

Regression Modeling of Fuel Consumption Optimization of Rotary Blades of Power Tiller Under Sandy Clay Loam Condition

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ABSTRACT

Fuel consumption optimization is one of the selection criteria of tractor tillage implementation. However, studies that concern with various rotary blades of power tiller fuel consumption optimization model under sandy clay loam conditions has not so far been determined and documented. The objectives of this paper were to modify the fuel consumption mathematical model, optimize the objective function and to evaluate the efficiency of a “pick”, a “C”, an “I”, an “L” and a “J”-shaped rotary blades. Ultimately a modified fuel consumption mathematical model accounting for the integrated system parameters of various rotary blades was derived. The derived system parameters in this model include rotational velocity (N), rotor radius (R), depth of tillage (L_d), cutting width (Bw), velocity ratio ($\tilde{a}$) and volume of soil tilled (V_{st}). Optimal solutions of these system parameters as well as the corresponding fuel consumption were obtained. To validate the model and test, sensitivity and correlation coefficient analysis were used. Results from the sensitivity analysis revealed that depth of tillage and cutting width were found to be highly significant parameters influencing fuel consumption requirement. Amongst the five rotary blades tested, however, depth of tillage of the “L” and the “J”-shaped were the most significant parameters to change fuel consumption requirement. The output of sensitivity analysis from the rate of depth of tillage showed a trend of reduction from 28.57% to 18.18 % for the “L” and 54.55% to 26.09 % for the “J”- shaped rotary blade. Consequently, fuel consumption rate reduced from 0.0843% to 0.0841% for the “L” and 0.272 % to 0.271 % for “J” -shaped. However, the cutting width of the “J” -shaped increased from 6.67 % to 7.69 %, while fuel consumption requirement rate increased from 0.017 % to 0.023 %. Similarly, correlation coefficient analysis revealed that depth of tillage and cutting width correlation coefficient (r) was predicted to be 0.7 and 0.5, respectively. Consequently, the p-value for depth of tillage was significant ($p < 0.05$), while for the cutting width was highly significant ($p < 0.01$).

Key words: fuel consumption, rotary blades, system parameters, sandy clay loam

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INTRODUCTION

Fuel consumption requirement is a major current issue of agricultural machinery management strategy. Sufficient energy is needed in the right form and at the right time for adequate crop production. One way to optimize fuel consumption in agriculture is to determine the efficiency of methods and techniques used. With the current increase in world population, fuel consumption needs effective planning.

Fuel consumption by power take-off (PTO) driven power tiller is a primary source of power for small land preparation in field conditions. Rotary tiller blades are the attachments of power tillers. They receive power from the engine of the tractor through the PTO shaft to the rotor shaft. The PTO shaft transfers mechanical power from the engine of the tractor to the rotary tillers (ASAE, 1998). The power assists the blades of the rotary tillers to disturb the surface of the top soil.

Tillage is the most energy consuming operation in crop production system, and rotary tillers are power intensive process among other tillage implements (Godwin *et al.*, 1984). This is because they cut the untilled soil and pulverize the soil clods simultaneously to give optimum soil pores for better soil moisture and nutrient holding capacity for the desire of plant roots.

There are several types of rotary blades commonly available in saturated and unsaturated soil conditions, namely, a “pick”, a “C”, an “I”, an “L” and a “J”-shaped. They are unlike in pattern of soil cutting operation due to different shapes, configurations, and system parameters. System parameters include rotational velocity, rotor radius, and depth of tillage, cutting width, velocity ratio and volume of soil tilled per second.

Fuel consumption is limited by the amount of work they have accomplished, soil

types and conditions, topography, particularly configurations and system of parameters. Size of the soil clods are the most dominant parameter determining fuel consumption requirement. The higher volume of soil tilled the lower soil pore and the higher tillage operation cost.

Many investigations have been conducted to evaluate the performance efficiency of rotary blades (Adams and Furlong, 1959; Beeny and Khoo, 1970, Hendrick and Gill, 1971; Salokhe *et al.*, 1993; Niyamapa *et al.*, 1994) under laboratory investigation and actual field conditions. Fuel consumption is one of the most significant measurement criteria of the performance of rotary tillers. Performance evaluation of rotary tillers assists either to determine fitness, optimum parameters, and power and energy requirement or develop the design of the implements. This kind of mechanism is very essential. However, material and energy input is considerably ineffective. Besides, using a mathematical model assists to give update information and remarkably reduces investment of inputs in the system.

Studies regarding various rotary blades of power tiller fuel consumption optimization model under this study has not so far been determined and documented.

The objectives of this paper were to modify fuel consumption mathematical model, optimize the objective function and to evaluate the efficiency of a “pick”, a “C”, an “I”, an “L” and a “J”-shaped. The result of this study will have practical significance and beneficial directly to small holders under sandy clay loam, as provide guidance to managers, planners, and designers in estimating the performance of tractor–tillage implements, select the best conservation practices for farm equipment and a common format for various rotary blade fuel consumption model with integrated system parameters.

