

Analysis and modeling of Stresses and Deflections Generated on the Reversible Moldboard plow Attached to the Angular Scraper Under various soil conditions

Rateeb Hussein Ali Abdul Haleem^{1*}, Adel Ahmed Abdullah Rajab²

¹ General Directorate of Education in Kirkuk Governorate, Ministry of Education

² Department of Agricultural Machinery and Equipment, College of Agriculture and Forestry, University of Mosul

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*Correspondence: Rateeb Hussein Ali

Abdul Haleem

Email:

rateeb.22agp99@student.uomosul.edu.iq

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Abstract: This study was conducted theoretically using the (Inventor) software, which relies on the finite element method to determine the values of both maximum stress, principal stress, and deflection for both the angular scraper and the moldboard plow under conditions similar to field conditions. The study was conducted in two stages: the first stage involved fixing the dimensions and measurements of the angular scraper and then manufacturing it. The second stage involved field evaluation of the performance efficiency of the locally manufactured reversible moldboard plow with the angular scraper, comparing it with the reversible moldboard plow without the angular scraper, and studying some field performance indicators through a practical experiment that included the following factors: the use of the reversible moldboard plow at two levels (with the locally manufactured angular scraper and without the angular scraper), soil condition at two levels (with weed soil and without weed soil), using a Randomized Complete Block Design (RCBD) with split-plot design, and the effect of these factors on the studied traits, which included stress, vertical deflection ratio, lateral deflection ratio, and performance efficiency. The results showed that the angular scraper recorded higher values for both maximum stress and principal stress, while the moldboard of plow recorded the highest value for deflection. Moreover, untilled soil condition significantly outperformed in providing higher values for performance efficiency, while tilled soil condition significantly outperformed in providing higher values for both vertical and lateral deflection ratios. As for the plow, the plow with the angular scraper significantly outperformed in recording higher values for performance efficiency, while the plow without the angular scraper significantly outperformed in recording higher values for both vertical and lateral deflection ratios.

Keywords: Reversible Moldboard Plow, Angular Scraper, Finite Element Method, Maximum Stress.

Introduction

Plowing is considered one of the important and primary operations for soil preparation by breaking up the surface layer and forming small soil clods that facilitate the movement of water and air into the soil, thereby improving its physical properties. The qualitative characteristics of plowing depend on the operational speed of the machine, the nature of the treated soil, and the optimal selection of plowing equipment. In case of inappropriate selection of this equipment, it leads to negative results in soil properties, which in turn negatively affects plant growth and yield production.

The reversible moldboard plow achieves most of the plowing objectives, including cutting, flipping, and loosening the soil, as confirmed by (Hashim & Al-Naama, 1988). The angular scraper is an auxiliary part of the plow body, and its function is to perform vertical cutting in the soil to a depth approximately half the depth of plowing (according to the adopted regulation), thereby reducing the lateral and vertical resistances of the soil that the plow encounters by a percentage ranging from (10-15%) (Bernacki et al, 1972). Its use also reduces the pressure on the surface of the plow's moldboard, and it scrapes or cuts a certain angle of the soil transferred on the surface of the moldboard to fall before the main section in the bottom of the previous furrow and fill the gap between the adjacent plowing lines, giving a homogeneous appearance to the plowed soil with minimal undulations and fewer soil clods, as indicated by (Ramu, 1990).

Studies have shown a positive effect of using the angular scraper with the reversible moldboard plow in increasing the burial of surface furrows, as well as weeds and plant residues [4]. The angular scraper closely resembles the shape of the moldboard of the reversible moldboard plow. Its proper use and selection of the appropriate forward speed can lead to increased operational productivity while achieving good quality work. Therefore, obtaining good performance of the reversible moldboard plow during work in different conditions and maintaining better stability of the plow came as a result of the lack of in-depth local studies on the locally manufactured angular scraper and its importance as an auxiliary part attached to the reversible moldboard plow in improving some performance indicators.

