Design and experiment on 2KF-15 type disc cutter and shallow fertilization machine in rubber plantation

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Abstract. At present, the trenching and fertilization machine has a serious weed plug problem when trenching and fertilization operation in rubber plantation. So a disc cutter and shallow fertilization machine in rubber plantation named 2KF-15 was designed, the design scheme used the front disc cutter cutting the grass, while using the rear of the disc furrow to trenching, the prototype of a disc anti-plugging trenching and shallow fertilization machine was completed. Afterwards, a series of trenching and fertilization field experiments were carried out, and the results showed that the ditching depth of this machine could achieve from 131 to 176 mm, and the average depth could reach 156 mm, the ditching depth stability coefficient could achieve 90.3%; The fertilizer amount of this machine could achieve from 113.2 to 156.4 kg/hm², the average fertilizer amount reach 134.2 kg/hm², the fertilizer amount stability coefficient could achieve 89.6%, the fertilizer broken rate was 0%, the fertilizer coverage rate of 98.4%; The situation of fertilizer accumulation occurred less by using this machine, and the fertilization performance was relatively stable. This new designed machine for trenching, fertilization and covering the soil were carried out at the same time. So the number of operations could be effectively reduced. This new designed machine does not only meet the agronomic requirements of rubber plantation fertilization, but also provides a reference for the trenching and fertilization operation in other.

1. Introduction
Natural rubber is an important strategic material in the national economy, which is also China's important economic crops, also one of pillar industries of tropical regions in China's. In the protection of national economy and people's livelihood and national strategic security, it plays an important role. In the natural rubber production cycle, the hevea brasiliensis needs to be multiple times fertilization each year to meet the growth needs of rubber trees. According to the requirement of natural rubber planting agronomy, each year it needs to be turning over of green manure once, and the dressing is 2-3 times, each time 0.3-0.5 kg/plant. Traditional mode of operation is between 4 rubber to a digning fertilizer hole, the fertilizer hole den specifications for 100-200cm×60cm×40cm (length×width×deep), turning over of green manure in the fertilizer hole in 7-9 months each year, within the again fertilization according to the situation of rubber trees grow in 5-20cm away from the surface soil layer top application in the cave [1-5]. At present, China's rubber garden management is still in the low mechanization degree, furrowing and fertilization is given priority to with artificial operation, still in the top application relying on artificial in the cave in first fertilization trenching, after fertilization and ridging, labor intensive, low efficiency and high cost. In recent years with rubber prices at the low end and rising labor costs, and lead
to low natural rubber planting benefit. In order to improve the work efficiency and reduce cost, at present a lot of rubber plantation at top application requires only a 10-15 cm shallow trench.

The author has developed a kind of trenching and fertilization Combined operating machinery in rubber plantation, device is mainly composed of frame, the fertilizer box, Fertilizer apparatus and furrow plough, etc., It can be a one-time trenching and fertilization joint operation[6-7], but due to the rubber producing belong to tropical monsoon climate, weeds grow quickly, soil compaction, and more leaves, and so on, weeds and vines on the trench plough when working, there are serious jam phenomenon, often need to stop for cleaning, which reduces the working efficiency and affects the application of machines.

For solving the blocking problems of machines, designed the disc cutter and shallow fertilization machine in rubber plantation, the design scheme is used the front disc cutter cutting the grass, while using the rear The disc to furrow trenching, sharply reduced the blocking phenomenon, improve through performance, it is mainly used for smooth rubber plantation trenching top application of fertilizer.

2. Overall structure and working principle

2.1. Prototype structure
The joint operation machine of the disc cutter and shallow fertilization in rubber plantation is suspended, with a schematic diagram of the whole machine, as shown in figure 1, which is mainly composed of disc cutter, disk coulter, fertilizer apparatus and chassis. The machine and tractor adopted for three-point-type suspension, and the auxiliary power is 36.8 kW and above wheeled tractor. Disc cutter by bolt connection in the middle of the frame front end, its high and low is can adjustable, the disc coulter by bolt connection on the rack, is located in the back of the disc cutter, two disc opener distance is adjustable.

