Tikrit Journal for Agricultural Sciences
ISSN:1813-1646 (Print); 2664-0597 (Online)
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq

TJAS
Tikrit Journal for Agricultural Sciences

DOI: https://doi.org/10.25130/tjas.25.1.2

Evaluation of the performance of developed combined plowing machine under different operation circumstances

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KEY WORDS:
Plowing Machine; Pulverization Index; Soil Moisture; Plowing Depth; Draft Force; Disturbed Area

Received: 01/04/2024
Revision: 30/09/2024
Proofreading: 26/12/2024
Accepted: 13/03/2025
Available online: 31/03/2025

ABSTRACT

Field experiments were conducted at the Agricultural Research Station of the College of Agriculture, University of Basrah, in Al-Hartha District, Basrah Governorate, to study the effect of soil moisture and plowing depth on the performance of a soil plowing machine consisting of a subsoiler plow, two shallow tins with wings on the outside, and addition to a disc harrows, including requirements draft force, soil disturbance, and Mean Weight Diameter (MWD). The machine has an important role in the plowing operations and preparing for agriculture in one operation, this will lessen the traffic times and the other economic works, the subsoil plowing, and the fragmentation of soil. The machine was used with and without discs for three levels of soil moisture content (SMC) (9, 18, and 28%), and three plowing depths (40, 50, and 60cm). The experiments were applied using a randomized complete block design (RCBD) of a factorial experiment (3 x 3 x 2) with three replications. The results showed a variation in the requirements of the draft force when the SMC changes, the values of draft force were 33.3, 32.64, and 31.66kN for the SMC of 9, 28, and 18%, respectively. Adding discs had a significant effect on the draft force it increased by 1.11kN. The draft force increased when the plowing depth was increased, the depth of 60cm gave the highest value of 35.92kN. The SMC of 18% was recorded as the largest disturbed area at 0.42m2 and the least MWD by 31.59mm, followed by the SMC of 28% and then 9%, it was the least disturbed area at 0.38 and 0.35m^2, and MWD by 40.25 and 38.65mm respectively. The depth of 60cm is recorded as the largest disturbed area of 0.51m^2, and MWD 30.59mm. The addition of discs decreased the MWD by 6.9 mm compared to the absence of discs.

تقييم الأداء الحقلي لآلة حراثة مركبة تحت ظروف تشغيل مختلفة

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الخلاصة

أجريت تجارب حقلية في محطة الأبحاث الزراعية التابعة الى كلية الزراعة جامعة البصرة في قضاء الهارثة محافظة البصرة، لدراسة تأثير رطوبة التربة وعمق الحراثة على أداء آلة حرث التربة المتكون من محراث تحت سطح التربة ومحاريث ضحلة عدد اثنان مزودة بأجنحة من الجهة الخارجية إضافة الى امشاط قرصية، لدراسة متطلبات قوة السحب، مساحة التربة المفككة ومعدل القطر الموزون (MWD) لما للآلة المركبة من دور مهم في عمليات الحرث واعداد التربة للزراعة في عملية واحدة وهذا الامر سوف يقلل من عدد مرات المرور فضلا عن الأمور الاقتصادية الأخرى الحراثة العميقة والتنعيم. اذ استخدمت الآلة مرة مع أقراص للتنعيم واخرى بدون أقراص لثلاثة مستويات لرطوبة التربة (9، 18، 28%) وثلاثة أعماق حراثة (40، 50، 60 سم). طبقت التجارب باستخدام تصميم القطاعات العشوائية الكاملة (RCBD) للتجربة عامليه (3×3×2) وبثلاثة مكررات. أظهرت النتائج اختلافاً في متطلبات قوة السحب عند تغير المحتوى الرطوبي للتربة، وكانت قيم قوة السحب 33.3، 32.64، 31.66 كيلو نيوتن للمستويات الثلاث 9، 28، 18% على التوالي. ادى إضافة الأقراص الى زيادة قوة السحب اذ زادت بمقدار 1.11 كيلو نيوتن. وازدادت قوة السحب بزيادة عمق الحراثة اذ أعطى العمق 60 سم أعلى قيمة بلغت 35.92 كيلو نيوتن. سجلت نسبة الرطوبة 18% أكبر مساحة مفككة بلغت 0.42 م2 وأقل معدل قطر موزون بمقدار 31.59 ملم، تلاها المستويين 28% ثم 9%، وكانت المساحة المفككة 0.38 و0.35 م2، ومعدل قطر موزون بلغ 40.25 و38.65 ملم على التوالي. بينما سجيل عمق الحراثة 60 سم أكبر مساحة مفككة بلغت 0.51 م2، ومعدل قطر موزون 30.59 ملم. أدى اضافة الأقراص إلى تقليل معدل القطر الموزون بمقدار 6.9 ملم مقارنة بالألة التي لا تحتوي على أقراص.

الكلمات الافتتاحية: آلة الحراثة، دليل التفتيت، رطوبة التربة، عمق الحراثة، قوة السحب، مساحة التربة المفككة.

