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UofKEJ Vol. 5 Issue 2 pp. 34-40 (August-2015)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UOFKEJ)

# Performance Evaluation of A Chisel Plow in Heavy Clay Soil of Central Sudan

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**Abstract**: This paper presents experimental study of the performance of chisel plow under conditions of central irrigated Schemes. The research was conducted in the Gezira irrigated Scheme at Experimental Field of Gezira University. Mounted 3-rows chisel plows mark RAU and 75 hp Massey Fergusson (GIAD) tractor were used in the experiment. The performance of chisel plow was evaluated by parameters, which included: losses of chiseling process (uncut area); aggregate size distribution; bulk density; soil moisture content; control of weeds and residues; degree of soil surface evenness; draft requirement; fuel consumption; and field capacity. Each of these parameter studied dependent of two parameters: working speed and depth of cut. A loss of uncut areas at critical depth was found to be 12%. The failure zone and overlap area was found to be 31.4 x 11 cm and 0.02 $m^2$ respectively. The later was dependent of the depth. Losses of plowed area were increased to 23% and 31% when depth was increased to 15cm and 20cm respectively. Based on mean weight diameter of soil clod, structure of the soil was improved by 14% when the speed and depth were increased from 3.34 to 5.85km/hr. and from 15cm to 20cm respectively. Soil natural bulk density was found to be 1.45, $g/cm^3$. Bulk density generally was decreased, in such that it decreased in the upper layer (0-10 cm) by 10%, in the middle layer (10-20 cm) by 7%, and in the bottom soil layer (20-30 cm) by only 1 %. Soil moisture content was decreased by 30% at the upper soil layer (0-15cm) during 9 hours only. Weeds and residues leaving at soil surface after chiseling (at 5.58 km/hr. and 20 cm) were found to be 13% and 37%. Degree of the soil level after chiseling was found to be improved by ±14% of the mean value. Draft force increased by 14% when the depth was increased from 15 to 20 cm at constant speed of 5.85 km/hr. Draft force at critical depth changed by 22% when the speed was increased from 3.34 to 5.85 km/hr. Fuel consumption of chisel plow at speeds of 3.34 km/hr and 5.85 km/hr was increased by 17% and 23% respectively when depth increased from 15cm to 20cm in both cases. Machine field capacity and energy consumption increased by 66% and 39% respectively when speed was changed from 3.34km/hr to5.85 km/hr. in both cases.

**Keywords**: *Irrigated Scheme; Gezira Scheme; Tillage system; Chisel plow performance; Clay soil characteristics*

## 1. INTRODUCTION

Obtaining stable and high yields of crops is largely depending on the quality of the soil tillage. High quality of soil tillage enhances the effectiveness of all subsequent agricultural processes. Machinery solutions are key to the improvement of soil quality, minimizing pollution and erosion on farms. Tillage is the major event in the process of the crop production which consumes nearly 30 to 35% of the total energy requirements of crop production.

Irrigated sector of agriculture in the Sudan is the most important sector, because it contains all necessary resources for production of many different crops. This sector characterized by light to heavy clayed soil and enough and good quality of water for irrigation. This research was conducted in Gezira scheme.

Currently, in Gezira and almost in all others irrigated schemes soil tillage is based on the primary disking of the soil of one land from the lands of forth-fifth plant rotation and others lands plowing by ridging system. For these processes often, using the off-set disk harrows and cultivating riders. In the last 10 years of previous century this traditional tillage system is negatively affecting productivity of the soil. The results of many researchers established that the low yield of cultivated crops in irrigated areas of the Gezira scheme (cotton - 1.673 t/ha, sorghum - 2.292 t/ha, peanut - 1.872 t/ha, wheat - 1.911 t/ha) [1] is mainly due to ineffective tillage system.

