INTERACTIVE COMPUTER APPLICATION FOR PREDICTING PERFORMANCE INDICATORS OF A TRACTOR-CHISEL PLOW SYSTEM IN C-SHARP ENVIRONMENT

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ABSTRACT

An interactive computer application in C-Sharp language was developed to predict the performance indicator of a tractor-chisel plow system. Moreover, the purpose of such application was to aid agricultural engineers in the field of farm machinery management to select suitable inputs to make proper matching of a tractor and a chisel plow. The required equations were formulated using the obtained weights from a trained artificial neural network model that trained using actual data field experiments. The application predicts actual field capacity (ha/h) and fuel consumption per unit area (lit/ha). Tractor loading factor was the main issue in the present application since it was used as a regulator for determination of the required draft. The application displays a chart during simulation to show the intersect point between both specific fuel consumption calculated by the application and specific fuel consumption calculated using the equation of ASABE standard. Overall energy efficiency in the range of 10–20% was acted to select the optimum values of the affecting parameters. The application outputs include theoretical field capacity, actual field capacity, field efficiency, fuel consumption per unit area, fuel consumption, energy required based on fuel consumption, draft, unit draft per unit plow width, unit draft per unit plowing area, draft power (drawbar power), energy required based on draft requirements, loafing factor, calculated specific fuel consumption, specific fuel consumption based on ASABE equation and overall energy efficiency.

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For validation the developed C-Sharp application, data from previous study was utilized for chisel plow- tractor system operated in specific condition, and the simulated draft was 16.73 kN (calculated specific fuel consumption and specific fuel consumption based on ASABE equation was 0.53 lit/kWh) and the loading factor was 0.62. The relative error between actual and simulated drat was 16%. The developed application is appropriate for farm machinery management, educational and research purposes. It is user-friendly and could be run on Windows desktop without C-Sharp environment. The application could be edited and/or updated to predict performance indicators of other tractor-tillage implement systems.

1. INTRODUCTION

Chisel plow is considered to be a primary tillage implement because it is mainly used for the initial soil working operations (**Srivastava et al., 1993**). It is widely used by Egyptian farmers to reduce soil strength and to cover plant materials (**Ahmed, 2011**). Moreover, it generally has odd number of shanks such as 5, 7, 9 and they connected on two or three rows in the frame (**Gulsoylu et al., 2012**). On the other hand, operation performance data of a chisel plow is essential to optimize its operation and to reduce the cost of tillage process (**Al-Suhaibani and Ghaly, 2010**). However, the performance parameters of a chisel plow included measurement of draft, drawbar power, actual field capacity, field efficiency and fuel consumption (**Bashir et al., 2015**). These parameters could be obtained by conducting field experiments using expensive instrumentation systems (**Korayem et al., 1985; El-Ashry et al., 1994; Ismail and Burkhardt, 1993; Al-Suhaibani and Al-Janobi, 1997; Mohamed et al., 2001; Naderloo et al., 2009; Al-Suhaibani et al., 2010; Younis et al., 2010; Askari et al., 2011; Altiniġik, 2012; Askari and Khalifahamzehghasem, 2013 Ranjbarian et al., 2015**). Additionally, empirical mathematical models are available in literature which can be utilized to get draft requirements, fuel consumption of tillage implements and field capacity as reported by different research papers (**Gee-Clough et al., 1978; Younis and El-Ashry, 1993; Sahu and Raheman, 2006**). Moreover, the famous model for estimating draft requirements for different tillage implements at different working conditions is reported by American Society of Agricultural Engineers standard (**ASABE, 2000**). However, the empirical mathematical models are the way to estimate the multiple effects of alternative operating variables that affect the performance indicators of the tillage implements. These operating variables are implement width, operating depth and plowing speed (**Kepner et al., 1978; Macmillan, 2002**), soil moisture content (**Rashidi et al., 2013; Al-Suhaibani et al., 2015; Tayel et al., 2015**).

Due to there are several variables that affect the performance of tillage implements, besides, draft requirements also depend on soil conditions, soil type and the implement type (**Upadhyaya et al., 1984; Grisso et al., 1994**). Thus the researchers have been of great interest to develop different techniques and efforts for ability to predict the performance indicators of farm machinery units during field operations (**Grisso et al. 2006**). One of these efforts is to model the draft and fuel requirements in tillage operations for optimizing tractor-implement systems (**Serrano Joao et al., 2005**). In Addition, computer programs have been developed to determine the optimal operation of agricultural tractors and machine system using Visual C language (**Al-Hamed and Al-Janobi, 2001a; 2001b**). Moreover, spreadsheets and dimensional analysis could also be utilized for tractor performance prediction and performance indicators estimation for chisel plow tractor combination (**Al-Hamed et al., 1994; Al-Janobi et al., 2010; Moeenifar et al., 2013**).

Prediction models programmed by computer languages could be a successful tool to save time and field experiments (**Catalan et al., 2008**). They represent a necessarily cost-free tool to the determination of the relative importance of a number of variables affecting actual tractor-implement systems operation to reduce the costs of tillage management (**Battiato et al., 2013**). So, considerable research has been conducted to develop computer based models to determine performance indicator of tractors and farm implements. **Omid (2006)** and **Abbaspour-Gilandeh et al. (2007)** used visual basic environment to develop Graphical User Interfaces computer program to predict the performance indicators as well the tractor's specific fuel consumption for agricultural soils. **Eldoma (2008)** developed a computer program on Turbo Pascal for farm machinery power estimation. The program was broken down into three major sections: the heading, the declarations and the block. The program used multi types of variables and constants for performing power calculations. **Sahu and Raheman (2008)** developed a decision support system in Visual Basic 6.0 programming language for matching tillage implements with 2-wheel drive (2WD) tractors for predicting the field performance of tractor– implement system. **Al-Hamed et al. (2010)** developed a comprehensive and easy to use computer program for the purpose of determining the farm energy requirements. The program was designed with visual C++ language. **Hassan et al. (2011)** developed a program for predicting performance of agricultural machinery in visual basic. The program predicts of field efficiency, field capacity, draft power required to operate machines and power take-off (PTO) power. **Canakci et al. (2011)** developed computer software to determine optimum size of mechanization vehicles used in farms. They employed Visual Basic to build the program. **Mehta et al. (2011)** developed a decision support system for selection of a tractor-implement system. **Mohamed et al. (2011)** developed an agricultural machinery performance program that predicts field efficiency, field capacity, selection of optimum equipment, draft power required to operate machines to meet the user requirements for machinery management and as educational and research tool. The program was written in Visual Basic programming language as user-friendly interactive program. **Ishola et al. (2010)** developed object-oriented and user friendly application program for predicting the performance of a tractor-implement system utilizing Visual C++ environment containing several windows that serve specific functions in the development process. **Pranav et al. (2012)** developed user friendly software for predicting the performance of power tiller to meet requirements in educational and research organizations by using visual basic. **Park et al. (2012)** developed a simulation program for the prediction of tractive performance of a tractor by applying widely used empirical models for tractive performance prediction of single tire. **Patel et al. (2012)** developed a decision support system in Visual Basic 6.0

programming language for 2WD tractors. The decision support system provides intuitive user interfaces by linking databases such as tractor parameters, tire and implement specifications, soil and operating conditions to support the decision for selection of tractor-implement system. **Zarini et al. (2013)** developed decision support software in Visual Basic 6.0 programming language for matching and selecting implements with tractors and time management of farm operations. This software had databases including variety of tractor models and implements sizes. **Al-Hamed et al. (2014)** built a program for predicting performance of tillage implements in visual basic based on trained artificial neural network model. The program was designed to predict the required draft and energy of chisel, moldboard and disk plows. **Zaied et al. (2014)** developed a computer program in C++ programming language to predict implement performance parameters. These parameters were total field time, theoretical field capacity, effective field capacity and field efficiency. The program was built, compiled and was then debugged. **Zaied et al. (2016)** developed a program using C ++ programming language to study effect of tool depth and width on angle of soil failure plane, soil cutting coefficients, soil resistance force and power requirements in three-dimensional soil cutting.

