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Research Article

Mathematically Predicting the Performance Rate of Plow-Type Trenchless Machine

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ABSTRACT

This research was aimed to identify the main factors that influence the performance rate of plow-type trenchless machine and mathematically correlate these variables to predict performance rate. The mathematical analysis ended with an equation correlating the performance rate with the factors affecting it. The derived relationship was checked in various operational circumstances. The performance rate's practical experiments revealed that only for the 0.92 and 0.76 m disturbed soil depths, respectively, did the theoretical performance rate variation from the actual performance rate range from -3.0 to -0.7%. Also, for the 0.92 and 0.76 m disturbed soil depth, respectively, the field efficiency of plow type trenchless machine ranged from 49.7 to 45.4%. The novelty and innovativeness of this article is in the use of an analytical method to deduce a mathematical equation that can predict the performance rate; in determining the actual factors affecting the performance rate of plow type trenchless machine.

Keywords: *Mathematical analysis, Modeling, Performance rate, Plow, Trenchless*

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INTRODUCTION

To maintain the ideal soil moisture-air balance for the crop that is growing, drainage in agriculture refers to the process of removing free water from soil that is present in the root zone of plants above the field capacity. The water excess is removed by a subsurface pipe drainage system placed at a suitable slope and depth to help get rid of the excess water which is drained to an open channel drain

(Rokochinskiy *et al*., 2019). Trenching machines typically come in three different types; plow type, wheel type, and chain type trenching machines, which vary in their design and methods of operation (Islam *et al*., 2019).

The advantage of a trenching machine is its high-performance rate due to it digs the trench, installs the drainage pipes, and, in the case of a plow type, it also fills the ditches with soil. In other words, the machine carries out its' entire task at the same time. It is distinguished by its great level of accuracy when placing the pipes at the necessary depth and slop. There are a number of obvious advantages when contrasting the trenching machine with other excavating machinery. A more precise control of trench depth and width is provided by the trenching machine, which enables a significantly greater output rate (Naghshbandi *et al*., 2021). However, due to the inherited characteristics of the machine itself, trenching machines' efficiency and output rates are generally regarded as low compared to other types of agricultural equipment. Most of the attempts to boost the productivity and efficiency of trenching machines were a trial and error types of attempts, and only a small number of early researches relied on descriptive analysis of variables influencing the effectiveness and performance of trenching machines. According to Sitorus *et al*. (2016), the three most important elements affecting the power and speed of digging machines are the trench depth and width, machine forward speed, and uniaxial compressive strength. Some mathematical models were used to describe the performance of the trenching machines. Ghonimy *et al*. (2022) concluded that the theoretical excavation force calculated by the mathematical model was lower than the actual excavating force by 4.0 kN and 3.5 kN for the 1.2 m and 1.5 m trench depths, respectively, for chain-type trenching equipment. And at trench depths of 1.2 m and 1.5 m, respectively, the theoretical excavation power was lower than the actual excavating power by 3.8% and 2.8%. Diep (2017) linked a number of digging unit specifications, such as the cutting assembly's angle, the distance between teeth, the speed of the tangential teeth, and the forward speed to the chain trenching machine's chipping depth. Reddy and Shailesh (2018) performed a study to find how long a bucket tooth on a backhoe digger would last. They observed that the costs related to the product lifecycle might be significantly reduced through computer-aided engineering (CAE). Ghonimy (2021) found that the machine chain-type trenching machine field efficiency ranged from 46.7 to 57% for the 150.7 cm and 120.7 cm trench depths, respectively. The goal of this research was to identify the main factors that influence the performance rate of plow-type trenchless machine and to mathematically correlate these variables to predict performance rate.