During the last fifteen years, the agricultural administrations of many irrigated schemes adopted, for tillage, the chisel implement. It introduced for two purposes firstly for uprooting the stalks of cotton, as the first step to clean the soil

for new crop and secondly for deep ploughing to improve the models and assumptions that were used for their design. cultivated soil layer by removing the soil compaction pan, which occurred due to continuing use of cultivating ridgers.
There are not enough researches conducted on the chisel implements in the irrigated sector; so there is need to study and evaluate the performance of the chisel implement in the heavy clay soil of the irrigated schemes.

The main objective of this study work was to determine and evaluate the performance of the chisel implement in heavy clay soil of Gezira scheme. The detailed objectives were:

- To assess the performance of quality of chisel plow.
- To assess the performance of energy of chisel plow.
- To determine the main economic parameters of the chisel plow.

## 2. REVIEW OF LITERATURE

Ahmadi *et al*. [2] recommended that soil particle size ranging from 1 to 5 mm is suitable for seeding crops. EI-Iraqi *et al.* [3] found that, increasing the operational speed lead to decreasing the clod mean weight diameter, and increasing the plowing depth raises the clod mean weight diameter. Also he studied the effect of tillage speed and depth on soil bulk density; they found that soil bulk density decreased after tillage and the effect was much greater in the top layers than the lower ones.

Abo-El-Naga *et al*. [4] concluded that more than 50% of the power required for agricultural production is consumed in soil tillage. In relation to this El-Iraqi *et al*. [3] reported that the draft force and tillage energy required during tillage using chisel plow is linear function of operation speed, directly proportional to plowing depth , width, tool characteristics, and soil properties .

The performance of chisel implements i.e. soil deformation and pull requirements in given soil conditions is influenced by design and operating factors, such as effective width, angle of approach, operating depth and forward speed.

Tillage depth is the most significant factor influencing the quality and draft of chisel implements. Jack Desboilles [5] reported that doubling the tillage depth from 50 to 100 mm is likely to quadruple the draft requirement or more where there are tillage pans and stones at the depth. Conversely, in looser soil conditions, the effect of looser tillage depth is less important.

Forward speed effect on draft and quality of chiseling originates from two different sources, namely i) the increase in soil strength under higher loading rates (i.e. characteristic of cohesive clay soils rather than frictional sandy soils) and ii) the soil inertia forces (i.e. related to the quantity of the soil disturbed and its distance moved per unit of time). Jack Desboilles [5] reported that for narrow winged chisel plow the draft increased by 15 to 30% when speed increased from 6-7km/hr. to 10-11 km/hr. in sandy-loam soil.

*Critical depth concept*: All chisel working tools eventually reach a threshold depth below which soil loosening does not occur and it is replaced by soil compaction. This transition depth is referred to as critical depth. Its actual location fluctuates in relation to soil strength and soil moisture. Below critical depth it is easier for soil to be displaced forward and sideways than it is to be pushed and lifted upward and loosened. In such situation, the lower part of the furrow can result in two compacted soil zones on either sides of an opened trench (see Fig.1). The process of soil compaction below the critical depth is less efficient and is associated with a draft penalty, compared with soil loosening to full depth.

## 3. MATERIALS AND METHODS

### 3.1 Materials

Machine system used in this study was selected based on popularity of usage in Gezira Scheme. A chisel plough mark RAU model EG30, was selected as an implement, its technical specifications are shown in **Table 1**. Two tractors-2WD Massey Fergusson (GIAD assembled), models 290 of 75hp were used as power sources.

***Study field characteristics*:** an area of one Feddan (65×65m) was selected in middle of Gezira scheme at experimental fields of University of Gezira; at Wad Madani City. Soil type of selected area is classified as heavy clay soil (65-80% clay particles). The level of the soil surface of the selected area is almost not more than 3 degree, the micro-level characterized with ridges and furrows with residues and weeds of previous crop-sorghum bicolor (Abu70).

### 3.2 Methodology:

The programs of laboratory and field studies included mainly three programs: i) Assessment of parameters of quality of the chiseling work, ii) Assessment of the draft of chiseling work and iii) Processing and interpreting the collected data.