Simulation programs in the field of farm machinery could be used to estimate performance data of tillage implements. Also, they could be used to study the relative importance of many variables affecting field performance of tillage implements without conducting expensive, as well as time consuming, field tests (**Hassan et al., 2011**). On the other hand, there is a rapid progress in developing interactive application software to facilitate the interaction between users and computers (**Hassan et al., 2011**). However, such interactive application software is effective and simple to access, by users than programs developed in traditional programming languages (**Al-Hamed and Al-Janobi, 2001b**). Additionally, most of the developed interactive applications that predict tractor-implement field performance are depended on standards equations of American Society of Agricultural and Biological Engineers. Thus, the objective of this study was to develop an interactive computer application for predicting performance indicators of a tractor-chisel plow unit in C-

Sharp language. The required equations were formulated using the obtained weights from a trained artificial neural network model that trained using actual data from field experiments. The application predicts actual field capacity and fuel consumption per unit area. Moreover, a loop was developed inside the application to determine the draft requirements based on altering tractor loading factor until both specific fuel consumption calculated by the developed C-Sharp application and specific fuel consumption calculated based on the equation developed by **ASABE (2000)** are equal.

2. MATERIALS AND METHODS

2.1.The required equations for developing C-Sharp application

The artificial neural network (ANN) model was trained using actual data from field experiments. The inputs to the ANN model were tractor power (X1, kW), plow width (X2,m), plowing depth (X3, cm), plowing speed (X4, km/h), sand percentage (X5, %), silt percentage (X6,%), clay percentage (X7,%), initial soil moisture content (X8, db%) and initial soil bulk density (X9,g/cm^3). The outputs from the ANN model were actual field capacity (ha/h) and fuel consumption per unit area (lit/ha) of a tractor-chisel plow unit. The artificial neural network used in the present study was characterized by the different parameters including: network layers are 3, input nods are 9, output nodes are 2, one hidden layer having 30 nodes, transfer function is sigmoid, learn rate is 0.010402 and momentum is 0.8 (**Al-Janobi et al., 2010**). Typically, a minimum of three layers which are the input layer, the hidden layer and the output layer is required to develop an ANN system (Figure 1). The input contains nodes that correspond to input variables while the output contains nodes that correspond to output variables (**Kaul et al., 2005**). The input layer is used to distribute the inputs to a number of hidden layers and the output of which is connected to an output layer, where the outputs of units are connected to the inputs of the next via connection weight (**Marchant et al., 2002**). In simpler way, the weighted connections allow data to move between layers through it, where the node accepts data from previous layer and calculates a weighted sum of all its net inputs:

$$t_i = \sum_{j=1}^{n} \left(w_{ij} \times x_j + b_i \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, n is the number of inputs, w is the weight of connection between node i and j, x is the input from node j, and b_i is a bias. In order to calculate the node output O_i, a transfer function f_i is then applied to the weighed value:

$$O_i = f(t_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For calculating fuel consumption per unit area and actual field capacity, each input was normalized and the equations for computing the normalized value of each input were as follows:

X1N=((Tractor Power - 25.35)*(0.7)/(104.40 - 25.35))+0.15……….(3)
X2N=((Plow width - 1.35)*(0.7)/(3.40 - 1.35))+0.15 ……………….(4)
X3N=((Plowing depth - 7.06)*(0.7)/(30.00- 7.06))+0.15…………….(5)
X4N=((Plowing speed - 2.00)*(0.7)/(6.92- 2.00))+0.15…………….(6)
X5N=((Sand - 11.38)*(0.7)/(80.00 - 11.38))+0.15…………………….(7)
X6N=((Silt - 11.00)*(0.7)/(55.20 11.00))+0.15……………..……….(8)
X7N=((Clay - 9.00)*(0.7)/(53.20 - 9.00))+0.15 ……………….…….(9)
X8N=((Initial soil moisture content - 7.30)*(0.7)/(50.20 - 7.30))+0.15 ....(10)
X9N=((Initial soil bulk density- 1.17)*(0.7)/(1.86 - 1.17))+0.15….(11)

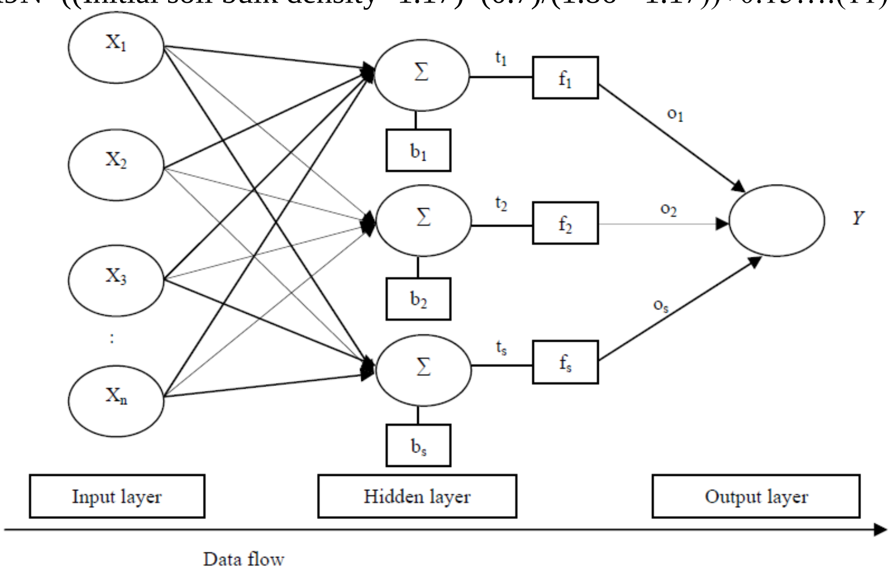


Figure (1). Layers and connection of a feed-forward back propagation ANN.

Then summation equations as indicated in Eq. (1) were computed for fuel consumption per unit area by the help of connection weight values obtained from the ANN model (Table 1). They were 30 equations as follows:

SUM1=0.39722* X1N +0.12486* X2N -4.86207* X3N +12.51644* X4N +1.28854* X5N +0.73622* X6N -0.39392*X7N-4.85972* X8N +5.4005* X9 +1.96082 …………………….………….………......(12)

SUM30= 0.87729* X1N -0.26943* X2N -1.85397* X3N +1.8802* X4N -1.89565* X5N +2.60764* X6N 1.40695*X7N+1.61195* X8N - 0.75101* X9 +0.29716………………………………………………..(13)

Then in order to calculate the node output as shown in Eq.(2), a transfer function is then applied to the weighted value (they were 30 equations) as follows:

F1 =1/((1+EXP(-SUM1)))………….....………………..………………(14)

F30 =1/((1+EXP(-SUM30)))… ………………………………….…(15)

Then again summation equation was computed for fuel consumption per unit area by the help of connection weight values obtained from the ANN model as follows:

