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Evaluating the Quality of Tillage for Simple Tillage Tools Using Finite Element Method

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Abstract

This study aims to develop a simulation model to evaluate tillage quality. The Finite Element Method (FEM) was used to simulate the interaction between soil and tillage tools using ABAQUS software. Model simulated to study the effects of tool and soil parameters on the quality of tillage. These parameters including tool speed (0.83, 1.38 and 2.22 m/s), tillage depth (0.05, 0.075 and 0.1 m), soil bulk density (1300, 1350 and 1410 kg/m³), and tool geometry (shovel, sweep, and winged tools) in clay loam soil. Three factors were used to evaluate the quality of tillage. These were power consumption, degree of soil loosening and soil stress.

Results indicated that there was a reasonable agreement in the values of power consumption and degree of soil loosening resulted from simulated as compared with measured data from soil bin with R^2 of 0.968 and 0.983, respectively. Sweep tool recorded the highest value of power consumption as compared with shovel and winged tool under different operational conditions. Furthermore, the highest value of degree of soil loosening resulted with shovel tool while sweep and winged tools resulted in the lowest and moderate values of degree of soil loosening. The highest values of soil stress obtained by shovel tool under various levels of soil bulk density and tool parameters. However, the lowest value recorded by sweep tool.

Keywords: Simple tillage tools, FEM, ABAQUS, Degree of soil loosening, Soil stress, Power consumption, Soil-Tool Interaction

Introduction

Tillage refers to the mechanical manipulation of soil to create apposite conditions for seed germination, root growth, and optimal crop growth **(Rao & Chaudhary, 2018)**. The significant energy demand of tillage operations, where nearly half of the total energy in crop production is consumed due to the substantial draft force required underscores the need to reduce tillage resistance **(Armin et al., 2015).** However, this energy consumption must be balanced against the tillage quality. This quality is defined by several key indicators, including the degree of soil loosening and the soil stress **(Usaborisut and Prasertkan, 2019; Bögel et al., 2016).**

Numerous studies on soil–tillage tool interactions have demonstrated that the magnitude of cutting forces and power requirements largely depends on soil properties (physical, mechanical, and dynamic characteristics), operational parameters of the implement (cutting depth, forward speed, and acceleration), and the geometric configuration of the tillage tool **(Cabrera et al., 2019)**. Efficient tillage power consumption is achieved by tool designs that reduce draft force and increase the degree of soil loosening **(Raper et al., 2005; Barr et al., 2016)**. Soil loosening and mixing the soil mechanically beneficial effect on soil properties **(Busari et al., 2015; Wilczewski et al., 2023)**. The study of soil-tool interaction employs three primary methodologies analytical calculation, physical experimentation, and numerical simulation. FEM and DEM are numerical simulations, which are widely used. FEM was applied in numerous studies to model soil-implement interactions for tools like plows and subsoilers **(Tamás 2009; Ibrahmi et al., 2014; Ucgul et al., 2018)**, which allows for optimization of tool design by accurately modeling soil particle movement and contact **(González et al., 2013)**. For Simulating soil behavior specifically, the Drucker-Pager model and its extended form are used to simulate where material yield is associated with hardening. Drucker-Pager model had various forms of yield surfaces. Such as linear, hyperbolic, or general exponential forms **(Abaqus, 2010).** Drucker-Pager model is integrated into FEM simulations to predict draft forces by modeling the soil as an elastoplastic material. This approach allows for detailed analysis of soil movement, stress distribution, and tool-soil interaction, providing accurate predictions of draft forces required for tillage operations **(Cabrera et al., 2019)**.

Arefi et al. (2022) developed a simulation model using FEM to predict draft force for non-winged chisel tool. They studied the interaction under levels of density (1.15 to 1.77) Mg/m3, tool speed (2, 3, and 5) km/h, tillage depths (0.15, 0.2, and 0.25) m and moisture content 15% of a sandy loam soil. They found that draft force increased with increasing the soil relative density, forward speed, and tillage depth and decreases with increasing relative water content.

Amoghin et al., (2025) used ABAQUS software to simulate soil tillage tool interaction by 3D FEM. The factors of study were tool speed (1, 1.5, 1.8, and 3 km h^{-1}), tool widths of (2.5, 3, 3.5, and 4 cm) at working depths of (10, 20, 30, and 40 cm) and four types of narrow tools with soil moisture 15%. They investigated the effect of the depth, speed and depth/width ratio of the narrow tillage tool on soil stress in clay loam soil. They found that tool speed has a major effect on soil stress. Maximum soil stress was recorded at highest speed of 3 km h^{-1} and width 4cm for the shallow depths. Furthermore, increasing the d/w ratio reduces the stress created in the soil. Where, at higher d/w ratios, the stress is distributed between a crescent-shaped failure in front of the tool and lateral failure, which lowers the overall stress concentration. **Yangeje and Korani (2022)** developed 3D simulations model for tillage tool interaction using FEM. Drucker-Pager model was used to calculate stress during soil-tool interaction in ABAQUS 6.10.1 software. They studied the effect of different tillage depths 0.06, 0.1, and 0.14 m and tool speed 2.5 kmh-1 in clay loam soil on soil stress concentration. Results from simulation indicated that there was a good agreement between simulation and experimental results. The maximum error model was about 7.3%. Tillage depth was significantly influenced at how stress is distributed in the soil. They found that with greater depth stress concentration decrease. At a shallow depth of 0.06 m, the highest stress intensity was on the topsoil surface. While as tillage depth increased to 0.1 and 0.14 m, the area of maximum stress shifted downward, away from the surface. At the deepest level of 0.14 m, the propagation of stress up to the soil surface was much less. **Song et al., (2025)** developed FE simulation model for the interaction between tillage tools and soil using ABAQUS software. They studied the stress of soil and subsoil for standard double-wing crank subsoilers and bionic subsoiler subsoiling tillage. They conducted simulation at tool speed 1.8 m/s, tillage depth (10, 20, 30, 40 and 50 cm) and bulk density (1.63 and 1.43 g/cm3) in clay soil. They found that the soil and subsoil model could accurately predict soil stress. Tool shape recorded a huge impact on soil stress. While, bionic subsoilers exhibit significantly lower soil stress distributions than standard subsoiler. The stress value of the subsoiler in the soil model plowing layer was greater than that in the soil model without a plough pan layer. Also, stated that relationship between bulk density and soil stress is nonlinear.