***Method of selection of the parameters of experimental work:*** Although many factors can affect the work of chisel implements, just like implement design parameters, properties

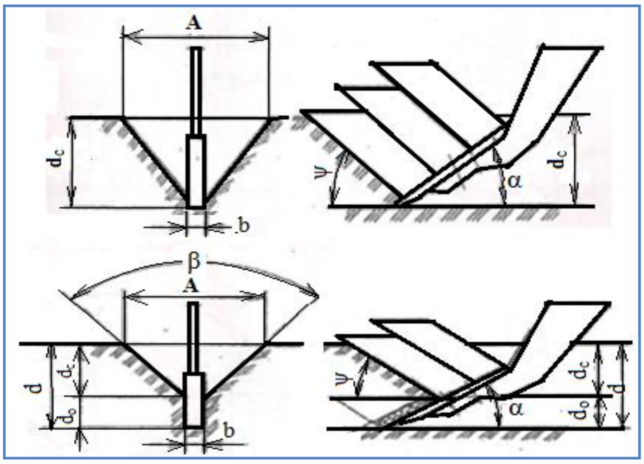


**Fig. 1**. Concept of critical depth for chisel narrow blade

**Table 1.** Technical specifications of experimental chisel

| Parameter | Unit | Volume |
|---|---|---|
| Model | - | RAU Chisel 2G 30 |
| Manufacturing Country | - | German |
| Total weight | kg (kN) | 400 (3.92) |
| Total width of plow | Cm | 198 |
| Number of tines (shares) | - | 9 |
| Width of tine | Cm | 5.4 |
| Thickness of tine | Cm | 1.2 |
| Tine rake angle | Degree | 30 |
| Number of rows | - | 3 |
| Number of tines in the row | - | 3 |
| Distance between tines in the row | Cm | 66 |
| Distance between rows | Cm | 55.8 |

and conditions of the soil, metrological factors, and operational parameters. In these studies the only main parameters, which can easily be controlled and measured were chosen. performance of the quality and energy of chisel plow in the irrigated scheme was evaluated by: losses of chisel work (uncut area); aggregate size distribution; bulk density; soil moisture content; control of weeds and residues; degree of soil surface level; draft requirement; fuel consumption; and field capacity. Each parameter was studied as function of two parameters: working speed and depth of cut.

***Method of determination of the losses of chiseling process*:**
Determination of uncut area was done by measuring the critical and total depths and the total width of chiseling. The height of the ridges at the level of the critical depth was also measured. The measurements were done by wooden ruler, three times at a distance of ten meters apart.

***Method of determination of soil aggregate size distribution*:**
Aggregate size distribution of the soil was determined after chiseling by randomly taking three samples from each three treatments. Each sample was taken through the whole depth of chiseling. A set of standard sieves (mesh openings of 63, 32, 16, 8, 4, and 2 mm) was used with shaking time of 30 seconds. The Aggregate size distribution of the soil was valued by mean weight diameter (MWD):

$$MWD = \sum X_i W_i / W \tag{1}$$

Where: $x_i$ is the mean diameter of any particular size range, i, of aggregates separated by sieving, and $w_i$ is the weight of aggregates in size range, i, as a fraction of total dry weight of the sample analyzed, w is total weight.

***Method of determination of the soil bulk density:***
Determination of soil bulk density was done before and after chiseling. Three samples at three levels of the depths throughout the whole depth of cut were taken. The experiments were repeated four times at different speed. The sample was taken randomly by a cylindrical core sampler of 100 $cm^3$. Each sample was dried in an oven at 105$^{\circ}$C for 24 hours. Each sample was weighed before and after drying. The bulk density of the soil was determined by the equation:

$$BD = W_d / V_s \tag{2}$$

where: $w_d$ – dry weight, $v_s$ – volume of core sampler

***Method of determination of degree of soil surface level:***
Surface level of the soil was determined experimentally before and after chiseling by means of profile-meter device. The experiment was repeated three times at an interval of ten meters apart.