Methodology

This study was conducted during the agricultural season of 2023 in one of the agricultural fields in Al-Zab district, Kirkuk Governorate. The area of the experiment field was 2 hectares, characterized by its flat topography. Soil texture analysis of the field revealed clayey soil with clay content (480 g/kg), silt content (327 g/kg), sand content (193 g/kg). Soil moisture content of the experiment field was 17.6%. A Turkish-made tractor (Massey Ferguson MF 285 S) with a horsepower of 75 was used for pulling and carrying the plow, and all performance indicators were measured (power source). Additionally, an Iraqi-made reversible moldboard plow (Alexandria) with a mass of 360 kg, a working width of 87 cm, and three shares, of moldboard type, was utilized. The angular scraper was manufactured by the researcher at the Tolerance Machinery and Agricultural Equipment Manufacturing Laboratory in Kirkuk. Furthermore, a metal test for the material used in

manufacturing the angular scraper was conducted at the Mechanical Engineering Department Labs, College of Engineering, University of Mosul.

Table (1) shows the mechanical properties and chemical composition of the metal used in manufacturing the angular scraper, while Figure (1) illustrates the design map of the angular skimmer. Values for maximum stress, principal stress, and deflection were obtained using the Inventor software, which relies on the finite element method, under conditions similar to field conditions. The experimental field was divided according to the randomized complete block design (RCBD) with a split-plot design (Dawood & Elias, 1990), where the main plots were allocated for soil conditions, and each main plot was further divided into two subplots allocated for the plow. Thus, the experiment was factorial with two factors: soil condition at two levels (with weed soil, without weed soil) and plow type at two levels (plow with angular scraper, plow without angular scraper), with a single treatment length in the replicate of 30 m.

Statistical analysis of the data and variance analysis were conducted using the Duncan multiple range test. After planning the experiment according to the designated design, the experimental field was irrigated using surface irrigation, and the change in soil moisture content was monitored using a soil moisture measuring device. The following traits were studied: stresses, vertical deflection ratio, lateral deflection ratio, and performance efficiency.

1. *Stresses*: Maximum stress, principal stress, and deflection for the angular scraper of the plow were determined using the Inventor software based on the finite element method (F.E.M) to assess the angular scraper's stress tolerance and distribution on the working surfaces under conditions similar to field conditions.
2. *Vertical Deflection Ratio*: This is the percentage by which the plow deviates from the designated plowing depth (regulated depth). Three random readings were taken for each treatment, and the average of these readings was calculated to determine the actual depth and calculate the vertical deflection ratio using the following equation [2]:

$$asr = \sum ap / np \dots \dots \dots (1)$$

$$\Delta a = \sqrt{\sum (ap - asr)^2 / np} \dots \dots \dots (2)$$

$$\delta_a = (\Delta a / asr) \times 100 \dots \dots \dots (3)$$

asr= Average depth (m).

ap= Measured depth (m).

np= Number of replicates.

Δa = Average deflection (m).

δ_a = Vertical deflection ratio (%).

- 3- *Lateral Deflection Ratio*: This is the percentage by which the plow deviates from its theoretical (design) width. This indicator is considered evidence of a fault in the technical condition of the plow. Three random readings are taken, and the average of these readings is taken to determine the actual working width of the plow. The lateral deflection ratio is calculated using the following equation [2]: $bsr = \sum bp / np \dots \dots \dots (4)$

$$\Delta b = \sqrt{\sum (bp - bsr)^2 / np} \dots\dots\dots (5)$$

$$\delta_b = (\Delta b / bsr) \times 100 \dots\dots\dots (6)$$

bsr= Average width (m).

bp= Measured width (m).

np= Number of replicates.

Δb = Average deflection (m).

Δ_b = Lateral deflection ratio (%).

4- *Performance Efficiency*: The productivity of a machine can be expressed by its performance rate, which depends on the type of machine and its production units.

