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Characterizing Performance of Agricultural Rotary Trencher

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Abstract: Field experiments were conducted in Guangzhou clay soil to evaluate the performance of tractor attachment rotary trencher. The trencher is primary comprised one rotating tilling disc and frame carrier. The disc is equipped with 6 or 12 cutting blades and the frame is connected to tractor by three-point linkage. Tests were conducted in 10-30 cm of ditching depth range, in step of 10 cm and for each ditching depth three tractor speed of 0.2, 0.4 and 0.6 m.s^{-1} were chosen, the trencher driving shaft is connected to tractor power takeoff (PTO) and rotated at two levels of rotation speed mainly 720 and 540 rpm. The WDA-1500 AT torque transducer was used to measure corresponding torque and power requirements of rotary trencher. The results indicated that small increment in tilling depth and tractor travel speed result in large increases in power requirement. The results also revealed that trencher operated at 720 rpm position consumed more PTO power than the one rotated at 540 rpm position. The number of blades has also great influence on performance of the trencher. Whereas, trencher equipped with 12 cutting blades consumed less PTO power and produce cleaner trenches.

Key words: Tractor attachment · Tilling disc · Ditching depth · Power requirement

INTRODUCTION

Tractor attachment rotary trencher is versatile agricultural implement used to dig trapezoidal trenches for applying fertilizer, laying pipes, installing drainage and road building jobs. It is an active tillage implement that processes the soil at a speed that is different from the forward travel speed of the tractor. Use of improved implement and agricultural machineries is required to uplift farm mechanization for increasing productivity [1].

Generally, improvement of any tillage implements is aimed to reduce their draft and power requirement as well as to give a good soil condition. Rotary trenchers have high efficiency and wide range of applications, but they relatively have high torque and power requirement. Therefore, reduction of power requirement becomes number one priority for improving rotary trenchers.

The power requirement can be reduced by considering design and operational parameters, these parameters include; blade configurations, direction of rotation, tilling depth, travel speed, number of blades, rotation speed of trencher and kinematic parameter. Whereas, the kinematic parameter is ratio of the blade rotation speed to the forward travel speed [2].

Similar to any tillage implement, the depth of operation has significant influence on the power requirement and the performance of tillage tool [3-4]. In most cases, energy requirement increases at an increasing rate with the depth of tillage [4]. According to Hendrick and Gill [2] power requirement might be reduced by considering the relationships between the implement design and its operational parameters. These parameters include the direction of rotation [5], depth of tillage, ratio of peripheral speed to the forward travel speed, blade configuration [6] and soil conditions.

This study aimed to quantify the performance of the rotary trencher through measurement of power requirement at four different design and operational parameters. The specific objectives of this study were to (1) quantify the performance of tractor attachment rotary trencher in term of power requirement over a wide range of ditching depth and tractor travel velocities. (2) Characterize the effect of rotation speed and number of blades on the performance of trencher.

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MATERIALS AND METHODS

Under working conditions of rotary trencher, the factors that affect its performance can be categorized into input and output factors. The input factors mainly take into consideration influence of different factors, viz, soil conditions, direction of rotations, depth of the tilling operation, bite delivery, rotation speed and blade shape. The output factors includes; torque and power requirement and the quality of the work. Whereas there is no precise definition of the quality of work, it is generally evaluated by the clod size, the evenness of the operative depth and percentage of plant residue covered after a tillage operation [7]. This formula was used to evaluate and characterize the performance of tractor attachments rotary trencher. This study mainly focused on the effect of trencher's ditching depth, travel speed, rotation speed and number of cutting blade on its power requirement. The proposed model for the study is shown in Figure 1.

Experimental Rotary Trencher: Experimental rotary trencher used in this study is shown in Figure 2.

The trencher is capable of producing trapezoidal channels. The implement is mounted on four wheels tractor. The specifications of trencher are shown in the Table 1.

