International Journal of Sustainable Agricultural Research
2014 Vol.1, No.3 pp.58-69
ISSN(e): 2312-6477
ISSN(p): 2313-0393

SOIL-BLADE INTERACTION OF A ROTARY TILLER: SOIL BIN EVALUATION

Subrata Kr. Mandal[1] --- Basudeb Bhattacharyya[2] --- Somenath Mukherjee[3] --- S Karmakar[4]

[1,2]*Scientist, CSIR-Central Mechanical Engineering Research Institute, Durgapur, India*

[3]*Associate Professor, Bengal Engineering & Science University, Shibpur, Howrah, India*

[4]*Associate Professor, Bidhan Chandra Krishi Viswavidyala, Mohanpur, India*

ABSTRACT

In this paper soil-blade investigation of a rotary tiller in a controlled soil bin is presented. Among the soil cutting agricultural tools currently used, the rotary tiller is one of the most promising equipment, saving operating time and labor. In a rotary tiller working tool is always a blade. For the tillage systems, accurately predicting the required torque and penetration force while cutting of soil with a blade is of prime importance as far as the farming operation is concerned. In the tillage operation almost 50% of total farm power is utilized. Draft require for tillage depend on the soil strength and moisture contents along with compactness. So tillage should be done at such a moisture content and soil strength where minimum power will be consumed. This moisture content and soil strength is the optimized value. It is needed to evaluate optimum values of these two important parameters for every type of soil before tillage operation to decrease the loss of power. Thus in this paper an investigation with regards to moisture content and soil strength which affects penetration resistance force and toque while soil cutting through a rotary tiller blade and has been presented.

Keywords: Rotary tiller, Blade, Cone penetrometer, Draft, Cone index.

1. INTRODUCTION

A rotary tiller is a specialized mechanical tool used to plough the land by a series of blades which are used to swirl up the earth (Hendrick and Gill, 1971c). Nowadays, utilization of rotary tillers has been increased in agricultural applications because of simple structure and high efficiency for this type of tillage implements. By taking advantage of rotary tillers, the primary and secondary tillage applications could be conjugated in one stage (Topakci *et al.*, 2008). Rotary tilling is a widely used tillage operation in Indian farming because of its superior ability to mix, flatten and pulverize soil. However, the use of rotary tiller is strongly restricted to "shallow" tillage because of its high energy requirements. Deep rotary tillage using less energy has recently become a subject of wide interest to combat soil fatigue caused by excessive use of chemicals among other reasons, and to convert paddy fields into dry fields such as kale fields. Despite of their high energy consumption, since rotary tillers have the ability of making several types of tillage applications in one stage, the total power needed for these equipments is low (Culpin, 1981). Because rotary tillers power is directly transmitted to the tillage blades, the power transmission efficiency in rotary tillers is high. Moreover, the negative traction existence in rotary tillers causes the required tractive force to be decreased and consequently, smaller tractors could be used with this type of tillage implements for land preparation. Power to operate the rotary tiller is restricted by available tractor power (Yatsuk *et al.*, 1981; Srivastava *et al.*, 2006). The rotating blades chop and mix the residues evenly throughout the working depth, outperforming any other implement.

At different moisture content soil strength is different. If soil strength is more than force requirement for tillage operation is also more. So it is necessary to select a optimize moisture content and soil strength so that force requirement for tillage will also be least. Generally in the field, the moisture content varies throughout the entire field as it is not under controlled. But in a soil bin moisture content can be controlled as per the requirement. The water content of the soil is an important property that controls its behaviour. Usually, the soil parameters in soil bins such as variation of cone index and soil compaction level are more constant (Naderi-Boldajim *et al.*, 2009). As a quantitative measure of wetness of a soil mass, water content affects the level of compaction of soil, which is indicated by its bulk density. Soil bulk density is an indicator of the degree of compaction in engineering construction works. The desired value of bulk density varies with the degree of stability required in construction. Bulk density is also used as an indicator of problems of root penetration, soil aeration and also water infiltration. The cone index of a soil which is the degree of its strength has been shown to be affected by its water content and bulk density. In the past, a number of studies were conducted to design suitable blades of rotavator in order to reduce the energy and power consumption (Shibusawa, 1993). In an experiment in a soil bin, Gill and Berg (1968) observed that tool draft varied with the tool traveling distance. Siemens and Weber (1964), Stafford (1979), Durant *et al.* (1979), Godwin and Kilgour (1980), and Onwualu and Watts (1989) made some small-scale soil bins whose length ranges from 5 to 13 m, and test speed of up to 5.5 m/s for a total working length of 10 m.