MATERIALS AND METHODS

Mathematical model

A mathematical model is a symbolic representation and essential aspects of an existing system in usable form and gives updated information for agricultural machinery managers, designers and investigators. Optimization modeling is described as a branch of mathematical modeling concerned with finding the best solution to a problem and finding of maximum or minimum values of a function in a given system (Rao, 1985). Optimizing fuel consumption mathematical model was described as integrated system parameters with corresponding fuel consumption requirement of various rotary blades in the present study. The process of a model and optimization is summarized in Figure 1.

Numerous studies have been reported on the performance and design parameters of various rotary tillers. Niyamapa *et al.* (1994) determined the design parameters of rotary cultivator, namely, depth of tillage, rotor and forward speed influenced on the power requirement to cut and throw the soil clods under soil bin laboratory study and

recommended the clod size development for soybean cultivation. Soehne (1957), under soil bin operation, studied the influence of rotary blade various geometric factors (cutting width, cutting angle, radius of curvature and operational speed) influenced on specific work requirement. Adams and Furlong (1959) studied the performance of the “pick”, the “L”, and the “C”- shaped blades on rotor horse power and soil reaction forces. Beeny and Khoo (1970) conducted some experiment to study of “I”, “L” and “C”- shaped rotary blades power requirements and forward thrusts.

Rotational velocity, depth of tillage, and ratio of rotor peripheral and forward velocities were rotary blade design parameters influenced on all phases of rotary tiller operations, from the power requirement to the final soil condition (Hendrick and Gill, 1971a).

Fuel consumption models

There are many rotary tiller fuel consumption models reported by a number of researchers and investigators. Fuel consumption model for a particular operation was exhibited by Grisso *et al.* (2001) as:

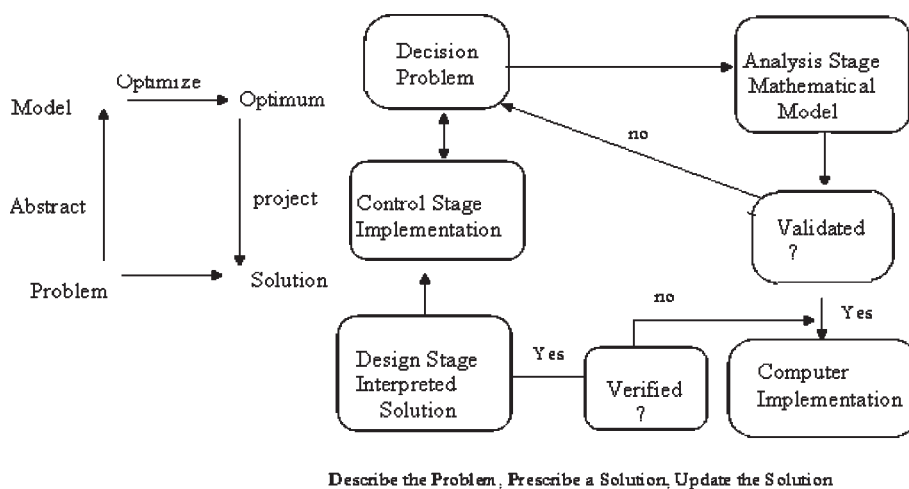


Figure 1 Procedure of optimization (Modified from Eudoxus Systems of Mathematical Programming 1995 – 2003)

$$Q_i = Q_s * P_T \quad (1)$$

Where Q_i is estimated fuel consumption for a particular operation, l/hr; Q_s is specific volumetric fuel consumption for the given tractor, l/kW and P_T is total tractor power (PTO equivalent) for the particular operation, kW.

As cited by American Society of Agricultural Engineers standards (ASAE, 2001) average fuel consumption of a tractor operating under a range of load conditions was determined as:

$$F_c = 2.64X + 3.91 - 0.203\sqrt{738X + 173} \quad (2)$$

Where F_c is fuel consumption in l/kWhr; X is ratio of equivalent PTO required by operation divided by the maximum available PTO.

Grisso *et al.* (2004) developed a generalized fuel consumption model and is computed as the following equation:

$$Q = (0.22X + 0.096) (1 - (0.0045XN_{Red} + 0.00877N_{Red})) PTO \quad (3)$$

Where Q is diesel fuel consumption at partial load and full/reduced throttle, l/hr; X is ratio of equivalent PTO power to rated PTO power, decimal; N_{Red} is percentage of reduced engine speed for a partial load from full throttle, % and PTO is rated PTO, kW.

Kheiralla *et al.* (2004) formulated fuel consumption model of rotary tiller in Serdang sandy clay loam soil as:

$$F_c = 0.2156PTO + 6.2347 \quad (4)$$

Where F_c is fuel consumption rate l/hr.

Suresh and Varshney (2005) calculated specific fuel consumption of power tiller engine

by dividing the fuel consumption (l/hr) with drawbar power (kW) and formulated the general form of empirical equation to relate fuel consumption and drawbar power on tilled land as follows:

$$SF_c = a + bB + cP^2 + eP^2 \quad (5)$$

$$F_c = a + bB \quad (6)$$

Where SF_c is specific fuel consumption, l/kWh, F_c is fuel consumption, l/hr; kW, a , b , c and e are parameters.

