

## Utilizing Godwin and O' Dogherty model for predicting draft force of no-tillage tine in silty clay soil in Ninawa province

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### Abstract:

Draft force is a fundamental parameter for assessing the performance of agricultural machinery and identifying the energy requirements per unit area. This study aimed to evaluate the effectiveness of the Godwin and O'Dogherty model (GO model) for calculating the draft force of two types of no-tillage tines. The assessment was carried out within three distinct working depths: 0.1, 0.2, and 0.3 m. Fieldworks were conducted in a farm where located at Tel Kaif district, Ninawa province, employing a field with silty clay soil. The observations indicated that the model provided an acceptable level of accuracy in estimating draft force of narrow no-tillage tine. The mean error in estimation of narrow tine ranged from -3%, 12% and 15% when compared to the experimentally determined results at depth 0.1, 0.2, and 0.3 m, respectively. These findings propose that the GO model could be effectively adapted as a reliable analytical tool for estimating draft force requirements and for performance assessment of conservation agriculture implements under silty clay soil in Ninawa governorate.

**Keywords:** No-tillage tine, Tractor, Implement, Force transducer, Data-logger.

### Introduction

Conservation agriculture (no-tillage farming) can play an effective strategic solutions to face the challenges of drought and climate changes in Iraq. This is as results of high effectiveness of no-tillage farming in managing water resources and maintaining soil fertility [1-2]. In Iraq, no-till farming has expansion significantly, rising from 15000 hectares in 2013 to approximately 25000 hectares at present [3-4]. Consequently, the development of no-tillage techniques would represent a pivotal step to raise its operational efficiency and enhance its spread among new farmers. within the advancements in no-tillage technique is the use of models to predict its

performance indicators, one of which is draft force of no-tillage seeder.

Draft force is an essential variable for quantifying and assessing soil-working implement performance to monitoring energy requirements [5]. Hence, development of modern models to estimate the draft force of no-tillage openers is a central element of this effort. These models can play a key role in cooperating manufacturers and farmers in optimizing machinery design and operation [6]. Accordingly, various kinds of mathematical models are available, generally classified into two main categories: Analytical models based on the theoretical equations of

the relationships between the factors affecting the draft force [7] and computational models which utilize computer simulation to reflect the functioning of the soil and the tine under varying conditions [8-9-10].

In this investigation, the analytical model was chosen to estimate the draft force of the no-tillage opener, where a number of research studies developed similar mathematical models that address estimating the draft force of soil-working implement [11-12-13-14-15]. An extensive review of previous works in this field was conducted, which clarified the possibility of predicting the draft force of the soil-working tool through investigating the relationship between the movement of tine in soil and its characteristics which included physical and mechanical properties [13-16]. This analysis depends on a set of performance parameters, soil properties, and tine specifications, which previous studies showed the nature of the interrelationship between them [17-18]. Soil parameters include its mechanical characteristics namely soil cohesion, adhesion strength, and soil-soil and

soil-metal friction angles; while the tine parameters include the geometric indicators of the tine like, geometric shape, operating depth, and movement speed [19-20]. These parameters are used as inputs in Godwin and O'Dogherty model (GO model) for the purpose of estimating the draft force of no-tillage opener tine.

Practically, the soil condition is regarded a heterogeneous medium, as its mechanical properties change spatially and in the field according to the difference in its components and environmental conditions [21]. Therefore, the interaction between the opener and the effective forces inside the soil is directly affected by this variation. Therefore, this study aims to evaluate the suitability of GO Model for predicting the draft force of conservation agriculture seeder openers under different operating depths. The findings are expected to improve the accuracy of mathematical modeling and support the development of conservation agriculture techniques in local environments.

## **Materials and methods**

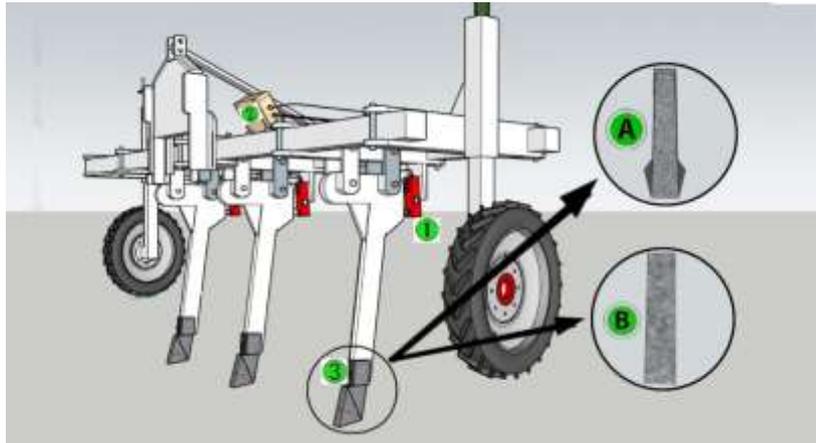
### **Field measurement of draft force:**

The field experiment was carried out in the field of a farmer in Telkaif district where is located approximately 13 km northeast of Mosul city. The field experiment was included two factors, were two types of no-tillage tine and working depths (0.1, 0.2, and 0.3 m). Randomized Complete Block Design (RCBD) under spilt plot was applied. Main plots were for no-tillage tines, and secondary plot was for working depths.

