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A Spiral Rotor Tiller for Tillage Heavy and Dry Clay Soil

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ABSTRACT

This trial is to use an innovative spiral rotor tiller for tillage heavy and dry clay soil texture. Efficiency of cutting and loosening soil layer indices soil pulverization, tillage profile, specific resistance (N/m^2) of spiral rotor share and power requirements (kW) are identified to evaluate the performance of spiral rotor tiller. The studied variables are four setting angles with direction line of zero, 25°, 50° and 75°, three tilling angles of 25°, 30°, and 35° and four forward speeds of 1.0, 1.5, 2.0, and 2.5 km/h in heavy and dry clay soil. The results related that increasing setting angle from 0° to 75° the MWD decreased by about 48%, and also both of the specific resistance of the spiral rotor share and power requirement decreased by 45.8 and 39.8% respectively, while the tillage width increased by about 50% at forward speed 1.5 km/h and tilling angle 25°.

Keywords: Spiral rotor share, tillage**,** fineness degree, heavy clay soil**,** soil pulverization, tillage profile, specific resistance

INTRODUCTION

Egyptian alluvial soils are classified according to "Soil Taxonomy" as order Vertisols. In general the Vertisols are the most difficult ones of the ten orders of Soil Taxonomy to manage. They are defined as "Mineral soils that have 30% or more clay, deep cracks when dry, and either (a natural) gilai-microrelief, intersecting sliknesides, or wedge shaped structural aggregates tilted at an angle from the horizontal" (Ahmed -2003). The soil aggregation size is a crucial parameter to determine the degree of tillage required by land. In order to improve the uniformity of seedbed by varying the degree of secondary tillage and also preparation of suitable seedbed for germination and crop growth Isavi and Mahmoudi (2013). Soil structure is an important measure of soil quantity that significantly affected by tillage systems (Ismail -2002). On the other side, improving tillage system gets the best soil structure and consequently achieves a high production (Ismail and Abo-Habage -2002). To fulfill the previous point, Egyptian farms used chisel plow with two or three perpendicular passes to reduce clods size of soil left and in order to obtain a suitable seedbed preparation. These operations have many of disadvantage such as need more energy, left poor soil surface and inversion, left plant residues without mixing with the soil particles, untilled area of about 14% and increases in soil volumes (Korayem and hindy-1974).

Ismail and El-Sheikha (1989) indicated that, about 5-6 billion tons of soil covering about 6 million feddans in Egypt are tilled 4 to 8 times for each crop rotation per year. This would in fact turn about 24-48 billion tons of soil and consume about 60 million litter of diesel oil. Therefore, most find a way to change tools of tillage. A try by Ismail (1994) and Srivastava *et al*. (2006) to use active shares in heavy soil type driven by PTO. A shaft containing blades is located at 90° to the line of travel and rotates in the same direction as the forward tractor travel. Since the shaft turns at a rate that is considerably faster than the corresponding tractor speed, soil pulverization is accomplished. Power to operate the rotary tiller is restricted by available tractor power. Another try was done by Topakci *et al*. (2008) which indicated that, rotary shares has been increased use in agricultural applications because of high tillage efficiency. By taking advantage of rotary shares, the primary and secondary tillage applications could be conjugated in one stage. But, because rotary shares power is directly transmitted to the soil surface, the power transmission efficiency in rotary shares is high. Soil disturbance and consequently plowing quality is affected by moisture content, depth and speed.

Also, many of authors and patents discussed how to change the tillage tools? one of them is an apparatus for forming helical plow screws plowing beneath the surface of soil, such as with submerged V-shaped or sweep plow blades, wherein the soil behind such blades is further worked by submerged rotary helical members which work the soil in two rotary modes that angularly related and follow the angular mode of working ahead thereof by the plow blades (Srivastava- 1973). Similarly, helical plow was investigated by Harian (1973). This invitation relates to new and useful improvements in plows, and has particular reference to a plow and including the plow share of which resembles a helical auger on a horizontal axis inclined relative to the direction of travel. To overcome the disadvantages for common different plows, the attempt investigates spiral share nearly to auger form but including different diameters and with conical wedge in front for tillage the heavy soil. Therefore, the main objectives of the present study were to; test the feasibility of using a spiral rotor share for tillage heavy and dry clay soil and select the optimum operation conditions during tillage operation that verification best seedbed preparation.

MATERIALS AND METHODS

One spiral rotor share constructs as a prototype as shown in figure (1). It consists of two flights and a conical wedge fixed on drive shaft. Total mass is 9 kg. The drive shaft is made of medium-carbon steel stem with 35 mm diameter and steel 42 to flight with 6mm thickness and average length of 350mm (figure 2). The prototype was installed and fixed on a specialist equipment to test and evaluate the proposed spiral rotor share.

The spiral share is connected with hydraulic motor that take the motion from hydraulic tractor pump. The prototype connected with two units of pressure indicator and controlling valves as shown in figure (3).

The general hydraulic motor specification was determine as investigated in appendix part. It is as following; motor displacement of 126.3 ml/rpm; Max. pressure drop are at cont. 14 MPa while intermittent 17.5 and peak of 20 MPa; Max. torque are at cont. 237 Nm while intermittent 296 and peak of 338 Nm; speed range is constant 9 – 475 rpm; Max. flow (cont.) of 60 l/min; Max. output power 10 kW and total mass of 7.3 kg. The general hydraulic tractor pump specifications are; Gear-type; it is part of H8 pump, which includes the steering servomechanism pump, too. It is fitted in the clutch housing. Output at working pressure and engine rated speed 40 l/min and output pressure 98.1 bar.

