Tractor Performance as Affected by Tilt Angle of Disc Plough under Clay Soil

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Abstract: **The three-bottom, fully mounted disc plough is the most commonly used primary tillage implement in the small scale farming in central and northern Sudan. In the disc plough, two angles (tilt and disc angles) affect tractor performance and ploughing quality. This research was conducted at the demonstration farm of the Faculty of Agriculture, University of Khartoum during November and December 2014 to study the effect of three tilt angles (15°, 20° and 25°) on disc plough field performance variables, namely, tractor rear wheel slippage, fuel consumption rate, draft force, power requirement, field capacity and field efficiency in clay soil. Randomized complete block design was used. Tractor forward speed and disc angle were maintained at 6 km/h and 45°, respectively. The highest field capacity (0.32 ha/h) and efficiency (74.75%) were recorded for the tilt angle 20° as compared to 71% and 69% under the tilt angles 15° and 25°, respectively. Both tilt angles 15° and 20° recorded the highest values of slippage (14.2% and 12.5%, respectively) while tilt angle of 25^0 recorded the lowest value of slippage (9.5%). The highest value of fuel consumption rate was 2.83 l/fed and it was recorded by 25^0 tilt angle followed by 2.72 L / fed and 2.54 l/fed for tilt angles of 20° and 15° respectively. The highest value of draft was 9.125 kN and it was recorded 250 tilt angle while the lowest values were 8.38 kN and 8.68 kN and they were recorded by tilt angles of 15° and 20° respectively. The results showed that the highest value of power was 15.05 kW was demonstrated by 25° tilt angle followed by 14.47 kW for the tilt angle of 20°, while the tilt angle of 15° recorded the lowest power (13.9 kW). It can be concluded that the tilt angle of 20° is the most appropriate for ploughing with the disc plough as it recorded the highest field capacity, field efficiency and low draft, moreover, such angle recorded moderate value of the required power, rear wheel slippage and fuel consumption.**

Keywords— Disc plough; tilt angle; tractor performance.

I. INTRODUCTION

Farm mechanization is application of engineering and technology in agricultural operations to do a job in a better way to improve productivity. It includes development, application, and management of all mechanical aids for field production, water control, material handling, storing and processing [1]. Mechanization of agriculture has two main objectives these are to increase the productivity per agricultural worker and to change the characteristics of farm work, making it less arduous and more attractive. Tillage is changing the state of the soil in order to provide conditions favorable for crop growth. The main objectives of tillage are the production of a suitable tilth, the destruction of weeds, the destruction of pests and burying the rubbish and the incorporation of fertilizers into the soil. The main source of power in agriculture is the tractor, which is now available in different sizes. Tractor power utilization is achieved through the driving wheels as traction to provide the drawbar power required for draft implements and to provide mobile support for attached machine. Reference [2] reported that proper selection and matching of agricultural machinery can reduce the amount of energy required for implement.

Draft, energy and fuel requirements for agricultural implements have been recognized as essential factors when attempting to correctly match an agricultural implement with tractor power. Soil condition and speed of operation to carry out tillage operation in clay soil were found to be important and should be given proper attention [3]. Disc plows are primarily suitable for the tillage of virgin, stony and wet soils, cut through crop residues and roll over the roots. The action of a concave disc is to lift, pulverize, partially invert, and displace the soil to one side and it is well adapted to plough extremely hard soils. The disc angle (horizontal angle between plane of disc and direction of travel) is usually 45° while the tilt angle is ranging between 15°-25° from the vertical and easily adjustable. The general objective of the present research was to study the effect of 15^0, 20^0 and 30^0 tilt angles on the disc plough performance on clay soil while disc angle was kept constant at 45^0

2. MATERIALS AND METHODS

2.1 Materials

Materials used in the study include auger, drying oven, paraffin wax, two tractors, hydraulic dynamometer, metering tape and graduated measuring cylinder.

The experimental work was carried out at the demonstration farm of the Faculty of Agriculture, University of Khartoum in Shambat, Sudan in 2014.