Upadhyaya *et al.* (1986) developed and used soil bins to study basic soil Machine. Wismer (1984) states that there were about 36 different facilities in 12 countries that had 90 soil bins constructed. Wood and Wells (1983) and Onwualu and Watts (1998) states that there may have been about 150 soil bins in use around the world with only several new soil bins built since 1983. So it appears that no work has been reported on the soil-blade interaction for a rotary tiller in a controlled soil bin. Hence this research work was undertaken to investigate the soil-blade interaction and to predict the effects on penetration force and toque while soil cutting through a rotary tiller blade in a controlled soil bin.

2. SOIL BIN DESCRIPTION

Soilbin is a generic term for a test facility for studying soil dynamics, especially on the soil machine interaction research in agriculture. Generally, a soil bin facility consists of soil bin, tool carriage, drive system, instrumentation and data acquisition systems (Mardani *et al.*, 2010). The application of soil bin for soil machine interaction research was initially established by several research institutes, such as the National Tillage and Machinery Laboratory (NTML) in the

United States, the U.S. Army Tank Automotive Center Land-Locomotive, the Vicksberg Waterways Experimental Station, and Caterpillar Tractor Co. (Clark and Lliljedall, 1968). Ideally, soil machine interaction test generally done in the field for development of a prototype machine or evaluation of an existing machine, so that the tests could emulate actual farm situation. Several problems often limit field testing. The problems come from two sources, the weather condition and the soil condition.

Testing can only be conducted when weather is suitable for farming operations. But weather condition and changes in climate affect farming operations (Hammer *et al.*, 2000). Soil condition consists of soil types, soil moisture content and roughness of soil surface. Soil type may vary greatly within one field (Clark and Lliljedall, 1968) and also from one field to another. Therefore, replicating the same soil condition is a challenge in field testing. Moisture content, which influences the mechanical and dynamical properties of the soil, varies within one field. Natural field condition is bumpy that might affect the machine travelling speed and the working depth of a test tool. But, controlling this parameter is essential for valid comparison of measurement of tools or traction devices (Gill and Berg, 1968).

3. EXPERIMENTAL PROCEDURE

All the experiments were conducted in the stationary soil bin to obtain the different parameters like cone penetration resistance, soil moisture content, torque on the blade etc.

3.1. Soil Bin

The soil bin facility used for this experimental study was located in the Tillage and Traction laboratory in the Department of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, India. The soil bin comprised of a stationary bin, a carriage system, implement and soil processing trolleys, power transmission system, control unit and instrumentation for measurement of different parameters as stated above (Fig. 1). The soil bin 20.0 m long, 1.8 m wide and 0.75 m deep. The transmission from a 18hp, 1450 rpm Electric motor was used as source of power for soil processing and tool carriage. The carriage was equipped with a rotary tiller, soil leveller, roller compactor, tool bar frame and tool bar and a water sprayer for spraying water on the soil to maintain the desired average moisture content. The rotary tiller was used for soil pulverization after each test run. The roller compactor was used to compact the pulverized soil in the soil bin to a uniform density. A 3.73 kW, three-phase electric motor served as the prime mover for the carriage and the rotary tiller. The different speeds of operation were obtained by choosing suitable gears of a gear reduction unit coupled to the input shaft of the revolving drum, which was attached to soil processing trolley with stainless-steel rope. A control unit, placed outside the soil bin, controlled the direction of movement of the soil processing trolley. The instrumentation for measuring the cone penetration resistance, soil moisture content, torque on the blade consisted of 8 channel data acquisition system coupled with a PC to store the values of different parameters.

