# SIMULATION OF DRAFT FORCE FOR THREE TYPES OF PLOW USING RESPONSE SURFACE METHOD UNDER VARIOUS FIELD CONDITIONS

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**ABSTRACT**

**In this study a mathematical models were developed to simulate draft force for three types of plows (moldboard, chisel and disk plow). The study was carried out in the experimental field of Agricultural Machinery Department at University of Basrah, which had silty clay soil texture. Independent parameters included three levels of tillage depth (0.15, 0.20 and 0.25m), three forward speeds (0.54, 0.83 and 1.53 m/s) and two levels of cone index (550 and 980 kPa). Response Surface Method (RSM) was utilized to produce models and to analyze results. Acquired results were used to extract accurate model for draft force. The draft force increased by 114% when tillage depth increased from 15 to 25 cm. Increasing forward speed from 0.54 to 1.53 m/s led to increased draft force by 80%. The cone index had positive effect on draft force by 42% when increased cone index from 550 kPa to 980 kPa. The most influential factor in draft force is the tillage depth, followed by the forward speed and cone index. The highest draft requirements were recorded for moldboard plow, followed by chisel and disk plow. Models validation was acceptable ( R-Squared = 0.97) and the draft force could be predicted with reliability of about 95%.**

**Keyword: modeling, response surface method, draft force, moldboard, chisel and disk plow.**

**مجلة العلوم الزراعية العراقية -2018 :49(6):1123-1131 المالكي**

**محاكاة قوة السحب لثلاث انواع من المحاريث باستعمال طريقة الاستجابة السطحية عند ظروف حقلية مختلفة**

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**المستخلص**

**في هذه الدراسة تم تطوير نماذج رياضية لمحاكاة قوة السحب لثلاثة أنواع من المحاريث (المطرحي القلاب، الحفار، القرصي). أجريت التجارب في الحقل التابع لقسم الآلات الزراعية في جامعة البصرة، كانت تربة الحقل ذات نسجة طينية غرينية. تضمنت الدراسة ثلاثة مستويات من أعماق الحراثة (0.15 ، 0.20 ، 0.25 م)، ثلاث سرعات أمامية (0.54 ، 0.83 ، و 1.53 م / ثانية)، ومستويان من مؤشر المخروط (550، 980 كيلو باسكال). استعملت طريقة الاستجابة السطحية لإنشاء النماذج ولتحليل البيانات. النتائج المستحصلة حقليا استعملت لاستخراج نموذج دقيق لقوة السحب. اظهرت النتائج زيادة قوة السحب بنسبة 114٪ عند زيادة عمق الحراثة من 15سم إلى 25 سم. كما ادت زيادة السرعة الأمامية من 0.54 متر/ثانية إلى 1.53 متر/ ثانية إلى زيادة قوة السحب بنسبة 80٪. كان لمؤشر المخروط تأثير إيجابي على قوة السحب بنسبة 42٪ عندما ارتفع مؤشر المخروط من 550 كيلو باسكال إلى 980 كيلو باسكال. العامل الأكثر تأثيراً في قوة السحب هو عمق الحراثة وتليه السرعة الأمامية ثم مؤشر المخروط. تم تسجيل أعلى متطلبات سحب في المحراث المطرحي القلاب ويليه الحفار ثم القرصي على التوالي. اظهرت نماذج التنبؤ بقوة السحب موثوقية عالية (R-Squared = 0.97) ويمكن التنبؤ بقوة السحب بمصداقية 95٪.**