MATERIALS and METHODS

Approach of the Mathematical Analysis

The rate of performance of plow-type trenchless machine depends on the trencher's forward speed, trenching width, and field efficiency. The machine's forward speed is correlated with the size of the power source and the amount of power used to operate it. Thus, the mathematical analysis relied on the mathematical relationship which related the tractor brake power and each of the forward speeds and the total forces acting on the plow-type trenchless machine during field operation. Equation 1 allows the estimation of the highest forward speed of the machine (Revenko *et al*., 2022) as well as the performance rate of plow-type trenchless machines by correlating the size of the power source with the overall amount of power necessary for machine functioning.

$$P_b = P_c + P_r + P_i + P_s + P_t \pm P_a + P_n \quad (1)$$

Where: P_b is the tractor brake power, kW; P_c is the required power to overcome cutting resistance, kW; P_r is the required power to overcome rolling resistance, kW; P_i is the power necessary to overcome the resistance of the soil surface slope, kW; P_s is the lost power in sliping, kW; P_t is the transmission systems lost power, kW; P_a is the required power to confrontation air resistance, kW; P_n is necessary power for the trenchless machine to reach its operational speed because of its inertia, kW.

Since the forward speed of plow-type trenchless machine during operation was so low in comparison to other moving trucks, both P_a and P_n were disregarded. Thus, Equation 1 could be simplified to Equation 2:

$$P_b = P_c + P_r + P_i + P_s + P_t \quad (2)$$

Construction and Mechanical Theory of the Plowing Unit of Plow-type Trenchless Machine

Figure (1) showed the plowing unit of the plow-type trenchless machine. Its consists of a cutting blade with an attached pipe chute. The cutting blade moves horizontally at a velocity *(V_m)* in the same forward direction of the trenching machine. The cutting edge starts vertically in front of the blade shank and extends to the plow bottom to a depth *(d)*. The performance theory of this type of the trenchless machine is that, while the machine travels horizontally at a speed *(V_m)*, the cutting edge of the blade causes fracturing of the soil. The shank pushes the soil, creating fracture lines from the trench bed to the surface Figure 2. The wedge-shaped fractures of the soil are lifted upwards without reaching the surface. Through the lifting and fracturing of the soil, impermeable layers are lastingly destroyed. These fracture lines create easy access for the flow of water to the subsurface drainage pipes. The pushing and lifting action of the shank prevents soil compaction.

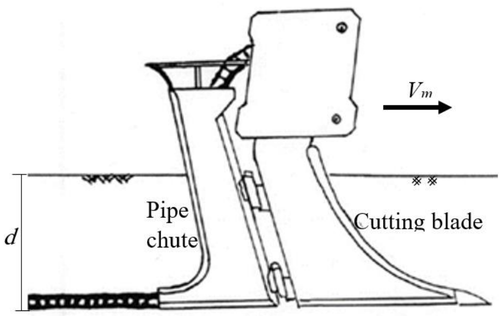

Figure 1. *The mechanism of the plow-type trenchless machine.*

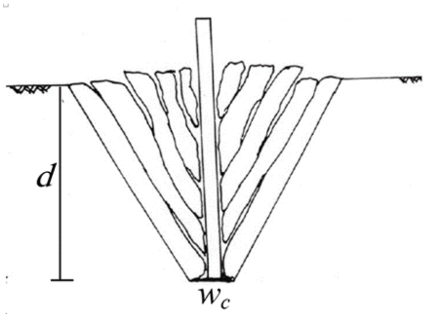

Figure 2. *The wedge-shaped fractures of the soil due to the plow-type trenchless machine action.*

Factors Impacting the Plow-type Trenchless Machine's Performance Rate

The performance rate of plow-type trenchless machinery is affected by variety of factors. These factors can be divided into two categories; **soil factors** which encompass; unit draft of soil *(U),* N m^{-2}, specific weight of soil *(ω),* N m^{-3}, coefficients of friction between soil and soil *(f_{ss})* and between metal and soil *(f_{ms}),* inclination angle of soil surface with the horizontal direction *(ψ),* degree, and coefficient of rolling resistance *(RR).* **Machine factors**; which encompass; weight of tractor and machine *(W_m),* N, brake power of tractor *(P_b),* kW, trench cutting width *(w_c),* m, machine forward speed *(V_m),* m s^{-1}, vertical cutting depth *(d),* m, tractor transmission efficiency *(η_t),* slip ratio of the tractor contact device with the ground *(S),* and field efficiency *(η_f).*

To make mathematical manipulation easier, several presumptions and simplifications were made. These simplifications were constant unit draft of soil, homogeneous and isotropic soil, and constants of machine forward speed, and disturbed soil depth.