Fig-1. Complete Soil bin

3.1.1. Soil Bed Preparation

Experiments were conducted under laboratory conditions in the soil bin. Before starting the experiments, the soil bed was prepared to achieve the required levels of cone penetration resistance and bulk density. Firstly, the tiller was used to pulverise the soil after spraying water to achieve the required moisture content.

Then, the soil was levelled with the levelling blade and compacted by the roller to achieve the required cone penetration resistance and bulk density in layers. At the end of each soil preparation, a hand operated soil cone penetrometer was used for measuring the cone penetration resistance to a depth of 0.14 mm at intervals of 2.5 m at six locations in the soil bin following the procedures outlined in the ASAE Standards (ASAE, 2002b).

At these locations along the centre of the bin three samples were taken across the bin to measure the moisture content.

3.2. Rotary Tiller

The rotary tiller attached with carriage comprising of standard "C" shaped blades as working tool was selected (Fig.2) as this implement is widely used for both primary and secondary tillage operations. The tiller was operated in a reference soil condition at different depths and speeds to determine parameters like torque & speed of rotary shaft. The detail specification of rotary tiller has given in Table1.

Fig-2. View of Rotary tiller

Table-1. Rotavator specification

No.	Parameters	Specification
1	Working width	1.2m
2	Distance between 1st blade to last blade	1.1m
3	No of blades	36
4	Angular spacing of two blades	90°
5	Linear spacing of two blades	0.05m

3.3. Plan of Experiment

A 5 by 5 by 3 factorial experiments (five forward speeds, five depths, and three replications) was used to determine the effect of torque, speed and effect of moisture on penetration resistance of rotary tiller n a reference soil condition. The levels of these variables along with other values are given in Table 2. The soil data were collected using core sample and hand-operated soil cone penetrometer before each tillage experiment. After fixing the desired depth and selecting a gear for particular speed, the implement trolley along with reference tillage tool/scale-model implement was pulled by the soil processing trolley in the soil bin keeping the pulling arm horizontal to the soil bed. With the help of the calibrated extended octagonal ring transducer, the data for draught of reference tillage tool/model implement were continuously acquired by the measuring system. Simultaneously, the time taken to cover a fixed distance of 10m was recorded using a mechanical stopwatch to calculate the speed of operation.

3.3.1. Measurement of Soil Moisture

Soil moisture in the soil bin is measured by gravimetric method. Project site in the soil bin divided into six parts and samples were taken to measure the moisture content. Soil in the oven is kept for 24 hours at 105°C.After drying is over; weight of dry soil with container is taken. Weight of water and dry soil is calculated.

$$\text{Moisture content} = \frac{\text{weight of water}}{\text{weight of dry soil}} \text{ X}100$$

3.3.2. Measurement of Cone Index

Soil resistance from each portion is measured with the help of the cone penetrometer. A Cone Penetrometer was attached with the carriage as shown in Fig. 3. This is typically used to measured soil strength and to identify compacted soil condition. Soil Cone Penetrometer was initially adopted as an ASAE recommendation in 1968 and was reaffirmed as an ASAE standard in 1978. Procedures for use of the soil cone penetrometer have been developed (ASAE Standards, 2002a) and indicates the most desirable moisture contents for sample collection is when the soil is near field capacity. Selection of least strength of soil at optimizes moisture content is done by cone penetrometer reading which is attached with soil bin facility.

Fig-3. Cone penetrometer attached with soil processing trolley

In the cone penetrometer (Fig. 4) there is a sensor which sense the soil resistance as an electrical resistance and send this electrical resistance as a signal to software through hardware and PC interface. Measurements for the force and displacement were taken with the cone penetrometer at six different locations on the soil bin. The values have shown in Table2. Cone index was found out by using formula ((ELE., 2010) as details below:

$$C.I = 0.098\frac{F}{A} \quad (1)$$

Where Where $C.I$ is the cone index (MPa), F is the force measures by penetrometer (kgf)

and A is cone base cm^2

3.3.3. Measurement of Torque

Motor torque which drives the rotary tiller was measured by a torque transducer-sensor mounted on the soil processing trolley as shown in Fig.5. This sensor measures the torque and speed with accuracy ±0.1%. Signal output is sent directly from the motor shaft with a cable to a PC/laptop. The torque sensor was calibrated before the test runs at static load conditions in the laboratory. The torque on the rotary tiller shaft was measured by using the standard design calculation using the values of motor torque, speed and rotary tiller shaft speed. The power was calculated by multiplying torque by tangential velocity. During the experiment, the width of cut was maintained at 1.2m. Measurements of torque were taken five places along the bin with five depths of cuts.