This productivity is expressed in area units per unit of time, such as hectares per hour or dunums per hour [6]. Field productivity can be categorized into two types:

a- *Theoretical Field Capacity (TFC)*: The theoretical field capacity of a machine is defined as the maximum (highest) productivity expected to be achieved at a certain speed, assuming that the theoretical width of the machine is fully utilized during operation, meaning the machine operates at 100% of its performance time, at the specified speed, and with its full working width. The theoretical field capacity can be calculated using the following equation:

$$TFC = S * W / A \dots\dots\dots (7)$$

TFC= Theoretical Field Capacity (hectares per hour).

S= Theoretical Speed (m per hour).

W= Machine Width (m).

A= Area Unit (10,000 square m) or (hectares).

Theoretical field capacity yields higher values than the actual (practical) productivity of the machine, which occurs in reality. This is not suitable for evaluating the performance rate of agricultural machinery. Hence, it is necessary to calculate the actual field capacity, which has lower values than the theoretical field capacity (Al-Tahan et al, 1991).

b- *Actual Field Capacity (EFC)*: Actual field capacity is defined as the actual performance rate of the machine in the field or during the processing of a certain crop within a specified time. It is the actual area (number of hectares) completed by the machine within a specific (defined) time. Actual field capacity can be calculated using the following equation:

$$EFC = S * W * E / A \dots\dots\dots (8)$$

EFC= Actual Field Capacity (hectares per hour).

S= Operational Speed (m per hour).

W= Machine Width (m).

A= Area Unit (10,000 m²) or (he).

E= Field Efficiency (%) with values ranging for the reversible plow from (70-90)% (Roth et al, 1977) (Al-Nama & Al-Jubouri, 2011), taking it as (80%).

Based on the foregoing, the performance efficiency of the machine can be calculated using the following equation [6]:

$$FE = (EFC/TFC) * 100 \dots \dots \dots (9)$$

FE= Performance Efficiency (%).

EFC= Actual Field Capacity (hectares per hour).

TFC= Theoretical Field Capacity (hectares per hour).

Table 1. The mechanical properties and chemical composition of the metal selected for manufacturing the angular scraper.

Angular scraper parts	The mechanical properties				The chemical composition						Metal type
	Tensile strength (Mpa) (N/mm ²)	Hardness (HRC)	Tillage-induced stress (Mpa) (N/mm ²)	Elongation percentage (%)	Carbon (c%)	Manganese (Mn%)	Chromium (Cr%)	Copper (Co%)	Sulfur (S%)	Phosphorous (P%)	
Cutting blade	700	40	430	10	0.7	0.85	0.003	0.003	0.01	0.01	AISI 1070
scraper body	700	20	430	10	0.7	0.85	0.003	0.003	0.01	0.01	

