Investigation on the application of subsoiler vibration to reduce the energy requirement

S Al-rajabo, Y Y Hilal* and R H Rajab

Department of Agricultural Machines and Equipment, College of Agriculture and Forestry, University of Mosul, Iraq.

Corresponding author: yousif.yakoub@uomosul.edu.iq

Abstract. The aims of this study were to investigate the input energy in vibrating and non-vibrating subsoiler wings based on field operations and to compare the field performance based on the energy use efficiency to determine the best between them. The study was carried out using vibrating and non-vibrating wings of the subsoiler and two rake angles in the soil (45° and 55°). Three tractor speeds (2.88, 4, and 5.6 km/h) were considered. The results showed that input energy in non-vibrating wings was higher than that in vibrating wings at all treatments. Analysis of the energy input showed the diesel fuel had the largest inputs form all input energy for both wings types. The treatment of 45° with 2.88 km/h had the largest share of input energy with 1528.95 MJ/ha in non-vibrating wings while the treatment of 55° with 2.88 km/h had the largest share 1239.86 MJ/ha in vibrating wings. Total volume of soil disturbance in vibrating wings and non-vibrating wings was 2704.185 and 3586.491 m³/ha, respectively. Accordingly, energy use efficiency for vibrating wings higher than non-vibrating wings. Finally, vibrating wings surpassed non-vibrating wings in field performance and it can produce higher cross-section soil with the least input energy consumed.

1. Introduction

Energy is a substantial variable for machinery during the agricultural process and it is inevitable in agricultural mechanization management [1]. Tillage has been powered by tractors that contain equivalent energy and fuel which important as effective parameters of tillage operation [2]. The selection of input energy consumption for planting is one of the major challenges faced by farmers. The energy consumption in tillage operations includes diesel or gasoline fuels, human power, etc. [3]. Energy is the key of agro-processing development and yield production in Iraq. However, energy and environment have different sides of the same coin. Energy consumption in agricultural production has negative effects on environmental change. It is widely accepted that global climate change, air pollution, and acid rain are the inevitable consequences of the fossil fuels burning [4]. Therefore, the development of energy-efficient agricultural systems that requires low energy input with high output of yield crop is a priority among designers and planners.

Agriculture produces and consumes energy at the same time [5]. Various agricultural processes for crop production such as soil preparation and equipment maintenance use huge amount of energy such as energy input for machinery and energy to operate the machinery. The energy input for machinery is
the energy requirement in producing the machine while energy to operate the machinery can be classified as energy input from human labour [6].

The factors that principally affect energy consumption in subsoiler plough is the speed of farm tractor, actual cross-section area of the cut, rake angle, soil strength, moisture content, and the operating depths [7-10]. An investigation by Moitzi et al [11] revealed that increasing operating depth and speed in subsoiler as well as raising the draft force and the slip increased fuel consumption rate.

Hilal [12] defines energy use efficiency as the volume of the soil disturbed by the subsoiler for one Mega Joule of spent energy. It stated that the use of double tines plow increased 90 % of energy use efficiency compare to the usage of single subsoiler plow because of the increasing volume of disturbed soil. Infield experiments to evaluate the energy use efficiency of subsoiler found that the addition of the wings to subsoiler significantly increased (p<0.01) energy use efficiency by 29.52% [13].

Investigation in various aspects related to agriculture is important given the dynamic conditions of vibration in subsoiler operation. Despite the strong need for accurate exploration, the current status of these investigates is far from satisfactory. No well-defined existing Investigating method takes into account most of the factors that control energy consumption. Although there are established models, they tend to be “one size fits all” and only use one variable while tillage operation typically influenced by many variables.

It is necessary to investigate the performance under different conditions and analyse the efficiency of the energy use as the criteria to determine the best methods and technologies [14]. Exploratory research on vibrating and non-vibrating wings of subsoiler has revealed that little has been done on vibration subsoiler plough in Iraq. Some published papers are available on the determination of energy requirements in subsoiler operations in the neighboring countries of Iraq. However, these studies use dissimilar protocols depending on the different circumstances. As the literature review indicated, no paper was found on energy investigation for vibrating subsoiler wings. In this paper, the first objective was to investigate the input energy in vibrating and non-vibrating of subsoiler wings based on field operations. The second objective was to compare the energy use efficiency in the field performance of the vibrating and non-vibrating to determine the best among them. The comparison was carried out using the three tractor speeds and two rake angles for both vibrating and non-vibrating subsoiler.

