

Simulation Model for Predicting Draft and Vertical Force of Simple Tillage Tools Using Finite Element Method

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Abstract

With advances in computer science, numerical methods like FEM, DEM, and ANN have been employed to study soil-tillage tool interaction, evolving from 2D to 3D analyses for complex tool shapes. FEM was supposed the soil as continuous materials with different behavior models. Thus, the main objective of this work is to develop a simulation model for predicting draft and vertical force and consequently power requirements affecting on tillage tools as a function of soil, tool and operational conditions parameters using finite element method. In order to study the interaction between soil and tool, a three-dimensional model was performed using Abaqus Explicit Software. The soil was modeled with linear forms of Drucker-Prager model, while the tool was considered as a rigid body. The effect of soil bulk density 1.30, 1.35 and 1.41 Mg/m³ at moisture content 10%, tool speed 3, 5 and 8 km/h and operational depth 0.05, 0.075 and 0.1 m for shovel – sweep – winged chisel tool on the draft and vertical forces were investigated. Triaxial tests were carried out using clay loam soil to determine the shear strength parameters such as soil cohesion and internal friction angle. The results found that the highest draft and vertical force values were recorded with high tillage depths and high tool speeds. The highest value of draft force was 69% for shovel chisel tool and the highest value of vertical force was 52% for sweep chisel tool when tillage depth increased from 0.05 to 0.1 m at different levels of soil and operation parameters. Results indicated that finite element method allows researchers to optimize tool designs to reduce energy consumption and improve soil handling.

Keywords: FEM, ABAQUS Explicit, draft force, vertical force, rigid body, Drucker-Prager model.

1. Introduction

Soil tillage is a fundamental agricultural practice that shares soil structure, influences crop growth, and determines the efficiency of farming operations. The interaction between soil and tillage tools is a complex phenomenon governed by factors such as soil properties, tool geometry, and operational parameters. Among the critical metrics used to evaluate this interaction are vertical force and draft force, which represent the vertical penetration resistance and horizontal pulling resistance encountered by the tool, respectively. These forces are key indicators of tillage performance, as they directly impact energy consumption, soil disturbance, and the quality of seedbed preparation. Accurate estimation of requirement draft force and vertical force of tillage implements is a crucial stage for farm machinery selection and management. Draft and vertical forces are pivotal in tractor-implement interactions, the

complexity of accurately measuring and managing these forces presents challenges. Current tillage systems (e.g. conventional tillage) may be too intricate for consistent energy-efficient operations, indicating a need for further research and development to simplify and enhance these technologies for broader adoption. So, draft and vertical force are the most important factors to study interaction between soil and tillage tool. It plays an essential role in tillage tools management.

The measurement of draft and vertical forces of tillage implements depends on establishing relationship between soil parameters (such as bulk density and internal friction angle), tool parameters (such as speed, share, and rake angle), and operational parameters (such as tillage depth [2, 8]. [8] developed a 3D FEM model using ABAQUS software to analysis the impact of depth and speed on soil stress and draft. They studied the effect of tool width (0.25- 0.3- 0.35 and 0.4) m tool

speed (1- 1.5- 1.8 - and 3) km/h and tillage depths (0.1, 0.2, 0.2, and 0.4) m with a constant length of 1 m under varying operational conditions in clay loam at soil moisture content 15%. Results indicated that higher forward speeds significantly increased soil stress and draft force. Additionally, increasing tillage depth also contributed to higher draft requirements. [32, 25] reported that the draft forces on implements increase significantly with speed and the relationship varies from linear to quadratic. [37] made a simulation model for predicting draft and vertical force for chisel tool in sandy loam soil under three levels of bulk density (1.338 – 1.605 – 1.781) Mg/m³, three levels of speed (4 – 8 - 12) km/h at tillage depths (0.025 – 0.05 – 0.075 – 0.1) m. They found that increasing in bulk density causing a high increase in draft force and a small increase in vertical force [9] developed a simulation model using FEM to predict draft force for non-winged chisel tool. They studied the interaction under levels from 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 explained that high bulk density leads to increases in soil mechanical properties, such as internal friction angle, cohesion, Poisson's ratio, and modulus of elasticity. [7] investigated the effect of tillage depth on draft force. They found that an increase in draft force was primarily due to the greater interaction area between the tillage tool and the soil, as well as the larger volume of soil being cut and displaced. This resulted in higher soil mechanical resistance, as indicated by the soil cone index. Additionally, the increase in inertial forces, caused by the need to accelerate a greater mass of soil, further contributed to the rise in the soil's reaction force against the tillage tool. [2] studied the effect of three levels of tillage depth (0.1-0.2-0.3) m, three levels of tool speed (2-5-7) km/h and different types of tillage tools at different levels of density. They found that at high level of bulk density, vertical force increased for all tillage tools.

They explained that compacted soils have higher mechanical strength, which increases the vertical force required for plowing. This is particularly evident in soils with high clay content, where maximum strength levels are observed in the dry, compacted state. [14] used Finite Element Model (FEM) to predict the soil behavior disturbed by tillage tool, as well as the necessary draft force to break it. They studied the effect of tillage depth and tool speed on draft force

Studying the soil-tool interactions can be classified into three ways: analytical calculation, physical experiments, and numerical methods. Theoretical and numerical analysis are validated by physical testing. Thus, numerical simulation is becoming the most popular method because it provides a cost-effective method for investigating soil-tool interaction and provides detailed insights into describing and understanding soil-cutting processes, such as soil movement and stress, which can be directly assessed at any given time [3, 29]. Simulation of soil-tool interaction in tillage is a difficult job. Numerical methods like finite element method (FEM) [34, 21, 33, 37, 15, 9, 30, 8] and discrete element method (DEM) [24, 20, 35, 37, 40, 36] are widely used to model the soil-tillage tools interaction. [21] performed research to study the influence of tillage depth from 0.05 to 0.3 m and tool speed 3.6 km/h on the tillage force components using FEM. They used the linear form of the Drucker-Pager yield criterion to model the soil using ABAQUS software. Their results indicated that Depth has a great influence on draft force and to a lesser extent on vertical force. They found that FEM is a reliable and accurate method to study the influence of tool geometry parameters on draft force. A numerical-statistical hybrid model was developed to estimate the draft force requirement of a subsoiler by [28]. They modeled the draft force of the subsoiler as functions of tillage depth, forward speed, and soil physical properties. Regression equations were developed to indicate the relationship between draft force and soil

bulk density and water content. They reported that the draft force varied linearly with moisture content and non-linearly with bulk density.

There are several commercial software packages to simulate soil-tillage tool interactions using finite element method. These include ANSYS (ANalysis SYStem), ABAQUS (calculating tool-symbolizing computation and engineering calculation), LS-DYNA (Livermore Software - DYNAmics), and EDEM (Engineering Discrete Element Method) [12, 33, 41]. Several studies have used ABAQUS to model the interaction between tillage tools (e.g., plows, cultivators, and subsoilers) and soil. Numerical modeling methods have significantly enhanced the accuracy of draft force prediction, often exceeding 90%, as demonstrated by [36, 39]. The stress-strain behavior of agricultural soils is inherently complex and challenging to characterize. Over the years, various criteria, including Mohr-Coulomb, Drucker-Prager, and Cam-Clay, have been employed to simulate soil behavior, as highlighted by researchers such as [13, 19, 27, 21, 8]. The Drucker-Prager model is particularly effective for modeling frictional materials like rocks and soils, as it relies on a direct relationship between material strength and stress level [38]. This model has been widely utilized to predict draft forces during tillage operations, a critical parameter for optimizing tillage tool design and minimizing energy consumption. Drucker-Prager model has been extensively used to predict draft forces during tillage operations. Draft force is a critical parameter for optimizing tillage tool design and reducing energy consumption. Studies have shown that the Drucker-Prager model can accurately simulate soil-tool interactions and predict draft forces with high precision. [12] used the Drucker-Prager model to simulate the interaction between a plow and soil, achieving good agreement between predicted and measured draft forces. The study highlighted the model's ability to capture the effects of soil cohesion and friction on draft force with the prediction accuracy

upper 98%. [41] employed the Drucker-Prager model to study the performance of subsoilers in cohesive soils, demonstrating its effectiveness in predicting draft forces and soil failure patterns. Drucker-Prager model is well-suited for simulating soil deformation and failure mechanisms during tillage. It can accurately represent shear zones, soil flow patterns, and failure surfaces around tillage tools. [33] used the Drucker-Prager model to analyze soil failure and deformation during the operation of a disc plow. The study demonstrated the model's capability to visualize soil disturbance and optimize tool geometry for reduced energy consumption. [36] applied the Drucker-Prager model to study soil-tool interactions in cohesive soils, showing that the model could effectively predict soil failure and draft forces under varying operating conditions.

The main aim of the study is to investigate the effect of soil parameters, tool parameters and operational parameters on predicting draft and vertical force of tillage tools using finite element method.

2. Materials and methods

2.1 Parameters for soil and tillage tool

Running the program was carried at computer lab throw 2023 and 2024 in Department of Biosystems Engineering, Collage of Agriculture, Benha University, Egypt. Soil mechanical properties resulted from Triaxial tests for clay loam soil are illustrated in Table (1). These were cohesion force, internal friction angle and coefficient of soil-soil friction under various levels of soil moisture and soil bulk density [4]. Data in Table (2) shows the other parameters used to simulate the model using finite element method. These include bulk density (ρ), Young's modulus (E), Poisson's ratio (ν), the dilation angle (ψ), the ratio of yield stress in triaxial tension to triaxial compression (k) and the angle of friction (β), and for plastic flow. The damage and failure features in the property module were employed. This setup allows Abaqus Explicit to remove elements

from the mesh when they fail, simulating the fracture process.