![Figure 1. Diagram of 2KF-15 type disc cutter and shallow fertilization machine in rubber plantation](image)

1. Disc cutter 2. Chassis 3. Hydraulic motor 4. Reducer 5. The reel of fertilizer 6. The board of scraping fertilizer 7. The disc of fertilizer 8. Fertilizer placements drum 9. Fertilizer placement tube 10. Disk coulter

2.2. Working principle
The joint operation machine of the disc cutter and shallow fertilization in rubber plantation use double disk design, in operations, tractor drive the machine, disc cutter rolling forward, weeds and vines in the disc cutter under the action of roll cutting cut, then the disc opener for trenching and will cut off the weeds and vines. To overturn to the side, and thus effectively prevent weeds and rattan and other entanglement and congestion, At the same time the hydraulic motor drives the disc of fertilizer to rotate, the fertilizer can fall into the fertilizer placement drum under the action of the board of scraping fertilizer. The machine can complete the opening ditch and fertilization at a time.

2.3. Main technical parameters.
According to the characteristics of agronomy and fertilization requirements of the garden, the main technical parameters of the design and determination of shallow fertilizer machine are shown in table 1.
### Table 1: Disc cutter and shallow fertilization machine in rubber plantation main technical parameters

| Item                                               | Technical parameters                          |
|---------------------------------------------------|-----------------------------------------------|
| Tractor power /kW                                 | above 36.8 kW wheeled tractor                 |
| Tractor hitch type                                | three-point-type suspension                   |
| Biggest depth of trenching and fertilization/cm   | 15                                            |
| Fertilizer types                                  | fertilizer and compound fertilizer and rubber fertilizer |
| Loading amount of fertilizer /kg                  | ≥200                                          |
| Fertilizing amount per unit area /kg/hm²          | 120-150                                       |
| Work efficiency/ m.h⁻¹                           | ≥1000                                         |
| Overall dimensions (length× width× eight) /mm     | 1200×1600×1500                                |
| Total weight/kg                                   | ≤600                                          |

3. Disc cutter selection and main parameters

3.1. Disc cutter selection.

The role of the disc cutter is cutting the weeds and vines in front of the disc coulter, don't turn around the soil, its resistance to random speed and width of the disc cutter and increases with increasing soil depth, and the guarantee to cut off the opener in front of weeds and vines conditions as far as possible to reduce working resistance. Disc cutter are flat disc, gaps in the disk, and corrugated plate form, and the plane trenching the disc cutter has good performance and narrow and small resistance[8], consider the processing and manufacturing cost, the trenching machinery disc cutter adopts double planar disc.

3.2. The size of the Disc cutter.

Under ideal conditions, neglected the weight of the weeds and vines, disc cutter in the process of the work force as shown in figure 2, the disc cutter diameter $D$, soil depth of $H$, the surface of the weeds and vines diameter $d$; The force and friction of the ground acting on the weeds and vines, $N$ and $f_2$ respectively. The cutting force and friction force of the cutting knife on the weeds and vines, $F$ and $f_1$ respectively. Because the change of diameter of weeds and vines is negligible for $\alpha$ influence, it is considered that $d$ is constant

![Figure 2 forces on stalk on the ground](image2)

![Figure 3 the disc openers work schematic diagram](image3)

The equilibrium conditions of the vertical force can be:

$$N = F \cos \alpha + f_1 \sin \alpha$$  \(1\)

The weeds and vines are cut off by the disc cutter without being pushed along the ground to be satisfied (2):

$$f_2 + f_1 \cos \alpha \geq F \sin \alpha$$  \(2\)

Substituting $f_1 = F \tan \eta_1$ and $f_2 = N \tan \eta_2$ equation (1) into equation (2) can be:
\[
\alpha \leq \eta_1 + \eta_2
\]  

(3)

In the formula, \( \eta_1 \) — the friction Angle of weeds and vines and disc cutter; \( \eta_2 \) — the friction Angle between the weeds and vines and the ground.

The geometric relationship in figure 2 shows that:

\[
\cos \alpha = 1 - \frac{2(H + D)}{D + d}
\]

(4)

Substitution formula (3) is available:

\[
\arccos(1 - \frac{2(H + 2d)}{D + d}) \leq \eta_1 + \eta_2
\]

(5)

When the diameter \( D \) of the disc cutter is certain, the larger the depth of soil \( H \), the bigger the \( \alpha \) value, the greater the working resistance, the greater the energy consumption. To meet type (3)-(5), the required \( H \) value as small as possible, but \( H \) value is too small can't guarantee completely to cut off weeds and vines, is generally thought that the depth of soil \( H \) Can meet cut off the subsurface root of weeds and vines [9-12].

When the soil depth \( H \) value is certain, the larger the diameter \( D \) of the disc cutter, the smaller the \( \alpha \) value, the formula (3) - (5) is easily satisfied, therefore, increasing the diameter of the disc cutter It is good for cutting off the weeds and vines that are covered in rubber plantation [13].