**الكلمات المفتاحية: النمذجة، طريقة الاستجابة السطحية، قوة السحب، المطرحي القلاب، الحفار، القرصي**

***Received:29/4/2018, Accepted:10/7/2018**

## INTRODUCTION

**The tillage operation considered the greatest consumer energy from tractor. This energy depletes** to overcome soil resistance force to cut and invert soil through tillage operations which is called draft force. Draft force is one of the most criteria to assess performance of primary tillage equipment in farm. To minimize tillage operation, it is important to know the draught requirement for different equipment of tillage. There are many parameters have impact on draft force of plows that involve type of plow, soil conditions and tractor-implements characteristics. There are studies documented in literature concerned with the evaluation of draft force of plows (1, 6, 10, 14 and 23). To select and to match tractors with implements, it is important to prepare information about the ability of the tractor and the implement and the accessible tractor load. Accordingly, draft force requirements vary with the implement size, soil type, speed and depth of operation. Therefore, to have an effective tractor-implement matching, there is a necessity to fulfill actual field efficiencies and draft requirements along with other indices of tractive performance (2, 13, 21 and 23). Draft force is considered as a pertinent measure of tractive performance parameters (12). Almaliki (6) revealed that the most influential factor in drawbar pull of moldboard plow is the tillage depth, followed by the forward speed and cone index. Mathematical models of soil-tool interaction established on empirical and semi-empirical models may be support tool for designers and researchers in the domain of tillage implements (15). Shafaei, et al. (28) studied the effect of forward speed and tillage depth on draft force of chisel plow using adaptive neural fuzzy inference system. Then compare their model with mathematical model suggested by American Society of Agricultural and Biological Engineers (ASABE) to select the best model. The variation of energy requirements and fuel consumption for primary ploughing related to parameters such as soil type and its conditions, depth and width of cut, tool shape and geometry, manner of tool movement, previous treatments and crops, ground cover, tillage system and operation speed (8 and 18). Several techniques have been used for predicting draft force, and they are analytical, empirical, and numerical methods (3, 4, 5, 7, 19, 20, 22 and 25). Al-Suhaibani et al. (9) assessed the effects of tillage depth and forward speed on draft of moldboard, disk and chisel plows on sandy loam soil, the results demonstrated significant effects of forward speed and tillage depth on draft force for all the studied implements. The moldboard and chisel plow had highest draft force. Appropriate selection of implements and tractors for a specific field situation to diminish energy inputs for crop yield can be determined from these performance parameters. Many researchers believed the increasing of overall energy efficiency for tractor and implements and correct matching of tractor and agricultural machinery can be effective in decreasing fuel consumption (8, 16 and 27). The objective of this research is to predict premium model which represent the draft force using three types of implements under different field conditions. For more accurate, the Response Surface Method (RSM) will be utilized to model and analyze the collected data using Design-Expert Software 8.0.6.

## MATERIALS AND METHODS

**Experiment Site:** Experiments were carried out at the experimental field of Agricultural Machinery Department at University of Basrah located in (19´´ 30´ 33˚N 54´´ 47´ 44˚E, Basrah province, Iraq). The soil at the experimental site has silty clay texture (49% silt, 20% sand, and 31% clay).

**Moisture content and bulk density**

For measuring moisture content and bulk density, several soil samples from depth levels of 0.15, 0.20 m and 0.25 m at different parts of the field were collected using a cylindrical core sampler. Collected samples were immediately put in plastic bags to conserve moisture during transferring to the laboratory. Samples were weighted before and after drying in oven at 105˚C. Moisture content and bulk density were calculated from equations 1and 2 respectively.

$$MC = \frac{WB-WA}{WB} \times 100 \quad (1)$$

where:

*MC*: Moisture Content (%)

*WB*: Wet weight of soil sample (g)

*WA:* Dry wet of soil sample (g)

$BD = ms/Vc$ (2)

where:

$BD$: Bulk density (kg/m$^3$)

$ms$: Dry weight of soil in the cylinder (kg)

$Vc$: Cylinder volume (m$^3$)

**Table 1. Corresponding calculated bulk density and moisture content at different cone index values**

| | | |
|---|---|---|
| Cone index (kPa) | 550 | 980 |
| Bulk density (kg/m$^3$) | 1015 | 1340 |
| Moisture content % | 16.34 | 17.67 |

### Cone Index measurement

Cone Index explains the resistance to penetration into the soil per unit cone base area. The cone index and its gradient with respect to penetration depth have been used as a basis for predicting off-road vehicle performance. Cone index values were obtained by taking penetrometer readings at 5 cm increments to depths of 25 cm at several locations of the plots using a cone penetrometer according to ASABE Standards S313.2 with a cone base area of 130 mm$^2$ and 30$^o$ (11).

### Tractor and implement

Two tractors were used in this research. The first tractor was a 55 (kW) CASE IH 71 tractor produce by India which was utilized to provide energy for pulling the used plows in the experiments. The second tractor was Massey Ferguson 285 (56 kW) which was employed for mounting the plows with it. The specifications of these tractors were demonstrated in Table 2. The experiments were conducted using three type of conventional tillage system which includes:

*__Moldboard plow__: The moldboard plow had three furrows. Furrow width was set to 330 mm, and its maximum tillage depth was 300 mm. The total work width of moldboard plow was 990 mm.