Table (1) Soil mechanical parameters from triaxial tests compaction level

Moisture content	Bulk density	Cohesion	Internal friction angle	Coefficient of friction
	Mg/m ³	kPa	degree	Unitless
10%	1.30	14.13	36.2	0.73
	1.35	15.82	37.6	0.77
	1.41	19.96	39.8	0.83
15%	1.38	10.15	28.1	0.53
	1.45	12.91	29.8	0.57
	1.52	13.43	31.5	0.61
20%	1.48	6.81	21.3	0.39
	1.57	7.71	23.2	0.43
	1.66	9.31	25.3	0.47

Table (2) Soil and tool properties used in FEM model

Parameter	Value	Source
Density for soil Mg/m ³	(1.30-1.35-1.41)	[4]
Young`s Modulus for soil MPa	4.02	[8]
Poisson`s ratio for soil Unitless	0.43	[8]
Dilatation angle for soil degree	32	[8]
Stress ratio for soil Unitless	0.82	[8]
Internal angle of friction of soil degree	(36.2-37.6-39.8)	
Density for tool Mg/m ³	7.8	[31]
Young`s Modulus for tool MPa	1×10 ⁶	[31]
Poisson`s ratio for tool Unitless	0.33	[31]
Tool width m	0.1	[4]
Tool rake angle degree	45	[4]

2.2 Modeling the interaction between soil and tillage tool

The Drucker-Prager model is a constitutive model used in soil mechanics to describe the plastic deformation and failure of soils. Drucker-Prager model helps predict draft and vertical forces based on soil-tool interaction. To study the interactions between soil and tillage tools to predict the draft and vertical force, the following parameters were investigated.

$$f = t - p \tan \beta - d$$

Where:

f = The yield function.

t = the deviatoric stress,

p = the normal stress,

β = internal friction angle and the

d = cohesion of the material.

Normal stress and deviatoric stress are expressed by the following equations:

$$P = \frac{1}{3} (\sigma_1 + \sigma_2 + \sigma_3) \quad (2)$$

$$t = \frac{1}{2} q \left[1 + \frac{1}{k} - \left(1 - \frac{1}{k} \right) \left(\frac{r}{q} \right)^3 \right] \quad (3)$$

$$q = (\sigma_1 - \sigma_3) \quad (4)$$

$$r^3 = (\sigma_1 - \sigma_3)^3 = -q^3 \quad (5)$$

Where:

k = Flow stress ratio.

r = The invariant of deviatoric stress.

It is the ratio of the tension yield stress to the compression yield stress in triaxial test ($0.778 \leq k \leq 1$) [1]. If $k = 1$ then $t = q$ and the yield surface in this case is identical to the Von Mises circle in the deviatoric principal stress plane.

σ_1 and $\sigma_2 = \sigma_3$ are compressive stress in triaxial test.

- 1- Three levels of soil bulk density (1.30 – 1.35 – 1.40) Mg/m³ at moisture content 10%.
- 2- Three chisel tools (shovel – sweep – winged).
- 3- Three operating depths (0.05– 0.075 – 0.1) m.
- 4- Three operating speeds (3 – 5 – 8) km/h.

Druck-Prager model (ABAQUS/Explicit) was used to model soil as an elastic–plastic with hardening property using the linear form. The model is defined as follows [18]:

$$(1)$$

2.3 Simulation procedures

Simulating the interaction between soil and a tillage tool using the ABAQUS software involves a systematic process to accurately model the complex behavior of soil and its response to mechanical forces.

2.3.1 Define the share geometry

The first part was 3D geometry of soil box domain created by using ABAQUS/CAE. It was considered as deformable part. The dimensions of the used soil

material box are (2 m, 1 m, 1 m) length, width and height, respectively. As shown in Figure 1.

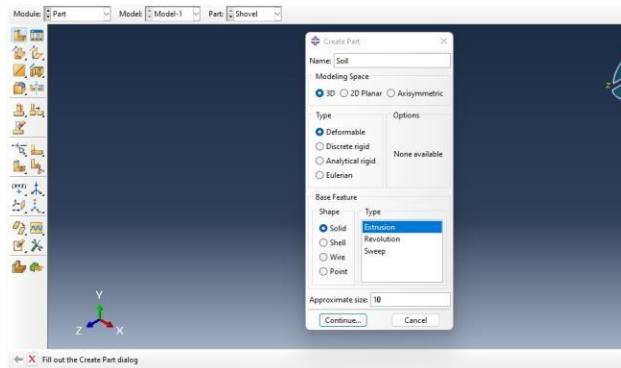


Fig. 1. 3D geometry for soil box in ABAQUS.

The second part contains three tillage tools that were defined as 3D discrete rigid body (It does not deform under any applied loads or constraints). It is an idealized representation of an object that remains perfectly rigid, meaning all points on the body maintain their relative positions regardless of external forces or moments as shown in Figure 2. These were shovel, sweep and winged chisel tools as shown in

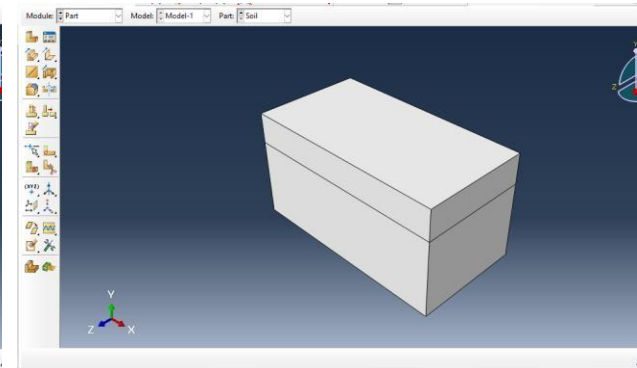


Figure 3. The fixed dimensions of tools are 0.6 m $\times$ 0.1 m length (L) $\times$ width (W) with rack angle (δ) 45°, shank angle (β) 30° and thickness (t) 0.007 m. In addition, shovel chisel tool has 0.26 m, sweep chisel tool has 0.28 m and winged chisel tool has 0.23 m radius of curvature (R), respectively. Reference point was designated for tool to facilitate the application of boundary conditions.

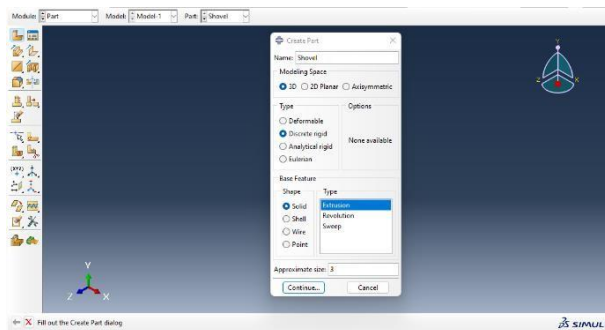
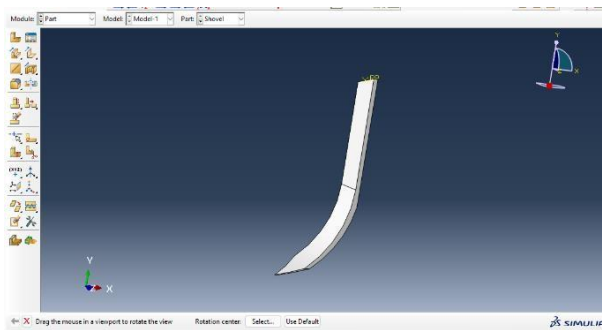


Fig. 2. The 3D geometry for tillage tool in ABAQUS.



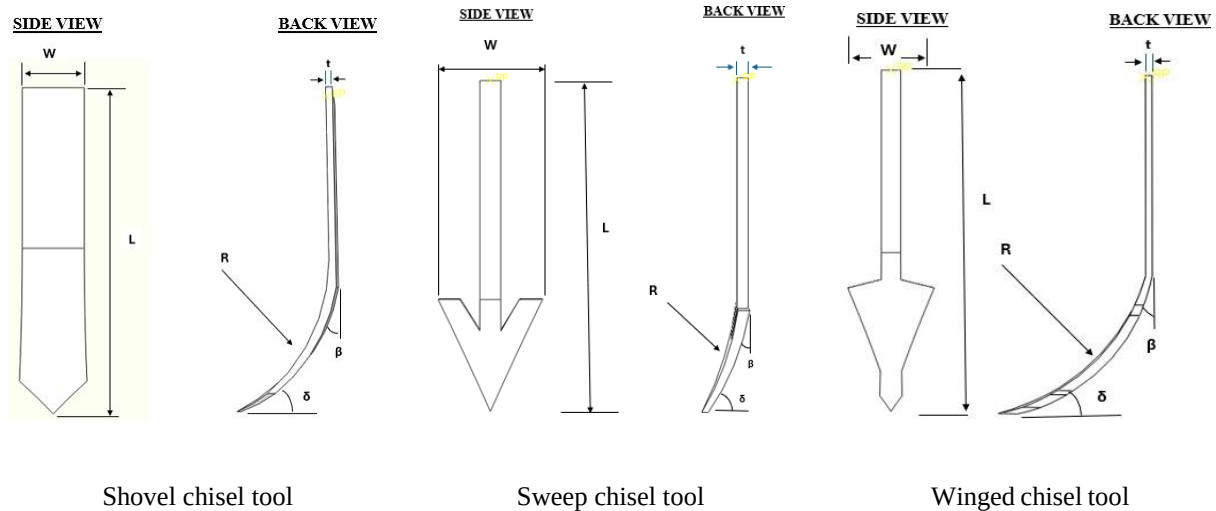


Fig. 3. Tillage tools used in simulation.

