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Effects of two shapes of teeth spike harrow on soil pulverization index and pulverization depth

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KEY WORDS:
spike tooth harrow; pulverization index; circular and rectangular

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ABSTRACT

The study was conducted in three phases. The first phase involved designing (circular and rectangular) spike tooth harrow implement using SolidWorks software according to the required dimensions and measurements. The second phase included testing and analyzing the stresses affecting the structure of the spike tooth harrow (circular and rectangular) under conditions similar to the field conditions in which the machine operates, using Inventor software and the Finite Element Method (F.E.M).The third phase involved field evaluation in a silty loam soil that had been plowed using moldboard plows, followed by Harrowing with those teeth to break up the clods of soil resulting from plowing and to assess their impact on the depth and of soil pulverization index. The results showed that the circular spike tooth harrow implement recorded the highest values for maximum stress and principal stress, while the rectangular spike tooth harrow implement recorded the highest deflection value. The disc plow significantly outperformed the moldboard plow in recording the highest value for the of pulverization index, while the moldboard plow significantly outperformed the disc plow in recording the highest value for the depth of pulverization. The forward speed of (8.20) km/h significantly outperformed the forward speed of (13.02) km/h in recording the highest values for both the of soil pulverization index and the depth of pulverization. The rectangular tooths outperformed in recording the less and best value the of soil pulverization index. The circular tooth outperformed in recording the highest value the of the depth of pulverization.

تأثير نوعان من أشكال أسنان الأمشاط الزاحفة في مؤشر تفتيت التربة وعمق التفتيت

سلطان جوهر دخيل عبد[1] وعادل أحمد عبدالله رجب[2]
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الخلاصة

أجريت الدارسة على ثلاثةِ مراحل، المرحلةُ الأولى تصميم آلة التمشيط بالأسنان الزاحفة المستقيمة ذات الأشكال (الدائرية والمستطيلة) بواسطة برنامج (Solidworks) حسب الأبعاد والقياسات المطلوبة للتصميم، المرحلة الثانية فهي فحص وتحليل الإجهادات المؤثرة على هيكل آلة التمشيط وأسنانها الزاحفة (الدائرية والمستطيلة) وفي ظروف مشابهة لظروف الحقل التي تعمل بها الآلة بواسطة برنامج (Inventor) وباستخدام طريقة العناصر المحددة (F.E.M) بالاعتماد على قيم الإجهاد الأعظم والإجهاد الرئيس والانحراف، أما المرحلة الثالثة فهي التقييم الحقلي في تربة مزيجية غرينية تم حراثتها بواسطة المحاريث القلابة ومن ثمَّ تمشيطها بواسطة تلك الأسنان لتفتيت الكتل الترابية الناجمة عن الحراثة ومعرفة مدى تأثيرها في صفتي عمق ودرجة تفتيت التربة، أظهرت النتائج أنَّ آلة التمشيط بالأسنان الزاحفة الدائرية سجلت أعلى قيمة للإجهاد الأعظم والإجهاد الرئيس، في حين سجلت آلة التمشيط بالأسنان الزاحفة المستطيلة أعلى قيمة للإنحراف، تفوق المحراث القرصي القلاب معنويا في تسجيله أعلى قيمة لدرجة التفتيت، بينما تفوق المحراث المطرحي القلاب معنويا في تسجيله أعلى قيمة لعمق التفتيت، تفوقت السرعة الأمامية (8.20) كم / ساعة معنويا على السرعة الأمامية (13.02) كم / ساعة في تسجيلها أعلى قيمة لدرجة التفتيت وعمق التفتيت، تفوق السن الدائري معنويا في تسجيله أعلى قيمة عمق التفتيت، فيما تفوق السن المستطيل في تسجيله أقل وأفضل قيمة لدرجة تفتيت التربة .

الكلمات المفتاحية: آلة التمشيط بالأسنان الزاحفة المستقيمة، الأشكال (الدائرية والمستطيلة)، درجة التفتيت

INTRODUCTION

This spike tooth harrowing is equipment for secondary tillage, used immediately after primary tillage, especially with moldboard plows that penetrate, cut, lift, turn, and loosens or the soil. However, these plows leave a tilled surface with large clods and an uneven, undulating appearance, which is unsuitable for seedbeds. This is where secondary tillage soil treatment equipment, particularly spike tooth harrow, play a crucial role. There are various types of this harrow with different tooth shapes, including horizontal rotary, disc, and spike types. The spike tooth Harrowing are designed to break up large soil clods through their creeping motion in tilled soil, with teeth arranged vertically and interleaved in rows, leading to the clods being compressed and fragmenting into smaller pieces both longitudinally and laterally. The tooth shape is one of the most significant factors affecting soil pulverization, and it is the component that researchers can control in design, especially regarding the thickness, length, width, curvature, and sharpness of the edges, primarily relying on the type and hardness of the metal used in manufacturing.