***Method of determination of weeds and residues:***
Weeds and residues were determined before and after chiseling, by using timber box of 1 $m^2$. In each of these cases, the experiment was repeated three times. The percentages of uncut weeds and remaining residues to the total were determined.

***Method of determination of soil moisture content*:**
Soil moisture content was determined by using the standard method.

***Method of determination of Draft force:***
The draft force was measured by using axial dynamometer. A simple factorial method of $2^2$ was used. The average data obtained were analyzed by using standard statistical method. As result a simple regression equation for the draft of chisel implement was obtained for a given studied condition. Also specific draft and power consumption were found.

***Method of determination of fuel consumption:***
The fuel consumption rate of chisel plow was determined by using the standard refilling method.

***Method of determination of field capacity:***
The theoretical field capacity ($C_{th}$) of chisel was found by determination of the average working speed and width. The efficiency ($E_{ff}$) of a chisel implement was determined by measuring the actual time of chiseling specified area and the time losses. Effective field capacity ($C_{act}$) was determined by the following equation:

$$C_{act} = E_{ff} \times C_{th}$$

## 4. RESULTS AND DISCUSSION

Based on the above methodology and materials of the research work the following results were obtained.

### 4.1. Losses of chiseling process (uncut area)

Soil critical depth and dimensions of the failure zone were shown in table 2.and table 3. Also in fig. 2 was shown schematic drawing of failure zone.
In the heavy clay soil the critical depth was, as average, 12.2 cm. Chiseling deeper than critical depth results in increasing uncut area, and increasing chiseling loss. The overlapping, as seen, was not affected by the depth. This can be explained by the fact that the chisels, with same type of narrow blades, disturb the soil by the same manner at the critical depth as

seen in **Fig. 2**. Hence for the narrow blade chiseling below critical depth is less efficient; not only for the reason of losses and compaction below critical depth but it is also associated with losses of power consumption. So, for deep chiseling in heavy clay soil, it is recommended, to use wide blades, rather than narrow. And, also, usage of higher operating speed may slightly increase the critical depth due to increasing soil strength effects associated with higher loading rates in clay soil.

### 4.2. Aggregate size distribution of the soil

In this research the mean weight diameter (MWD) was used as assessment indicator of soil structure for chisel implement. Results of soil structure indicator after chiseling were shown in **Table 4**. The average value of mean diameter of soil clod changed from 21mm to 18 mm (14%) when the speed and depth increased, respectively from 3.34km/hr to 5.85 km/hr and from 15cm to 20 cm.

### 4.3. Bulk density of the soil

The results of the average values of soil bulk density at different soil layers were shown in **Fig.3**. Heavy clay soil bulk density decreased through all soil layers. It decreased in the upper soil layer (0-10 cm) by 10% and by 7% in the middle soil layer (10-20 cm), and decreased by only 1 % in the bottom soil layer (20-30 cm). Operating speed had no effect on the bulk density in these experiments. So, the chiseling process affects the structure of the soil in the top cultivated layer more extensively than in lower layers. This agrees with theory of chisel tools failure. This agrees with results obtained by other researchers [3]. This is explained by the fact that in above zones of critical depth (12.2 cm) soil layer can easily be pushed and lifted upward and loosened, but below critical depth soil is displaced forward and sideways, thus, compacted on the sides of an opened trench.

