Comparison between the field performance of a Movable boards Ditch opener and conventional ditch opener in cultivated and uncultivated soils Part 4: The Energy Utilization Efficiency

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Abstract: Energy utilization efficiency (EUE) for Movable boards ditch opener (MB) and for conventional ditch opener (CD) were compared using three operating depths for MB (30, 40 and 50 cm), three angles between its movable boards, three foot wings widths and two soil types (cultivated and uncultivated soils). For CD there was one angle between its boards (65°), they were permanently fastened, one share width (35 cm), one operating depth in the uncultivated soil only (25 cm), could not penetrate such soil, and three operating depths in the cultivated soil. The results showed that EUE for MB increased as the operating depth increased in the cultivated and uncultivated soil whereas, for CD it increased in the cultivated soil only whereas, it could not penetrate the uncultivated soil more than 25 cm. However, the rate of increase was almost the same for both implements in the cultivated soil, EUE for CD increased from 5.57 to 7.93 m³ MJ⁻¹ (2.36 m³ MJ⁻¹) whereas, for MB, it increased from 9.64 to 11.78 m³ MJ⁻¹ (2.14 m³ MJ⁻¹). EUE for MB also increased with angle between its boards and the width of the wings of its foot while for CD did not occurred because it boards were permanently fastened to the machine frame at angle of 65° and it was provided with share rather than wings. EUE for MB was higher in the cultivated soil comparing with uncultivated soil. EUE for MB was higher than that for CD for all operating depths, angle between the boards and the width of the wings of the foot and in both soil types. The results showed that MB surpassed CD in field performance in addition to that it can penetrate the soil to the required depth whether it was cultivated or uncultivated soil. It also can produced different cross-section width ditches whereas, CD can produce one cross-section width ditches.

Keywords: Abbreviation: EUE= Energy Utilization Efficiency; MB= Movable boards ditch opener; CD= conventional ditch opener

1. Introduction

The energy utilization efficiency is widely used as a parameter to compare the field performance of different types of implements to determine the best performance among them, i.e. to determine the implement which spent less energy in doing useful work and dissipated the less amount of energy. EUE is defined as the number of cubic meters of disturbed soil by the implement for one Mega Joule of energy spent by the implement. EUE depends completely on the volume of the soil disturbed by the
implement and the energy spent to disturb this volume of soil. The volume of the disturbed soil, on the other hand, depends on the cross-section area of the disturbed soil by the implement and on its operating depth (Godwin and Spoor 1977, Mckyes and Ali 1977, Ramadan 2011 and Spoor and Godwin 1978). As the cross-section area of disturbed soil and the operating depth increase the volume of disturbed soil increases and that positively affect EUE. The draft force also affected the field performance of deep operating machines, it increases the energy spent to overcome the soil resistance (Godwing et al 1984, Mckyes 1984 and Mckeys and Masware 1997). To improve EUE of any soil preparing implement the operator should presents the best condition to increase the volume of the disturbed soil and in the same time reduces the energy spent in disturbing the soil. EUE is widely affected by many factors, some of these factor were studied by some researchers, Their results are summarized as follows:

EUE increased when the operating depth is increased. Whereas, EUE decreases as the forward speed increased (Aday, 2012, Aday et al 2004). The soil types and the moisture content also affected EUE. It is higher in the cultivated soil comparing with the uncultivated and it is also higher in the friable soil state but it is low in the hard and plastic soil states. EUE also depends on the implement type, it is high for deep operating implements while it is low for shallow operating implements (Aday et al 2001 and Aday and Al-Adan 2003). For conventional subsoiler EUE is low, whereas, for modified subsoiler, which was provided with shallow tines or wings attached to its foot or both of them, EUE increased considerably regardless of the increase in energy spent in manipulating the soil. This was occurred because the rate of increase in the soil disturbed volume was greater than the rate of energy spending.

The aim of this work is design new ditch opener machine as alternative to the conventional ditch opener which suffers from many drawbacks. These drawbacks are it cannot penetrate the soils especially the hard ones and uncultivated soils. It also suffers from high draft force requirement and specific resistance and low disturbed area and EUE. The new ditch opener (MB) was designed to overcome the problems which CD suffers from. MB completely differed from CD in term of the design. The field performance of the two implements were compared using EUE to determine the best among them. The two implements performance was also compared using the draft force requirement, disturbed area and the specific resistance in parts 1, 2 and 3 respectively. The comparison was carried out using the operating depths, the angle between the movable boards of newly designed implement and the width of the wings of the foot and two soil types (cultivated and uncultivated soils).