As the above mentioned models the one developed by Kheiralla *et al.* (2004) that described only one configuration of rotary blades was employed the latest as it was used for sandy clay loam soil was similar to this study.

Power tiller

The power tiller is a multi-purpose hand tractor designed for small paddy and dry land preparations up to 2.5 ha. Potential of a power tiller would make available in hilly areas and narrow bench terraces are difficult to negotiate, where farmers cannot afford to buy tractors. It creates the least disturbance of soil structure, can cross over the bunds separating the small holdings, does not sink in wet paddy fields, can climb steep hill slopes and conveniently operates in bench terraces and can manoeuvre the narrow pathways of rural areas. Power tiller reduces the drudgery of long walking in the field during operations as compared to operations by bullocks. Power tiller demands less body effort as compared to operation by bullocks. The bullock implements require the hand and body pressure to achieve depth and alignment of the implement in use, whereas, in power tiller the implements are mostly self guided. This reduces human drudgery to a great extent. Farming operating exceeded more than 8 hours per day. Power tiller would be more suitable in the smaller holdings as an immediate alternative to animal power.

A typical power take-off driven rotary power tiller and transmission system are illustrated in Figure 2 and 3, the engine power was 3.7 to 9.0 kW (Mamansari,1998) and the traveling speed ranged from about 0.25 to 0.4 m/s for hard soil and 0.40-0.50 m/s for normal soil condition (Sakai,1973). Approximately 4.77 kW and 0.25 to 0.4 m/s were used in the present study.

Rotary blade design parameters

Five different types of tiller rotary blades of power tiller (Figure 4), a “pick”, a “C”, an “I”, an “L” and a “J”-shaped with their system parameters such as rotational velocity, rotor radius,

depth of tillage, cutting width, peripheral and traveling speed ratio, and volume of soil tilled were constraint parameters affected fuel consumption requirement and their dimensional values were given by some researchers (Table 1). Cutting width of 10 to 22 mm, rotor radius of 220 mm, depth of tillage of 50 to 100 mm and rotational velocity of 150 to 300 rpm under soil bin unsaturated lateritic sandy clay loam condition for a “pick” (Sarasswat,1987), 35 to 45 mm of the cutting width and 225 to 245 mm of rotor radius for the “C”-shaped (Sakai, 2000), 127 mm of cutting width of the “I”, the “C” and the “L”-shaped (Beeny and Khoo,1970), 45 to 80 mm

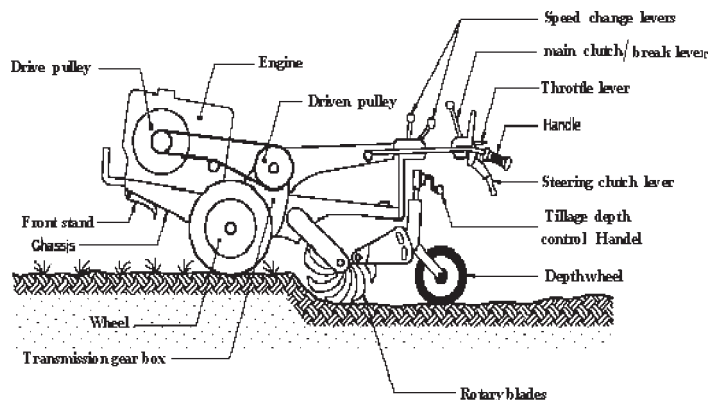


Figure 2 Typical PTO - driven rotary power tiller (Sakai, 1973)

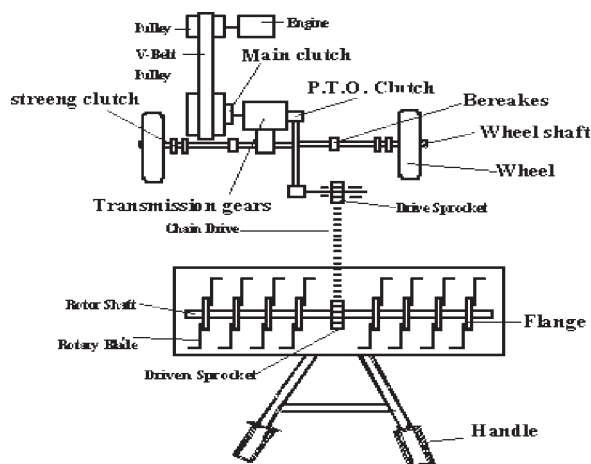


Figure 3 Transmission system of power tiller (Sakai, 1973)