**Table 2.** Critical depth in heavy clay soil

| No. of treatment | Critical depth, cm | Cross-sectional distance, cm | Longitudinal distance, cm |
|---|---|---|---|
| 1 | 12.5 | 33.4 | 12 |
| 2 | 13 | 29.4 | 10.5 |
| 3 | 11 | 31.4 | 10.5 |
| Average | 12.2 | 31.4 | 11 |

**Table 3.** The losses of chiseling process in heavy clay soil

| Estimated areas | Chiseling depth, cm | | | |
|---|---|---|---|---|
| | Critical | deeper than critical | | |
| | 12.2 | 15 | 17.5 | 20 |
| Total cross-sectional plowing area (theoretical), $m^2$ | 0.24 | 0.30 | 0.35 | 0.40 |
| Actual cutting area, $m^2$ | 0.21 | 0.23 | 0.24 | 0.25 |
| Actual uncut area, $m^2$ | 0.03 | 0.07 | 0.11 | 0.15 |
| Actual overlap area, $m^2$ | 0.02 | 0.02 | 0.02 | 0.02 |
| Ratio of actual cutting area to total cross-sectional plowing area, (%) | 88 | 77 | 69 | 63 |
| Ratio of actual uncut area to total cross-sectional plowing area, (%) | 12 | 23 | 31 | 37 |

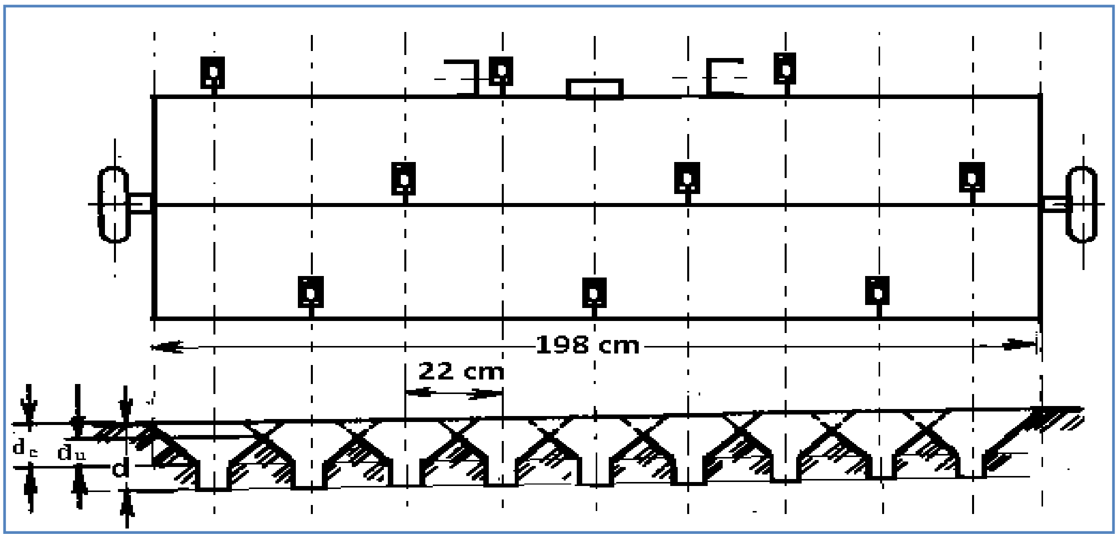


**Fig. 2.** Cross-sectional failure zone in heavy clay soil

**4.4. Moisture content of the soil:**

The effect of experimental chisel plow on moisture content of heavy clay soil is shown in Figure 4. In general soil moisture content was conserved at the lower layers of clay soil. Chiseling process affected negatively conservation of moisture content; it was decreased by 30% at the upper soil layer (0-10cm) after chiseling. This is explained by the fact that the chiseling process increased the capillary pores especially at the top layer and, so, the rate of evaporation increased. To eliminate this effect a different shape of chisel tool may be used specially that which conserves crop residues on surface of soil. The selected speed had little effect on the loss of moisture content.

**4.5. Control of weeds and residues**

The result of control of weeds and residues of the previous crop by experimental chisel plow is shown in **Table 5**. In heavy clay soil at speed of 5.58 km/hr. and 20 cm depth the chisel plow cut 87% of the weeds and shopped and covered 63% of the crop residues.

**4.6. Degree of soil surface evenness**

The results of average values of soil surface evenness are shown in **Fig.5** and **6**. The chisel plow generally improved the degree of evenness of the soil surface. It fluctuated by ±14% with respect to the mean value (5.53 cm).