Amoghin et al., (2025) used ABAQUS software to simulate soil tillage tool interaction by 3D FEM. The factors of study were tool speed (1, 1.5, 1.8, and 3 km h^{-1}), tool widths of (2.5, 3, 3.5, and 4 cm) at tillage depths of (10, 20, 30, and 40 cm) and four types of narrow tools with soil moisture 15%. They investigated the effect of tillage depth and tool speed on degree of soil loosening in clay loam soil. They found that the effect of speed on degree soil loosening is evident at shallow depths. They attributed the reason to higher speeds accelerate soil failure which increases soil loosening. **Yangeje and Korani (2022)** developed 3D simulations model for tillage tool interaction using FEM. Drucker-Pager model was used to calculate stress during soil-tool interaction in ABAQUS 6.10.1 software. They studied the effect of different tillage depths 0.06, 0.1, and 0.14 m and tool speed 2.5 kmh-1 in clay loam soil on degree of soil loosening. They found that at shallow depth of 0.06 m tool performance was superiority for degree soil loosening which resulted from more visible soil deformation on the surface. **Song et al., (2025)** developed FE simulation model for the interaction between tillage tools and soil using ABAQUS software. They studied the stress of soil and subsoil for standard double-wing crank subsoilers and bionic subsoiler subsoiling tillage. They conducted simulation at tool speed 1.8 m/s, tillage depth (10, 20, 30, 40 and 50 cm) and bulk density (1.63 and 1.43 g/cm3) in clay soil. They found that FE analysis produced accurate simulations of the disturbance area of soil failure at the tool head and the crushing shape of the soil mass. Furthermore, shovel tools achieved good soil loosening. Furthermore, shovel tool achieved a good soil loosening effect, especially for improving the plowing layer.

Ibrahmi and Bentaher (2025) employed a 3D Finite Element Model (FEM) in ABAQUS to analyze power consumption during disc plow operation by simulating draught forces under various parameters. They investigated the influence of four operational factors tillage depth (varied from 100 to 300 mm) and tool speed (from 7.2 to 18 km/h). The increase in tillage depth from 100 to 300 mm resulted in increasing power consumption by 40%. Furthermore, as tool speed increased from 7.2 to 18 km/h power consumption increased by 15% for disc plow in sandy loam soil. **Song et al., (2025)** developed FE simulation model for the interaction between tillage tools and soil using ABAQUS software. They studied the stress of soil and subsoil for standard double-wing crank subsoilers and bionic subsoiler subsoiling tillage. They conducted simulation at tool speed 1.8 m/s, tillage depth (10, 20, 30, 40 and 50 cm) and bulk density (1.63 and 1.43 g/cm3) in clay soil. They studied the effect of bulk density on power consumption. They concluded that increasing soil bulk density resulted in increasing power consumption. They attributed this to higher mechanical resistance of soil.

The main aim of this study is to develop a simulation model to evaluate tillage quality for three simple tillage tools (shovel, sweep and winged) under various levels of both soil bulk density and tool operational parameters using ABAQUS software.

Materials and methods

1. The 3D-FEM Approach

The 3D FEM of soil-tillage tool interaction was developed using ABAQUS.2022 software. It consists of three rigid tools and a deformable soil box. ABAQUS/CAE modeling environment was used for creating them. The mesh density of soil box is very effective in the accuracy of FE simulation results in. So, for soil around the tool, a finer mesh size was used. It was fixed 0.03 m for soil around the tool. The element type (C3D8) was used for soil media and (R3D4) for rigid tools. Simulations were performed at three different depths, tool speeds, soil bulk density and tool shapes **Darwish- et al., (2025).**

2. Power consumption

Data of draft force for tillage tools was used from **Darwish et al., (2025**). It was converted to power consumption using Equations (1) **Rangapara et al. (2017):**

$$P = F_d \times V \tag{1}$$

Where:

P = power consumption (W).
F_d = draft force (N).
V = tool speed (m/s).

3. Factors influencing tillage quality

3.1 Degree of soil loosening

Degree of soil loosening refers to theoretical soil disturbance area and the surface-heaved soil area Eq. (2). It was determined using the established formula from (**Liu et al., 2025)**

$$\text{SL} = \frac{\text{Ae}}{\text{Ao}} \tag{2}$$

Where:

SL = degree of soil loosening (%)
Ae = The initial soil cut area (m^2)
Ao = The final disturbed area (m^2)

Initial soil cut area was the theoretical cross-sectional area of the soil directly engaged and cut by the tool before any deformation occurs. This area is red, orange, yellow and green regions as visualized in Figure (1). Also, final disturbed area represents the total cross-sectional area of the soil profile after the tillage tool has passed, which is known as blue regions.

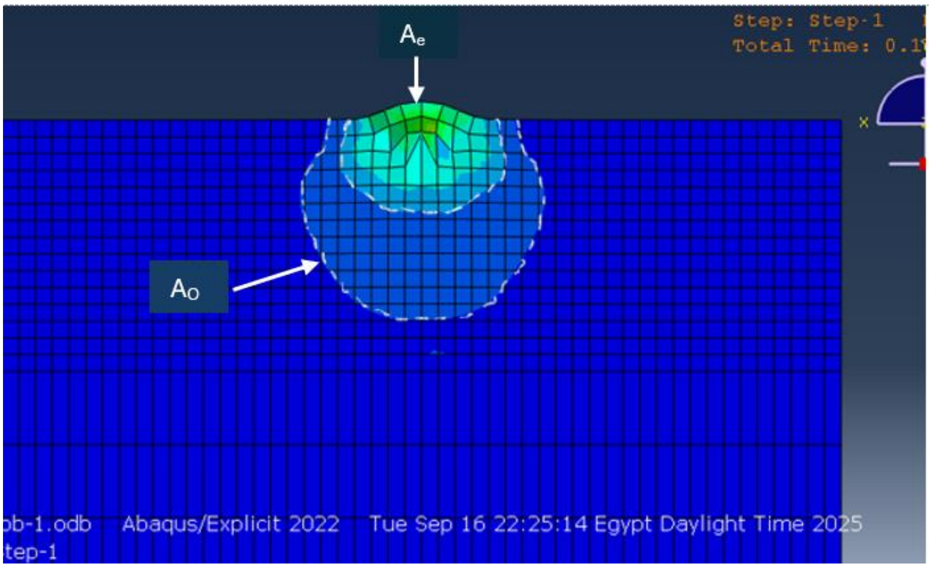

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Figure (1) Sectional view from simulation for final disturbed area and initial soil cut area

The cross-sectional areas were determined computationally using output results from the ABAQUS simulation. These areas were calculated by counting the number of disturbed elements by the known area of a single element 0.0009 m² (0.03 m × 0.03 m).

2.3.2 Soil stress

The Drucker-Pager yield criterion introduces the von Mises strength criterion into geotechnical analysis, and its equation expression is as follows **Song et al., (2025)**:

$$\alpha I_1 + \sqrt{J_2} - D = 0 \qquad (3)$$

Where:

I_1= the first invariant of the stress tensor

J_2= the second invariant of the stress bias

α and D= the Drucker–Prager strength parameters.

These can be calculated using the following equations.

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 \qquad (4)$$

$$J_2 = 1/6\ [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2] \qquad (5)$$

$$\alpha = \frac{2\sin\Phi}{\sqrt{3(3-3\sin\Phi)}} \qquad (6)$$

$$D = \frac{2\,c\cos\Phi}{\sqrt{3(3-3\sin\Phi)}} \qquad (7)$$

Where:

$\sigma 1$, $\sigma 2$ and $\sigma 3$= the first, second, and third principal stresses.

