

Development and Optimization of Rotary Blade for Tillage Equipment

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ABSTRACT

In comparison with tractor drawn implements, rotary tillers are of particular interest in final seedbed preparation. In India vertical axis rotary tiller has been introduced in recent years by some farm equipment manufacturers. Farmers claim difference between horizontal and vertical axis rotary action but there are no scientific work compare them. Some research has been done on comparison between rotavator and conventional tillage implements. In this research, a quantitative basis for the description of torque created by different rake angle is given. The design optimization in terms of torque requirement has been carried out for the different rake angle *viz.*, 5, 10 and 15 degree; forward speed *viz.*, 2.0, 2.5, 3.0 and 3.5; rotor rpm *viz.*, 220, 270 and 310. At all groups the investigations indicated that the optimum torque was produced at 2.5 kmph with 270 rpm when the rake angle is 10°.

Highlights

- Rotary tillage system saves 35 % of time and energy compared to drawn type implement.
- Vertical axis rotavator eliminates the soil compaction.
- It provides a through pulverization.

Keywords: Rotary blade, vertical axis, rake angle, rotary tiller, torque, tillage

Nowadays, tractor mounted seedbed preparation with driven rotary tools have gained more and more importance in comparison with drawn seedbed combinations. The pertinent reasons explaining these developments are recent tractors develop more power than they can transmit efficiently to a draft implement through tyres and the soil break up created and the easy combination with other machines *viz.*, sowing machines allow a reduced number of passages. However, these machines are sometimes used improperly. If the forward speed and the angular velocity of the rotors are not appropriate to the soil, then the latter becomes pulverized. In certain circumstances, soil crusts are created which compromise seed germination.

The mechanical characterization of a rotary tool is essentially based upon kinematics. Hendrick and Gill (1978) gave a theoretical analysis of the

motion for a machine having its axis parallel to the soil surface and perpendicular to the direction of motion. Kinzel *et al.* (1981) presented equations easily programmed for a graphical representation of the relative motion of a rotary tiller blade with respect to the trochoidal path of the cutting edge. There is less literature concerning the effects of these machines on soil structure. Most of the researchers use a simple method, but which is rather imprecise, consisting of the measurement of clod size. Dexter (1976 and 1979) presented a technique which consists of impregnating soil samples with paraffin wax melted on a portable gas stove. The impregnated blocks were removed and sawn to see the arrangement of soil particles and associated voids. This technique allows one to fill all the pores down to ~ 1 mm diameter. A statistical method is used for describing the soil macrostructure created

by a mould-board plough, a set of spring tines and a rotary cultivator. In this study, Dexter's technique is developed further in order to fill smaller pores.

The aim of this study is to correlate the design and kinematic parameters of a rotary cultivator with the created soil structure. This implies finding the suitable parameters characterizing the tool from a mechanical point of view and dealing with a quantitative basis for the description of soil structure.

MATERIALS AND METHODS

The present study deals a vertical axis rotary tiller (Fig. 1) with three different rake angles, as represented in Fig. 2 any point on the rotor travels on a path which is a combination of the machine forward motion and the distance from the rotational axis to the point of interest. Assuming that the starting point is with the rotor axis at the origin of the reference axis, the parametric equations describe the path of extremity points A and B of the rotor.

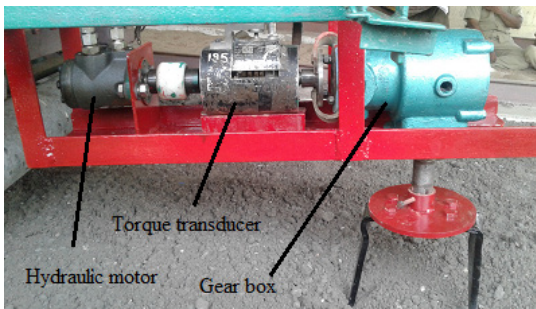


Fig. 1: Vertical axis rotary tiller experimental setup for torque measurement



Fig. 2: Vertical rotary tiller blade's rake angle

$$\left. \begin{aligned} X_A &= vt + R \cos \omega t \\ Y_A &= R \sin \omega t \end{aligned} \right\} \dots(1)$$

and

$$\left. \begin{aligned} X_A &= vt - R \cos \omega t \\ Y_A &= R \sin \omega t \end{aligned} \right\} \dots(2)$$

Where, R = rotor radius; t = time; v = machine forward velocity; ω = angular velocity of rotor, positive when the rotor rotation is counterclockwise; ωt = displacement angle; at $t = 0$, ωt is along the x -axis.