The trencher comprises vertical disc operating in the up-cut direction of rotation and equipped with12/6 blades of IT245(C-type blade) shown in Figure 3 and another 6 special blades to help in cleaning up the trenches and throwing tilled soil. The trencher was driven by tractor PTO trough drive shaft.

Two operating parameters affect the performance of trencher mainly; ditching depth and trencher kinematics parameter. The required depths were archived hydraulically by tractor control lever and two stabilizing wheels. The trencher kinematic parameter (λ) is dimensionless ratio of the trencher peripheral velocity V_{cir} to the machine forward travel speed V_f. This parameter is expressed in the equation:

$$\lambda = \frac{V_{CIR}}{V_F} = \frac{R.\omega}{V_F} \quad (1)$$

whereas, R is Trencher radius, m; ω is Trencher angular velocity, rad/sec; V_F is Forward travel velocity, m.s^{-1}; V_{CIR} Is Peripheral velocity of trencher disc, m.s^{-1}.

Data Acquisition System: The tractor's PTO or stub shaft transfers power from the experimental tractor to the drive shaft of trencher, the series of WDA-1500 AT torque transducer were used to measure corresponding torque and power requirements of rotary trenchers. Whereas, this system has a non-contact transmission system that provides digital outputs proportional to the torque and rotational speed on the drive shaft of the trenchers. The transducer has a 6 splines female coupling on one end and a male fitting on the opposite end. The female end is coupled to the male end of the trencher drive shaft. The system is adopted to record and analyze the data onto a pc or laptop with torque software shown in Figure 5. The installation of torque sensor is shown in the Figure 4.

Table 1: Specification of experimental rotary Trencher

Tractor matched power (kw)	37-50
Pto shaft rotation speed (r/min)	720
Disc rotation speed (rpm)	228
Ditch depth (cm)	30-40
Blade number	18
Overall weight (kg)	290
Overall dimensions (cm)	150*70*140

Experiments Site and Setup: Soil parameters (soil physical, mechanical and dynamic properties) have great influence on the power and torque requirement of rotary trencher.

The TZS-1 water content sensor and TYD-2 soil hardness sensor were used to measure soil water content and soil hardness. This is because of the great influence of these parameters on the performance of rotary trencher. The measuring producers included: selecting ten different points to cover the entire experimental site, then for each measuring point both parameters at different depth levels were measured. Average value of soil moisture was 10.7%, while the soil strength was 2.16 Mpa. Figure 6 shows the way of measuring soil parameters using soil sensors.

The field experiments were carried out in South China Agricultural University experimental orchard. The experiments were conducted in winter because the experiments site is situation in an area that receives summer rainfall. Thus, it is easier to control the level of soil water content. The experiments were done to assess the performance of rotary trenchers. Figure 7 and 8 show the experimental setup and layout used for the study, respectively.

Experiments Details

First Experiment: The aim of this test is to determine the effect of the depth of tillage on the power requirement of experimental rotary trencher. These tests were done at 0.4 m.s^{-1} travel speed of tractor and PTO rotational speed was on position of 720 rpm. Three depths of tillage, namely 10cm, 20 cm and 30 cm have been used and a minimum of three tests were done for each set of ditching depth.

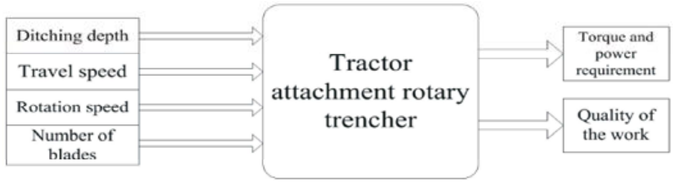

Fig. 1: Proposed block diagram for trencher-soil interaction process

Fig. 2: Experimental rotary Trencher functional components (1- it 255 blades; 2- rotating disc; 3-special blade; 4- upper linkage point; 5- down left linkage point; 6- frame carrier; 7-trencher gearbox)