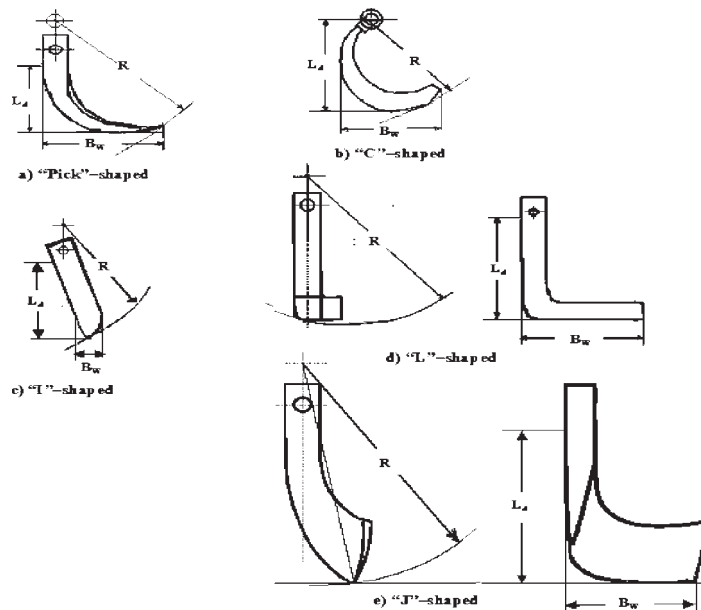


Figure 4 Type of rotary blades.

R , rotor radius; L_d , depth of tillage; B_w , Cutting width

of cutting width and 260 mm of rotor radius for the “L”- shaped (Yatsuk *et al.*, 1983), 60 mm of cutting width and 250 mm of rotor radius for the “J”- shaped (Kataoka and Shibusawa, 2002).

Modification and description of the model

Model selection criteria

1. As cited in the literature review the soil type of the study was similar to the Kheiralla *et al.* (2004) rotary tiller fuel consumption model which was tested under

unsaturated sandy clay loam.

2. Power take-off (PTO) in the Kheiralla *et al.* (2004) fuel consumption model was converted into system parameters with corresponding fuel consumption requirement following the description by Berger *et al.* (1963), Bernaski *et al.* (1972) has used for various rotary blades in the present study.

Based on the system parameters with corresponding fuel consumption requirement was evaluated the performance of each rotary blades in terms of fuel consumption requirement. Detail

Table 1 Design parameters of various rotary blades.

Types of rotary blade	Rotational velocity (N) rpm	Rotor radius (R) m	Depth o tillage (L_d) m	Cutting width (B_w) m
“Pick”-shaped	150 to 300	0.17 to 0.220	0.050 to 0.100	0.01 to 0.022
“C”-shaped	150 to 300	0.245 to 0.250	0.050 to 0.150	0.035 to 0.045
“T”-shaped	150 to 300	0.200 to 0.225	0.050 to 0.150	0.035 to 0.065
“L”-shaped	150 to 300	0.235 to 0.260	0.050 to 0.150	0.045 to 0.080
“J”-shaped	150 to 300	0.235 to 0.250	0.050 to 0.350	0.040 to 0.060

analysis is exhibited as the following

From Kheiralla *et al.* (2004) the empirical model was constrained by power was best expressed by the following regression equation.

$$F_c = 0.2156PTO + 6.2347 \quad (7)$$

Where F_c is fuel consumption rate h/hr, PTO is Power take-off, kW. Further for investigation of the model, Barger *et al.* (1963) PTO power was defined by the torque and rotational velocity of the rotary machine. The rotary power was exhibited by the following equation

$$PTO = 2\pi NF_T / 60000 \quad (8)$$

Where PTO is power take off supplied to the rotor of rotary tiller, kW, N is rotational velocity, rev/min and F_T is rotor torque, Nm. Consequently, the rotor torque was defined by peak peripheral force $K_p = F_p K_V$ (Bernacki *et al.*, 1972), C_V is factor = 1.5 for stoneless soil, $C_V = 2$ for stony soil. Therefore $C_V = 2$ for the present study. The peak moment on the rotor equals to the torque, $F_T = K_p R = 2RF_p$. Peripheral force F_p was exhibited by Bernacki *et al.* (1972) in the following equation

$$F_p = \left(\frac{750P_e}{V_p} \right) \eta_c \eta_z \quad (9)$$

Where F_p is peripheral force, N, P_e is engine power of the power tiller, $P_e = 6.45$ hp; V_p is peripheral speed of rotary blade, m/s; η_c is power tiller efficiency mounting to about 0.9 for machines with concurrent revolutions, η_z is coefficient including a reverse of power tiller power mounting to 0.7 to 0.8,

Volume of soil tilled and velocity ratio were given (Hendrick and Gill, 1971) as

$$V_{ST} = B_W L_d V_f \quad (10)$$

Where V_{ST} is volume of soil tilled per

second, $10^{-6}m^3$, B_W is cutting width, m, L_d is depth of tillage, m; V_f is machine forward velocity, m/s,

$$\text{Velocity ratio, } \frac{V_p}{V_f}$$

$$\lambda V_f = V_p$$

$$V_f = \frac{V_{ST}}{B_W L_d} \quad \text{putting in } \lambda V_f = V_p \text{ has}$$

$$\text{become } \frac{\lambda V_{ST}}{B_W L_d};$$

$$\text{Substituting } \frac{\lambda V_{ST}}{B_W L_d} \text{ into Eqn (9) the}$$

$$\text{peripheral force is obtained } \left(\frac{750P_e B_W L_d}{\lambda V_{ST}} \right) \eta_c \eta_z.$$