The average diameter of the weeds and vines in the rubber plantation of Hainan and Guangdong provinces of China is 6.5 mm (the maximum 10.4 mm). Most of weeds and vines grow on the surface of the soil, and the average depth of the root stubble is 96mm, so its takes 150mm. The friction Angle of weeds and vines and the disc cutter is about 23° ~ 33°[14], its takes the maximize 33° when calculating. Due to the lower overburden soil humidity of the rubber plantation, the average moisture content is about 10% ~ 15%, the friction Angle of weeds and vines and the ground an average is 30 ° [15].

The formula (3) - (5) is available, \( D \geq 384 \text{mm} \).

In conclusion, in order to prevent slippage the weeds and vines and can’t to cut off it, the diameter of disc cutter should be not less than 384 mm, but due to the machine structure and frame height restrictions, the disc diameter also cannot too big, combined with the common disc cutter size on the market, the disc cutter diameter of 430 mm, the thickness of the disc cutter of 2 mm.

4. The ditcher selection and the main parameters

4.1. The ditcher selection

Disc plough is concave disk working parts, under the tractor traction, depend on the interaction force of between weight and soil generated to drive disc plough turns, the soil was extrusion and shear and Tear, and turn out the weeds, finish the trenching operation, at the same time on the way forward, disc plough lateral shear the soil, is helpful to remove weeds, so the disc plough have strong ability to broken soil and cut grass and residues, not easy to jam, which can effectively prevent blockage, Especially suitable for complex soil work such as gravel blocks in hard soil and weedy soil. It has the characteristics simple and easy to pass without clogging. The passive disc plough has the characteristics of simple structure and low energy consumption, so it chooses the passive disc coulter when the weeds are overgrown, the stones are large and the ground is uneven.

4.2. The main parameters of the disc ditcher

The main parameters affecting the operation quality of the disc ditcher are the disc diameter, the curvature radius of the disc, the deflection Angle of the disc ditcher and the inclination of the disc ditcher.

The smaller the dip Angle of the disc ditcher, the easier it is to get into the soil; the larger dip Angle, the more difficult it is to get into the soil, but tillage depth stability is better, usually dip Angle
is 15° ~ 25°. according to weed infestation and hard soil in the rubber plantation weeds, the difficult it is to get into the soil, so determine the disc ditcher dip Angle is 15°.

The size of the Angle that disc ditcher and heading direction had important effect on cut soil and crushed soil, the small the poor of crushed soil and turn soil performance of the disc ditcher, the larger the stronger of crushed soil and turn soil performance of the disc ditcher, the larger the buried depth, but the resistance will increase also, usually the Angle to 30° ~ 45°[16], according to the situation of rubber plantation soil and fertilizer agronomic requirements, so determine the Angle is 30°.

As shown in FIG. 3, the radius of the disc coulter can be determined according formula (6) [17-18].

$$R \cos \beta = H_g + J + r$$  (6)

According to the agronomic requirements, determine the plow deep is 150 mm, according to the requirement of install shaft strength and stiffness to install shaft radius is 45 mm, the ground clearance of install shaft radius to 50 mm, by type (6), R is 253.6 mm, in combination with the size of the standard disc plough [19], the radius of the disc coulter Diameter is 275 mm. The thickness of the disc coulter is 4mm.

5. Test and analysis

5.1. Test conditions and materials.

After completed of the prototype of a disc anti-plugging trenching and shallow fertilization machine and manufacture, the 2017-07-20 days the state-run friendly farm in Xuwen county in Guangdong province open cut rubber plantations on the field experiment, the rubber plant spacing of 6.0 m and planting distance of 3.0 m in the experimental field, the testing soil types is the laterite, soil moisture content is 20.6%, measured in experiment of soil sampling depth 0 ~ 40 cm, solid degrees for an average of 1185 kpa, There are many weeds on the surface of the soil. The measuring area of the test area is 100m, and the length of the preset area is 20m. The test time is in summer, the surface soil moisture content is low and the firmness is bigger. The test area is the interline area of natural rubber plantation, covering 25 ~ 30cm of vegetation layer in the surface layer, and the experimental tractor is Dongfang red - 604 wheeled tractor, and the working time is slow 2. The prototype test is shown in FIG. 4. Test mainly use tape, stopwatch, depth meter, electronic balance, ruler to measure the trenching machinery operation length, time and trenching depth, uniformity of the fertilizer and fertilizer, etc., the related data measurement reference to national standard (20-21).