Mathematical Analysis Steps

Equation 3 was used to calculate the theoretical performance rate *(PR_{th})* of the plow-type trenchless machine according to (Ghonimy, 2021):

$$PR_{th} = 60 \times V_m \times \eta_f \tag{3}$$

Where:

PR_{th} = theoretical performance rate, m min^{-1};
V_m = forward speed of plow-type trenchless machine, m s^{-1};
η_f = the field efficiency, decimal.

The parts of Equation 2 were obtained as the following in order to determine the value of V_m.

a) Determination of P_c

The required power to overcome cutting resistance *(P_c),* Equation 4, depends on the cutting force (F_c) and the machine forward speed *(V_m)* (Ranjbarian, *et al.*, 2017).

$$P_c = 0.001\,.\,F_c.\,V_m \tag{4}$$

$$F_c = U^*.\,A \qquad \text{(Ghonimy, 2021)} \tag{5}$$

Referring to Figure 3, the cross-section area *(A)* of the disturbed soil due to cutting can be calculated as follows:

$$A = d^2 . \left(\frac{w_c}{d} + \frac{1}{\tan\theta} \right) \quad (6)$$

Thus,

$$F_c = K^* . U . d^2 . \left(\frac{w_c}{d} + \frac{1}{\tan\theta} \right) \quad (7)$$

Where: F_c is the cutting force, N; K^* is the dimensionless coefficient = $\frac{U^*}{U}$; U^* is the unit draft of soil including the friction forces acting on bucket metal during cutting, N m^{-2}; U is the unit draft of soil, N m^{-2}; $U^* = K^* . U$; d is disturbed soil depth, m; w_c is the cutting width, m; θ is the soil shear angle, degree $= \frac{\pi}{2} - \left(\frac{\beta+\zeta+\phi}{2} \right)$, (Equation 8) according to Das and Luo (2016); β is the tool cutting angle, degree; ζ is the metal soil friction angle, degree; $= \tan^{-1}\left(\frac{\tan\phi}{2} \right)$, (Equation 9), according to Das and Luo (2016); $\emptyset$ is the internal soil friction angle, degree; = 12 degree for clay soil.

Substituting from Equation 7 into Equation 4 gives:

$$P_c = 0.001\, V_m . K^* . U . d^2 . \left(\frac{w_c}{d} + \frac{1}{\tan\theta} \right) \quad (10)$$

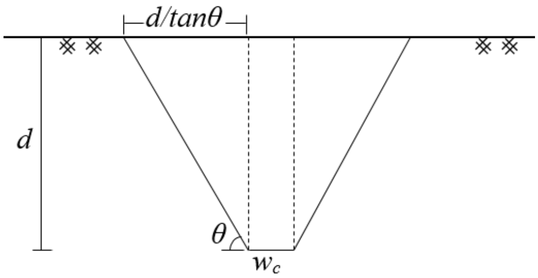

Figure 3. *Cross sectional area of the disturbed soil.*

There is a draft force on the shank of the plow due to the effect of the friction of the cut soil on it. However, this draft resisting force was included in the unit draft *(U*)* used in the analysis. This resisting draft force on the shank depends on many factors such as the repose angle *(ε)* of the pulverized soil, the friction coefficient *(f_{ss})* between soil and soil, the friction coefficient *(f_{ms})* between soil and metal, and the width of the plow shank.

Referring to Figure 4, the weight of the disturbed soil (W^*) by the plow action can be calculated as:

$$W^* = w_{sh} . \omega . d^2 . \left(\frac{w_c}{d} + \frac{1}{\tan\theta} \right) \quad (11)$$

Where, w_{sh} is the shank width in meter.

