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Field study of a modified chisel plow performance on the Specific and equivalent energy and energy utilization efficiency

***Shaker H. Aday** ****Ageel J. Nassir**
Agri. Mechanization Dept, Agri. College, Basra university, Basra, IRAQ
*Email: shaker.h.1953@gmail.com
**Email: aqeelwafi@gmail.com

Abstract

A conventional chisel plow was provided with two rotors to increase its ability in pulverizing the soil and energy consumption. The field performance the modified chisel plow was evaluated by the draft force requirement and its soil pulverization ability in part (A). Further evaluation of its field performance will also be carried out in this part (B) using the specific and equivalent energy and energy utilization efficiency and through different operating depths (10, 15 and 25cm) and forward speeds (0.30, 0.50, 0.88 and 1.1m/s).

The specific energy, the energy spent by the modified chisel plow to cut, disturb and pulverize the soil, was higher for the modified chisel plow compared with that of the conventional plow, for operating depth of 15cm the specific energy for the conventional chisel plow was 102kJ/m^3 it increased to 106 and 114.2kJ/m^3 for the modified chisel plow provided with one and two rotors respectively. However the deeper operating depth (25cm) decreased the specific energy of the modified chisel plow from 106.2 and 114.2kJ/m^3 to 91.8 and 93.1kJ/m^3 and this regarded an improvement in the field performance of the modified chisel plow.

The forward speed decreased as the forward speed increased from 97.36kJ/m^3 for the convention plow to 82.8 and 58.23kJ/m^3 for the modified chisel plow with one and two rotors.

The equivalent energy decreased for both plows but in greater amount for the modified chisel than for the conventional chisel plow.

The energy utilization efficiency which is regarded the best parameter to evaluate the plow field performance was higher for the modified chisel plow by 27% and 44% compared with that of the conventional chisel plow for operating depths of 25 and 25cm respectively. The energy utilization efficiency of the modified plow increased from 25.4 to 88.8 which is greater that that for the conventional plow by 28.8% when the forward speed was increased from 0.3 to 1.1m/sec. The results reveled clearly that the field performance of the modified chisel plow improved considerably when was provided with two rotors.

1.0 Introduction

The chisel plow is regarded one of primary plows to cultivate the soil, it has many advantages among them are the wider working width so it reduces the time required to plow a certain area and it leaves the soil surface rough which reduces the soil water and air erosion. However this advantage is regarded on the other hand serious drawback when the soil is wanted to be plant immediately after plowing, thus heavy harrowing should be carried out to smooth the soil for accurate seeding. The harrowing can cause soil compaction especially when heavy tractor and implement are used and many passes are required to break the soil clods efficiently [5,7,8]. Also the chisel plow has another drawback which it required great deal of energy to plow the soil which big part of it dissipated in no useful work and little is used in cutting the soil and breaking up the soil clods [9,10]. Therefore to eliminate or it lest reduce

these problems to minimum a modification carried out on the conventional plow. It was provided with to rotors to pulverize the soil clods by chopping them to smaller clods to smooth the soil up for planting.

The soil clods breaking up improve the efficiency of energy utilization by the chisel plow [1,2,4]. The high efficiency reduces the waste of energy dissipated in the field by the plow.[1,3] The energy is used to cut the soil, moving and pulverizing the soil. The chisel plow cuts the soil as all plow types do but the soil movement is limited and that the reason of low soil pulverization as well as the chisel plow does not squeeze the soil as the mold board plow does in its moldboard. To improve this property two rotors were attached to the chisel and this addition properly consume energy in breaking the soil clods.

The modified chisel plow which is described in details in part (1) and its field performance was evaluated compared with conventional chisel plow using the draft force requirement and the mean weight diameter (MWD) as parameters of comparison. In part (2), the specific and the equivalent energies and the energy utilization efficiency will also be used as evaluation parameters to the field performance of the modified plow.

Three operating depths (10, 15 and 25cm) and four forward speeds (0.3, 0.5, 0.88 and 1.1m/sec were used as variable parameters to test the modified and conventional chisel plows in the field.

2.0 Materials and methods

2.1 The modified chisel plow

The modified chisel plow consists two parts (fig. 1). The front part includes the conventional chisel plow which consists of five tines

fixed on a frame of dimensions of 189x196cm. The frame is made of angled iron. The height, width and thickness of the angled iron were 10, 10 and 0.8cm respectively. The frame consists of two parts the front part for the tines and the rear part to the rotors fixed on them. The five tines were arranged in two rows. The front row includes two tines the lateral distance between them is 40cm. The rear row includes three tines the lateral distance between the is 40cm and they were fixed on the frame alternatively with the front row tines which made the lateral distance between the adjacent tines in the two rows is 20cm . This arrangement reduces the chances of leaving soil with out plowing. The distance between the two rows was 35cm. each tines was fixed on the frame at angle of 60^{o} (rake angle). The shank of the tine was provided with foot of 15cm length and 10cm width. The attack angle of the front of the foot was 30^{o}. The foot was provided with wings of 8cm wide and there inclination angle with horizontal line is 30^{o} to facilitate the soil penetration during the plowing operation.