The area of the experimental area was 8829 m^2 (2.10 fed, 0.8829 ha) with clay soil. The experiment was arranged in a randomized complete block design with three treatments which include 15°, 20°, and 25° tilt angle which were replicated four times.

2.2 Method

2.2.1 Soil physical properties Determination

W1= Cold weight (g). Soil analyses were carried out at the soil science laboratory of the Faculty of Agriculture, University of Khartoum. The soil physical properties under the study were bulk density, particle density, moisture content, and soil porosity.

i- Bulk density

The bulk density of soil was measured using the cold paraffin wax method as follow:

Form each main plot undisturbed soil clods were taken using an auger. The samples were collected from two depths 0-15 and 15-25cm.These clods were weighed, coated with paraffin wax and weighed again. The coated volume was then determined. The bulk density was calculated from the following equation [4]:

$$\rho_b = \frac{W_1}{v - [(W_2 - W_1)]/D} \dots\dots\dots\dots(1)$$

Where,

ρ_b =Bulk density (g/cm^3).

W2 = Cold and paraffin wax weigh (g).

v = Coated clod volume (cm^3).

D = Paraffin wax density (g/cm^3).

ii- Moisture content

From each plot undisturbed soil samples were taken using the auger. The samples were collected from two depths 0 – 15 cm and 15-25 cm. The colds were weighed before drying and after drying (W2). The moisture content was calculated from the following equation:

$$MC = \frac{W_1 - W_2}{W_2} \times 100 \dots\dots\dots\dots(2)$$

Where:

W1 = Wet mass (g).

W2 = Dry mass (g).

iii- Particle density

Particle density of the soil was determined using the cylinder method as described by [5] Blake (1965). The increase in the volume of water column in a measuring cylinder was found after pouring into the soil samples, the following formula was used to calculate the particle density:

$$Pd = \frac{M}{V} \dots\dots\dots\dots(3)$$

Where:

Pd = Particle density (g/cm^3).

M = Mass of the soil cold (g).

V = Volume of the soil (cm^3).

iv- Measurement of soil porosity

The soil porosity was calculated by using the formula proposed by [4] as follows:

$$P = \left(1 - \frac{\rho_d}{PD}\right) \times 100 \dots\dots\dots\dots(4)$$

Where:

ρ_b = Soil bulk density (g/cm^3).

Pd = Soil particle density (g/cm^3).

2.2.2 Measurement of Field performance parameters
i- Theoretical field capacity

Theoretical field capacity is the rate of work when the implement uses its full width and time and it was calculated as follow:

$$TFC = \frac{S \times W}{C} \quad \dots\dots\dots\dots (5)$$

Where:

TFC = Theoretical field capacity (ha/h)

S = Working speed (km/h)

W = cutting width of implement (m)

C =Conversion factor = (10)

ii- Effective field capacity

Effective field capacity is the actual rate of work and it was calculated as follow:

$$EFC = \frac{A}{T}$$

Where:

EFC = effective field capacity (ha/h).

A = hectare.

T = hour.

iii- Field efficiency

Field efficiency was calculated as follow:

$$FE = \frac{TFC}{EFC} \times 100 \dots\dots\dots\dots (7)$$

iv- Rear wheel slippage

The rear wheel slippage was determined as follows:

$$S = \frac{D_U - D_L}{D_U} \times 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots(8)$$

Where:

S = rear wheel slippage (%)

D_U = distance travelled by unloaded tractor

D_L = distance travelled by loaded tractor

v- Fuel consumption rate

The fuel consumption rate are detected as follow:

$$FCR = \frac{CR}{A} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(9)$$

Where:

FCR = fuel consumption rate (L / ha)

CR = reading of cylinder (L)

A = plot area (ha)

$$FCR = \frac{C_R}{T} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(10)$$

T = time required to cover the plot (h)

vi- Measurement of draft

Draft force was measured as follow:

A hydraulic type dynamometer was between frond auxiliary tractor and rear tractor on which the disc plough was mounted, the reading of dynamometer were recorded when the rear tractor was unloaded with disc and was then recorded while the tractor was loaded with the implement and the draft was Draft was calculated as follows

$$D = F_L - F_U \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(11)$$

D = net draft force (kN)