Referring to Figure 4, weight of this disturbed soil causes a resisting draft force on both sides of the plow shank as shown in Figure 4. The inclined resultant force *(F_{rt})* acting on one side of the shank is:

$$F_{rt} = \frac{W^*}{2}.(\sin\epsilon - f_{ss}.\cos\varepsilon) \quad (12)$$

The resisting friction force (F_{rs}) acting on the shank is:

$$F_{rs} = f_{ms}.w_{sh}.\omega.d^2.\cos\varepsilon.\left(\frac{w_c}{d} + \frac{1}{\tan\theta}\right).(\sin\epsilon - f_{ss}.\cos\varepsilon) \quad (13)$$

When substituting reasonable values for the parameters in Equation 13, the magnitude of the draft resisting force will be very limited compared with the force needed for cutting, and it can be ignored.

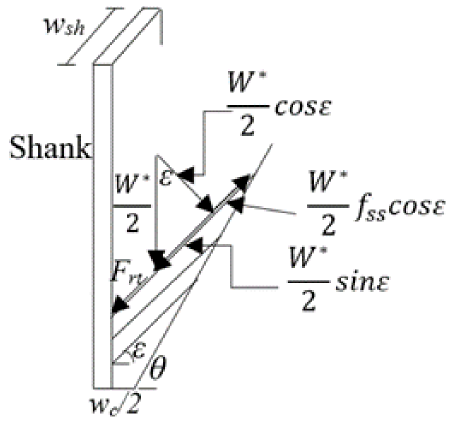

Figure 4. *The normal force acting on the shank of the plow.*

a) Determination of P_r

The required power to overcome rolling resistance (P_r) was calculated from Equation 14 (Srivastava *et al.*, 2006; Kepner *et al.*, 2017).

$$P_r = 0.001\,F_r.V_m \quad (14)$$

$$F_r = RR.cos\psi.(W_m + F_{cv}) \quad (15)$$

Where:

F_r= The resistance force due to rolling, N;
W_m= Tractor and machine weight, N;
RR= Rolling resistance coefficient;
F_{cv}= The vertical component of the cutting force;
Ψ= The inclination angle of soil surface with the horizontal direction, degree.

Referring to Figure 5, the F_{cv} was calculated as follows

$$F_{cv} = F_c.\tan\theta = K^*.U.d^2.\left(1 + \frac{w_c\tan\theta}{d}\right) \quad (16)$$

Substituting from Equation 16 into Equation 15 gives:

$$F_r = RR.cos\psi.\left(W_m + K^*.U.d^2.\left(1 + \frac{w_c.\tan\theta}{d}\right)\right) \quad (17)$$

Substituting from Equation 17 into Equation 14 gives:

$$P_r = 0.001\, V_m.RR.cos\psi.\left[W_m + K^*.U.d^2.\left(1 + \frac{w_c.\tan\theta}{d}\right)\right] \quad (18)$$

b) Determination of P_i

The P_i, Equation 19, depends on the machine weight *(W_m)*, the machine forward speed *(V_m)*, and the angle *(ψ)* between the inclined soil surface and the horizontal direction (Kepner *et al.*, 2017).

$$P_i = 0.001\, W_m.sin\psi.V_m \quad (19)$$

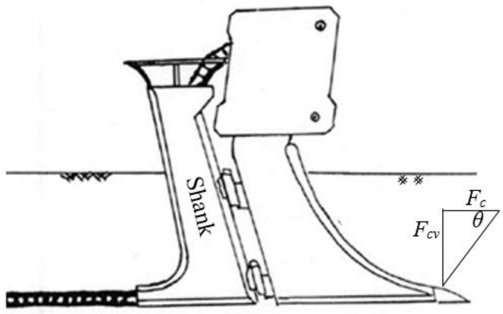

Figure 5. *The component of the cutting force acting vertically on the share for the plow.*

c) Determination of P_i

The power lost in sliping *(P_s)* and loss in machine speed due slippage *(V_s)* are calculated from Equations 20 and 21 (Baek *et al.*, 2022)

$$P_s = 0.001\, F_s.V_s = 0.001\,(F_c + F_r).V_s \quad (20)$$

Where P_s is the power lost in slip resistance, F_c is the cutting force, F_r is the resistance force due to rolling and V_s is the loss in machine speed due slippage *(S)*.