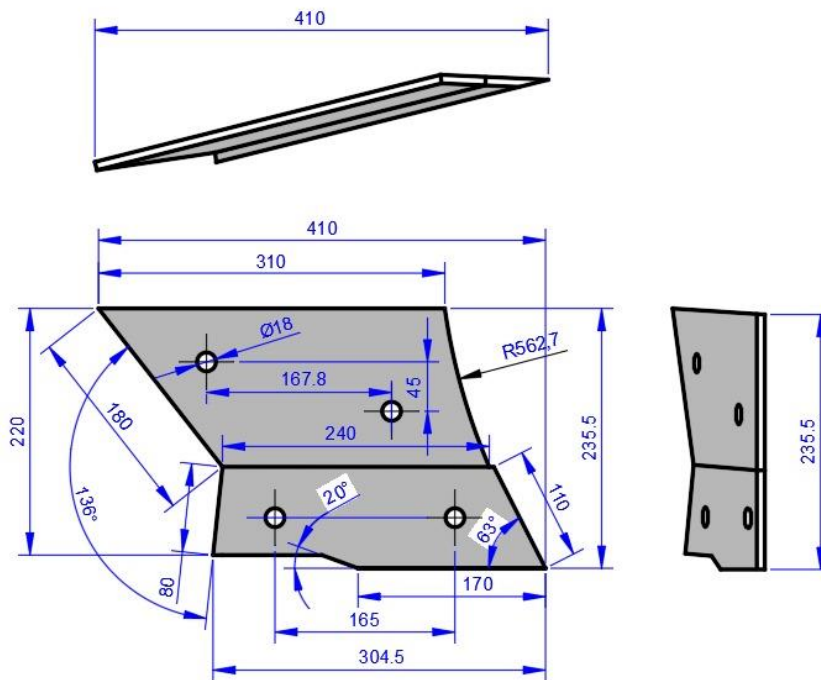


Figure 1. illustrates the design map of the angular scraper.

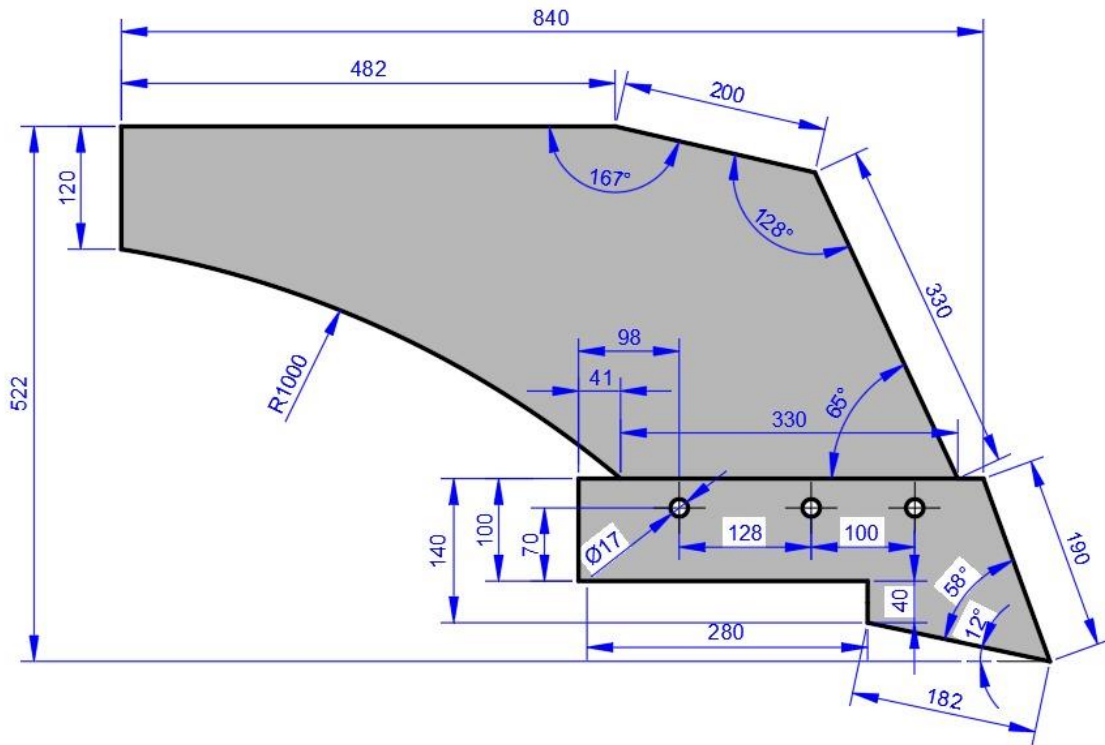


Figure 2. moldboard bottom.