2.3.2 Assign Material Properties

The material properties for both the soil and the tillage tool were defined. For the soil, Drucker-Prager model was used to capture its elastic-plastic behavior

with hardening properties. Parameters like density, Young's modulus, Poisson's ratio, cohesion, and friction angle for the soil were inputted from Table 2 as shown in Figure 4.

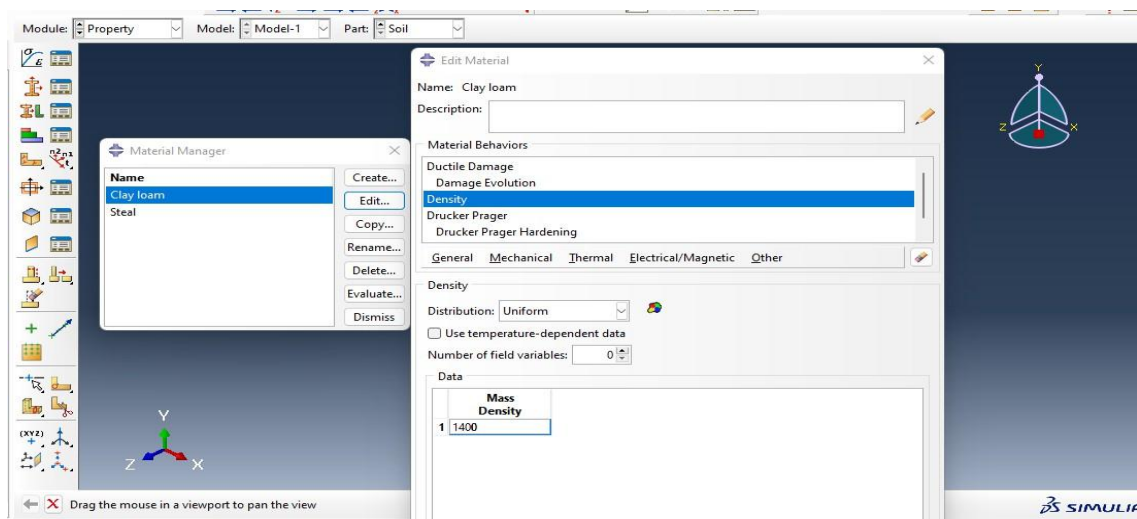


Fig. 4. Input data for deformable soil

For tillage tool, material properties of carbon steel (20% carbon) were applied from Table 2 as shown in Figure 5.

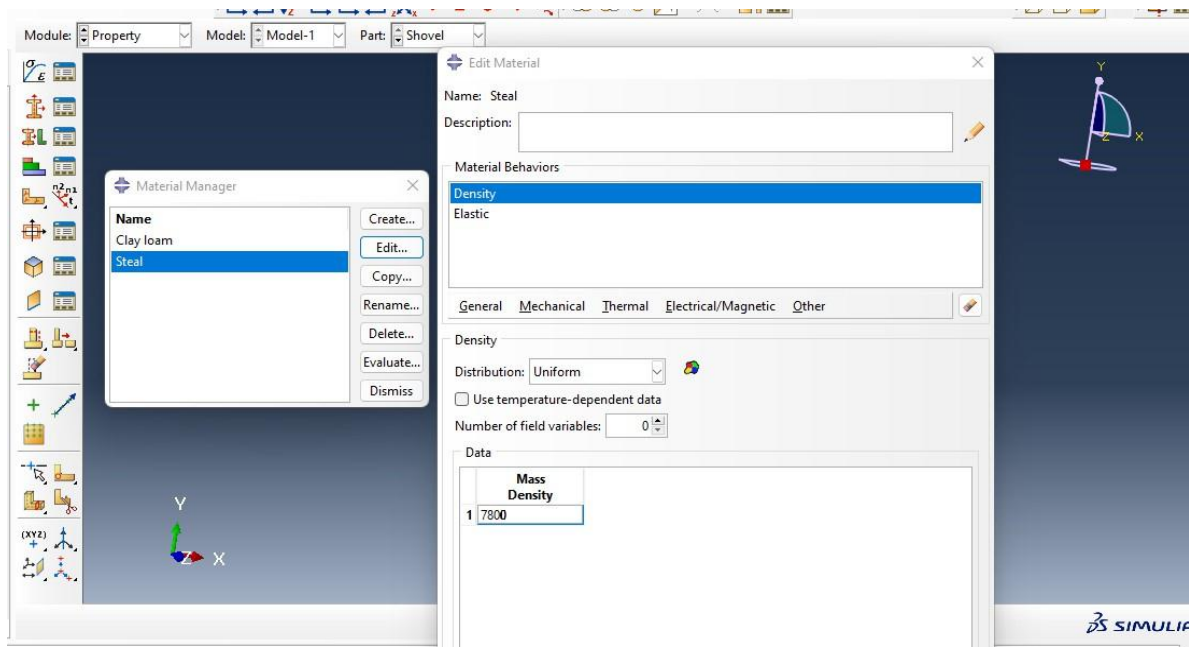


Fig.5. Input data for tool.

2.3.3 Mesh Generation

Soil and tillage tools were meshed using suitable element types. Rigid body of each tool and the soil box were divided into finite elements using two main element types, namely a quadratic, (8-node linear brick, reduced integration, hourglass control) and

rigid bilinear element (4-node and 3 degrees of freedom per node element) as shown in Figure 6 and Figure 7 for soil and tool, respectively. Finer mesh was used for soil in areas of high stress concentration or interaction near the tool-soil interface to improve accuracy.

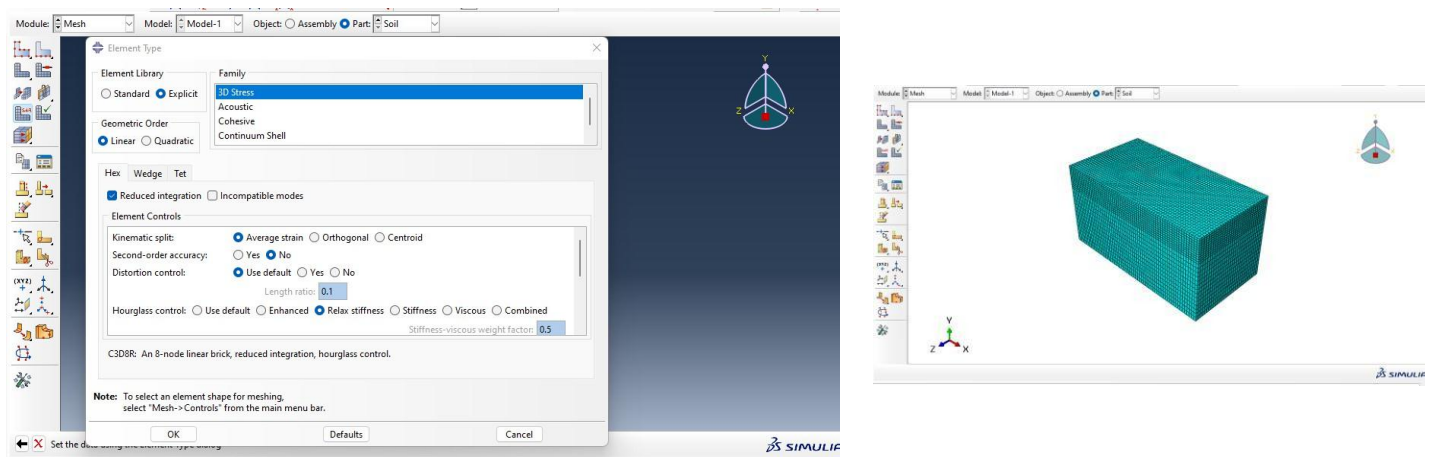


Fig. 6. Meshing soil box.

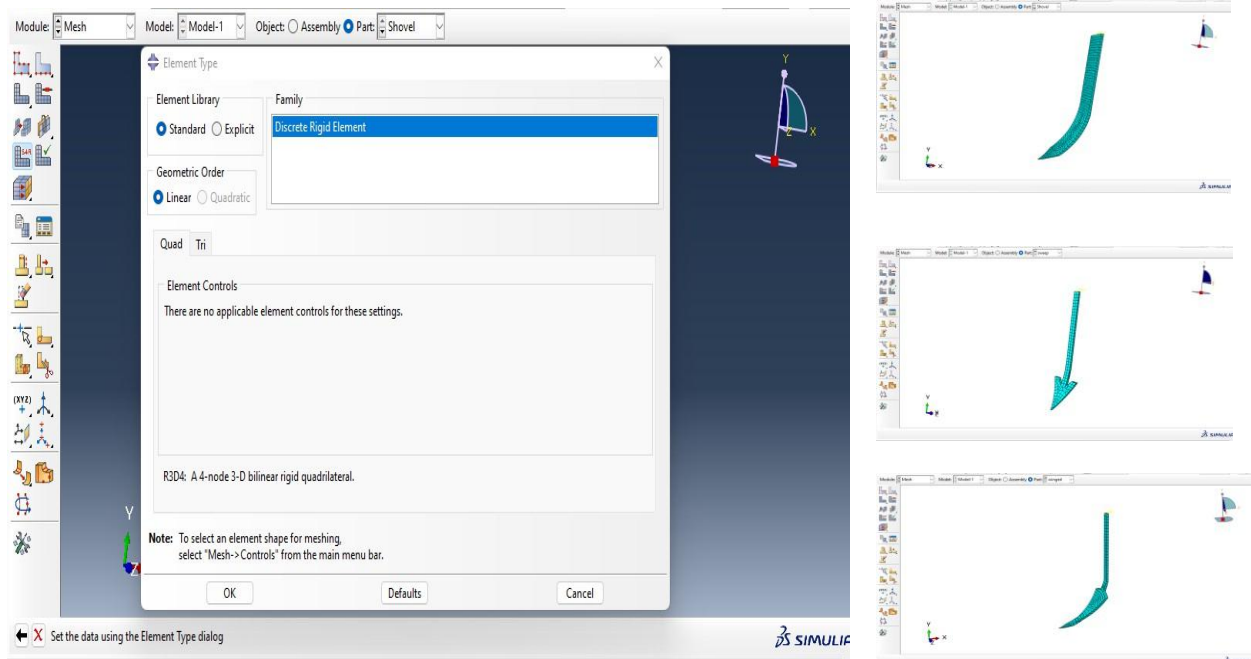


Fig. 7. Meshing tillage tools.