Loading car-rotary tiller system

A loading car frame of size 1.750 m length, 2.850 m width and 1.40 m height was mounted on four iron wheels with one side projected rims fitted to two axles. Two more guide wheels were provided opposite to each other to avoid slippage of loading car from the rails. The processing implements like cultivator, leveller and compaction roller were fitted to the bottom portion of the loading car. The power transmission system along with electrical motors and control systems for driving the loading car in the reverse direction, for operating the rotary tiller and to lift or lower the implement up and down were mounted on the loading car.

Power transmission system

For operating the loading car on the rails in the forward direction during rotary tiller at four forward speeds, the loading car is attached to the rope provided in the power drive system. After completion of the above operations, each time the loading car was brought back to the other end of the soil by means of power transmission system provided on the top of the loading car. A 7.5 hp electrical motor was fitted on a sliding base and two stage double groove 'V' belt transmission system was provided to one of the axle of the loading car. Speed reduction of 2.5:1 and 3:1 and a belt tensioner were provided with linkages for easy operation.

A 10 hp electric motor and gear box were mounted on top of the loading car parallel to each other. The input shaft of the gear box was directly connected to a clutch and double grooved 'V' pulley. For this purpose the clutch system available in the power tiller was used. The motor and gear box are connected by means of two 'V' belts with a speed reduction of 5:3. For operating the rotary tiller coupled with torque transducer at one side and the hydraulic pump another side, a 5 hp electric motor was used. The rotor revolutions can be adjusted by using the variable speed drive mounted on the top of the loading car.

For operating the loading car and other controls, an operator seat was provided on the top of the loading car. Main switch, starter for the two electrical motors, control lever for operating the hydraulic pump, clutch lever and gear box lever were placed within the reach of the operator's seat. In addition, inch control system was also provided for inching the loading car which is essential while the loading car is operated in the reverse direction. Power for operating the motors was obtained through the power cable in the form of coils connected through insulated rings which moves on a wire cable positioned at 2.1 m height over the center rail of the soil.

The torque transducer is a transmission dynamometer, placed at the appropriate location in the power transmission line between the gear box and rotor input shaft on the wheel axle, for the purpose of measuring torque. The In-line torque transducer used in this study is based on calibrated measurement of unit or total strain in elastic load carrying members, and it employs bonded strain gauges, applied to a section of torque transmitting shaft. The strain gauges are so applied on the torque shaft so that it is sensitive to torque, but not to axial loads and relatively insensitive to bonding. A complete four arm bridge is employed, incorporating temperature compensated gauges. Electrical connections are made through slip rings with provision to lift brushes, wherever torque measurement is not required.

The salient features of the torque transducer are compact and rugged construction, easy to operate, remote measurement and easy automatic control. It is capable of measuring, in all conditions and the power loss is held to a minimum and also kept free from influence provided by bending or thrust force of measuring object. The torque transducer senses the torque transmitted through its shaft, which can be directly read on a digital load indicator.

Digital load indicator

The digital load indicator, used in the study to display the rotor torque sensed by the torque transducer, comprises of highly stable integrated circuit power supply for the operation of the instrument, DC amplifier and the indicating voltage is obtained from a stabilized DC power supply from AC main. The accuracy of the instrument is \pm one

per cent. The inherent unbalance in bridge can be balanced out to zero by respective potentiometer balancing across the bridge supply, the variable arm being connected to one end of the input amplifier through a resistor. Independent bridge balancing and calibration circuit is incorporated for each channel to increase usage of the instrument. Bridge output is amplified by an integrated current DC amplifier. The amplifier output is fed to calibrated rectangular digital panel meter. The instrument has internal calibrator facility and the digital meter sensitivity can be adjusted by respective channel calibration potentiometer on the front panel

A three factorial completely randomized block design was adopted by using the AGRES software and three replications were made on each treatment.

RESULTS AND DISCUSSION

An experimental set up was developed and tested at Tamil Nadu Agricultural University to find out torque of the rotary blade. So the loading car was allowed to plough the rotary tiller at different forward speed of 2, 2.5, 3 and 3.5 kmph and rotary rpm of 220, 270 and 310. The measurements were taken for different forward speed, rotary rpm and depth.