*__Chisel plow__: A mounted-type chisel plow implement was used for the experiment. The implement included seven spring curved shanks linked to a toolbar in two rows. The blade width of each shank was 50 mm). Also, working width of the plow was 1650 mm. Angle of attack for each shank was 25$^o$. The width of each shank was 60 mm.

*__Disk plow:__ The disk plow comprised of three disks. Diameter of each disk was 700 mm. Tilt and disk angles for all disks were 35$^o$ and 45$^o$. The active width of the plow was 1200 mm. The maximum operating depth of the disks was about 250 mm. These tillage implements used for collecting data at three levels of depth (0.15, 0.20 and 0.25m) and three speeds of operation (0.54, 0.83 and 1.53 m/s) in two locations of soil with cone index values (550 and 980 kPa). All experiments had three replications resulting in a total of 162 tests.

**Table 2. Specifications of used tractors in experiments**

| Specifications | CASE IH 7 Model | Massey Ferguson 285 Model |
|---|---|---|
| No. of cylinders | 4CYL | 4CYL |
| Power (kW / hp) @ 2500 rpm | 75 / 55 | 77 / 56 |
| Max. torque (Nm @ rpm) | 242Nm @ 1500 rpm | 248 @ 1300 rpm |
| Fuel Tank Capacity | 62 | 120 |
| Transmission clutch | Mechanical | Mechanical |
| Total number of speeds | 8 forward, 2 reverse | 8forward, 2 reverse |
| PTO speeds (rpm) | 540 | 540 |
| Wheelbase 2WD / 4WD (mm) | 2160 / 2200 | 2100 / 2290 |
| Ground clearance under rear axle (mm) | 555 | 450 |
| Type Size 2WD Front/Back | 16 – 7.50 / 30 -16.9 | 24 -12.4 / 30 -18.4 |

**Data logging system**

The draft force of the plows (chisel, disk and moldboard) for each experiment of the treatments was also registered based on the RNAM system (26). The drawbar load cell is an *S* shaped (Model H3-C3-3.0t-6B-D55 from Zemic with capacity of 30 kN). It is mounted between two tractors. The first one is a as puller CASE JX75T and the other one is Massey Ferguson (MF 285) as auxiliary. The auxiliary tractor pulls the implement-mounted tractor with the latter in neutral gear but with the implement in the operating position. Recorded force data were considered as rolling resistance force of the auxiliary tractor wheels. An instrumentation package was developed by Almaliki, (8) which used for measuring draft force of implements. This package included the data logging system and the transducers. The data logging system consisted of an Arduino electronic board and portable computer (laptop) linked via a USB port. Data were sampled at 50 ms intervals.

**RESULTS AND DISCUSSION**

In this research, a total of 162 tests were carried out for producing acceptable models of draft force, for three type of implements. After averaging treatments, for opting more roboust and more dependable models, a assortment of several polynomial models were analyzed by using Design Expert software. In order to optimize and diminsh the amount of candidate regressors, a stepwise regression algorithm, as a most widely used variable selection technique (17), was then utilized, resulting in the reduced models (Table 3).

**Table 3. Summary of statistics of reduced quadratic models**

| Std. Dev. | Mean | C.V. % | PRESS | R-Squared | Adj R-Squared | Pred R-Squared | Adeq Precision |
|---|---|---|---|---|---|---|---|
| 0.30 | 6.41 | 4.74 | 18.12 | 0.9760 | 0.9715 | 0.9649 | 57.327 |

ANOVA table (Table 4) was accomplished utlizing Design Expert software to determine the level of significance effects of the plow type, cone index, tillage depth, and the forward speed on draft force. The results ilustrated that significant effect of the type of plow, cone index, tillage depth, and the forward speed on dradraft force. Moreover the ANOVA table exposed a significant effect between interactions of these parameters at various probability value (lower than 0.05).