2.3.4 Define Interaction Properties

The interaction between the soil and the tool was established during a contact step. The contact between tool and soil surfaces was modeled using a surface-to-surface (explicit) contact definition. Due to the higher modulus of elasticity of tool compared to the soil, tool was designated as the master surface, while the soil was assigned as the slave surface. The

mechanical constraint penalty contact method was employed to define the interaction between the two surfaces. Instead of selecting only the soil surface, all elements in contact with the tool surface were chosen as the slave to incorporate internal elements into the constraint. The simulation was carried out using the dynamic explicit solution method as shown in Figure 8.

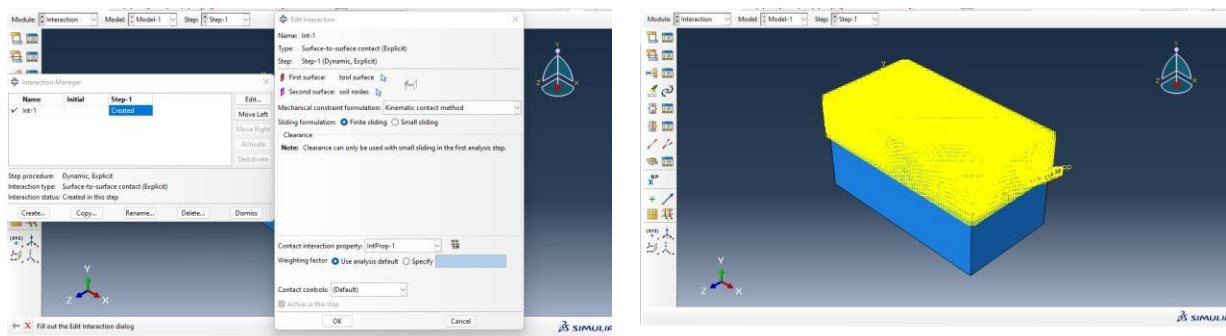


Fig. 8. Interaction between soil and tillage tool

2.3.5 Boundary Conditions

Boundary conditions were applied to the soil and tools to replicate real-world conditions, which

included: (1) fully fixing both side walls of the box (in the y-z plane), (2) completely fixing the bottom face of the box (in the x-z plane) while leaving the

top face free of any constraints, and (3) fixing the velocity applied to the reference node in the horizontal penetration direction as shown in Figure 9. The displacement of the bodies, some energy

components of the model including kinetic energy, total internal energy and elastic plastic strain energies were selected for step.

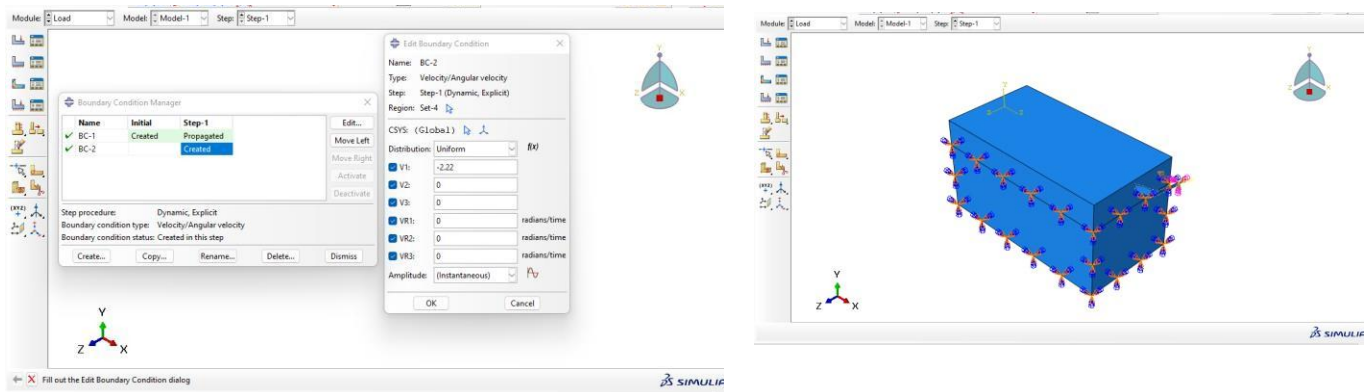


Fig.9. Boundary conditions for soil and tools

2.3.6 Set up the Analysis Step

The analysis step defined as a dynamic explicit step depending on the nature of the simulation. The time

duration for the analysis was Specified as 2.4, 1.44 and 0.9 s as shown in Figure 10.

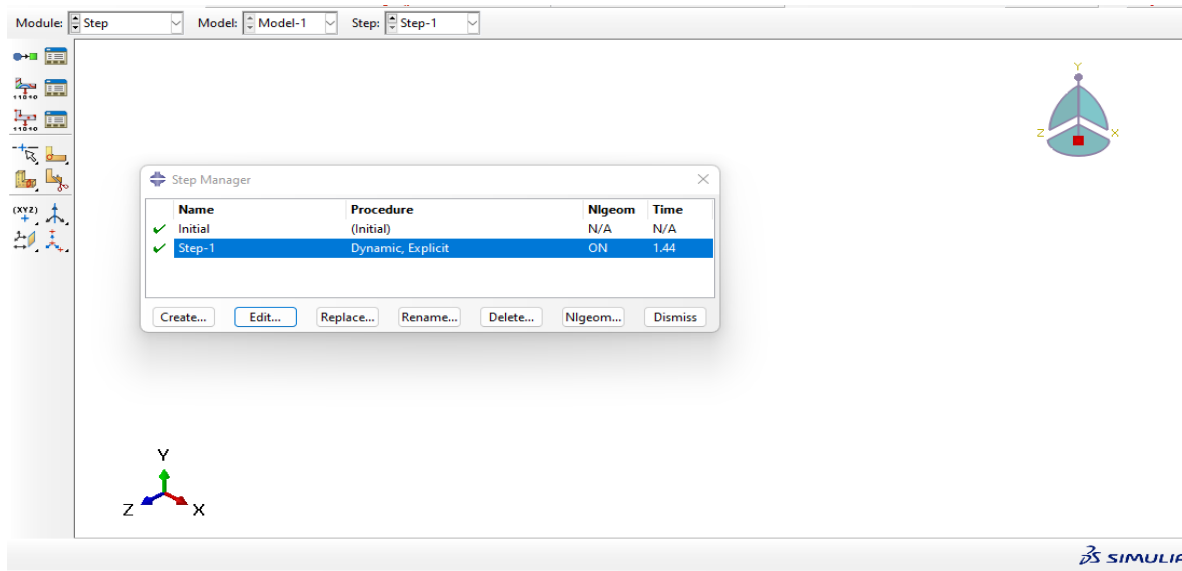


Fig .10. Dynamic-Explicit step for model

2.3.7 Run the Simulation

Runs were submitted to the ABAQUS solver (ABAQUS/Explicit). The simulation was monitored

until the process was completed as shown in Figure 11. The outputs of the model were draft force and vertical force on reference point of the tool.

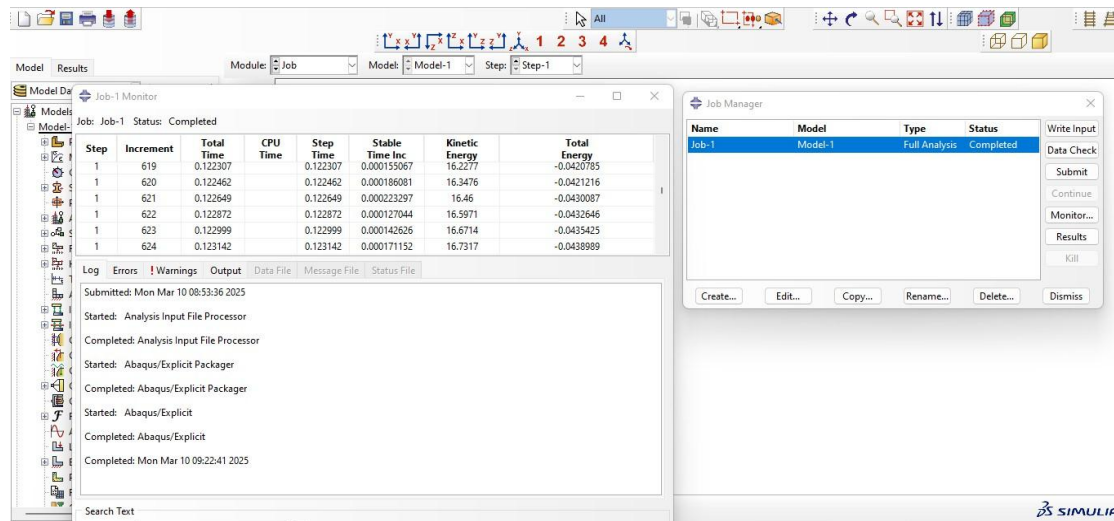


Fig .11. Running the model

3. Results and Discussion

3.1 Results from FEA

The results of the study of the interaction between soil and tillage tools showed the effect of different levels of soil and operation parameters on draft and vertical force. Figures 12,13, 14, 15, and 16 illustrate the soil cutting stages using different tool shares at

various levels of plowing depths, plowing speeds, and bulk density at moisture content 10%. It's indicated that as the plowing tool moves forward and its surfaces push soil elements up and down to form a furrow. Therefore, the deformation in front of the tool varies with operating conditions. So, cutting area varies between tools under the same conditions due to differences in traction force and vertical force, as confirmed by [16].