Then

$$F_T = 2RF_p = \left(\frac{1500P_e B_W L_d R}{10^{-6} \lambda V_{ST}} \right) \eta_c \eta_z \quad (11)$$

$$\text{Substituting } \left(\frac{1500P_e B_W L_d R}{10^{-6} \lambda V_{ST}} \right) \eta_c \eta_z$$

in place of F_T in Eqn (8), the PTO become as:

$$PTO = \frac{539691.42 N B_W L_d R}{\lambda V_{ST}} \quad (12)$$

Substituting Eqn in to Eqn (7), the modified fuel consumption model has the formation:

$$F_c = 116357.47 (N * R * L_d * B_W / \lambda * V_{ST}) + 6.2347 \quad (13)$$

In order to analyze the optimum fuel consumption requirement for various rotary blades several mathematical functions were tried. Nonlinear optimization method was best fitted to formulate the mathematical model in the present study.

Mathematical optimization

Fuel consumption optimization mode (Z) has been defined in terms of the constraints parameters N , R , L_d , B_w , λ and V_{ST}

Objective function

Minimize $\phi(X) = \phi(N, R, L_d, B_w, \lambda, V_{ST})$
and $\phi(X) > 0$, $\phi \in Z$ (14)

Subject to:

$$\begin{aligned} X_L &\leq X \leq X_U \\ \{X \in Z / X_L &\leq X \leq X_U\} \end{aligned}$$

Where ϕ is the objective function, X is the set of non-negative integers represent the input variables, namely, the rotational velocity, rotor radius, depth of tillage, cutting width, velocity ratio and volume of soil tilled and their magnitude is limited with lower bound, X_L and upperbound, X_U of the inequality constraints.

Fuel consumption optimization mathematical model is computed in the following mathematical expression

$$\begin{aligned} \text{Min} &= Z \\ Z &= 116357.47(N * R * L_d * B_d / \lambda * V_{ST}) \\ &+ 6.2347 \end{aligned} \quad (15)$$

Subject to inequality constraints:

$$\begin{aligned} N_{\min} &\leq N \leq N_{\max}; R_{\min} \leq R \leq R_{\max}; \\ L_{d\min} &\leq L_d \leq L_{d\max}; B_{w\min} \leq B_w \leq B_{w\max}; \\ \lambda_{\min} &\leq \lambda \leq \lambda_{\max}; V_{ST\min} \leq V_{ST} \leq V_{ST\max}; \end{aligned}$$

Where N is rotational velocity, rpm; R is rotor radius m; L_d is depth of tillage, m; B_d is cutting width of the rotary blade, m; λ is Velocity ration and V_{ST} is volume of soil tilled, m^3 .

Sensitivity analysis

To validate the model, Rao's optimization sensitivity analysis method (Rao,

1985) was fitted how the significant parameters sensitive the model as keeping other system parameters constant, namely, velocity ratio and volume of soil tilled in all cases. Method of sensitivity analysis formulated in the following mathematical expression.

$$Y_s = (X_F - X_I / X_I) * 100\% \quad (16)$$

Where Y_s : sensitivity analysis, X_F : final significant parameter (m) or fuel consumption requirement (l / hr) and X_I : initial significant parameter (m) or fuel consumption requirement (l / hr).

Correlation coefficient analysis

Pearson Correlation Coefficient was fitted to analyze for the most significant design parameters which were determining factor of fuel consumption requirement for the various rotary blades in the present study.

Data analysis

Data were analyzed using Lingo (2006) version 10.0 to optimize integrated system parameters with corresponding fuel consumption requirements correlation coefficient analysis was used.

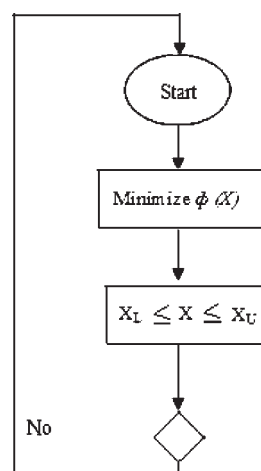


Figure 5 Flow Chart of optimization function

RESULTS AND DISCUSSION

Optimization

Optimal solution of system parameters, namely, rotational velocity, rotor radius, depth of tillage, cutting width, velocity ratio and volume of soil tilled with corresponding fuel consumption requirement of individual rotary blade is exhibited in Table 2-6.

Effect of the system parameters on fuel consumption requirement of various rotary blades is revealed as follows:

1. “Pick”-shaped rotary blade

Keeping other conditions constant, rotor radius and velocity ratio increased from 150 to 270 rpm, and 96.8 to 174.24, respectively. Keeping other conditions constant, fuel consumption increased with rotor radius from 0.180 to 0.210 m. Similarly, with depth of tillage and cutting width from 0.0650 to 0.090 and 0.0124 to 0.0196 m, respectively Table 2).