**Table 4. Analysis of variance table for Draft force**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|---|---|---|---|---|---|
| **Model** | **503.10** | **25** | **20.12** | **217.57** | **< 0.0001** |
| **A-Type of plow** | **83.04** | **2** | **41.52** | **448.86** | **< 0.0001** |
| **B-Cone index** | **38.94** | **1** | **38.94** | **421.04** | **< 0.0001** |
| **C-Forward speed** | **45.41** | **2** | **22.71** | **245.50** | **< 0.0001** |
| **D-Depth** | **329.71** | **2** | **164.86** | **1782.31** | **< 0.0001** |
| **AB** | **1.36** | **2** | **0.68** | **7.35** | **0.0009** |
| **AC** | **0.57** | **4** | **0.14** | **1.55** | **0.0308** |
| **AD** | **1.47** | **4** | **0.37** | **3.96** | **0.0045** |
| **BC** | **1.46** | **2** | **0.73** | **7.91** | **0.0006** |
| **BD** | **0.53** | **2** | **0.26** | **2.85** | **0.0415** |
| **CD** | **0.60** | **4** | **0.15** | **1.63** | **0.0203** |

Figure 1 (A-F) explains the effects of studied parameters and their interactions on draft force. Draft force increased by 114% when depth of tillage increased from 15 to 25 cm. This is due to the increased magnitude of the cultivated soil by plow with increasing tillage depth that posteriorly results in increasing of draft force. one more cause is that increasing of plowing depth would produce an increase of soil tear, volume and mass, so that more energy is need to shear the soil. Moreover, increment the soil mass gathered around the plow causes the sidelong stress on the plow, consequently the friction between runner and furrow surface increases. These results are in agreement with the findings of other researchers (1,15 and 25). The results demonstrated that requirements of draft force at tillage depth 25cm were recorded 18.27, 15..47 and 12.07 kN for moldboard, chisel and disk plow, respectively. This is in assent with the findings of the Al-Suhaibani et al. (9). They reported that moldboard and chisel plow had highest draft force from disk plow in sandy loam soil. The effect of forward speed on draft force was positive. Increasing forward speed from 0.53 to 1.53 m/s led to increased draft force by 80%. This goes back to increment of acceleration of cutting soil particles. Also the disk plow had lowest draft force with increasing forward speed by 8.24 kN followed by chisel plow (10.87 kN) and moldboard plow (11.79 kN) at forward speed 1.53 m/s. The effect of cone index on draft requirement was apparent. Draft force increased by 42% when the cone index increased from 550 to 980 kPa. This attributed to considering cone index as indicator for soil strength. Raising cone index of soil, cohesion and friction of soil particles will be increased. This lead to need more energy for cutting soil by plow which reflects on draft requirement. The requirements of energy for draft force were highest for moldboard plow from the other plows. It was recorded 8.55 kN at cone index 980 kPa while chisel and disk plow recorded 6.87 kN and 4.34 kN, respectively. The results are disagreement to finding by Arvidsson et al. (10) .They found the draft force of the chisel plow to be higher than moldboard plow and referred that to the differences in implement geometry and mode of soil break-up. Results showed that the interaction between depth of tillage and forward speed had the biggest effect on draft force from cone index for all types of studied plows. where draft force recorded 20.21 kN at tillage depth 25 cm and forward speed 1.53 m/s. consequently, the most influential factor in draft force is the tillage depth, followed by the forward speed and cone index.

