Design of Strip Tiller for Conservation Tillage

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Abstract: In order to meet the agronomic requirements of implementing conservation tillage and dual-row planting for maize, a strip-tillage machine specifically designed for conservation tillage was developed in this study. The structure and operating parameters of the strip-tillage machine were determined through the specific design of transmission ratio, row-unit, and rotary tillage mechanism. Detailed analysis of the overall parameters of the implement, crucial parameters of the row guidance component, and specific parameters of the rotary tillage component was conducted, ensuring that the machine can accomplish row guidance, seedbed preparation, and compaction simultaneously for three operating strips. Moreover, the design of the row guidance and compaction devices was considered to minimize energy consumption during operations. This research provides a reliable foundation for the development of strip-tillage machines with conservation tillage capabilities. The strip-tillage machine not only meets the requirements of conservation tillage and dual-row planting for maize but also contributes to the efficient and sustainable cultivation of crops, optimizing soil conditions, reducing labor costs, and decreasing environmental impact.

Keywords: Conservation Tillage; Strip Tillage; Straw Collected to Pile; Rotary Tillage

1. Introduction

Through agricultural production practices, it has been proven that conservation tillage has significant significance for fertilizing the soil, reducing black storms, soil erosion, and water erosion. Among them, strip tillage is a type of conservation tillage with minimal tillage operations, which can effectively reduce problems such as low soil temperature and uneven emergence caused by excessive straw cover [1-2]. The main workflow of strip tillage includes straw alignment, rotary tillage, and soil compaction. Firstly, the crop straw is neatly arranged on the field surface to form a series of inter-row strips. Then, strip tillage machinery is used to rotary till the soil on both sides of the straw strips, forming tilled strips for planting. Finally, a compaction device is used to lightly compact the soil, improving its stability and water retention. Through these steps, strip tillage not only protects the soil but also improves the planting environment, increasing crop yield and quality. The introduction of strip tillage machinery for conservation tillage enables the completion of multiple operations such as straw alignment, strip tillage, and soil compaction in one go, meeting the technical requirements of conservation tillage with minimal tillage operations and wide-narrow row planting. This is of great significance for the promotion of conservation tillage [3].

2. Materials and Methods

Conservation tillage strip tiller is mainly composed of straw collection row device, soil rotary tillage device, compaction device, etc. The overall structure is shown in Figure 1. the main technical parameters is listed in Table 1.

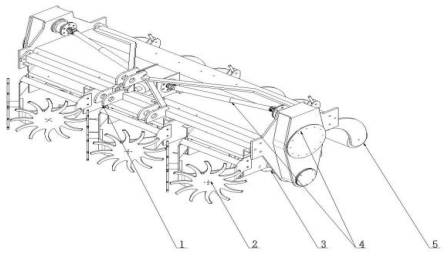

Figure 1. Schematic Diagram of the Overall Structure of the Strip Plow: 1. Suspension Device 2. Cutter Plate 3. Rotary Plowing Device 4. Transmission Structure 5. Compaction roller

It is connected to the tractor by a three-point suspension. Three sets of return cutters are

mounted symmetrically in front of the soil tillage belt in each row and slightly below the rotary axle of the rotary tillage unit, and the soil rotary tillage unit is mounted behind the return cutters to contain the tillage cutter rollers and multiple sets of tillage knives. The soil rotary tillage device is installed behind the compaction roller. The transmission mechanism mainly consists of a bevel gear reduction gearbox, a universal shaft, a transmission box and so on, which is mainly used for the power drive of the soil rotary tillage device. The bevel gear reducer is connected to the power output shaft at the rear of the tractor through spline and universal shaft, and the side end of the bevel gear reducer is connected to the universal shaft through flange, and the universal shaft will be accelerated by the transmission box to the tillage knife roller in the soil rotary tillage device after the power input transmission; the tillage knife roller drives the multiple tillage knives to rotate and break up the soil, so as to achieve the purpose of plowing and breaking up the soil.

When the soil strip rotary plowing operation, the tractor traction equipment walking, through the return to the rows of the knife plate will be the soil and cross-stacked straw out of the plowing strip, and the soil of the plowing strip to clean up, to prevent the existence of stones in the soil, iron and other hard materials. Then the tillage knife roller in the soil rotary tillage device drives the tillage knife to carry out soil rotary tillage operation, and its power is mainly driven to the operation of the tillage knife roller through the power output shaft at the rear of the tractor through the bevel gear set and two sets of sprockets. Then the compaction roller will be crushed and mixed soil compaction also facilitates the subsequent convenient mechanical operation, complete the plow strip plowing operation. Through this series of mechanical operations can be realized in conservation tillage only on the plowed soil strip plowing operations, the rest of a large number of straw pile to return to the field, a small portion of straw crushed and soil mixing, so as to improve the nutrient content of the soil, as well as to solve the problem of straw accumulation, and at the same time, through the soil cleanup and plowing, in order to improve the subsequent operation of the quality and efficiency of the seeding.

