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Determination of Energy Requirements, Plowed Soil Volume Rate and Soil Pulverization Ratio of Chisel Plow Under Various Operating Conditions

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Abstract: A field experiments were conducted using a chisel plow in silty loam soil at Agricultural Research Station of Garmat Ali in 2017. Three different levels of forward speed (0.56, 0.87 and 1.36 m sec^{-1}) and plowing depth (10, 20 and 30 cm) were used to study their effect on energy utilization efficiency, specific energy, plowed soil volume rate and soil pulverization ratio. The results showed that increasing the forward speed from 0.56 to 1.36 m sec^{-1}, the specific energy, plowed soil volume rate and soil pulverization ratio were increased by 139.43%, 85.10% and 51.72%, respectively, while decreased the energy utilization efficiency by 30.04%. Increasing plowing depth from 10 to 30 cm led to increasing the energy utilization efficiency and the plowed soil volume rate by 34.30% and 87.38%, respectively. In contrast, the soil pulverization ratio and the specific energy decreased by 45.83% and 19.86%, respectively. The interaction between the forward speed and the plowing depth had a significant effect on all parameters in this study.

Key words: Energy utilization efficiency, plowed soil volume rate, specific energy, soil pulverization ratio, chisel plow.

Introduction

The tillage of soil is considered to be one of the biggest farm operations and it requires the most energy spent on farms (Abbaspour-Gilandeh *et al*., 2006 and Al-Suhaibani *et al*., 2010). Also, draft and energy requirements are important in order to determine the size of the tractor that could be used for a specific implement (Al-Suhaibani and Ghaly, 2013). About 60% of total energy required for preparing the soil used for tillage and preparing a good seedbed (Jacobs and Harrell, 1983). Therefore, the efficiency of using the energy sources of agricultural machinery should be studied. ASAE (2000) showed that one of the main aims of a good farm manager was to prepare the soil for planting in the shortest possible time and this can be accomplished by maximizing the field capacity of the tillage implement.

The specific energy is used energy to cut, disturb, and breakup of soil. It was affected by soil conditions, the degree of soil compaction, soil type and agricultural tool geometric as well as travel speed and plowing depth (Mckyes, 1985; Van Muysen *et al*., 2000). Aday and Nassir (2009) found that the specific energy of combined chisel plow increased with increasing forward speed and decreased with increasing the plowing depth. Khader (2008) discovered that the required energy of chisel plow for cutting and pulverizing a unit volume from the soil increased with increasing of the plowing speed, it increased from 79.51 to 108.02 kJ m^{-3} when the plowing speed increased from 0.89 to 1.92 m sec^{-1}.

Energy utilization efficiency was defined as a number of cubic meters of the disturbed soil per one Mega Joule from the energy consumed (Mckyes, 1985). It is reflect of plow ability on energy utilization. The energy utilization efficiency was improved by increasing the volume of soil disturbed and decrease the energy requirements (Aday and Hilal, 2001). In study conducted by Mckyes and Maswaure (1997), it was evaluated the effect of design parameters of flat tillage tools on loosening of a clay soil, the result found that the energy utilization efficiency increased from 6.11 to 6.50 m^3 MJ^{-1} when the operating depth increased from 10 to 20 cm. However, Aday *et al*. (2001) found the energy utilization efficiency decreased by 6% when the forward speed increased from 0.28 to 0.77 m sec^{-1}.

Plowed soil volume rate (volume of the disturbed soil per unit time) was one of important parameters due to determine the field performance of plows. Its affected by forward speed and plowing depth, as increase forward speed and/or plowing depth, the volume of soil disturbed will increase (Bukhari *et al*., 1988; Mari *et al*., 2011).

The preparation of seedbed was depended on amount of soil pulverization or mean weight diameter (MWD) values. For producing a good seedbed, the clod size must be ranged from 10 to 25 mm (El-Haddad *et al*., 1995). Soil pulverization ratio affected by soil conditions, plow type and work conditions in term forward speed and plowing depth. Soil pulverization ratio increased with increasing the forward speed and decreases with increasing the plowing depth (Yassen *et al*., 1992). Taniguchi *et al*. (1999) and Meselhy (2014) found that an increase in tillage operating speed resulted in more soil pulverization.

This study used a chisel plow which is consider one of the primary tillage implements widely used by farmers for the soil preparation because its functions are most effectively when the soil is dry and firm (Srivastava *et al*., 1993).

The aim of this study was to evaluate the field performance of the chisel plow at various forward speed and plowing depth by studying the effects on energy utilization efficiency, specific energy, plowed soil volume rate and soil pulverization ratio.

Materials and methods

Chisel plow: A medium size chisel plow (Model KNR-568, Serial No. 1344) Kvernland company, Norway was used in the study. The plow specifications are: weight 458.87 kg and had a design width 1.65 m and 7 blades (curve type) in two rows, three blades in the front row and four blades in the back row and each blade has 5cm width. The blades are fixed on the frame alternatively. The distance between blades in same row is 48 cm. The distance between front row and back row is 55 cm .