4. RESULTS & DISCUSSION

4.1. Cone Penetration Resistance & Cone Index

Measurements were taken for Cone penetration resistance for different depth at six locations (Fig.4) on the soil bin through cone penetrometer as discussed in section 3.3.2. Cone index is calculated by using formula as stated in equation (1). These values were shown in Table 2. Post process graph which were generated has been shown in Fig.5. It appears that force increases as depth increases except some cases where moisture content play an important role which decreases the force vales. Fig.6 shows the effect of Penetration resistance with depth of penetrometer for different locations marked on the soil bin. Average values of depth and penetration force were found out for six locations and at the same time Cone Index (CI) were calculated against each average values which were shown in Table 3. Fig.9 represents the effect of cone index with penetration resistance and soil moisture respectively. The best fit equation has also found out predicting cone index.

Fig-4. Marked distances on the bin

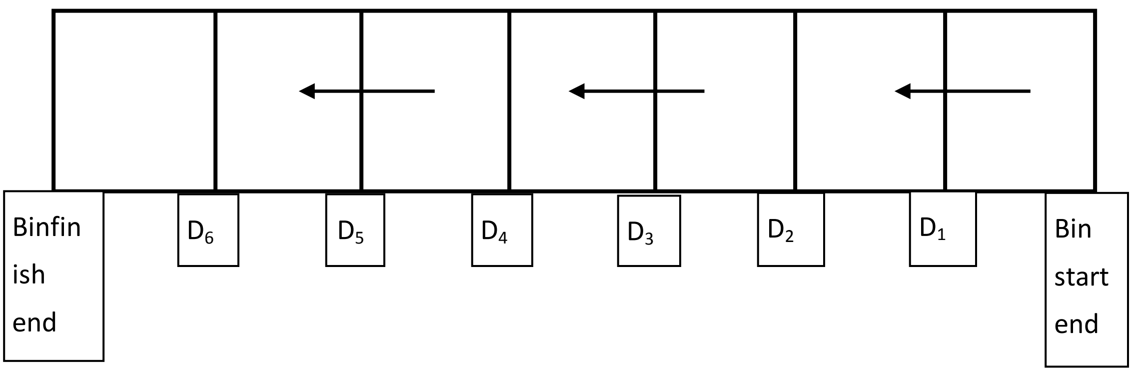
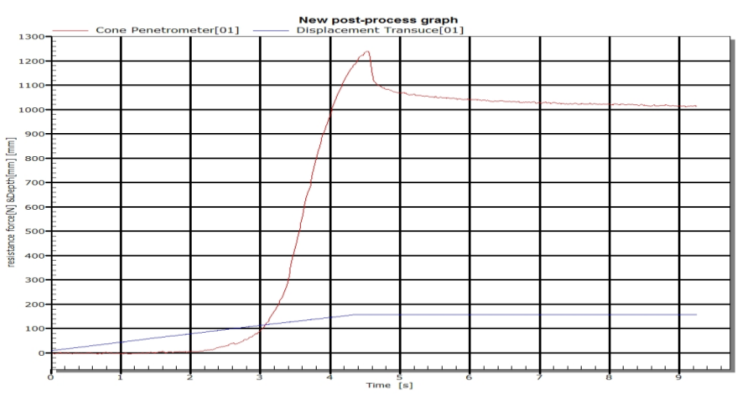


Fig-5. Post process graph of penetration resistance force and displacement over time