2. “C”-shaped rotary blade

Keeping other conditions constant, rotor radius and velocity ratio increased from 150 to 270 rpm, and 103.40 to 186.12, respectively. Keeping other conditions constant, fuel consumption increased with rotor radius from 0.227 to 0.233 m. Similarly, with depth of tillage and cutting width from 0.070 to 0.130 and 0.053 to 0.109 m, respectively (Table 3).

3. “I”-shaped rotary blade

Keeping other conditions constant, rotor radius and velocity ratio increased from 150 to 270 rpm, and 101.20 to 182.16, respectively. Keeping other conditions constant, fuel consumption increased with rotor radius from 0.226 to 0.229 m. Similarly, with depth of tillage and cutting width from 0.070 to 0.130 and 0.053 to 0.109, respectively (Table 4).

4. “L”-shaped rotary blade

Keeping other conditions constant, rotor radius and velocity ratio increased from 150 to 270 rpm, and 114.40 to 205.92, respectively. Keeping other conditions constant, fuel consumption increased with rotor radius from 0.240 to 0.255 m. Similarly, with depth of tillage and cutting width from 0.070 to 0.130 and 0.053 to 0.109, respectively (Table 5).

5. “J”-shaped rotary blade

Keeping other conditions constant, rotor radius and velocity ratio increased from 150 to 270 rpm, and 110.00 to 198.00, respectively. Keeping other conditions constant, fuel consumption increased with rotor radius from 0.238 to 0.247 m. Similarly, with depth of tillage and cutting width from 0.110 to 0.290 and 0.045 to 0.056, respectively (Table 6).

In addition to this, Hendrick and Gill (1971) reported that rotor peripheral velocity was one of rotary blade design parameters influenced on all phases of rotary tiller operations, from the power requirement to the final soil condition.

Hendrick and Gill (1971b) reported that an increase of depth of tillage of rotary tiller, keeping other parameters constant, increases the power requirement. Singh (1979) (from Hendrick and Gill, 1971c) reported that the energy requirement for rotary tillage decreased with increase in ratio of peripheral and forward velocities.

Fuel consumption requirement was observed higher for the “Pick”- shaped and minimum for the “C”- shaped rotary blade. However the volume soil tilled per second was exhibited the lowest by the “Pick”-shaped. The lower volume of soil tilled and the most effective and optimum soil tillage operational cost.

Sensitivity analysis

Results of sensitivity analysis was obtained by percentage composition analysis

Table 2 Global optimal solution of “Pick”-shaped rotary blade

N rpm	R m	L_d m	B_W m	λ	V_{ST} 10^{-6}m^3	F_C L/hr
150	0.170	0.050	0.010	96.8	550	6.262565
180	0.170	0.050	0.010	116.16	550	6.262565
210	0.170	0.050	0.010	135.52	550	6.262565
240	0.170	0.050	0.010	154.88	550	6.262565
270	0.170	0.050	0.010	174.24	550	6.262565
150	0.180	0.050	0.010	96.80	550	6.264205
150	0.190	0.050	0.010	96.80	550	6.265844
150	0.200	0.050	0.010	96.80	550	6.267483
150	0.210	0.050	0.010	96.80	550	6.269122
150	0.170	0.060	0.010	96.80	550	6.268139
150	0.170	0.070	0.010	96.80	550	6.273712
150	0.170	0.080	0.010	96.80	550	6.279285
150	0.170	0.090	0.010	96.80	550	6.284858
150	0.170	0.050	0.0124	96.80	550	6.269253
150	0.170	0.050	0.0148	96.80	550	6.275941
150	0.170	0.050	0.0172	96.80	550	6.282629
150	0.170	0.050	0.0196	96.80	550	6.289316

Table 3 Global optimal solution of “C”- shaped rotary blade

N rpm	R m	L_d m	B_W m	λ	V_{ST} 10^{-6}m^3	F_C L/hr
150	0.225	0.050	0.035	103.40	4762.50	6.248656
180	0.225	0.050	0.035	124.08	4762.50	6.248656
210	0.225	0.050	0.035	144.76	4762.50	6.248656
240	0.225	0.050	0.035	165.44	4762.50	6.248656
270	0.225	0.050	0.035	186.12	4762.50	6.248656
150	0.227	0.050	0.035	103.40	4762.50	6.248780
150	0.229	0.050	0.035	103.40	4762.50	6.248904
150	0.231	0.050	0.035	103.40	4762.50	6.249028
150	0.233	0.050	0.035	103.40	4762.50	6.249152
150	0.225	0.070	0.035	103.40	4762.50	6.254238
150	0.225	0.090	0.035	103.40	4762.50	6.259820
150	0.225	0.110	0.035	103.40	4762.50	6.265402
150	0.225	0.130	0.035	103.40	4762.50	6.270985
150	0.225	0.050	0.053	103.40	4762.50	6.255833
150	0.225	0.050	0.072	103.40	4762.50	6.263409
150	0.225	0.050	0.090	103.40	4762.50	6.270586
150	0.225	0.050	0.109	103.40	4762.50	6.278162