2. Materials and methods

2.1 Experiments Site
The field experiments were conducted on an experimental farm in agricultural and forest college, Mosul University, Nineveh province, Iraq. This farm is located within 36°23'24.1"N 43°07'55.1"E longitude and latitude as shown in Figure 1. The soil texture at the experimental sites was clay with a pH of 7.6, the characteristics of the soil are illustrated in Table 1.

![Figure 1](image-url) Description of the study sites (36°23'24.1"N longitude 43°07'55.1"E latitude).
Table 1. Soil properties and texture

| Soil depths cm | Bulk Density Mg/m³ | Moisture Content (%) | Penetration Index kPa |
|----------------|-------------------|---------------------|----------------------|
| 30-40          | 1.50              | 21.95               | 3166.23              |
| 50-40          | 1.58              | 21.99               | 3174.19              |
| Soil texture   |                   |                     |                      |
| Clay           |                   |                     |                      |
| Silt           |                   |                     |                      |
| Sand           | 44.98             | 32.5                | 22.52                |

2.2 Test subsoiler plow and input data for energy models

The subsoiler plow used in the study was a single tine with vibrated wings shown in Figure 2. The wings are vibrated by a crank mechanism, driven by the tractor PTO (Power Take Of). The plow has characteristic as follow: maximum working depth 60 cm, width of vibrating body 35.8 cm, machine weight 260 kg, and P.T.O. shaft rotations 540 Rpm with required tractor power 60 HP.

![Figure 2. Vibrating subsoiler used in an experiment](image)

Experiment treatments included vibrating and non-vibrating wings, two rake angles (45° and 55°), and three tractor speeds of 2.88, 4, and 5.6 km/h. The depth in the experiment was conducted with a single depth of 45 to 50 cm. The soil profile area of the subsoiler made by vibrating and non-vibrating wings were measured in the field for two rake angles in the soil and every forward speed. The soil profile or cross-section area of the soil tillage was calculated as described in [15, 16]. The volume of the disturbed soil (V) was then calculated by multiplying the cross-section area of the soil tillage (m²) by the length of tillage (m).

The input energy data were used to select the most significant variables in the energy used for subsoiler operation by developing models to predict energy consumption in field operations. Energy consumption is defined as the usage of energy for vibrating and non-vibrating wings until it completed all treatment in the farm field.

The typical analysis of energy input was carried out by calculating the direct and indirect energy sources. The direct energy source refers to the energy that is directly involved in performing a subsoiler activity while indirect energy source implies the energy source that is used via conversion process, such as energy consumed by machinery. The energy consumption was calculated per total hectare in each treatment and the results were then converted to the forms of energy for the evaluation of the input analysis. The estimation of labour energy used was calculated to estimate the total number.
of labour on subsoiler operations. Human labour input was calculated as the energy expended by farmhands per hour per hectare [17] as presented in Equation 2.1:

\[
\text{Total human energy (input)} = \frac{\text{Total equivalent human energy input for a typical worker by the total number of labour by farmhand’s hours}}{2.1}
\]

The main fuel used in subsoiler treatments is diesel. It is quite obvious that the fuel used in subsoiler treatments is related to many factors; thus, it is incorrect to apply a similar rate of fuel for other various operations. However, considering the total fuel consumed in treatments and the best coefficients as referred to by various reports and studies, the ASAE reported by [18] was used. The energy input is established from fuel consumption per operation for total hectare and the fuel equivalent energy per litre, as showed in Equation 2.2:

\[
\text{Total fuel energy (input)} = \text{Operation fuel consumption (l)} \times \text{Energy equivalent for Fuel (MJ/l)}
\]