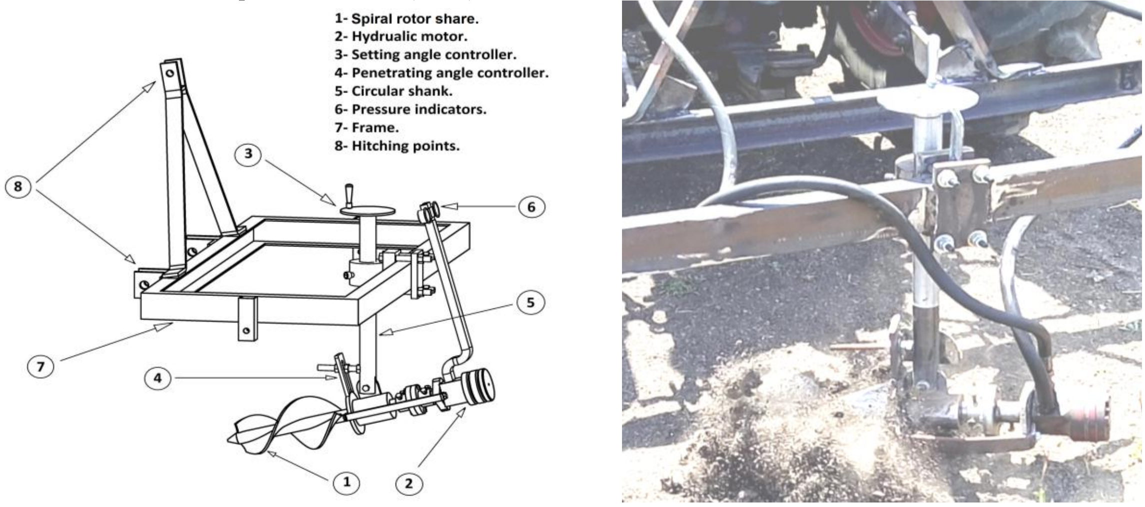

Figure 1. the spiral share with rotary axis

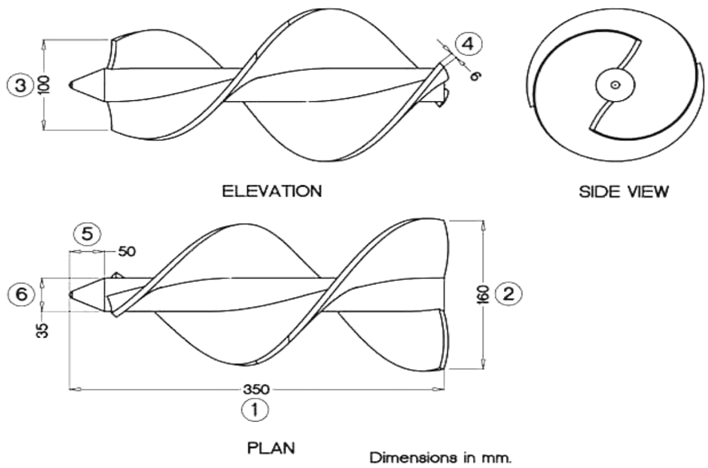

Figure 2. Spiral rotor share

1- Over all length of share 2- Rear cutting width 3- Front cutting width 4- Flight thickness 5- conical wedge length 6- Stem diameter

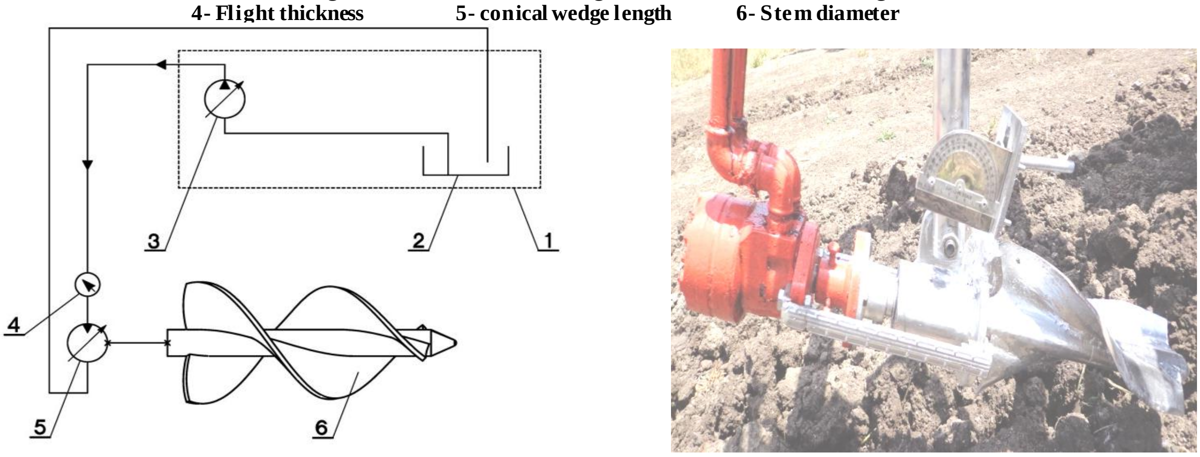

Figure 3. A diagram of the hydraulic cycle

1- Boundary of tractor 2- Reservoir oil 3- Hydraulic pump 4- Pressure indicator 5- Hydraulic motor 6- Spiral rotary share

Field Test Experiment

The experimental studies were executed to determine the effects of forward speed of 1.0, 1.5, 2.0 and 2.5 km/h at rotational speed with about constant rotation for spiral share of 110±20 rpm at different tilling angles of 25°, 30° and 35° from tillage surface and four different setting angles of zero, 25°, 50° and 75° relative to traveling spiral share, as shown in figures 4 and 5 on efficiency of cutting and loosening soil layer indices, soil pulverization, tillage profile, specific resistance of the spiral rotor share (N/m^2) and power requirements (kW). All above treatments were operated at constant spiral rotary tiller depth of 15±2 cm.