Tractors: Massy Ferguson (MF) tractor model 440 xtra and Case IH (CH) tractor model JX75T were used in this study. The MF tractor was provided with diesel engine of 77 kW (4 cylinders) for testing chisel plow as the gear shaft was put on idle, while CH tractor with diesel engine of 55 kW (4 cylinders) was used to pull the MF tractor with chisel plow during measuring draft force under different given testing variables. The draft was measured by using a load cell sensor that coupled between two tractors (pull tractor in the front (CH) and mounting chisel plow tractor in the rear (MF).

Determination of energy utilization efficiency:

The energy utilization efficiency was determined according to Mckyes (1985) by the following formula:

$$\eta = \frac{1}{S.R} * \frac{m}{m} * 10^3 \quad \ldots\ldots\ldots (1)$$

where:

η : Energy utilization efficiency ($m^3\ MJ^{-1}$)

$S.R$: Specific resistance ($kN\ m^{-2}$) (draft force / disturbed area of soil)

m: Unit of length (m)

Determination of specific energy:

The specific energy (SEV) is the energy required (kJ) for plowing a unit volume from the soil (m^3) which determined by dividing the drawbar power (kW), (draft force (kN) × actual speed ($m\ sec^{-1}$)) per the plowed soil volume rate ($m^3\ sec^{-1}$). The following formula was used to determine the specific energy (Khadr, 2008):

$$\text{SEV} = \frac{P_{db}}{\mathbf{V}} \quad \ldots\ldots\ldots (2)$$

where:

SEV: Specific energy ($kJ\ m^{-3}$)

P_{db} : Drawbar power (kW)

V: Plowed soil volume rate ($m^3\ sec^{-1}$)

Determination of plowed soil volume rate:

The plowed soil volume rate (V) determined by formula (3) from Ahaneku *et al*. (2011):

$$V = D * ATF * 10^4 \quad \ldots\ldots\ldots (3)$$

where:

V: Plowed soil volume rate ($m^3\ hr^{-1}$)

D: Plowing depth (m)

ATF: Actual field capacity ($ha\ hr^{-1}$)

Soil pulverization ratio:

Soil pulverization ratio is the ratio of the soil weight fraction composed of soil clods less than or equal 25 mm which passes from the sieve mesh of 25 mm to the total weight of clods produced by plowing.

Soil properties:

The basic soil properties such as moisture content, bulk density and soil penetration were measured at different soil depths (0-10, 10-20 and 20-30 cm) with three different positions of the field of experiment, while the soil texture was measured of 0-10 cm depth. The results are summarized in table (1).

The moisture content of soil was measured for all soil depths by core sample method then soil samples were dried in oven at 105C° and time period 24 hour. The moisture content of each sample was calculated on a percent dry weight basis. The following formula was used to calculate the moisture content of soil (Black *et al*., 1965):

$$M.C\ \% = \frac{W_{wet} - W_{dry}}{W_{dry}} * 100 \quad \ldots\ldots\ldots (4)$$

Where:

M.C= Moisture content (%)

Wwet = Weight of the wet soil sample (g)

Wdry = Weight of the dried soil sample (g)

The soil bulk density was measured by the core sample method for each soil depths. The bulk density was calculated by using the equation (5) and according from Black *et al*. (1965):

$$\rho b = \frac{ms}{vt} \quad \dots\dots\dots (5)$$

Where:

ρb = Dry bulk density (Mg m^{-3})

ms = Weight of the dried soil sample (Mg)

vt = Total volume of the soil sample (m^3)

The soil penetration resistance (cone index) was measured of each the soil depths using a penetrometer (0.02815m cone diameter and 35° angle cone based). The soil penetration resistance was calculated by using the equation (6) from Roozbeh *et al*. (2010):

$$C.I = \frac{F}{A} \quad \dots\dots\dots (6)$$

Where:

C.I = Cone index (kN m^{-2})

F = Average of recorded forces (kN)

A = CI base area (m^2)

Table (1): Basic soil properties.

Soil depth cm	*M.C* %	*ρb* Mg m^{-3}	*C.I* MN m^{-2}	Clay g kg^{-1}	Silt g kg^{-1}	Sand g kg^{-1}	Soil texture
0-10	10.54	1.17	1.88	200	550	250	Silty loam
10-20	12.17	1.25	1.94				
20-30	13.47	1.31	2.25				
Average	12.06	1.24	2.02				

The experiment design:

The experiment was arranged in a randomized complete block design. Three levels of plowing depth (10, 20 and 30 cm) and three levels of forward speed (0.56, 0.87 and 1.36 m sec^{-1}) were used as an independent factor in order to study it effect on energy utilization efficiency, specific energy, plowed soil volume rate and soil pulverization ratio. An experimental unit of 30 m long and 5 m wide was used for each treatment with three replications. A block of approximately 5 m long was used as a practice area prior to the beginning of the experimental runs to enable the tractor and the implement to reach the required forward speed and tillage depth. All the obtained data were subjected to analysis of variance (ANOVA) using Genstat 14 Statistics software. Mean treatments were compared using RLSD at 5% level of probability.