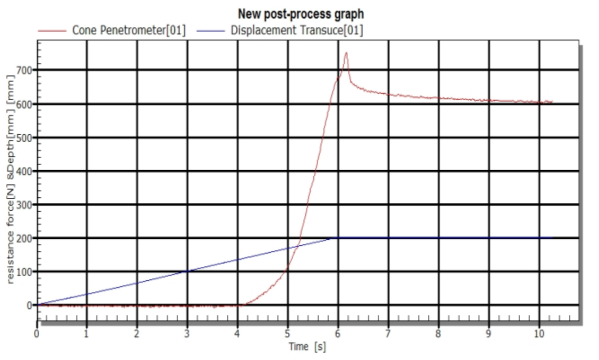


Table-2. Cone penetration resistance for different depth at six locations on the soil bin

D_1		D_2		D_3		D_4		D_5		D_6	
Depth (mm)	Force (N)	Depth (mm)	Force (N)	Depth (mm)	Force (N)	Depth (mm)	Force (N)	Depth (mm)	Force (N)	Depth (mm)	Force (N)
7.6	0.6	8.4	151.8	10.3	-0.6	10.9	-0.6	10.7	1.2	10.2	-1.8
11.2	1.2	15.3	248.4	20.9	-1.2	20.7	1.2	25.8	0.0	20.8	-1.2
25	-0.6	26.0	375.6	30.7	-2.4	30.7	0.8	30.7	0.6	30.9	1.2
30.5	0	30.8	437.4	36.0	0.6	40.9	1.6	35.6	1.2	40.9	-1.8
40	1.2	35.9	496.8	45.8	-1.8	50.8	0.0	41.0	1.2	50.9	-0.6
60.2	7.8	40.8	554.4	50.8	-1.2	61.0	6.8	56.0	1.8	61.0	-2.4
71.9	13.8	45.7	589.8	60.9	0.6	70.7	35.8	65.8	0.0	70.8	-1.2
79	27	50.9	666.0	70.7	4.2	80.9	254.0	71.0	4.2	80.7	-0.6
89	81	60.4	804.0	80.9	6.6	90.6	457.0	80.3	6.0	90.7	-1.2
100.8	166.8	65.8	838.2	85.8	12.0	95.7	488.0	85.7	13.8	100.9	0.6
105	213	75.9	878.4	90.9	16.8	100.7	523.0	91.0	37.2	110.8	4.2
115	438	80.8	919.2	100.9	37.2	110.5	560.0	100.9	122.4	120.7	10.2
120.5	536.4	85.9	987.0	110.8	78.6	121.0	621.0	110.9	255.6	131.0	30.0
125.5	641.4	95.8	1024.8	120.5	181.2	130.9	674.0	120.8	481.8	140.2	80.4
135	774	101.0	1029.6	130.9	484.8	135.5	706.0	130.1	620.4	150.9	173.4
140.8	880.8	106.0	1162.8	140.8	850.2	140.9	730.0	135.8	657.6	160.9	357.0
142	989.4	109.6	1079.4	150.8	1092.6	145.8	752.0	140.9	685.8	170.6	634.8