A rectangular area was divided into forty eight plots, the width of each plot was two meters and length of 100 m for running, this distance was enough to take three readings. Field experiments were conducted on heavy and dry clay soil at El-Gemmiza Agricultural Research Station – El-Gharbia Governorate. The physical properties of the experimental field were measured and summarized in table (1). The average moisture content and bulk density of soil surface layer (0-20 cm) were determined and found to be 10% (db) and 1.32 $g.cm^{-3}$, respectively. In all tests a tractor, Romanian model (Universal 650 M) rated at 48.5 kW was used.

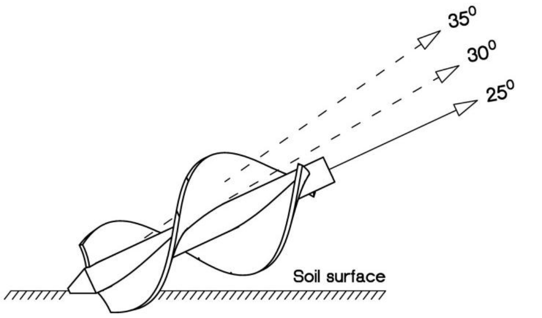

Fig. 4. Three tilling angles

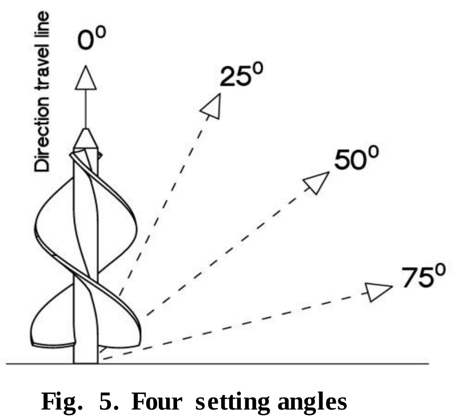

Fig. 5. Four setting angles

Table 1. The soil mechanical analysis of experimental field.

Texture class	Coarse sand, %	Fine Sand, %	Silt, %	Clay, %
clay	2.96	21.11	28.01	47.92

Fineness degree

The fineness degree can determine as a percentage of size distributions by weighted and sieves each sample using six different sieves with mesh sizes of 100, 50, 20, 10, 5 and less than 2 mm and weight the samples on each sieve. The percentage of size distributions calculated by:

$$\text{Percentage size distribution} = \frac{\text{On sieve mass}}{\text{Total mass of sample}} \times 100 \quad ....\%$$

The clod mean weight diameter (MWD, mm) determined by using the sieved samples. The MWD was determined according to RNAM (1983) as follows:

$$MWD = \frac{1}{W}(150\,A + 75\,B + 35\,C + 15\,D + 7.5\,E + 3.5F + 1.5G)............mm$$

Where: A + B +… E = mass of clods soil, kg.

W = A + B +... E, kg.

The tillage profile

It was drawing using a simple device was prepared as inverse profile-meter according to Abo-Habga and Ismail (2002).

Specific resistance of spiral rotor share (R)

It was measured by a pressure gauge located on the oil hose which comes from the tractor pump to the hydraulic motor as shown in figure 2. Pressure has been measured in load (R_1) and no-load (R_2). Therefore, the specific resistance of soil calculated as follows:

$$\mathbf{R = R_1 - R_2 \quad (N/cm^2)}$$

Power requirement (P) kW, was determined from the principles following formulas as in appendix part.

Experimental analyses

The strip plot design was used to evaluate the field experiments. Data was collected for all parameters of different treatments and was statistically analyzed by the statistical analyses program (SAS).

RESULTS AND DISCUSSION

Fineness degree

To focus on the effect of operating factors included tilling angle and forward speed for the spiral rotor tiller on fineness degree (particles size distributions (PSD) (Fig. 6) and mean weight diameter (MWD) in figure (7) at different setting angles referred as the following:

The figure shows that the all data of particles size distributions had a normal distribution curve via the spiral rotor tiller forward speed. The figure clear that the peak percentage of (PSD) 46.2, 34.6, 46.6 and 44.5% at 1.0, 1.5, 2.0 and 2.5 km/h respectively using sieve hole diameter of 35 mm and tilling angle of 25°. On the other side, at traditional tillage (chisel plow one pass at forward speed of 2.5 km/h) the percentage of (PSD) was 54.1% using sieve hole diameter of 75 mm. The corresponding percentages at tilling angle of 30° were 38.9, 42.1, 36.6 and 39.5 % at 1.0, 1.5, 2.0 and 2.5 km/h and at tilling angle of 35° were 42.0 and 32.6 % at 1.0 and 1.5 km/h respectively using sieve hole diameter of 35 mm. However (PSD) were 38.7 and 35.4 % at 2.0 and 2.5 km/h at tilling angle of 35° and sieves hole diameters of 75 mm. Therefore, Fig. (7) illustrated that the MWD has an inversely proportional to setting angle but it has directly proportional to tilling angle and spiral rotor tiller forward speed. From the figure it seen that by increasing the forward speed of spiral rotor tiller from 1.0 to 2.5 km/h, increased the MWD at all treatment under study. The highest roughness of clod size was 75.58 mm obtained at tilling angle of 35°, setting angle of zero and forward speed of 2.5 km/h. Vice versa, the highest fineness MWD was 20.37 mm achieved at penetrating angle of 25°, setting angle of 75° and forward speed of 1.0 km/h.