Fig. 3: IT245 blades, C-type blade

Fig. 4: Installation of WDA-1500 AT torque transducer

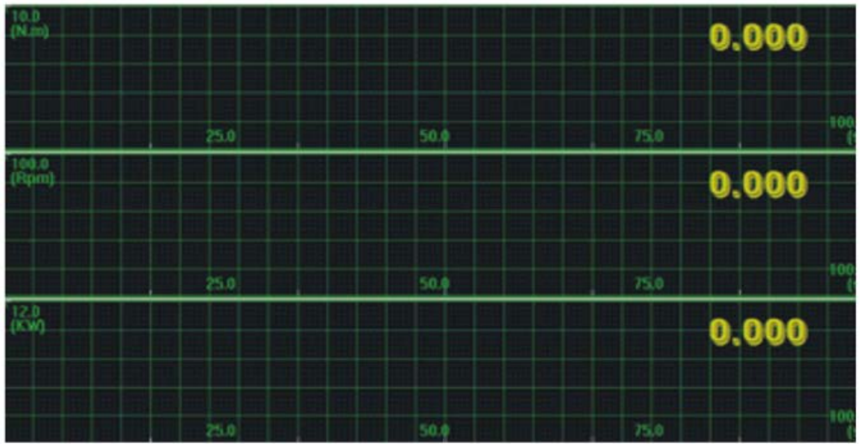

Fig. 5: Torque software installed on pc

Fig. 6: TZS-1 water content sensor, TYD-2 soil hardness sensor

Fig. 7: Experimental setup, tractor and trencher, attached by a three-point linkage and driven by a PTO shaft

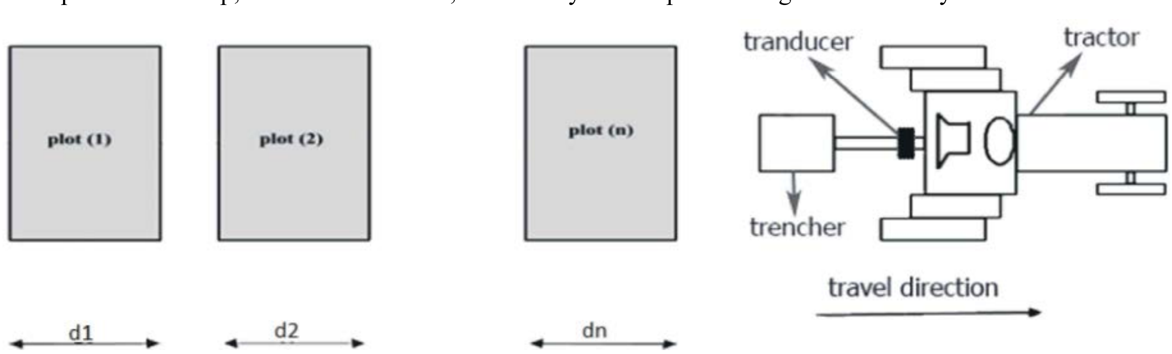

Fig. 8: Experimental layout (d1, d2….d_n distance covered in respective plot during a test run)

Second Experiment: This test aimed at investigating the effect of tractor speed on power requirement of experimental rotary trencher. Whereas, changing the tractor velocity will affect in changing of Blade delivery, which is determined the by considering the process of soil cutting by two adjacent blades. The field tests using the experimental rotary trencher were done at different depth of tillage for the set of tractor velocities 0.2, 0.4 and 0.6 m.s-1. The trencher was equipped with 12 cutting blades and PTO rotation speed was 720 position. A minimum of three tests were carried out for each set of tillage.

Third Experiment: The aim of this experiment is to study the effect of rotation speed of cutting disc on the power requirement of the trencher. The field test using the experimental rotary trencher where done at two different rotating speeds of tilling disc, the two levels of rotating speed were obtained using two positions of pto lever which controlling its rotation speed. The first position was 720 rpm pto rotation speed and the second was 540 rpm position. The trenchers was operated at two levels of tilling depth and 0.2 (m/s) travel speed. A minimum of three tests were carried out for each set of rotating speed.