Arranging the teeth vertically on the Harrowing machine structure ensures uniform depth of pulverization and enhances the pulverization process, whereas positioning them at a forward curve leads to excessive penetration, resulting in irregular depth and the sliding of soil clods when colliding with the curved teeth, thus reducing their pulverization (Kurbanov, 2023). Caban *et al*. (2024) confirmed that spike combs with forward-curved teeth at a 45-degree angle recorded the highest stress values compared to vertical teeth due to deeper penetration into the soil, which increased soil resistance and, consequently, the stress exerted on the teeth. The use of moldboard plow reduces the actual need for high pulverization levels by Harrowing machines of in all its forms and types, as they stir and break the soil into smaller clods, resulting in lower pulverization levels. In contrast, disc plows, penetrate deeply into the soil, increasing clod size and thus raising the actual need for pulverization, which leads to higher pulverization levels (Patel, 2023). The repeated passes of the spike tooth Harrowing machine with a pointed shape provided a suitable seedbed for barley and pea crops, positively impacting both the quantity and quality of production (Ogórek *et al*., 2019). Increasing the forward speed of the spike tooth Harrowing machine reduced the need for high pulverization levels due to the accelerated ejection and collision of soil clods with one another and the machine's teeth (Jishna *et al*., 2023). Therefore, the aim of this research is to conduct a theoretical stress analysis to determine the metal's capacity to withstand these stresses for the manufacturing of spike tooth Harrowing machines (circular and rectangular) and to evaluate their performance in terms of depth and of pulverization index in soil tilled with two types of plows at two different speeds.

MATERIALS AND METHODS

The experiment was conducted during the autumn agricultural season of 2024 in a farm field located in the southern part of Nineveh Governorate, covering an area of 3 hectares, with a silty loam soil. A Turkish-made Massey Ferguson tractor (MF - 285S) was used, along with two types of plows (moldboard plow and disc plow) for soil tillage. Additionally, a locally manufactured this spike tooth harrow implement with both circular and rectangular tooth was employed to break up soil clumps shown in the Figure(1). This machine was designed by the researcher according to the dimensions and measurements specified in Figures 2 and 3 and shown in a three-dimensional view in Figure 4, following a metal test conducted at the University of Mosul / College of Engineering / Mechanical Engineering Department laboratories. Table 1 shows the chemical composition and Table 2 presents the mechanical properties of the metal.

Figure (1) picture of the combing machinery (A) with circular tooth and (B) with the rectangular.

Table (1): The chemical composition of the metal.

No.	Specimen	C	Mn	Si	Cr	Mo	Ni	P	S	Ti	V	Grade Designation
1	Circular Tooth	0.255	0.452	0.074	0.034	0.063	0.036	0.005	0.005	0.001	0.005	AISI 1025
2	Rectangular Tooth	0.113	0.423	0.065	0.036	0.057	0.046	0.006	0.003	0.003	0.002	AISI 1010
3	U-Shaped Metal	0.062	0.346	0.034	0.024	0.038	0.045	0.004	0.002	0.001	0.003	AISI 1005
4	Square Metal	0.059	0.335	0.026	0.025	0.032	0.049	0.003	0.004	0.002	0.001	AISI 1005

Table (2): The mechanical properties of the metal.

No.	Specimen	Yield strength (MPa)	Tensile strength (MPa)	Hardness HRB	Standard
1	Circular Tooth	375	465	73	AISI 1025 CS
2	Rectangular Tooth	298	375	60	AISI 1010 CS
3	U-Shaped Metal	210	327	50	AISI 1005 CS
4	Square Metal	215	334	53	AISI 1005 CS

Note: The results indicated that the samples were made of carbon steel and comply with the specification (A512-17 ASTM).

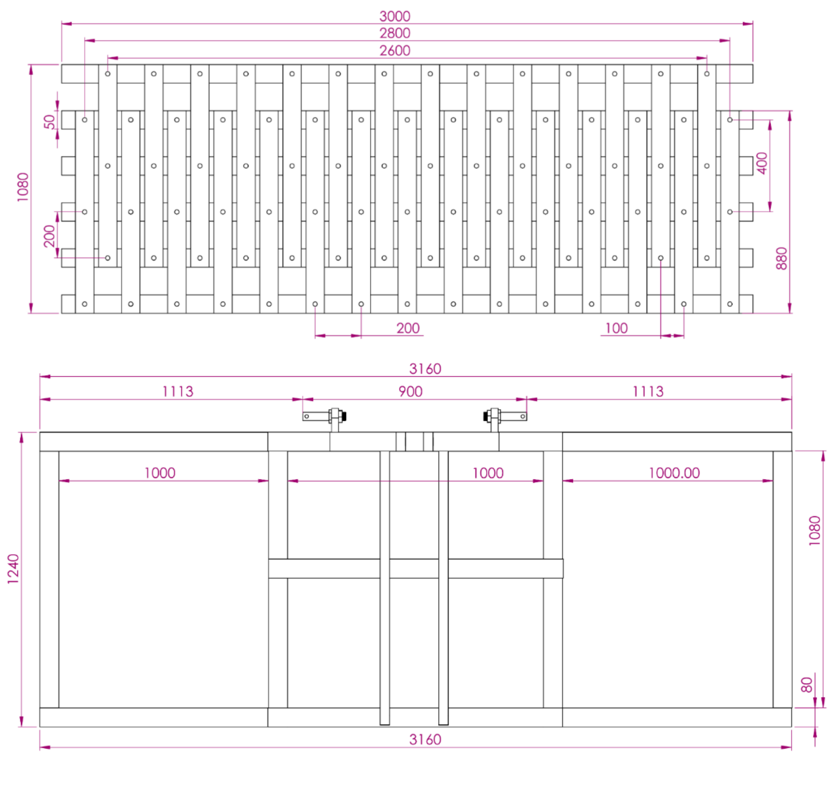

Figure (2): A vertical view indicating the number of rows, their arrangement, the external support of the structure, and its dimensions in millimeters (mm).