The equivalent energy produced through oil for lubrication, tractor and subsoiler per operations for total hectare is estimated using Equations 2.3, 2.4, and 2.5, as suggested by [19, 20]:

\[
\begin{align*}
\text{Total oil energy (input)} &= \text{oil consumption (l)} \times \text{Energy equivalent for oil (MJ/l)} \\
\text{Total tractor energy (input)} &= \text{Operation tractor consumption (h)} \times \text{Energy equivalent for the tractor (MJ/h)} \\
\text{Total subsoiler plow energy (input)} &= \text{Operation subsoiler consumption (h)} \times \text{Energy equivalent for the subsoiler plow (MJ/h)}
\end{align*}
\]

Measurement of the energy use efficiency (m3/MJ) was calculated using eq. (2.6).

\[
\text{Energy use efficiency} = \frac{V}{E} \tag{2.6}
\]

Where:

V: volume of the disturbed soil (m3).

E: Energy spent by subsoiler to disturbed the volume of soil (MJ).

3. Results and discussion

3.1. Analysis of energy input used in vibrating wings and non-vibrating wings of subsoiler

Production systems and modelling in agricultural fields are quite different given their energy utilities and energy provision potential [21]. For each energy source and field operation, there is a corresponding norm, called as a conversion coefficient or energy equivalent. Conversion coefficients help to standardize the unit of all inputs to MJ/ha. Selecting a suitable energy coefficient for each energy input is one of the most critical aspects of energy studies and models. The next section discusses the energy resources used, specifically, in vibrating and non-vibrating wings of subsoiler:

3.1.1. Human labour and machinery. Human labour and machinery energy consumption and its sources for subsoiler plow are presented in Table 2. As can be seen from Table 2, the total human labour and machinery energy in vibrating wings treatments were 15.527 and 179.915 MJ/ha, respectively, in which the highest shares were recorded in treatment of 45° + 2.88 km/h and treatment of 55° + 2.88 km/h respectively. Of all the inputs, the treatment of 45° + 2.88 km/h energy has the largest share (23.907 %) followed by treatment of 55° + 2.88 km/h (21.917%), and energy for treatment of 55° + 4.0 km/h (15.934%).

Non-vibrating wings subsoiler consumed energy for human labour and machinery as much as 19.642 and 227.582 MJ/ha, respectively, in which the highest shares were recorded for treatment 55° +
2.88 km/h and treatment 45° + 2.88 km/h. The total energy equivalent consumption of 55° + 2.88 km/h placed first among the energy inputs and constituted 24.88 % of the total human labour and machinery energy input, followed by 45° + 2.88 km/h (23.465 %) in second place. Accordingly, the amount of human labour and machinery energy in non-vibrating wings processing was higher than that in vibrating wings processing in the subsoiler plow. The reason is that vibrating wings finished its job with the least amount of time per unit area. Vibration is worked to reduce soil compaction that led to decreasing traction requirements. Soil crumbling is well observed by using this tool [9,22,23]. Therefore, vibrating wings get the work done in the least amount of time per unit area.

| Inputs energy: | Vibrating wings | Non-vibrating wings |
|----------------|-----------------|---------------------|
| Human labour   |                 |                     |
| (55° + 2.88 km/h) | 3.403           | 21.917              |
| (55° + 4.0 km/h)  | 2.474           | 15.934              |
| (55° + 5.6 km/h)  | 1.979           | 12.746              |
| (45° + 2.88 km/h) | 3.712           | 23.907              |
| (45° + 4.0 km/h)  | 2.227           | 14.343              |
| (45° + 5.6 km/h)  | 1.732           | 11.155              |
| Total           | 15.527          | 100                 |
| Machinery tractor |               |                     |
| (55° + 2.88 km/h) | 28.500          | 21.912              |
| (55° + 4.0 km/h)  | 20.727          | 15.936              |
| (55° + 5.6 km/h)  | 16.582          | 12.749              |
| (45° + 2.88 km/h) | 31.091          | 23.904              |
| (45° + 4.0 km/h)  | 18.655          | 14.343              |
| (45° + 5.6 km/h)  | 14.509          | 11.155              |
| Total           | 130.064         | 100                 |
| Subsoiler plow  |                 |                     |
| (55° + 2.88 km/h) | 10.924          | 21.912              |
| (55° + 4.0 km/h)  | 7.944           | 15.936              |
| (55° + 5.6 km/h)  | 6.356           | 12.749              |
| (45° + 2.88 km/h) | 11.917          | 23.904              |
| (45° + 4.0 km/h)  | 7.150           | 14.343              |
| (45° + 5.6 km/h)  | 5.561           | 11.155              |
| Total           | 49.851          | 100                 |