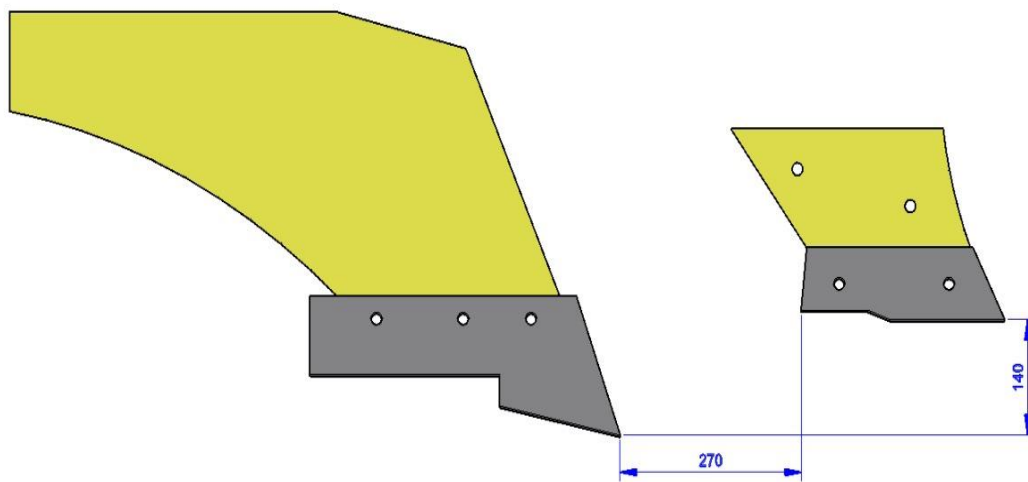


Figure 3. model of a locally manufactured angle scraper and moldboard bottom.

Result and Discussion

1. Stresses

The maximum stress, principal stress, and deviation for the plowshare and the locally manufactured angled scraper were determined using the (INVENTOR) program, which relies on the Finite Element Method (F.E.M), aiming to understand the tolerance of the angled scraper to the applied stress and how it is distributed on the working surfaces under conditions similar to field conditions. Table (2), supplemented with figures (4), (5), and (6), illustrates this. Figure (4) shows the maximum stress for the angled scraper and the plowshare, where the angled scraper recorded the highest maximum stress value of (45.36) MPa compared to the plowshare, which recorded the lowest maximum stress value of (38.63) MPa. Figure (5) illustrates the principal stress, where the angled scraper recorded the highest principal stress value of (43.1) MPa, while the plowshare recorded the lowest principal stress value of (35.55) MPa. The reason for this can be attributed to the design, technical, and operational aspects between the angled scraper and the plowshare, as well as the position of the angled scraper in front of the plowshare and its exposure to pressures and stresses during field work. It absorbs pressures and forces as it penetrates the soil to approximately half the depth of tillage, thereby reducing the amount of stress and force required by the plowshare to perform soil penetration, disassembly, and overturning. Figure (6) illustrates the deviation that occurs on the angled scraper and the plowshare during operation, where the plowshare recorded the highest deviation value of (0.05056) mm compared to the angled scraper, which recorded the lowest deviation value of (0.01699) mm. The reason for this is that the surface area of the plowshare dealing with the soil is larger during its penetration, disassembly, and overturning of the soil (Oude & Adelkhani, 2024) (He et al, 2022) (Garus et al, 2014) (Gheorghe, 2023).

Table 2. Results of stress analysis using the Inventor program for the angle planer and planer.

Variables Factors	Maximum stress (MPa)	Principal stresses (MPa)	Deviation (mm)
The angled scraper	45.36	43.1	0.01699
The plowshare	38.63	35.55	0.05056