INTRODUCTION

The soil of southeastern Iraq, especially Basrah Governorate, is classified as heavy soil in which clay minerals are predominant. The soil clay is characterized by the formation of solid, compact layers that hinder the spread of plant roots. (Fitzpatrick & Land, 2004; Al-Marsoumi & Al-Jabbri, 2007).The compaction of the heavy soil is created naturally or as a result of the passage of machines (Botta *et al*., 2009). Appear of a hardpan lead to disturbs root growth and its permeation of subsoil layers lowering growth for the plants (Bengough *et al*., 2011; Schneider *et al*., 2017). The tillage must be performed at a depth that includes the hardpan layer formed within the soil layers to ensure the tillage operation is performed at a depth appropriate (Tekeste *et al*., 2020; Xiaofang Yu *et al*., 2023). The hardpan locating from the measured test of the cone penetration and bulk density for the average depth where the hardpan layer begins to appear, and that a successful plowing operation should include breaking the hardpan in soil (Tekeste *et al*., 2008; Kim *et al*., 2020; Ruiwen Hu *et al*.,2024). The conduct of tillage operations takes place within the moisture levels in which the soil is in a fragile state to exploit the available power and the soil is also at its weakest strength (Javadi & Hajiahmad, 2006,). The process of the tillage sometimes produces rather large dirt blocks, so it requires the use of secondary equipment for tillage. The use of this equipment has negative effects, such as compacting the soil and breaking up the soil into fine particles to the point where it is deposited below the surface of the soil. (Prem *et al*., 2016), causing an increase in the bulk density of the soil and the formation of solid layers, as well as the exploitation of time, effort, and economic cost in conducting smoothing operations after tillage (de Lima *et al*., 2017; Sarkar *et al*., 2021) .

Many factors affect the draft force of agricultural machinery, especially the primary soil tillage equipment, such as the design and area of the cutting tool, some are related to the soil such as soil texture and moisture, and some are related to the tool and soil such as depth and width of work, and it is related to the source of pulling and practical speed (Bainer *et al*., 1956; Naderloo *et al*., 2009; Igamberdiyev & Usmanova 2024). The moisture content of the soil effect significant in the draft force for the subsoiler plow, the driest soil recorded the highest while the lowest value when moist soil and increased when the soil became wet (Raper & Sharma, 2002). (Arvidsson *et al*., 2004) Found the draft force for the chisel plow was dependent on soil moisture content which increased in dry soil and decreased in moist soil than wet soil, while at disk harrow the draft increased with increased soil moisture.The draft force increases with increased depth of tillage as proven by many researchers (Naderloo *et al*., 2009; Askari *et al*., 2016; Usaborisut & Prasertkan, 2019; Sadek *et al*., 2021). A one important factor for the disturbed area and tilling appearance of soil it's soil moisture. (Manuwa & Ademosun, 2007) noted to increase the disturbed area with increased soil moisture cusses and increased rupture distance for front soil. (Salar *et al*., 2013) funded a significant effect of soil moisture on disturbed areas because of generating soil failure patterns outer cutting in edge of the shank. Disturber area increment depending on depth when using a narrow tine because it makes cracks in the soil front and side of the cutting tool (Aday & Ramadhan, 2016; Gebregziabher *et al*., 2016).

The research aims to study the effect of soil moisture content and plowing depth in evaluating the performance of the combined machine for soil plowing in the surface layers and dissociation of the layers under the soil surface in terms of the requirements of draft force, the disturbed area, and Mean Weight Diameter.

MATERIAL AND METHODS

The machine used in the experiments

The machine consists of a structure fixed in the front of two chisel plows provided with wings on the outside of the shear tool, the width of which is 20cm, followed by a subsoiler plow with a distance of 36cm. The depth of the Chisel plows is 80% of the subsoiler plow depth, the rear of the machine is connected with seven discs with a diameter of 45cm installed on an axis associated with the structure by two arms in an arc so that its depth is always constant and does not affect the depth of the machine, can be folded over during transportation Figure (1).

Afield experiments:

The experiments were carried out in soil unused agricultural, during the months (of February, March, and May 2022, at the Agricultural Research Station of the College of Agriculture, University of Basrah, in Al-Hartha District, Basrah Governorate). The initial characteristics of the soil were measured for depths 0 - 60cm for each 10cm depth. The average values were taken to represent the initial characteristics (Table 1) and consistency limits (Figure 2) of the soil experiment. The plowing process was carried out on 20m length lines, a distance of 5m for the plowing was left as free space to reach the specified depth, and then the data were taken. The experiments included studying the following factors:

Figure (1) picture of the machine (A) with discs and (B) without the discs

1- three levels of field soil moisture 9, 18, and 28%.
2 - three plowing depths depending on the depth of the subsoiler plow: 40, 50, and 60cm.
3 - pulverization disc: The machine was used with and without the discs.

Experiments were applied using a randomized complete block design (RCBD) of a factorial experiment (3 x 3 x 2) with three replications. The Gen Stat program was used to analyze the data statistically, and the averages of the coefficients were compared with the LSD test at the probability level of 0.05.