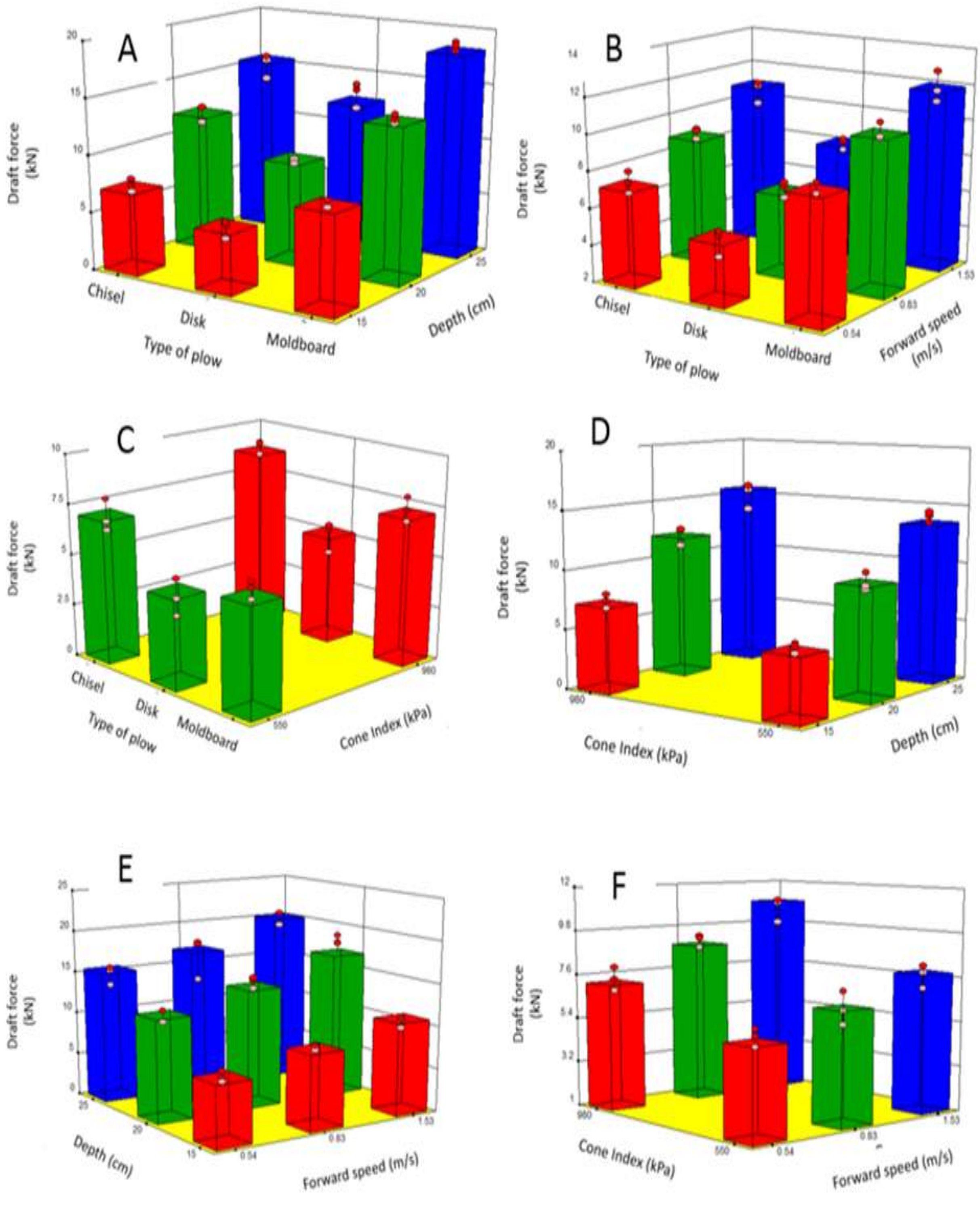


**Figure 1 (A-F). (A) Interaction between Type of plow -Depth; (B) Type of plow-Forward speed; (C) Type of plow-Cone index; (D) Depth-Cone index;(E) Depth-Forward speed and Cone index-Forward speed for the draft force**

The correlation between measured and predicted values of draft force under different field conditions is shown in Figure 2. The small variation between the predicted and experimental values promoted the reliability of this model in predicting the draft force. Figure 3 explained the most compatible power transformation (lambda) for responses by the Box-Cox diagram that results the least residual sum of squares in the transformed model for draft force. It can Also be noted, the internally studentized residuals vs run number (Figure 4) and internally studentized residuals (Figure 5) of the models vs predicted values, are in the proper range.The results illustrated the developed models by using RSM are significantly eligible to predict draft force for three types of plow (moldboard, chisel and disk plow) under various field conditions (three levels of tillage depth (0.15, 0.20 and 0.25m), three forward speeds (0.54, 0.83 and 1.53 m/s) and two levels of cone index (550 and 980 kPa). ANOVA table exposed a considerable increment in draft force for all the three tillage implements with an increase in tillage depth, forward speed and cone index. Moreover the results showed a significant effect between interactions of these parameters at various probability values (lower than 0.05). Also the obtained results demonstrated that the most influential factor in draft force is the tillage depth, followed by the forward speed and cone index. The moldboard plow showed greatest draft requirement, followed by chisel and disk plow at the same depth, forward speed and cone index. The small variation between the predicted and experimental values promoted the reliability of this model in predicting the draft force.