FL = draft force of loaded rear tractor (kN)

FU = draft force of unloaded rear tractor (kN)

vii- Unit draft

Unit draft is the measurement of the effectiveness of implement per unit width and it is given by following equation:

$$UD = \frac{D}{W} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(12)$$

Where:

UD = unit draft (kN / m)

W = implement width (m)

lix Power measurement

Power required to operate the implement is calculated as follow

$$P = \frac{D \times S}{C} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(13)$$

Where:

P = Power (kW)

D = Draft (kN)

S = Speed (km/h)

C = factor (3.6**)**

3. RESULTS AND DISCUSSION

3.1 Effect of ploughing on soil moisture content

The results of soil moisture content before and after the application of tillage at depths 0-15 cm and 15-25 cm are shown in Fig. 1 Before applying tillage treatments, high moisture content values (4.87% and 5.7%) were recorded at 0-15 and 15-25 cm two respectively, while low soil moisture content values (4.65%, and 4.66%) were recorded after tillage operation at the two depths. Generally, soil moisture content decreases after tillage operations. The decrease of soil moisture content may be attributed to the inversion of soil clods by the disc plough which subject the soil to direct sun rays and to the increase of soil macro pore. These results agree with [6] who stated that, soil moisture content for deep tillage practices was high when compared to no-tillage and conventional tillage practices.

3.2 Effect of ploughing on soil bulk density

The results of the effect of tillage on soil bulk density (g/cm^3) are presented in Fig 2. It can be seen that, generally, tillage operation resulted in a decrease of bulk density. Values of soil bulk density decreased from 1.39 and 1.37 g/cm^3 to 1.37 and 1.36 g/cm^3 at depths 0-15 cm and 15-25 cm, respectively. These results agree with [7] who reported that, tillage directly affects soil bulk density by decreasing it. When soil is pulverized or disturbed its volume increase and hence its bulk density decrease. Reference [8] found that no-tillage generally had higher soil bulk densities. These finding also agree with the result reported by [9] which indicated that the tillage operations decrease soil bulk density.

3.3 Effect of ploughing on soil porosity (%)

The results of soil porosity values (%) as affected by tillage are shown in Tables 3 and presented in Fig 3. It can be seen the soil porosity values increased after tillage operation from 46.72% to 47.8% and 47.88% to 48.5% at depths 0-15 cm and 15-25 cm,

respectively. The result agrees with [9] who reported that soil porosity increased after tillage operation.

3.4 Effect of tilt angle on tractor field capacity and efficiency

The results of the effective field capacity and efficiency as affected by tilt angles are shown in presented in Fig 4 and Fig. 5, respectively. It can be clear that the tilt angle 15° recorded the lowest effective field capacity (0.30 ha/h), as compared to tilt angles 20° and 25° which recorded 0.32 ha/h and 0.31 ha/h, respectively. Small value of tilt angle results in great depth and penetration. These results agree with [10] who reported that increase the effective field capacity increase the field efficiency because of the proportional relationship between them. The results also agree with the results of [11] who stated that, the field capacity increases with the increase of tilt angles. Reference reported that, there are many factors affecting field efficiency, one of these factors is the theoretical field capacity of the machine. The statistical analysis shown showed that the significant different between the field efficiency of the tree tilt angles (P < 0.05), while the disc plough with tilt angle 20° suitable than others.

3.5 Effect of tilt angle on tractor rear wheel slippage

The results of tractor rear wheel slippage, as affected by tilt angles, are shown in presented in Fig 6. It is clear that the tilt angle 15° recorded the highest slippage (14.2%), while the tilt angle 25° recorded the lowest value of slippage (9.5%). As mentioned earlier the small tilt angle results in greater depth of penetration. These results disagree with [11] who stated that increasing disc and tilt angles led to an increase in the wheel slippage but it agrees with [13] who found that the wheel slippage decreases when tilt angle increases. Reference [14] stated that the reason

of increasing slippage may be attributed to the increase of the tensile force.