SUMQ=-8.02663*F1-0.96115*F2+1.18893*F3-0.42434*F4-1.06352*F5+1.46531*F6+3.67216*F7-0.65551*F8-1.47706*F9+9.90728*F10+6.6397*F11-0.26946*F12-1.95977*F13-1.53764*F14-4.09288*F15+2.0003*F16-10.5647*F17-0.90989*F18-4.27277*F19+6.00605*F20-6.58363*F21+11.92589*F22-0.61813*F23-0.38999*F24+4.46134*F25-1.30542*F26-1.46609*F27+1.04353*F28-1.98823*F29+ 2.33077*F30 -0.23665……………..…………….….….. (16)

Then node output was computed as follows:

FF=1/((1+EXP(SUMQ)))…….....…...………………………………..(17)

Then the normal fuel consumption per unit area (lit/ha) will be computed as follows:

Fuel consumption per unit area (Q_F ,lit/ha) =((FF-0.15)*(74.88-8.22)/(0.7))+ 8.22……………………………………………….…(18)

The same procedure was also applied for actual field capacity but the final connection weight values are different and the summation equation was as follows:

SUMQ1=1.12757*F1+3.28986*F2+0.52704*F3-1.14918*F4+1.7983*F5+2.37183*F6-0.35981*F7+1.57607*F8-6.33971*F9-0.59344*F10-0.42763*F11-2.11729*F12-1.73017*F13+0.64729*F14+1.50214*F15-0.38546*F16+0.51856*F17-2.11879*F18 +0.07551*F19-0.44633*F20-0.82182*F21-0.77743*F22-0.66159*F23-0.36466*F24+0.00725*F25+1.17782*F26-0.96086*F27+0.94193*F28-1.13411*F29+2.0885*F30+ 0.23825.... (19)

Then node output was computed as follows:

FF1=1/((1+EXP(-SUMQ1)))…………………………………………..(20)

Then the normal actual field capacity (ha/h) will be computed as follows:
Actual field capacity (AFC, ha/h) =((FF1-0.15)*(1.68- 0.25)/(0.7))+ 0.25……………………………………………………………...……(21)

2.2. Calculation of performance indicators of a chisel-tractor system

The outputs from the developed C-Sharp application were two performance indicators including effective field capacity (ha/h) and fuel consumption per unit area (lit/ha). However, fuel consumption per unit area is the measure of amount of fuel required for a given tractor-implement system to cover 1 ha.

2.2.1. Fuel consumption

Fuel consumption (Q_P, lit/h) was calculated using the following relationship,

$$Q_p = Q_F \times AFC \quad \text{……………………………………………(22)}$$

2.2.2. Energy requirement

Energy requirement (kWh/ha) of a given tractor- chisel plow system was calculated using the following relationship (**Hassann et al., 2009**),

$$Energy\ requirement = \frac{Engine\ \ power\ (kW)}{\text{Actual field capacity (ha/h)}} \quad \text{………………..(23)}$$

Table (1). Connection weight values for Eq. (1) for fuel consumption per unit area and actual field capacity calculations.

Inputs	W_{1j}	W_{2j}	W_{3j}	W_{4j}	W_{5j}	W_{6j}
X1	0.39722	-2.59718	0.15226	0.39834	1.10704	1.83383
X2	0.12486	-2.74496	0.14251	-0.52509	-0.79652	0.95674
X3	-4.86207	0.80024	0.33475	-0.28979	0.76551	0.71465
X4	12.51644	2.80618	-0.1318	0.58862	1.84167	0.2252
X5	1.28854	1.76009	0.08386	-0.01332	1.26791	1.69606
X6	0.73622	0.59998	-0.09897	-0.46831	-0.8686	-1.26869
X7	-0.39392	0.85959	0.02079	-0.40584	-0.4772	-1.30893
X8	-4.85972	-1.98496	0.36208	-0.22182	-0.52989	0.13083
X9	5.4005	-0.56073	0.83834	-0.35355	-0.22577	0.21203
Basis (b_i)	1.96082	2.23146	-0.44346	0.20232	-0.30311	-0.34721

Table (1) continue.

Inputs	W_{7j}	W_{8j}	W_{9j}	W_{10j}	W_{11j}	W_{12j}
X1	1.32998	-0.02559	1.48799	-1.13475	-1.67889	0.59306
X2	-2.7585	0.44216	-6.00512	-2.5489	0.47201	-0.88455
X3	1.11137	-0.8995	0.63055	0.77049	-3.11167	0.05388
X4	-0.03357	-0.0549	-2.80145	-0.93781	0.01907	-0.65772
X5	0.48876	0.23543	3.74265	-3.48957	-1.46296	1.39836
X6	-0.88811	0.62317	0.18245	7.17023	5.2655	0.21884
X7	-2.08343	0.63213	1.64563	-2.41606	-2.75351	-0.11064
X8	0.83713	0.02579	0.87455	12.98619	2.34616	-1.5697
X9	1.93983	0.50154	-3.03682	-5.00842	6.05786	-1.24502
Basis (b_i)	-0.92985	-0.05889	5.13738	-0.40234	0.81188	1.50732

Table (1) continue.

Inputs	W_{13j}	W_{14j}	W_{15j}	W_{16j}	W_{17j}	W_{18j}
X1	-0.49237	0.34686	-2.18367	-0.05577	1.19557	0.06084
X2	0.69674	-0.1692	-2.00022	-0.08335	-1.68696	-1.70154
X3	-0.85422	-1.48651	-2.76148	1.18435	-1.23562	0.29931
X4	-1.95764	0.13638	2.49323	-0.21499	-0.414	1.18852
X5	0.76953	0.06909	-0.23732	-0.06079	5.30863	0.34741
X6	1.8932	0.65738	0.93256	0.06539	-8.29622	-0.30293
X7	-0.00889	0.38946	0.07021	-0.70767	-1.93227	0.14814
X8	-1.48486	-0.57055	1.91469	0.61804	14.59406	1.55237
X9	-0.11972	-0.74341	-2.17494	1.36955	1.39645	1.5111
Basis (b_i)	0.85489	-0.06863	-0.09487	-0.26524	-2.78596	0.82888

Table (1) continue.

Inputs	W_{19j}	W_{20j}	W_{21j}	W_{22j}	W_{23j}	W_{24j}
X1	-0.00371	-3.51617	-0.36589	1.78558	0.19317	0.16359
X2	-1.72182	-2.20865	-1.93524	-1.67427	-0.31931	-0.1789
X3	-0.3105	-1.31165	-2.15559	-2.46662	-0.25848	-0.44366
X4	-2.77389	-2.24697	-0.90876	-1.91466	0.14647	0.03132
X5	-1.84264	4.79743	4.55436	4.35832	-0.08961	-0.21534
X6	3.97886	-0.26087	-1.09388	-11.6051	0.03291	-0.04524
X7	0.59902	-1.82853	-2.67285	4.2073	-0.42139	-0.32806
X8	-1.61755	-1.25338	-0.42203	-0.70279	-0.27805	0.2651
X9	-3.06923	-1.3406	4.84537	2.07136	-0.51104	-0.39296
Basis (b_i)	1.39987	3.8611	1.94293	1.04252	0.52423	0.20113

Table (1) continue.

