Horizontal Screw-Type Blade

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Horizontal screw-type blade, usually sold as "rotary-plow" has been used widely for tilling and ground-making operations such as ridge making and ridge breaking and also for crop-security operations, for example, mulching.

There are a number of remarkable advantages with regard to its function. However, the design criteria of the blade are dependent mainly upon empirical data because of lack in theoretical basis.

In the present paper, description is given of the results of experimental and theoretical studies to obtain the theoretical basis necessary for the design of the horizontal screw-type blade.

Shape and function of blade

The blade tested shows the shape as indicated in Plate 1. Practically, three blades with approximately the similar shape as illustrated in Fig. 1 are welded to the hollow shaft. Generally, the blade can be divided, in view of its function, into three parts, namely, the vertical cutting blade, the cutting blade, and the turning blade.

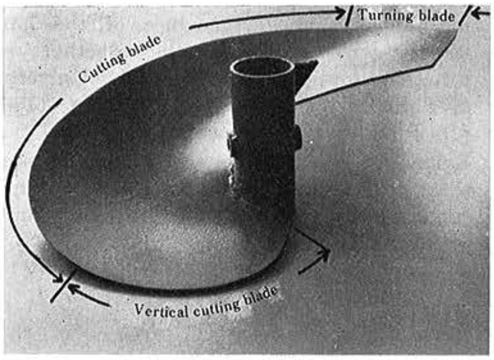

Plate 1. Shape and function of the blade

The vertical cutting blade serves as a disk coulter to form the furrow wall. On the other hand, the cutting blade forms the bottom of the furrow by removing the soil in the direction of the tilling shaft. The turning blade serves to turn the block of soil cut by the aforementioned two blades. These three blades have characteristic functions, and their applicability affects greatly upon the accuracy of the operation.

Cutting resistance of soil

The average tilling power requirements generally become greater as the working depth (7 to 13 cm), the tilling pitch (5 to 14 cm) and the tilling width (9 to 13 cm) are increased. The power range was 0.1 to 0.4 ps. The sandy loam required the largest power, and the sandy clay loam and the silt loam called for smaller power in this order.

In regard to the component forces acting upon the blade, the upward force was 2 to 16 kg, the forward force was 2 to 12 kg and the transverse force was 1 to 3 kg, in which the sandy loam required the largest force. The difference of the tilling power requirement among cutting methods was slight.

However, in the upward cutting method, the longitudinal component force acts as the backward force to prevent the advancement of the machine, showing the magnitude almost as large as the forward force in the downward cutting method.

Theoretically, the average cutting torque T_{s1} in a revolution of the rotor shaft is given by the following formula, handling the cutting resistance of soil bidimensionally under

