appropriate, it will also lead to a larger recoil force. Therefore, the size of the recoil force needs to be determined according to the motion state of the cutterhead in the actual calculation.

Combining the above factors, we can get the formula for the recoil force of the cutter head on the desert:

$$F_r = -m * v_1 \tag{1}$$

where v_1 is the rebound speed of the cutter head. According to the theorem of energy conservation, the following calculation formula can be obtained:

$$0.5mv_2 - 0.5mv_1 = F\delta \tag{2}$$

After finishing, you can get the rebound velocity of the cutterhead v_1:

$$v_1 = v_2 - \left(\frac{2F}{m}\right)\delta \tag{3}$$

where v_2 represents the speed of the cam when it touches the ground. According to the kinetic energy theorem, the following formula can be obtained:

$$v_2 - v_1 = 2gh \tag{4}$$

Where, v_2 is the initial velocity of the cutterhead when it falls, g is the acceleration of gravity, and h is the cam hammer falling height.

Summarize the above 4 formulas, you can get the cutter head in the desert by the recoil force.

Cutterhead in operation by the normal pressure, normal pressure is the force acting on the surface of the object perpendicular to the surface. In the case of a cutterhead grooving on desert ground, the normal pressure is the force perpendicular to the soil surface exerted by the cutterhead on the sand. According to Newton's third law, when the cutterhead exerts a force F_1 on the sand, the sand also exerts an equal but opposite force F_2 on the grooving plow, i.e:

$$F_2 = -F_1 \tag{5}$$

Since the cutterhead moves horizontally while grooving the desert floor, consider the vertically downward force exerted by gravity on the grooving plow G. Therefore, the contact force between the cutterhead and the sand in the horizontal direction is:

$$F_n = G * \cos\theta \tag{6}$$

where F_n is the normal pressure, G is the force of gravity, and θ is the angle between the inclined plane and the horizontal.

4.2. Simulation experiment results

In the theoretical study and analysis of the driving force and resistance of the whole machine, and the experimental study on the mechanical properties of sandy soil. It aims to provide reliable experimental data for calculating the driving force and resistance of the whole machine, so as to theoretically predict the generalized performance of this laying machine in the desert. Finally, the calculation is carried out by the following formula:

The paver vehicle studied in this paper has many wheels, and the rear wheels always roll in the ruts left by the passage of the wheels in front of them; therefore, the sand conditions encountered by the wheels on different axles are different, and there are also significant differences in the amount of subsidence, the resistance to compaction, and the traction force acted by the ground on them. Therefore, the study in this paper takes into account the effect of repeated passes of the wheels on the sand and the resulting changes in the compaction resistance of the wheels.

To calculate the compaction resistance of a multi-axle vehicle on the m st pass, simply determine the values of soil parameters k and n after each pass of the wheel, and calculate the compaction resistance F_{Rd_m} on the m th pass of the wheel using Eq:

$$F_{Rd_m} = \frac{b\left(p_t + p_c\right)^{\frac{n_m+1}{n_m}}}{\left(n_m+1\right)k_m \frac{1}{n_m}} \tag{7}$$

Then the compaction resistance acting on each set of wheels on the axle is:

$$R_m = 2F_{Rdn} \tag{8}$$

Then the push resistance acting on each set of wheels on the axle is:

$$F_m = 2F_{Rbm} \tag{9}$$

When the transverse cutter enters and exits the soil, the cutter will push on the sand in front of it because the whole machine is advancing at a uniform speed.

Sand pushing resistance can be solved by Rankin's passive earth pressure theory, instead of using numerical methods with a lot of calculations. For sandy soil $(c=0)$, Rankin's passive earth pressure calculation formula is:

$$P_{h1} = \gamma z N(\varphi) \tag{10}$$

Where $N(\varphi) = tg^2\left(45° - \frac{\varphi}{2}\right)$ is the coefficient of passive earth pressure, γ is the density of sand and soil kN/m^3, φ is the angle of internal friction, z is the depth of entry, m.

Passive earth pressure P_{h1} along the depth of z is a straight line distribution, then the maximum horizontal reaction force of the sand on the transverse cutter that is pushing sand resistance.

If a total of 3 transverse knife, so the total resistance to push sand for:

$$P_h = 3P_{h1} \tag{11}$$

The resistance of the longitudinal rollers to compacting the sandy soil is:

$$P_{z1} = b\int_0^{0_0} kz^n dz = bk\frac{z_0^{n+1}}{n+1} \tag{12}$$

Where b is the sum of the widths of the rollers and the grass curtain, z_0 is the depth of the rollers into the soil, k is the modulus of deformation of the sand, n is the index of deformation of the sand, dimensionless.

If the longitudinal grass laying mechanism has a total of 4 rollers, the total roller grass resistance is:

$$P_z = 4P_{z1} \tag{13}$$

The simulation results of the whole machine resistance are shown in Table 3, and the combined values of compaction resistance, push resistance, roller resistance and cutterhead push resistance are 19265.7N, 2033.5N, 2157.3N and 2875.2N, respectively. The resistance level of the whole machine is 26313.9N.