Table (1) the initial properties and texture of soil field

Date	Moisture content %	Bulk density Mg m^{-3}	Con index kN m^{-2}	Cohesion kN m^{-2}	adhesion kN m^{-2}	Texture %	
February	28.00	1.25	1648.31	16.25	0.35	Sand	7.16
March	18.00	1.27	1442.2	17.34	0.28	Silt	38.50
May	9.00	1.20	1896.22	18.22	0.16	Clay	54.34

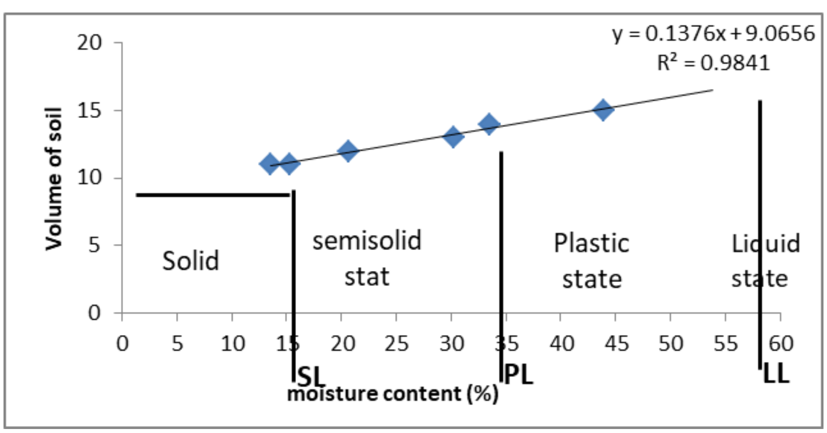

figure (2) the consistency limits of soil
where SL= solid limit, PL= plastic limit, LL= liquid limit

Measurements and data collection

1 - Draft force

A load cell device was used to measure draft force. The tractor MF 2680 had a four-wheel drive, a power engine of 97kW, the engine fixed at 1500RPM, a forward speed of 0.34m/s, used to pull another tractor 52kW, a two-wheel drive, which was left on neutral used to control the depth of the machine through the hydraulic system.

The disturbed area

The disturbed area of soil was calculated by removing the soil plowed from the plowing line, as shown in Figure (3). Where, the width of the plowed soil area from the up of soil surface (S), the depth of the compression failure (dc) from the crescent failure of soil (du), and the width of the bottom of the plowed section under the foot of the subsoiler plow (w), the total depth of the machine (d). The disturbed area was calculated through the equation (1).

A=S*dc + w*d …… (1)

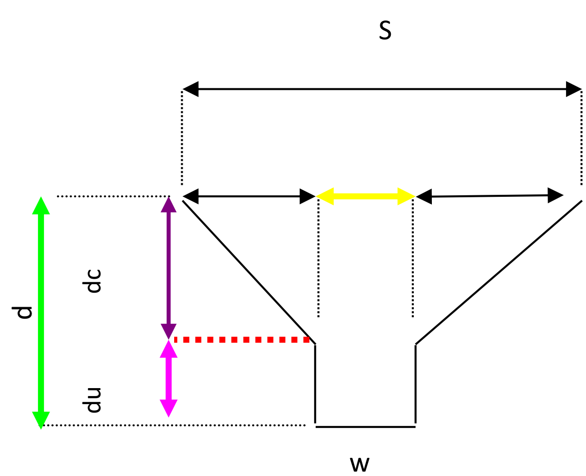

Figure (3) geometric section to soil disturbed

The mean weight diameter

After plowing random samples were taken from the line of plowing reaching working depth. The samples were sieved through a set of sieves of different sizes 120, 90, 50, 30, 10, and 2mm. The MWD was calculated by using equation (2) by Gill and Mecreey (1960).

$$Xi = \sum_{i=1}^{n} \frac{Wi * M}{W} ....(2)$$

where: MWD = mean weight diameter (mm); Wi = weight of the soil remaining between two connect sieves (kg); W= total weight of the soil sample (kg); M= mean diameter of two connect sieves meshes (mm).

RESULTS AND DISCUSSION

Table (2) shows that there is a significant effect of the moisture content (SMC) in the draft force. Figure (4) shows the variation in the draft force when the SMC changes. The highest draft force of 33.30kN was recorded at the SMC 9% then decreased by 5.16 and 1.99% at SMC 18 and 28% respectively.

Table (2) Analysis of variance for components of the draft force, disturbed area, and MWD

S. O. V	df	draft force	disturbed area	MWD
SMC	2	69.46**	698.17**	2029.15**
depth	2	1129.53**	6438.31**	3590.54**
discs	1	94.93**	0.00ns	3408.28**
SMC× depth	2	13.85ns	77.38**	461.06**
SMC× discs	2	0.15ns	0.00ns	118.56**
depth× discs	4	2.01ns	0.00ns	11.90**
SMC× depth× discs	4	0.09ns	0.00ns	23.42**