Fourth Experiment: The aim of this experiment is to study the effect of the number of blade on the power requirement of the experimental rotary trencher. The experiment will run at two levels of tilling depth, mainly 15, 25 cm ditching depth and tractor travel speed was 0.2 (m/s). The first run of this experiment was carried out for the trencher equipped with 12 cutting blades. The second part of experiment was done for trencher equipped with 6 cutting blades (3 blades in each side of the disc).

RESULTS

The trencher was mounted on the tractor for testing on dry land that had already been plowed with a shallow rotary tiller. The tests were carried out to evaluate the trencher at four different parameters.

Effect of Tillage Depth at Constant Travel Speed of Tractor: Figure 9 shows the typical variation in power requirement with the depth for soil processing by trencher. This curve indicates that there is linear relationship between trenches depth and power requirement. Whereas, excessive power requirements accompany relatively small increments in the depth of tillage. Like other tillage machines, this observation is consistent to that made by other researchers (Hendrick & Gill; Shibusawa) [1, 4]; and is responsible for the lack of adoption of deep tilling machinery as an alternative primary tillage implement [7]. The curve exhibited strong evidence that the trencher power requirement increases with the increases of ditching depths.

Table 2: Effect of depth and tractor forward speed on the power requirement of trencher

Test run	Depth (m)	Tractor velocity (m.s^{-1})	Power (kw)
1	10	V1(0.2)	4.922
2	10	V2(0.4)	5.499
3	10	V3(0.6)	10.534
4	20	V1(0.2)	11.435
5	20	V2(0.4)	15.534
6	20	V3(0.6)	22..761
7	30	V1(0.2)	21.031
8	30	V2(0.4)	26.359
9	30	V3(0.6)	32.162

Table 3: Effect of cutting disc rotation speed on the power requirement of rotary trencher

Test	Depth (cm)	Pto speed (rpm)	Power requirement (kw)
1	15	500	6.152
2	15	650	9.414
3	25	500	17.694
4	25	650	20.435

Effect of Tractor Forward Velocity: Figure 10 shows the typical variation in power requirement for soil processing by trencher with the depth at different levels of tractor velocities. For given ditching depth, the trencher power requirement increases with the increases of tractor velocity. The increment in power requirement is depend heavily on the chosen ditching depth, for 10 cm of ditching depth the power requirement increases slightly as the tractor velocity increased from 0.2to 0.6 m.s^{-1}.this rate in higher for 20cm of ditching depth and the highest occurs at the depth of 30cm. The result indicated that the power requirement of trencher is sensitive to change in tractor velocity, that because changing the tractor velocities will lead to changing in both blade delivery and trencher kinematics parameters (λ) as result the volume of soil chip will be increased.

Effect of Rotation Speed of Cutting Disc: The result of corresponding power requirement are shown in Table 3 and Figure 11. The result indicated that trenchers working at different rotating speed of cutting disc are different in term of power requirements. For trencher working at 15 cm of tilling depth increasing rotation speed at 30% result in 53% increasing in power requirement. For trencher working at 25 cm of tilling depth results indicated that increasing rotation speed at 30% result in 15% increasing in power requirement.