The main technical parameters of this strip-tillage machine are primarily determined by agronomic requirements. The key agronomic requirements include the width of the tillage strip and the depth of tillage. Since the machine operates in a dual-row system with large ridges, the width of the tillage strip is set at 800mm. As for the depth of tillage, considering the conservation tillage practice of returning straw to the field, a deeper tillage depth of 200mm is selected [4-6].

Furthermore, the number of operating strips on the machine is determined by considering both the desired operating speed and the required workload. After comprehensive comparison, it is decided that the machine will simultaneously operate with three tillage strips. Based on this, the length of the machine is determined to accommodate three tillage strips and two rest zone.

In addition, since the machine needs to cover straw in the cultivated soil, a faster cutting speed and appropriate type of rotary blades are required. Therefore, curved rotary blades with a blade turning radius of 270mm are chosen to meet the cutting and rotary tilling needs [7-8].

Table 1. Main Technical Parameters

Items	Parameter
Length×Width×Height/mm	3000×1900×1100
Tillage strip number/pcs	3
Bottom width/mm	1200
Tillage strip width/mm	800
Total number of knives/pcs	32
Rotary radius of blade/mm	270
Tillage depth/mm	200
Blade type	curved blade

3. Main Components Design

3.1 Transmission System Design

The faster the rotary tangential speed of the end point of the tillage blade and the forward speed of the unit, the higher the working efficiency of the implement, but the movement trajectory constituted by the end point will also change. After comprehensive consideration, it should be ensured that the ratio of the rotary tangential speed of the end point of the tillage blade and the forward speed of the machine set, i.e., the rotary speed ratio λ is greater than 1. Therefore, the rotary speed of the rotary tillage is selected as n=250 r/min, the forward speed of the strip tiller is v=5 km/h, and the radius of rotation of the

blade is r=270 mm.

From the rotary speed design can be determined by the rotary speed of the knife roller n=250 r/min, select the tractor power output shaft speed n_1=640 r/min, the total transmission ratio $i=n_1/n$=640/250=2.56. which contains the transmission ratio components were bevel gear set reduction gearbox and transmission box. The main role of the bevel gear reducer is to transfer the rotation of the tractor output shaft to the cardan shaft to realize the speed adjustment. The main function of the transmission box is to transmit the power from the upper universal shaft to the lower tillage knife roller to realize the operation of the tillage knife roller. The design and cooperation of these two components can effectively realize the transmission of power and the adjustment of rotational speed to ensure the normal operation of the machine in the process of plowing. The distribution of transmission ratios at all levels is shown in Table 2.

Table 2. Transmission Ratios at All Levels

Transmission Ratio	Ratio
Bevel gearbox ratio	1
Total transmission ratio	2.56
Gearbox ratio per stage	1.6

Due to its width of 1900 mm and height of 1100mm, this agricultural machine requires long-distance transmission and sufficient power for three 800 mm plowing strips. To meet these requirements, the machine adopts two transmission methods: bevel gear transmission and chain transmission. Firstly, bevel gear transmission is used to transmit power and achieve directional conversion. Bevel gear transmission can transfer power from one shaft to another and change the direction of transmission through the pairing of helical gears. This transmission method has high transmission efficiency and large load-bearing capacity, and is suitable for use in the transmission system of large agricultural machinery. Secondly, chain transmission is used as a secondary transmission and achieves variable speed function. Chain transmission transmits power from one shaft to another through the combination of chains and gears, and can achieve different transmission ratios, thereby achieving variable speed. This transmission method is often used in agricultural machinery to transmit large amounts of power, and has good impact resistance and a long service life. By using both bevel gear transmission and chain transmission simultaneously, this agricultural machine can meet the requirements of long-distance transmission, direction change, and speed change. Bevel gear transmission provides efficient transmission of power and direction conversion, while chain transmission achieves secondary transmission and variable speed functions. This transmission system can ensure that agricultural machinery obtains sufficient power and flexibility during operation to complete farming work. The main technical parameters of the transmission system are shown in Table 3.

Table 3. Technical Parameters of the Transmission System

Item	Value
Bevel gear teeth/pcs	16
Number of teeth of small sprocket/pcs	16
Number of teeth of large sprocket/pcs	26
Sprocket material	Q235
Hardness/HBS	240HBS

3.2 Design of Straw Returning Device

The straw returning device for the whole soil mainly consists of two parts: the row-collecting cutter plate and the bracket. The row-collecting cutter disk is a knife mounted on the bracket, which is fixed through the bracket and extends into the soil strip that needs to be plowed. When the tractor drives the whole implement forward, the row-collecting cutter disk will carry out row return operation on the soil to be tilled, and collect the straw or other plant residues scattered on the land into the resting strip, so that they are arranged in rows, which is convenient for subsequent processing and utilization. By passive rotation and movement of the row-collecting blade, the straw is pushed to one side or concentrated in the resting belt to realize the effect of row returning. This reduces the impact of straw on crop growth and harvesting, and also facilitates soil protection and management. The design and operation of the whole straw returning device improves the farming efficiency and soil quality of the farmland.