Inputs	W_{25j}	W_{26j}	W_{27j}	W_{28j}	W_{29j}	W_{30j}
X1	1.34187	-0.08706	-0.31426	0.11654	0.29089	0.87729
X2	1.71035	1.17914	-0.36778	0.21117	-0.67129	-0.26943
X3	0.47329	-0.92997	-0.87548	0.28102	-0.16173	-1.85397
X4	2.78154	-1.40862	-0.04305	0.02212	-0.84651	1.8802
X5	2.6222	0.32806	-0.18932	0.5289	-1.29037	-1.89565
X6	-3.0136	0.82891	0.69578	-0.12965	2.20423	2.60764
X7	-3.37846	-0.19147	0.35165	-0.2092	-0.02916	1.40695
X8	0.13597	-0.61914	-0.04826	-0.18149	-0.39168	1.61195
X9	2.33001	-0.11619	-0.9047	1.2018	-1.34934	-0.75101
Basis (b_i)	-1.9734	0.20514	0.81245	-0.10465	0.42771	0.29716

Where engine power (kW) was calculated from fuel consumption using the following relationship (**Embaby, 1985**),

$$\text{Engine power}(kW) = \frac{Q_P \times \rho_f \times LCV \times \eta_{th} \times \eta_m}{3600} = 3.433 \times Q_P (lit/h) \quad \text{........(24)}$$

$\rho_f =$ Density of fuel, kg/lit (for diesel fuel = 0.85 kg/lit) as reported by **Hassann et al. (2009)**.

$\eta_{th} =$ Thermal efficiency of the engine, (considered to be about 40% for diesel engine) as reported by **Hassann et al. (2009)**.

$\eta_m =$ Mechanical efficiency of the engine, (considered to be about

80% for diesel engine) as reported by **Hassann et al. (2009)**.

LCV= Lower calorific value of fuel, kJ/kg, (average LCV for diesel fuel is 45434 kJ/kg).

3600= Units constant.

2.2.3. Theoretical field capacity

The theoretical field capacity of an implement is the rate of field coverage that would be obtained when the machine is performing its function using hundred percent of the time at the rated forward speed and always covering hundred percent of the rated width (**Kepner et al., 1978**). The theoretical field capacity (TFC, ha/h) was calculated using the following relationship (**Culpin, 1976**),

$$TFC\ (ha/h) = \frac{W \times S}{10} \quad \text{...(25)}$$

Where S is plowing speed (km/h) and W (m) is chisel plow width which could be calculated as following:

$$W\ (m) = \frac{N \times B}{2 \times 100} \quad \text{...(26)}$$

Where N is the number of chisel shares and B is horizontal distance between two adjacent shares in one row (cm).

2.2.4. Field efficiency

The field efficiency (F_E , %) was calculated using the following relationship (**Kumar et al., 2013**),

$$F_E\ (\%) = \frac{AFC}{TFC} \times 100 \quad \text{...(27)}$$

2.2.5. Draft and drawbar power requirement

To obtain the required draft, assume value of (loading factor, X, decimal), however, X is calculated from the following formula (**Ismail and Burkhardt, 1993**),

$$X\ (decimal) = \frac{E_{PTO}}{A_{PTO}} \quad \text{...(28)}$$

Where E_{PTO} is the implement equivalent power take-off and A_{PTO} is the tractor available take-off power. E_{PTO} was calculated using the drawbar power (D_{BP}) and tractive efficiency (TE). However, the tractive efficiency was taken from Table (2) based on tractor type and soil condition. E_{PTO} could be calculated from **Ismail and Burkhardt (1993)** and **Akinnuli et al. (2014)** as follows:

$$E_{PTO} = \frac{D_{BP}}{0.96 \times TE} \quad \text{...(29)}$$

$$E_{PTO} = \frac{D_F \times S}{0.96 \times TE \times 3.6} \quad \text{...(30)}$$

Where TE is tractive efficiency (decimal), D_{BP} is drawbar power (kW), D_F is implement draft (kN) and S is plowing forward speed (km/h) and 3.6 is conversion factor. Also, A_{PTO} could be calculated as follows (**Zoz and Grisso, 2003**):

$$A_{PTO} = T_{Power} \times 0.83 \quad \text{...(31)}$$

Where T_{Power} is tractor power, so, Eq. (28) could be rewrite as follows:

$$X\ (decimal) = \frac{D_F \times S}{0.96 \times TE \times 3.6 \times T_{Power} \times 0.83} \quad \text{..........................(32)}$$

Thus, by rewrite Eq. (32), the draft could be calculated as follows:

$$D_F = \frac{X\ (decimal) \times 0.96 \times TE \times 3.6 \times T_{Power} \times 0.83}{S} \quad \text{......................(33)}$$

$$D_{BP} = \frac{D_F \times S}{3.6} \quad \text{...(34)}$$

Where D_{BP} is drawbar power (kW).

Table (2). Tractive efficiency (TE, decimal) corresponding to soil type and tractor type.

Soil condition	Tractor type		
	2WD	FWA	4WD
Firm soil	0.72	0.77	0.78
Tilled soil	0.67	0.73	0.75
Sandy or soft soil	0.55	0.65	0.78

Source: ASABE (2000).

Specific fuel consumption for tillage process (SFC_P lit/kW.h) could be calculated from fuel consumption estimated by C-Sharp application as follows.

$$SFC_P = \frac{Q_P}{D_{BP}} \qquad (35)$$

Also, standard specific fuel consumption (SFC_{ASABE}, lit/kWh) could be estimated from **ASABE (2000)** above 20% load for diesel type of fuel, however, specific fuel consumption for diesel engines typically ranges from 0.244 to 0.57 lit/kWh and affects by percent load on the engine (**Omid, 2006**). The following relationship is for estimating specific fuel consumption (SFC_{ASABE}, lit/kWh) according to **ASABE (2000)**,

$$SFC_{ASABE} = 2.64 \times X + 3.91 - 0.203\sqrt{738 \times X + 173} \qquad (36)$$

To estimate the required draft of a chisel plow, X is changed starting of 0.01 using the loop as illustrated in Figure (2) inside the C-Sharp application until $SFC_P = SFC_{ASABE}$ however, the new value of (D_F, kN) was obtained from the final value of X after $SFC_P = SFC_{ASABE}$ and the required draft could be obtained using the following relationship,

$$D_F = \frac{X\ (decimal) \times 0.96 \times TE \times 3.6 \times T_{Power} \times 0.83}{S} \qquad (37)$$

The final drawbar power or draft power is calculated from the following relationship,

$$D_{BP} = \frac{Final\ \ value\ \ of\ \ D_F \times S}{3.6} \qquad (38)$$

In the case of $SFC_P \neq SFC_{ASABE}$, or X=0.99, the draft could be obtained as follows:

$$Draft = \frac{T_{Power} \times 0.83 \times 3.6}{S \times SF \times 1.25} \qquad (39)$$

Where SF is soil factor (**Yousif, et al., 2013**) and could be obtained from **Edwards (2007)** as shown in Table (3).

Table (3). Soil factor (SF) corresponding to soil type and tractor type.