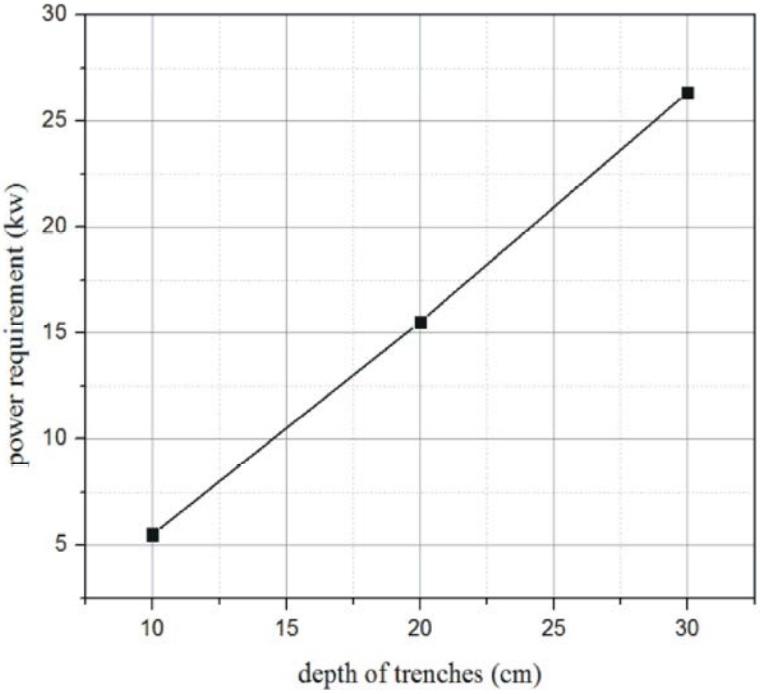

Fig. 9: Graph showing the effect of ditching depth on the power requirement of the trencher at constant tractor velocity of 0.4 m/s

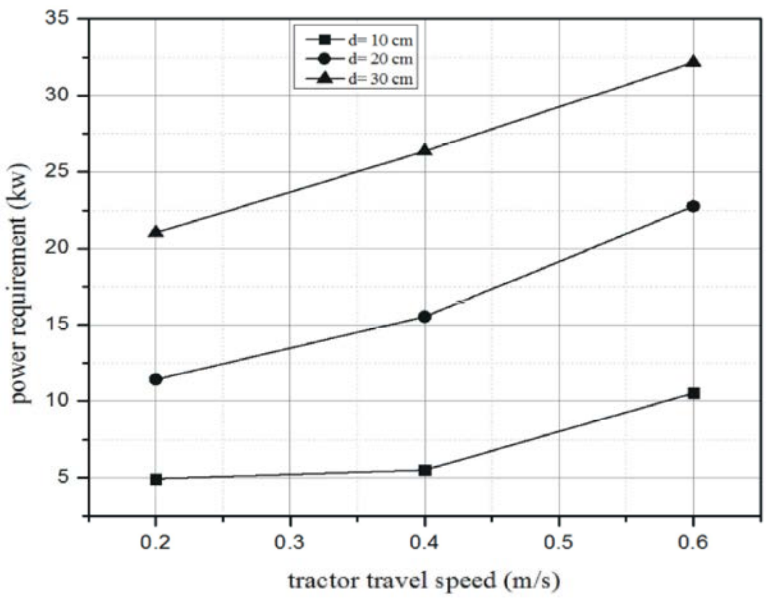

Fig. 10: Graph showing the effect of tractor velocities on the power requirement of the trencher at different ditching depth

The result indicated also that for trencher equipped with 12 cutting blades and 540 rpm rotation speed increasing tilling depth at 67% result in 188% increasing in power requirement.

Effect of Number of Blades on One Side of The Trencher: Figure 12 and Table 4 are showing the typical variation in power requirement of trencher equipped with 6 and 12 cutting blades at two levels of trenches depth. Results indicated that the trencher equipped with 6 cutting blades consume more power than the one equipped with 12 cutting blades. Whereas, for trencher working at 15cm tilling depth reducing number of blade to 6 cutting blade result in a 44% increasing in power requirement.