2. Materials and Methods

2.1. The conventional and the movable boards ditch openers

CD consists of a frame, two big boards fixed on the frame and wide share which used to cut and penetrate the soil. The angle between the two boards was 65° (constant). The outside edges of the boards were sharp to cut off the sides of the ditches, Fig. 1.

MB consists of a frame, subsoiler, two movable boards, foot and wings, Fig. 2. The frame was made of steel to withstand the stress imposed by the soil on the implement,. The subsoiler consists of Leg (shank) and foot fix at the lower end of the leg. The forward inclination angle (rake angle) of the leg is 60°. The foot was provided with wings. The inclination angle of the wings relative to the horizontal line was 30° to facilitate the soil penetration. The attack angle of the front of the foot was 25°. The subsoiler was fastened tightly on the frame. The two boards length and width were 75 and 50cm respectively. A steel shaft of 25mm diameter was fixed behind the leg of the subsoiler.
The two boards were attached to the shaft by number of hinges. These hinges enable the two boards to move freely in and outward to obtained different angles between the two boards. To keep the angle between the two boards constant, they were provided with telescopic bar (length changeable bar) fixed between them from inside. The lower edges of the two boards making an angle of 45° with the soil surface. This angle was to prevent the boards from ribbing on the soil surface and to enable the machine to penetrate the soil easily. To prevent the two boards from drifting sideways when unequal lateral force imposed on one of them, a supporting bar was provided to one of them fixed on its top edge from one end and on the implement frame from the other end. many holes were made on the frame to change the supporting bar position when the angle between the two boards was changed.

Figure 1: The conventional ditch opener

Figure 2: the movable boards ditch opener

(A): geometrical view

(B): Side view
2.2. The soil properties measurement

The soil bulk density and the soil moisture content were measured by the methods described in Black (1968). The results are shown in table (1). The soil strength parameters, cohesion and internal friction angle, and the soil penetration index were measured by the Annual ring and the penetrometer tool using the methods described by Gill and Vander (1968). The results are shown in table (2). These parameters were measured for the uncultivated and cultivated soils and for five soil depths.

2.3. The experiments parameters

Both machines were tested in the field using three operating depths (30, 40 and 50cm) For MB in the uncultivated and cultivated soil whereas, for CD only in the cultivated soil while in uncultivated soil it did not penetrated the soil more than 25cm. Three angles between the implement movable boards were used (for MB 45, 60 and 75°, for CD one angle (65°) because its board were fixed on the frame) and three widths of wings of the foot (for MB 25, 35, 45cm, for CD one width, (35cm) (share width)). The experiments were carried out in uncultivated and cultivated soils. The soil texture of both soils was silty clay. The moisture content of the cultivated and uncultivated soils (average) were 27.81% and 18.83% respectively.

2.4. The draft force requirement measurement

The draft force requirements of both implement were measured using hydraulic dynamometer. The implements were attached to a tractor sequentially. The tractor-implement combination was towed by another tractor using flexible cable. The hydraulic dynamometer was attached to the towing tractor from one end and to the flexible cable from the other end. The operating depth of the implement was determined in advance and the towing tractor put in gear while the gear box of the towed tractor left in neutral. The towing tractor was left to move at least three meters to approach the maximum speed then the readings from the dynamometer were recorded. The tractor –implement combination was left to move distance of 15m. each run was repeated three times. The experiments were carried out for all operating depths, angle between the boards, width of the wings and in both soil types.

The draft force was calculated using the eq. (1)(calibration equation)

\[ F=0.88+ A \times X \]

Where:

- \( F \)= draft force (kN)
- \( X \)= the dynamometer readings (kNm\(^{-2}\))
- \( A \)= Cross-section area of the hydraulic cylinder (0. 44156m\(^2\))

2.5. measurement of the disturbed area

The cross-section area of the ditches made by CD and MB were measured in the field for every operating depth, angles between the boards, widths of wings and in both soil types. The soil of the cross-section area was dogged out by hand to keep the ditch sides undisturbed until the disturbed soil completely out of the ditch bottom. The widths of the ditch at the soil surface and bottom and the depth were measured. The measurements were repeated three times for each run, Fig 3. The real shape of the ditch in the field, Fig.3 (1) was change to geometrical shape, Fig 3 (2). The cross-section area of the ditch was calculated by Eq. (2)
Figure 3: The cross-section area of the ditch

\[
A = 2 \left[ \frac{1}{2} \left( b - Wi \right) d \right] + d \cdot Wi = \frac{(b + Wi)d}{2} \\
\text{…………………………(2)}
\]

A= cross-section area of the ditch (m²)
D= ditch depth (m)
b= the width of the ditch at the soil surface (m)
Wi= the width of the ditch at bottom (m)

2.6. The energy utilization efficiency

EUE was calculated using eq. (3).

\[
EUE = \frac{A}{F} \text{…………………………(3)}
\]

Where:
A= cross-section area of the ditch (m²)
F= draft force (kN)

The nominator and dominator of Eq.(3) were multiplied by (L). L is one-meter length of the ditch.

\[
EUE = \frac{A \cdot L}{F \cdot L} = \frac{V}{E} \text{…………………………(3)}
\]

Where:
V= volume of the disturbed soil (m³).
E= energy spent by MB and CD to disturbed the volume of soil (V) (kJ).