Soil condition	Tractor type		
	2WD	FWA	4WD
Firm soil (untilled soil)	1.64	1.54	1.52
Tilled soil	1.75	1.61	1.56
Sandy or soft soil	2.13	1.82	1.67

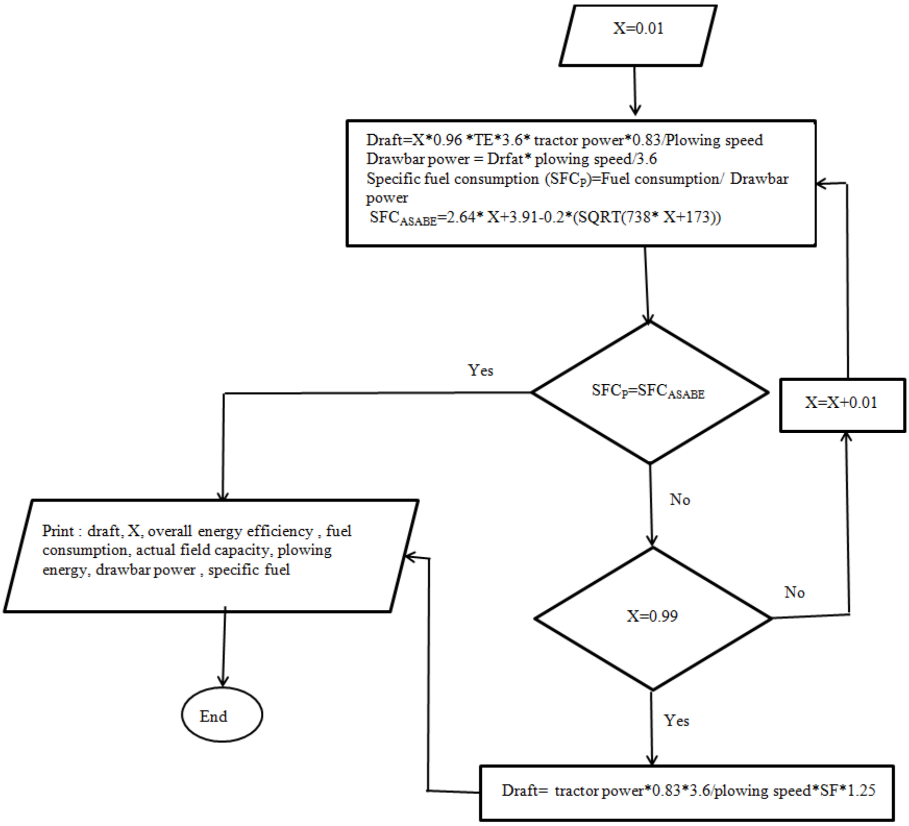


Figure (2). Loop to estimate SFC_P and SFC_{ASABE} by changing value of X.

2.2.6. Unit draft

There are different forms of to represent draft requirements of a chisel plow. However, the two famous forms to represent draft requirements of a chisel plow are as follows (**Al-Suhaibani and Ghaly, 2013; Ndisya et al., 2016**):

$$\text{Unit draft per implement width } (N/m) = \frac{Draft\ (N)}{implement\ width\ (m)} \text{......(40)}$$

$$\text{Unit draft per plowing area } (N/cm^2) = \frac{Draft\ (N)}{implement\ width\ (cm) \times plowing\ depth\ (cm)} \text{...(41)}$$

2.2.7. Overall energy efficiency

Overall energy efficiency was determined according to the equation appeared in **Crowell and Bowers (1985)**.

$$OEE(\%) = \frac{D_{BP}}{P_f} \times 100 \text{...(42)}$$

Where OEE is overall energy efficiency (%) and P_f is fuel equivalent power (kW) and it could be calculated as follows:

$$P_f\,(kW) = \frac{Q_P\,(lit/h) \times 45434\,(kJ/kg) \times 0.85\,(kg/lit)}{3600} = 10.727 \times Q_P\,(lit/h) \quad \ldots(43)$$

Ranjbarian et al. (2015) used value of 10.2 as a conversion unit in their equation for calculating OEE. However, **Crowell and Bowers (1985)** reported that the normal range for overall energy efficiency is 10–20%. A tractor-implement combination having an overall energy efficiency below 10% indicates poor load matching or/and low tractive efficiency, while a value above 20% indicates a good load match or/and high tractive efficiency.

2.4. C-Sharp application description

The C-Sharp application was written in C-Sharp programming language to determination of actual field capacity (ha/h) and fuel consumption per unit area (lit/ha) of a tractor-chisel plow system. The required equations were formulated using the obtained weights from a trained artificial neural network model that trained using actual data from field experiments. In C-Sharp application, determination of actual field capacity (ha/h) and fuel consumption per unit area (lit/ha) of a tractor-chisel plow system is associated with tractor power, plow width, plowing depth, plowing speed, initial soil moisture content, initial soil bulk density, sand percentage, silt percentage and clay percentage. Tractor loading factor was the main issue in the present application as it was used as a controller for determination of the required draft by comparing both specific fuel consumption calculated by the application and specific fuel consumption calculated using the equation of ASABE standard (**ASABE, 2000**). Overall energy efficiency in the range of 10–20% was acted to select the values of the optimum affecting parameters that match the pull provided by a tractor with the draft requirement of a chisel plow. The application displays some performance parameters of a tractor-chisel plow system such as drawbar power, total implement draft, field efficiency and fuel consumption.

2.5. Field experiment data for validation of C-Sharp application results

For validation of the developed C-Sharp application, field experiment was conducted using chisel plow (7 shares) and the horizontal distance between the adjacent two shares was 50 cm, so, the plow width was 175 cm. The experiment was conducted in loamy sand soil in private farm located at Riyadh region, Saudi Arabia. The latitude of the experiment site was 24.23°N, longitude was 47.65 °E and Altitude was 396.36 m. The arrangements for leveling the chisel plow were made. Four soil samples were gathered by an auger to depth of 25 cm. The experiment purpose was to determine actual field capacity, fuel consumption and draft.

Soil moisture content was determined by the standard oven method by drying soil samples in electric oven at 105°C for 24 hours and soil moisture content was determined based on dry base (**Black et al., 1965**) as averaged of four samples. Average soil bulk density is also determined according to **Black et al. (1965)**. Moreover, soil cone index was measured by a hand digital penetrometer (Figure 3). The model of penetrometer is SC900 soil compaction meter from field Scout. It could be connected to the computer to retrieve the stored cone index and the related depth. The readings were taken up to 17 cm. Mean characteristics of the soil in the experiment site are shown in Table (4).

Figure (3). Hand digital penetrometer for measuring soil cone index.

Table (4). Mean characteristics of the soil in the experimental site.

Soil parameters	Value	Unite
Sand	75.6	%
Silt	12.4	%
Clay	12	%
Soil texture	Loamy sand	(---)
Soil moisture content	10.06	%,db
Soil bulk density	1.53	g/cm^3
Soil cone index	847.2	kPa

The fuel consumption (lit/ha) was measured by refilling the fuel tank after plowing plot specific area and at the same time, draft measurements and the time required for plowing the plot area were recorded. Plowing depth was measured as the vertical distance from the top of the undisturbed soil surface to the plow's deepest penetration. In this work, the plowing depth was 25 cm. The horizontal force (draft) was measured using a load cell (model Omega with a capacity of 0-10000 lb) using the method described in (**PAES, 2001**). The plowing speed was 3 km/h. The plow was passed one time on the soil. An experimental block about 60 m long by 4 m wide was utilized during experiments. A small block of approximately 15 m long by 4 m wide, in the beginning of each tested block, was used to enable the tractor and chisel plow to reach a steady state condition of the required plowing speed and plowing depth. The chisel plow was hitched to Kubota L4400 tractor (gross engine power was 33.8 kW, net engine power was 32.1 kW and PTO power was 28 kW) as shown in Figure (4) and the other tractor was New Holland 100-90 (FWA) tractor with power of 74.6 kW. The draft was recorded within the distance of 50 m. The plowing speed was calculated by measuring of distance of five turns of the tractor rear wheel with time. On the same field, the plow was lifted out the ground and the rear tractor was pulled to record the idle draft force. The difference gave the draft requirement of the chisel plow. The actual field capacity was calculated according to the following equation:

$$\text{Actual field capacity}\,(ha/h) = \frac{(A_P, m^2)\times(3600, s/h)}{(TP, s)\times(10000, m^2/ha)} \ldots\ldots\ldots\ldots\ldots(44)$$

Where A_p is the plot area (width × length, m^2), TP is the time required for plowing plot area (s). However, fuel consumption (lit/ha) was calculated as follows:

$$\text{Fuel consumption per unit area (lit/ha)} = \frac{(Q_{Diesel}, cm^3)\times(10000, m^2/ha)}{(A_P, m^2)\times(1000, cm^3/lit)} \ldots\ldots(45)$$

Where Q_{Diesel} in cm^3 is the amount of consumed fuel during plowing A_p area.