The rear part consists of two rotors. These two rotors fixed on the frame by two bearings. One bearing fixed at each end of the cylinder to let the rotors move freely during the plowing operation. The rotor consists of a cylinder of 12.5cm diameter ten groups of blades. Each group includes three blades. The blades of the groups were fixed at alternative position with that in the neighboring groups on both sides. The groups on both rotors were also fixed at alternative position to let the rotors cover the total width of the plow. The distance between the groups on one rotor is 18cm. and on the two rotors is 9cm. The distance between the front and the rear rotors is 52cm. The blades of the end groups on both rotors were

fixed in a way that there width is parallel to the axle of the cylinder to help in rotating the rotors in the field when the plow working in the soil.

2.2 The conventional plow

The conventional plow consists of frame and five tines. During the experiments in the field the rotors were dismantle from the modified plow to converted it to conventional plow and this means the same tines used in the experiments and that render the comparison more real than using another chisel plow where the mechanical description could not same.

2.2 The specific energy

The specific is the energy required by the plow in field to cut, pulverize and mix or turn up the soil. The specific energy was calculated by the following equation:

SE= [F/A]x [m/m]

Where:

SE= specific energy (kJ/m^3)

F= draft force (kN)

A=working width of the plow (m)x working depth (m)

To convert the draft force per unit area (kN/m^2)to energy in kJ per cubic meter (m^3) the above equation should be multiplied and divided by distance of one meter (m).

2.3 The equivalent energy

The equivalent energy is the energy required to pulverize the soil only which regarded as useful energy and some time is called the soil pulverization energy. It was measured in laboratory. The method which

was proposed by [6] was used to estimate the soil pulverization energy. Different sizes of soil blocks were collected from the field after the plowing operation and left in the laboratory to dry up. The weight of each block was measured separately.

Each block was dropped from height of 80cm and the resulted smaller blocks were collected and passed through sieves of different sizes and the Mean Weight Diameter(MWD) was calculated as shown in part(1). The energy required to pulverize the block was calculated as in following equation:

$Q=M*g*Z$

Q= the potent ional energy (kJ)

M= mass of the dropped block (kg)

Z= height of dropping the block (80m)

The collected blocks from the first drop of the block were through again from height of 80cm and the same calculations were repeated. The energy required to pulverize the soil from the second drop was calculated from the following equation:

$Q=2*M*g*Z$

The same method was repeated ten times until the soil block was pulverized to the sizes less than. A sample that found in the field from calculation is shown in table (1).

The calculated values of the pulverization energy (Q) in kJ/kg were changed to kJ/ ton and were drawn versus MWD in figure ( ). MWD which was obtained from the field was used to obtain the energy required to pulverize the soil in the field. And that was done by projecting the values of MWD (values of the field) on the line represents the

relationship between MWD and Q (fig.2). The corresponding values of Q on the Q-axis in (kJ/ton) was multiplied by the by the bulk density value in (ton/kg) to obtained the equivalent energy in kJ/kg which represent the energy required to pulverize the soil in the field only.

Table (1): The results of the laboratory experiments showing the equivalent energy (pulverization energy) kJ/ton and the mean weight diameter for soil block of 23.16kg.

Number of drops of soil block	Pulverization energy (kJ/kg) (Q)	Pulverization energy (kJ/ton) Q*1000/23.16	Mean weight diameter (MWD) (mm)
1	0.1817	7.84	146.33
2	0.3634	15.69	136.00
3	0.5451	23.53	98.02
4	0.7268	31.38	71.96
5	0.9080	39.33	69.22
6	1.0900	47.07	62.22
7	1.2720	55.91	51.95
8	1.4535	63.76	41.72
9	1.6353	71.60	38.12
10	1.8170	78.45	23.16

2.4 The energy utilization efficiency

The energy utilization efficiency was calculated by the following equation:

η=[EQE/ SPE]

where EQE= the equivalent energy (kJ/m^3)

SQE= the specific energy (kJ/m^3)

2.5 Soil properties

The soil properties such as the soil texture, moisture content, penetration resistance, cohesion and angle of internal friction were measured. The soil texture was measured by the pipette method. The moisture content was measured across the field of the experiments for depths of 0-10, 10-20, 20-30cm using the core sample method and the measurements were repeated three times for each depth. The soil penetration resistance was measured by a hydraulic penetrometer for the same previous depths. The soil cohesion and angle of internal friction were measured by annuls ring. The results are shown in table (2).