However, the unit kilo Joule is small therefore, Eq. (3) was multiplied by (1000) to change the kilo Joule to Mega Joule. Therefore, unit of EUE becomes (m³MJ⁻¹)

\[
EUE = \frac{V}{E} \cdot 1000 \text{…………………………(4)}
\]
3. Results and discussions

3.1. The effect of the operating depth and the soil types on EUE of CD and MB.

The effect of the operating depth and the soil types on EUE of CD and MB is shown Fig. (4). EUE for both of them increased as the operating depth increased. The rate of increase in EUE for both implements were almost the same with operating depth in the cultivated soil, for example, EUE for CD increased from 5.57 to 7.93\(\text{m}^3\text{MJ}^{-1}\) (2.36\(\text{m}^3\text{MJ}^{-1}\)) whereas, for MB, EUE increased from 9.64 to 11.78\(\text{m}^3\text{MJ}^{-1}\) (2.14\(\text{m}^3\text{MJ}^{-1}\)).

![Fig. (4): The relationship between EUE of MB and CD and the operating depth in cultivated and uncultivated soils](image)

Comparing EUE for MB and that for CD, EUE for MB was higher than that for CD in both soil types. However, the difference between their values reduced as the operating depth increased in the cultivated soil. For operating depth of 30, EUE for MB was 9.64 \(\text{m}^3\text{MJ}^{-1}\) while for CD was 5.57\(\text{m}^3\text{MJ}^{-1}\), higher by (73%), however, increasing the operating depth to 50cm, EUE for MB increased to 11.78\(\text{m}^3\text{MJ}^{-1}\) whereas, for CD increased to 7.93\(\text{m}^3\text{MJ}^{-1}\), higher by (48%). The reasons for the supervision of MB over CD was related to that CD suffered from higher resistance from the soil because its share was very wide which required greater force to penetrate the soil and moves (skid) on the ditch bottom. In addition to that the lower edges of its boards relay on the ditch sides cutting thin layer from the soil and skidding on the remaining soil when CD moving forward. The soil cutting and the boards skidding on the ditch sides required extra energy which resulted in lower EUE. MB did not suffer from such problems. Because of the high resistance on CD, it consumed greater amount of energy and produced less disturbed soil lead to lower EUE. For MB the controversy occurred, it penetrated the soil easily because the suitability of its foot and wings and that enabled MB to disturbed greater volume of soil with less energy spending which resulted in higher EUE.

In the uncultivated soil, EUE of MB was considerably higher than that of CD and that was because CD could not penetrate the soil more than 25cm due to the high soil resistance. To overcome the high resistance of the soil, CD consumed great amount of energy and produced small volume of soil. However, despite of the great energy consumption but did not penetrate the soil more than 25 cm. Whereas, MB was easily penetrated the soil to the required depth with limited energy consumption.
3.2. The effect of the operating depth and the angles between the boards on EUE of CD and MB.

EUE increased as the angle between the boards were increased, so that to obtained higher EUE greater angle between the boards should be used. When the angle was bigger the edges of the boards can cut slice from the ditch sides which resulted in wider ditch, Fig. 5. EUE also increased with operating depth for the same angle between the boards except for angle of 45° were the values of EUE decreased. This was because the cross-section area of the ditch was smaller while the energy consumed was higher due to the greater increase in the soil strength with the operating depth and that require more energy to be penetrated and disturbed (compacted deep layers).

![Fig. (5): The relationship between EUE of MB and CD and the operating depth for different angles between the boards of MB (for MB 45, 60 and 75°, for CD only 65°)](image)

Comparing EUE for MB with that of CD, EUE for MB was higher for all operating depths. This showed that MB required less energy to produce the same cross-section width ditch whereas, CD required higher energy. The supervision of MB was because it can penetrate the soil easily due to the sharpness of its foot and inclined wings. The highest value of EUE was recorded for MB at operating depth of 50cm and angle of 75° between the boards while, the lower values of EUE were recorded for CD in uncultivated soil.