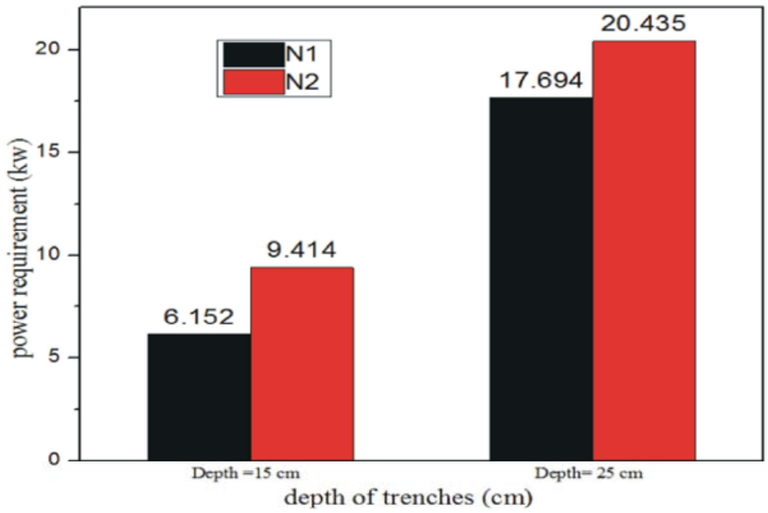

Fig. 11: Column showing the effect of PTO rotation speed (N1= 500, N2=650) on power requirement of trencher at two levels of trenches depth

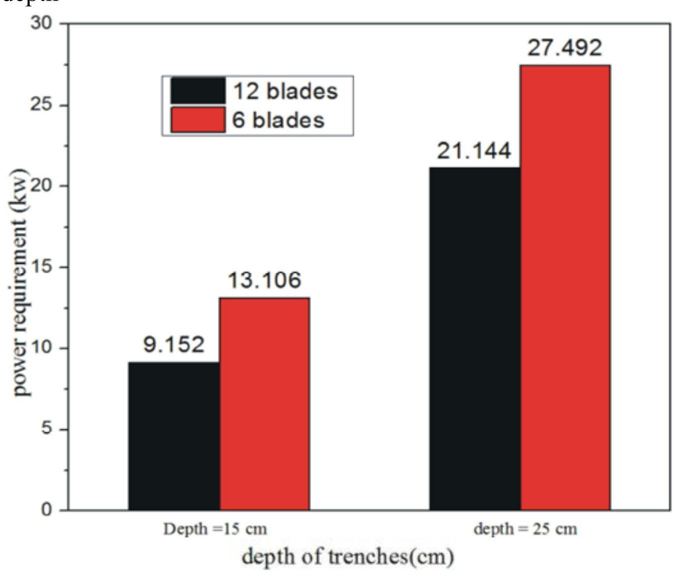

Fig. 12: Column showing the effect of number of cutting blades on power requirement of trencher at two levels of trenches depth

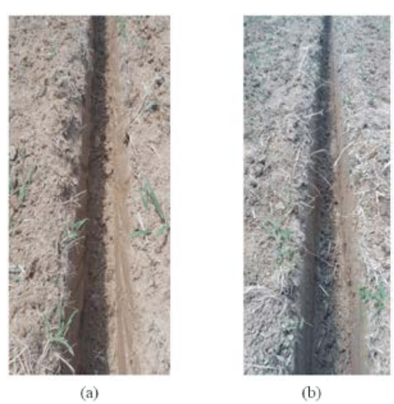

Fig. 14: Trenches produced by six cutting blades trencher (a) and twelve cutting blades trencher (b)

Table 4: Effect of cutting blades number on the power requirement of rotary trencher

Test	Depth (cm)	Cutting blades	Power requirement (kw)
1	15	12	9.152
2	15	6	13.160
3	25	12	21.144
4	25	6	27.492

Same results have been seen for trencher working at 25 cm of tilling depth, whereas decreasing number of blades to 6 cutting blades result in a greater value of power requirement. The percentage of increasing power requirement was about 30%.

The result indicated that for trencher equipped with 12 cutting blades 67% increasing in tilling depth result in 131% increasing in power requirement. For trencher equipped with six cutting blades results indicated that 67% increasing in tiling depth result in 110% increasing in power requirement. For the specification of trenches have been produced using trencher with 12 and 6 cutting blades. The trenchers produced by 12 cutting blades trenchers is trapezoidal in cross section and more clean and regular in dimensions. Whereas, the trenchers equipped with 6 cutting blades produce relatively unclean trenches (more tilling soil have been seen inside trenches) and more side irregularities have been seen.