**Table 4**. Mean weight diameter of heavy clay soil after chiseling

| No. of treatment | Speed, km/h | Depth, cm | Mean weight diameter, mm |
|---|---|---|---|
| 1 | 5.85 | 20 | 19.35 |
| 2 | 5.85 | 15 | 17.44 |
| 3 | 3.34 | 20 | 22.96 |
| 4 | 3.34 | 15 | 18.06 |

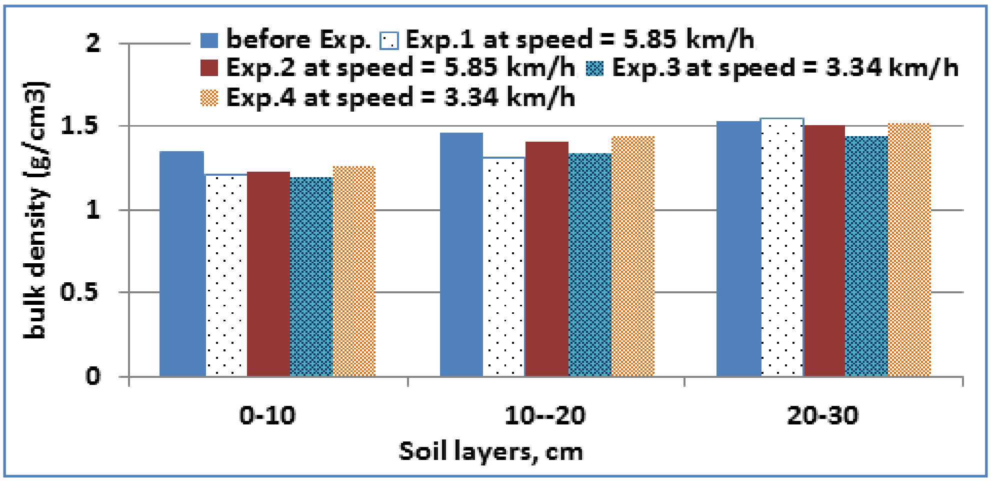


**Fig. 3**. Variation of bulk density of heavy clay soil during chiseling process at various speed

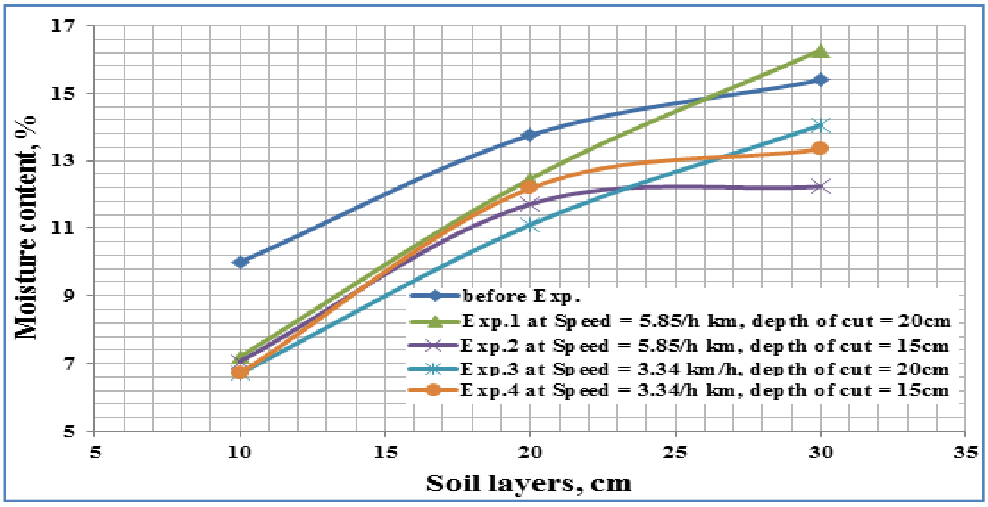


**Fig. 4**. Effect of soil moisture content for experimental chisel plow in heavy clay soil

**Table 5.** Control of weeds and residues by chisel plow

| No. of treatment | No. of weeds | | No. of residues | |
|---|---|---|---|---|
| | Before exp. | After exp. | Before exp. | After exp. |
| 1 | 102 | 13 | 82 | 28 |