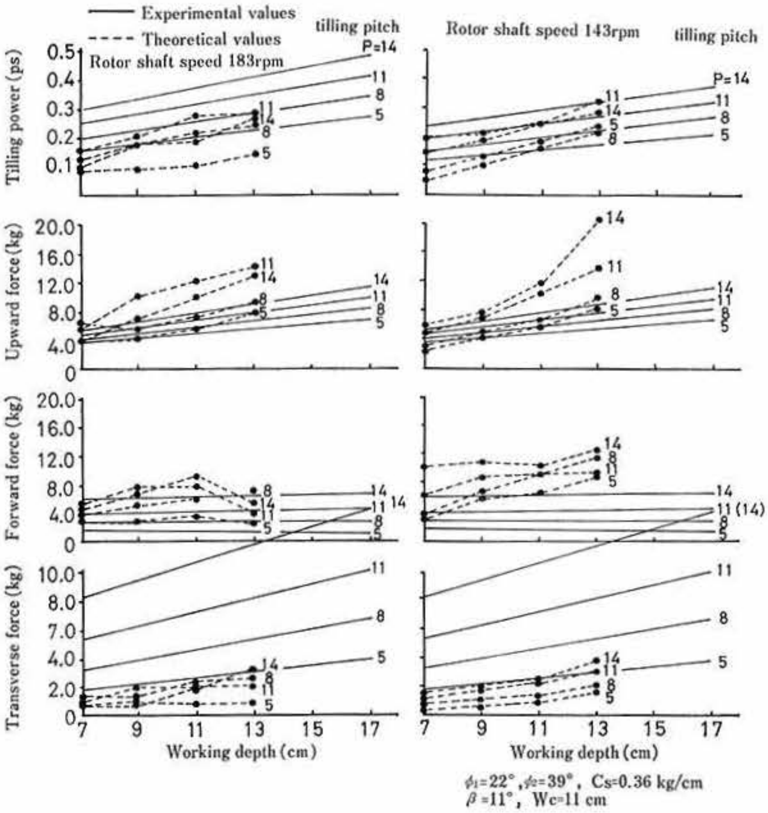

Fig. 1. Relation between experimental values and theoretical values

the condition of the revolution without forward movement, and neglecting the pushing resistance:

$$T_{s1}=\frac{f}{4\pi}\sin(\beta+\phi_1)\left[\frac{P\sqrt{4R^2-P^2}}{2}+\frac{P(P-h)}{R^2}\{P\sqrt{2Rh-h^2}-\sqrt{R^4-P^2(R-h)^2}\}\right.$$
$$\left.+R^2\left(\sin^{-1}\frac{P\sqrt{4R^2-P^2}}{2R^2}-\sin^{-1}\frac{P\sqrt{R-h}}{R^2}\right)\right]$$

Considering the pushing resistance force acting upon the blade tip and the circumference, the average cutting torque T_{s1} is expressed as follow:

$$T_{s2}=\frac{1}{4\pi}\{f\sin(\beta+\phi_1)+t'q\}\left[\frac{P\sqrt{4R^2-P^2}}{2}+\frac{P(P-h)}{R^2}\{P\sqrt{2Rh-h^2}-\sqrt{P^4-P^2(R-h)^2}\}\right.$$
$$\left.+R^2\left(\sin^{-1}\frac{P\sqrt{4R^2-P^2}}{2R^2}-\sin^{-1}\frac{P\sqrt{R+h}}{R^2}\right)\right]+\frac{1}{2}R^2t'q\left(\frac{\pi}{2}-\theta_s\right)\tan\phi_1$$

where

$$f=\frac{C_sW_e}{\cos\left(\frac{\beta+\phi_1}{2}\right)\left\{1-\tan\left(\frac{\beta+\phi_1}{2}\right)\right\}\tan\phi_2}$$

C_s=soil cohesion (kg/cm²)
h=working depth (cm)
p=tilling pitch (cm)
W_s=tilling width (cm)

t' = thickness of cutting blade (cm)
q = coefficient of pushing resistance of soil (kg/cm²)
R = outside radius of blade (cm)
β = helix angle (deg)
ϕ_1 = friction angle between soil and cutting blade (deg)
ϕ_2 = internal friction angle of soil (deg)
$\theta_s = \sin^{-1}\frac{R-h}{R}$

The main cause of torque is the shearing resistance of soil, which is expressed by T_{s1}.

The analysis of one blade is described above. The average cutting torque of multiple blades T_{n2} is given by the following formula, considering the blade disposition with little load fluctuation:

$$T_{n2} = \frac{2\pi}{\Omega} T_{s2}$$

The number of blade is given by $n=2\pi/\Omega$ is where Ω is phase angle. Theoretical formulas of each component force were induced under the same condition as above.

Fig. 1 shows both experimental and theoretical values of the tilling resistance for a blade in the downward cutting method. Relatively, both values are approximate except in case of the transverse component of cutting force. This means that it is possible to obtain the tilling resistance of such tilling blades from this formula irrespective of the shape and dimension of the blade.

The theoretical value of the transverse component of cutting force is associated with the component, in respect to the direction of shaft, of the resultant force acting on the side face of the blade, and the experimental value indicates the force in the direction of shaft acting on the tilling rotor shaft.

However, in this study, the theoretical value of the transverse component of cutting resistance was higher than the experimental value. With regard to the reason for this difference, it is considered that the component, in respect to the direction of the shaft, of the force acting on the face of the blade could not be recorded entirely on the component pick-up device, some of which were absorbed in the portion between the vertical cutting blade and the face of untilled soil.

Turning performance

The turning blade acts to the soil slice only when it is in the rising process. This is not varied by the cutting method. Therefore, the important factor to affect the turning performance is the positional relationship between the locus of the turning blade in the rising process and the center of gravity of a slice.