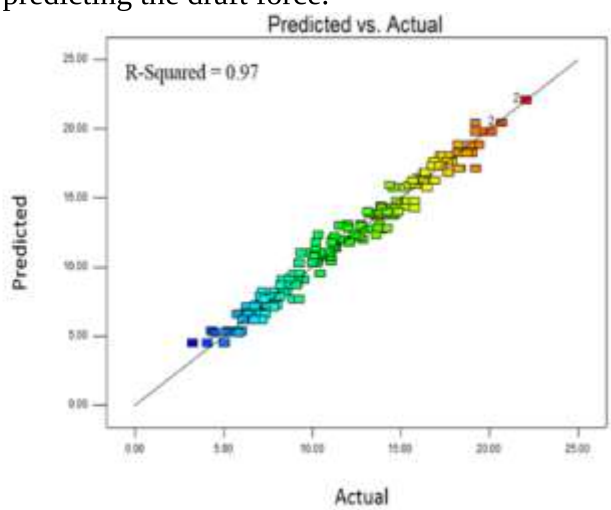


**Figure 2. The internally studentized residuals versus run number**

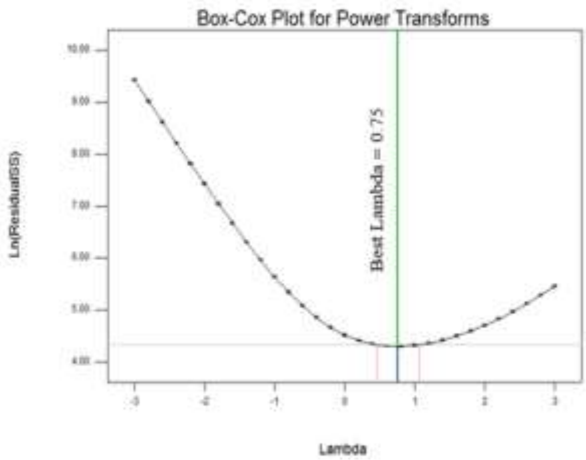


**Figure 3. The Box-Cox plot for power transformation draft force**

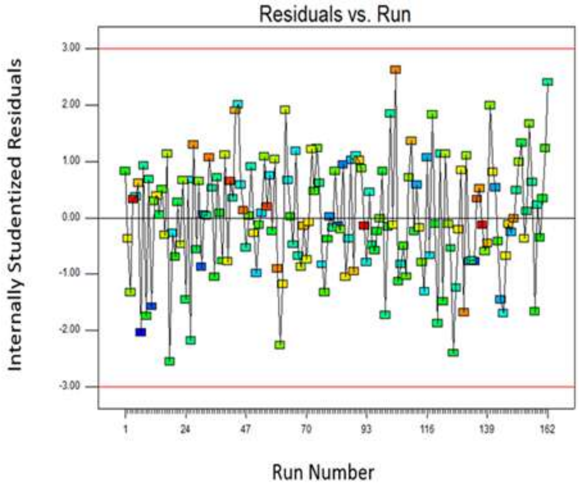


**Figure 4. The internally studentized residuals versus run number**

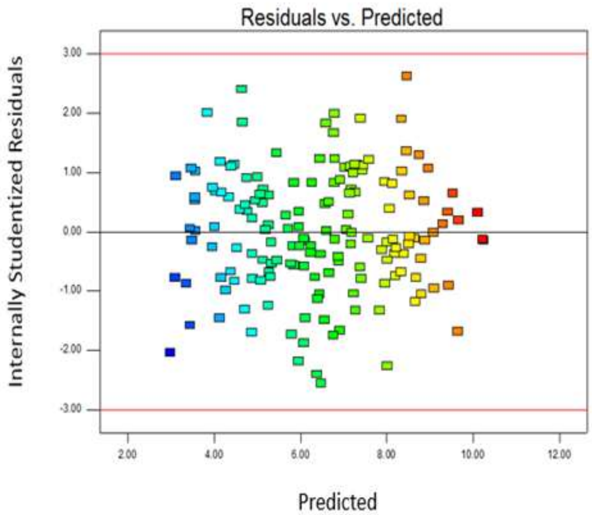


**Figure 5. The internally studentized residuals versus predicted values**

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