** = significant differences at level 0.01, ns = no significant differences.

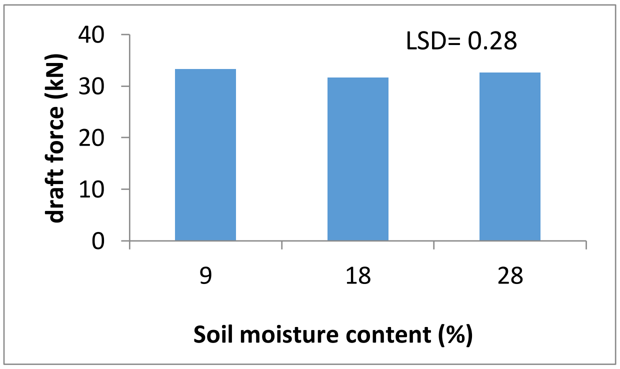

Figure (4) the effect of moisture content on the draft force

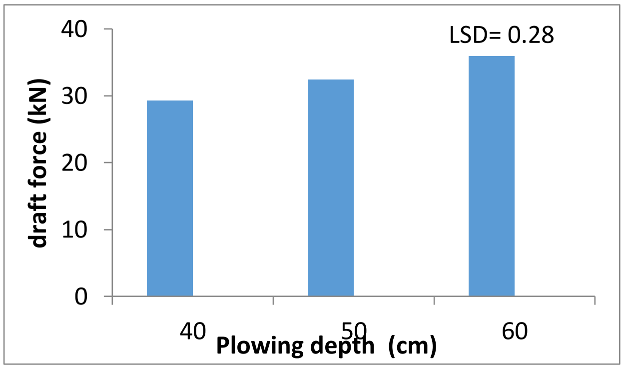

Figure (5) the effect of plowing depth on the draft force

The draft force was increased with increased the depth of plowing. The depth of 60cm recorded the highest force requirement, with a significant increase of 10.89 and 22.67% compared to the depths of 50 and 40cm respectively Figure (5). A significant difference in the draft force with the discs, as the draft force increased by 3.47% Figure (6).

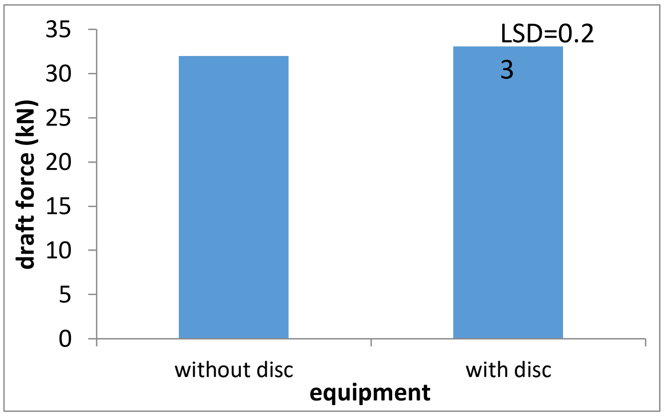

Figure (6) the effect of adding discs on the draft force

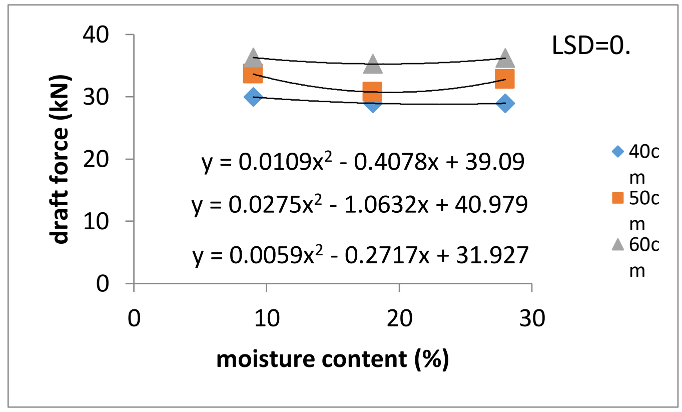

Figure (7) the effect of the interaction between soil moisture content and plowing depth on the draft force

This variation in the draft force is due to the increase in the strength of the soil when the SMC decreases and the cohesion increases when it reaches the contraction limit in which the soil is in a solid state. The increase in depth the strength of the soil increases as a result of the compressive weight of the soil (Al Nuaimi & Al Rijabo 2020). when the SMC is 18% the soil is in a friable state, before reaching the plastic limits, the strength of the soil is as weak as possible at this level of moisture as a result of enveloping the soil particles with moisture films. With the increase in the SMC to 28%, the soil becomes closer to the plastic limits which increases the strength of the adhesion of the soil with the machine and then increases the draft force (Wang *et al*., 2020). many researchers have mentioned that the draft force increases with increasing depth and the soil moisture content (Aday, 2019; Askari *et al*., 2017; Godwin *et al*., 2007) .

The interaction between the SMC and the depth of plowing caused a significant difference in the draft force, as shown in Figure (7) the increase in the draft force with the increase in plowing depth and the decrease in SMC. In general, at the same depth of plowing the draft force decreased at the SMC at 18%, and the draft force increased with the increase in SMC To 28%. The highest value of the draft force was 36.19kN recorded at a depth of 60cm and an SMC9%. While the SMC18% recorded the least draft force by 35.28 kN. the SMC9% and the SMC no significant differences for the required draft force at the depth of 60cm.

