Design and Fabrication of Rotary Tiller Blade

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Abstract - *Rotary tiller blades are used to achieve advantages of lower draft requirements better soil breakup and more efficient inversion and trash mixing. Since these blades are fabricated in different shapes and dimensions and this study is aimed at development of rotary blades in order to reduce the energy requirement for tillage by optimizing the parameters which affect the cutting force of the rotary blades. For this reason the mathematical model of power requirement of the rotary blades and the equations of surface area per unit volume of soil tilled as well as cutting angle are determined and computer programs to sole those equations are developed. From the results of computer programs, blade geometrical dimensions corresponding to the minimum and optimum blade surface area per unit volume of soil tilled and cutting angle are selected to fabricate the rotary blades.*

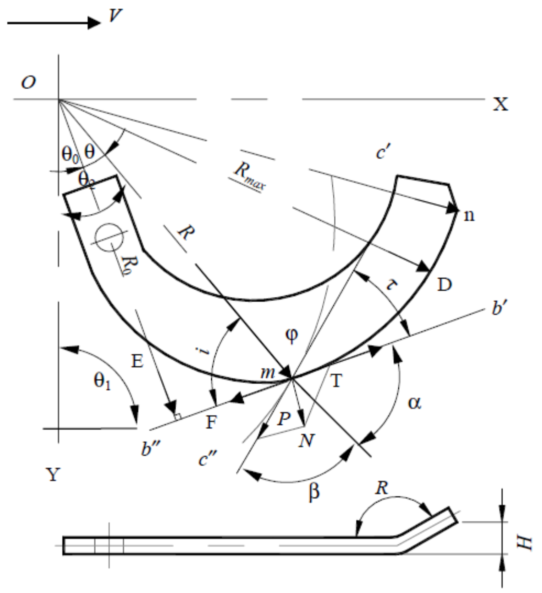
Key Words: *Rotary, Tiller blades, Soil, Dimensions, Power requirement.*

1. INTRODUCTION

A **rotary tiller**, also known as a **rototiller**, **rotavator**, **rotary hoe**, **power tiller**, or **rotary plough** (in US plow), is a motorized cultivator that works the soil by means of rotating tines or blades. Rotary tillers are either self-propelled or drawn as an attachment behind either a two-wheel tractor or four-wheel tractor. For two-wheel tractors they are rigidly fixed and powered via couplings to the tractors' transmission. For four-wheel tractors they are attached by means of a three-point hitch and driven by a power take-off a rotary tiller [1,4] is a mechanized cultivating implement that is used to prepare soil for planting. Rotary tillers are primarily designed to break up sod or compacted earth for new vegetable gardens, flowerbeds, or lawns. They are also used to plow furrows for seeds or seedlings, as well as dig planting holes. The rotary tiller is especially well-suited for use in small space gardens. A tiller [3.4] is also used for maintenance tasks in existing gardens. These include weeding and aerating around growing plants. The tiller tines also help to mix manure, spent plants, and other organic material into the soil. Some gardeners use their rotary tillers to make their own homemade potting mixture. A rotary tiller is engineered with two sets of specially-designed circular blades or tines that are attached to a motorized horizontal shaft. The tiller spins the tines, digging them down into the topsoil to a pre-determined depth. The tines loosen and lift the soil, turning it over. Rotary tillers fall into one of three categories based on the positioning of their tines front tine tillers, rear tined tillers, and tractor-mounted tillers. The front and rear tined tillers have their tines mounted at the front and back of the machine respectively. Each type of tiller is best suited for different purposes. Types of rotary tillers Front-tine and rear-tine tillers are the types most commonly used for lands tasks. For larger-scale operations, tractor-mounted tillers are appropriate.