Φ= the internal friction angle.

The von Mises contour plot in a soil simulation effectively visualizes the intensity of the shear stress within the soil mass. The color gradient, which typically ranges from blue (low stress) to red (high stress), illustrates the spatial distribution and magnitude of this shearing action. The contour plot shows how the mechanical load from the tillage tool is transmitted through the soil. The gradient from high stress at the tool-soil interface to lower stress in the far-field soil.

Results and Discussion

1. Power consumption.

Data in Table 1 indicates the power consumption from simulation model for three simple tillage tools under different levels of tillage depth, tool speed and soil bulk density at 10% moister content of clay loam soil. Results indicated that power consumption increased by 60.66%, 59.55% and 34.27% when soil bulk density increased from 1300 to 1410 kg/m³ at tillage depth 0.05 m and tool speed 1.388 m/s for shovel, sweep, and winged tools, respectively. The highest value of power consumption was recorded with shovel tool under different levels of tillage depth, tool speed and soil bulk density. Nevertheless, sweep tool recorded the lowest value of power consumption under the same conditions. These findings were agreed with pervious findings of **Song et al. (2025)** for standard double-wing crank subsoilers and bionic subsoiler subsoiling tillage**.**

As tillage depth increased from 0.05 m to 0.1 m at soil bulk density 1300 kg/m³ and tool speed 0.83 m/s the power consumption was increased by 74.37%, 62.7% and 33.47% for shovel, sweep, and winged tools, respectively. Shovel tool recorded the highest value of power consumption for under different levels of tillage depth, tool speed and soil bulk density. In contrast sweep tool recorded the lowest value of power consumption under different levels of tillage depth, tool speed and soil bulk density. These findings were agreed with pervious findings of **Ibrahmi and Bentaher (2025)** for disc plow.

Furthermore, power consumption increased by 79.85%, 70.44% and 73.59% when tool speed increased from 0.83 to 2.22 m/s at tillage depth 0.05 m and soil bulk density 1350 kg/m³ for shovel, sweep, and winged tools, respectively. Shovel tool recorded the highest value of power consumption under different levels of tillage depth, tool speed and soil bulk density. Nevertheless, sweep tool recorded the lowest value of power consumption under different levels of tillage depth, tool speed and soil bulk density. These findings were agreed with pervious findings of **Ibrahmi and Bentaher (2025)** for disc plow.

Results indicated that maximum power consumption was 1958.7 W recorded for sweep tool at tillage depth 0.1 m, tool speed 2.22 m/s and soil bulk density of 1410 kg/m³. In contrast, the minimum value of power consumption was 77.9 W for shovel tool at tillage depth 0.05 m, tool speed 0.83 m/s and soil bulk density of 1300 kg/m³. Moreover, the moderate value of power consumption was obtained with winged tool.

Data in Table 1 was used to derive a relation between power consumption in relation to tillage depth, tool speed and soil bulk density for three tillage tools by using multivariate regression method. The equations derived are:

For shovel tool:

$$p = -3689.88 + (7646.66\times d) + (424.946\times v) + (2.213\times pd)$$

For sweep tool:

$$P = -6136.586 + (9226.444\times d) + (697.024\times v) + (3.864\times pd)$$

For winged tool:

$$P = -4478.272 + (7551.778\times d) + (601.043\times v) + (2.757\times pd)$$

Where:

P = power consumption (W)

v = tool speed (m/s)

d = tillage depth (m)

pd = soil bulk density (kg/m³)

Table 1. Power consumption results from finite element simulation.

Bulk Density kg/m^3 **moisture content 10%**		**1300**			**1350**			**1410**		
Depth	Speed	0.83	1.388	2.22	0.83	1.388	2.22	0.83	1.388	2.22
m	m/s	Power Consumption (W)								
0.05	Shovel chisel tool	77.9	170.6	376.7	92.3	203	458.2	213.5	433.7	858.2
	Sweep chisel tool	117	282	693	295.6	585.8	1000.3	363.7	697.2	1385.1
	Winged chisel tool	190	330.6	715	235.1	494.4	890.4	257.4	502.1	1042.7
0.075	Shovel chisel tool	158.7	458.6	552.1	199.3	439.7	825.4	304.6	505.2	1053.5
	Sweep chisel tool	223.2	459.7	943.7	374.5	562.2	1403.8	556.26	960.9	1558.4
	Winged chisel tool	229	392	873.3	398.7	701.9	1255.8	432.7	799.7	1329.5
0.1	Shovel chisel tool	304	569	888	416	660	1118.2	384.3	670.7	1314.9
	Sweep chisel tool	313.7	891.5	1446	507.8	1076	1642.8	580.3	1154.8	1958.7
	Winged chisel tool	285.6	516.2	1119.1	492.1	923.4	1636.6	501	956	1626

Figure 2 shows a relation between the power consumption from simulated results (Tables 1) and from measured data (Table 2), which was obtained by **Afify, (1999)** for three simple tillage tools. The simulated results are in agreement with that from measured data with $R^2 = 0.968$.

Table 2. Power consumption from soil bin tests under same conditions of the model (Afify., 1999).

Bulk Density kg/m^3 **moisture content 10%**		**1300**			**1350**			**1410**		
Depth	Speed	0.83	1.388	2.22	0.83	1.388	2.22	0.83	1.388	2.22
m	m/s	Power Consumption (W)								
0.05	Shovel chisel tool	72.3	154.6	329.4	84	201.3	406.7	191	437.5	826.3
	Sweep chisel tool	126.3	243.3	661.4	239.5	504	829.3	298.2	565.1	1089
	Winged chisel tool	151	263.3	569.1	176	391.7	758.1	183	464.9	903.9
0.075	Shovel chisel tool	149.5	383.4	536.1	213.3	410.6	811.8	293.9	495.5	1048
	Sweep chisel tool	195.3	385.6	840.1	304	592.4	1134.7	437.9	844.2	1439.5
	Winged chisel tool	226.7	388.5	646	282.4	551.6	901.5	353.7	646	991.8
0.1	Shovel chisel tool	251.6	508.6	758.1	372.2	591	1110.4	377.1	663	1298.5
	Sweep chisel tool	310.6	769.5	1235.2	407.8	888.5	1505.4	509	1060.5	1770.5