$$V_s = \left(\frac{S}{100-S}\right).V_m \quad (21)$$

Substituting from Equations 7, 17, and 21 into Equation 20 gives:

$$P_s = 0.001\left(\frac{S}{100-S}.V_m\right).\left[K^*.U.d^2.\left(\frac{w_t}{d} + \frac{1}{\tan\theta}\right) + RR.cos\psi.\left[W_m + K^*.U.d^2.\left(1 + \frac{w_c.\tan\theta}{d}\right)\right]\right] \quad (22)$$

d) Determination of P_t

The P_t was calculated from Equation 23 according to Srivastava *et al.* (2006) and Kepner *et al.* (2017) as follows:

$$P_t = P_b.(1 - \eta_t) \quad (23)$$

Where, η_t is the machine transmission efficiency.

From Equations 2, 10, 18, 19, 22 and 23;

$$1000P_b.\eta_t = V_m.\left\{K^*.U.d^2.\left(\frac{w_c}{d}+\frac{1}{\tan\theta}\right)+RR.cos\psi.\left[W_m+K^*.U.d^2.\left(1+\frac{w_c.\tan\theta}{d}\right)\right]\right.$$
$$+W_m.sin\psi$$
$$+\left(\frac{S}{100-S}\right).\left[K^*.U.d^2.\left(\frac{w_c}{d}+\frac{1}{\tan\theta}\right)\right.$$
$$\left.\left.+RR.cos\psi.\left(W_m+K^*.U.d^2.\left(1+\frac{w_c.\tan\theta}{d}\right)\right)\right]\right\}$$

$$1000P_b.\eta_t = V_m.\left(\frac{100}{100-S}\right).\left\{\left[K^*.U.d^2.\left(1+\frac{w_c.\tan\theta}{d}\right).\left(\frac{1}{\tan\theta}+RR.cos\psi\right)\right]+\left[W_m.\left(RR.cos\psi+sin\psi.\frac{s}{100-s}\right)\right]\right\} \quad (24)$$

Solving for V_m:

$$V_m = \frac{1000P_b.\eta_t}{F_t} \quad (25)$$

$$F_t = \left(\frac{100}{100-S}\right).\left\{\left[K^*.U.d^2.\left(1+\frac{w_c.\tan\theta}{d}\right).\left(\frac{1}{\tan\theta}+RR.cos\psi\right)\right]+\left[W_m.\left(RR.cos\psi+sin\psi.\frac{100-s}{100}\right)\right]\right\}, \text{N.} \quad (26)$$

Using Equations 3, and 23, the actual performance rate of the machine *(PR)* can be obtained as follows:

$$PR_{th} = 6\times10^4\times\frac{P_b}{F_t}\times\eta_t\times\eta_f \quad (27)$$

Where; PR_{th} is the theoretical machine performance rate (m min^{-1}), P_b is the tractor brake power (kW), η_t is the transmission efficiency, η_f is the field efficiency, F_t is total forces affecting the trenchless machine (N), S is the loss in machine speed due to slippage (%), K^* is the dimensionless coefficient, U is the unit draft of soil (N m^{-2}), d is disturbed soil depth (m), w_c is the cutting width (m), θ is the soil shear angle (degree), RR is the rolling resistance coefficient, ψ is the angle between inclined soil surface and the horizontal direction (degree), and W_m is the tractor and machine weight (N).

Experiments work is the second step of this scientific approach's plan. This experimental work is considered as a way to validate Equation 27.

Field Experimental Work

The plow-type trenchless machine (Figure 6) was tested in two experimental areas in Beheira Governorate, Egypt. Table 1 shows the specifications of the tractor and machine used. The plow-type trenchless machine was tested at two disturbed soil depths 0.75, and 0.90 m for first and second site respectively.