Results and discussion

Energy utilization efficiency:

The effect of forward speed on the energy utilization efficiency showed in fig. (1). The energy utilization efficiency significantly decreased ($p \leq 0.05$) with an increasing in forward speed. Increasing forward speed from 0.56 to 0.87 and 1.36 m sec^{-1}, decreased the energy utilization efficiency from 9.88 to 7.93 (19.74%) and 5.61 m^3 MJ^{-1} (43.22%), respectively. Rate of increase was presented because of increasing the draft force was greater than increasing in the volume of soil disturbed.

The effect of plowing depth on the energy utilization efficiency showed in fig. (2). The energy utilization efficiency significantly increased ($p \leq 0.05$) with increasing the plowing depth. When plowing depth increased from 10 to 20 and 30 cm, the energy utilization efficiency increased from 6.57 to 7.82

(19.03%) and 9.03 m^3 MJ^{-1} (37.44%), respectively. This was mainly because of the increasing in the volume of soil disturbed with less energy spending at increase the plowing depth (Mckyes and Maswaure, 1997).

The interaction between the operating depth and forward speed had significant effect ($p \leq 0.05$) on the energy utilization efficiency (fig. 3). The energy utilization efficiency was decreased by 39.21, 43.86 and 45.47% when the forward speed was increased from 0.56 to 1.36 m sec^{-1} (142.86%) at the operating depth of 10, 20 and 30 cm, respectively. While, it was increased by 38.76, 45.33 and 24.66% when the operating depth was increased from 10 to 30 cm (200%) at the forward speed 0.56, 0.87 and 1.36 m sec^{-1}, respectively. The lowest value of the energy utilization efficiency recorded at plowing depth of 10 cm and forward speed of 1.36 m sec^{-1} which was 5.01 m^3 MJ^{-1}, while, the highest value of the energy utilization efficiency recorded at plowing depth of 30 cm and forward speed of 0.56 m sec^{-1} which was 11.43 m^3 MJ^{-1}. This was because of increasing the volume of soil disturbed greater than increasing in requirements of energy with increasing the plowing depth, as well as decreasing the energy requirements with decreasing the forward speed. All results above were in agreement with Aday and Hilal (2001) and Khader (2008).

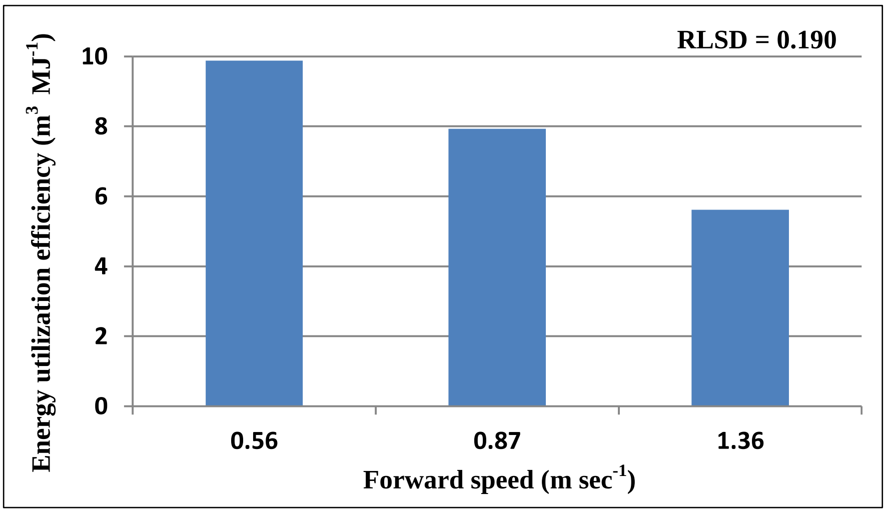

Fig. (1): Effect of forward speed on energy utilization efficiency.

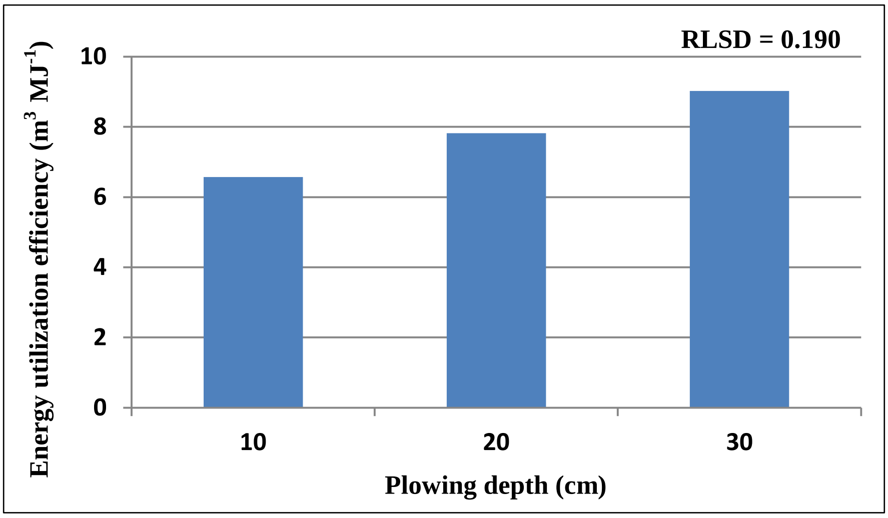

Fig. (2): Effect of plowing depth on energy utilization efficiency.