	Winged chisel tool	298.6	574.1	1031	401.6	799.3	1451.7	451	849.3	1746

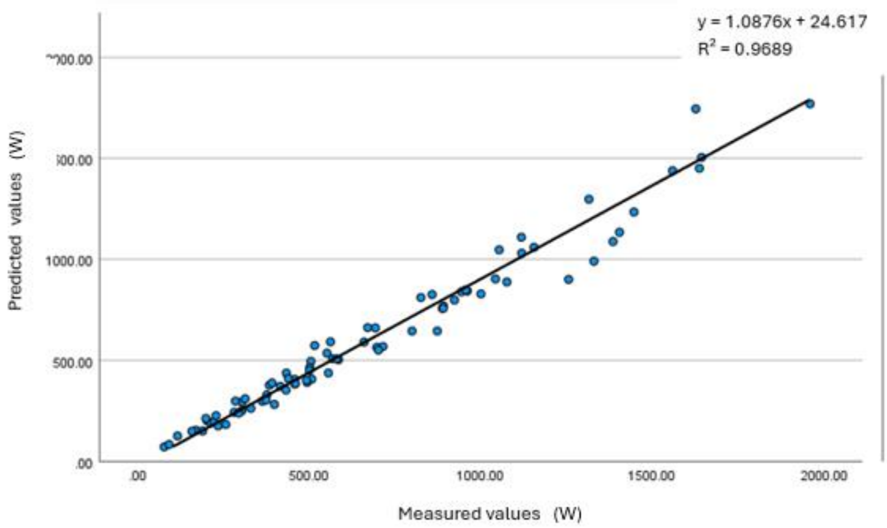
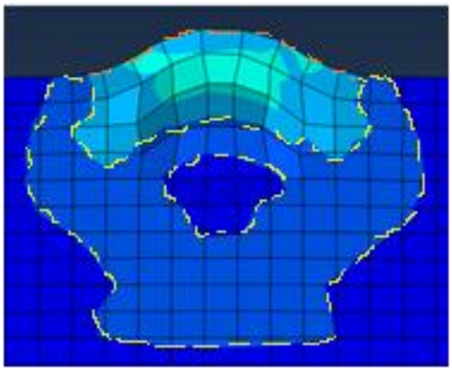


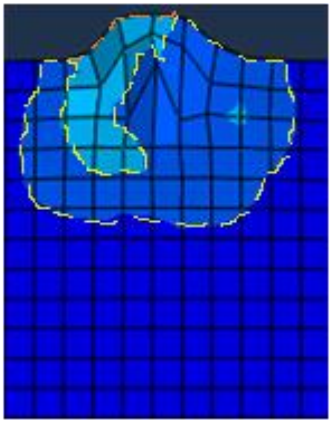
Figure (2) Relation between measured and simulated power consumption.

3.2 Degree of soil loosening.

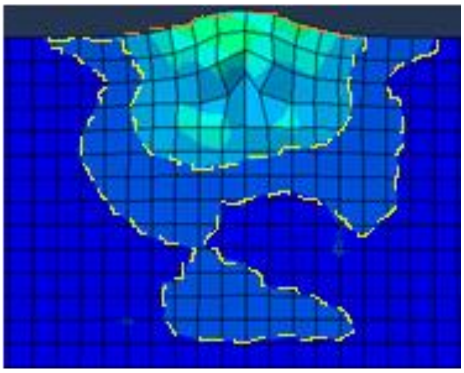
Figures from 3 to 6 show sectional view from simulation of degree of soil loosening in soil box of FE for different tools shapes under various levels of tillage depth, tool speed and soil bulk density at moisture content 10%. It's cleared that as tillage depth, tool speed and soil bulk density increased the deformation in front of the tool changed. Therefore, cutting area varies between tools. So, the degree of soil loosening varies between tools under different operation conditions, as confirmed by **Amoghin et al., (2025) and Song et al., (2025)**

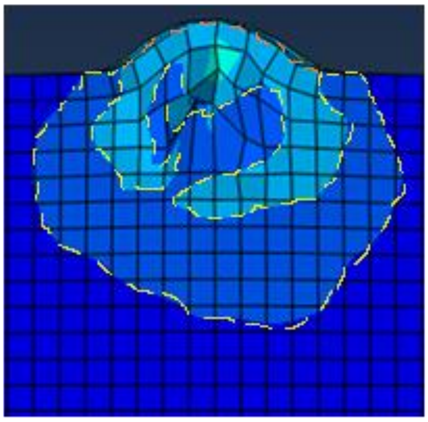


Shovel tool

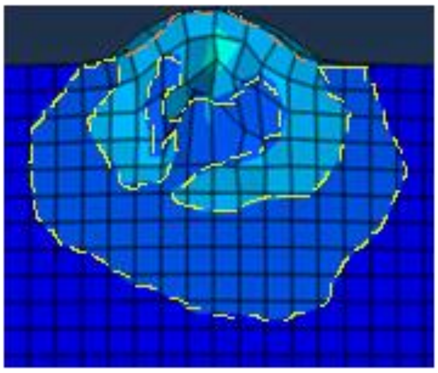


0.05 m





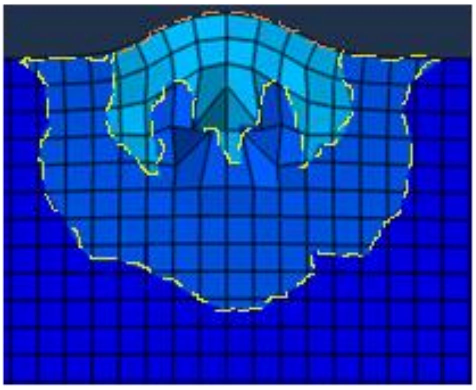
Sweep tool



Winged tool

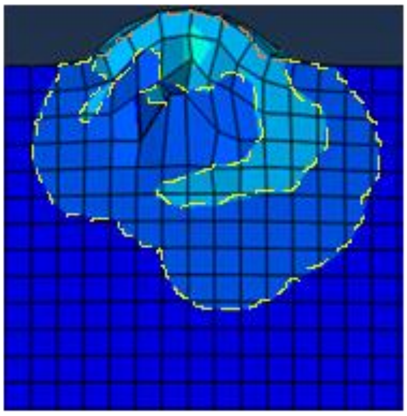
Figure (3) Sectional view from simulation of degree of soil loosening for different tools shape, at tillage depth 0.075m, tool speed 1.388 m/s and bulk density 1350kg/m^3.

0.075 m

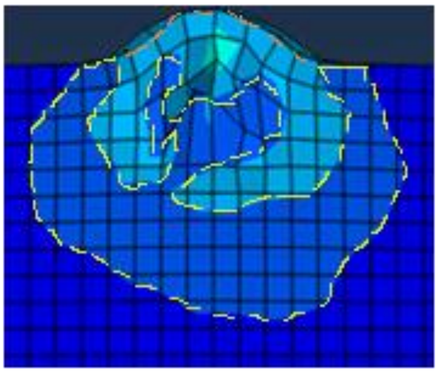


0.1 m

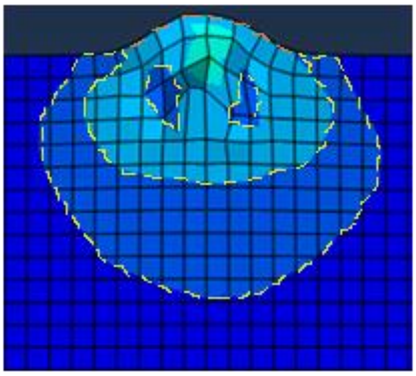
Figure (4) Sectional view from simulation of degree of soil loosening at different levels of tillage depths, at tool speed 1.388 m/s and soil bulk density 1350 kg/m^3 for winged tool.