3.6 Effect of tilt angle on tractor fuel consumption

The results of fuel consumption rate (l/fed) are presented in Fig 7. It can be seen that the disc plough when operated with the tilt angle 15° was recorded the highest value of fuel consumption rate 2.83 l/fed), while the tilt angles 20° and 25° recorded low fuel consumption rates 2.72 l/fed and 2.54 l/fed, respectively. These results agree with [11], [13] who found that fuel consumption increased as tilt angles was increased.

The suitable fuel consumption rate 2.54 l/fed i.e. the disc plough with tilt angle 25° is the best specially in large areas

3.7 Effect of tilt angle on draft (kN)

The results of the draft as affected by tilt angles are presented in Fig. 8. It can be seen that the tilt angle 15° recorded the highest draft (9.129 kN), while the tilt angle 25° recorded the lowest draft (8.38 kN). These results agree with [11] and [15] who found that the draft increased as tilt angle was increased. Draft of disc plough is influenced by the speed of operation; increasing the tilt angle and speed leads to increase the draft.

3.8 Effect of tilt angle on power (kW)

The results of power are shown in presented in Fig 9. Highest value of power (15.05 kW) was recorded by the tilt angle 15°, while the tilt angle 25° recorded the lowest value (13.9 kW). These results agree with [16] who reported that, the power increase as implement draft increased, but it is not necessary to have a maximum draft force. These results disagree with [13] who reported that the power required for dragging the implement increase by increasing of tillage depth.
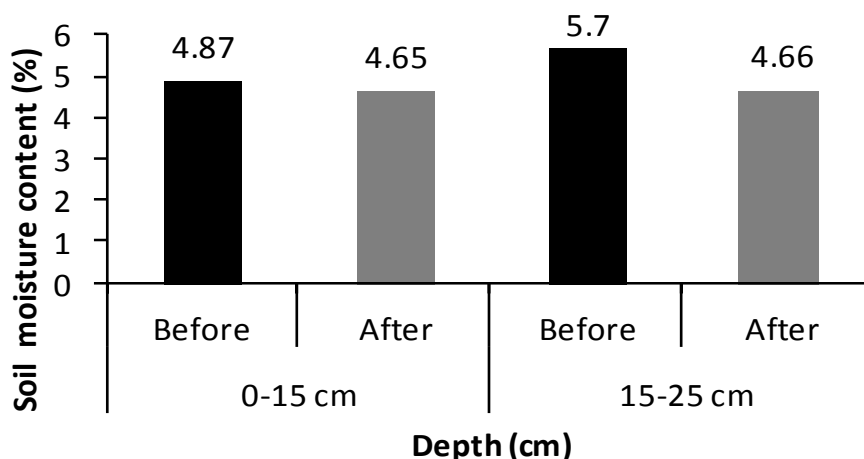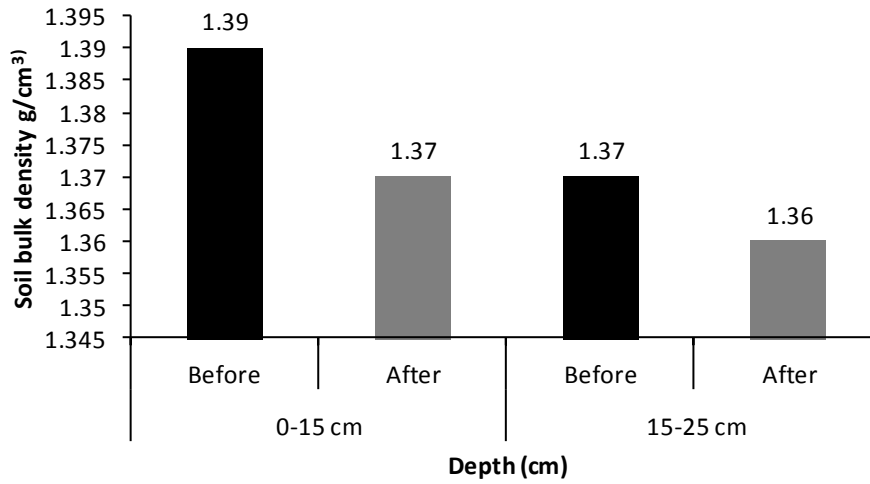