Table 4 Global optimal solution of “T”- shaped rotary blade

N rpm	R m	L_d m	B_W m	λ	V_{ST} 10^{-6}m^3	F_C L/hr
150	0.225	0.050	0.035	101.20	4762.50	6.248959
180	0.225	0.050	0.035	121.44	4762.50	6.248959
210	0.225	0.050	0.035	141.68	4762.50	6.248959
240	0.225	0.050	0.035	161.92	4762.50	6.248959
270	0.225	0.050	0.035	182.16	4762.50	6.248959
150	0.226	0.050	0.035	101.20	4762.50	6.249022
150	0.227	0.050	0.035	101.20	4762.50	6.249086
150	0.228	0.050	0.035	101.20	4762.50	6.249149
150	0.229	0.050	0.035	101.20	4762.50	6.249213
150	0.225	0.070	0.035	101.20	4762.50	6.254663
150	0.225	0.090	0.035	101.20	4762.50	6.260366
150	0.225	0.110	0.035	101.20	4762.50	6.266070
150	0.225	0.130	0.035	101.20	4762.50	6.271774
150	0.225	0.050	0.053	101.20	4762.50	6.256292
150	0.225	0.050	0.073	101.20	4762.50	6.264440
150	0.225	0.050	0.090	101.20	4762.50	6.271366
150	0.225	0.050	0.109	101.20	4762.50	6.279107

Table 5 Global optimal solution of “L”- shaped rotary blade

N rpm	R m	L_d m	B_W m	λ	V_{ST} 10^{-6}m^3	F_C L/hr
150	0.235	0.050	0.035	114.40	4762.50	6.247874
180	0.235	0.050	0.035	137.28	4762.50	6.247874
210	0.235	0.050	0.035	160.16	4762.50	6.247874
240	0.235	0.050	0.035	183.04	4762.50	6.247874
270	0.235	0.050	0.035	205.92	4762.50	6.247874
150	0.240	0.050	0.035	114.40	4762.50	6.248155
150	0.245	0.050	0.035	114.40	4762.50	6.248435
150	0.250	0.050	0.035	114.40	4762.50	6.248715
150	0.255	0.050	0.035	114.40	4762.50	6.248996
150	0.235	0.070	0.035	114.40	4762.50	6.253144
150	0.235	0.090	0.035	114.40	4762.50	6.258414
150	0.235	0.110	0.035	114.40	4762.50	6.263684
150	0.235	0.130	0.035	114.40	4762.50	6.268953
150	0.235	0.050	0.053	114.40	4762.50	6.254650
150	0.235	0.050	0.073	114.40	4762.50	6.262178
150	0.235	0.050	0.090	114.40	4762.50	6.268577
150	0.235	0.050	0.109	114.40	4762.50	6.275729

Table 6 Global optimal solution of “J”- shaped rotary blade

N rpm	R m	L_d m	B_w m	λ	V_{ST} 10^{-6}m^3	F_C L/hr
150	0.235	0.050	0.040	110.00	5250	6.248905
180	0.235	0.050	0.040	132.00	5250	6.248905
210	0.235	0.050	0.040	154.00	5250	6.248905
240	0.235	0.050	0.040	176.00	5250	6.248905
270	0.235	0.050	0.040	198.00	5250	6.248905
150	0.238	0.050	0.040	110.00	5250	6.249086
150	0.241	0.050	0.040	110.00	5250	6.249267
150	0.244	0.050	0.040	110.00	5250	6.249449
150	0.247	0.050	0.040	110.00	5250	6.249630
150	0.235	0.110	0.045	110.00	5250	6.265950
150	0.235	0.170	0.045	110.00	5250	6.282996
150	0.235	0.230	0.045	110.00	5250	6.300042
150	0.235	0.290	0.045	110.00	5250	6.317087
150	0.235	0.050	0.045	110.00	5250	6.250680
150	0.235	0.050	0.048	110.00	5250	6.251746
150	0.235	0.050	0.052	110.00	5250	6.253166
150	0.235	0.050	0.056	110.00	5250	6.254587

method for optimal solution of significant parameters, keeping other conditions constant with corresponding fuel consumption requirement of individual rotary blade in the present study (Table 7). The optimal solution of these rotary blades is presented in Table 2-6. Results revealed that fuel consumption requirement was strongly influenced by significant parameters, namely, rotational velocity, rotor radius, depth of tillage and cutting width. Among the significant parameters rotational velocity did not show any increment rate of fuel consumption requirement for the rotary blades (Table 2-6). The effect of other significant parameters on fuel consumption requirement was analyzed as follow.

Rotor radius

Rotor radius rate declined from about 5.56 to 5.00 % (by “Pick”-shaped), 0.881 to 0.866 % (by “C”-shaped), 0.442 to 0.439 % (by “I”-shaped), 2.083 to 2.00 % (by “L”-shaped) and 1.260 to 2.23 % (by “J”-shaped), while

fuel consumption requirement rate declined by 0.026, 0.002, 0.001, 0.005 and 0.0029 %, respectively. From the point view of sensitivity analysis, the changing rotor radius rate did not show significant different over fuel consumption requirement of various rotary blades.