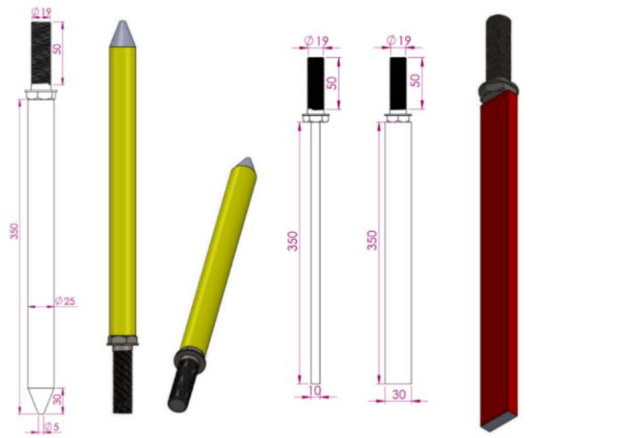

Figure (3): provides a side view showing the shapes of the circular and rectangular teeth, along with their dimensions in millimeters (mm)

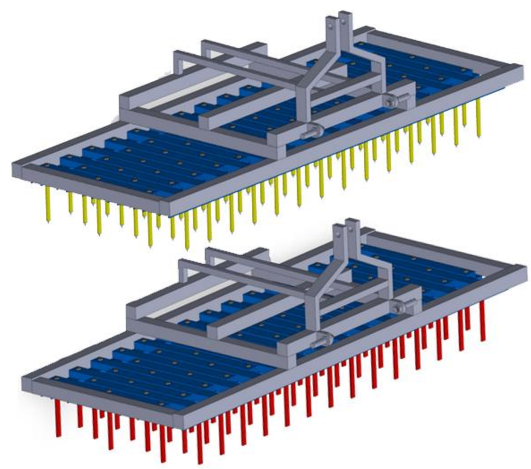

Figure (4): Represents my three-dimensional view combing machinery with circular tooth and with the rectangular

The experimental field was divided according to a Randomized Complete Block Design (RCBD), and the Split Plot Design method (Dawood and Elias, 1990) was used to carry out the experiment. Thus, the study was factorial with three factors: the first factor being the moldboard plows types with two levels (moldboard plow and disc plow), the second factor being the forward speed with two levels (8.20 km/h and 13.02 km/h), and the third factor being the shapes of this teeth (circular and rectangular) spike tooth harrow. The study aimed to assess effects of two shapes of teeth spike harrow on soil pulverization index and pulverization depth on the following traits: soil pulverization index and pulverization depth.

1. Stress: The theoretical stress values were calculated for both the spike tooth harrow with the circular tooth shape and the spike tooth harrow with the rectangular tooth shape after applying forces and loads to each tooth under conditions that closely resemble the actual field conditions in which the harrow operates. The calculations were performed using the Inventor program, a specialized software for mechanical design and stress analysis through computer simulations based on the Finite Element Method (F.E.M). Figure 5 illustrates the mesh of nodes and finite elements this spike tooth harrowing with circular tooth shape and rectangular, where the maximum stress, principal stress, and resulting deformations due to the applied forces were determined.

2. Pulverization Index : After collecting dry soil samples from the field, with three samples for each replicate, totaling 72 samples, the weight of each sample was measured using a METTLER TOLEDO balance, which is considered the total sample weight ($w\,t$). The samples were then placed in the top sieve and sieved in the laboratory using a KS10 shaker for 6 minutes through a series of sieves with varying mesh sizes (9.5, 4.75, 2.36, 1, 0.5, and 0.3 mm). After sieving, the weights of the soil aggregates remaining on each sieve ($w\,i$) were recorded, and the Pulverization Index was calculated using the equation referenced in Hillel (1980).

Figure (5): The mesh of nodes and finite elements for the (circular and rectangular) spike tooth harrow.

$$PI = \frac{\sum_{i=1}^{n} wi * di}{\sum Wt}$$

Where:

PI : Pulverization Index (mm)

wi : Weight of the sample remaining on the sieve (g)

di : Average sieve size (mm)

wt : Total sample weight (g).

3. Pulverization Depth :

The pulverization depth was measured by manually displacing the fragmented soil until reaching soil that was difficult to remove by hand. The depth was then measured using a 30 cm vertical ruler and a second horizontal ruler parallel to the soil surface. Three random readings were taken for each treatment at the speeds of 8.20 km/h and 13.02 km/h for each type of tooth used in the pulverization. The average of these readings was calculated to determine the actual depth for each speed and each shape of the harrowing teeth.

RESULTS AND DISCUSSION

Figures 6 and 7 show that the circular spike tooth harrow implement shape with recorded the highest values for both maximum stress (215.5 MPa) and principal stress (249.6 MPa). In contrast, Figures 8 and 9 indicate that the rectangular spike tooth harrow implement with of shape recorded the lowest values for maximum stress (109.9 MPa) and principal stress (69.05 MPa). This difference is attributed to the circular tooth being harder than the rectangular tooth, which makes it more resistant to deflection, allowing it to penetrate deeper into the soil during harrow-ing. As a result, the maximum stress increases on the teeth and near the attachment points on the structure, while the principal stress rises on the rear part of the machine, causing vibrations that lift it slightly.