Figure (4). Measuring of draft requirement of chisel plow –tractor system.

3. RESULTS AND DISCUSSION

3.1. General

Most of the previous computer programs (**Eldoma, 2008; Al-Hamed et al., 2010; Ishola et al., 2010; Mohamed et al., 2011**) of the prediction of performance of a tractor-tillage implement system were employed draft equation developed by ASABE Standard D497.5 (**ASABE, 2006**). This draft equation is as follows:

$$D_f = F_i\left[A + B\,(S) + C\,(S)^2\right]\times W \times d \quad \ldots\ldots(46)$$

Where D_f = Implement draft (N), F_i = Dimensionless and it used for soil texture adjustment parameter i = 1 for fine; 2 for medium and 3 for coarse soil, A, B and C = machine specific parameters, S =Field speed (km/h), W = Width of the implement (m) and d = Plowing depth (cm). As shown in Eq. (46), every developed computer programs for the prediction of performance of a tractor-tillage implement system used the same constants for calculating draft of the tillage implements. Due to draft requirement of tillage implements is depended on soil texture and soil properties (**Jafari et al., 2011**), thus actual field experiments have to execute to gather such draft data under various soil conditions (**Manuwa and Ogunlami, 2010**). Accordingly, one of the settlements of the developed C-Sharp application is depended on actual field experimental data for obtaining the constants of the required equations.

3.2. C-Sharp application performance

The application was implemented in C-Sharp programming environment for use in different purposes such as educational and research needs. C-Sharp offers a flexible, object-oriented, user friendly language which is focused on user and his interaction with the program. The developed application is aimed to predict the field performance indicators of a tractor-chisel plow system. The application comprises three windows that serve specific purposes in the development process. After building the application, it was converted to a free-standing executable version in order to run the application directly on the Windows desktop, without starting up the C-Sharp environment. The application could be edited and/or updated to predict performance indicators of other tractor-tillage implement systems.

The application starts with about window (Figure 5), then move to input variable window (Figure 6) and ends with the final result required by the user. In addition, user can select chart to show the relationship between specific fuel consumption and loading factor with all iterations until intersection of both specific fuel consumption based on ASABE equation and calculated specific fuel consumption as shown in Figure (7). The application confirms that all entered values for different variable are in the specific range as shown in Table (5) that specified in the application.

Table (5). The range of inputs variables in C-Sharp application.

Inputs	Range
Plow width (cm)	100-300
Tractor power (kW)	25-104
Plowing depth (cm)	7-30
Plowing speed (km/h)	2-7
Sand (%)	11-80
Silt (%)	11-55
Clay (%)	9-53
Soil moisture content (%,db)	7-50
Soil bulk density (g/cm^3)	1.2-1.8

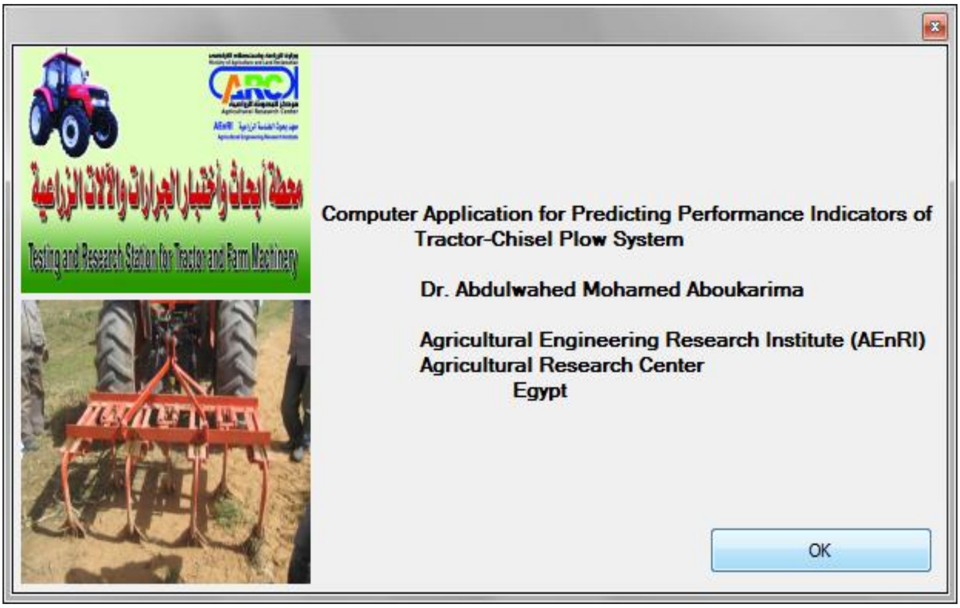


Figure (5).The C-Sharp application starts with about window.

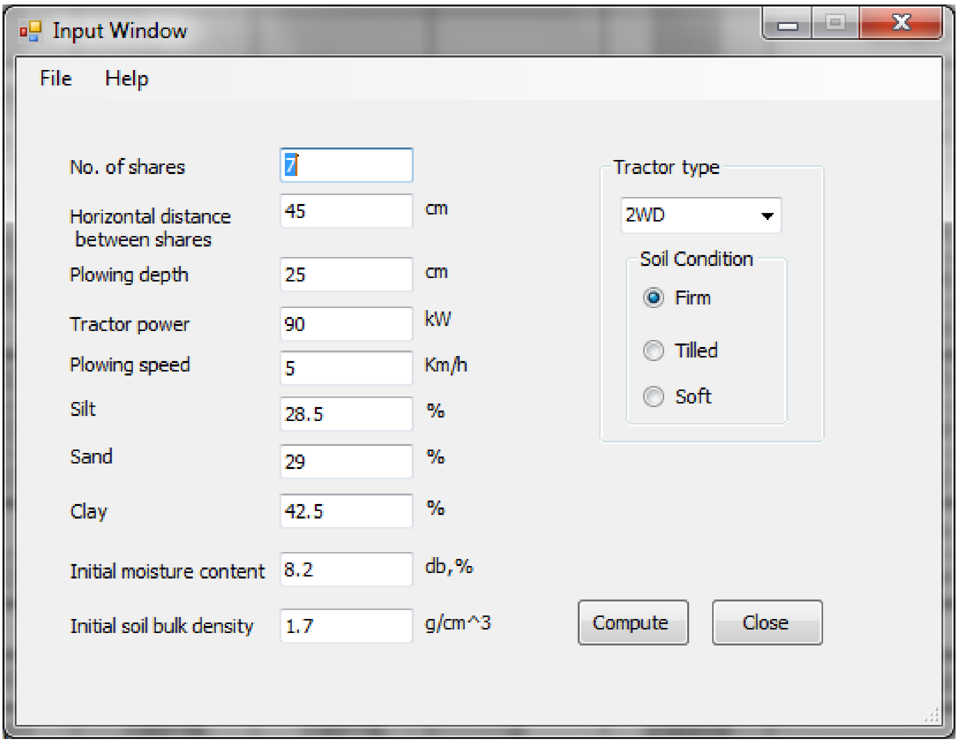
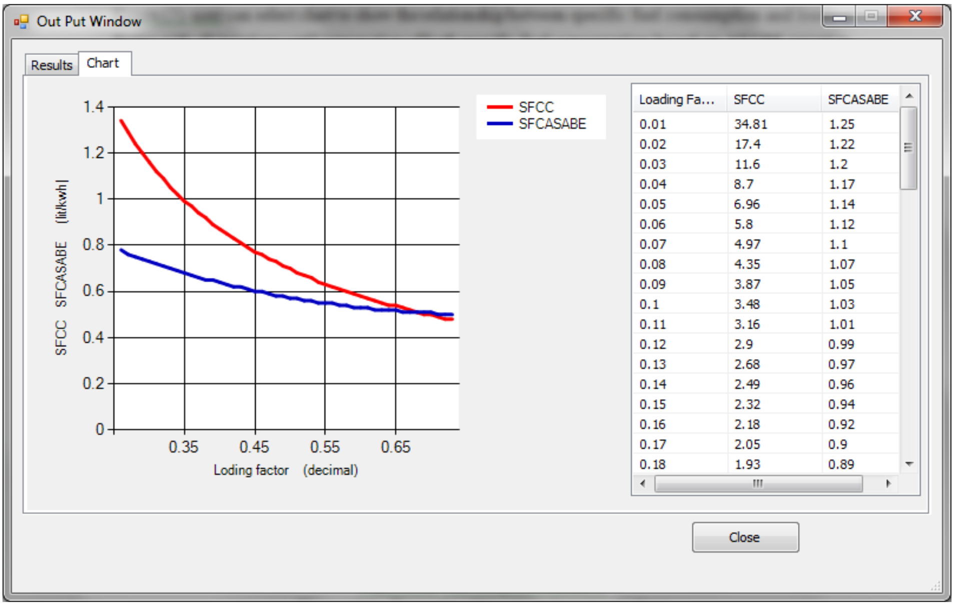