DISCUSSION

The field performance evaluation carried out on the rotary trenchers mounted on four wheel tractor. The study findings are listed below:

- The PTO energy requirements of the trencher increased with increment in the set tillage depth and tractor travel speed. However, travel speed had a greater influence on the energy requirements than the set tillage depth. Therefore, a strict control over possible changes in the kinematics parameter (λ) must be integrated in the design of trencher as means for controlling the potential for excessive increments in the energy demand during operation.
- Increasing number of cutting blades will result in a better performance of the trencher. Whereas, power requirement have been reduced and better trenches have been produced.
- Increasing value of rotation speed of tilling disc result in increasing trencher power requirement. Increasing rate is depending heavily on the other working parameters,
- The four parameters have been investigated in this study have influence on the trencher power requirement. Similar observations have been observed by other researchers (Maciej; Jafar *et al.*) [9-10]. The main reason is any changes in these parameters lead to change the mechanics of tool-soil interaction process. Following examples are listed: (1) Increasing trencher travel speed will decrease the value of kinematics parameters ë, this result in increasing trencher power requirement. (2) Increasing cutting blades rotation speed result in increase the value of trencher kinematics parameter ë, this result in increasing trencher power requirement. (3) Reducing number of cutting blades result in increasing the volume of the soil chip cut by trencher blade. As result, the power requirement should be increased.

In spite of fact that orchard and perennial tree crops can greatly benefit from the use of this implement, future efforts should be made in attempt to find ways for utilizing the trencher in agricultural works. The core of future effort should be investigation the components of total energy requirements for overall trencher design and operational parameters. This approach will lead to a reduction of energy requirement by optimizing soil, tool and operating parameters based on the collected information.

CONCLUSIONS

Using Rotary trencher as agricultural implement has become increasingly important in china and abroad. To obtain a good design of trencher with good performance all parameters involving in trencher –soil interaction process must be taken into consideration. Further study should be done to investigate the effect of interaction between these parameters on performance of trencher.

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REFERENCES

1. Raheman, H. and R.K. Sahu, 2006. Design of tractor operated rotary cultivator- a computer simulation. Agricultural Mechanization in Asia, Africa and Latin America, 37(3): 27-31.
2. Hendrick, J.G. and W.R. Gill, 1971a. Rotary tiller design parameters: Part I, - Direction of rotation. Transactions of the ASAE, 14(4): 669-674.
3. Hendrick, J.G. and W.R. Gill, 1971b. Rotary tiller design parameters: Part II – Depth of tillage. Transactions of the ASAE, 14(4): 675-678.
4. Shibusawa, S., 1993. Reverse-rotational rotary tiller for reduced power requirements in deep tillage. Journal of Terramechanics, 30(3): 205-217.
5. Salokhe, V.M. and N. Ramalingam, 2001. Effects of direction of rotary tiller on properties of Bangkok clay soil. Soil & Tillage Research, 63(1): 64-74.
6. Salokhe, V.M., M. Hanif and M. Hoki, 1993. Effect of blade type on power requirement and puddling quality of a rotavator in wet clay. Journal of Terramechanics, 30(5): 337-350.
7. Srivastava, A.K., C.E. Goering and R.P. Rohrbach, 1993. Engineering principles of agricultural machines. ASAE textbook agricultural machines.NO. 6. American society of agricultural engineers 2950 Nile Road, St Joseph, Michigan, USA.
8. Marenya, M.O. and H.L.M. Du Plessis, 2006. Torque Requirements and Forces Generated by a Deep Tilling Down-Cut Rotary Tiller. ASABE, Paper No. 061096.
9. Maciej, M., 2005. A torque evaluation for a rotary subsoiler. Soil and Tillage Research, 84(2): 175-183.
10. Jafar Habibi Asl, Surendra Singh, 2009. Optimization and evaluation of rotary tiller blades: Computer solution of mathematical relations. Soil and Tillage Research, 106(1): 1-7.