The results showed that there are highly significant differences in the disturbed area of soil, as a result of the change in the SMC. The SMC18% was recorded as the largest disturbed area of soil, followed by the SMC28% and then 9%, which recorded the least disturbed area, the disturbed area of soil reached 0.42, 0.38, and 0.35 m2 for the three levels of moisture, respectively Figure (8). The reason for this may be attributed to the weakness of the cohesion forces between the soil particles,(Xu *et al*., 2021). At the SMC18%, in the soil is close to the friable state figure (1), this contributed to the exploitation of available energy in increasing the soil cracks with the contact area with plows. while when the SMC was increased to 28% water films increased around the soil particles, which made the soil close to the plastic state, and thus led to a decrease in soil cracks, which contributed to a decrease in the disturbed area. When the SMC was decreased to 9% The strength of the soil increased as a result of the increased cohesion between the soil particles due to their closeness with each other, which led to the consumption of the available power to overcome the strength of the soil to disintegrate it (Bláhová *et al*., 2013; Xue *et al*., 2018), which caused a decrease in the disturbed area compared at the SMC 18 and 28%.

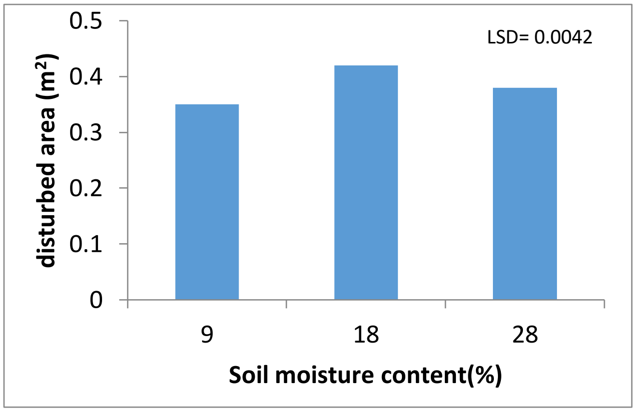

Figure (8) the effect of the moisture content on the disturbed area

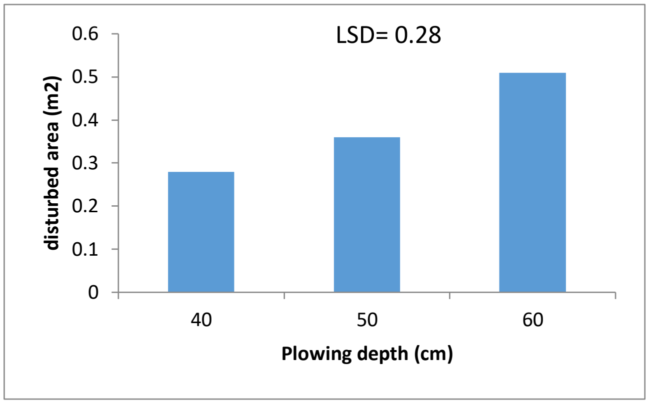

Figure (9) the effect of plowing depth on a disturbed area

The plowing depth significantly affected the disturbed area, the disturbed area increased when the plowing depth increased Figure (9). the largest disturbed area of 0.51 m^2 recorded at the depth of 60cm is, while it was 0.28 and 0.36 m^2 for the depths of 40 and 50 cm, respectively. the reason it's the depth of the shallow plows that operate in front of the subsoiler plow led to a decrease in the suffocating pressure of the soil on the foot of the plow, and thus caused an increase in lateral soil cracks, and then an increase in the crescent failure and the critical depth retreated to the bottom (Aday *et al*., 1993). The interaction between the SMC and the depth of plowing has a significant effect on the disturbed area. The SMC18% with a depth of 60cm was recorded as the largest disturbed area by 0.57m^2, increasing by 0.11 and 0.04 m^2 compared to the SMC 9 and 28% respectively. At the depth of 40cm the disturbed area increased by 0.4 and 0.3 m^2, and at a depth of 50cm by 0.09 and 0.06 m^2 for the SMC 9 and 28%, respectively Figure (10). The SMC had a major effect in reducing the difference in the disturbed area at the three depths by exploiting the available power to loosen the soil with the plows of the machine (Xuening Zhang *et al*. 2024).

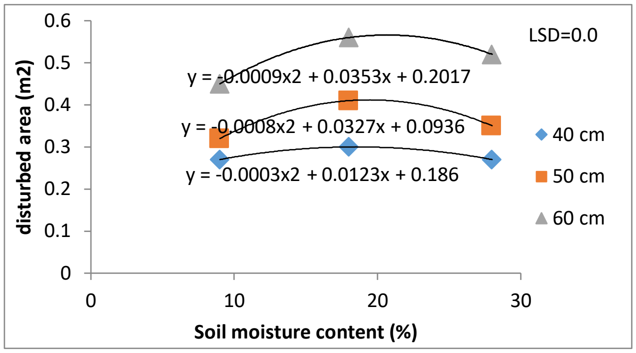

Figure (10) the effect of the interaction between soil moisture content and plowing depth on the disturbed area