Figure 6. *Plow-type trenchless machine.*

Table 1. *Technical specifications of the machine and tractor*

Plow model	**Soil Max Zd Plow Tilling**
Boot, mm	101.6, 152.4,and 203.2
Machine weight, daN	275
Ploughing depth, mm	Up to 1250
Blade Length, mm	965
Blade width, mm	190
Tractor model	**CaseIH MX230**
Factory	Racine, Wisconsin, USA
Chassis	4WD
Weight, daN	8935
Height, m	3.16
Gears	18 forward and 4 reverse
Brake power, kW	174.5
Power at PTO, kW	141.7
Power at Drawbar, kW	123.2
Transmission efficiency, %	70.5

Measurements and Calculations

Soil texture and physical properties

Some of the soil's mechanical and physical characteristics, which were listed in Equation 27, were determined in this research work.

Unit draft of soil *(U)*

The average value of soil unit draft was taken 10 N cm^{-2} according to Jia *et al.* (2018).

Rolling resistance coefficient *(RR)*

The values of rolling resistance coefficient (*RR*) ranged between 3.0 and 5.0% according to Jia *et al.* (2018). Thus, it was taken the experimental field's average *RR* 4.0%

Dimensionless coefficient *(K^*)*

The value of K^* was taken as 9 since it was found ranging between 5 to 15 (Ghonimy, 2021).

Soil shear angle *(θ)*

The θ angle was calculated from Equation 8.

Disturbed soil depth *(d)*

Five trenches with three measurements each were used to measure the average disturbed soil depth for two experimental sites.

Slip percentage *(S)*

The S of the traction device was calculated from Equation 28, (Baek *et al.*, 2022)

$$S = \frac{D_1 - D_2}{D_1} \times 100 \tag{28}$$

Where: D_1 is the distance travelled by the machine with no load as the tracks had three complete rotations (m), and D_2 is the distance travelled by the machine with a load as the tracks had three complete rotations (m).

Machine weight *(W_m)* and transmission efficiency *(η_t)*

The W_m and η_t were taken from specification catalogue.

The machine field efficiency *(η_f)*

The η_f was calculated from Equation 29.

$$\eta_f = \frac{net\ axcavating\ time}{total\ time} \times 100 \tag{29}$$

RESULTS AND DISCUSSION

Soil Particle Size Distribution and Texture

The average values of soil texture for two experimental areas are shown in Table 2.

Table 2. *Soil mechanical analysis and texture for field experiments.*

Operating depth, m	Particle size distribution (%)			Texture class
	Sand	Silt	Clay	
0.76	19.2	27.1	53.7	clay
0.92	17.7	27.3	55.0	Clay

Field measurements

Table 3 shows the average values of field measurements.

Table 3. *Average values of field measurements for plow-type trenchless machine.*

Nominal disturbed soil depth, m	0.75		0.90	
Field measurements	**Average**	**SD**	**Average**	**SD**
d, m	0.76	+0.02	0.92	+0.04
w_c, m	0.323	+0.04	0.323	+0.04
S, %	5.00	---	5.00	---
RR, %	4.00	---	4.00	---
U, N m^{-2}	100000	---	100000	---
K^*	9.00	---	9.00	---
θ*, degree*	80	---	80	---
W_m*, N*	92100	---	92100	---
ψ, degree	0.00	---	0.00	---

d = Disturbed soil depth, w_c =cutting width, *S* = slip percentage, *RR*=traction rolling resistance, *U*= unit draft of soil, K^* = a dimensionless coefficient, θ= soil shear angle, W_m= tractor and machine weight, ψ = inclination angle of soil surface with the horizontal direction.