Figure 10 demonstrates that the rectangular spike tooth harrow implement shape with recorded the highest deflection value (0.8316 mm), while Figure 11 shows that the circular spike tooth harrow implement shape with recorded the lowest deflection value (0.5035 mm). This can be explained by the larger surface area of the rectangular tooth compared to the circular tooth, which increases frictional force with the soil clumps. Additionally, the lower hardness of the rectangular tooth makes it easier for it to deflect.

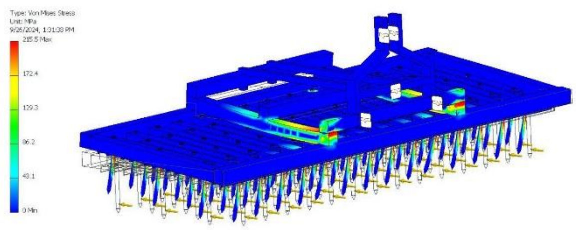

Figure (6): The distribution of the maximum stress for the circular spike tooth harrow

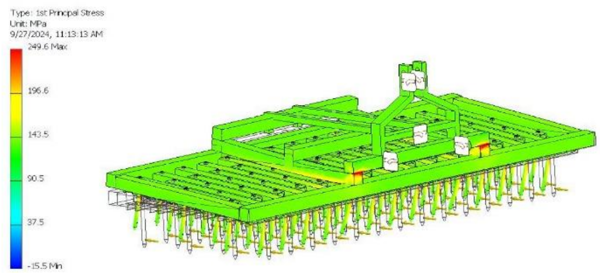

Figure (7): The distribution of the principal stress for the circular spike tooth harrow

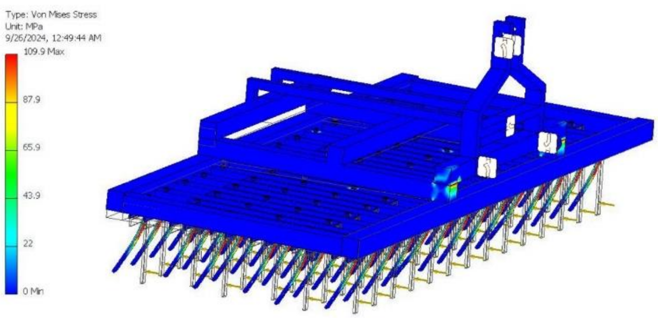

Figure (8): the distribution of the maximum stress for the rectangular spike tooth harrow

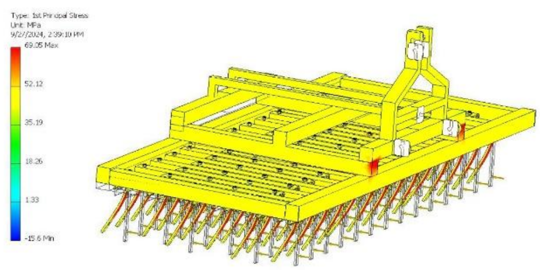

Figure (9): The distribution of the principal stress for the rectangular spike tooth harrow

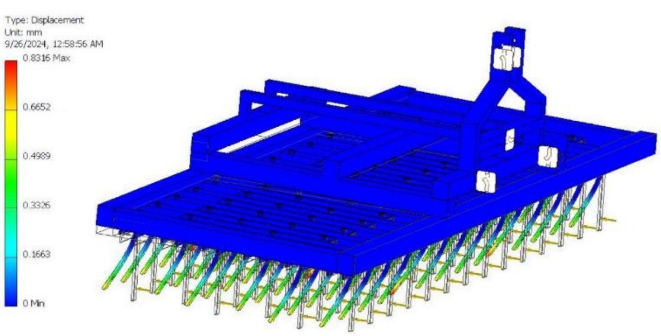

Figure (10): The displacement generated in the rectangular spike tooth harrow

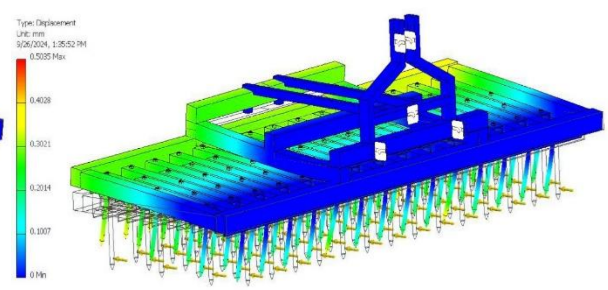

Figure (11): The displacement generated in the circular spike tooth harrow

Figure (12) shows that the disc plow recorded the highest actual requirement for the of soil pulverization index (11.64 mm) compared to the moldboard plow, which recorded the lowest actual requirement for the of pulverization index (9.15 mm). This is attributed to the fact that the disc plow leaves a strip of large, unbroken soil clods, which increases the need for a high of soil pulverization index by the spike tooth harrow of various types and shapes. In contrast, the moldboard plow loosens or the soil and stirs it, thereby reducing the need for a high of soil pulverization index by the spike tooth harrow.