The Draft force was measured in the field using special tillage implement (**Figures 1, 2**).

This implement consist of a main frame equipped with three freely moving. A force transducer, specially designed to measure horizontal force (draft force), was mounted behind each shank. These transducers provide individual force readings for each shank. Data acquisition was managed by a system, designed and programmed by the Australian company Rimik, which records a reading every 2 seconds. Each of these recorded values represents an average of approximately 165 individual measurements. Consequently, this

methodology yields results that are as possible.  
 representative of real-world conditions as



**Figure 1: Assembly of the special implement (CTF implement) utilized in the field study; (1): Force transducer, (2): Data-logger; (3): No-tillage tine; (A): Winged tine; and (B): Narrow tine.**



**Figure 2: CTF implement operated in the field: (a) back view and (b) side view**

**Laboratory measurements**

According to the model equation (1) below, several input parameters required laboratory determination. These consisted of the soil's engineering properties namely, soil-soil cohesion, soil-metal adhesion, and soil-soil

and soil-metal friction angles, as well as blade characteristics, such as width and rake angle, and operational parameters, which include depth of work and forward speed [15].

$$P = \left( \gamma d^2 N_\gamma + CdN_c + C_a dN_{ca} + qdN_q + \frac{\gamma v^2}{g} dN_a \right) w \dots\dots\dots(1)$$

Where:

- $P$  = draft force (kN),
- $\gamma$  = soil density (kN.m<sup>-3</sup>),
- $C$  = soil-soil cohesion (kN.m<sup>-2</sup>),
- $d$  = operating depth (m),
- $C_a$  = soil-metal adhesion (kN.m<sup>-2</sup>),
- $q$  = surcharge pressure (kN.m<sup>-2</sup>),
- $g$  = gravitational acceleration (m.s<sup>-2</sup>)
- $v$  = forward speed (m.s<sup>-1</sup>),
- $w$  = width of tine (m),
- and.  $N_\gamma, N_c, N_{ca}, N_q,$  and  $N_a$  = dimensionless factors.

The soil's mechanical variables of the field were measured in the soil laboratory. Multiple soil samples were prepared in the laboratory to replicate the in-situ field condition (undisturbed soil) at the time of testing, with specific control over bulk density of and moisture content of soil. The testing program was conducted with four replicates for each treatment. A direct shear box was employed to determine the required soil mechanical parameters (**Table 1**). Historical data of some of soil mechanical parameters were adapted.

**Table 1: Input parameters of GO model**

Variables	Variables symbol	Operating depth (m)		
		0.1	0.2	0.3
Density of soil (kN m <sup>-3</sup> )	$\gamma$	9.95	12.31	12.86
Soil-soil cohesion (kN m <sup>-2</sup> )	$C$	19.9	24.62	25.72
Soil-metal adhesion (kN m <sup>-2</sup> )	$C_a$	1.3	1.7	1.7
Angle of internal friction (°)	$\Phi$	18.5	23	24
Angle of interface friction (°)	$\Delta$	17	21	22
Width of the foot (tip) (m)*	$w 1$	0.01	0.01	0.01
	$w 2$	0.035	0.035	0.035
Rake angle (°)	$A$	67	67	67
Ground speed (m.s <sup>-1</sup> )	$v$	1.5	1.5	1.5

\* w 1= narrow no-tillage tine, w 2= winged no-tillage tine

**Results and discussions**

The experimental findings (**Table 2**) indicated that the tine types and working depth had a significant effect (**p-values <0.001**) on

measured draft force; the measured draft force of no-tillage tines significantly increased by approximately 145 % and 335% when the

operation depth increase from 0.1 m to 0.2 m for winged and narrow tines, respectively, at the same time, they rose by 31% and 85% when the operation depth raise from 0.2 m to 0.3 m, for winged and narrow tines, respectively. Predicted draft force of no-tillage tine also followed the same trend across the previously mentioned depths. This is in good consistency with the findings presented by [22-23-24]. The explanation is that at deeper depths more volume of soil is influenced beside this the soil is harder and compacted due to overburden pressure and variations in strength characteristics of soil [10-17-25]. Additionally, the increased soil disturbance results in grown shear force. This also corresponds to the mechanical characteristics of field soil in Table 1. These results showed that second depth (0.2m) and third depth (0.3

m) had higher cohesion (typically 24.62 and 25.72 kN.m<sup>-2</sup>), respectively, compared with the first depth (0.1 m) (typically 19.9 kN.m<sup>-2</sup>).