Figure (6). The inputs window.



Loading Fa...	SFCC	SFCASABE
0.01	34.81	1.25
0.02	17.4	1.22
0.03	11.6	1.2
0.04	8.7	1.17
0.05	6.96	1.14
0.06	5.8	1.12
0.07	4.97	1.1
0.08	4.35	1.07
0.09	3.87	1.05
0.1	3.48	1.03
0.11	3.16	1.01
0.12	2.9	0.99
0.13	2.68	0.97
0.14	2.49	0.96
0.15	2.32	0.94
0.16	2.18	0.92
0.17	2.05	0.9
0.18	1.93	0.89

Figure (7).Online relationship between both calculated specific fuel consumption and specific fuel consumption based on ASABE and loading factor.

An alert message as shown in Figure (8) was displayed to the user if he entered input values out of the specific range. The output window (Figure 9) was classified to three performance indicators. The performance indicators I include:

- Theoretical field capacity (ha/h).
- Actual field capacity (ha/h).
- Field efficiency (%).
- Fuel consumption per unit area (lit/ha).
- Fuel consumption (lit/h).
- Energy required based on fuel consumption (kWh/ha).

The performance indicators II include:

- Draft (kN).
- Unit draft (draft per unit plow width, N/m).
- Unit draft (draft per unit plowing area, N/cm^2).
- Draft power (kW).
- Energy required based on draft requirements (kWh/ha)

The performance indicators III include:

- Loafing factor (decimal).

- Calculated specific fuel consumption (lit/kWh).
- Specific fuel consumption based on ASABE equation (lit/kWh).
- Overall energy efficiency (%)

Before running the application on the computer, user has to enter values of number of chisel shares and the horizontal distance between two adjacent shares in one row (cm). The parameters of a tractor-chisel system data (tractor power, plowing speed, plowing depth) must entered by the user and the application is verified that they are in the appropriate range. The soil data (sand, silt and clay percentages, initial soil moisture content and initial soil bulk density) must entered by the user and the application is also verified that these parameters are in the appropriate range.

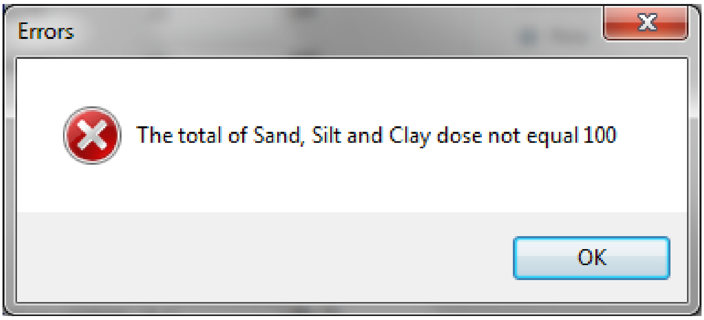


Figure (8). Alert message flag to re-enter values of input variables within the specific range.

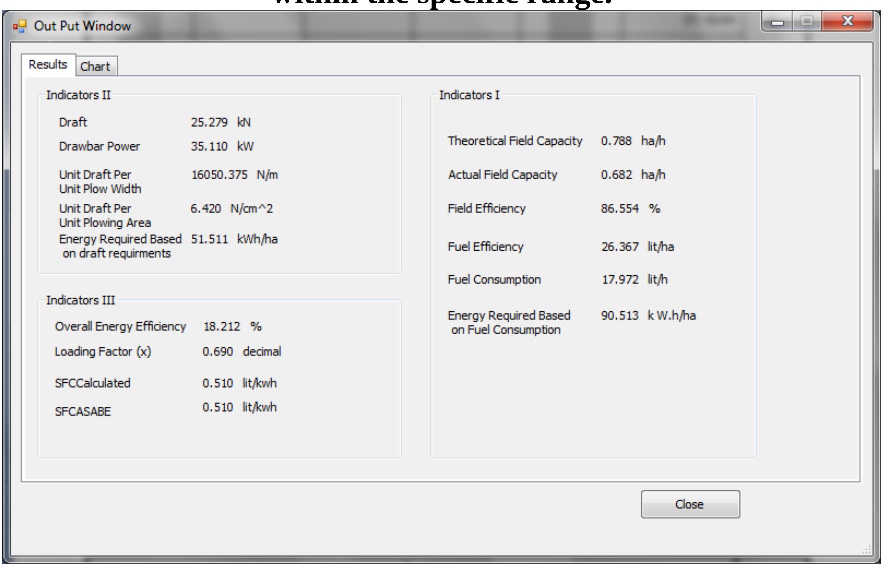


Figure (9). The outputs window.

3.3. Validation of C-Sharp application

3.3.1 Using experimental data from previous study

To validate the developed C-Sharp application for estimation of draft of a chisel-plow-tractor unit, field experimental data are collected from **Aboukarima (2007)**. These data are as follows: tractor power was 50 kW (FWA), soil condition was Firm, plowing speed was 4.8 km/h, plowing depth was 15 cm, sand percentage was 18.12%, clay percentage was 34.78% and silt percentage was 47.10%. The chisel was 7 shares and the horizontal distance between two shares was 50 cm, the initial soil moisture content was 15.40 % (db) and the initial soil specific weight was 13.44 kN/m^3 (initial soil bulk density was 1.366 g/cm^3). These values of the inputs are illustrated in Figure (10) and the outputs for such inputs are shown in Figure (11). It is clear that the simulated draft was 14.053 kN after adjusting the loading factor to be 0.620 in the developed application, meanwhile, the actual draft from **Aboukarima (2007)** was 16.73 kN. The relative error was (16.73-14.053)/16.73*100=16%.