Front-tine tillers are most popular for smaller landscaping and gardening situations. These tillers are usually somewhat smaller in nature and are easier to handle during operation than pull-behind units. Horsepower ranges for this type are commonly from 2 to 8 hp, although certain models may have larger power plants. Front-tine tillers are versatile. You can use them, with care, in tight places without causing unwanted damage to plant life or property. In fact, you usually can control tilling operation to within an inch or 2 of plantings and other desirable objects. Rear-tine tillers are usually larger by nature. You use them for larger jobs in landscaping, gardening, renovating and constructing. Because the tines are rear-mounted, work areas are limited to more open spaces away from buildings, sidewalks and other objects. Rear-tine tillers are typically more heavy-duty with power ranges from about 3.5 hp and up, depending on the manufacturer. The unit's size and type of tine determines it's tilling width. Widths range from 6 inches on small stationary- and adjustable-tine tillers up to 48 inches or greater on the larger heavy-duty tillers, depending again on the manufacturer. Larger-type tillers are usually tractor-mounted and range in size from 36 inches up to 13.5 feet. These tillers are usually not appropriate for most landscaping and gardening operations. However, they are excellent for large landscape and construction projects. Tips for tiller operation [2] your tiller's mode of operation depends on many factors. Size, tine-type or location, tilling width, power rating, the task you will be doing, soil type and the desired soil results all effect the method and rate of tiller operation. Most front-tine tillers have a depth-stick feature you can adjust to the desired working depth to control the tilling rate and penetration. Harder compacted soils demand a slower tilling speed, and you should set the depth stick shallow so you don't overwork the equipment or the operator. You must make numerous passes over the same area until you've reached the desired soil condition and depth. For incorporating soil amendments or deep-tilling established beds, adjust the depth stick to a middle-to-deep setting. This allows the tiller to penetrate to a desired depth without moving forward too quickly. The size and diameter of your front-tine tiller blades [2] determine the tilling depth you can accomplish. Usually 4 to 8 inches is desirable for this operation. A self-propelled/drive action usually controls the rate of operation of rear-tine tillers. These units commonly offer variable ground speeds along with variable tilling speeds for operating in all different soil conditions. Most rear-tine tillers, like front-tine tillers, have a depth-stick attachment for controlling tilling depth and balancing the tiller. In many cases, the rear-tine tillers offer greater control and ease of operation. However, most rear-tine tillers also have safety shields over the tilling unit. Thus, some do have limitations on tilling depth, along with operating-area restrictions, which you should keep in mind when purchasing a unit. There are two types of rear tined tillers counter rotating tines (CRT) and standard rotating tines (SRT). CRT models have tines that rotate towards the rear, making it easier to till compact soil, while SRT models have tines that rotate in the forward direction. Some rear tined tillers are designed with reversible tines, providing the user with the benefit of both functions. Motorized rotary tillers dig deep within the soil. The most basic type of tilling is simply turning over large portions of soil with a garden spade or shovel. Specialized tilling tools lift soil, flip soil and break clumps of dirt into smaller particles. Tilling not only improves the workability and drainage of soil but also allows the garden to incorporate mulch, compost and fertilizers with native soil. Task-specific tilling tools, called tillers and cultivators, are available as both manually operated hand tools and engine-driven machines. The term hand tiller generally refers to pronged tools that mount to poles or short, straight handles. The most common type of hand tiller has a metal head of three claw-like prongs, similar in design to a back-scratching tool. To use this type of tiller, the gardener plunges the prongs into the soil and pulls toward his body to move and break soil. Another common type of hand tiller, often called a hand cultivator, has a head of straight prongs that jut outward at various angles to form a web of sharp points. When plunged into the earth and rotated, the hand cultivator breaks up soil. Like the hand tiller, the hand cultivator mounts either to a short, straight handle for working close to the ground or a long pole for working from a standing position. The power cultivator shares the arrangement of its tilling blades with the hand tool of the same name. However, unlike the manually-operated hand cultivator, the power cultivator's web-like arrangement of prongs rotates with force supplied by an electric or gas-powered motor. The power cultivator's blades sit at the end of a long, curved body, typically similar in design and appearance to the body of a string trimmer. To use the power cultivator, the gardener holds the tool waist-high, grips its handle and pulls the trigger to activate the prongs' rotation. Common among both amateur and professional projects, the rotary tiller turns and breaks soil with a set of rotating blades. The rotary tiller drives its blade with a gas-powered motor. Wheels mounted aside the engine allow the machine's operator to push the machine with a waist-high, walk-behind handle. The rotary tiller's set of blades often stretch 2 or 3 feet wide and plunge several inches to more than a foot below the soil's surface. Aside from tractors, rotary tillers are the most expensive tilling tool. However, most tool rental companies keep rotary tillers on hand for hourly or daily.

2. GEOMETRY OF SCOOP-SURFACE OF TILLER BLADES



The shapes' scoop-surface and cutting function of tiller blades.

Fig 1. Function of Tiller blades

The geometry of tiller blades is considered to be the most important factor in their design, since both the shape of the blade tip and the length of the tiller blade facilitate cutting. The blade tip width exceeds the blade length. The contact between the blade and the soil moves slowly from the handle near the center of the shaft to the blade length. The blade tip cuts the intact grass at the boundary between the blade length and the blade tip. The grass can also be thrown away or torn off by the outward rotation. This class of blade performs well in the soil in Asia, and is extensively adopted in Taiwan and Japan. Figure 1 illustrates both the blade tip and the blade length, as segments Dn and ED, respectively. The blade length must meet two conditions, namely the absence of intertwisting and low drag force. During cultivation.