| 2 | 70 | 8 | 85 | 14 |
| 3 | 173 | 24 | 62 | 41 |
| Average | 115 | 15 | 76 | 28 |
| % of remaining | 13% | | 37% | |

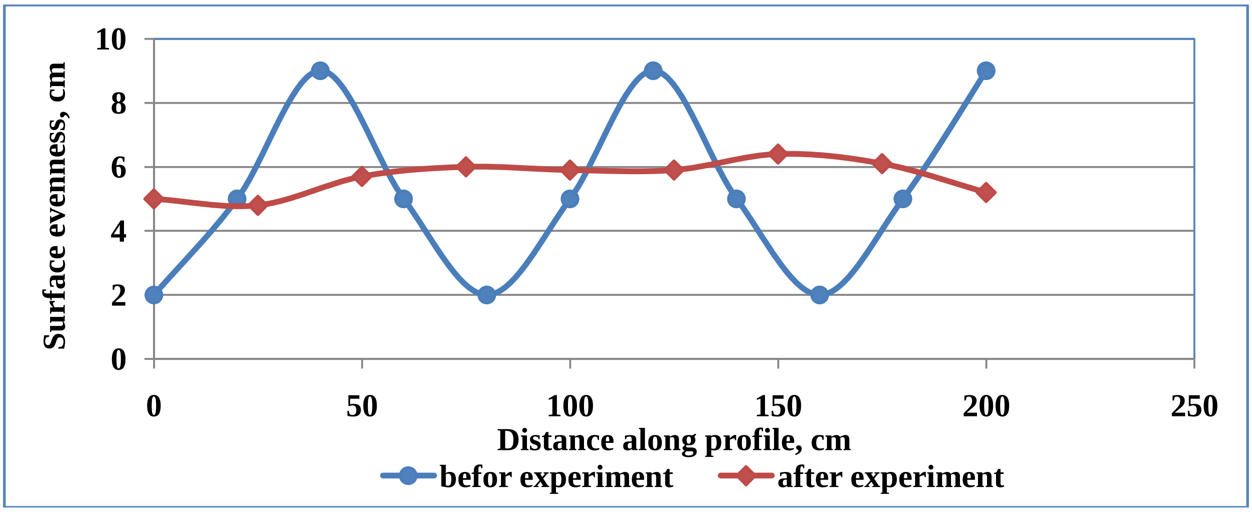


**Fig. 5.** The degree of soil surface evenness, (Plowing at 5.85 km/hr speed and 20 cm depth)

**Fig. 6**. Profile of field soil surface: a) before chiseling and b) after chiselling

### 4.7. Draft force

Draft force of experimental chisel plow in heavy clay soil was determined; the results were shown in **Fig. 7**.Generally, draft force of chisel plow increasing, as, operating speed and depth of cut increasing.

### 4.7. Fuel consumption

Results of fuel consumption in heavy clay soil were shown table 6. In average, fuel consumption changed from 12.6 to14.0 L/ha (11%) for the given speed and depth.