Table (2): soil mechanical and physical properties

Depth (cm)	Moisture content %	Bulk density (ton/m^3)	Cohesion (kN/m^2)	Angle of internal friction (Φ)	Cone Index Cn (kN/m^2)	Adhesion c_α (kN/m^2)	Angle of friction between soil and metal δ
0-15	12.61	1.18	8.25	34.12	1951.62	0.65	28.44
0-20	12.28	1.27	12.50	33.62	2243.20		
0-20	17.62	1.30	16.70	29.10	3326.50		

3.0 Results and Discussions

3.1 the Specific energy

The specific energy is the energy required by the chisel plow to cut, disturb and pulverize the soil. The specific energy decreased slightly as the operating depth increased (fig.3). This means the amount of increase in the volume of the soil with the operating depth was greater than that in the specific energy required by the modified chisel plow to perform its work in the field. This also means at deeper operating depth more energy was diverged to the useful work and less energy for parasite work. Also at deeper operating depth the great volume of soil reduce the plow forward speed and that reduce the energy used to accelerate the soil particles.

For the three chisel plow combinations (CP, CP+R and CP+2R) the specific energy of the modified chisel plow combinations (CP+R, CP+2R) were higher than that for the conventional chisel plow (CP). The reason was that the rotors required more energy to break the soil clods up and the rotation of the rotors also required energy to overcome the soil resistance on them. However, the difference in the energy requirement decreased as the operating depth decreased, for example at operating depth of 15cm the specific energy of CP, CP+R and CP+2R is 102,106.2 and 114.2kJ/m^3 but at the operating depth of 25cm the specific energy is 88.2, 91.8 and 93.1kN/m^3 respectively.

The specific energy of CP, CP+R and CP+2R increased slightly with the forward speed of the chisel plow.(fig.4) The forward speed increased the soil particles acceleration and that required more energy. The specific energy of the three combinations is CP+2R>CP+R>CP. The higher

specific energy of the modified chisel plows weather with two rotors or one rotor was because the extra energy is required to pulverize the soil clods as well as there are many pulverizing blades working in the soil at the same time which face grater resistance from the soil and that required more energy to overcome the is resistance. However, despite of the slight increase in the specific energy of CP+R and CP+2R but the soil pulverization was great which surpasses the increase in the energy.

3.2 Equivalent energy

The equivalent energy is the energy used for pulverizing the soil only in the field and can be used as an indicator to evaluate the performance of the chisel plow.

The equivalent energy is calculated from the result obtained in the laboratory (kJ/ton) using MWD of the field and multiplied by the soil bulk density in ton/m^3. The results showed that the equivalent energy was less than the specific energy and that was because the specific energy includes the energy spent in cutting, disturbing and turning the soil up , however the last operation is limited in case of the chisel plow, and these cases required a great deal of energy especially when the soil cohesion and friction are high and that occurred when the soil is hard or wet.

The equivalent energy of CP+R, CP+2R was higher than that for CP and that was because the first two chisel plow combinations used more energy for soil pulverization than CP (fig. 5). For example, at the operating depth of 15cm the equivalent energy of CP+2R, CP+R and CP is 97.36, 82.80 and 58.22kJ/m^3 respectively. However the specific energy is 102.12, 106.30 and 114.28kJ/m^3 which were higher by 4.7%, 22.2% and 49.1% respectively. However, the equivalent energy increased as the

operating depth increased and that was because the collusion and the squeeze action between the soil clods increased due to the greater volume of the soil which increased the soil pulverization and that required grater energy to conduct these operations. And this can be seen clearly from the results, for example, at operating depth of 15cm the equivalent energy of CP+R is 89.38, 82.80 and 74.25kJ/m^3 respectively.

The forward speed increased the equivalent energy of the modified chisel plow combinations compared with that of the conventional plow (fig. 6). It was 42.22kJ/m^3 for CP while there are 55.20 and 70.55kJ/m^3 for CP+R, CP+2R respectively.

2.4 The energy efficiency

The energy efficiency is the ratio between the equivalent energy and the specific energy. The energy efficiency decreased slightly as the operating depth increased (fig. 7) and that was because the specific energy increased with operating depth due to the higher resistance showed by the greater volume of the disturbed soil to the plow movement. Also the friction between the soil and the plow increases because the high confine pressure created by the great volume of the soil cumulated in front of the plow. However the small reduction in the energy efficiency due to the increase in operating depth is accomplished by increase in soil pulverization.

The combinations of the modified chisel plow (CP+R, CP+2R) had greater energy efficiency than the conventional chisel plow (CP) by 27.22% and this because the rotors increased the ability of the modified chisel plow combinations to use the energy. CP+2R had greater energy efficiency than CP+R but with small difference.