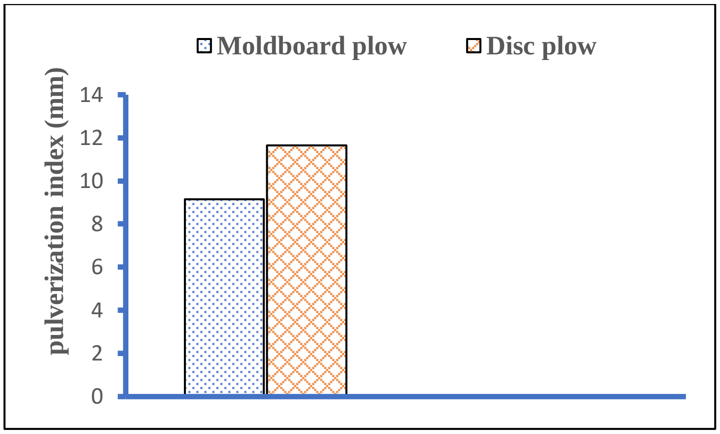

Figure (12): Effect of types of moldboard plows.

Figure (13) shows that the forward speed of Harrowing (8.20 km/h) recorded the highest actual requirement for the of soil pulverization index (12.01 mm), while the forward speed of Harrowing (13.02 km/h) recorded the lowest actual requirement for the of soil pulverization index (8.77 mm). This is attributed to the fact that higher speed increases the movement and impact of soil clods against each other and against the working parts of the spike tooth harrow, which enhances their stirring and pulverization more effectively than at lower speeds. Consequently, the value of the of soil pulverization index is lower in millimeters.

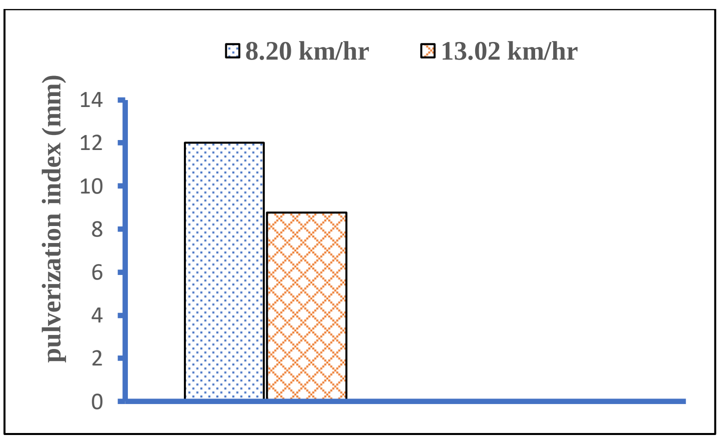

Figure (13): Effect of forward speed

Figure (14) shows that the circular spike tooth harrow implement recorded the highest actual requirement for the of soil pulverization index (11.52 mm), while the rectangular spike tooth harrow implement recorded the lowest actual requirement for the of soil pulverization index (9.27 mm). This is attributed to the fact that the rectangular tooth provides a larger contact area with the soil, allowing this working rectangular area, especially its sharp edges, to exert high impacts and friction against the soil clods from all directions, thereby enhancing the breaking and pulverization of the tilled soil based on its sizes and diameters in millimeters. In contrast, the circular teeth have a conical pointed working part that facilitates the sliding of soil clods through it due to lower friction with the soil. Consequently, the of soil pulverization index with circular teeth is lower based on the sizes and diameters of soil particles.

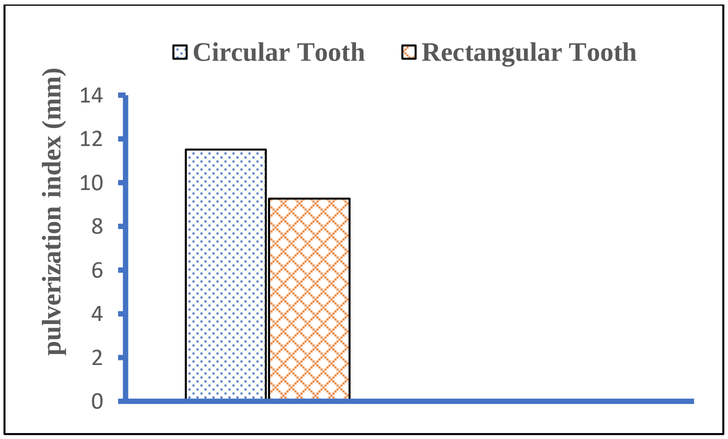

Figure (14): Effect of the shapes of the creeping teeth.

Figure (15) indicates that the interaction between the disc plow and the circular spike tooth harrow implement recorded an actual requirement for the of soil pulverization index (13.02 mm), while the interaction between the moldboard plow and the rectangular spike tooth harrow implement recorded the lowest actual requirement for the of soil pulverization index (8.27 mm). The effective pulverization of the rectangular spike tooth harrow in soil tilled by the moldboard plow is due to the moldboard plow's ability to loosens or the soil and stirs it compared to the disc plow, which aids in the pulverization process when using spike tooth harrowing in all its forms and types, especially the creeping ones. Additionally, the design of the rectangular tooth, in terms of its dimensions, edges, and contact area while working in the tilled soil, played a significant role in breaking and pulverizations soil clods, resulting in a more level appearance due to increased soil pulverization.