In general, the outcomes of the narrow tine indicated that the estimation of draft force was lower than the observed draft force (underestimated) (**10%**), while for winged tine the estimation was greater than that measured values in the field (overestimated) (**60%**). The reason for this difference may associated with width of tine; the GO model assumption that the ratio of tine width to shank thickness remains constant along the entire working depth, but the specific value of this ratio differed in the winged tine case. This explains the results for the narrow tine, which also maintained a constant ratio, leading to outcomes aligned with the model's predictions.

**Table 2: Effect of tine type and working depth on predicted and measured draft force (n=4)**

Tine type	Working depth (m)	Predicted (kN)	Measured (kN) ±SD	Differences ±SD
Narrow tine	0.1	0.330	0.326 ±0.04	-3% ±11%
	0.2	1.250	1.420 ± 0.09	12% ±6%
	0.3	2.220	2.625 ± 0.12	15% ±4%
Winged tine	0.1	0.930	0.983 ± 0.08	5% ±7%
	0.2	3.840	2.424 ± 0.14	-60% ±9%
	0.3	7.070	3.186 ± 0.16	122% ±10%-

SD = Standard Deviation; n = replication number

The prediction of draft force derived from the GO model for narrow tine was successfully predicted. These observations are in agreement with the results which found by [15].

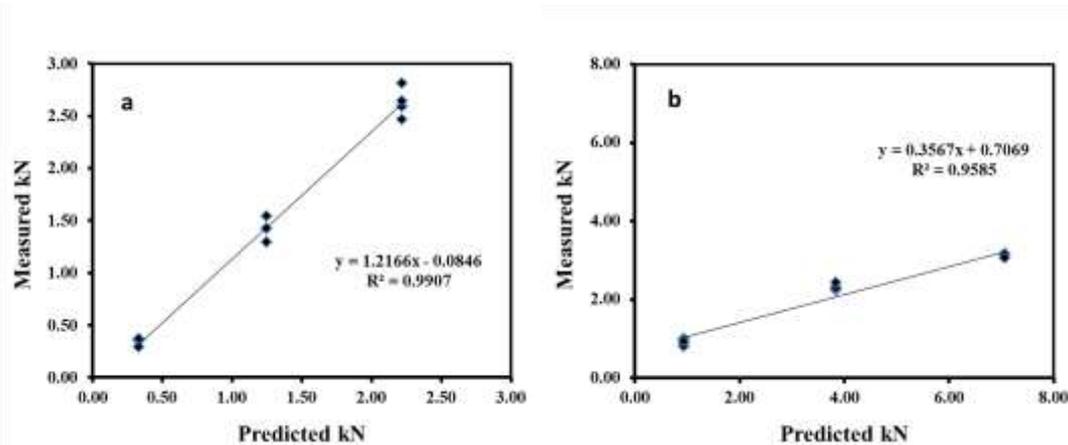
The linear regression model also applied to draw attention to the interconnection between

the observed draft force of no-tillage tines and the estimated draft force according to the GO model of soil-working tine force prediction for no-tillage tines in the studied field. There was significantly different in associations between the observed and estimated draft force (**p-**

values  $<0.001$ ) and ( $R^2 \leq 0.99$  and  $0.95$ ) for narrow and winged tines, respectively. As shown in **Figure 3a**, The form and magnitude level of the estimated curve shows a strong predictions ( $R^2 = 0.99$ ) within the estimated results for draft force of narrow no-tillage tine. In conjunction with this, the data of draft force estimation according to the GO model indicated that the model has estimated the draft force of narrow tine within model's average error. GO model concluded that the model can predict the draft force of tines within an average error of  $\pm 20\%$  [15]. Hence, it was established that the estimation of draft force by the GO model in silty caly soil for

narrow no-tillage tine was satisfactorily estimated.

In **Figure 3b**, it is noticeable that the estimated draft force of the winged no-tillage tine in comparison with the observed draft force reveals a non-similar trend to that exhibited for the narrow no-tillage tine. Although regression model for winged tine achieved  $R^2 0.95$ , but the differences between measured draft force compared with predicted draft force was  $60\%$ , thus the results of draft force estimation according to the GO model were largely ineffective in most working depths.



**Figure 2: interaction between observed and estimated draft force according to the GO model in estimations of tine draft force for narrow tine (a) and winged tine (b).**

## Conclusion

The ability to predict draft requirements for soil-working implement provides a pathway to minimize draft force through the optimization of no-tillage tine design. The GO model of tine force estimations is able to be successfully adapted to estimate the draft force of narrow no-tillage tine in the silty clay soil, which was tested in this study. The predicted draft force for narrow no-tillage tine was within an average error of  $\pm 10\%$ . The GO model is

easier in relation to model inputs and is able to be successfully applied to estimate of draft force for narrow no-tillage tine for the silty clay soil. However, The predicted draft force for winged no-tillage tine was within an average error of  $\pm 60\%$  specially at deeper depth. Thus the model requires modification and further development to enhance its capability for predicting the draft force of winged tines, or adaption of numerical simulation technique such as Discrete Element

Method (DEM) to simulate the draft force of winged tines at depth more than 0.2 m.

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