The energy efficiency increased for CP+2R, CPR and CP as the forward speed of the plow increased (fig. 8). However the energy efficiency for CP+R and CP+2R was greater than that for CP, it was 73.59% for CP+R and CP+2R and 47% for CP. It increased to 60%, 81% and 88% for CP, CP+R and CP+2R when the forward speed increased to 1.1m/sec respectively.

The results showed clearly that the modified chisel plow surpassed the conventional chisel plow in energy efficiency and the addition of the rotors increased the energy efficiency by 46.6% compared with conventional chisel plow and the soil pulverization by 140.7% and this means the rotors improved the field performance clearly.

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دراسة حقلية لأداء المحراث الحفار المطور من متطلبات الطاقة النوعية والمكافئة والكفاءه على استهلاك الطاقة

***شاكر حنتوش عداي **عقيل جوني ناصر**
قسم المكننة الزراعية / كلية الزراعة / جامعة البصرة
*Email: shaker.h.1953gmail.com
**Email: aqeelwafi@gmail.com

تم تطوير المحراث الحفار الاعتيادي بإضافة منعمتين له خلف الأسلحة الحفارة وتم تقيم أداءه الحقلي من خلال متطلبات قوة السحب وقابليته على تفتيت التربة مقارنه مع المحراث الحفار الاعتيادي في الجزء الاول (part1) ويقيم هذا التطوير مرة أخرى باستخدام الطاقة النوعية والمكافئة و الكفاءة على استخدام الطاقة ومن خلال استخدام أعماق حراثه مختلفة (15و 20 و 25 سم) وكذلك سرع امامية مختلفة وهي (0.3 و 0.5 و 0.88 و 1.1 م/ثا)

أظهرت النتائج زيادة الطاقة النوعية (الطاقة التي يحتاجها المحراث لقطع وتفكيك وخلط التربة) للمحراث المطور عند أضافه المنعمات آليه مقارنه مع المحراث الحفار الاعتيادي ، أذ زادت من 102 كيلو جول/م3 للمحراث الحفار الاعتيادي الى 114.2,106.2 كيلوجول /م3 للمحراث الحفار المطور وباستخدام منعمه أو منعمتين على التوالي للعمق (15سم) ألا أن زيادة العمق من 15سم الى25سم أدى الى خفض الطاقة النوعية للمحراث المطور من 114.2و106.2 كيلو جول/م3 الى 93.1 و91.8 كيلو جول/م 3بأستخدام منعمه أو منعمتين على التوالي كما أدت زياده السرعة الامامية الى زياده الطاقة النوعية للمحراث الاعتيادي والمطور ولكن بمقدار أكبر للمطور منه للاعتيادي أما الطاقة المكافئة والتي تستخدم لتفتيت التربة فقط ، فقد انخفضت للمحراث المطور مقارنه بالمحراث الاعتيادي، أذ انخفضت من 97.36 للاعتيادي الى 58.23 و82.8 كيلوجول /م3 للمطور المزود بمنعمه ومنعمتين عند العمق (15سم) ، كما انخفضت الطاقة المكافئة مع زياده العمق للمحراث المطور مقارنه بالمحراث الاعتيادي .

أما كفاءه أستخدام الطاقه وهي أفضل معيار لقياس الاداء الحقلي فقد زادت للمحراث المطور بنسبه 27% مقارنه بتلك للاعتيادي عند العمق 15سم وزادت الى 44% عند العمق 25سم وهذا يعتبر تطوراً كبيراً بأداء المحراث المطور كما أدت زياده السرعه الامامية الى زيادة كفاءه المحراث المطور على أستخدام الطاقه من 25.4% عند السرعه 0.3 م/ثا الى 88.8% عند السرعه 1.1م/ثا وكليهما أعلى من تلك للاعتيادي بمقدار 28.8% .