Table 3. Simulation results of machine resistance

Categories	Compaction resistance	Thrust resistance	Roller resistance	Cutting resistance
First set of wheels	10555.1	1573.2	—	—
Second set of wheels	4675.7	460.3	—	—
Third set of wheels	2468.2	—	—	—
Fourth set of wheels	1566.7	—	—	—
Longitudinal head	—	—	2157.3	—
Cross head	—	—	—	2875.2
Tot	19265.7	2033.5	2157.3	2875.2
Machine resistance	28488			

Under the action of the driving torque, a driving force will be generated on the part of the tire in contact with the sand to push the vehicle forward. Calculate the driving force generated by the interaction between the driving wheel and the sand to push the vehicle forward, the calculation takes into account the influence of the tire tread height and the tire slip rate. The driving force of the tractor under different rowing rate, the driving force of the tractor under different slip rate is shown in Table 4, the calculation shows that the driving force increases with the increase of slip rate, and also tends to be close to 0. When the slip rate is bit 1%, the total driving force is 1618.17N, and when the slip rate reaches 100%, the total driving force reaches the maximum value of 36534.06N.

Table 4. The driving force of the tractor in different sliding speed

Slip rate	Driving force	Rear wheel drive	Total driving force
1	833.15	785.02	1618.17
5	3174.49	2793.02	5967.51
10	6330.32	6001.11	12331.43
20	10610.11	10153.32	20763.43
30	13391.02	12847.21	26238.23
40	15802.00	14203.15	30005.15
50	16062.01	15554.05	31616.06
60	16862.34	16348.32	33210.66
70	17441.01	16930.07	34371.08
80	17987.83	17480.00	35467.83
90	18275.35	17762.68	36038.03
100	18518.03	18016.03	36534.06

The relationship curve obtained from the whole machine resistance, driving force and slip rate is shown in Fig. 2, when the whole machine resistance is 28488N, it can be found out that the actual slip rate of the tractor drive wheel is 35%.

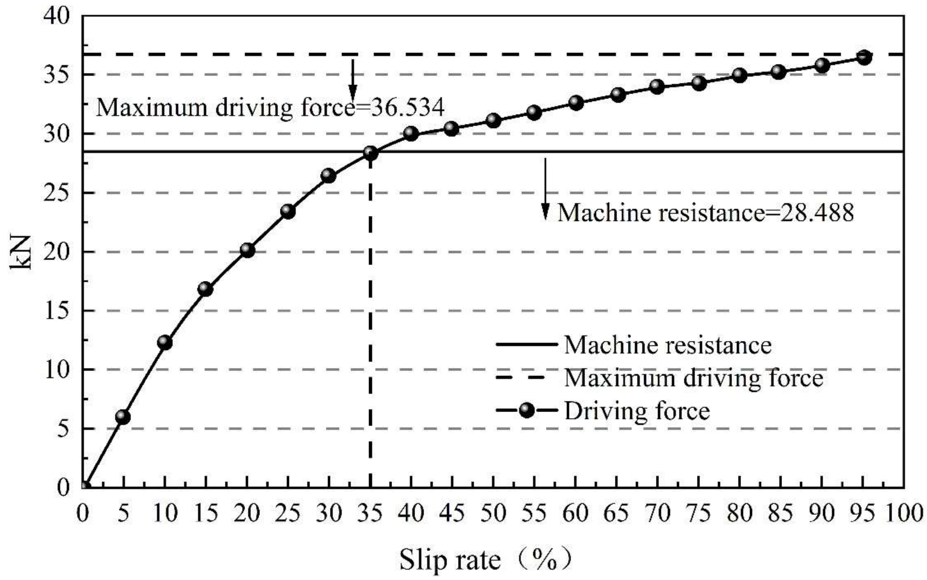

Fig. 2. Relationship curve

The formula for calculating the traction DP and traction coefficient when the paving machine is traveling is based on the generality assessment formula:

$$DP = H - \sum P_f \tag{14}$$

$$\prod = \frac{DP}{W} = \frac{H - \sum P_f}{W} \tag{15}$$

Where, H is the driving force and $\sum P_f$ is the traveling resistance.

The traction efficiency η_d is calculated as:

$$\delta = \frac{rw - v}{rw} \tag{16}$$

$$w = \frac{v}{(1-\delta)r} \tag{17}$$

$$\eta_d = \frac{P_d}{P} = \frac{DP \times v}{Mw} = \frac{DP \times (1-\delta)r}{M} \tag{18}$$

Where δ is the slip rate of the driving wheel, r is the wheel radius, w is the wheel angular velocity, v the whole machine traveling speed.

From the calculation results can be seen, from DP>0, indicating that the tractor to obtain the driving force in addition to overcoming all the resistance in the driving process, there is a part of the "net thrust", can be used to overcome the resistance generated by accelerating, climbing. From the calculation of $\prod$ for 0.04 and η_d for 0.14, it can be seen that the salix sand barricade laying machine has a better performance of the desert through, to meet the needs of this topic.

5. Conclusion

In this paper, a self-propelled salix sand barriers lateral spreader insertion cutter head was designed to improve the efficiency of salix sand barriers spreading, aiming to provide a powerful mechanical tool for solving land desertification. The results of the study are as follows:

1) In the study of desertification, it is found that the degree of desertification in both Africa and Australia is more than 50%, 1/4 of the global landmass and 1 billion people are affected by

desertification, and global desertification is serious, which has serious negative impacts on the living environment of human beings, and it is also the main background of the research in this paper.
2) In the research on the laying method of salix sand barriers, it is found that the survival rate of the flat salix sand barriers is the highest 75%, followed by the flowing dune (62.5%) and the low vertical salix sand barriers (52.5%). Therefore, the design of the cutterhead in this paper is mainly oriented to the design of the laying method, which provides the support of practical data for the cutterhead design in this paper.
3) This paper combines theoretical research and practical needs, the self-propelled sand willow sand barriers inserted into the cutterhead design, through numerical simulation to find out the laying machine driving force, resistance, traction parameters, and then use the simulation calculations to find out that this paper under the design of the laying machine through the performance of the good, to meet the needs of the sand willow sand barriers laid horizontally.

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