In the downward cutting method, its relative position becomes nearer as the tilling pitch increases to give better turning performance. In the upward cutting method, although its relative position is separated when the tilling pitch is increased, reliable inductive turn to the transverse direction is obtained because of the restriction to the forward and the backward movements by the blade surface and the untilled soil. Under this condition, smaller tilling pitch rather results in worse turning performance.

Examining the relationship between the shape of a slice and the turning performance, the slice should be moved parallel to the transverse direction preserving the shape when it is cut. The inferior turn results when the slice is broken into small clod or the backward movement is great.

Seeing the relationship between the tilling condition and the turning performance, one of the important points is the radio of the tilling width to the tilling depth, and the ratio is greater than one gives good turning. Dry soil which has weak coherence resulted in the worse turning ratio nearly 50 per cent. Among the cutting methods, the upward method showed a little better result.

Examining the horizontal movement of soil during tilling in the same dry soil, the uniform distribution was obtained at the tilling pitch of 10 cm, and this was proved not to be much affected by the tilling depth and the rotor shaft speed.

The moving direction of a slice is affected

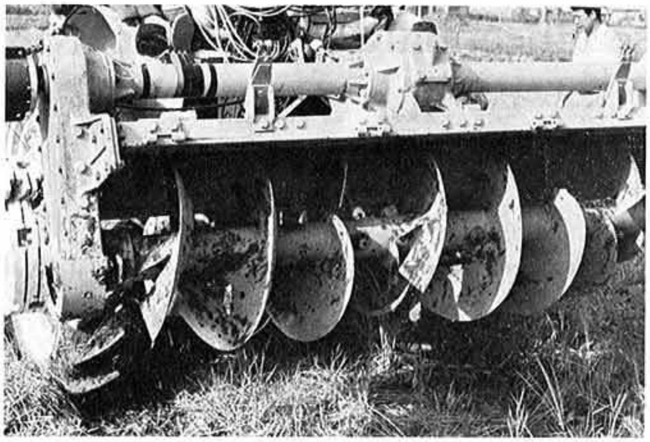

Plate 2. Trial tilling device with 9 blades

by the shape of the curved surface of the blade. As the blade has a helicoidal surface, the large helix angle makes the turning worse.

Trial-tilling device

Plate 2 shows a trial-tilling device having nine blades. In this device, that the blades with the same shape are configured in the same direction in order to be able to perform the plane-tilling operation.

The load characteristics and the turning performance of the trial-tilling device were examined experimentally.

As a result, the tilling power was 2.5 to 10 ps with 1.5 m of operating width, 13 cm of tilling depth and 10 to 25 cm of tilling pitch, and was 5 to 19 ps when only the tilling depth was varied to 18 cm. The required power tends to increase as the tilling width for a blade rises even if the operating width is the same.

The result of the measurement of the forward force which acts as the driving force of the tractor and the transverse force is as follows. The forward force was 10 to 150 kg and the transverse force was 100 to 200 kg with 18 cm of tilling depth and 10 to 20 cm of tilling pitch.

The turning ratio of the tilled soil greatly varied when the tilling width for a blade is changed from 18 to 21 cm. The tilling width of 21 cm resulted in a good turning ratio. However, in the multiple blades, the turning performance is not enough owing to the interference between blades, which should be improved in the future.

On the field of soft soil, the straight travelling of the tractor was slightly affected by the transverse force of the tilling device.

The tilling device was rolled by the rotor shaft revolution, which cannot be avoided because of the disposition of blades. This oscillating motion was small during the tilling operation and was proved not to impede operation.

Several performance tests were conducted for the trial-tilling device, the rotavator and the plow. The turning ratio decreases in the order of the plow, the trial-tilling device and the rotavator. The pulverizing ability at tilling time decreases in the order of the rotavator, the trial-tilling device and the plow. Further, tilling volume per hr per ps decreased in the order of the trial-tilling device, the plow and the rotavator. Although other operating performances should be examined and compared in the future, the trial-tilling device proved to have enough practical value at this level of trial manufacture.

Reference

1) Okada, Y.: Studies on the horizontal screw type blade. *Bull. of the Faculty of Agriculture, Miyazaki Univ.*, 20(2), 107–205 (1973).