The cutting conditions are $T \geq$ □F (Figure 1)

$$T = N \cot\tau$$

$$F = N \tan\phi$$

$$\cot\tau > \tan\phi$$

$$\tan(90^\circ - \tau) > \tan\phi$$

$$90 - \tau > \phi \therefore \tau < 90 - \phi$$

Where

ϕ = denotes the friction angle of the rootstock with
Respect to the blade edge
T = cutting force (in N)
F = friction force (in N)
N = normal force (in N)
i = angle between tangent & R
θ = inclination angle from the y axis
τ = angle between tangent & the line R
R_o =the line perpendicular to the tangent form the center axis of load applied

The blade length is part of an Archimedean curve whose Parametric equation is,

R = *R* (1 + K θ) (1)

Consider *i* as the angle between *b'b"* and line *Om*;

$$\theta_\circ + \theta = \theta_2$$

$$\theta_1 = i + \theta_2$$

$$\theta_1 \therefore i = \theta_1 - \theta_2$$

$$\tan i = \tan(\theta_1 - \theta_2)$$

$$= \frac{\tan(\theta_1 - \theta_2)}{1 + \tan\theta_1 \tan\theta_2} \quad (2)$$

However,

$$\tan\theta\, i = \frac{dx}{dy} \quad (3)$$

Thus, when θ is considered to be parametric, *R* = *R*=(1 + *K* θ) a polar coordinates equation for the curve of tiller's blade scoop surface can be change to an orthogonal coordinate equation.

$$x = R(\theta)\sin\theta 2$$

$$y = R(\theta)\cos\theta 2$$

Eq. (3) gives

$$\tan\theta i = \frac{dx}{dy} = \frac{dx/d\theta}{dy/d\theta} = \frac{R'(\theta)\sin 2 + R(\theta)\cos\theta 2}{R'(\theta)\cos 2 + R(\theta)\sin\theta 2}$$

$$= \frac{R\prime(\theta)\tan\theta 2 + R(\theta)}{R\prime(\theta) - R(\theta)\tan 2} \quad (4)$$

Substituting Eq. (4) into (2) yields,

$$\tan i = \frac{R(\theta)(1+\tan^2\theta 2)}{R\prime(\theta)(1+\tan^2\theta 2)}$$

$$i = tan^{-1}\frac{1+K\theta}{K}$$

$$= \tan -1\,\frac{1+(1x45^\circ)}{1} = 61^\circ$$

$$i = 61^\circ$$

Although the angle *i* increases with the angle θ , the angle τ decreases as determined by the graphical analysis. The low τ positively affects the cutting work.

The spiral trajectory and rotary radius of the blade, given by R. can be computed from the following parametric Eq. (6). These equations have the same result as Eq. (5).

$$\alpha = \alpha_t + \left\{tan^{-1}\frac{n\pi\sqrt{H(2R-H)}}{30V - n\pi(R-H)}\right\} + 90^\circ$$

$$\alpha = 61^\circ$$

Where
n= rotary speed (in rpm)
V = Forward speed of tractor (cm/sec)
H = depth of working (in cm)
R = rotation radius of the blade (in cm)

2.1. Design Calculation For Existing Model

1.Radius R = 11.25mm
2. R_{max} =R+deflection
= 11.25 +1.60
=12.85 mm
3. θ_1 = 90°
4.P=load applied in newton
5. i = 61°
6.R_0=R+perpendicular distance
=11.25 +.75
=12mm
7.C^1=R_{max} +1.0=13.85mm
8.α =61°

$$9.\beta = \frac{tan2\alpha}{5} = \frac{tan(2x61^\circ)}{5} = 85.526^\circ$$

$$10.\phi = 180 - (\alpha + \tau)$$

$$= 180 - 61 + 38$$

$$= 81^\circ$$

11.θ_0 =120-θ_1 = 120-90=30 °

3. EQUATIONS AND CALCULATIONS

3.1. Equations For The Cultivation Angle Curves

The trajectory curve of the blade, the rotary radius direction and the tangent curve of the trajectory con¬verge at one point, generating a cutting angle.

