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Design and Tests of Biomimetic Blades for Soil-rototilling and Stubble-breaking

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Abstract

Biomimetic blades for soil-rototilling and stubble-breaking were designed learning from the geometrical structure of the tips of toes of mole rat (*Scaptochirus moschatus*). The orientation, the number and the central angle of the biomimetic structure were taken as the testing factors. The optimal structure of the biomimetic blade was determined through the tests of soil-rototilling and stubble-breaking operation in an indoor soil bin. The optimal combination of the biomimetic structure parameters is that three arc concave teeth are equally arranged on the front cutting edge with a central angle of 60˚. The results of comparative tests between the optimal biomimetic blade and a conventional universal blade show the torque acting on the biomimetic blade is lower during soil-rototilling and stubble-breaking operations. The results of field tests show that the working quality of the biomimetic blades meets the requirements of the national standard of China. Tests of soil-rototilling show that, when the orientation of the biomimetic structure was at low and middle levels, the torque of biomimetic blades decreased from 34.17 N·m to 31.03 N·m. The torque also decreased with the increase of the number of biomimetic structure. The average torques were 34.57 N·m, 33.44 N·m and 31.37 N·m, respectively. The maximum different value between two levels of central angle was 0.41 N·m. Tests in field indicate that for soil-rototilling operation, the tillage depth is deeper than 80 mm, the soil-crushing rate (length of soil block less than 40 mm) is over 50 %, and the vegetation coverage rate is over 55 %. For stubble-breaking operation, the stubble-breaking depth is deeper than 70 mm, the stubble-breaking rate (length of stubble less than 40 mm) is over 60%, and the stubble coverage rate is over 80%, which can meet the stubble-breaking requirement of corn.

Keywords: biomimetics, mole rat (*Scaptochirus moschatus*), soil-rototilling, stubble-breaking, torque, working quality

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1 Introduction

Compared with the traditional moldboard plowing, rotary tillage has some advantages, such as improvement of the working quality and efficiency, reduction of working time required for machine in farmland. Therefore, lightening compaction of soil, as a result, a better surroundings for seed growth can be developed[1–4]. Single soil-rototilling or stubble-breaking machine is widely used in the world at present. Some multi-functional machines have been developed in China to perform different operations of soil-rototilling and stubble-breaking. The machine to perform the two operations needs to equip with two rotors and two sets of blades, resulting in higher manufacturing and utilizing cost[5]. Jia *et al*.[6] designed a machine which is characterized by a universal rotor and blade mounting disc mechanism that allows the two operations to be performed respectively by changing the blades. Comparing with a machine which has two rotors, this kind of machine increases utilization, reduces manufacturing cost and material consumption, but it still requires two kinds of blades. Then, based on the structure parameters of L-type stubble-breaking blade and wide soil-rototilling blade, the universal blade which could be mounted on the universal rotor to perform both of soil-rototilling and stubble-breaking was designed[7].

Biomimetics is an effective method to reduce the cutting resistance and soil adhesion on soil-engaging components[8]. Based on biomimetics, some soil-cutting

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and soil-excavating tools have been developed, such as biomimetic plow mouldboard[9] and biomimetic furrowing opener[10]. The biomimetic tools not only reduce the power consumption and soil adhesion, but also improve the working efficiency and working quality.

In order to achieve both soil-rototilling and stubble-breaking operations by one kind of blade and reduce energy consumption, the biomimetic blades learning from the geometrical structure of the claws of mole rat (*Scaptochirus moschatus*) were designed taking a precondition for requirement of agricultural production. The power consumption and working quality of the biomimetic blades were examined through tests of an indoor soil bin and field respectively.