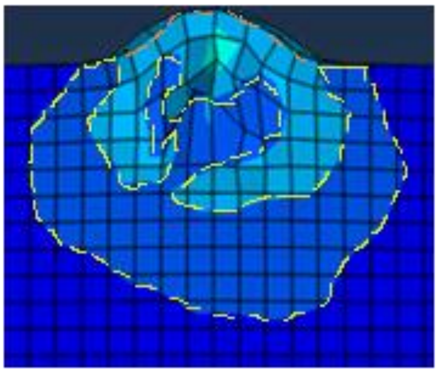
0.83 m/s



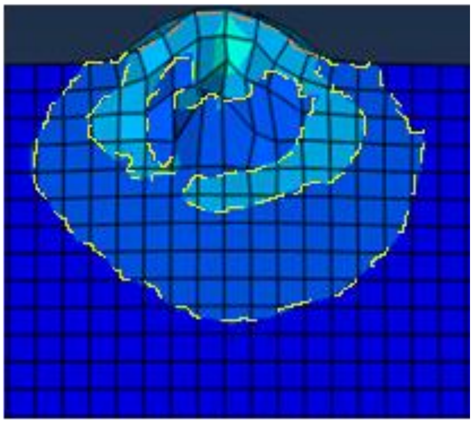
1.388 m/s



1300 kg/m^3

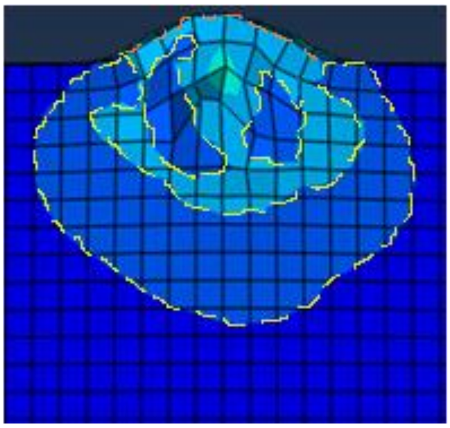


1350 kg/m^3



2.22 m/s

Figure (5) Sectional view from simulation of degree of soil loosening at different levels of tool speeds, at tillage depth 0.075 m and soil bulk density 1350 kg/m^3 for winged tool.



1410 kg/m^3

Figure (6) Sectional view from simulation of degree of soil loosening at different levels of soil bulk density, at tool speed 1.388 m/s and tillage depth 0.075 m for winged tool.

Data in Table 3 indicates the degree of soil loosening from simulation model for three simple tillage tools under different levels of tillage depth, tool speed and soil bulk density at 10% moister content of clay loam soil. Results indicated that degree of soil loosening decreased from 56.52% to 54.54% for shovel tool and from 44.11% to 37.5% for sweep tool and from 57% to 63.15% for winged tool as soil bulk density increased from 1300 kg/m^3 to 1410 kg/m^3 at tillage depth 0.05m and tool speed 2.22 m/s. Results showed that shovel tool achieve a good degree of soil loosening. These results are consistent with those of **Song et al. (2025)** for standard double-wing crank subsoilers and bionic subsoiler subsoiling tillage.

As tillage depth increased from 0.05 m to 0.1 m at tool speed 0.83 and soil bulk density 1300 kg/m^3 the degree of soil loosening recorded the similar trend which decreased from 56.25% to 45.9% for shovel tool and from 51.35% to 42.5% for sweep tool and from 61% to 50% for winged tool. Results showed that winged tool recorded a good value of degree of soil loosening. These results agreed with results of **Yangeje and Korani (2022)**.

Conversely, the degree of soil loosening increased from 52.25% to 56.25% for shovel tool and from 60% to 61.5% for winged tool but it decreased from 47.6 to 43.47% for sweep tool when tool speed increased from 0.83 to 2.22 m/s at tillage depth 0.075 m and soil bulk density 1350 kg/m^3. Results showed that the highest value of degree of soil loosening recorded by winged tool. These results were consistent with those of **Amoghin et al., (2025).**

Results indicated that maximum degree of soil loosening was 65.71% recorded for shovel tool at tillage depth 0.075 m, tool speed 2.22 m/s and soil bulk density 1410 kg/m^3. Furthermore, the minimum value of degree of soil loosening was 31.5% for sweep tool at tillage depth 0.1 m, tool speed 2.22 m/s, and soil bulk density 1410 kg/m^3. Moreover, the moderate value of power consumption was obtained with winged tool.

Data in Table 3 was used to derive a relation between degree of soil loosening in relation to tillage depth, tool speed and soil bulk density for three tillage tools by using multivariate regression method. The equations derived are:

For shovel tool:

$$SL = 73.896 + (-211.044\times d) + (1.182\times v) + (-0.005\times pd) \quad R^2=0.88 \quad (11)$$

For sweep tool:

$$SL = 82.456 + (-207.778\times d) + (0.313\times v) + (-0.015\times pd) \quad R^2=0.94 \quad (12)$$

For winged tool:

$$SL = 87.261 + (-174.222\times d) + (1.897\times v) + (-0.019\times pd) \quad R^2=0.86 \quad (13)$$

Where:

SL= degree of soil loosening
v = tool speed (m/s)
d = tillage depth (m)
pd = soil bulk density (kg/m^3)

Table 3. Degree of soil loosening results from finite element simulation**.**

Bulk Density kg/m³		**1300**			**1350**			**1410**		
moisture content 10%										
Depth	Speed	0.83	1.388	2.22	0.83	1.388	2.22	0.83	1.388	2.22
m	m/s	Degree of Soil Loosening (%)								
0.05	Shovel chisel tool	56.25	59	56.52	57.14	59	54.54	59.25	61.53	54.54
	Sweep chisel tool	51.35	46.66	44.11	48	41.37	40	41.66	37.99	37.5
	Winged chisel tool	61	56	57	60.5	61.7	62.2	55.8	58.82	63.15
0.075	Shovel chisel tool	50.87	55.8	54.16	52.17	53.12	56.25	54.9	62.9	65.71
	Sweep chisel tool	49.12	43.75	41.66	47.6	38.88	43.47	37.5	34.88	33.33
	Winged chisel tool	55	52.6	53.5	60	60.7	61.5	53.33	56.16	62.5
0.1	Shovel chisel tool	45.9	54.34	52.63	50	51.92	54.54	51.56	58.46	62.85
	Sweep chisel tool	42.5	40.4	38.5	40	38	34.78	37	32.5	31.5
	Winged chisel tool	50	48.8	51.56	58.57	57.33	59	50	51.6	53.5

Figure 7 shows a relation between the degree of soil loosening from simulated results (Tables 3) and from measured data (Table 4), which was obtained by **Afify, (1999)** for three simple tillage tools. The simulated results are in agreement with that from measured data with $R^2 = 0.983$.