Depth of tillage

Depth of tillage reduction rate exhibited 16.67 to 12.5, % and 54.55 to 26.09 % by “Pick” and “J”-shaped. 28.57 to 18.18 % by “C”, “I” and “L”-shaped. While fuel consumption requirement reduction rate 0.091, 0.0843 to 0.0841%, 0.272 to 0.271% by “I”, “L” and “J”- shaped and 0.089 % by “Pick” and “C”-shaped. Depth of tillage by “L” and “J”-shaped was predicted to be the most significant parameters to sensitive fuel consumption requirement.

Cutting width

Cutting width rate declined from about

Table 7 Results of sensitivity analysis of various rotary blades fuel consumption and significant parameters rate (Unit = %)

Types of Blade	Rotor radius (%)	Fuel consumption rate (%)	Cutting depth (%)	Fuel consumption rate (%)	Cutting width (%)	Fuel consumption rate (%)
Pick-shaped	5.56 to 5.00	0.026	16.67 to 12.50	0.089	19.35 to 13.95	0.107 to 0.106
C-shaped	0.881 to 0.866	0.002	28.57 to 18.18	0.089	35.85 to 21.11	0.121 to 0.120
I-shaped	0.443 to 0.439	0.001	28.57 to 18.18	0.091	37.74 to 21.11	0.130 to 0.123
L-shaped	2.083 to 2.00	0.005	28.57 to 18.18	0.0843-0.0841	37.74 to 21.11	0.121 to 0.114
J-shaped	1.26 to 1.23	0.0029	54.55 to 26.09	0.272 to 0.271	6.67 to 7.69	0.017 to 0.230

Table 8 Results of correlation coefficient and probability value of significant parameters with corresponding fuel consumption rates of various rotary blades.

Type of blade	Radius		Depth of tillage		Cutting width	
	r	p	r	p	r	p
Pick-shaped	-0.9017	0.4647	0.49852	0.0417	0.6936	0.002
C-shaped	-0.19017	0.4647	0.49852	0.0417	0.69366	0.002
I-shaped	-0.19017	0.4647	0.49852	0.0417	0.6936	0.002
L-shaped	-0.19017	0.4647	0.49852	0.0417	0.6936	0.002
J-shaped	-0.19017	0.4647	0.49852	0.0417	0.6936	0.002

r = correlation coefficient, r = 0.7-10 highly correlated, r = 0.4 - 0.7 moderately correlated, r = 0 - 0.3 weak. p = Probability value, p < 0.001 highly significant, p < 0.01 moderately significant, p < 0.05 significant.

19.36 to 13.95 % (by -shaped), 35.85 to 21.11 % (by “C”-shaped), 37.74 to 21.11 % (by “I” and “L”-shaped) and increased from 6.67 to 7.69 % (by “J”-shaped) while fuel consumption requirement rate declined by 0.107 to 0.106 % (by “Pick”-shaped), 0.121 to 0.120 % (by “C”-shaped), 0.130 to 0.123 % (by “I”-shaped) and 0.120 to 0.114 % (by “L”-shaped) and increased from 0.017 to 0.023 % (by “J”-shaped). However, cutting width and fuel consumption requirement rate linearly increased by “J”-shaped.

Fuel consumption model of individual rotary blade

Regression analysis was performed on fuel consumption data of different type of rotary blade which showed a significant effect of rotor radius, depth of tillage and cutting width on fuel consumption requirement. Regression

analysis result for the blades exhibits a linear relationship between fuel consumption rate of rotor radius, depth tillage and cutting width with coefficient of determination equals to 1.00.

Correlation analysis

Results from correlation coefficient revealed that depth of tillage and cutting width were the most significant determining parameters influencing fuel consumption requirement for various rotary blades in the present study. Hence, the correlation coefficient(r) was predicted to be 0.5 and 0.7, respectively. Consequently, the P-value for depth of tillage was predicted to be moderately significant ($P < 0.05$) and while, for the cutting width significant ($P < 0.01$), respectively (Table 8).

CONCLUSION AND RECOMMENDATION

This study focused on mathematical modeling of fuel consumption optimization model of rotary blades, namely, a “Pick”, a “C” an “I”, an “L” and a “J”-shaped rotary blades under sandy clay loam condition. For validation the model, sensitivity and correlation coefficient analysis were used to determine how the significant parameters, rotor radius, depth of tillage and cutting width, influenced fuel consumption requirement. From the analysis the following have been concluded.

From the point view of minimizing fuel consumption requirement, the “C”-shaped was exhibited the least fuel consumer, while the highest was the “pick”-shaped rotary blade. However the volume soil tilled per second was exhibited the lowest by the “Pick”-shaped. The lowest volume of soil tilled and the most effective and optimum soil tillage operational cost. Therefore, the “Pick”-shaped was predicted to be optimum. The study might be applicable to rotary tiller development in local condition for sandy clay loam of Ethiopia.

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