In the first step of the verification process, comparison of the results obtained in this study was for different rake angle of a rotary tiller. To ensure the compatibility of the results, the input parameters of the developed model were made the same as the specifications of the rotary tiller utilized in the experimental study. The common parameters are listed in Table 1.

Table 1: List of parameters taken for the measurement of torque

Parameters	Unit
Number of blades	2
Rotor diameter, mm	200
Blade thickness, mm	10
Type of soil	Clay
Soil moisture content, %	14

Effect of rake angle and forward speed on torque

The following figure shows the effect of rake angle and forward speed on torque of rotary tiller (Fig. 3).

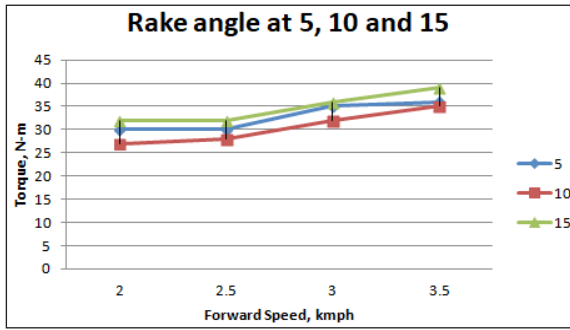


Fig. 3: Effect of Forward Speed and rake angle on torque

The influence of forward speed rake angle resulted in the highest torque at 3.5 kmph when compared to 2.0, 2.5 and 3.0 kmph. At all groups rake angle of 15 degree registered highest torque in comparison to 5 and 10 degree.

Effect of rake angle and rotor rpm on torque

The influence of rotor rpm and rake angle resulted in the highest torque at 220 when compared to 270 and 310 rpm. At all groups rake angle of 15 degree registered the higher torque in comparison to 5 and 10 degree. The following figure shows the effect of rake angle and rotor rpm on torque of rotary tiller (Fig. 4).

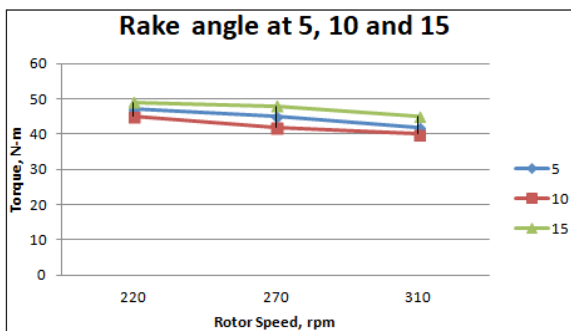


Fig. 4: Effect of Rotor speed and rake angle on torque

The effect of four forward speeds (F) viz., 2.0, 2.5, 3.0 and 3.5; three rotor rpm (R) viz., 220,270 and 310; three rake angle (B) viz., 5, 10 and 15 degree on torque have been analysed in this experiment. Table 2 shows analysis of variance for torque.

Table 2: ANOVA for Torque at different forward speed, rotor rpm and rake angle

SV	df	SS	MS	F
Treatment	35	1579.727292	45.135065	260.5288**
Forward Speed (F)	3	114.727662	38.242554	220.7438**

Rotor rpm (R)	2	211.291250	105.645625	609.8081**
Rake angle (B)	2	123.422639	61.711319	356.2103**
FR	6	321.786713	53.631119	309.5698**
RB	4	556.031111	139.007778	802.3813**
FB	6	48.398657	8.066443	46.5612**
FRB	12	204.069259	17.005772	98.1608**
Error	70	12.127083	0.173244	1.0000
Total	107	1889.605625	17.659866	101.9363
C.V. (Treatment) :: 0.96%				

** Significant at 1 per cent level.

CONCLUSION

Optimal design parameters of rotary tiller blade's rake angle were determined for total torque requirements. The highest torque requirement was exhibited at 3.5 kmph with a rotor speed of 220 rpm. The optimum torque results in most effective and optimum soil tillage operation is achieved. This research focuses on the design optimization of rotary tillers blade's rake angle. From the results, it has been observed that the angle of 10 degree and machine forward velocity of 2.5 kmph leads to better control on torque requirement. The results of this study should be verified by further tests on rotary tillers according to the results offered in this paper.

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