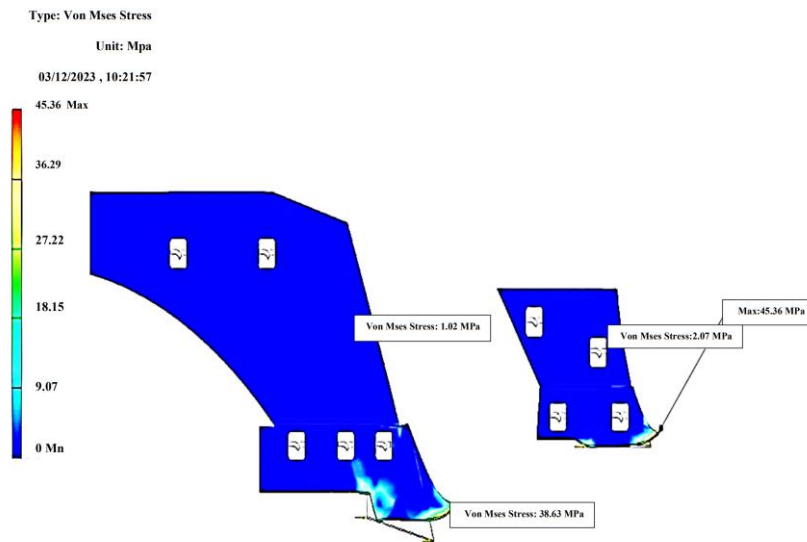


Figure 4. The distribution of the maximum stress for the angled scraper and the plowshare.

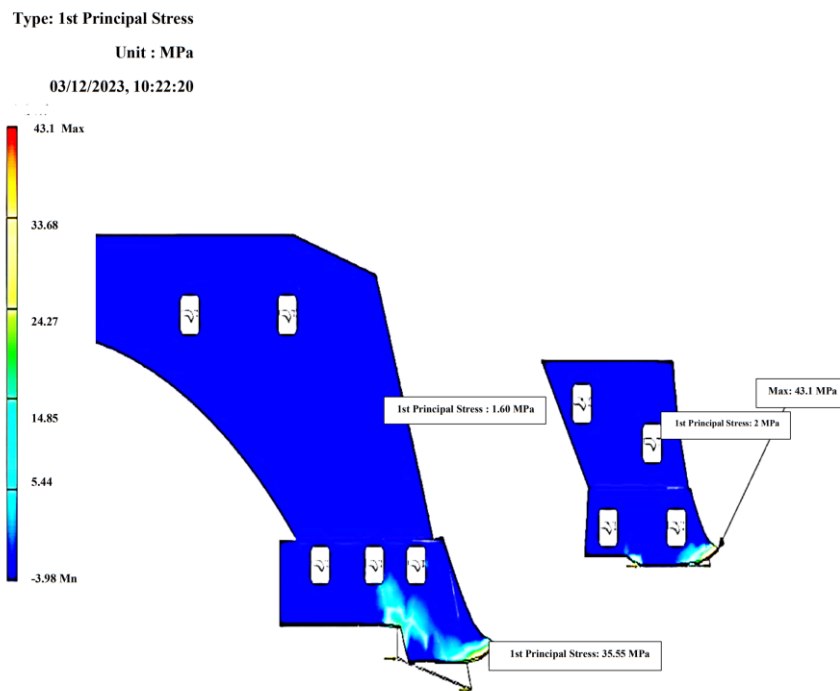


Figure 5. shows the distribution of the principal stresses for the angled scraper and the plowshare.