3.1.2. Diesel fuel and oil. The most diesel fuel and oil energy consuming was found in the non-vibrating wings treatments. According to Table 3, percentage shares for treatment of 45° + 2.88 km/h is 23.377%, treatment of 55° + 2.88 is 20.779%, and treatment of 45° and 55° with 4 km/h is 16.450% are the three highest for total diesel fuel while the treatment of 55° + 2.88 km/h recorded the highest oil energy used in non-vibrating wings of subsoiler. As can be seen from Table 3, the highest energy inputs for diesel fuel and oil energy in vibrating wings were treatment 55° + 2.88 km/h and treatment 45° + 2.88 km/h (23.158 and 23.904 %), respectively. The total amount of diesel fuel and oil energy using in non-vibrating wings treatments were 6208.125 and 83.905 MJ/ha that were higher than vibrating wings treatments energy consumption.

3.2. Effect of the tractor speeds and the rake angles on total inputs energy and soil volume disturbance

The results of the input energy in subsoiler processing are shown in Figure 3. The amount of input energy in non-vibrating wings treatments was higher than vibrating wings treatments in all of subsoiler
processing. In the non-vibrating wings processing, of all the inputs, treatment of 45° + 2.88 km/h had the largest share (1528.95 MJ/ha), followed by the treatment of 55° + 2.88 km/h (1372.39 MJ/ha). Energy for treatments of 55° + 4.0 km/h and 45° + 4.0 km/h rank third (1066 MJ/ha). The total energy equivalent of treatment rake angle 55° + 5.6 km/h placed at the lowest level (630.88 MJ/ha) of the total energy input for both non-vibrating wings and vibrating wings operations. The treatment of 55° + 2.88 km/h had the largest share (1239.86 MJ/ha) of input energy in vibrating wings operations. In this study, the highest share of total input energy in both processing related to the speed of the tractor.

Various studies have reported that is a conflict regarding the total power requirement of the oscillating tools. It may increase, decrease, or remain the same for the tillage operation [24-26]. Some researchers reported that there was an increase of 30-35% power consumption when using the oscillatory tool [10].

Table 3. Energy equivalents of diesel fuel and oil in subsoiler treatments.

| Inputs energy | Vibrating wings (MJ ha⁻¹) | % | Non-vibrating wings (MJ ha⁻¹) | % |
|---------------|---------------------------|---|-------------------------------|---|
| **Diesel fuel** |                           |   |                               |   |
| (55° + 2.88 km/h) | 1182.5                    | 23.158 | 1290                      | 20.779 |
| (55° + 4.0 km/h)  | 967.5                     | 18.947 | 1021.25                    | 16.450 |
| (55° + 5.6 km/h)  | 591.25                    | 11.579 | 591.25                     | 9.524 |
| (45° + 2.88 km/h) | 1075                     | 21.053 | 1451.25                    | 23.377 |
| (45° + 4.0 km/h)  | 806.25                    | 15.789 | 1021.25                    | 16.450 |
| (45° + 5.6 km/h)  | 483.75                    | 9.474  | 833.125                    | 13.420 |
| **Total**        | 5106.25                   | 100   | 6208.125                   | 100   |
| **Oil engine**   |                           |   |                               |   |
| (55° + 2.88 km/h) | 14.535                    | 21.912 | 20.877                     | 24.882 |
| (55° + 4.0 km/h)  | 10.571                    | 15.936 | 11.364                     | 13.543 |
| (55° + 5.6 km/h)  | 8.457                     | 12.749 | 10.042                     | 11.969 |
| (45° + 2.88 km/h) | 15.856                    | 23.904 | 19.688                     | 23.465 |
| (45° + 4.0 km/h)  | 9.514                     | 14.343 | 11.364                     | 13.543 |
| (45° + 5.6 km/h)  | 7.399                     | 11.155 | 10.571                     | 12.598 |
| **Total**        | 66.331                    | 100   | 83.905                     | 100   |

**Figure 3.** Effect of the tractor speeds and the rake angles on energy input of vibrating and non-vibrating wings.

The effect of the rake angles and the tractor speeds on soil volume disturbance of vibrating wings and non-vibrating wings is shown in Figure 4. The soil volume disturbance for both of them decreased.
as the tractor speed increased with the smallest rake angle. The rate of decrease in soil volume disturbance for both wings was almost the same with tractor speed and rake angle.