Fig. 1 Soil moisture content (%)
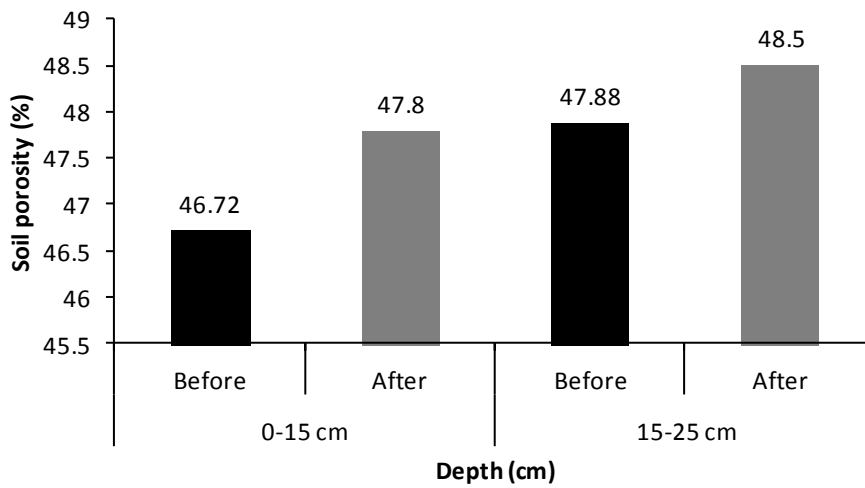
Fig. 2 Soil bulk density (g/cm³)