Actual Performance Rate *(PR)* and Field Efficiency *(η_t)*

Table (4) shows the average values of the breakdown items of the daily machine time, machine performance rate *(PR),* and field efficiency *(η_f)* as they were really observed in the field. It is evident that the average *PR* values were 13.6 and 10.1 m min^{-1} for disturbed soil depths of 0.76 and 0.92 m, respectively, while the η_f values were 54.4 and 49.7% for disturbed soil depths of 0.76 and 0.92 m, respectively. The field results showed decrease (about 50%) in the field efficiency of the plow-type trenchless machine due to the low of speed operation to control the depth and slope of the pipe drain that have been installed. These results were similar to those found by Ghonimy (2021); Ghonimy *et al.* (2023). Ghonimy (2021) indicated that the chain-type trenching machine's field efficiency ranged from 46.7 to 57% for the 150.7 cm and 120.7 cm trench depths, respectively. Also, Ghonimy *et al.* (2023) found that the wheel-type trenching machine field efficiency ranged from 43.0 to 50.1% for the 90.5 cm and 60.4 cm trench depths, respectively.

Table 4. *Breakdown of the plow-type trenchless machine's daily machine item, performance rate, and field efficiency.*

Activities	*Average consumed time, min day^{-1}		SD, min day^{-1}	
	Disturbed soil depth, m		Disturbed soil depth, m	
	0.76	0.92	0.76	0.92
Net installed time	286	252	6.17	4.22
Turning and travelling to start digging another trench	60	63	0.62	1.51
Setup time for reaching the depth	30	42	2.42	2.65
Rest periods	75	75	2.36	3.74
Field quick maintenances	30	35	1.82	1.23
Refill of fuel tank	25	25	3.27	2.54
Other lost time	20	15	2.65	3.72
Average total time, min day^{-1}	526	507	8.33	12.36
**Total installed length, m day^{-1}	7153	5100	5.87	6.17
Actual performance rate, m min^{-1}	13.6	10.1	0.12	1.12
*** Field efficiency, %	54.4	49.7	1.65	2.33

* Average value of ten estimates, each for a different operating day.
**Average value (m day^{-1}) of the total excavated trench lengths within the ten days period.
***Average field efficiency within the ten days period.

Theoretical Estimation of the Performance Rate of Plow-type Trenchless Machines

Equations 26, and 27, which theoretically predicted the performance rate, were used. Table 1 displays the applicable plow-type trenchless machine's specifications (1). Also, the experimental field's measured results are displayed in Table 3.

For 0.76 m disturbed soil depth

Theoretically, 13.5 m min^{-1} was predicted for the PR_{th} of the plow-type trenchless machine using Equations 26, and 27. This estimate was extremely near to the actual performance rate that was experimentally determined to be 13.6 m min^{-1} for the 0.76 m disturbed soil depth. The deviation of predicted for the performance rate from the actual performance rate was only -0.7%.

For 0.92 m disturbed soil depth

Theoretically, the PR_{th} of the plow-type trenchless machine was predicted to be 10.1 m min^{-1} using Equations 26), and 27. This number was extremely near to the actual performance rate that was experimentally determined to be 9.8 m min^{-1} for the 0.92 m disturbed soil depth. The deviation of theoretical prediction of the performance rate from the actual performance rate was only -3.0%. These results were similar to those found by Ghonimy (2021); Islam *et al*. (2019); Ghonimy (2021) in their study indicated that the chain-type trenching machine's theoretical performance rate was 3.4% and 2% lower than its actual performance rate at disturbed soil depths of 120.7 cm and 150.7 cm, respectively.

CONCLUSION

The following conclusions can be made:

1. The predicted performance rate (PR_{th}) was 13.5 and 10.1 m min^{-1} for 0.76 m and 0.92 m disturbed soil depth, respectively. While the actual values of performance rate were 13.6 and 9.8 m min^{-1} for 0.76 m and 0.92 m disturbed soil depth respectively.
2. The actual field efficiency (η_f) was 54.4 and 49.7 % for 0.76 m and 0.92 m disturbed soil depth, respectively.
3. The predicted performance rate from the actual performance rate ranged from -3.0 to -0.7 % only for the 0.92 and 0.76 m disturbed soil depth, respectively.

The resultant equation can be used to theoretically predict the performance rate of a plow-type trenchless machine with a high degree of confidence.