$$\beta = cos^{-1}\left\{\frac{30v}{R}\sqrt{\frac{H(2R-H)}{(30V)^2 - 60nV(R-H) + (Rn)^2}}\right\} \quad (5)$$

$$\beta_1 = \beta - \gamma$$

The above equation is utilized to compute the moving speed of the cultivation

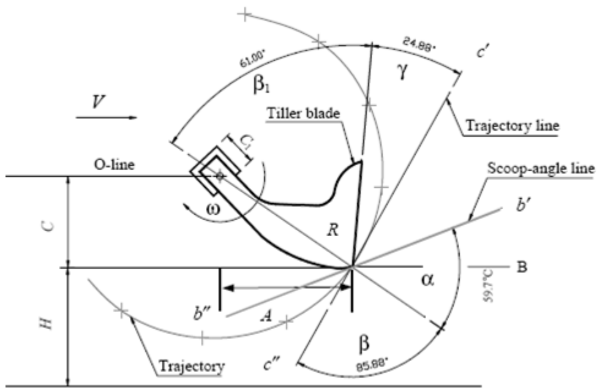


Fig 2. The trajectory curves of the different angles of the tiller blades while plowing.

3.2 Calculation

$$\beta = cos^{-1}\left\{\frac{30v}{R}\sqrt{\frac{H(2R-H)}{(30V)^2-60nV(R-H)+(Rn)^2}}\right\}$$

$$\beta = cos^{-1}\left\{\frac{30x3}{35}\sqrt{\frac{20(2x35-20)}{(30x3)^2-(60x300x3)(35-20)+(35x300)^2}}\right\}$$

β = 85.526 °

$\beta_1 = \beta - \gamma$ where γ = 24.88°

$\beta_1 = 85.526° - 24.88°$

β_1=61°

Fig 3 New Blade Design

3.3 .Design Calculation

1. β = 85.526 °
2. $\beta_1 = \beta - \gamma$

$\gamma = 25°$ relief angle

$\beta_1 = 85.526° - 24.88° = 61°$

3. C_1=16mm (standard mesurment)
4. C=35mm (inclined position)
5. A = 38mm (horizontal position)
6. $H = C + \frac{(\cos\beta)}{2}$

$$H = 35 + \frac{(\cos(61°))}{2}$$

$$H = 42mm$$

3.4. Specification

1. The blade is high temperature salt holistic quenching; Tempering medium temperature and hardness is HRC40 to 55.
2. Specification 130mm*50mm*2mm(length*width*thickness)

Table 1. Operational Model for Different types of Tiller Blades.

Blade types	V(cm/sec)	N(rpm)	γ	a (cm/sec²)
Cultivation blade	20-30	300-400	5°-10°	0-ν
Cultivation broken bit blade	30-40	250-300	10°-15°	2-3ν
Cultivation wasteland blade	40-60	150-250	15°-20°	0-ν
Tiller blade	40-60	150-300	20°-30°	2-3ν
Cutting blade	20-30	250-500	20°-30°	2-3ν

Table 2. Comparison between Tiller Peak and Maximum Torque across Different Scoop-Angles

Scoop-angle	90°	80°	60°	40°
Peak (μ) kgf	50-55	42-46	47-54	50-58
maximum torque kgf	45-50	38-41	42-49	45-52
Relief angle	-4.50°	5.10°	25.10°	45.10°

In polar coordinates using tiller blades with a relief angle of by **γ=** 25° and cultivation blades given by **γ** =10° The polar curve of the tiller blade indicates that a plowing and throwing angle of smaller than 25□in the tiller blade results in highly effective plowing and throwing functions. A plowing and throwing angle of below 90° for the cultivation blades minimizes the friction exerted on the blade as it enters the soil, minimizing cracking during plowing.

Table 3. Trajectory data in polar coordinates for Tiller blades and cultivation blades

	Tiller blade (γ=25°, a =3v			Cultivation blade (γ = 10°,a =v)	
	r(cm)	θ		r(cm)	θ
P_0	23.00	12°33'	P_0'	23.00	12°33'
P_1	20.30	5°18'	P_1'	20.78	-3°58'
P_2	17.70	-1°19'	P_2'	18.57	-20°09'
P_3	15.11	-7°31'	P_3'	16.32	-35°49'
P_4	12.56	-12°19'	P_4'	14.09	-50°46'
P_5	10.24	-15°30'	P_5'	11.91	-64°37'
P_6	7.86	-14°10'	P_6'	9.74	-76°17'
P_7	6.01	-6°18'	P_7'	7.74	-84°49'
P_8	5.03	12°11'	P_8'	6.05	-87°21'

Table 4. Technical Specifications of Power Tiller

Specification	Value
Number of cylinder	1
Engine maximum power at 2400 rpm	13 hp
Engine maximum torque at 1900 rpm	4.2 kh-m
Rotational speed PTO shaft	540 rpm
Total weight	120 ka

4. Specific work method (SWM)

In order to design a rotary tiller the special work of the tiller and also the performable work of the tractor should be determined. The specific work of rotary tiller is defined as the work carried on by rotary tiller at each rotation of tillage blades per the volume of broken soil. Which could be calculated by the following equation

$$A = A_0 + A_B \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

Where

A_0= Static Specific Work

A_B = Dynamic Specific Work

$$A_0 = 0.1\ C_0\ K_0 \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

$$A_B = 0.00\ 1\ a_u u^2 \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

$$A_B = 0.001 a_v V^2 \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

Where

C_o = the coefficient relative to the soil type.