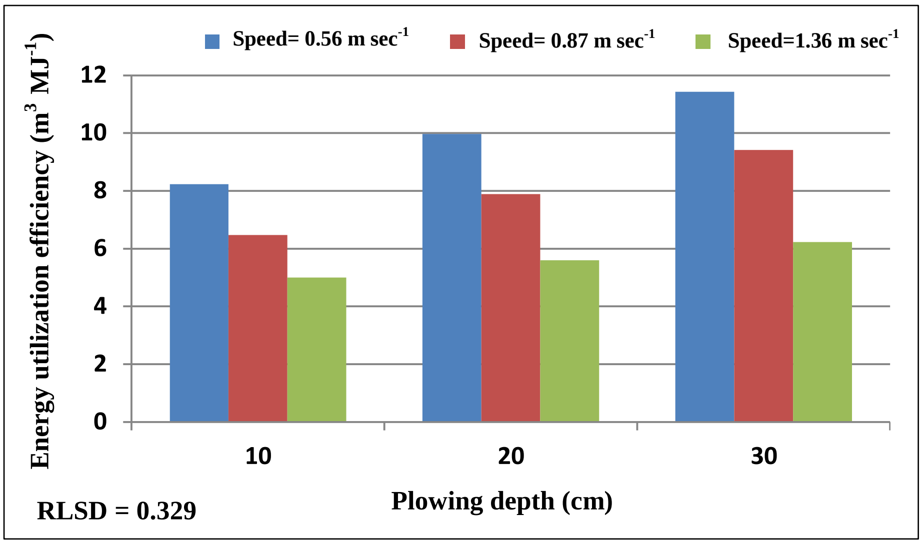

Fig. (3): Effect of plowing depth and forward speed on energy utilization efficiency.

Plowed soil volume rate:

Fig. (4) showed the effect of forward speed on the plowed soil volume rate. Plowed soil volume rate significantly increased ($p \leq 0.05$) with increasing the forward speed. When the forward speed increased from 0.56 to 0.87 and 1.36 m sec^{-1}, the plowed soil volume rate increased from 597.69 to 900.73 (50.70%) and 1414.60 m^3 hr^{-1} (136.68%), respectively. This results could be attributed to increase in plowed soil area per unit time with increasing the forward speed and this led to increase the plowed soil volume rate.

The plowing depth had a significant effect ($p \leq 0.05$) on the plowed soil volume rate. Fig. 5 showed that increasing plowing depth from 10 to 20 and 30 cm, increased the plowed soil volume rate from 502.89 to 1013.55 (101.54%) and 1396.58 m^3 hr^{-1} (177.71%), respectively. That can be attributed to direct relationship between the plowed soil volume rate and the plowing depth, where the plowing depth increased the depth of the disturbed soil section, this cycle increased the volume of soil disturbed.

The interaction between the plowing depth and forward speed had significant effect ($p \leq 0.05$) on the plowed soil volume rate (fig. 6). The plowed soil volume rate was increased by 133.89, 149.51 and 128.73% when the forward speed was increased from 0.56 to 1.36 m sec^{-1} (142.86%) at the plowing depth 10, 20 and 30 cm, respectively. Furthermore, the plowed soil volume rate was increased by 179.57, 183.26 and 126.64% when the plowing depth was increased from 10 to 30 cm (200%) at the forward speed 0.56, 0.87 and 1.36 m sec^{-1}, respectively. The maximum value of the plowed soil volume rate was obtained at forward speed of 1.36 m sec^{-1} and plowing depth of 30 cm, which was 1996.77 m^3 hr^{-1}. While, the minimum value of plowed soil volume rate was obtained at forward speed of 0.56 m sec^{-1} and plowing depth of 10 cm, which was 312.26 m^3 hr^{-1}.