Table 4. Degree of soil loosening from soil bin tests under same conditions of the model (Afify., 1999).

Bulk Density kg/m³		**1300**			**1350**			**1410**		
moisture content 10%										
Depth	Speed	0.83	1.388	2.22	0.83	1.388	2.22	0.83	1.388	2.22
m	m/s	Degree of Soil Loosening (%)								
0.05	Shovel chisel tool	56.04	58.62	56.01	57.01	60.40	57.27	58.68	60.73	57.55
	Sweep chisel tool	53.6	51.80	50.61	53.45	52.23	51.74	50.37	51.95	52.16
	Winged chisel tool	57.26	54.55	56.08	53.82	53.96	55.59	52.05	53.28	57.48
0.075	Shovel chisel tool	51.46	54.47	53.98	50.58	53.68	55.35	50.64	52.44	54.90
	Sweep chisel tool	48.92	48.03	47.49	48.12	47.62	47.56	45.53	45.19	47.65
	Winged chisel tool	52.61	51.32	54	51.27	51.80	53.20	48.77	50.72	52.45
0.1	Shovel chisel tool	50.26	47.95	49.39	46.28	46.75	48.56	44.27	45.70	48.18
	Sweep chisel tool	41.92	42.97	43.54	41.79	39.99	42.87	39.03	39.85	42.45
	Winged chisel tool	47.13	46.51	48.10	45.16	46.65	48.31	41.58	44.75	47.48

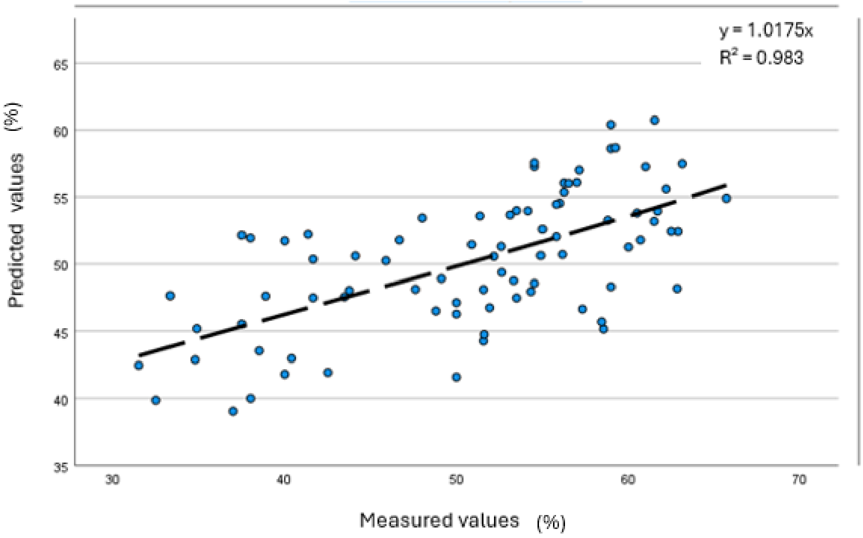
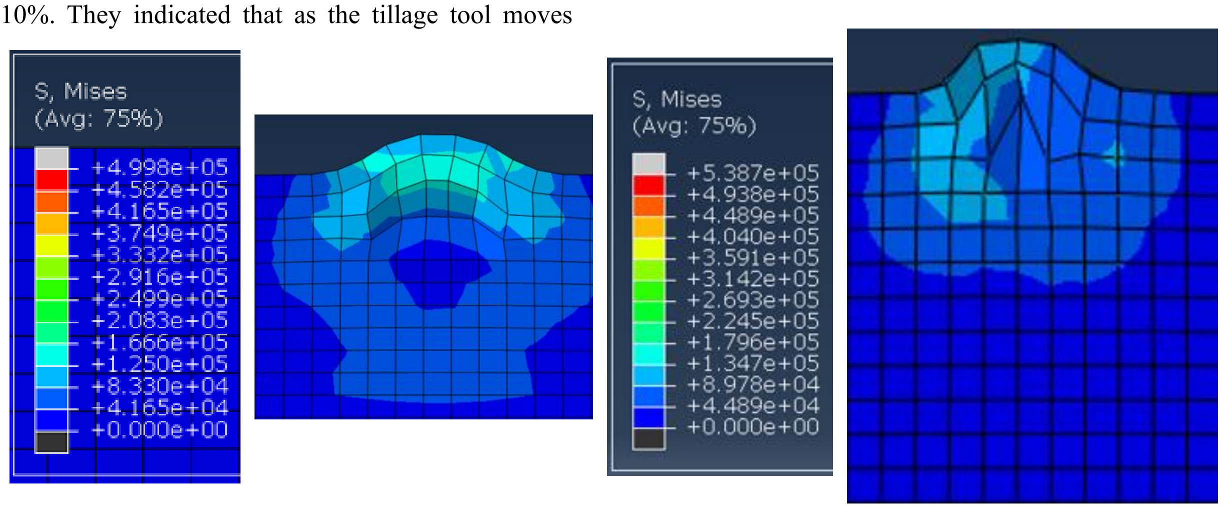


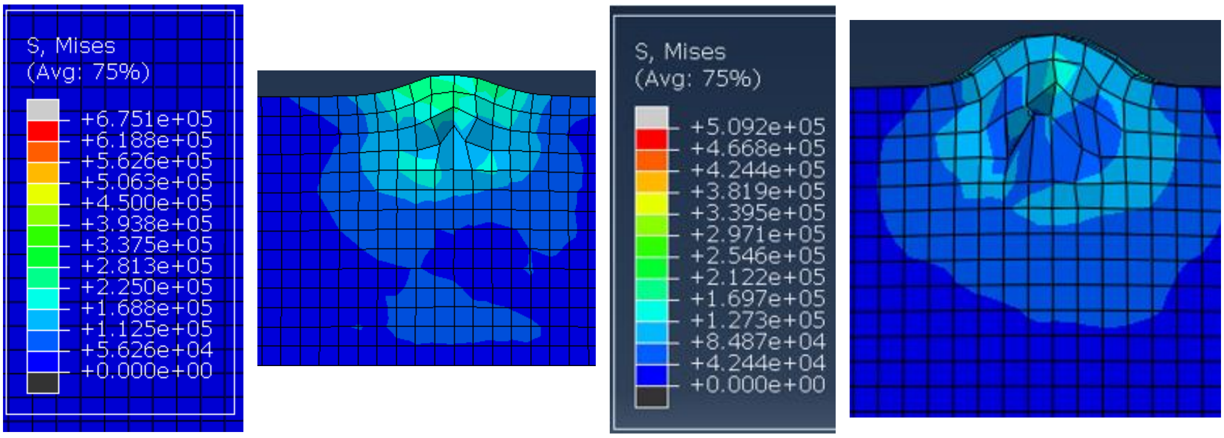
Figure (7) Correlation between measured and simulated degree of soil loosening.