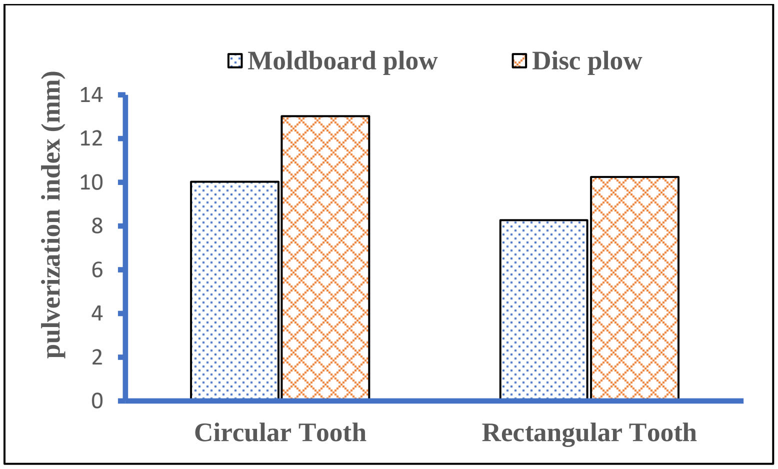

Figure (15): Interaction between types of plows and the shapes of the creeping teeth

Figure (16) shows that the interaction between the forward speed (8.20 km/h) and the circular spike tooth harrow implement recorded the highest actual requirement for the of soil pulverization index (12.53 mm), while the interaction between the forward speed (13.02 km/h) and the rectangular spike tooth harrow implement recorded the lowest actual requirement for the of soil pulverization index (7.04 mm). The increase in the of soil pulverization index and the breaking of its clods is attributed to the same reasons previously mentioned regarding the design of the rectangular tooths and its impact on the tilled soil, as well as its role in the Harrowing and smoothing process when subjected to high speeds during operation. This, in turn, facilitates the pulverization of soil clods through impacts and collisions with each other, which positively reflects on the soil, resulting in an increased of soil pulverization index.

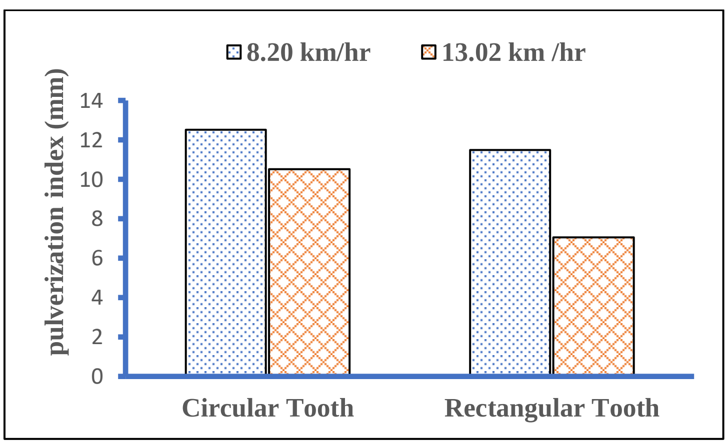

Figure (16): Interaction between forward speed and the shapes of the creeping teeth.

Figure (17) shows that the moldboard plow significantly outperformed in recording the highest value for the depth of pulverization (17.25 cm) compared to the disc plow, which recorded the lowest value for the depth of pulverization (15.85 cm). This is attributed to the fact that the Harrowing machine with creeping teeth, which operates in soil tilled by the moldboard plow, can penetrate deeper because, the moldboard plow loosens or the soil and stirs it, effectively, allowing for greater penetration of the teeth. In contrast, the disc plow leaves a strip of unbroken soil clods, which hinders the penetration of the teeth into the soil.

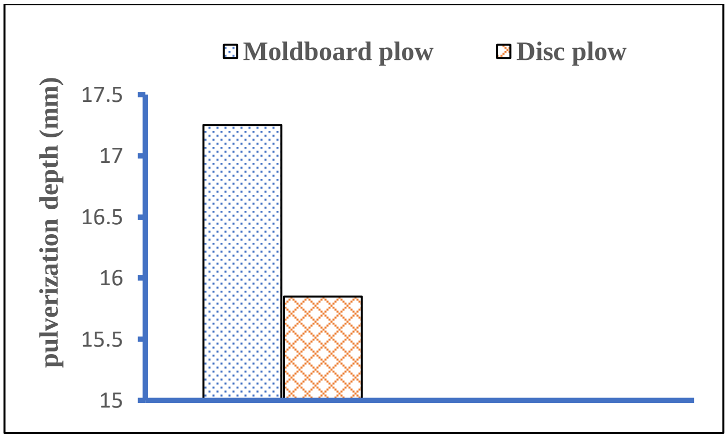

Figure (17): Effect of types of moldboard plows.

Figure (18) shows that the forward speed (8.20 km/h) significantly recorded the highest value for the depth of pulverization (17.32 cm), while the forward speed of (13.02 km/h) recorded the lowest value for the depth of pulverization (15.77 cm). This is attributed to the fact that the depth of pulverization is affected by the increase in the forward speed of the spike tooth harrow due to the increased resistance of the soil during the Harrowing process at higher speeds, which results in the spike tooth harrow being lifted slightly upward.