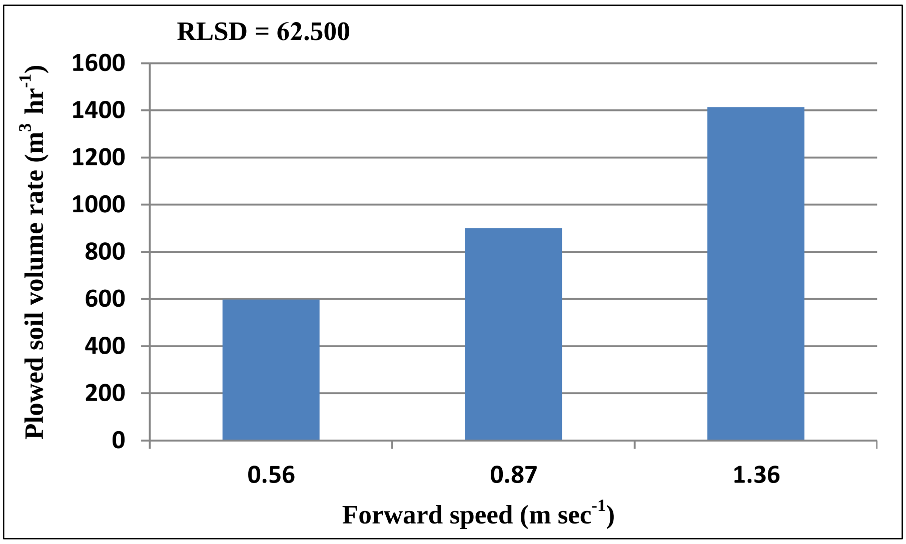

Fig. (4): Effect of forward speed on plowed soil volume rate.

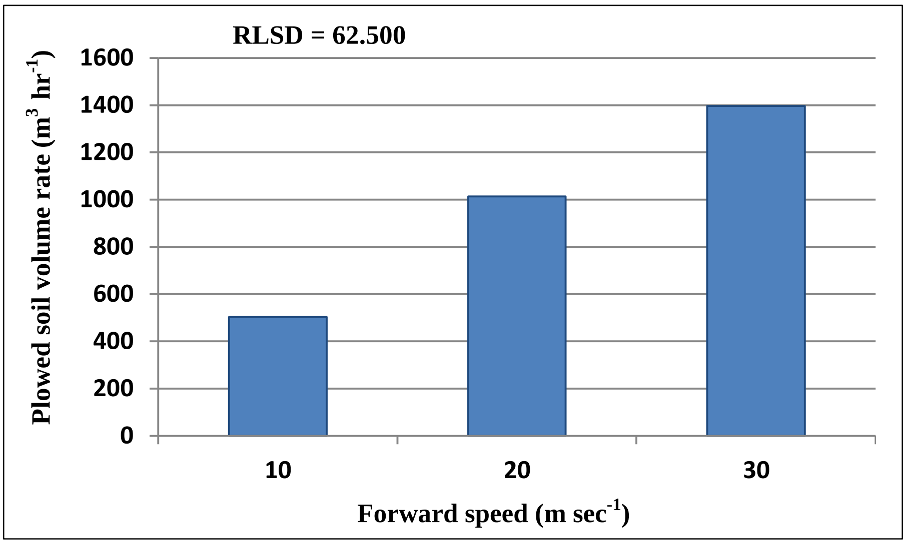

Fig. (5): Effect of plowing depth on plowed soil volume rate.

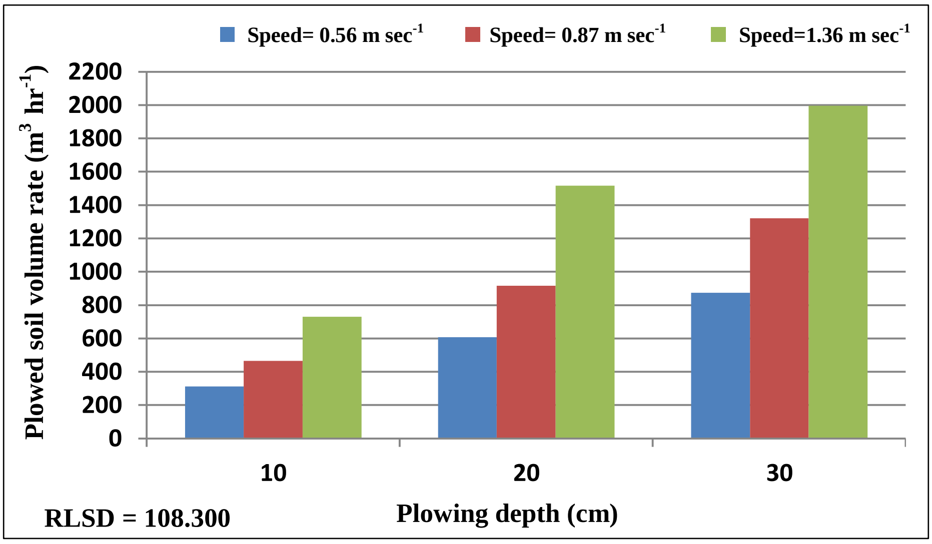

Fig. (6): Effect of plowing depth and forward speed on plowed soil volume rate.

Specific energy (SEV):

The specific energy significantly increased ($P \leq 0.05$) with increasing the forward speed (fig. 7). The specific energy increased from 103.10 to 129.18 (25.30%) and 179.69 kJ m^{-3} (74.29%) when the forward speed increased from 0.56 to 0.87 and 1.36 m sec^{-1}, respectively. This finding was in agreement with Aday and Nassir (2009) who found that the energy requirement was increased due to increasing the draft force of the chisel plow with higher the forward speed.