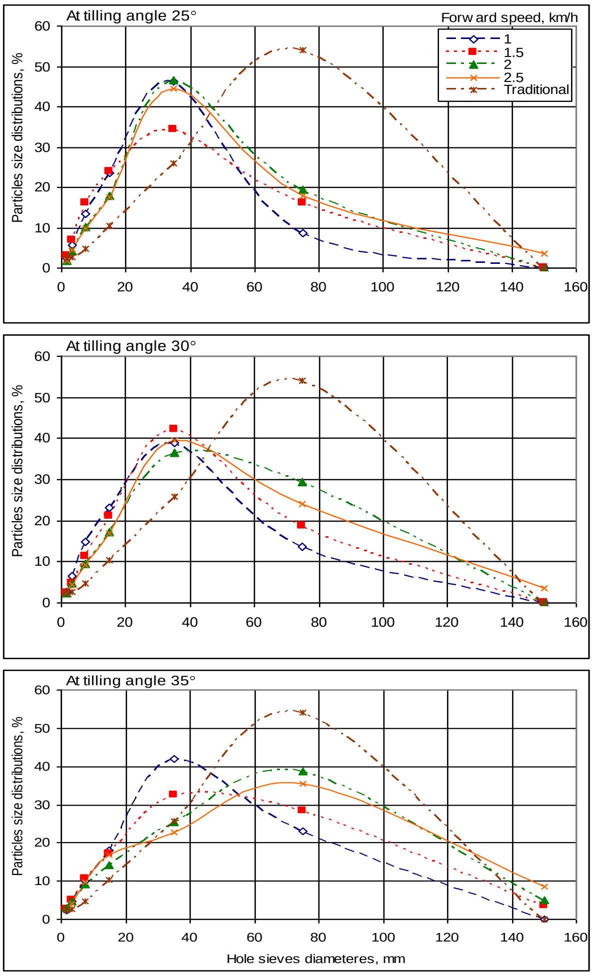

Fig. 6. Effect of forward speed on particles size distributions %.

On the other hand at using chisel plow MWD was 51.6 mm. This trend is attributed to the increment effect of forward speed on preventing the spiral rotor tiller to take enough time to cut and loosen soil layers. Also increasing forward speed at a constant the rotational speed of spiral rotor tiller around 110 rpm leads to decrease speed ratio then it is not sufficient to the corresponding tractor speed, and as a result, soil pulverization is awful, but at decreasing traveling speed led to increasing in speed ratio that means increasing the revolution number of spiral rotor tiller per specific length of land thus fine tillage can be obtained. On the other hand, increasing in setting angle prevented the spiral rotor tiller to tilling soil and then cut a shallow layer of soil surface and consequently the MWD decreased. However, by increasing the tilling angle the MWD increased, and resulted in more deep of spiral rotor tiller into soil led to the biggest obstruct for spiral rotor tiller rotation. The best similarity ratio of the mean weight diameter was 24.5% occurred at operation factors of 25°, 25° and 1.5 km/h of penetrating and setting angle and forward speed respectively.

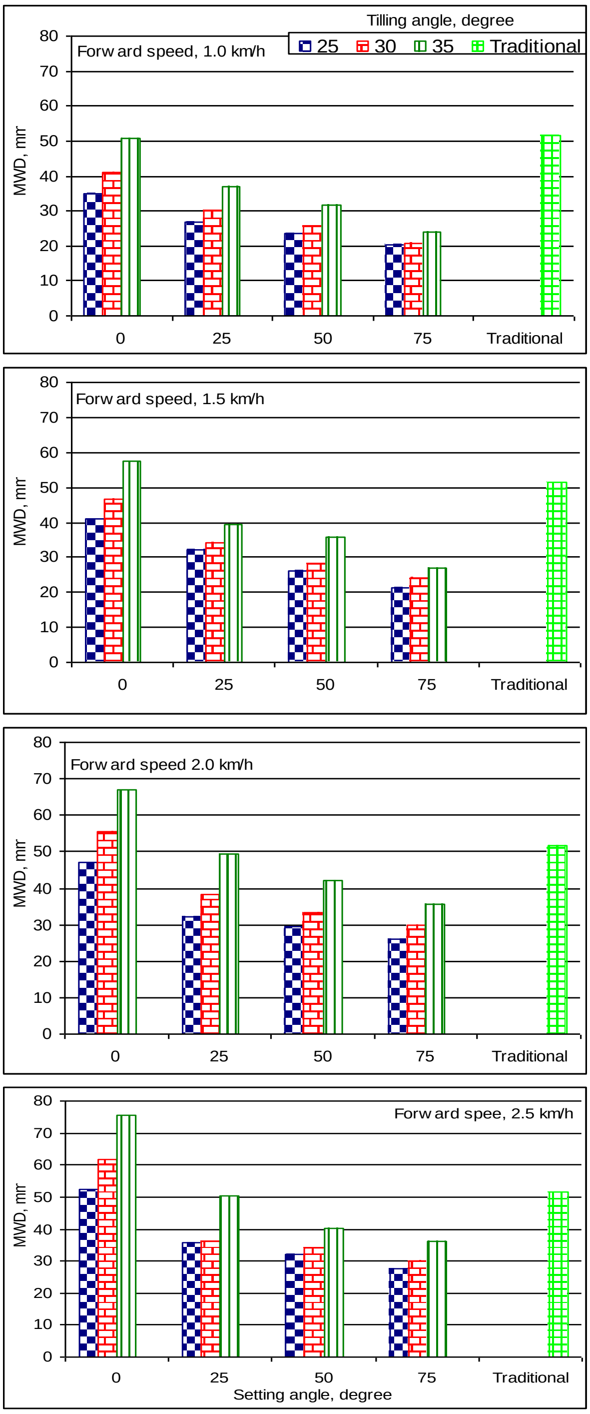

Fig. 7. Effect of forward speed on mean weight diameter (MWD).

The effect of forward speed "F", tilling angle "T" and sitting angle "S" on MWD shows by the multiple regression analysis. The follow equation illustrates the relation as see in Eq. (1):

The regression analysis declares that both of forward speed and tilling angle have a direct proportional with tillage depth. But the setting angle has an inversely relationship to the MWD. The factors affected the MWD arranged as the following ascending on relative to analysis of variance as follow: setting angle (the p-value from analysis as $Pv1 = 1.2\times10^{-17}$) > forward speed (the p-value from analysis as $Pv2 = 6.8\times10^{-9}$) > tilling angle (the p-value from analysis as $Pv3 = 3.3\times10^{-9}$).