Fig-6. Effect of Penetration resistance with Depth of penetrometer

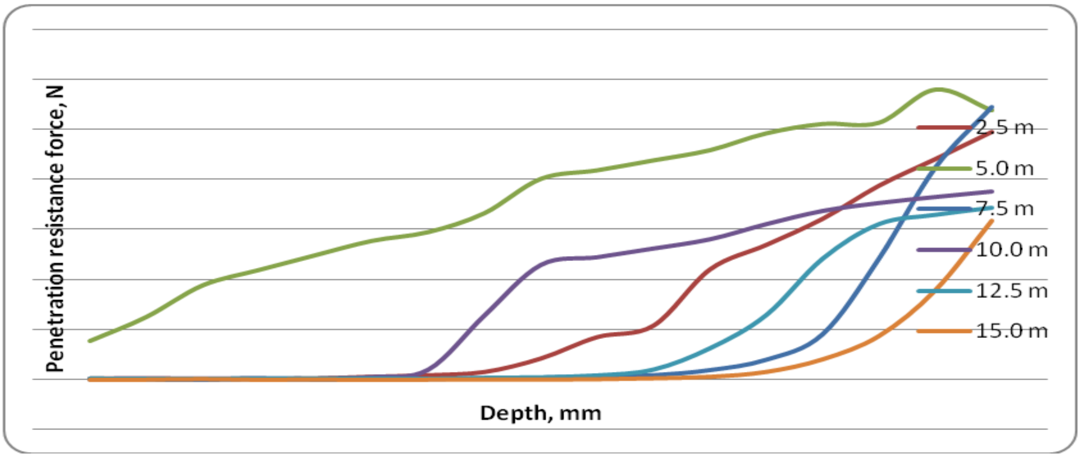
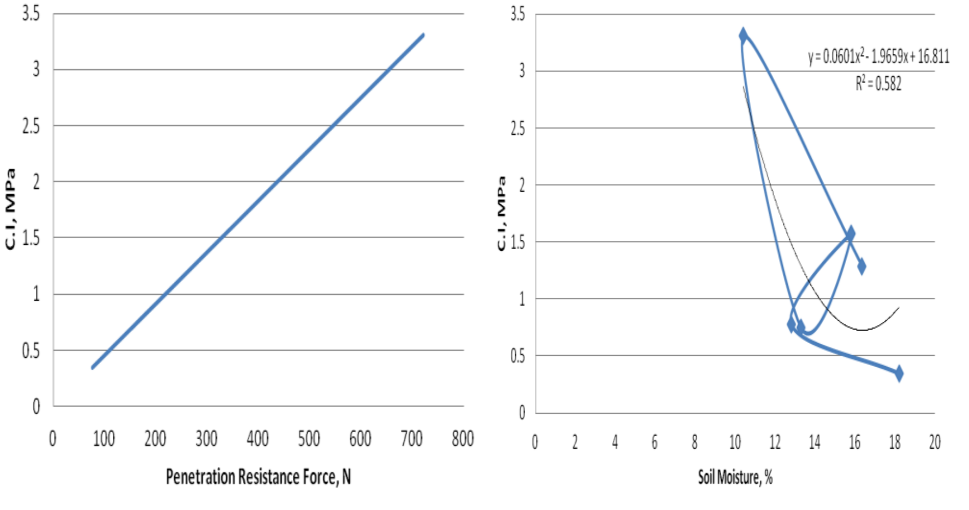


Table-3. Average values for six distances

Depth (mm)	Penetration Resistance Force, N	CI, MPa	Moisture content (%)
82.294	280.69	1.2887	16.35
60.885	720.2118	3.306	12.165
78.729	162.247	0.744	13.3
84.6	341.8	1.569	15.8
78.41	170	0.781	11.89
90.75	75.35	0.345	17.6

Effect of moisture content versus cone index for various depth of cut at different moisture content is shown in the Fig.7; in the figure it is seen that at high moisture content cone index is comparatively low than low moisture content. At high moisture content, there are no voids in the soil and the soil is sticky in nature that's why force of penetration is medium. But when the moisture decrease gradually soil resistance increased up to a certain level of soil moisture content. At low moisture content soil is hard due to its cohesive force. But at particular moisture content soil compactness and strength is least and it reached towards the optimum tilt condition and this is called optimum moisture content for that soil. After reaching optimum moisture conditions, soil resistance increasing gradually.

Fig-7. Effect of cone index with Penetration resistance and soil moisture respectively



4.2. Torque, Speed

Measurements were taken for torque of the motor driving the rotary tiller for different depth at five locations in five forward velocities on the soil bin through torque sensor. These values were shown in Table 4. A typical post process graph generated during the experiment has shown in Fig.8. The torque–speed effect has also shown in Fig.9 along with best fit equations predicting optimum torque for a particular speed.