DECLARATION OF COMPETING INTEREST

There is no conflict of interest because the manuscript has only one author.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mohamed Ghonimy is responsible for the various parts of this paper including.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

REFERENCES

Baek SY, Baek SM, Jeon HH, Kim WS, Kim YS, Sim TY, Sim TY, Choi KH, Hong SJ and Kim YJ (2022). Traction performance evaluation of the electric all-wheel-drive tractor. *Sensors*, *22(3): 785.* https://doi.org/10.3390/s22030785

Das BM and Luo Z (2016). Principles of soil dynamics. *Cengage Learning*.

Diep DD (2017). Analysis the factors affecting conveyance rate of unbucket chain trenching machine. In *Agricultural, Forest and Transport Machinery and Technologies, 4(1): 38-44.*

Ghonimy M (2021). Prediction the performance rate of chain type trenching machine. *In Turkish Journal of Agricultural Engineering Research, 2(2): 390-402.* https://doi.org/10.46592/turkager.2021.v02i02.012

Ghonimy M, Abd El Rahman E and Alzoheiry A (2022). Mathematical prediction of excavating force and power of chain type trenching machine. *Acta Technologica Agriculturae, 25(4): 197-204.* https://doi.org/10.2478/ata-2022-0029

Ghonimy M, Morcos MA, and Badr AE (2023). Mathematical analysis for prediction performance rate of wheel type trenching machine. *Journal of Agricultural Machinery*, *13(1): 1-13.* https://doi.org/10.22067/jam.2021.71081.1049

Islam MN, Iqbal MZ, Kabir MSN, Jung KY, Mun DH and Chung SO (2019). Performance evaluation of trenchless subsurface drainage piping machine. *Journal of Biosystems Engineering, 44(4): 218-225.*

Jia J, Jia and Schmidt (2018). Soil dynamics and foundation modeling. New York: *Springer.*

Kepner RA, Bainer R and Barger EL (2017). Principles of Farm Machinery. Published by Satish Kumar Jain and produced by Varun Jain for *CBS Publishers & Distributors Pvt. Ltd.*

Naghshbandi SN, Varga L and Hu Y (2021). Technologies for safe and resilient earthmoving operations: A systematic literature review. *Automation in Construction*, *125: 103632.* https://doi.org/10.1016/j.autcon.2021.103632

Ranjbarian S, Askari M, and Jannatkhah J (2017). Performance of tractor and tillage implements in clay soil. *Journal of the Saudi Society of Agricultural Sciences*, *16(2): 154-162.* https://doi.org/10.1016/j.jssas.2015.05.003

Reddy Y and Shailesh P (2018). Design and analysis of excavator bucket tooth. In *International Journal of Modern Trends in Engineering and Research, 5(4): 79-86.*

Revenko VU, Ivanov AB, and Petukhov DA (2022, June). Power balance of all-wheel drive mobile power vehicle. *In IOP Conference Series: Earth and Environmental Science, 1045(1): 012080.* IOP Publishing. https://doi.org/10.1088/1755-1315/1045/1/012080

Rokochinskiy A, Jeznach J, Volk P, Turcheniuk V, Frolenkova N and Koptiuk R (2019). Reclamation projects development improvement technology considering optimization of drained lands water regulation based on BIM. Przegląd Naukowy. *Inżynieria i Kształtowanie Środowiska, 28(3): 85.* https://doi.org/10.22630/PNIKS.2019.28.3.40

Sitorus PE, Ko JH and Kwon OS (2016). Parameter study of chain trenching machines of underwater construction robots via analytical model. In OCEANS 2016 MTS/IEEE Monterey. Monterey, CA, USA: IEEE, pp. 1–6. ISBN: 978-1-5090-1537-5. https://doi.org/10.1109/OCEANS.2016.7761072

Srivastava AK, Goering CE, Rohrbach RP and Buckmaster DR (2006). Engineering principles of agricultural machines. 2nd ed., pp. i-xiv. St. Joseph, Michigan: ASABE. Copyright 2006 American Society of Agricultural and Biological Engineers, *St. Joseph*, Mich.