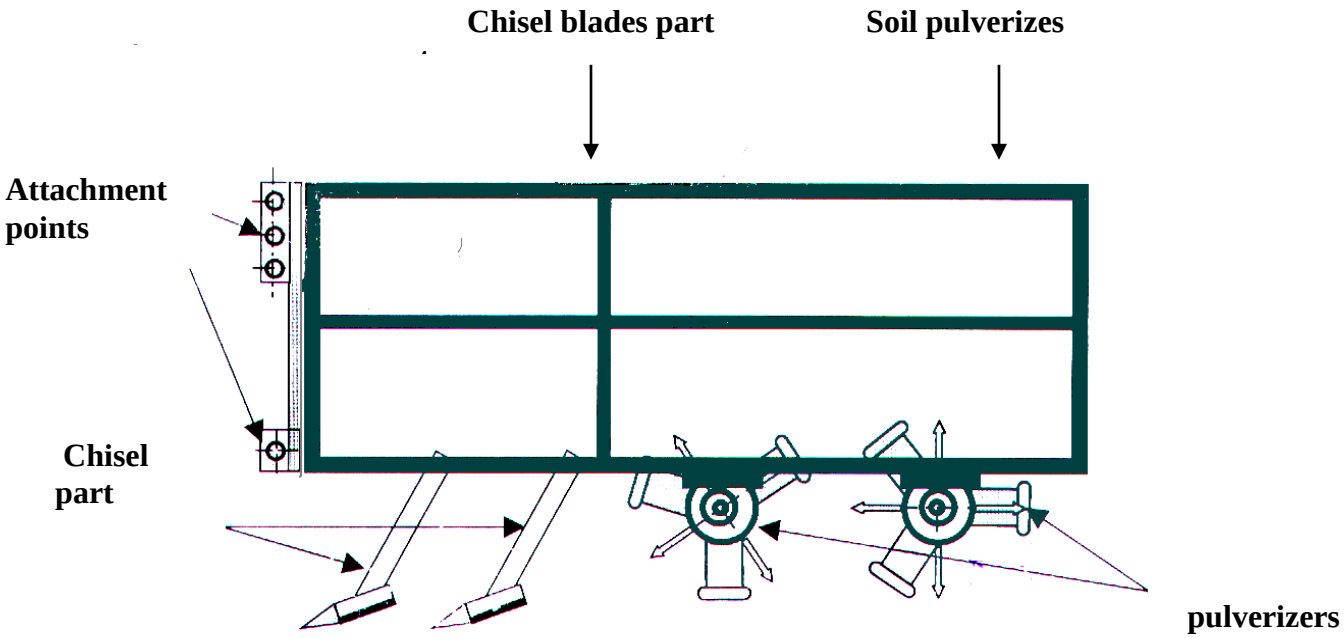


Figure (1A) : The modified chisel plow (Side view)

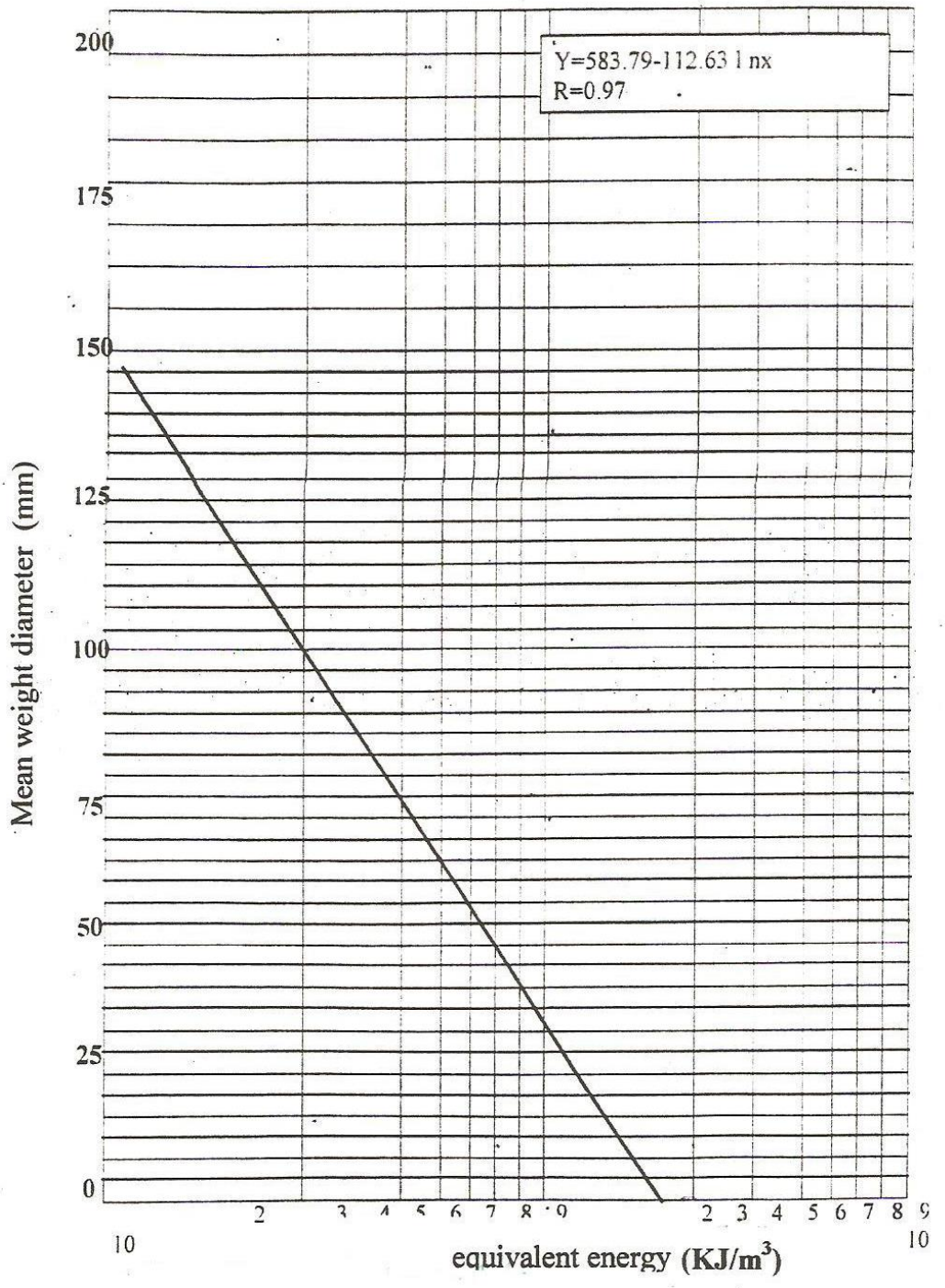
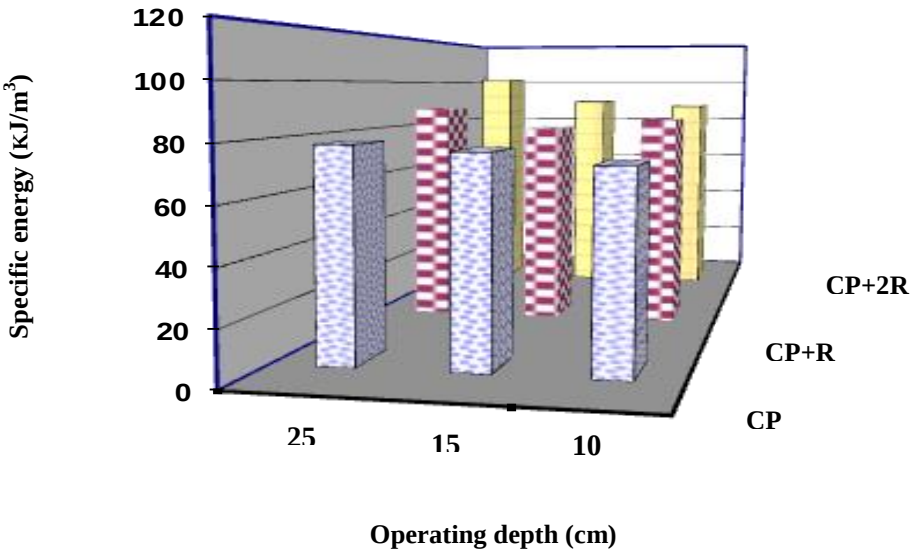