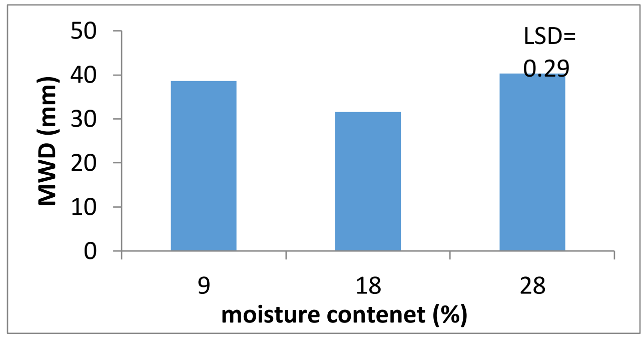

Figure (12) The effect of the soil moisture content on the mean weight diameter

The mean weight diameter (MWD) decreased significantly when the depth of plowing increased in Figure (11), with the depth of 40cm recording the largest MWD values of 42.85 mm, then it decreased by 5.8 and 12.26 mm at the depths of 50 and 60cm, respectively. When increasing the depth of plowing, the volume of the loose soil increased, which led to the impact of the dirt clods with each other, a result of moving the machine which led to an increase in its fragmentation, as well as the contact area between the loose soil and the wings of the feet on the plows of the machine.

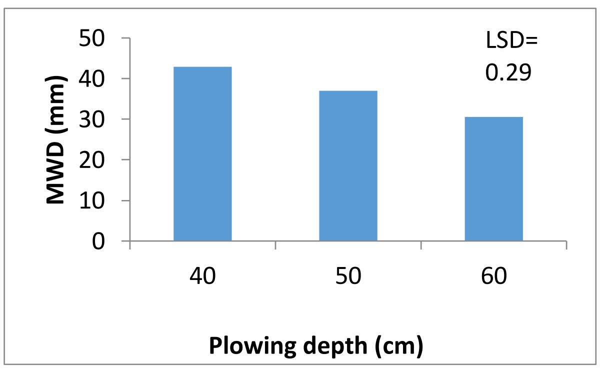

Figure (11) Effect of the plowing depth on the mean weight diameter

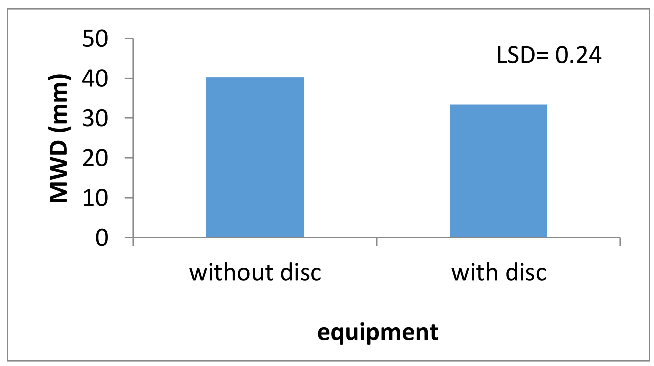

Figure (13) The effect of the discs on the mean weight diameter

The SMC had a highly significant effect on the MWD. The SMC of 28, 9, and 18% gave the MWD of 40.25, 38.65, and 31.59mm respectively Figure (12). This variation in the MWD is a result of the affecting the cohesion forces in the soil. When decreases the SMC as in the first content, or when it increases in the third content. The cohesion forces between the particles of soil increase as a result of the decrease in moisture and its closeness to each other and then large soil clods are formed. But when the SMC increases, the cohesion between the soil clods increases as a result of the film of water enveloping the soil particles (Arvidsson *et al*., 2004; Xu *et al*., 2021; You *et al*., 2017), and then connecting these particles and forming large soil clods as well. At the SMC 18%, the cohesion force was small, which helped in the exploitation of the available energy by the machine in increasing soil pulverization into small clods.

The addition of discs led to a significant decrease in the mean MWD (increased pulverization), as the MWD decreased by 6.9 mm compared to treatment without discs Figure (13), due to the discs in soil fragmentation during the plowing process. These results are consistent with what was found by Kazbek & Vladimir (2023).

The interaction between the depth of plowing, SMC, and discs, the effect was significant ($p<0.01$) in MWD, Table (3) shows the interaction between moisture content and discs, with the SMC 9% for the treatment without discs giving the largest MWD to 41.20mm, while at the SMC of 18% with discs amounts to 28.49 mm, while the interaction between plowing depth and discs, gave the MWD 26.86mm at depth 60cm, and the effect of the interaction between plowing depth, the SMC and discs, was clear in the depth of 60cm and the SMC 18%, the MWD was 25.33mm, while it was 35.71mm without discs for the same SMC.

Table (3) The effect of the interaction between soil moisture content, plowing depth, and disc harrow on mean weight diameter

Moisture %		Tillage depth (cm)			
		40	50	60	Disc& moisture.
Without disc	9	45.53	40.14	37.93	*41.20*
	18	38.98	35.76	29.31	*34.69*
	28	54.72	44.41	35.71	*44.95*
Disc& depth		*46.41*	*40.11*	*34.32*	
With disc	9	38.35	36.01	33.93	*36.09*
	18	32.95	31.16	21.35	*28.49*
	28	46.55	34.82	25.29	*35.55*
Disc& depth		*39.28*	*33.99*	*26.86*	

CONCLUSION

From the results reached, we conclude soil moisture content, plowing depth, and adding discs had a significant effect ($P = 0.05$) on the draft force of the plowing machine, disturbed area, and MWD however. The draft force decreased by increasing Soil moisture content when the soil was at a friable state and increased by increasing plowing depth. A significant influence on MWD with soil moisture content at a friable state. The more influence on decreased MWD at the interaction between the soil moisture content of 18%, and increased plowing depth of 60cm with adding discs.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the staff of the Department of Agriculture Machines and Equipment for their technical and general support.