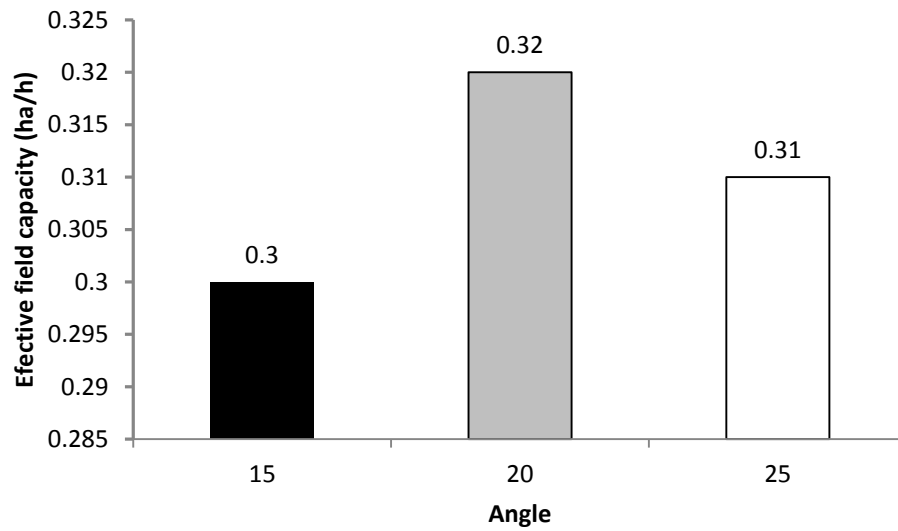**Fig. 3 Soil porosity (%)**

Fig. 4 Effect of tilt angle on field capacity (ha/h)
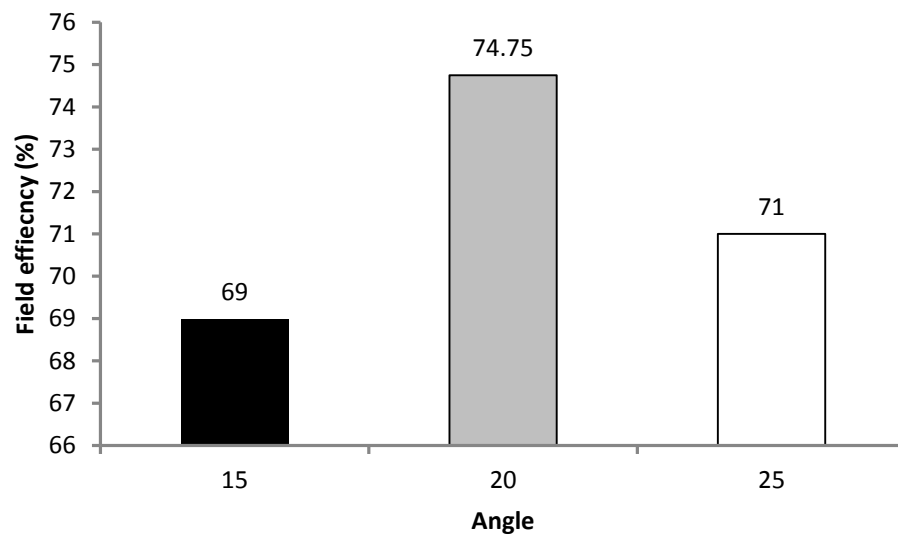

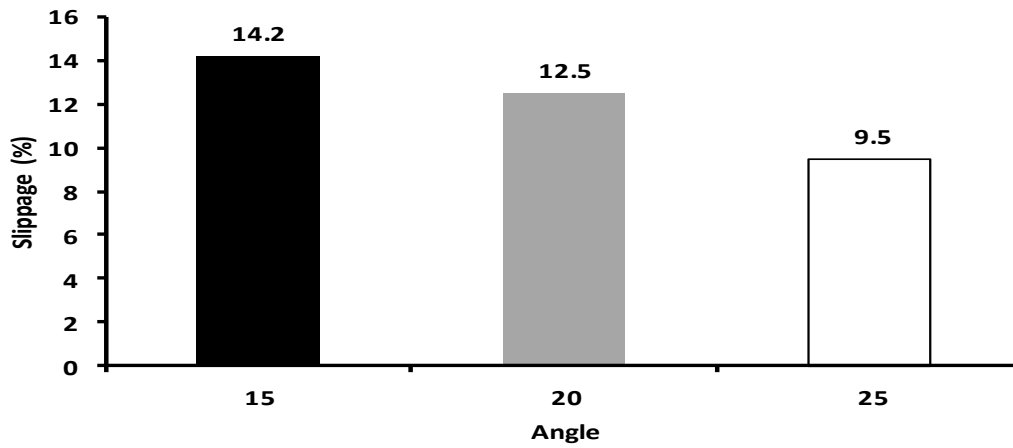**Fig. 5 Effect of tilt angle on field efficiency (%)**

Fig. 6 Effect of tilt angle on tractor rear wheel slippage (%)

TABLE 9 STATISTICAL ANALYSIS OF THE EFFECT OF TILT ANGLE ON FUEL CONSUMPTION RATE L/FED

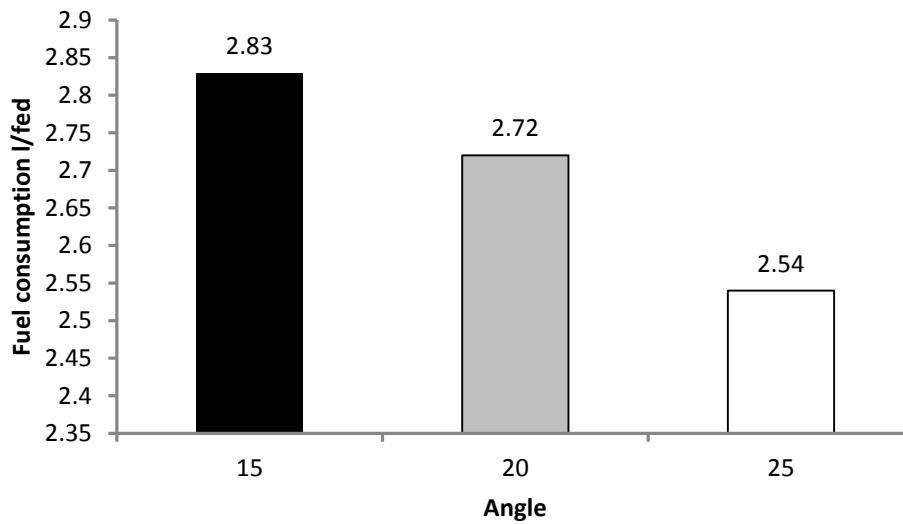| Source of variation	Df	Sum of squares	Mean square	F.ca	
Treatment	2	0.169	.084	0.244	Significant
Plot	9	3.115	.346		0.789
Error	11	3.284			