Figure (2): The relationship between equivalent and mean weight diameter



Figure(3):The Specific energy versus the plowing depth of three chisel plow combinations

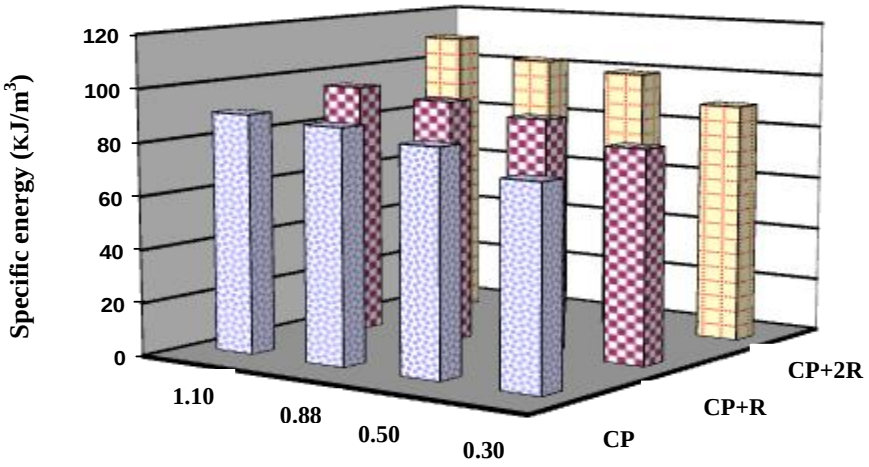


Figure (4):The Specific energy versus plow the forward speed for three chisel plow combinations