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MWD = -1.28 + 8.47 F + 1.19 T- 0.33 S (R² = 0.87) (1)

Tillage profile

The relationship between tillage profile included (tilling depth & tilling width) and setting angle with different forward speeds of spiral rotor tiller at different tilling angles was illustrated in Figs. (8, 9 and 10).

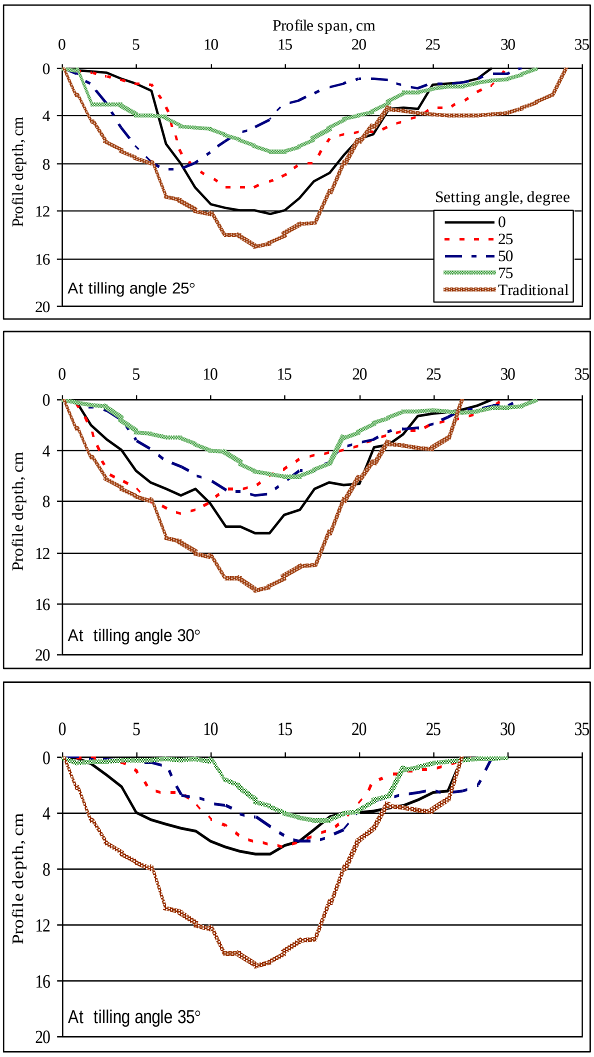

Fig. 8. Tillage profile at different tilling angle.

The results indicated that the highest value of tilling depth was 12cm, which obtained at adjusted spiral rotor tiller at tilling angle of 25° and setting angle of zero with forward speed of 1.0 km/h. While the lowest value of tilling depth was 4.5 cm, at tilling angle of 35° and setting angle of 75° with forward speed of 2.5 km/h. On the other hand, the highest value of tilling width was 32 cm that was obtained when spiral rotor share adjusted at tilling angle of 35° and setting angle of 75° with forward speed of 1.0 km/h. While the lowest value of tilling width was 16 cm at tilling angle of 25° and setting angle of zero with forward speed of 2.5 km/h.

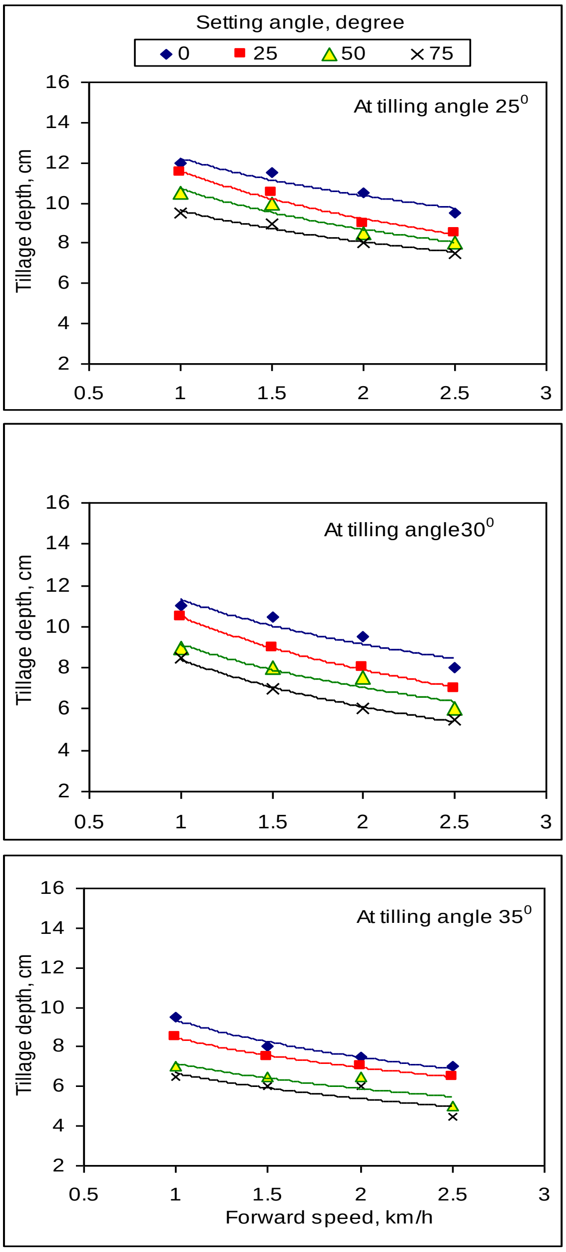

Fig. 9. Forward speed effect on tillage depth.

This trend may be attributed to the increment effect of traveling speed on preventing spiral rotor tiller into soil. Also the increasing in setting angle leads to increasing in operation width work and more obstruction to tilling soil for spiral rotor tiller and decreases in tilling depth. It was obvious that increasing the tilling angle, decreased the tilling depth for at all treatment under study due to increase both of digging resistance and fraction resistance. Also, increasing the setting angle led to decrease the tillage depth for all treatment.