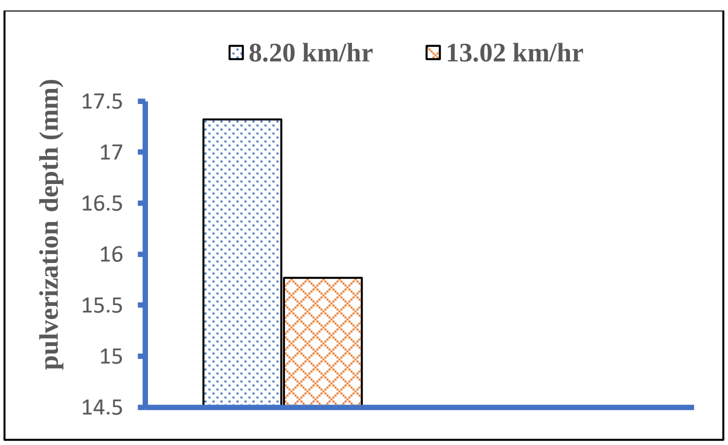

Figure (18): Effect of forward speed.

Figure (19) shows that the circular spike tooth harrow implement significantly outperforms, recording the highest value for penetration depth 17.77 cm, while the rectangular spike tooth harrow implement recorded the lowest value for penetration depth 15.32 cm. The increased penetration of circular teeth is due to the presence of a conical pointed tip with a small surface area in contact with the soil; the smaller the surface area of the part in contact with the soil, the deeper it penetrates, and vice versa.

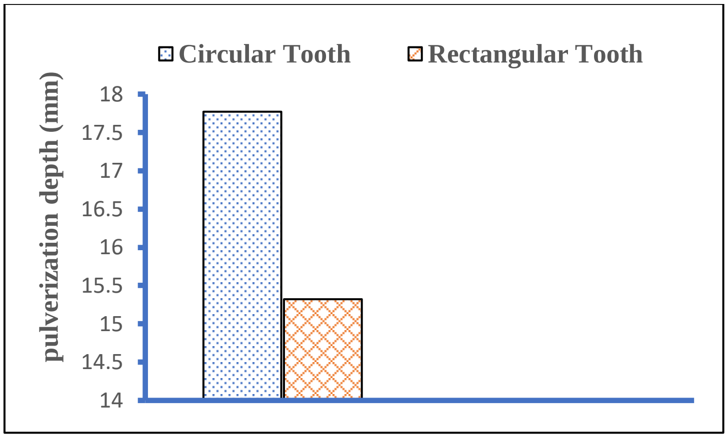

Figure (19): Shapes of the creeping teeth.

Figure (20) illustrates the superiority of the interaction between the moldboard plow and the circular spike tooth harrow, recording the highest value for penetration depth at 18.65 cm. In contrast, the interaction between the disc plow and the rectangular spike tooth harrow recorded the lowest value for penetration depth at 14.80 cm. This is attributed to the fact that the circular spike tooth harrow, when used in soil tilled by the moldboard plow, penetrates deeper into the soil because the moldboard plow loosens or the soil and stirs it, Additionally, the conical pointed tip of the circular spike tooth harrow allows for better penetration into the soil, unlike the rectangular spike tooth harrow, which achieve less penetration depth when working in the tilled soil of both moldboard plow types, especially the disc plow.

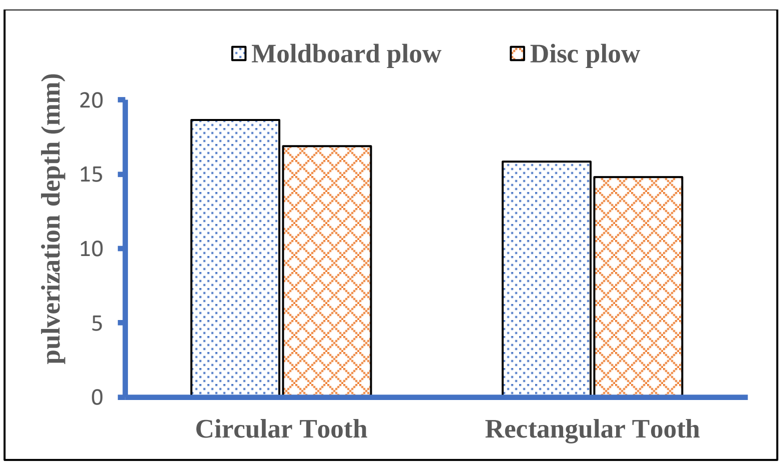

Figure (20): Interaction between types of plows and the shapes of the creeping teeth.

CONCLUSIONS

It was concluded that recorded the circular tooth shape with the highest values maximum stress (215.5 MPa) principal stress (249.6 MPa)and the lowest deflection value (0.5035) mm in contrast, the rectangular tooth shape recorded the lowest values for maximum stress (109.9 MPa) and principal stress (69.05 MPa) and the highest deflection value (0.8316 mm). and that recorded the rectangular tooth shape the best value soil pulverization in soil tilled by the moldboard plow at a forward speed of 13.02 km/h. that recorded the circular tooth shape with the highest value depth the pulverization in soil tilled by the moldboard plow at a forward speed of 8.20 km/h.