3.3 Soil stress

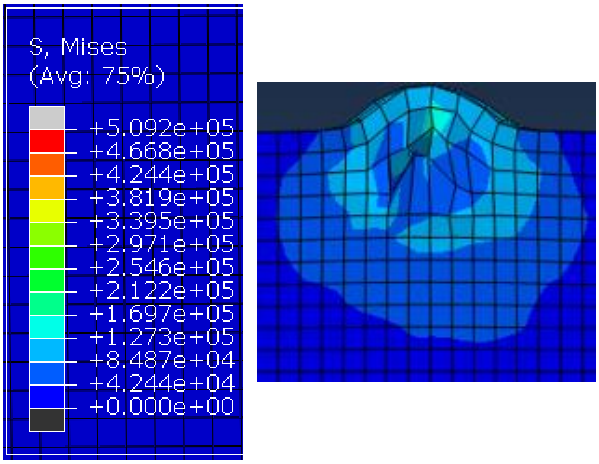
Figures from 8 to 11 show the Von mises stresses and sectional view for stress distribution under different levels of tillage depths, tool speeds and soil bulk density for three tillage tools at moisture content 10%. They indicated that as the tillage tool moves forward, it causes changes at stress distribution in soil box. Therefore, the deformation in front of the tool varies under different operation conditions, as confirmed by **Yangeje and Korani (2022) and Song et al., (2025).**



Shovel tool 0.05 m



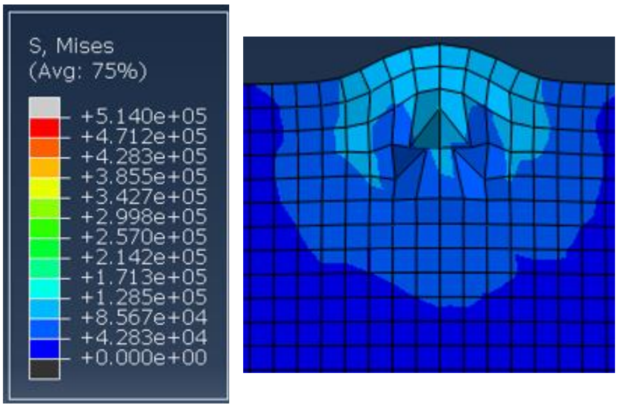
Sweep tool 0.075 m



Winged tool

a b

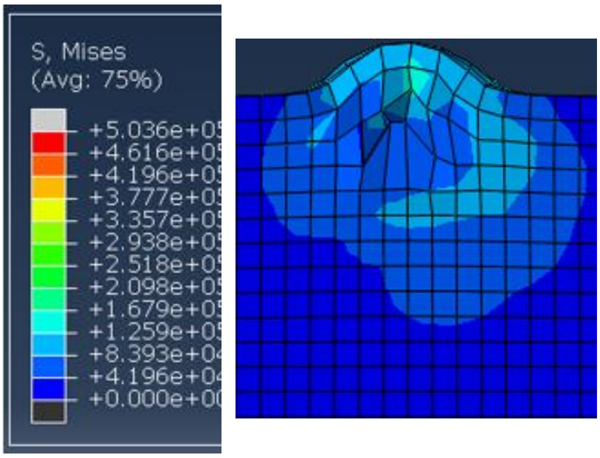
Figure (8) a. Von mises stresses. b. sectional view for stress distribution for different tools shape, at tillage depth 0.075m, tool speed 1.388 m/s and soil bulk density 1350kg/m^3.



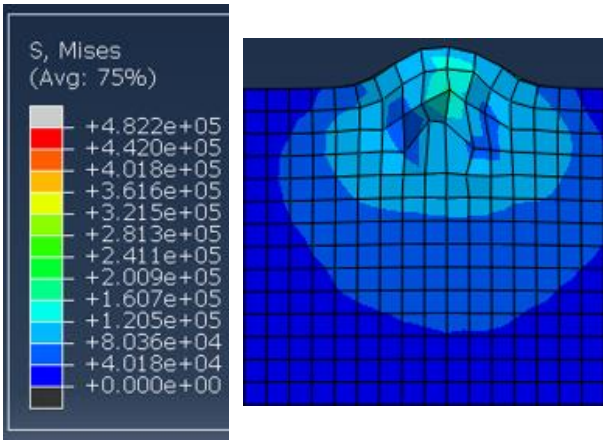
0.1 m

a B

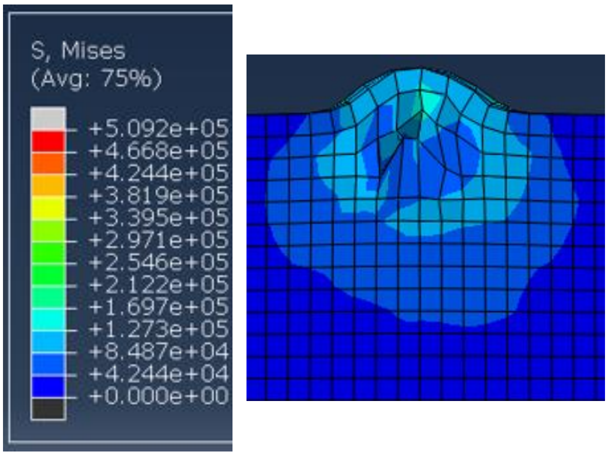
Figure (9) a. Von mises stresses. b. sectional view for stress distribution at levels different tillage depths, at tool speed 1.388 m/s and soil bulk density 1350 kg/m^3 for winged tool.