The multiple regression analysis shows the effect of forward speed "F", tilling angle "P" and sitting angle "S" on tillage depth "D" and tillage width "W". The relation equation can see in Eq. (2 and 3):

D = 6.20 - 3.14 F - 0.34 T - 0.04 S (R² = 0.941) (2)

W = 18.91 - 2.38 F + 0.23 T + 0.12S (R² = 0.936) (3)

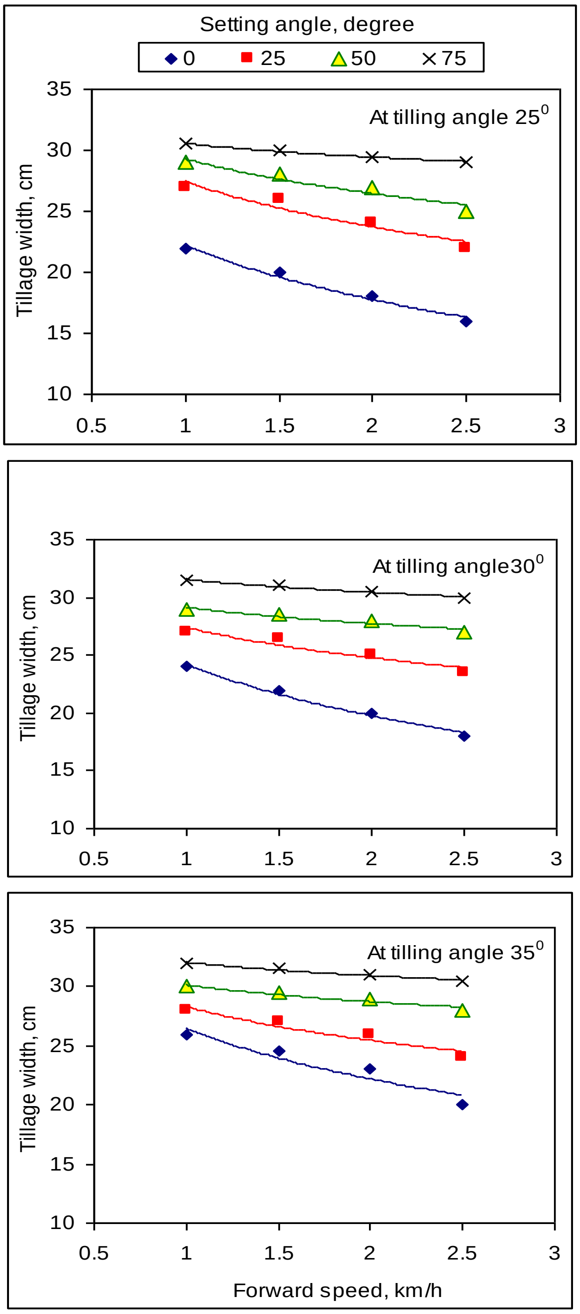

Fig. 10. Forward speed effect on tillage width.

Specific resistance of spiral rotor share

The effects of forward speed, setting angle, and tilling angle on the spiral rotor share resistance (N/cm^2) were illustrated in Figure (11). The general trend of this relationship is that spiral rotor share resistance increased directly with increasing the forward speed for all treatments. But in the other hand, the specific resistance decreased by increasing in both of setting angle and tilling angle. This trend may be attributed to increasing in operation speed increased the soil layer particles are characterize by the augmentation of kinematics energy which needed more force to beat on cutting resistance of soil and it is known that share resistance have direct proportion to the force. The previous data indicated that increases in tilling angle decrease tilling depth also increasing setting angle, cutting depth become shallow which decreases tillage depth. These explain why share resistance decreased with increases both of tilling and setting angles.

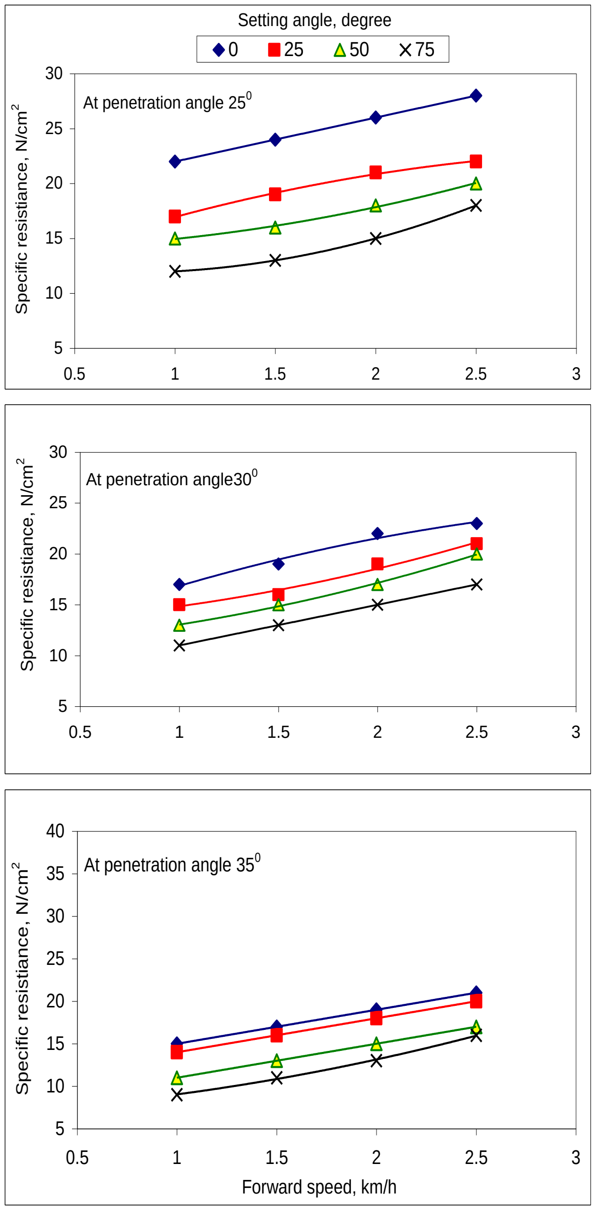

Fig. 11. Effect of forward speed on specific share resistance N/cm^2

The results indicated that the highest value of the cutting resistance was 28 N/cm^2. It was obtained when adjusting setting angle on zero angle with direction of traveling line, penetrating angle of 25^0 and forward speed of 2.5 km/h. While, the lowest value is 9 N/cm^2 at the sequence conditions of setting angle of 75°, penetrating angle of 35° and speed of 1.0 km/h.