The planting method of the strip-tiller designed in this paper uses a double-row planting method with a large ridge with a width of 1200mm at the bottom of the ridge and 900mm at the top of the ridge, so two

row-collecting cutter disks are needed for each ridge to clean up the planting soil, and at the same time two row-collecting cutter disks clean up the planting belt to ensure that the planted soil is free of stones and other hard materials during the subsequent planting process, so as to provide the environment suitable for the crop's growth. The angle between the row cutters is chosen to be 90°, and the angle of entry into the soil is kept at 30°.

3.3 Soil Rotary Tillage Device Design

The tillage knife roller is the main working part of the soil rotary tillage device, and the knife roller shaft is selected to rotate clockwise. The rotary radius of the tillage knife of this machine is 270 mm, and the rotary of the tillage knife rotates clockwise. Tillage knife material selection of $60Si_2Mn$, can meet the needs of the working conditions, the metallurgical organization of the knife body for the tempered martensite, its hardness after heat treatment up to 45~54HRC, the metallurgical organization of the knife handle for the tempered quartzite, its hardness after heat treatment up to 38 ~ 45HRC.

In order to ensure the normal operation of the strip tiller, attention must be paid to the rotational balance between the knife roller and the tillage knife during the design process. Correct arrangement and installation is very critical to enhance the operating efficiency, otherwise it will easily cause the offset of the tillage blades and aggravate the oscillation of the machine [7-8]. As the strip-tillage machinery mainly consists of three segments of non-contiguous soil strips that need to be tilled, so in the left and right segments of the soil strips using the inner hybrid mounting method to balance the balance of the two sections of the tillage knives, the middle position of the tillage knives using the helix sorting that is, this sort of sorting that can be balanced by the stress, but also can be left in the straw collection line device through the helix to the side of the soil strips in the machinery to choose the hybrid mounting method of installation [9]. The order is shown in Figure 2.

The tillage knife roller is mainly used to fix the tillage knife blade and determine the specific position of each part of the tillage knife, the whole knife roller is made of a steel pipe with a wall thickness of 10 mm, a length of 2660 mm and a diameter of 100 mm, and a flange is welded at both ends of the pipe and in the middle of the linkage of the tillage knife partly, and a flange with a thickness of 20 mm and a diameter of 200 mm is welded on both sides, and a flange with a thickness of 10 mm and a diameter of 250 mm is welded in the middle of the pipe. The flanges at both ends of the knife rollers are used as transmission boxes to provide power for the tillage knife rollers. The flange in the middle is used for linking the tillage knife and fixing the tillage knife to complete the soil rotary tillage work.

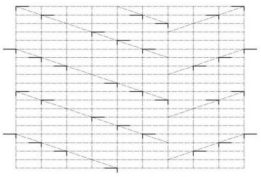

Figure 2. Schematic Diagram of Tillage Knife Sequencing

3.4 Compaction Device Design

The compaction device of the implement is mainly used to compact the soil during the tillage process, in order to achieve a certain degree of soil density and stability [10]. The compaction device of this machine adopts a passive compaction method, utilizing the gravity of the machine's own weight and spring pressure for compaction. This approach not only ensures a certain level of soil density and stability but also reduces the power consumption of the machine. The width of the compaction roller is chosen to be smaller than the tillage strip, set at 700mm, to avoid any vibration and additional power consumption caused by rolling over the residue-covered area of the inter-row zone. This allows for compacting the soil without affecting the residue-covered area.

4. Conclusions

In this study, we designed a continuous strip tillage machine with a rear three-point suspension structure for conservation tillage, straw alignment, strip tillage, and soil compaction operations.

By referring to the structure of existing strip tillage machines for conservation tillage and making improvements to address existing issues, we conducted a detailed analysis of the structure and working principle of the strip tillage machine. By changing the alignment

and compaction operations to passive forms, we reduced power consumption and enabled the machine to complete the strip tillage operation in one pass. To meet the requirements of conservation tillage and strip tillage in agriculture, we selected a suitable transmission system and designed specific parameters for the main components. We determined that the angle between the alignment discs is 90°, the entry angle is 30°, the parameters of the rotary tillage roller and the order of the rotary tillage blades were determined based on the length of the tilled strip. Additionally, we determined the rotation radius of the tillage blade to be 270 mm and the length of the compaction drum to be 700 mm based on the tilled strip.

Through these design and analysis efforts, we have laid the foundation for the development of the strip tillage machine for conservation tillage. This type of agricultural machinery will help improve crop production efficiency, promote sustainable agricultural development, and meet the demand for conservation tillage, straw alignment, and other technical requirements in the agricultural sector.

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