### 4.8. Field capacity

The results of calculations of actual field capacity showed that at speeds of 3.34km/hr and 5.85 km/hr the field capacity changed from 0.6 ha/hr to 1.0 ha/hr. (67%) respectively, when depth in case was changed from 15cm to 20cm. Therefore, for average value of draft force and field capacity of chisel plow the energy consumption required was between 27.8 and 20.0 MJ/ha**.**

## 5. CONCLUSIONS

- Based on the above research objectives and the results and evaluation of the performance of chisel plow in central heavy clay soil, the following conclusions can be written:

- Performance of quality of chisel plow was assessed as follows:

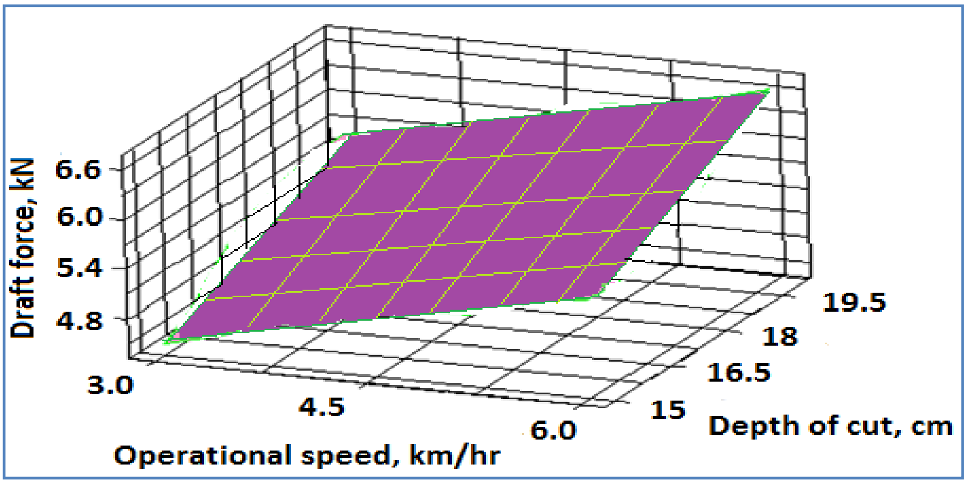


**Fig.7.** The variation of the draft force of experimental chisel plow in heavy clay soil

**Table 6**. Fuel consumption in chiseling heavy clay soil

| No. of exp. | Speed, km/h | Depth, cm | Specific fuel consumption, L/ha | |
|---|---|---|---|---|
| | | | value | average |
| 1 | 3.34 | 20 | 13.60 | 12.6 |
| 2 | 3.34 | 15 | 11.66 | |
| 3 | 5.85 | 20 | 15.54 | 14 |
| 4 | 5.85 | 15 | 12.63 | |

- Critical depth of chisel plow with narrow blades obtained at an average value of 12.2 cm.
- An uncut area of chisel plow at critical depth was found to be 12%.
- Increasing chiseling depth from critical to 15cm and to 20cm were increased uncut areas by 23% and 31% respectively.
- Soil structure was improved by 14% when was used lower speed.
- Average value of soil bulk density was found to be 1.45**,** g/cm$^3$ in nature condition, which was decreased by10%, in upper cultivated layer (0-20 cm) after chiseling.
- Moisture content was loosed by 30% from upper soil layer (0-15cm) after chiseling.
- Weeds and residues were controlled by 87% and 63% respectively.
- Degree of evenness of the soil surface was improved by ±14%.

Performance of energy of chisel plow was assessed as follows:

- Draft force at speed of 5.85 km/h was increased by 14% when the depth was increased from 15 to 20 cm; and increased by30% at speed of 3.34km/hr and at the same range of the depth.
- The draft force at critical depth (12.2cm) increased by 22% when speed was increased from 3.34 to 5.85 km/hr.
- Fuel consumption at speeds of 3.34 km/hr. was increased by 17% when depth was increased from 15cm to 20cm; and at the same range of depth and at speed of 5.85 km/hr fuel consumption increased by 23%.

Economic performance of chisel plow was assessed as follows:

- Field capacity of chisel plow at speed of 3.34km/hr was found to be 0.6 ha/hr and at 5.85 km/hr was increased to 1.0 ha/hr when depth increased from 15cm to 20cm in both cases.
- Energy consumption at speed 3.34 km/hr was found to be 27.8 MJ/ha and was increased to 20.0 MJ/ha when speed increased to 5.85 km/hr.
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