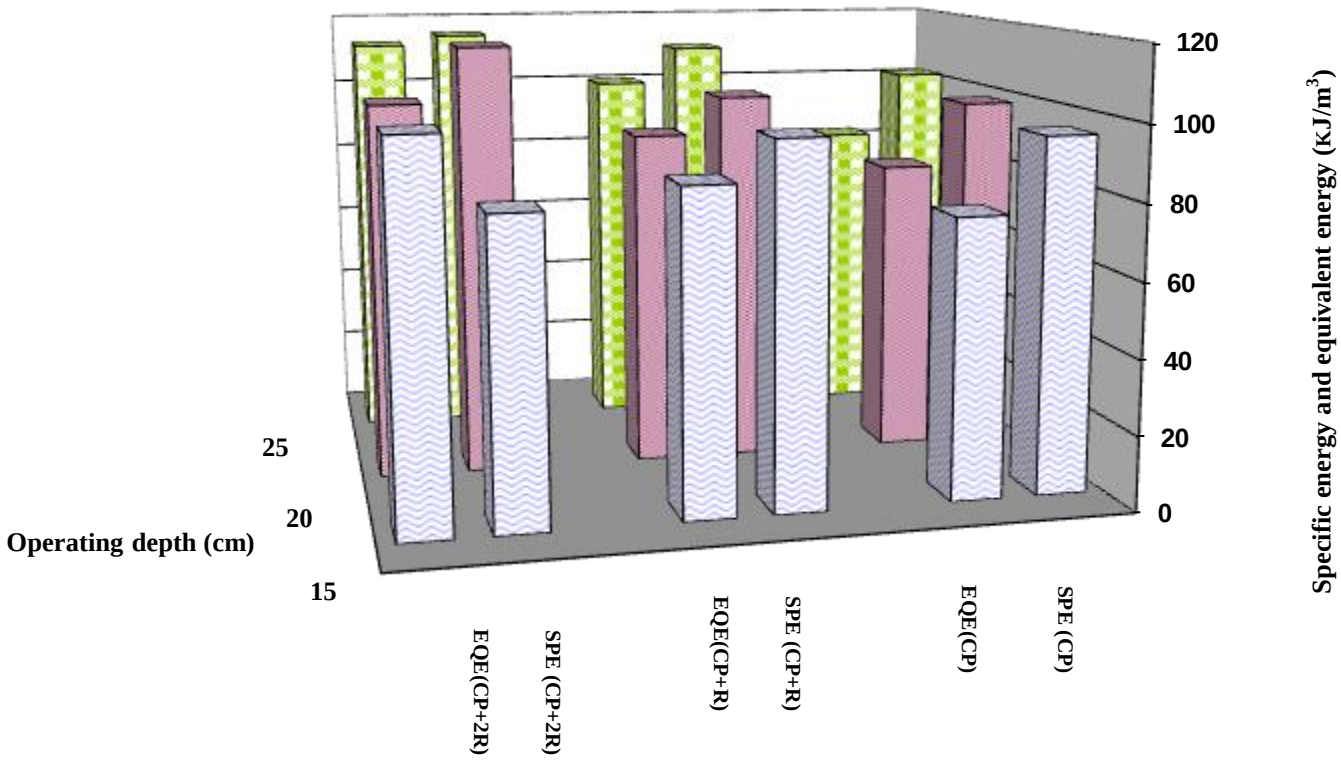


Figure (5) : The operating depth versus the equivalent energy for three chisel plow combinations

- **Equivalent energy**
- **Specific energy**

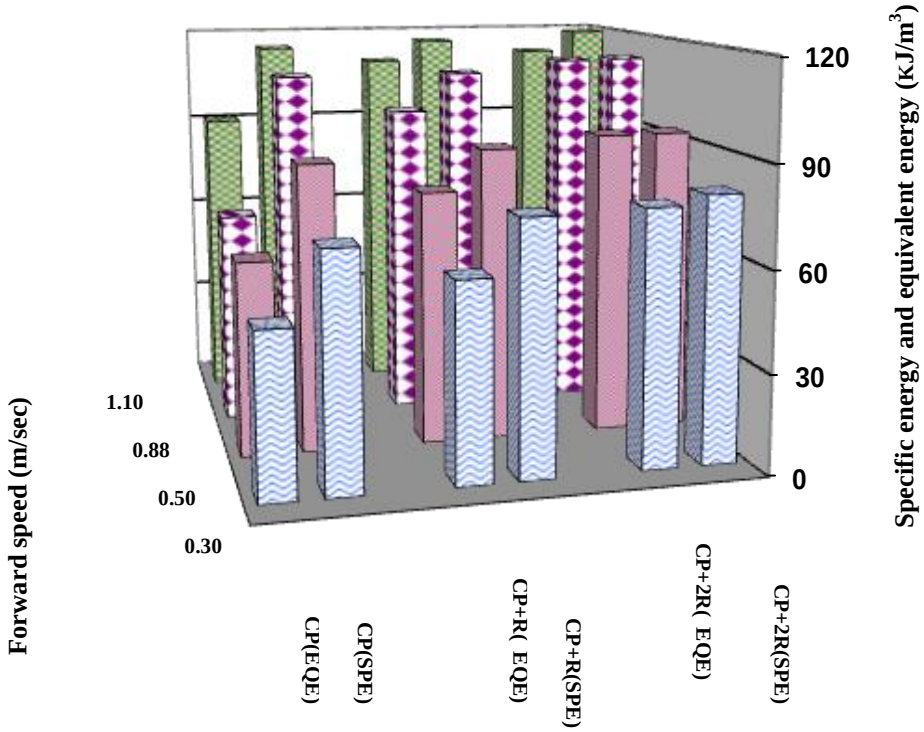


Figure (6):The forward speed versus the equivalent energy for three chisel plow combinations