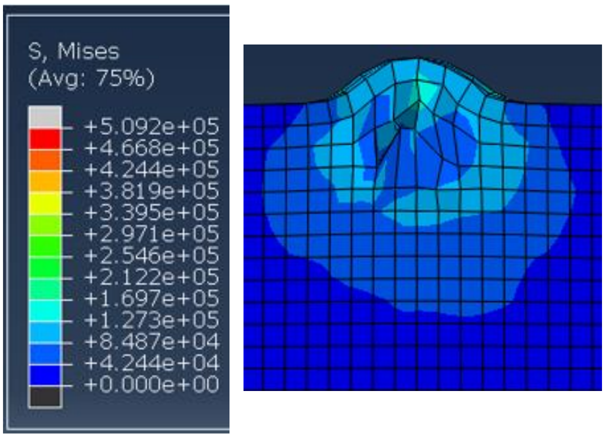
0.83 m/s



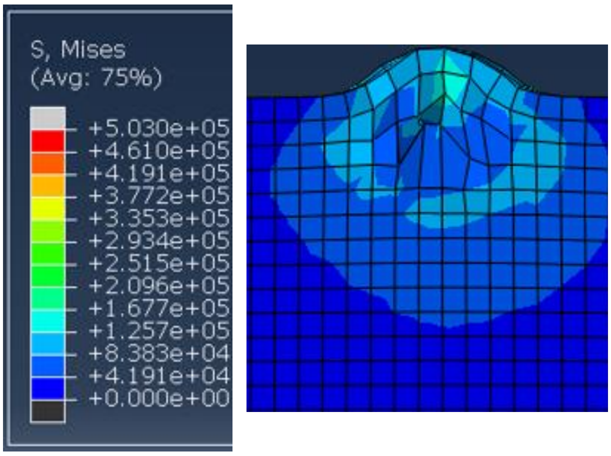
1300 kg/m^3



1.388 m/s



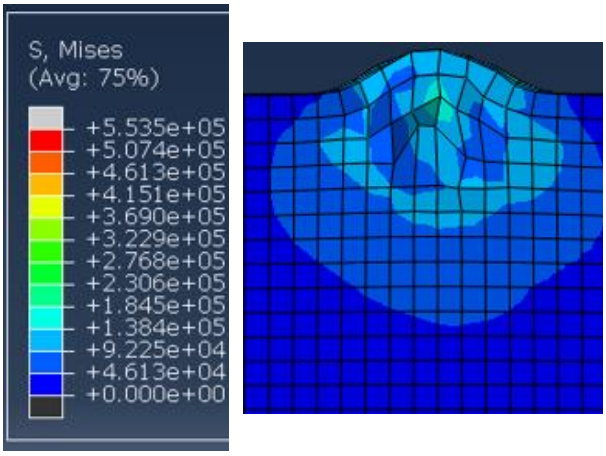
1350 kg/m^3



2.22 m/s

a b

Figure (10) a. Von mises stresses. b. sectional view for stress distribution at levels different tool speeds, at tillage depth 0.075 m and bulk density 1350 kg/m^3.



1410 kg/m^3

a b

Figure (11) a. Von mises stresses. b. sectional view for stress distribution at levels different soil bulk density (b), at tool speed 1.388 m/s and tillage depth 0.075 m for winged tool.

Data in Table 5 indicates the soil stresses from simulation model for three simple tillage tools under different levels of tillage depth, tool speed and soil bulk density at 10% moister content of clay loam soil. Results indicated that soil stress increased by 32.3%, 11.18% and 13.75% when soil bulk density increased from 1300 to 1410 kg/m³ at tillage depth 0.075 m and tool speed 0.83 m/s for shovel, sweep, and winged tools, respectively. The highest value of soil stress was recorded for shovel tool under different levels of tillage depth, tool speed and soil bulk density. Nevertheless, sweep tool recorded the lowest value of soil stress under different levels of tillage depth, tool speed and soil bulk density. These findings align with the findings of **Song et al. (2025).**

Table 5. Soil stresses results from finite element simulation.

Bulk Density kg/m^3 **moisture content 10%**		**1300**			**1350**			**1410**		
Depth m	Speed m/s	0.83	1.388	2.22	0.83	1.388	2.22	0.83	1.388	2.22
		Soil Stress (kN/m^2)								
0.05	Shovel chisel tool	388	404	520	319	362	427	464	525	637
	Sweep chisel tool	488	496	516	389	490	480	854	470	460
	Winged chisel tool	353	360	362	523	538	520	555	570	550
0.075	Shovel chisel tool	430	495	546	290	499	527	569	644	827
	Sweep chisel tool	474	643	1170	549	675	691	527	504	1110
	Winged chisel tool	480	482	477	503	509	503	546	553	550
0.1	Shovel chisel tool	336	589	735	568	590	1060	626	679	970
	Sweep chisel tool	602	498	748	702	768	650	648	717	824
	Winged chisel tool	468	489	478	493	514	512	540	545	565

As tillage depth increased from 0.05 m to 0.1 m at tool speed 1.388 m/s and soil bulk density 1300 kg/m^3 resulted in increasing soil stress by 45.7%, 0.40% and 35.8% for shovel, sweep, and winged tools, respectively. The highest value recorded by shovel tool under different levels of tillage depth, tool speed and soil bulk density. On the other hand, lowest value of soil stress was recorded for sweep tool under different levels of tillage depth, tool speed and soil bulk density. These results were agreement with the results of **Amoghin et al., (2025).**

Furthermore, increasing tool speed from 0.83 to 2.22 m/s at tillage depth 0.05 m and soil bulk density 1300 kg/m^3, soil stress increased by 34%, 5.7%, and 2.5% for shovel, sweep, and winged tools, respectively. The maximum value of soil stress was recorded for shovel tool under different levels of tillage depth, tool speed and soil bulk density. Whereas the lowest value of soil stress was recorded for winged tool under different levels of tillage depth, tool speed and soil bulk density. These results were consistent with those of **Amoghin et al., (2025).**

Sweep tool was recorded the highest soil stress values 1170 kN/m^2 at tillage depth 0.075 m, tool speed 2.22 m/s, and soil bulk density 1300 kg/m^3. Furthermore, the minimum value of soil stress was 290 kN/m^2 for shovel tool at tillage depth 0.075 m, tool speed 0.83 m/s, and soil bulk density 1350 kg/m^3. Moreover, the moderate value of soil stress was obtained with winged tool.

Conclusions

Results of this study could be concluded as the following:

1- Power consumption increased with increase in tool speed, tillage depth and soil bulk density for the three simple tillage tools. The highest value of power consumption was obtained by sweep tool (198.7 W) at 2.22 m/s tool speed, 0.1 m tillage depth and 1400 kg/m^3 soil bulk density. Conversely, the lowest value of power consumption was recorded with shovel tool (77.9 W) at 0.05 m tillage depth, 0.83 m/s tool speed and 1300 kg/m^3 of soil bulk density. A good agreement was found between results from simulation model and measured data from soil bin for power consumption with $R^2 = 0.96$.

2- Degree of soil loosening decreased as tillage depth and soil bulk density increased for the three simple tillage tools. However, the degree of soil loosening increased for shovel and winged tool with increase in tool speed. The maximum value of degree of soil loosening recorded with shovel tool (65.71 %) at tillage depth 0.075, tool speed 2.22 m/s and soil bulk density 1410 kg/m^3. Conversely, the minimum value of degree of soil loosening recorded with sweep tool (31.5 %) at tillage depth 0.1, tool speed 2.22 m/s and soil bulk density 1410 kg/m^3. The relation between results from simulation model and soil bin was an agreement by $R^2 = 0.98$ for degree of soil loosening.

3- Soil stress increased with increase in tool speed, tillage depth and soil bulk density. The highest value of soil stress was obtained by sweep tool (1170 kN/m^2) at tillage depth 0.075 m, tool speed 2.22 m/s and soil bulk density 1300 kg/m^3. However, shovel tool recorded the lowest value of soil stress (290 kN/m^2) at tillage depth 0.075 m, tool speed 0.83 m/s and soil bulk density 1350 kg/m^3.

4- The finite element model is an effective tool for evaluating the performance of simple tillage tools, as it provides an efficient alternative to traditional methods in developing tillage tools.

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