Table-4. Different values of torque and power consumption

Depth (mm)	Forward velocity (m/s)	Rotary tiller shaft speed (rpm)	Torque on Rotary tiller shaft (N-m)	Power consumed (hp)
100	0.3	194	8.39	0.23
125	0.23	257	8.0	0.29
130	0.28	280	7.2	0.28
135	0.34	120	6.8	0.15
140	0.32	152	10.8	0.23

Fig-8. A typical post process graph for torque transducer

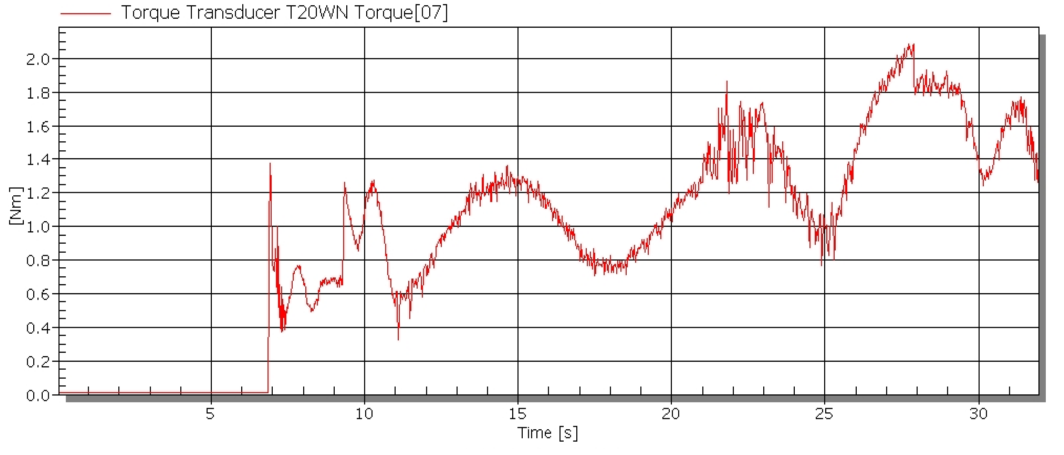
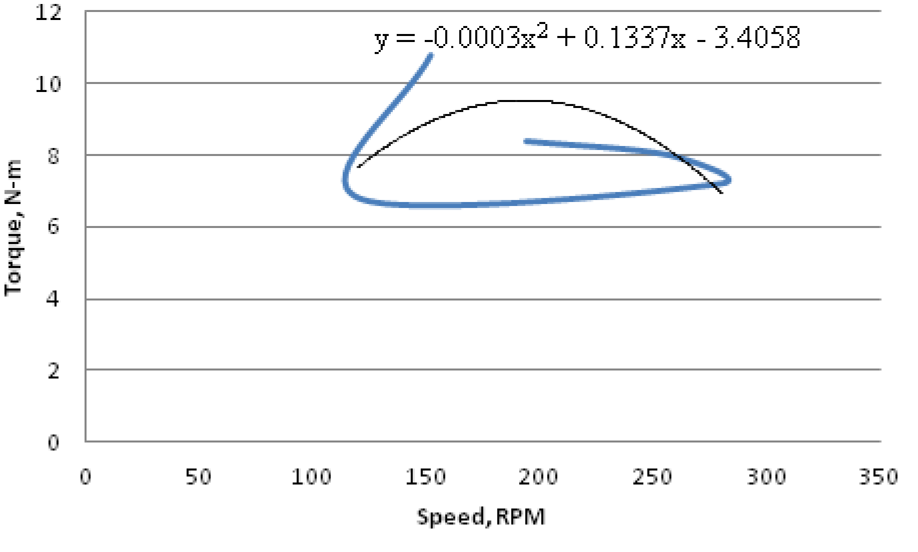


Fig-9. Torque-speed characteristics along with best fit equation



5. CONCLUSION

Soil-tool interaction of a rotary tiller was observed in a controlled soil bin. It has been found out that cone index increases with increase of penetration forces. A typical relation has been obtained for torque speed effect. From the above experiment it has been observed that soil has its optimized moisture content at which soil strength is minimum, that's why before tillage operation we should know the optimized moisture content of that type of soil. If it is known then draft requirement for tillage operation will be minimum. So power loss will reduce. The results of this study should be further verified by field evaluation on rotary tillers according to the results offered in this paper.

REFERENCES

ASAE, S., 2002b. S313.2: Soil cone penetrometer. St. Joseph, MI, USA.