REFERENCES

Aday, Shaker, Jamal N. Abdulrahman, H. J. A. (1993). Determining the subsoiler critical depth and the factors increasing the deep loosening in heavy soils. *Basrah Journal of Science*, *6 (2)*(February), 261–274.

Aday, S. (2019). *Determining the subsoiler critical depth and the factors increasing the deep loosening in heavy soils*. *February*.

Aday, S., & Ramadhan, M. N. (2016). *Evaluation of the field performance of partially swerved double tines subsoiler in two different soil textures and two levels of moisture contents Part 1*. *June*.

Al-Marsoumi, A. M. H., & Al-Jabbri, M. H. A. (2007). Basrah Soils; Geochemical Aspects and Physical Properties-A Review. *Basrah Journal of Science*, *25*(1C English), 89–103. https://doi.org/10.13140/2.1.1334.3689

Al Nuaimi B. A. M. & Al Rijabo S. A. A. (2020). Design and Manufacture of Chisel Plow Shares and Their Effect on Some Field Performance Indicators. Tikrit Journal for Agricultural Sciences, 20 (1):10-19.

Arvidsson, J., Keller, T., & Gustafsson, K. (2004). Specific draught for mouldboard plough, chisel plough and disc harrow at different water contents. *Soil and Tillage Research*, *79*(2 SPEC.ISS.), 221–231. https://doi.org/10.1016/j.still.2004.07.010

Askari, M., Shahgholi, G., & Abbaspour-Gilandeh, Y. (2017). The effect of tine, wing, operating depth and speed on the draft requirement of subsoil tillage tines. *Research in Agricultural Engineering*, *63*(4). https://doi.org/10.17221/4/2016-RAE

Askari, M., Shahgholi, G., Abbaspour-Gilandeh, Y., & Tash-Shamsabadi, H. (2016). The effect of new wings on subsoiler performance. *Applied Engineering in Agriculture*, *32*(3), 353–362. https://doi.org/10.13031/aea.32.11500

BAINER, R., KEPNER, R. A., & BARGER, E. L. (1956). Principles of Farm Machinery. In *Soil Science* (Vol. 81, Issue 2). https://doi.org/10.1097/00010694-195602000-00021

Bengough, A. G., McKenzie, B. M., Hallett, P. D., & Valentine, T. A. (2011). Root elongation, water stress, and mechanical impedance: A review of limiting stresses and beneficial root tip traits. *Journal of Experimental Botany*, *62*(1), 59–68. https://doi.org/10.1093/jxb/erq350

Bláhová, K., Ševelová, L., & Pilařová, P. (2013). Influence of water content on the shear strength parameters of clayey soil in relation to stability analysis of a hillside in brno region. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *61*(6), 1583–1588. https://doi.org/10.11118/actaun201361061583

de Lima, R. P., da Silva, A. P., Giarola, N. F. B., da Silva, A. R., & Rolim, M. M. (2017). Changes in soil compaction indicators in response to agricultural field traffic. *Biosystems Engineering*, *162*. https://doi.org/10.1016/j.biosystemseng.2017.07.002

Fitzpatrick, R. W., & Land, C. (2004). Changes in soil and water characteristics of natural, drained and re-flooded soils in the Mesopotamian marshlands : Implications for land management planning. *Contract*.

Gebregziabher, S., De Swert, K., Saeys, W., Ramon, H., De Ketelaere, B., Mouazen, A. M., Gebray, P., Gebrehiwot, K., Bauer, H., Deckers, J., & De Baerdemaeker, J. (2016). Effect of side-wings on draught: The case of Ethiopian ard plow (maresha). *Computers and Electronics in Agriculture*, *127*, 131–140. https://doi.org/10.1016/j.compag.2016.06.004

Gill, W. R. & Mecreey, W. F. (1960). Relation of size cut tillage tool efficiency Adric. Eng. 44: 327-374.

Godwin, R. J., O'Dogherty, M. J., Saunders, C., & Balafoutis, A. T. (2007). A force prediction model for mouldboard ploughs incorporating the effects of soil characteristic properties, plough geometric factors and ploughing speed. *Biosystems Engineering*, *97*(1), 117–129. https://doi.org/10.1016/j.biosystemseng.2007.02.001

Grisso, R. D., Yasin, M., Kocher, M. F., R. D. Grisso, M. Yasin, & M. F. Kocher. (1996). Tillage Implement Forces Operating in Silty Clay Loam. *Transactions of the ASAE*, *39*(6), 1977–1982. https://doi.org/10.13031/2013.27699

Igamberdiyev A., & Usmanova G. (2024) Study of soil tillage process from parameters and working depth of the working bod. BIO Web of Conferences 105, 05002. https://doi.org/10.1051/bioconf/202410505002.