5.2. Test method.

**Blocking test.** Measurement five trips of forward and return respectively in the measuring area, and the number of shutdown and no shutdown cleaning was recorded respectively.

**Trenching depth and stability testing.** Measure two trips of forward and return respective in the measurement zone, Measure 10 points at the same distance in each trips, each point spacing distance not less than 2 m, with deep tillage feet measurement, measurement method: clean the soil of the surface and bottom, measure the vertical distance of the bottom to the surface, respectively calculate the average trenching depth and coefficient of variation and stability coefficient.
Fertilizer quality test. Fertilization quality mainly includes fertilization amount, fertilization uniformity, fault rate and fertilization coverage. Fertilizer amount and fertilizer uniformity test on the cement floor or other flat smooth place. The machine is running at a normal operation speed of 20 m, take 3 points, the length of each point not less than 2 m, divided into a small sections every 20 cm, measure the quality of fertilizer in the small sections every, the fertilizer amount and fertilizer uniformity calculation is the same as the trenching depth and stability calculation. Measure the broken rate at the same time when test the fertilizer and fertilizer uniformity, the length above 10 cm no fertilizer section is broken, Measure the broken length within 3m, and calculate the percentage of the broken length. Measure three times and take the average. Fertilizer coverage test in the field experiment, observation the fertilizer coverage condition after operations, according to the five point determination, every point take 10 m, experiment after test fertilizer cover length is the percentage of the total length, and push open the soil to observation fertilizer condition.

5.3. Test results.

Complete machine test results. The test results of the main operational performance indicators are as table 2. It can be seen from table 2 that the speed of the machine and the amount of fertilizer can meet the design requirements, and the machine can be completed the trenching and fertilizing and overlaying operation once. The work efficiency can be reached 1218 m/h. During the field tests, the passing ability of machine is good, does not appear to stop cleaning the congestion, the trenching and fertilization stable performance and fertilizing evenly, guarantee the hevea brasiliensis root system to fully absorb the fertilizer.

| Work efficiency (m·h⁻¹) | Trenching depth (mm) | Stability of trenching depth (%) | Minimum turning radius of the unit (mm) | Fertilizer coverage (%) | Fertilization uniformity (%) | Broken rate (%) | Fertilizing amount per unit area (kg/hm²) | Consumption per unit area (kg/hm²) |
|--------------------------|----------------------|---------------------------------|----------------------------------------|-------------------------|-----------------------------|----------------|------------------------------------------|----------------------------------|
| 1218                     | 156                  | 90.3                            | 6100                                   | 98.4                    | 89.6                        | 0              | 134.2                                    | 8.9                              |

Blocking test results. The field test of 10 trips, the blinding phenomenon is less, not present need downtime blinding, no stop cleaning blinding 5 times, reduced downtime cleaning time, and improved the machines working efficiency.

Test results of trenching depth and stability of trenching depth. In the four times test of trench, the ditching depth was 131 to 176 mm, the average depth could reach 156 mm, the ditching depth stability coefficient was 92.2%, which met the design and agronomic requirements.

Results of fertilization quality test. In fertilizing quality test, the fertilization amount was 113.2-156.4 kg/hm², the average was 134.2 kg/hm² in three times test, fertilizing uniformity is 89.6%, broken rate was 0%. In the field test, the fertilizer base are covered by soil, fertilizer coverage rate was 98.4%, push open the soil, fertilization evenly, compost heap and broken phenomenon is very few, meet the requirements of rubber planting agronomic, is advantageous to the hevea brasiliensis root absorption of the fertilizer.

6. Conclusions

Designed the machine of 2kf-15 type disc cutter and shallow fertilization, the whole machine structure is reasonable, the disc cutter to cut the grass and disk couter furrow f trenching, sharply reduced the blocking phenomenon, improves the working efficiency, achieve furrowing and fertilizing joint operation in the smooth rubber plantation, meet the agronomic requirements of partial dressing in rubber plantation. Change the traditional operation way of fertilization, and the machine can be completed the trenching and fertilizing and overlaying operation once, reduce operation times, and fertilization evenly, is advantageous to the hevea brasiliensis root absorption of the fertilizer.

In the field test, the blinding phenomenon is less, not present need downtime blinding, no stop cleaning blinding 5 times, reduced downtime cleaning time, and improved the machines working efficiency.
The trench test in the field, the ditching depth was 131 to 176 mm, the average depth could reach 156 mm, and the ditching depth stability coefficient was 92.2%, which met the design and agronomic requirements.