Regression analysis shows the effect of forward speed "F", tilling angle "P" and sitting angle "S" on specific resistance "S_r". The relation equation can see in Eq. (4):

S_r = 26.3 - 3.14 F - 0.42 T - 0.01 S (R^2 = 0.951) (4)

Power requirements

To evaluate the effect of operating factors included setting angle, tilling angle and forward speed on the on the power requirements needed to operate the spiral rotor tiller for cutting and loosening soil, the data are illustrated in Fig. (12). By increasing setting angle and tillage angle the power requirement decreased. At setting angle zero, the rate of decrement was about 42% at increasing the tilling angle from 25^0 to 35^0 at forward speed of 1.5 km/h and by 26.9% at increasing setting angle from zero to 75^0 at forward speed of 2.0 km/h, and tilling angle of 25°. While this rate is increased by 47.8% at increasing forward speed from 1.0 to 2.5 km/h at setting angle of 50°and tilling angle of 25°.

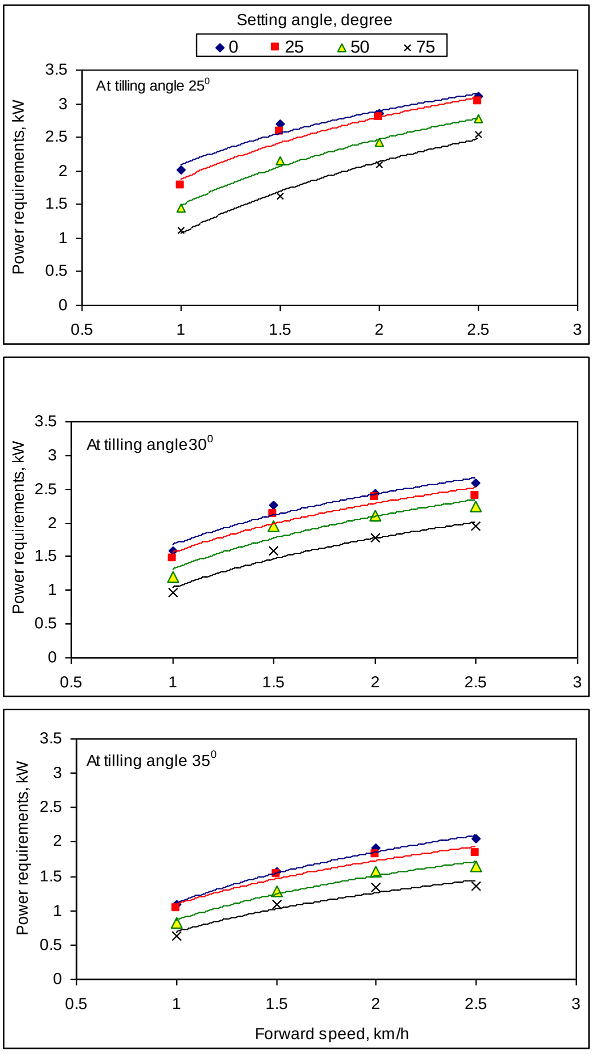

Fig. 12. Effect of forward speed on power requirement (Watt)

The highest value of power requirement was 3.11 kW obtained when spiral rotor tiller was adjusted at 2.5 km/h, setting angle of zero and at tilling angle of 25^0. While the lowest value was 640 watt recorded at 1.0 km/h, setting angle of 750 and tilling angle of 35.

The regression equations between the power requirements (P), kW, and forward speed "F", tilling angle "T" and sitting angle "S" was in agreement with the previous gained results as presented in Eq. (5):

P = 3.78 + 0.67 F – 0.09 T - 0.01 S (R² = 0.951) (5)

CONCLUSION

The highest fineness degree of the mean weight diameter MWD was 20.37 mm achieved at tilling angle of 25°, setting angle of 75° and forward speed of 1.0 km/h with consumption power of 1.11 kW. However, the best similarity ratio of the mean weight diameter of 40mm was 24.5% occurred at operation factors of 25°, 25° and 1.5 km/h of tilling and setting angles and forward speed respectively, that needed a 2.57 kW of power. The results indicated that the highest value of tilling depth was 12cm, which obtained at adjusted spiral rotor tiller at tilling angle of 25° and setting angle of zero with forward speed of 1.0 km/h and consumption power was 2.01 kW. The best results of the particles size distributions percentage were 46.58 and 46.21 % obtained at adjusted the spiral rotor share at traveling speed of 2.0 and 1.0 km/h respectively on tilling angle 25° and setting angle of 50°. it is recommended to using the spiral rotor share and performing it with forward speed from 1.5 to 2.0 km/h and rotating speed 110 rpm under tillage angle 25° and setting angle 25° to get a suitable seedbed.