The effect of plowing depth on the specific energy presents in fig. (8). At increasing the plowing depth from 10 to 20 and 30 cm, the specific energy significantly decreased ($p \leq 0.05$) from 158.60 to 135.28 (14.70%) and 118.10 kJ m^{-3} (25.54%), respectively. This was because of increasing in the volume of the disturbed soil more than from increasing in the draft force requirements.

The interaction between the forward speed and the operating depth had a significant effect ($p \leq 0.05$) on the specific energy (fig. 9). When the forward speed was increased from 0.56 to 1.36 m sec^{-1} (142.86%), the specific energy was increased by 64.70, 77.96 and 83.34% at the plowing depth of 10, 20 and 30cm, respectively, while, it was decreased by 27.92, 31.14 and 19.76% when the plowing depth was increased from 10 to 30 cm (200%) at the forward speed of 0.56, 0.87 and 1.36 m sec^{-1}, respectively. The highest value of the specific energy was recorded at forward speed of 1.36 m sec^{-1} and operating depth of 10 cm, which was 199.95 kJ m^{-3}, while the lowest value of the specific energy was recorded at forward speed of 0.56 m sec^{-1} and operating depth of 30 cm, which was 87.51 kJ m^{-3}. This result indicated that specific energy was depended on the change of the volume of the disturbed soil with increasing the plowing depth. As well as, decreasing the draft force requirement with decreasing the forward speed.

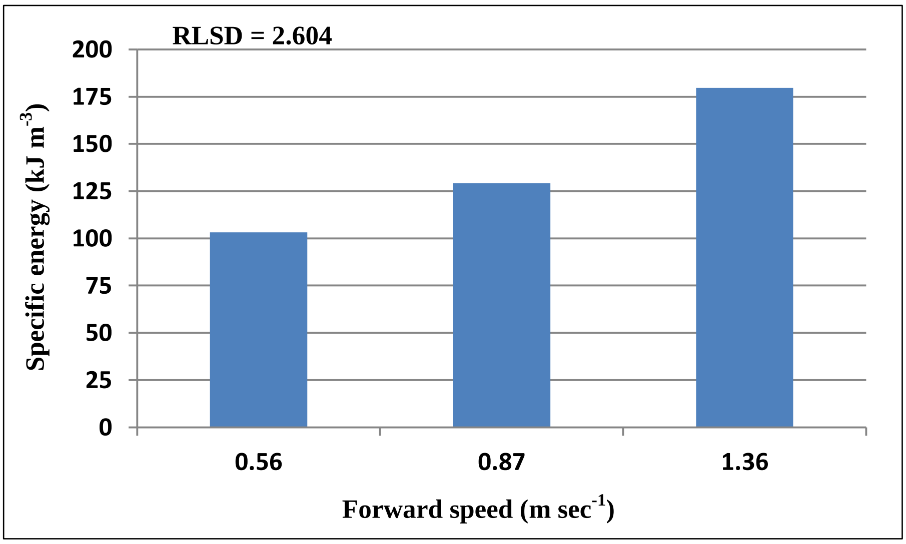

Fig. (7): Effect of forward speed on specific energy.

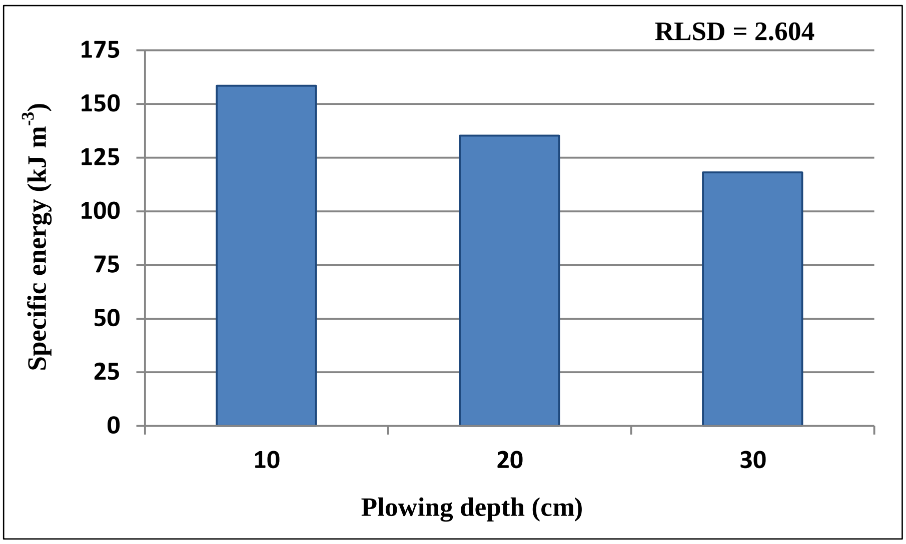

Fig. (8): Effect of plowing depth on specific energy.