Fertilization quality mainly includes fertilization amount, fertilization uniformity, fault rate and fertilization coverage. Fertilizer amount and fertilizer uniformity test on the cement floor or other flat smooth place. The machine is running at a normal operation speed of 20m, take 3 points, the length of each point not less than 2 m, divided into a small sections every 20cm, measure the quality of fertilizer in the small sections every, the fertilizer amount and fertilization uniformity calculation is the same as the trenching depth and stability calculation. Measure the broken rate at same time when test the fertilizer and fertilization uniformity, the length above 10 cm no fertilizer section is broken. Measure the broken length within 3m, and calculate the percentage of the broken length. Measure three times and take the average. Fertilizer coverage test in the field experiment, observation the fertilizer coverage condition after operations, according to the five point determination, every point take 10m, experiment after test fertilizer cover length is the percentage of the total length, and push open the soil to observation fertilizer condition.

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References
[1] Liu J, Liu J, Luo W. Distribution of Nutrient Roots of Rubber Trees Close to Manure Hole in Rubber Plantation. Chinese Journal of Tropical Crops, 2006, 27(3):5-10.
[2] HUA Y, LUO W, LIN Z. Coupling Effects of Water and Fertilizer on Vertical Distribution Characteristics of Fine Roots of Hevea Brasiliensis. Chinese Journal of Tropical Crops, 2012,33(8):1342-47.
[3] HE J, LIN Z, LUO W. Research progress and prospect on Roots and growth influence factors of Heave Brasiliensis. Guangdong Agricultural Sciences, 2008, (5):19-21, 30.
[4] NY/T 221-2016, Technical regulations for cultivation of rubber tree. Beijing: China Architecture Press, 2016.
[5] Zhou Z. Notes on fertilization of rubber tree. Nong Cun Bai Shi Tong, 2014, (12):40.
[6] Tropical Agricultural Machinery Research Institute, Chinese Academy of Tropical Agricultural Sciences. A kind machine of double row open ditch fertilizing in rubber plantation. China, ZL201620416788.9[P].
[7] Zhang Y, Wei L, Deng Y. Test and Effect Evaluation of 3XSP-1 Rubber Fertilizer Modern Agricultural Equipments. Modern Agricultural Equipment, 2017, (1):37-41.
[8] Cheng.Y. Design and Experiment of Testing Device for Different Passive Discs. Northwest Agriculture and Forestry University, 2015.
[9] Bai X. Study on Key Parts of No-till Planter and Parameterization Design Method. Shenyang Agricultural University, 2012.
[10] Zhang S, Ma X, Zuo C. Forces acting on disk colter and computer simulation. Transactions of the CSAE, 1995, 11(4):52-56.
[11] Zhang S, Zuo C, Ma C. Study on the force model of the disc furrow. Transactions of the Chinese Society of Agricultural Machinery, 1998, (S1):71-75.
[12] Zhu R, Li C, Cheng Y. Working performance of passive disc coltuer. Transactions of the CSAE, 2014, 30(18):47-54.
[13] Wan Q, Bu K, Li Y. Structure Analysis of the Large No-till Seeder Openers. Journal of Agricultural Mechanization Research, 2012, (03):45-48.
[14] Wang Q, He J, Yao Z. Design and Experiment on Powered Disc No-tillage Planter for Ridge-tillage. Transactions of the Chinese Society of Agricultural Machinery, 2008,(06): 68-72.
[15] Bao W. Study on Key Parts and Holistic Device of the No-till Planter of the Ridge Cropping System in northeast Area of China. Shenyang Agricultural University, 2009.
[16] Beijing university of agricultural engineering, Agricultural mechanics (volume one). China Agriculture Press, Beijing, 1999.
[17] Cao W, Ding J, Li Z. Driver Disk Plow Research and Design. Journal of Agricultural Mechanization Research, 2009, 31(6): 50-53, 61.
[18] Zhang X, Li H, Yi K. Experiment and Design on Disk Cutter with Power Type of Wheat No-till Planter. Journal of Agricultural Mechanization Research, 2009, 31(7): 53-55, 58.
[19] JB/T 10287-2015, Disc plough. Beijing: Mechanical Industry Press, 2016.
[20] NY/T740-2003, Field operation quality of ditchers. Beijing: China Standards Press, 2004.
[21] JB/T11908-2014, Agricultural disc ditcher. Beijing: Mechanical Industry Press, 2014.