ASAE Standards, 2002a. EP542: Procedures for using and reporting data obtained with the soil cone penetrometer. St. Joseph, MI, USA.

Clark, S.J. and J.B. Lliljedall, 1968. Soil bins, artificial soils and scalr –model testing. Trans. Of ASAE, 11(2): 99-104.

Culpin, C., 1981. Farm machinery. 10th Edn., Spain: Granada Technical Books Press.

Durant, D.M., J.V. Perumpral and C.S. Desai, 1979. Soil bin test facility for soil-tillage tool interaction studies. ASAE Paper No. 79-1586, ASAE, St. Joseph, MI 49085.

Gill, W.R. and G.E.V. Berg, 1968. Soil dynamics in tillage and traction. USDA - Agricultural Research Center, 511p (USDA Agricultural handbook, 316).

Godwin, R.J. and G. Kilgour, 1980. The design and operation of a simple low cost soil bin. Journal of Argicultural Engineering Research, 28(2): 99-104.

Hammer, G.L., P.S. Carberry and R. Stone, 2000. Comparing the value of seasonal climate forecasting systems in managing cropping systems. In: Hammer GL, Nicholls N, Mitchell C (Eds.), Applications of seasonal climate forecasting in agricultural and natural ecosystems: The Australian experience. Dordrecht, The Netherlands: Kluwer. pp: 183–195.

Hendrick, J.G. and W.R. Gill, 1971c. Rotary tiller design parameters, part III-Ratio of peripheral and forward velocities. Transactions of the ASAE, 14(4): 679-683.

Mardani, A., K. Shahidi, A. Rahmani, B. Mashoofi and H. Karimmaslak, 2010. Studies on a long soil bin for soil-tool interaction. Agronomic Research in Moldova, 2(142): 5-10.

Naderi-Boldajim, M., R. Alimardani, A. Sharifi and A. Tabatabaeefar, 2009. Economical hand-pushed digital cone penetrometer. Int. Agrophysics, 23(1): 55-60.

Onwualu, A. and R. Watts, 1998. Draught and vertical forces obtained from dynamic soil cutting by plane tillage tools. Soil Tillage Research, 48(4): 239-253.

Onwualu, A.P. and R.C. Watts, 1989. Development of a soil bin test facility. ASAE Paper No. 89-1106. Michigan: ASAE, St. Joseph.

Shibusawa, S., 1993. Reverse-rotational rotary tiller for reduced power requirements in deep tillage. Journal of Terramechanics, 30(3): 205-217.

Siemens, J.C. and J.A. Weber, 1964. Soil bin and model studies on tillage tests and traction devices. Journal of Terramechanics, 1(2): 56- 67.

Srivastava, A.K., C.E. Georing and R.P. Rohrbach, 2006. Engineering principles of agricultural machines. 2nd Edn., Michigan: St. Joseph Press.

Stafford, J.V., 1979. A versatile high speed soil tank for studying soil and implement interaction. Journal of Agricultural Engineering Research, 24(1): 57-60.

Topakci, M., H.K. Celik and D. Yilmaz, 2008. Stress analysis on transmission gears of a rotary tiller using finite element method. Akendiz Ünivresitesi Ziraat Fakultesi Dergisi, 21(2): 155-160.

Upadhyaya, S.K., J. Mehkschau, D. Wulfson and J.L. Glancey, 1986. Development of a unique, mobile, single wheel testing device. Trans of the ASAE, 29(5): 1243–1246.

Wismer, R.D., 1984. Soil bin facilities: Characteristics and utilization. In Proc. 8th International Conference, International Society for Terrain- Vehicle Systems. 6 10 August, Cambridge, England, 3: 1201-1216.

Wood, R.K. and L.G. Wells, 1983. A soil bin to study compaction. ASAE Paper No. 83–1044. MI, USA: ASAE, St. Joseph.

Yatsuk, E.P., I.M. Panov, D.N. Efimov, O.S. Marchenkoc and A.D. Chernenkov, 1981. Rotary soil working machines (Construction, Calculation and Design). 1st Edn., New Delhi: Amerined Publishing Company Pvt. Ltd.