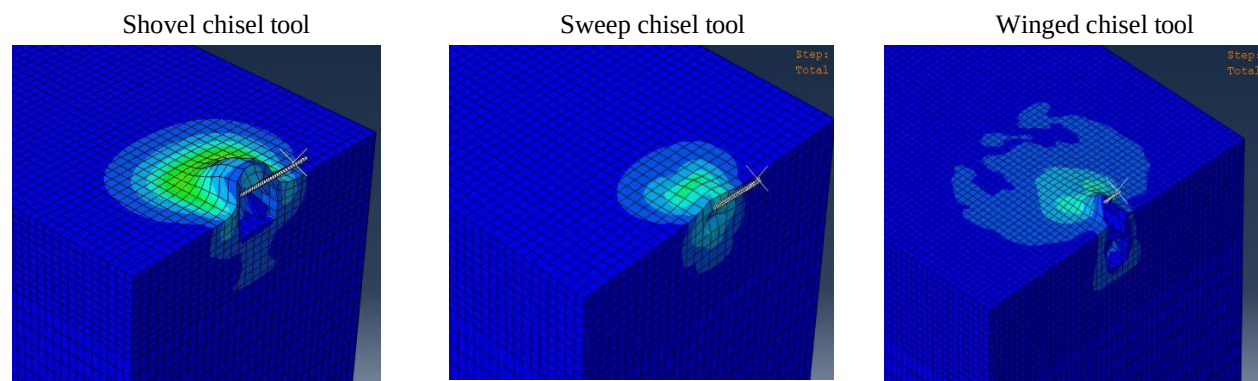


Fig.12. Soil cuts and deformation in front of the tool at tillage depth 0.075 m, tool speed 5 km/h and bulk density 1.35 Mg/m³ for three chisel tools at moisture content 10%.

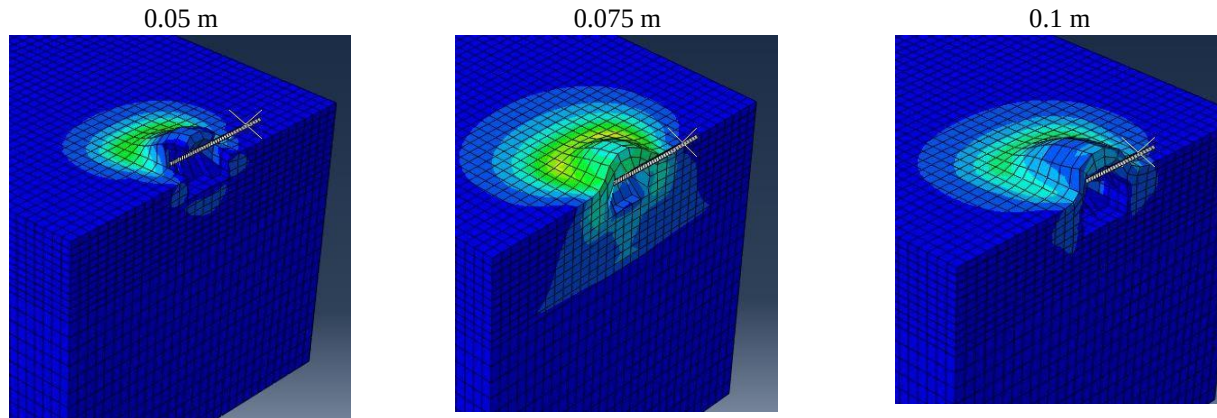


Fig .13. Soil cuts and deformation in front of the tool at tillage depth 0.05, 0.075 and 0.1 m for shovel chisel tool at speed 5 km/h and bulk density 1.35 Mg/m^3 at moisture content 10%.

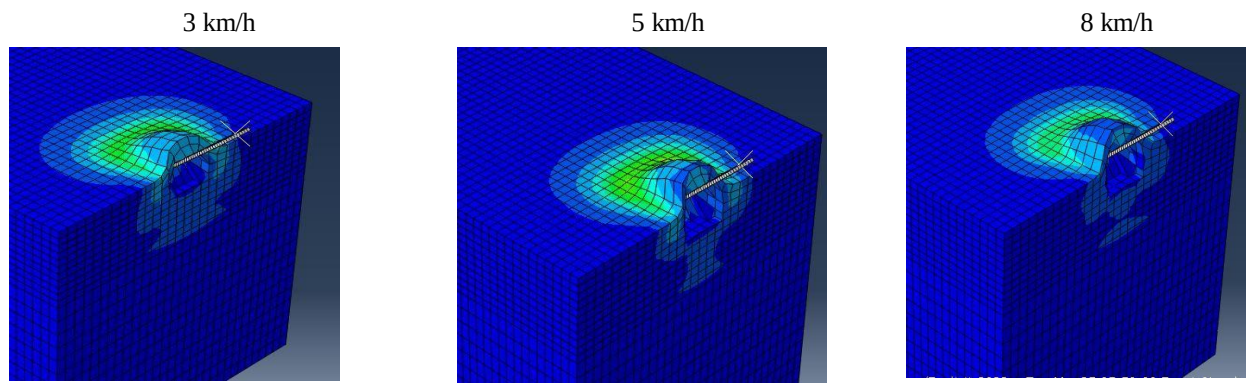


Fig .14. Soil cuts and deformation in front of the tool at tool speed 3, 5 and 8 km/h for shovel chisel tool at tillage depth 0.075 m and bulk density 1.35 Mg/m^3 at moisture content 10%.

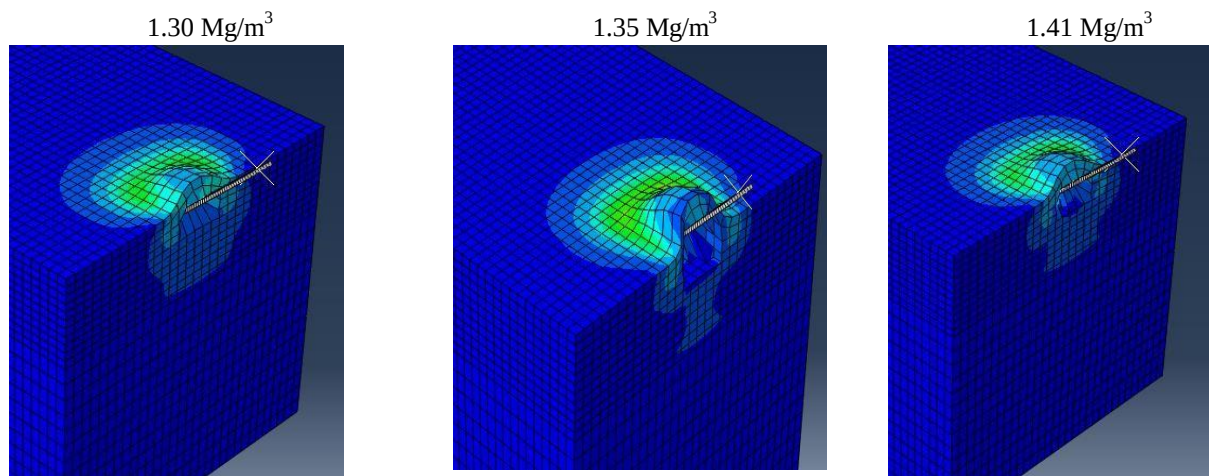
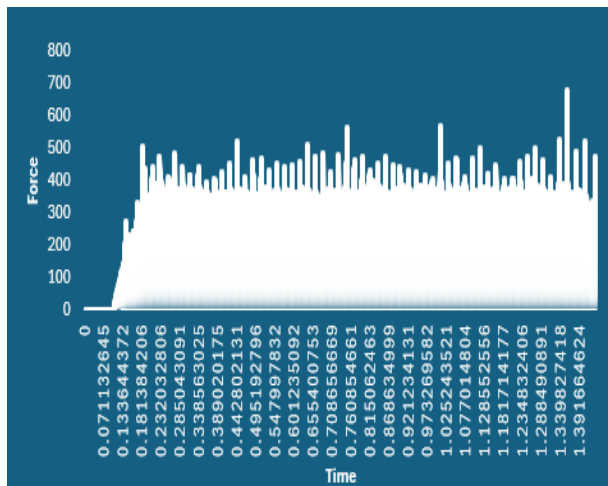
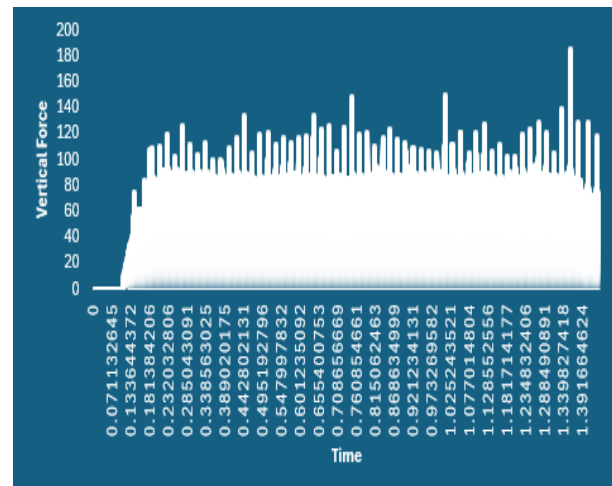
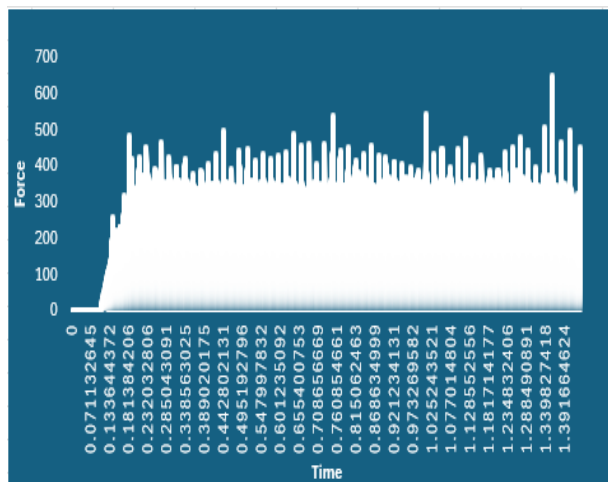
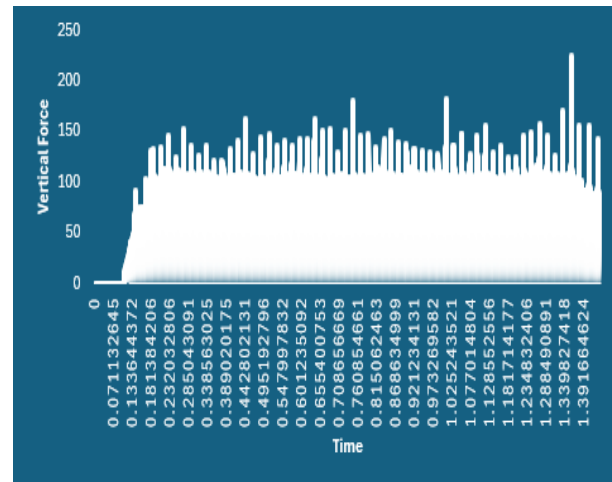