Fig. 7 Effect of tilt angle on tractor fuel consumption l/fed
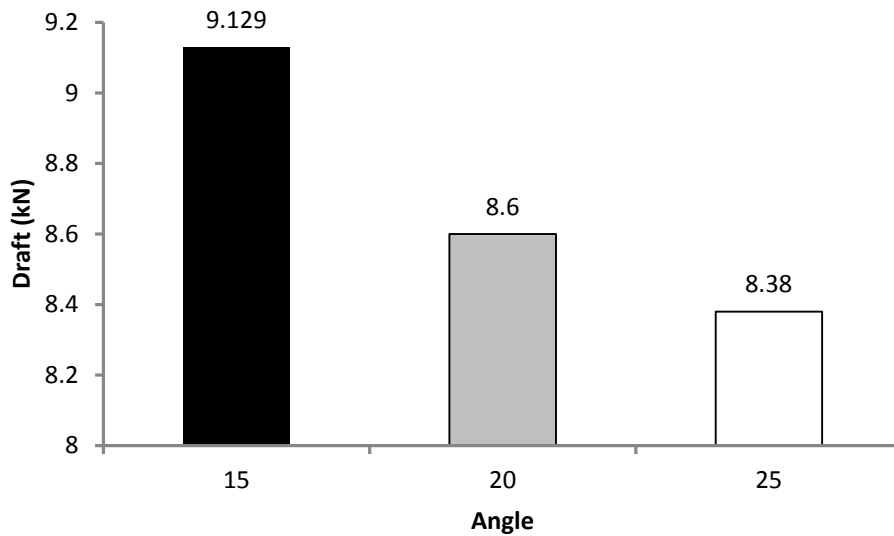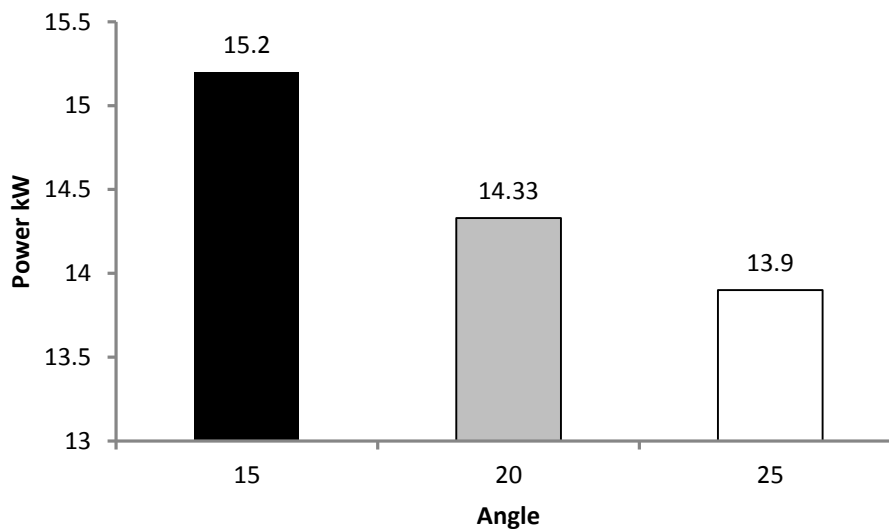
Fig. 8 Effect of tilt angles on draft (kN)

Fig. 9 Effect of tilt angle on power (kW)

4. CONCLUSIONS

The results indicated that the tilt angle of 20° is the most appropriate for ploughing with the disc plough as it recorded the highest field capacity, field efficiency, low draft, recorded moderate value of the required power, rear wheel slippage and fuel consumption.

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