REFERENCES

Abduvahobov, D. A., Muhamedov, J., & Umurzakov, A. H. (2016). Layout diagram of the hinged oscillatory spike-tooth harrow and determination of its row-spacing width. *European Science Review*, 175–176. https://doi.org/10.20534/ESR-16-5.6-175-176

Al-Banna, Aziz Rammo (1990). Soil Preparation Equipment. Directorate of *Dar Al-Kutub for Printing and Publishing, University of Mosul, Ministry of Higher Education and Scientific Research.*

Al-Tahan, Yasin Hashem, Midhat Abdullah Hamida, and Mohammed Qudri Abdul Wahab (1991). Economics and Management of Agricultural Machines and Equipment. *Dar Al-Kutub for Printing and Publishing, University of Mosul, Ministry of Higher Education and Scientific Research.*

Caban, J., Nieoczym, A., & Krzywonos, L. (2024, May 22). *Strength analysis of subsoiler tooth*. 23rd International Scientific Conference Engineering for Rural Development. https://doi.org/10.22616/ERDev.2024.23.TF057

Daoud, Khaled Mohammed and Zaki Abdul Yass (1990). Statistical Methods in Agricultural Research. Directorate of *Dar Al-Kutub for Printing and Publishing, Ministry of Higher Education and Scientific Research, University of Mosul.*

Dunarea de Jo, Capatana, Potirniche, & Musca Anghelache. (2022). Considerations regarding 3d modelling and finite element analysis of a cultivator type equipment. *International Journal of Modern Manufacturing Technologies*, *14*(3), 27–32. https://doi.org/10.54684/ijmmt.2022.14.3.27

E Kurbanov. (2023). Justification of the parameters of the ripper of the harrowing unit. *BIO Web of Conferences*, *71*(01016). https://doi.org/10.1051/bioconf/20237101016

Eremenko, Ya. V., Nesmiyan, A. Y., Kulakov, A. K., & Asaturyan, S. V. (2018). Comparative analysis of the consumer characteristics of needle and tooth harrows. *Traktory i Sel Hozmashiny*, *85*(2), 8–12. https://doi.org/10.17816/0321-4443-66366

Hillel, D. (1980): Fundamentals of soil physics. Academic Press. New York.

Jishna, K. P., Gajera, M. N., Vagadia, V. R., & Gajjar, P. P. (2023). Design and Performance Evaluation of a Mini Tractor Mounted Clod Crusher. *Current Journal of Applied Science and Technology*, 42(35), 1–8. https://doi.org/10.9734/cjast/2023/v42i354232

Lu, Z., Du, C., Chen, Q., Niu, T., Wang, N., & Song, W. (2021). Wear and Friction Characteristics of 65Mn Steel for Spike-Tooth Harrow. *Coatings*, *11*(3), 319. https://doi.org/10.3390/coatings11030319

Nassir, A. J., Muhsin, S. J., Mishall, A. A., & Almusawi, F. M. (2023). The impact of the tillage systems on input-output energy, soil pulverization, and grain yield of barley. *CIGR Journal*, *25*(4), 68–83. http://www.cigrjournal.org

Ogórek, R., Lejman, A., & Sobkowicz, P. (2019). Effect of the Intensity of Weed Harrowing with Spike-Tooth Harrow in Barley-Pea Mixture on Yield and Mycobiota of Harvested Grains. *Agronomy*, *9*(2), 103. https://doi.org/10.3390/agronomy9020103

Okoko, P., & Akpankpuk, S. N. (2023). Effects of Tillage Depth and Tractor Speed on Implement Speed for Three Tillage Implements on a Clay Loam Soil. *Asian Journal of Advances in Agricultural Research*, *22*(4), 1–7. https://doi.org/10.9734/ajaar/2023/v22i4444

Patel, C., Naik, R., & Patel, G. (2023). Comparative performance evaluation of spade plough: A case study. *International Journal of Statistics and Applied Mathematics*, *8*(5), 204–208. https://www.mathsjournal.com

Saleh, A. W., Abdullah, A. A., & Tahir, H. T. (2020). Performance evaluation and analysis stress (theoretical and practical) of auxiliary parts (coulter knives) locally manufactured for moldboard plow during tillage. *Plant Archives*, *20*, 4109–4118.

Shahgholi, G., & Moinfar, A. (2019). Investigation Tine Type Effect on Soil Fragmentation for Conservation Tillage. *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi*, *29*(3), 548–558. https://doi.org/10.29133/yyutbd.564789

Tilaye, A., & Ahmed, B. (2018). Design Modification, Adaptation and Verification of Spike Tooth Harrow for Pack Animals. *Civil and Environmental Research*, *10*(4).

Vegad, G. M., Yadav, R., & Jakasania, R. G. (2016). Structural Analysis of Hatchet Type Rotavator Blade in CAD Software. In National Conference on Recent trends in Engineering, Management, Pharmacy, Architecture and Science, „ncetempas-2016.

Yegül, U., EmiNoğlu, M. B., Orel, O., & Çolak, A. (2014). Determination of Equivalent Stress and Total Deformation in Different Types of Harrows. *Journal of Agricultural Machinery Science*, 10(1), 65–71. https://dergipark.org.tr/en/download/article-file/119310

Ivanov, A. G. (2020). Substantiation of Process Variables and Modes of Heavy Spring-Tooth Harrow. *International Journal of Emerging Trends in Engineering Research*, *8*(3), 695–704. https://doi.org/10.30534/ijeter/2020/14832020