Fig .15. Soil cuts and deformation in front of the tool for soil bulk density 1.30, 1.35 and 1.41 Mg/m^3 at tool speed 5 km/h for shovel chisel tool at tillage depth 0.075 m at moisture content 10%.

A finer mesh was applied only to the area around the cutting zone of the tool to improve the accuracy of the predicted forces. Research supports this approach, indicating that increasing mesh density enhances the precision of force predictions. This is because a finer mesh captures the complexity of soil behavior. However, while higher mesh density improves the accuracy of soil reaction force predictions, it also significantly increases computation time. This trade-off poses a challenge, as longer solution times can hinder the practical application of finite element analysis (FEA). Therefore, achieving an optimal balance between mesh density for accuracy and the computational resources available is crucial for

effective soil-tool interaction modeling. This approach also helps reduce calculation time costs [22, 17].

Draft force extracted in the opposite direction of x-axis on a reference point of the crane which was obtained from the finite element simulation as shown in Figures (16,18,20 and 22) at different tool shares, plowing depths, plowing speeds, and bulk density. Also, vertical force was extracted in the opposite direction of x-axis on a reference point of the crane which was obtained from the finite element simulation as shown in Figures (17,19, 21 and 23) at different tool shares, plowing depths, plowing speeds, and bulk density.

Bulk density (1.30 Mg/m^3)Bulk density (1.30 Mg/m^3)Bulk density (1.35 Mg/m^3)Bulk density (1.35 Mg/m^3)Bulk density (1.41 Mg/m^3)Bulk density (1.41 Mg/m^3)

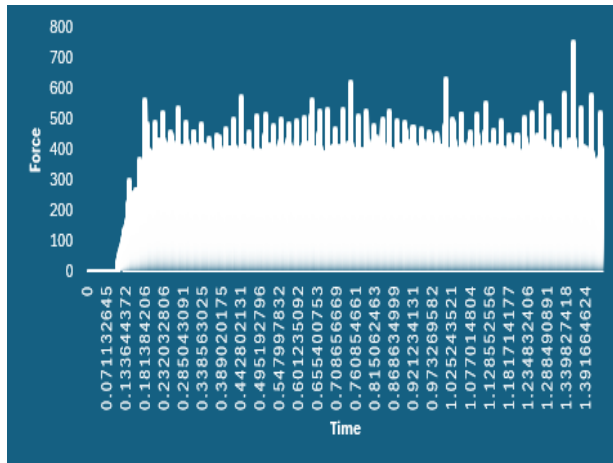


Figure 16 Draft force for shovel chisel tool at tillage depth 0.075 m and tool speed 5 km/h at different soil bulk density at moisture content 10%.

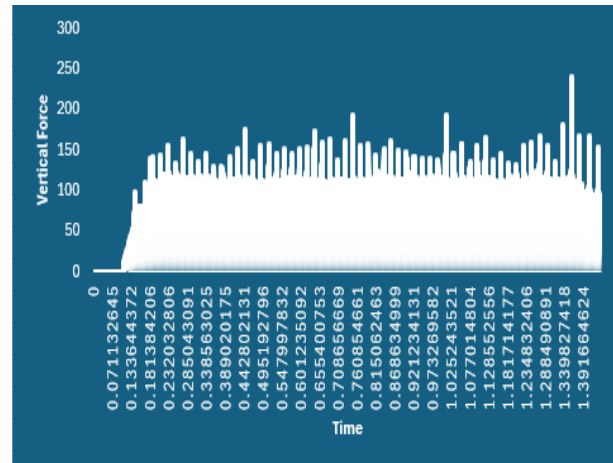
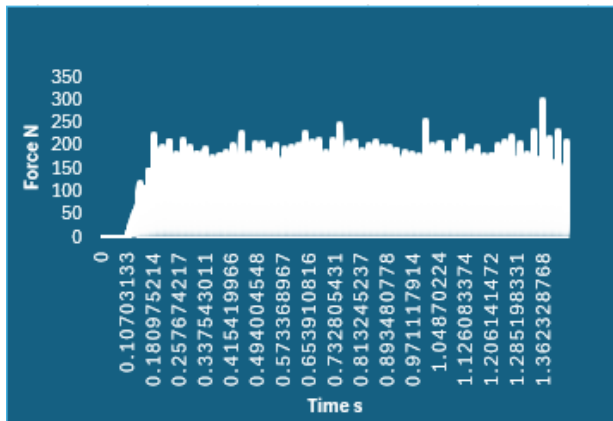
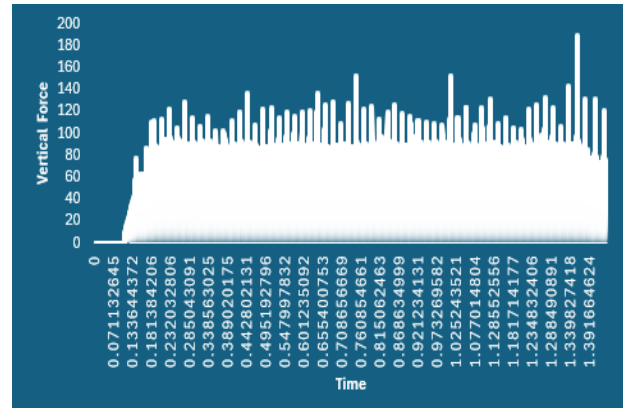


Figure 17. Vertical force for shovel chisel tool at tillage depth 0.075 m and tool speed 5 km/h at different soil bulk density at moisture content 10%.

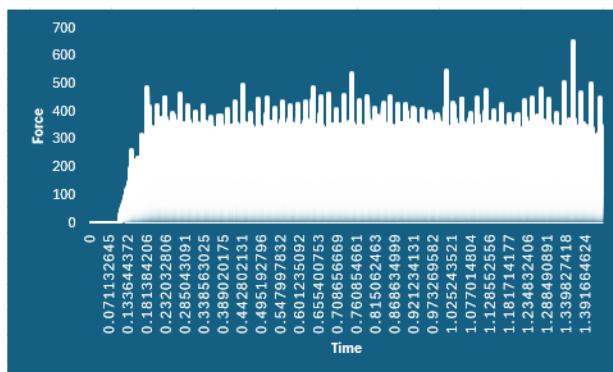
Tillage depth 0.05 m



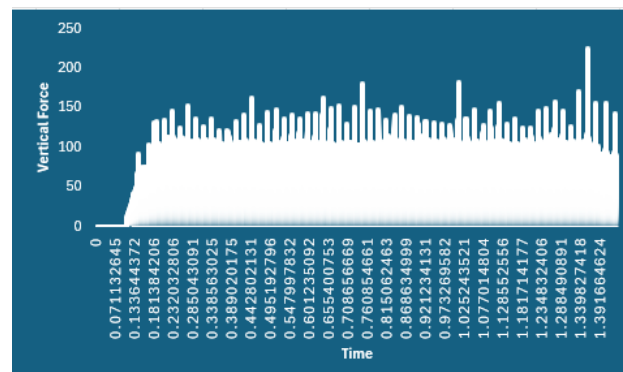
Tillage depth 0.05 m



Tillage depth 0.075 m



Tillage depth 0.075 m



Tillage depth 0.1 m

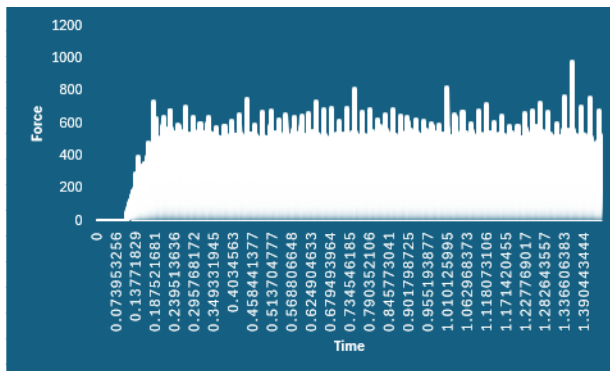


Figure .18. Draft force for shovel chisel tool at tool speed 5 km/h and bulk density 1.35 Mg/m^3 at moisture content 10%.