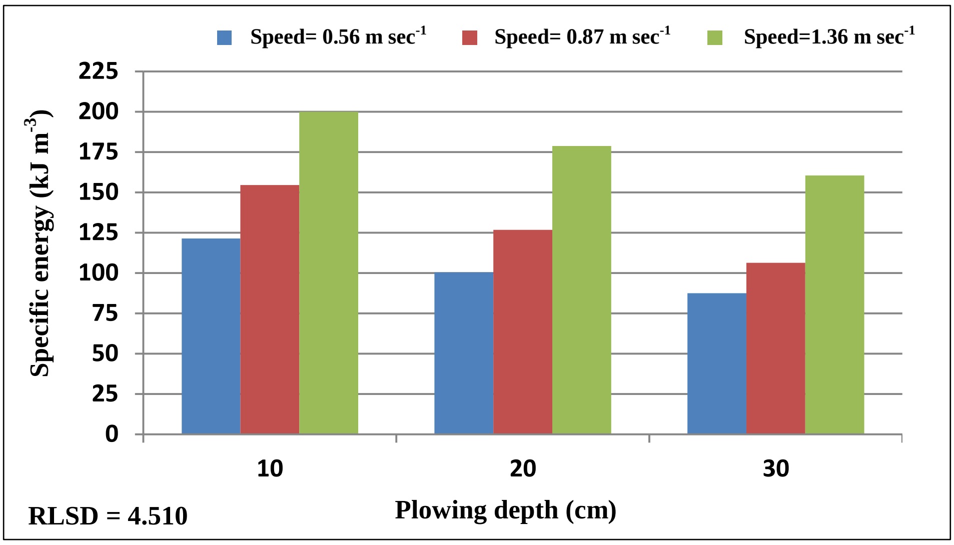

Fig. (9): Effect of plowing depth and forward speed on specific energy.

Soil pulverization ratio (≤ 25mm):

The soil pulverization ratio is defined as the volume of clod soil which less than 25 mm diameters. The effect of forward speed on the soil pulverization ratio showed in fig. (10). The soil pulverization ratio significantly increased ($P \leq 0.05$) as the forward speed increased. The soil pulverization ratio increased from 0.29 to 0.33 (13.79%) and 0.44 (51.72%) when the forward speed increased from 0.56 to 0.87 and 1.36 m sec^{-1}, respectively. Increasing the soil clods acceleration and moving may cause an increasing of the collision of the soil blocks, thereby the soil blocks breaking up to small pieces resulting in increased the soil pulverization ratio.

The effect of the operating depth on the soil pulverization ratio showed in Fig. (11). The soil pulverization ratio significantly decreased ($p \leq 0.05$) from 0.48 to 0.32 (33.33%) and 0.26 (45.83%) when the plowing depth increased from 10 to 20 and 30 cm, respectively. This result may be due to increasing the soil blocks greater than 25 mm diameters with increasing the operating depth consequently reduce the soil pulverization ratio.

The interaction between the forward speed and plowing depth had a significant effect ($P \leq 0.05$) on the soil pulverization ratio (fig. 12). When the forward speed was increased from 0.56 to 1.36 m sec^{-1} (142.86%), the soil pulverization ratio was increased by 36.58, 57.69 and 75.00% at the plowing depth of 10, 20 and 30 cm, respectively, while, it was decreased by 51.22, 48.94 and 37.50% when the plowing depth was increased from 10 to 30 cm (200%) at the forward speed of 0.56, 0.87 and 1.36 m sec^{-1}, respectively. The highest value of the soil pulverization ratio recorded at the forward speed of 1.36 m sec^{-1} and plowing depth of 10 cm, reaching 0.56. While the lowest value of the soil pulverization ratio recorded at forward speed of 0.56 m sec^{-1} and plowing depth of 30 cm, reaching 0.20. This could be attributed to increasing in the volume of soil blocks with increasing the operating depth and this led to reducing the soil pulverization ratio, however increasing the forward speed led to increasing the soil pulverization ratio due to increasing the soil blocks collision and breaking into small sizes.