3.3. The effect of the soil types and the angles between the boards on EUE of CD and MB.

EUE for MB and CD in the cultivated soil were higher than in the uncultivated soil, Fig. 6. This was because the uncultivated soil required greater energy to be penetrated and disturbed. In additional to that it formed bigger soil clods which required greater energy to be dogged out form the ditch. The results also showed that EUE for MB were higher than that for CD in both soils types. The differences between their values increased as the angle between the boards of MB increased. For example, in the uncultivated soil the difference between the value of MB at angle of 45° and the value of CD (angle of CD is 65°) is 2.83m³MJ⁻¹, increasing the angle of MB to 75° the difference between them became 4.41m³MJ⁻¹. This means the field performance of MB improved as the angle between its boards increased.
3.4. The effect of the operating depth and the width of the wings on EUE of CD and MB.

The effect interaction of the operating depth and the width of the wings on EUE of CD and MB is shown in Fig. 7. EUE of MB increased considerably with wings width for all operating depth tested. This means the wider wings produced bigger cross-section ditch (wider ditch) with less energy consumption and that was because the wings created many cracks in the soil appeared from their edges and then developed sideways in inclination path toward the soil surface. These cracks loosen the soil and broken it in different size clods which finally resulted in wider ditch at the soil surface and at the bottom (Aday and Al-muthafar 2018 and 2019).

The results also showed that MB produced greater EUE for all wings width and operating depth comparing with CD. However, the difference between EUE of both machines decreased as the operating depth increased. For example, for operating depth of 30cm and wings width of 25cm, EUE for MB was 7.80m³MJ⁻¹, and for CD was 5.61m³MJ⁻¹, the difference between them was only 2.19m³MJ⁻¹. Increasing the wings width of MB to 45cm, EUE increased to 8.55m³MJ⁻¹ for the same operating depth and this resulted in greater difference between the two values (2.94m³MJ⁻¹). However, increasing the operating depth to 50cm, EUE for MB with wings width of 25 was 8.43m³MJ⁻¹ while for CD was 8.11m³MJ⁻¹, the difference is only 0.31m³MJ⁻¹. The small difference between EUE of the implements was not improvement in CD performance but the values were average for the cultivated soil only because CD could not penetrate the uncultivated whereas, for MB were average for the uncultivated and cultivated soils.
4. Conclusions

The following conclusions can be drawn from the results:

(1) EUE for MB increased as the operating depth increased in the cultivated and uncultivated soil. For CD, it increased in the cultivated soil only because it could not penetrate the uncultivated soil. EUE for CD in the cultivated soil increased from 5.57 to 7.93 m$^3$MJ$^{-1}$ (2.36 m$^3$MJ$^{-1}$) whereas, for MB, it increased from 9.64 to 11.78 m$^3$MJ$^{-1}$ (2.14 m$^3$MJ$^{-1}$).

(2) EUE for MB increased with angle between the boards and the width of the wings of the foot.

(3) EUE for MB was higher than that for CD for all operating depths, angle between the boards and the width of the wings of the foot and in both soil types. It can be deduced that MB has many advantages on CD among then it easily penetrate the soils whether they were cultivated or uncultivated, hard or friable. In addition that it save more energy because the lower soil resistance acting on it.

5. References

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Table (1): soil physical properties for cultivated and uncultivated soils

| depth (cm) | Cultivated soil | Uncultivated soil |
|------------|-----------------|------------------|
|            | Bulk density (kg/m³) | Cone index (kN/m²) | M.C (%) | Bulk density (kg/m³) | Cone index (kN/m²) | M.C (%) |
| 0-10       | 1266            | 1713.2            | 23.8    | 1458            | 3115.0            | 9.25    |
| 10-20      | 1150            | 1495.2            | 26.65   | 1449            | 3893.8            | 13.20   |
| 20-30      | 1367            | 2803.5            | 24.7    | 1417            | 3166.7            | 16.61   |
| 30-40      | 1240            | 2118.2            | 30.61   | 1272            | 2219.4            | 24.77   |
| 40-50      | 1141            | 1869.0            | 33.30   | 1161            | 1619.8            | 30.33   |

Table (2): soil mechanical properties

| Soil types     | Cohesion C (kN/m²) | Angle of Internal Friction Ø (Degrees) | Soil texture | consistency |
|----------------|--------------------|----------------------------------------|--------------|-------------|
| cultivated     | 9.48               | 40.09                                  | 4.2          | 51.6        |
| uncultivated   | 6.83               | 34.37                                  | 44.2         | 56.4        |

P.L. = Plastic limit
L.L. = Liquid limit