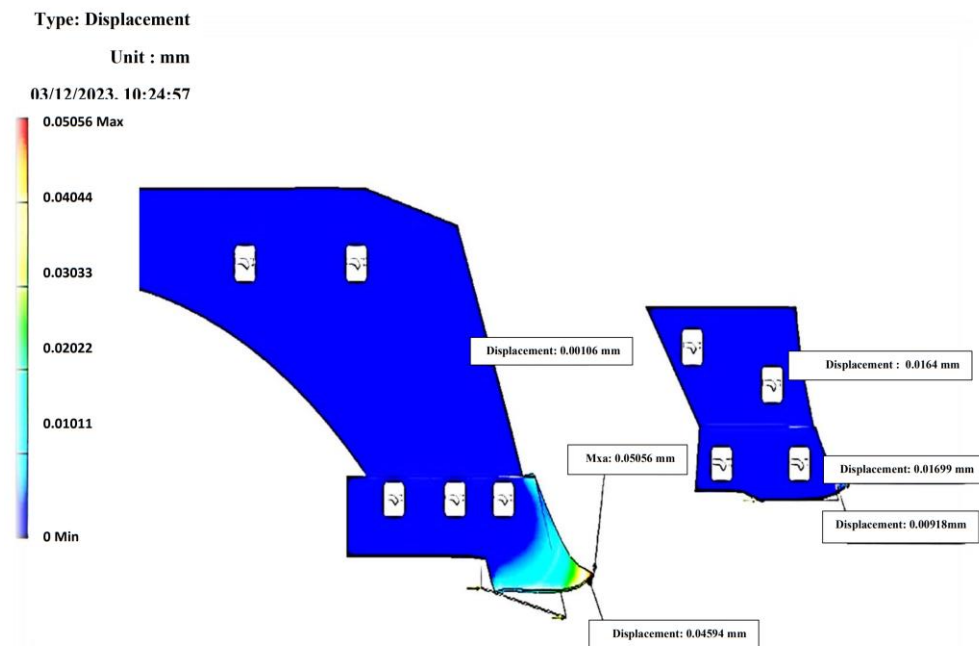


Figure 6. shows the deviations (displacement) for the angled scraper and the plowshare.

2. Vertical deviation ratio

Table (3) indicates that there were significant differences in the vertical deviation ratio depending on the soil condition. The lowest value of the vertical deviation ratio (2.77%) was recorded for without weed soil condition, while the highest value (3.44%) was recorded for the with weed soil condition. The reason for this is that the presence of vegetation in the soil hinders the depth of the plowshare's penetration into the soil, resulting in reduced achieved depth. The shallower depth leads to an increase in the vertical deviation ratio. This indicates a reciprocal relationship between vertical stability and tillage depth, meaning that greater depth results in greater vertical stability.

The table also demonstrates significant differences in the plows used, where the plow with the angled scraper recorded the lowest value of vertical deviation ratio (2.58%), while the plow without the angled scraper recorded the highest value (3.63%). The presence of the angle scraper with the plow facilitated the penetration of the plow into the soil by cutting the soil at an angle, thus reducing the pressure on the body of the plow and increasing the depth. This maintained greater vertical stability, resulting in a lower vertical deflection ratio. This is consistent with the findings (Hamoud, 2013) (Al-Khaldi, 2017) (Abdullah & Abed, 2018) (Saleh et al, 2023).

Furthermore, the table shows significant differences in the interaction between soil condition and type of plow. The lowest value of the percentage of vertical deviation (2.16%) was recorded for the case of the soil without weed with the angle scraper, while the highest value (3.87%) was recorded for the case of the soil with weed without the angle scraper. This is because the absence of the angular scraper and the presence of vegetation caused the plow to become unstable, resulting in a lower depth and a higher vertical deviation ratio.

Table 3. The impact of the studied factors and their interactions on the vertical deviation ratio (%).

Variables factors	Soil condition	Plow effect		Effect of soil condition
		With skimmer	without skimmer	
The interaction between soil condition and the plow	With weed	3.00 C	3.87 A	3.44 A
	Without weed	2.16 D	3.38 B	2.77 B
The effect of the plow		2.58 B	3.63 A	

*The lower value is better.

3. Lateral deviation ratio

Table (4) demonstrates significant differences in the lateral deviation ratio depending on the soil condition. The highest value of the lateral deviation ratio was recorded at (0.630%) for the soil with weed condition, while the lowest value was recorded at (0.507%) for the soil without weed condition. The reason for this is that the presence of vegetation in the soil causes the plow to deviate from its path, directly affecting the working width of the plow. Additionally, vegetation causes pressure on the plow, leading to a reduction in its designed working width, hence increasing the lateral deviation ratio, i.e., reducing lateral stability.

The table also indicates significant differences in the plows used, where the plow with the angled scraper recorded the lowest value of lateral deviation ratio at (0.529%), while the plow without the angled scraper recorded the highest value at (0.609%). The presence of the angled scraper with the plow, positioned in front of the main plowshare, absorbs pressure and reduces the lateral forces coming from the furrow wall, thus maintaining better lateral stability. This aligns with the findings of (Hamoud, 2013) (Abdullah & Dahham, 2014) (Amer, 2017).