The comparison of soil volume disturbance for vibrating wings and non-vibrating wings showed that vibrating wings has higher results than non-vibrating wings in all treatments. However, the difference between their values reduced as the tractor speeds increased in the rake angle 45°. For the treatment of 55° + 2.88km/h, the soil volume disturbance for vibrating wings was 751.557 m³/ha while for non-vibrating wings was 534.66 m³/ha, higher by (40.56%). However, faster tractor speed at 5.6 km/h with rake angle 45° resulted in the lower volume of soil disturbance into 445.65 m³/ha whereas for non-vibrating wings decreased to 346.64 m³/ha, higher by (28.56%).

The reason for the outperform of vibrating wings over non-vibrating wings is related to the ability of vibrating wings to fracture the soil which reduces the soil cohesiveness in dry soils and lead to less draft and resistance. Moreover, the stress pulses are transmitted through the wet soil that resulting in a burst of hydrodynamic pressure and excess pore water pressure which reduces the effective stress and soil strength [10]. Therefore, vibrating wings outperform in the soil volume disturbance which was done in the least amount of time per unit area.

![Figure 4. Effect of the tractor speeds and the rake angles on soil volume disturbance of vibrating and non-vibrating wings.](image)

3.3. **Effect of the tractor speeds and the rake angles on energy use efficiency**

The effect of the rake angles and the tractor speeds on energy use efficiency of vibrating wings and non-vibrating wings are present in Figure 5. Energy use efficiency for both of them increased as the tractor speed increased with the highest energy use efficiency at 55° rake angle. The increasing trend in energy use efficiency for both wings was similar to tractor speed and rake angles. Energy use efficiency for vibrating wings was higher than that for non-vibrating wings in all treatments. However, the difference between their values increases as the tractor speeds increase at both the 55° and 45° rake angles. For example, in treatment of 45° + 2.88km/h, energy use efficiency for vibrating wings was 0.502 m³/MJ while for non-vibrating wings was 0.306 m³/MJ, higher by (64%), however, increasing the tractor speed to 5.6 km/h at rake angle 45° decreased the energy use to 0.868 m³/MJ in vibrating wing whereas for non-vibrating wings decreased to 0.396 m³/MJ, higher by (119%). Energy use efficiency of vibrating wings was considerably higher than that of non-vibrating wings because the amount of input energy in non-vibrating wings treatments was more than vibrating wings treatments while the volume of the soil disturbance by the vibrating wings is greater for all treatments.

The results also showed in the vibrating wings processing, the treatment of 55° + 5.6 km/h has the largest value of energy use efficiency (0.987 m³/MJ), followed by treatment of 45° + 5.6 km/h (0.868 m³/MJ). The efficiency of energy for treatments of 45° + 4.0 km/h was in third rank (0.661m³/MJ).
4. Conclusions
A detailed study was carried out to investigate the influence of wing conditions, tractor speed, and rake angles on input energy, soil volume disturbance, and energy use efficiency. The following conclusions can be drawn from the results: the diesel fuel recorded the largest inputs form all input energy for both wings conditions, and input energy in non-vibrating wings of subsoiler was higher than vibrating wing of subsoiler at all treatments. Moreover, vibrating wings had the highest output of soil volume disturbance while the non-vibrating wings is the lowest. Therefore, the energy use efficiency for vibrating wings was higher than that for non-vibrating wings. Input energy for both wings conditions decreased while the energy use efficiency increased as the tractor speed increased in both of the rake angle 45° and 55°. It can be deduced that vibrating wings have many advantages on non-vibrating wings among them it saves more energy. Besides, this information could also facilitate future research into the optimization of the subsoiler.

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