K_o = the specific strength of soil (kg/dm3).

$$a_v = a_u\ \lambda^2 \quad \left(\frac{\text{Kg}-\text{s}^2}{\text{m}^4}\right)$$

Where

$$\lambda = \frac{u}{v}$$

The performable work of the tractorcould be calculated by the following equation

$$A_C = \frac{7.5 N_C \eta_C \eta_Z}{vab} \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

Where N_c. is the power of tractor (hp), v is the forward Speed (m/s), is the traction efficiency that its value for the forward rotation of the rotary tiller shaft is 0.9 whilst the value for the reverse rotation of the rotary

Tiller is considered between 0.8-0.9. Is the coefficient of reservation of tractor power which is between 0.7-0.8 *a* is the rotary tiller work depth (m) and *b* is the tiller work width (m).

The forward rotation of the rotary tiller shaft, the tillage power consumption is decreased 10-15 %. in comparison with the shaft reverse rotation. Hence, in this design the forward rotation was considered for the rotary tiller shaft to reduce the tiller power consumption and also utilization of the rotary tiller thrust force at the forward rotation. In designing the rotary tiller. The hard condition of the soil was considered. The values of *Co, K,* and *a,,* in very heavy soils are 2.5. 50 (kg/dm^3) and 400 (kg.s^2/m^4) respectively Therefore the static special work of the rotary tiller could be calculated by replacing the values in the equation (2)

$$A_0 = 0.1 x 2.25 x 50 = 11.25 \quad \left(\frac{\text{Kg}-\text{m}}{\text{dm}^3}\right)$$

5. DESIGN OF THE POWER TRANSMISSION SYSTEM

After calculating the rotor speed, a transmission system should be designed for the rotary tiller. The coefficient of power transmission for the rotary tiller could be calculated by the following equation

$$i_c = \frac{\eta_d}{\eta_a}$$

In the equation. η_a and η_d are the rotational speed of the power tiller PTO shaft (rpm) and the rotational speed of the rotary tiller rotor (rpm). Respectively. The rotational speed of the power tiller selected for this design is 540 rpm .The rotational speed of the rotary tiller rotor also calculated at the previous section. By representing the values of η_a and η_d at the equation (1). The coefficient of power transmission will be obtained

i_c= 0.127

This means that a power transmission system should be selected for this design to give the calculated coefficient of speed alteration equal to 0.127.

6. RESULTS AND DISCUSSIONS

The Figure 5 and 6 denotes the performance of Old blades and New Blade. Which indicates the new design calculation of blade improve soil breakup, inversion and trash mixing. The new design calculation blade have some following advantages and uses.

Fig 4. Old blade Performance

Fig 5. New Blade Performance

i. Rotary Tiller produces a fine seed bed with one or two operation before or after rains. it is most suitable for removal of sugarcane stubble, wheat stubble, caster, grass, vegetables etc
ii. It retains soil moisture and increases soil porosity and aeration, which enhance germination and growth of crops.
iii. It can be used in dry and wet paddy condition for pudding.
iv. It tilts soil finely, incorporating every kind of crop residues into the soil and improves the organic structure of soil.
v. Specially designed Blade Rotor reduces load on tractor and avoids tyre slippage and reduces diesel consumption.
vi. Rotary tillers can also be used for road-making.
vii. Hand operated rototillers were modified to clean the exterior of oilfield pipes.

7. CONCLUSION

Optimal working width and optimal diameter of rotary tiller proportionate to the power tiller are determined in order to achieve to the maximum field efficiency for the rotary tiller and to minimize the consumed materials in the building of this machine. The rotary tiller is designed with the working width of 70 cm having 3 flanges on the rotor shaft and four blades on each flange. It is also concluded that the power tiller selected for supporting the rotary tiller, could only pull the rotary tiller at first heavy gear. A rotational speed of 69 rpm is selected for the rotor. The optimal value of rotor's diameter considering the values of maximum tangent force is determined about 3.94 cm. This paper presents a theoretical method for rotary tillers design.

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