2 Design of biomimetic blades

Mole rat (*Scaptochirus moschatus*) has high working efficiency of digging soil[11,12], and the toes of its foreclaws are better biomimetic prototypes for designing the soil-cutting and soil-excavating tools[13,14]. During digging procedure, the mole rat only uses two foreclaws (including five toes each claw) to cut soil and has a motion with elliptical locus[15]. The movement form of toes of mole rat is similar as the blades mounted on the machine of soil-rototilling or stubble-breaking machine. The fitting arc was used to simulate the geometrical characters of the toe tip of mole rat as shown in Fig. 1.

The structural parameters of universal blade for soil-rototilling and stubble-breaking were determined[14]. Based on these parameters, the geometrical characters of the toe tip were applied for design of the frontal cutting geometry of the biomimetic blades for soil-rototilling and stubble-breaking.

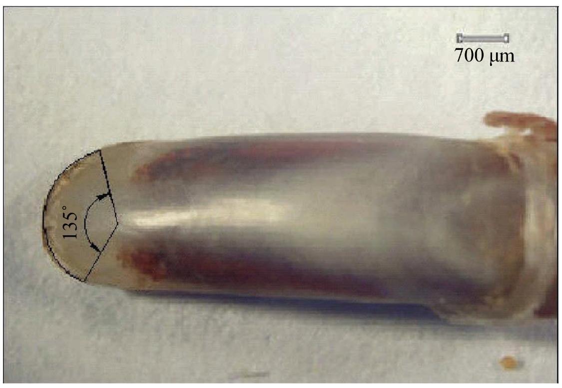

Fig. 1 The geometrical character of a toe of mole rat (*Scaptochirus moschatus)* for simulation.

Through the geometrical analysis, it is found that a right-angled triangle with an angle of $\theta/2$, the length of opposite side to the angle $\theta/2$ is $L/2n$, r is as the hypotenuse which is the side opposite the right angle, where L is the working width of single blade, r is the radius of the fitting arc of toe of the claw, θ is corresponding to the central angle of the fitting arc, and n is the number of the fitting arc. Then the Eq. (1) is computed by using sine function. So, the structures of the biomimetic blades were determined by the equation as:

$$\frac{L}{2nr} = \sin\frac{\theta}{2}. \tag{1}$$

The working width of single universal blade was 60 mm. If n is given, then the chord length (L) can be determined. If one of the r and θ is defined, the structure of the biomimetic blade can be known. When n is 2 and the biomimetic structure is outward, there will be a convex arc cutting edge (Fig. 2a). While, if the biomimetic structure is inward, there will be a concave arc cutting edge, the structural diagram of this type of the biomimetic blade for soil-rototilling and stubble-breaking is shown in Fig. 2b.

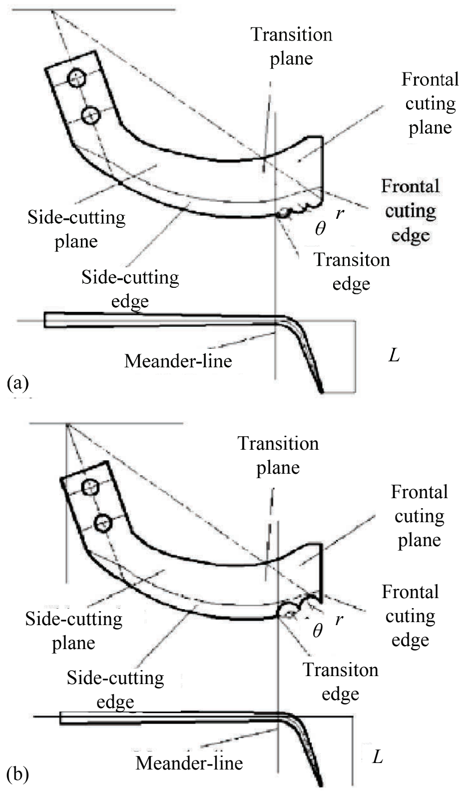

Fig. 2 The structural diagram of the biomimetic blade designed. (a) Orientation of biomimetic structure is outward; (b) orientation of biomimetic structure is inward.