Tillage depth 0.1 m

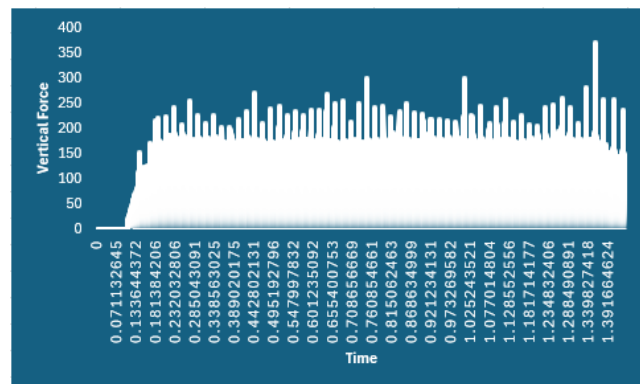
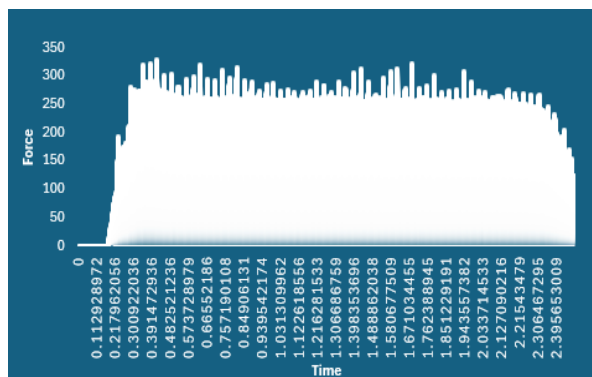
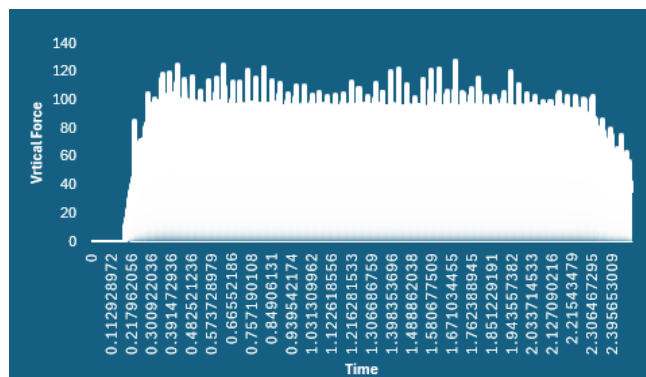


Figure .19. Vertical force for shovel chisel tool at tool speed 5 km/h and bulk density 1.35 Mg/m^3 at moisture content 10%.

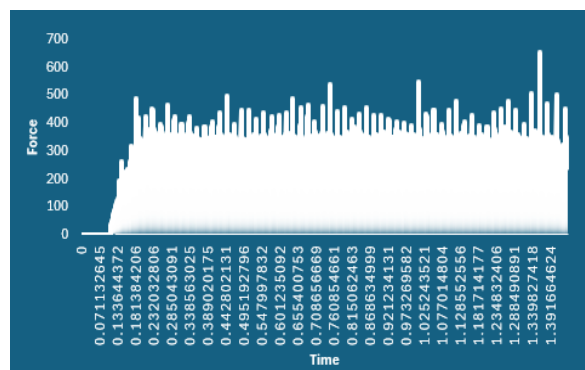
Tool speed 3 km/h



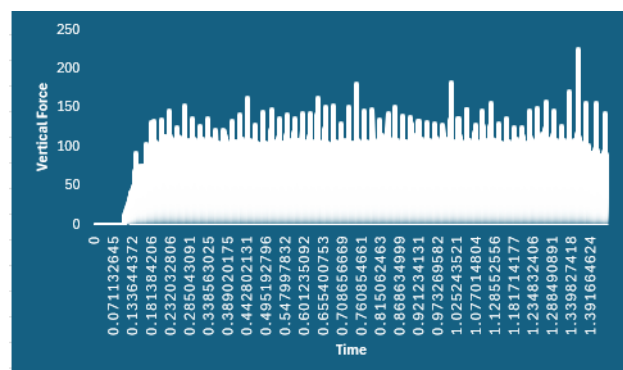
Tool speed 3 km/h



Tool speed 5 km/h



Tool speed 5 km/h



Tool speed 8 km/h

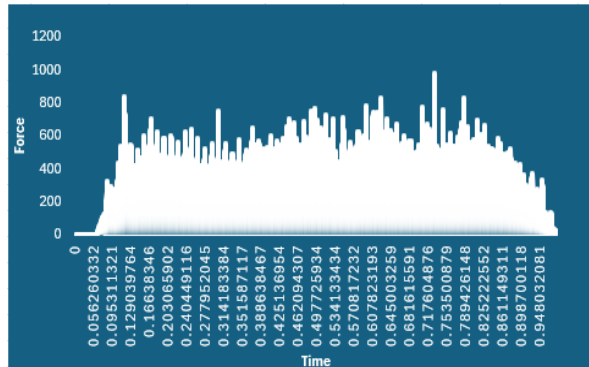


Figure 20. Draft force for shovel chisel tool at tillage depth 0.075 m and bulk density 1.35 Mg/m^3 at different tool speed at moisture content 10%.

Tool speed 8 km/h

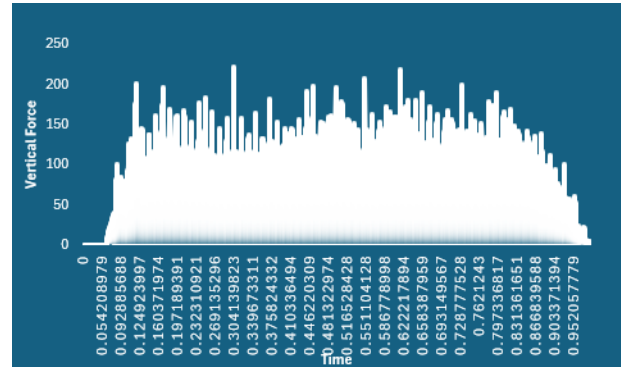
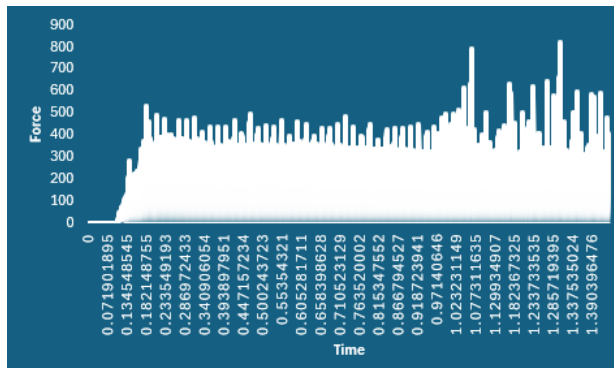
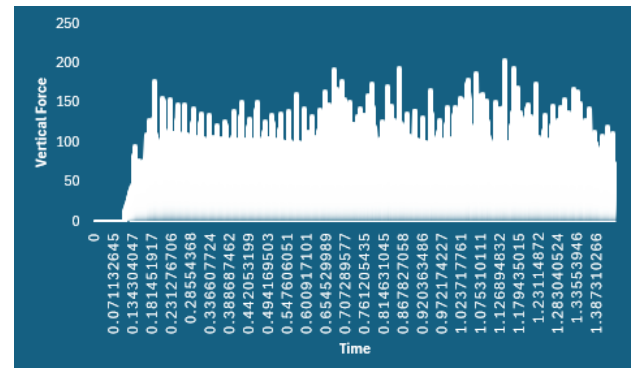


Figure 21. Vertical force for shovel chisel tool at tillage depth 0.075 m and bulk density 1.35 Mg/m^3 at different tool speed at moisture content 10%.