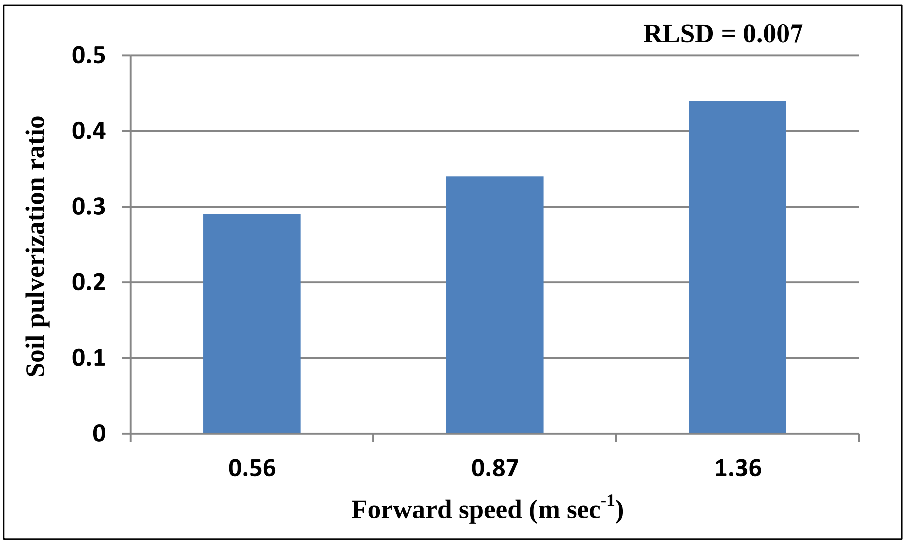

Fig. (10): Effect of forward speed on soil pulverization ratio.

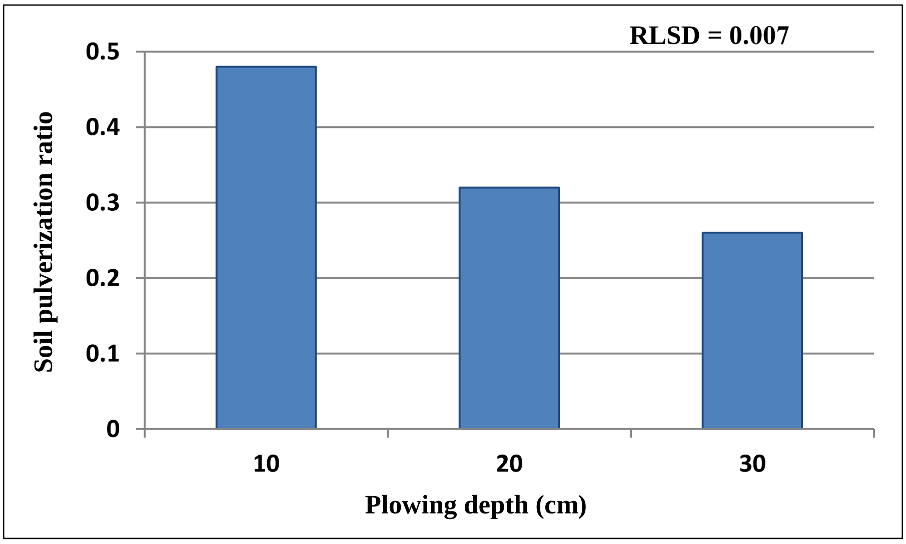

Fig. (11): Effect of plowing depth on soil pulverization ratio.

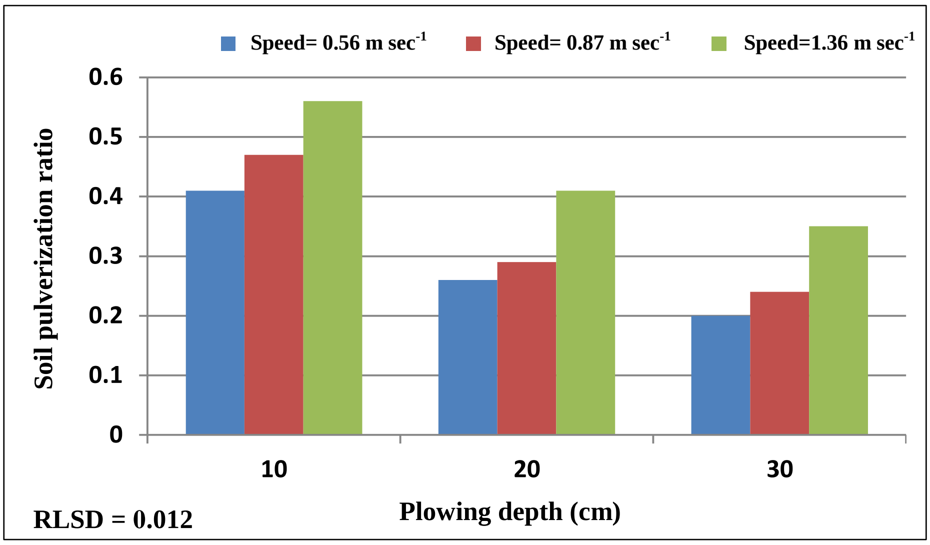

Fig. (12): Effect of plowing depth and forward speed on soil pulverization ratio.

Conclusion

The results were indicated that increasing the forward speed increased the specific energy, the plowed soil volume rate and the soil pulverization ratio, whereas decreased the energy utilization efficiency. Also, the plowing depth was increased the energy utilization efficiency and the plowed soil volume rate whereas decreased the soil pulverization ratio and the specific energy.

This study can be recommended that the best combination of work accompanying with shallow plowing depth (10-20 cm) and high forward speed (1.36 m sec^{-1}) to obtain high pulverization of soil thereby available suitable seed bed for germination and emergence. While prefer to use the chisel plow at deeper depth (30 cm) and slow forward speed (0.56 m sec^{-1}) to obtain high energy utilization efficiency.

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