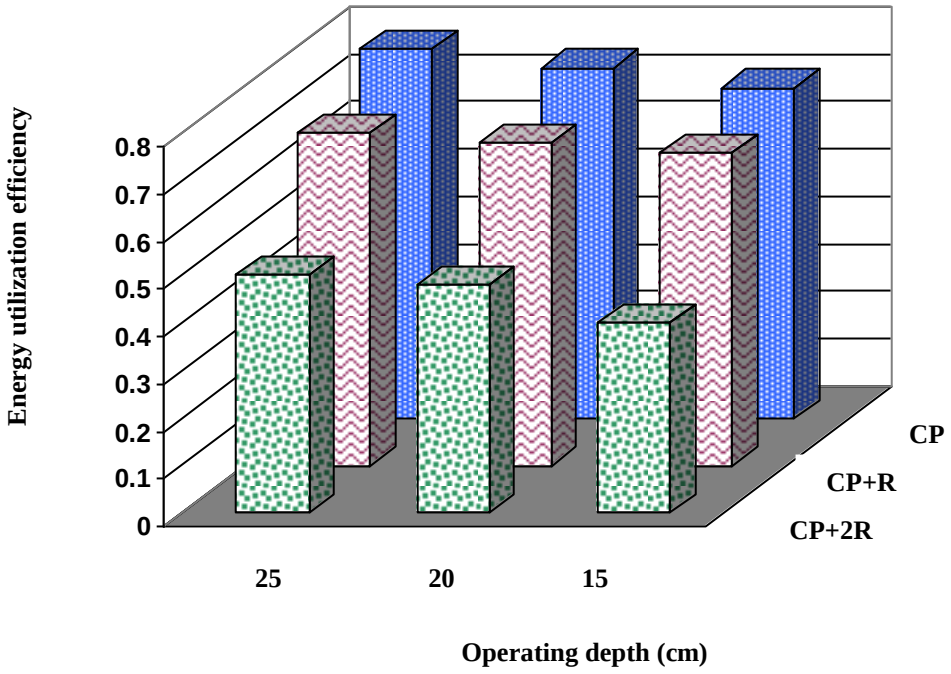


Figure (7) : Energy utilization efficiency versus the operating depth for three plow combinations

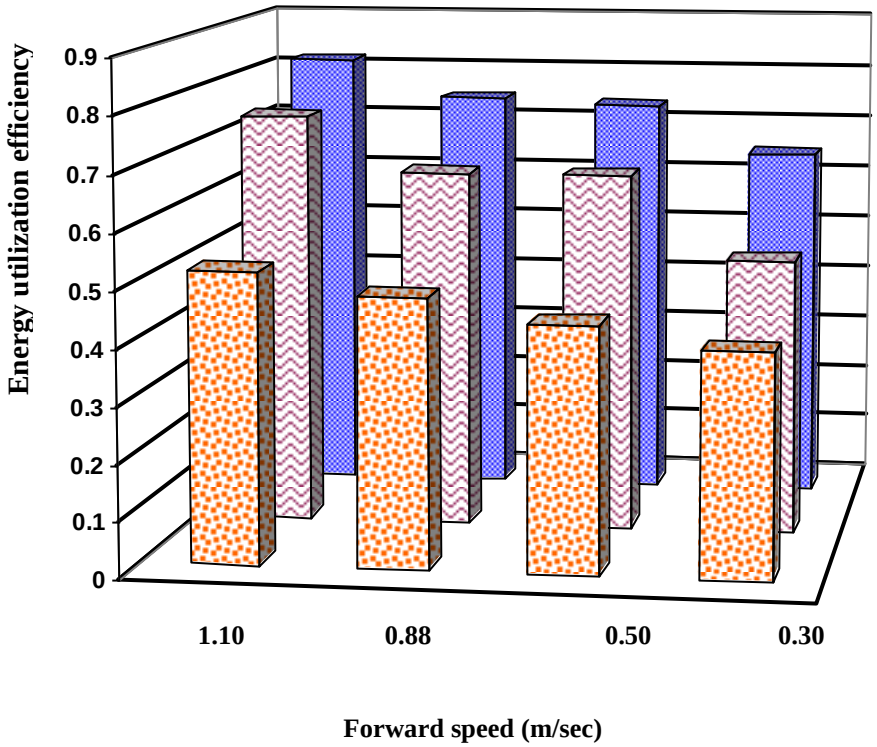


Figure (8) : Energy utilization efficiency versus the forward speed for three plow combinations