Appendix

Determination of hydraulic motor specification

Many authors discussed the required forces or power need to complete the tillage operation. Bernacki *et al.* (1972) and Ismail and Ismail (2013) investigated the principle equation to calculate the rotor share moment according torque (M) may be used to determine or select the specification of:-

$$M = A \times V \quad kg_f.m$$

$$M = A\left(\frac{zlab}{2\pi}\right) \quad kg_f.m$$

Where:-

$$A = (A_o + A_B) \quad kg_f.m/cm^3$$

$$A_o = (C_o K_o) \times 10^{-4} \quad kg_f.m/cm^3$$

$$A_B = (a_u u^2) \times 10^{-6} \quad kg_f.m/cm^3$$

$$l = 100\left(\frac{v.60}{nz}\right) \quad cm$$

$$M = \left(10^{-4} C_o K_o + 10^{-6} a_u u^2\right)\left(\frac{zab}{2\pi}\right)\left(\frac{v.6000}{nz}\right) \quad kg_f.m$$

$$M = \left(10^{-4} C_o K_o + 10^{-6} a_u u^2\right)\left(\frac{6000 \times ab \times v}{2\pi n}\right) \quad kg_f.m.....(1)$$

Where:

M mean torque on shaft of working element ($kg_f.m$)
V displacement volume of the soil (cm^3)
A the specific work ($kg_f.m/cm^3$)
A_o the static specific work ($kg_f.m/cm^3$)
A_B the dynamic specific work ($kg_f.m/cm^3$)
C_o the coefficient relative to the soil type
K_o the specific strength of soil (kg_f/cm^2)
a_u the dynamic resistance coefficients ($kg_f.s^2/m^4$)
v forward speed (m/s)
u peripheral speed of the rotor element (m/s)
n rotational speed of rotor element (rpm)
ω Angular velocity of rotor element (sec^{-1})
z number of working elements operating in one plane of cutting
l length of soil slices (cm)
a working depth (cm)
b working width of the tool (cm)
r outside radius of the rotor element (cm)

In heavy soils the values of C_o, K_o and a_u are 2.5, 50 kg_f/dm^3, and 400 $kg_f.s^2/m^4$, respectively (Bernacki *et al.*, 1972) and Ismail *et al.* (2007). In current case, the optimum operating condition for the proposed design rotary tool was, z=1; a=10cm; b=16cm; v=0.69m/s; n=110rpm; u=0.92m/s; l=37.63 cm; r=8cm. Thus, the theoretical moment torque (M), needed to cut and loosen the soil could be calculated by replacing previous values in the equation (1):

$$M = (0.0125 + 0.0003385)\left(\frac{6000\times10\times16\times0.69}{2\pi110}\right) = 12.3 \quad kg_f.m$$

$$M = 12.3\times9.81 = 120.7\ N.m$$

$$Power = M\times\omega \quad Watt$$

$$= 120.7\times\frac{2\pi110}{60}$$

$$Power = 1390.36\ W = 1.39\ kW$$

So, the suitable hydraulic motor that gives the power needed to drive the proposed design rotary tool was selected.

Determination of power requirements (kW): was determined by the following formulas,

$$P = \tau\times\omega \quad kW$$

$$\tau = R\times\frac{V}{(2\pi)\times100} \quad N.m$$

$$V = a\times l\times b \quad cm^3$$

$$l = \frac{v\times6000}{n} \quad cm$$

Where

P power requirement (kW)

τ the moment torque needed to cut the soil (N.m)

R specific share resistance (N/m^2)

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محراث لولبى دوار لحرث التربة الطينية الثقيلة الجافة

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تتدرج الأراضى المصرية فى التصنيف العالمى تحت الأراضي الطينية الثقيلة خاصة فى شمال ووسط الدلتا، والتى عند جفافها بدرجة شديدة تؤدى إلى إنفصال سطح التربة إلى قطاعات مندمجة ومتكتلة مع بعضها البعض تُصعب من إجراء عمليات الخدمة، ونظرا لضيق الوقت الراجع إلى الارتباط بمواعيد الزراعة وعدم توفر المياه، يصعب إعطاء ريه كدابة، وتتم عمليات الخدمة عند محتوى رطوبي منخفض قد يصل في بعض الأحيان إلى ١٠% والذي ين.ترتب عليه حرث غير جيد للتربة الطينية الثقيلة. لذا يهدف هذا البحث إلى دراسة إمكانية استخدام سلاح لولبى دوار لتحسين جودة الحرث في الأراضي الطينية الثقيلة شديدة الجفاف مع تحديد العوامل المثلى للحصول على أفضل جودة حرث.واشتملت عوامل الدراسة علي:أربع زوايا توجيه مع خط السير صفر، ٢٥، ٥٠، ٧٥ درجة،ثلاث زوايا لاختراق التربة ٢٥، ٣٠، ٣٥ درجة أربع سرعات تقدم وهي ١,٠ ، ١,٥، ٢، ٢,٥ كم/ساعة.مع تثبيت سرعة دوران السلاح عند ١١٠±٢٠ لفة/دقيقة ومحتوى رطوبي للتربة حوالي ١٠% على أساس جاف.وتم تقييم الأداء من خلال توزيع نسب أقطار حبيبات التربة ومتوسط القطر الموزون، بروفيل الحرث، المقاومة النوعية للسلاح ومتطلبات القدرة اللازمة لإدارة السلاح. وقد أظهرت النتائج أن أفضل نسبة تجانس لأقطار حبيبات التربة هي ٢٤,٥% بمتوسط قطر حوالي ٤٠ مم عند زاوية اختراق ٢٥° وزاوية توجيه مقدارها ٥٠° وسرعة تقدم ١,٥ إلى ٢,٠ كم/ساعة. وللحصول على أعلى درجات النعومة لحبيبات التربة بمتوسط قطر ٢١,٣ مم يتم ضبط زاوية الاختراق عند ٢٥° وزاوية التوجيه عند ٧٥° وسرعة تقدم ١,٠كم/ساعة وكانت مقدار القدرة اللازمة حوالى ١,١٢ كيلو وات ومقاومة نوعية للسلاح مقدارها ١٢ نيوتن/سم٢. ويوصى باستخدام المحراث المبتكر فى حراثة الأراضى الطينية الثقيلة شديدة الجفاف.