Javadi, A., & Hajiahmad, A. (2006). Effect of a New Combined Implement for Reducing Secondary Tillage Operation. *International Journal of Agriculture & Biology*, *8*(6), 724–727. http://www.fspublishers.org

Kazbek A. S. & Vladimir I. K., (2023). Uniformity of the soil tillage depth with tools with disk working bodies. E3S Web of Conferences 398, 01012. https://doi.org/10.1051/e3sconf/202339801012.

Manuwa, S. I., & Ademosun, O. C. (2007). *Draught and Soil Disturbance of Model Tillage Tines Under Varying Soil Parameters*. *IX*, 1–18.

Naderloo, L., Alimadani, R., Akram, A., Javadikia, P., & Zeinali Khanghah, H. (2009). Tillage depth and forward speed effects on draft of three primary tillage implements in clay loam soil. *Journal of Food, Agriculture and Environment*, *7*(3–4), 382–385.

Prem, M., Swarnkar, R., Kantilal, V., Jeetsinh, P., & Chitharbhai, K. (2016). Combined Tillage Tools– A Review. *Current Agriculture Research Journal*, *4*(2), 179–185. https://doi.org/10.12944/carj.4.2.07

Raper, R. L., & Sharma, A. K. (2002). *SOIL MOISTURE DRAFT*. 12–14.

Ruiwen Hu, Bufan Zheng, Yongjun Liu, Shuguang Peng, Jia Gong, Junhui Li, Tian Qin, Jingsong Liang, Kunlong Xiong, Lanjun Shao, Zhongyi Zheng, Zhenxie Yi, Qingming Zhou, Juan Li. (2024). Deep tillage enhances the spatial homogenization of bacterial communities by reducing deep soil compaction. Soil and Tillage Research, 239. https://doi.org/10.1016/j.still.2024.106062.

Sadek, M. A., Chen, Y., & Zeng, Z. (2021). Draft force prediction for a high-speed disc implement using discrete element modelling. *Biosystems Engineering*, *202*, 133–141. https://doi.org/10.1016/j.biosystemseng.2020.12.009.

Salar, M. R., Esehaghbeygi, A., & Hemmat, A. (2013). Soil & Tillage Research Soil loosening characteristics of a dual bent blade subsurface tillage implement. *Soil & Tillage Research*, *134*, 17–24. https://doi.org/10.1016/j.still.2013.07.005

Sarkar, P., Upadhyay, G., & Raheman, H. (2021). *Active-passive and passive-passive configurations of combined tillage implements for improved tillage and tractive performance : A review*. *19*(4), 1–14.

Schneider, F., Don, A., Hennings, I., Schmittmann, O., & Seidel, S. J. (2017). The effect of deep tillage on crop yield – What do we really know? *Soil and Tillage Research*, *174*(June), 193–204. https://doi.org/10.1016/j.still.2017.07.005

Usaborisut, P., & Prasertkan, K. (2019). Specific energy requirements and soil pulverization of a combinedtillage implement. *Heliyon*, *5*(11), e02757. https://doi.org/10.1016/j.heliyon.2019.e02757

Wang, S., Liu, P., Hu, Q., & Zhong, J. (2020). Effect of dispersant on the tangential adhesion strength between clay and metal for EPB shield tunnelling. *Tunnelling and Underground Space Technology*, *95*(October 2019), 103144. https://doi.org/10.1016/j.tust.2019.103144.

Xiaofang Yu, Jiawei Qu, Shuping Hu, Peng Xu, Zhaoxu Chen, Julin Gao, Daling Ma, (2023) The effect of tillage methods on soil physical properties and maize yield in Eastern Inner Mongolia. European Journal of Agronomy, 147. https://doi.org/10.1016/j.eja.2023.126852.

Xuening Zhang, Yong You, Decheng Wang, Zhaoyu Wang, Yangyang Liao, Sibiao Li, (2024). Soil failure characteristics and loosening effectivity of compacted grassland by subsoilers with different plough points. Biosystems Engineering 237, 170-181. https://doi.org/10.1016/j.biosystemseng.2023.12.008.

Xu, X. tang, Shao, L. jin, Huang, J. bin, Xu, X., Liu, D. qi, Xian, Z. xing, & Jian, W. bin. (2021). Effect of wet-dry cycles on shear strength of residual soil. *Soils and Foundations*, *61*(3), 782–797. https://doi.org/10.1016/j.sandf.2021.03.001

Xue, J. F., Ren, A. X., Li, H., Gao, Z. Q., & Du, T. Q. (2018). Soil physical properties response to tillage practices during summer fallow of dryland winter wheat field on the Loess Plateau. *Environmental Science and Pollution Research*, *25*(2), 1070–1078. https://doi.org/10.1007/s11356-017-0684-9

You, Y., He, C., Wang, D., & Wang, G. (2017). Interaction Relationship between Soil and Very Narrow Tine during Penetration Process. *Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery*, *48*(6), 50–58. https://doi.org/10.6041/j.issn.1000-1298.2017.06.006