Furthermore, the table illustrates significant differences in the interaction between soil condition and the plow, where the lowest value of lateral deviation ratio was recorded at (0.465%) for the soil without weed condition with the plow with the angled scraper, while the highest value was recorded at (0.668%) for the soil with weed condition with the plow without the angled scraper. This is due to the increase in compressive lateral forces on the plow, leading to a decrease in its lateral stability and consequently an increase in the lateral deviation ratio.

Table 4. The impact of the studied factors and their interactions on the lateral deviation ratio (%).

Variables factors	Soil condition	Plow effect		Effect of soil condition
		With skimmer	without skimmer	
The interaction between soil condition and the plow	With weed	0.593 B	0.668 A	0.630 A
	Without weed	0.465 D	0.550 C	0.507B
The effect of the plow		0.529 B	0.609 A	

*The lower value is better.

4. Performance efficiency

Table (5) demonstrates that the soil condition has a significant impact on performance efficiency, with the soil without weed condition showing the highest performance efficiency at (76.83%), while the soil with weed condition exhibited the lowest performance efficiency at (75.53%). The reason for this is that the presence of vegetation affects the lateral stability of the plow, thus increasing lateral deviation, which directly affects the working width of the plow, considered one of the actual productivity determinants.

The table also indicates significant differences in the plows used, with the plow with the angled scraper showing the highest performance efficiency at (78.71%), while the plow without the angled scraper exhibited the lowest performance efficiency at (73.65%). The presence of the angled scraper with the plow enables the penetration of the soil slice to approximately half the depth, reducing the vertical pressure of the soil on the plow body by absorbing shocks and vibrations encountered during work. This ultimately reduces the lateral deviation of the plow, resulting in higher lateral stability. Consequently, the plow maintains its working width, leading to increased actual productivity. Since actual productivity is one of the determinants of performance efficiency and has a reciprocal relationship with it, this leads to increased performance efficiency. This aligns with the findings of (Hamoud, 2013) (Swain et al, 2022).

Furthermore, the table highlights significant differences in the interaction between soil condition and the plow, with the soil without weed condition with the plow with the angled scraper showing the highest performance efficiency at (79.24%), while the soil with weed condition with the plow without the angled scraper exhibited the lowest performance efficiency at (72.89%). The reason for this is the increase in soil pressure on the plow and the deviation of the plow from its working width, resulting in decreased performance efficiency.

Table 5. The impact of the studied factors and their interactions on performance efficiency (%).

Factors	Variables	Soil condition	Plow effect		Effect of soil condition
			With skimmer	without skimmer	
The interaction between soil condition and the plow		With weed	78.17B	72.89 D	75.53 B
		Without weed	79.24 A	74.41 C	76.83 A
The effect of the plow			78.71 A	73.65 B	

*The lower value is better.

Conclusion

This study demonstrates the collaborative efficiency between the angular scraper and the reversible moldboard plow. Finite element analysis confirmed that the angular scraper withstands significantly higher stresses (45.36 MPa maximum stress; 43.1 MPa principal stress) than the plow (38.63 MPa; 35.55 MPa), absorbing operational forces to protect the plow body. Conversely, the plow exhibited greater deflection (0.05056 mm vs. 0.01699 mm)

due to its larger soil-contact surface area. Field validation established distinct advantages of angular scraper integration:

- Vertical deflection decreased from 3.63% to 2.58%
- Lateral deflection declined from 0.609% to 0.529%
- Performance efficiency increased from 73.65% to 78.71%

These improvements resulted from reduced soil resistance and enhanced plow stability. Although weed presence amplified deflection, the scraper effectively mitigated this effect—particularly in untilled soil, where efficiency peaked at 79.24%. Thus, the angular scraper fulfills dual functions: stress absorption and precision enhancement. Future development should prioritize hardening the scraper's cutting edge while evaluating performance in diverse soil environments to optimize universal application.

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