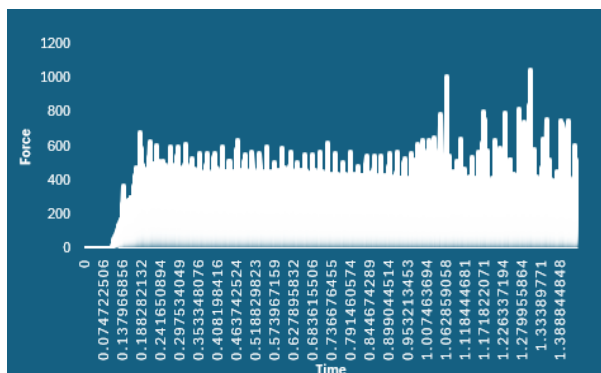
Shovel chisel tool



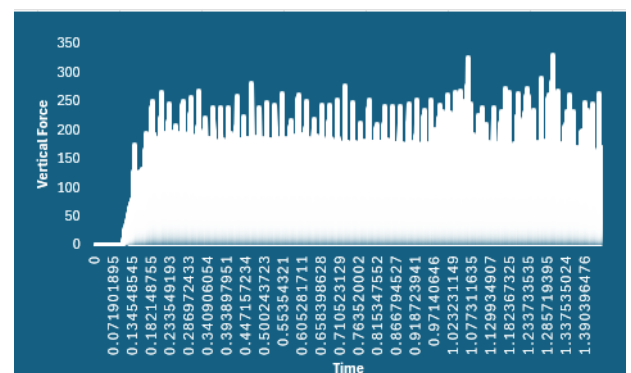
Shovel chisel tool



Sweep chisel tool



Sweep chisel tool



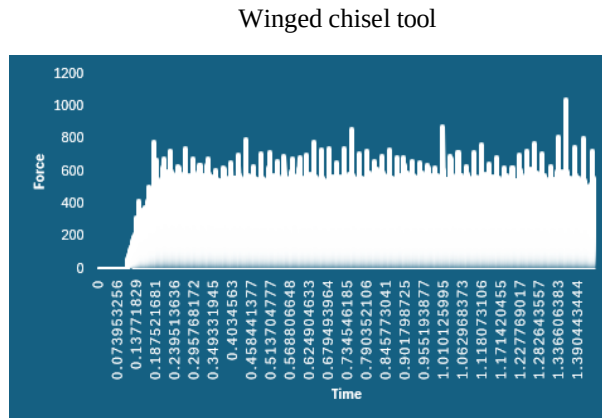


Fig. 22. Draft force for shovel, sweep and winged chisel tools at tillage depth 0.075 m, tool speed 5 km/h and bulk density 1.35 Mg/m^3 at moisture content 10%.

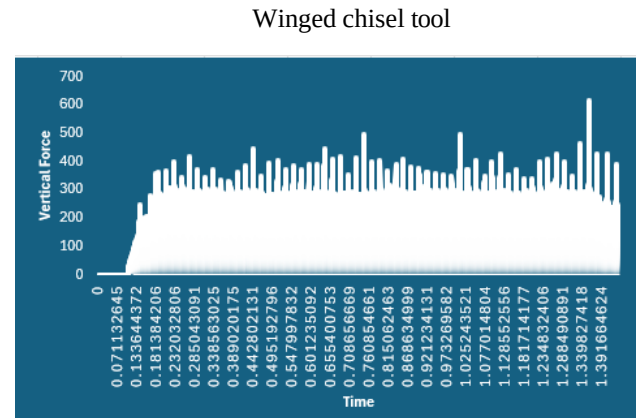


Fig. 23. Vertical force for shovel, sweep and winged chisel tools at tillage depth 0.075 m, tool speed 5 km/h and bulk density 1.35 Mg/m^3 at moisture content 10%.

3.2 Effect of soil and operation parameters on the draft force for the three tillage tools

Data in Table (3) showed the resulted from FEM model. Each number was obtained from one run of the model at different soil and operation parameters for the three chisel tools. It's indicated that the increase in soil bulk density from 1.3 to 1.4 Mg/m^3 resulted in an increase in draft force by 15%, 22.8%, and 46% for the shovel, sweep, and winged chisel tools, respectively. The highest values of draft force were obtained by winged chisel tool at different levels of soil and operation parameters. On the other hand, the lowest values of draft force resulted by shovel chisel tool. These results are in agreement with pervious findings by [9].

The draft force increased by 69%, 45%, and 46.5% when tillage depth increased from 0.05 m to 0.1 m

for the shovel, sweep and winged chisel tools, respectively. However, On the other hand, data in table (3) shows This result shows that when tillage depth increased by 50%, the highest value of draft force was recorded to shovel chisel tool at different levels of soil and operation parameters. On the other hand, the lowest value of draft force resulted by sweep chisel tool. These results are in agreement with previous findings by [7].

Increasing the tool speed from 3 to 8 km/h resulted in an increase in draft force by 35.4%, 28.6%, and 15.15% for the shovel, sweep, and winged chisel tools, respectively. When tool speed increased by 62%, shovel chisel tool has the highest value of draft force 35.4% and winged chisel tool have the lowest value of draft 15.15 % at different levels of soil and operation parameters. The results are consistent with prior research conducted by [32,25, 9].

Table (3): Draft force results from FEM simulation of soil-tool interaction.

Bulk Density Mg/m ³ moisture content 10%		1.3			1.35			1.41		
Depth m	Speed km/h	3	5	8	3	5	8	3	5	8
Draft force (N)										
0.05	Shovel chisel tool	93.93	122.95	469.68	111.30	146.30	206.40	257.30	312.50	386.60
	Sweep chisel tool	141.48	203.22	312.19	356.20	422.10	450.60	438.27	502.30	623.92
	Winged chisel tool	228.90	238.23	322.11	283.30	356.20	401.10	310.12	361.75	469.70
0.075	Shovel chisel tool	191.20	330.39	248.70	240.20	316.80	371.80	367.00	363.99	474.57
	Sweep chisel tool	268.90	331.19	425.11	451.30	405.04	632.35	670.20	692.28	702.00
	Winged chisel tool	275.90	282.40	393.40	480.40	505.67	565.70	521.33	576.20	598.90
0.1	Shovel chisel tool	366.20	409.90	400.00	501.20	475.50	503.70	463.10	483.20	592.30
	Sweep chisel tool	377.96	642.27	651.39	611.80	775.45	740.00	699.20	832.00	882.31
	Winged chisel tool	344.10	371.90	504.10	592.90	665.30	737.20	603.70	688.70	732.40

3.3 Effect of soil and operation parameters on the vertical force for the three tillage tools

Data in Table (4) was obtained from FEM model indicated that the effect of soil and operation parameters on the vertical force for three tillage tools. Results indicated the increasing in soil bulk density from 1.3 to 1.4 Mg/m³ leads to increase in vertical force by 21.6%, 24.66% and 42.07% for Shovel, sweep and winged chisel tools, respectively. The highest values of vertical force were obtained by winged chisel tool at different levels of soil and operation parameters. On the other hand, the lowest values of draft force resulted by shovel chisel tool. These results are in agreement with pervious findings by [8].

On the same side, table (4) shows that increasing in tillage depth from 0.05 to 0.1 m happens increase in

vertical force by 49%, 52% and 49.6% for Shovel, sweep and winged chisel tools, respectively. As tillage depth increased by 50%, the highest value of draft force was recorded to sweep chisel tool at different levels of soil and operation parameters. In addition to that, the lowest values of draft force resulted by shovel chisel tool. These findings align with the reports by [2, 21].

Table (4) shows that changed in tool speed from 3 to 8 km/h vertical force increased by 18%, 14% and 12% for Shovel, sweep and winged chisel tools, respectively. When tool speed increases by 62%, shovel chisel tool has the highest value of draft force 18% and winged chisel tool have the lowest value of vertical 12 % at different levels of soil and operation parameters. Results are in harmony with previous findings by [8].

Table (4): Vertical force results from FEM simulation of soil-tool interaction.

Bulk Density Mg/m ³ moisture content 10%		1.3			1.35			1.41		
Depth m	Speed km/h	3	5	8	3	5	8	3	5	8
		Vertical force (N)								
0.05	Shovel chisel tool	54.20	55.20	99.50	58.20	80.75	102.10	63.30	65.17	111.64
	Sweep chisel tool	105.20	97.30	87.20	109.40	123.76	132.60	129.20	157.45	193.57
	Winged chisel tool	141.30	136.28	-146.70	152.95	157.30	170.25	182.47	201.70	224.43
0.075	Shovel chisel tool	77.34	78.87	83.40	88.70	96.00	108.15	92.86	102.40	137.80
	Sweep chisel tool	151.10	155.89	153.20	157.30	167.09	183.11	189.10	215.64	251.73
	Winged chisel tool	156.20	152.40	167.53	241.43	246.70	262.33	273.98	277.74	279.13
0.1	Shovel chisel tool	102.60	127.23	168.50	121.42	158.65	203.23	141.32	162.40	211.13
	Sweep chisel tool	221.50	237.46	261.67	236.79	257.30	282.77	289.00	315.20	326.47
	Winged chisel tool	198.40	201.35	207.63	293.28	312.17	356.76	321.74	338.17	349.56

4- CONCLUSIONS

In this study, the FEM was used to for Predicting Draft and Vertical Force for shovel, sweep and winged chisel tools. In addition to, studying the effect of working conditions and soil physical properties on draft and vertical force. The results can be summarized as follows:

- 1- By using FEM, researchers can optimize tool designs for lower energy consumption and better soil handling.
- 2- The highest values of draft force were winged chisel tool at different levels of soil and operation parameters. On the other hand, the lowest values of draft force resulted by shovel chisel tool.
- 3- The highest values of draft were obtained by shovel chisel tool when tillage depth increased

from 0.05 to 0.1 m at different levels of soil and operation parameters. On the other hand, the highest values of vertical were obtained by winged chisel tool.

- 4- The highest values of draft were obtained by shovel when tool speed increased from 3 to 8 km/h at different levels of soil and operation parameters. On the other hand, the highest values of vertical were obtained by sweep chisel tool.
- 5- Future research could expand the method's application to more complex tillage tools. Overall, the results highlight FEM's value in improving tillage tool efficiency and performance.

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