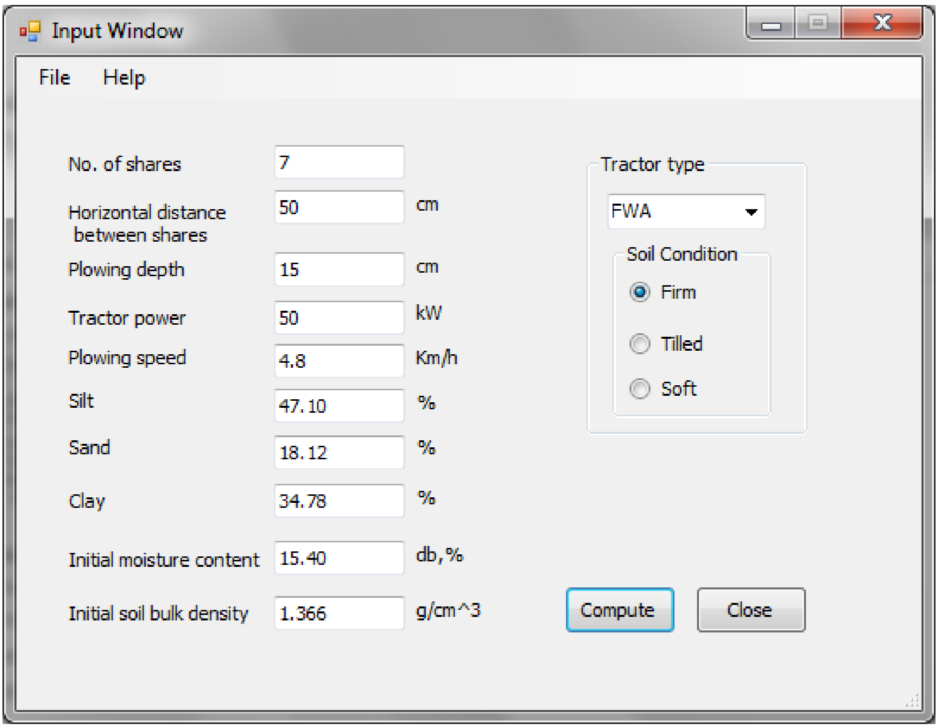


Figure (10). Input data from Aboukarima (2007) to validate the performance of the developed C-Sharp application.

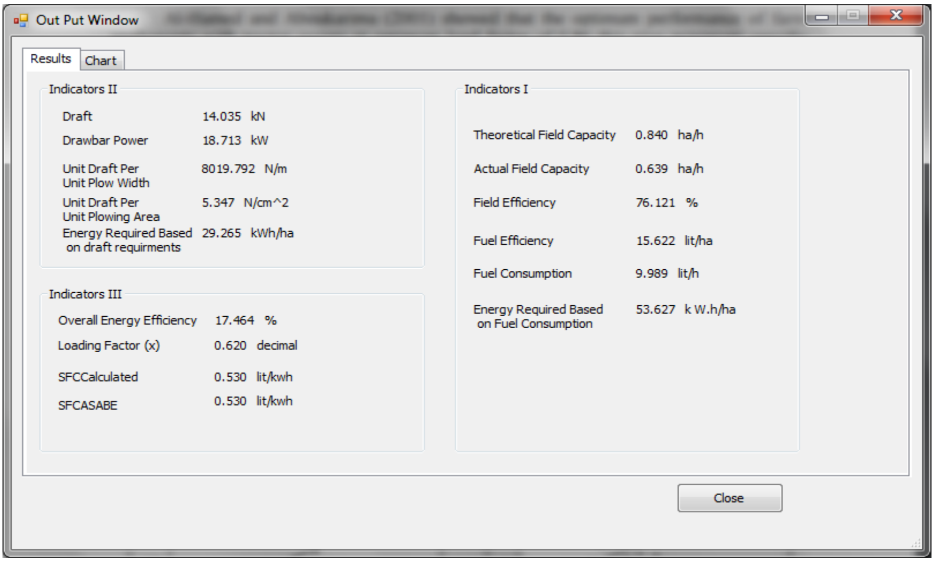


Figure (11). Output data from the developed C-Sharp application (the input data were taken from Aboukarima (2007) (fuel efficiency means fuel consumption per unit area (lit/ha).

3.3.2 Using data from a field experiment

The inputs of the data of the described experiment in section 2.5 are shown in Figure (12) and the outputs for plowing speed of 3 km/h are shown in Figure (13). However, Table (6) illustrates actual and simulated actual field capacity, fuel consumption and draft. It is clear that the relative error was 27% for actual field capacity, and its values were -21% and -17% when simulated fuel consumption and draft, respectively using the developed C-Sharp application .

Table (6). Actual and simulated actual field capacity, fuel consumption and draft.

Performance indicators	Item	Value	Relative error (%)*
Actual field capacity (ha/h)	Actual	0.362	27
	Simulated	0.263	
Fuel consumption (lit/h)	Actual	7.25	-21
	Simulated	8.764	
Draft (kN)	Actual	11.24	-17
	Simulated	13.182	

$$* \text{ Relative error} = \left(\frac{\text{Actual} - \text{Simulated}}{\text{Actual}} \right) \times 100$$

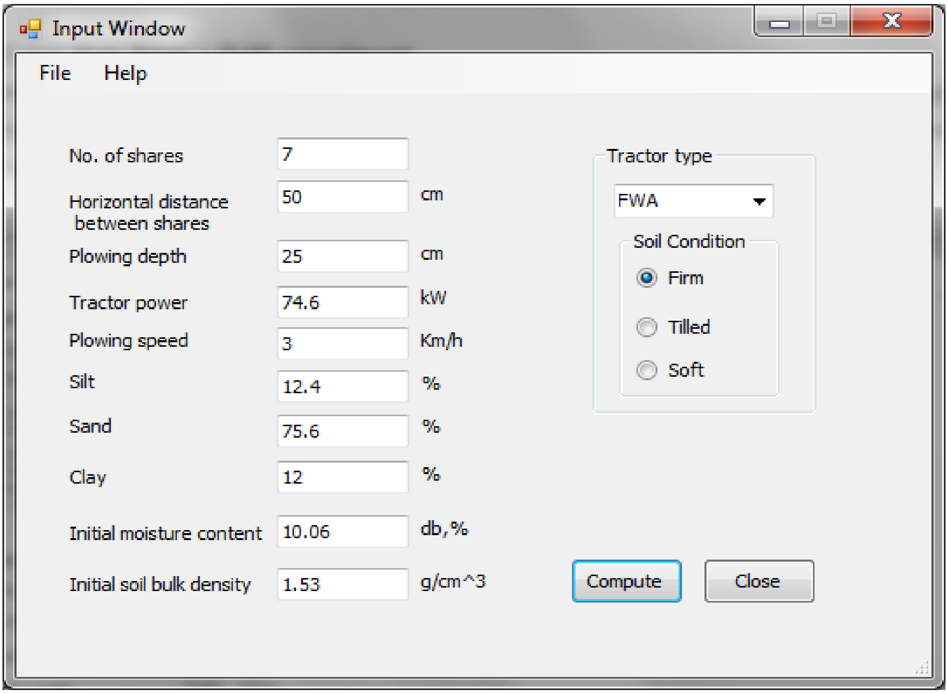


Figure (12). Input data from experimental work described in section 2.5 to validate the performance of the developed C-Sharp application.

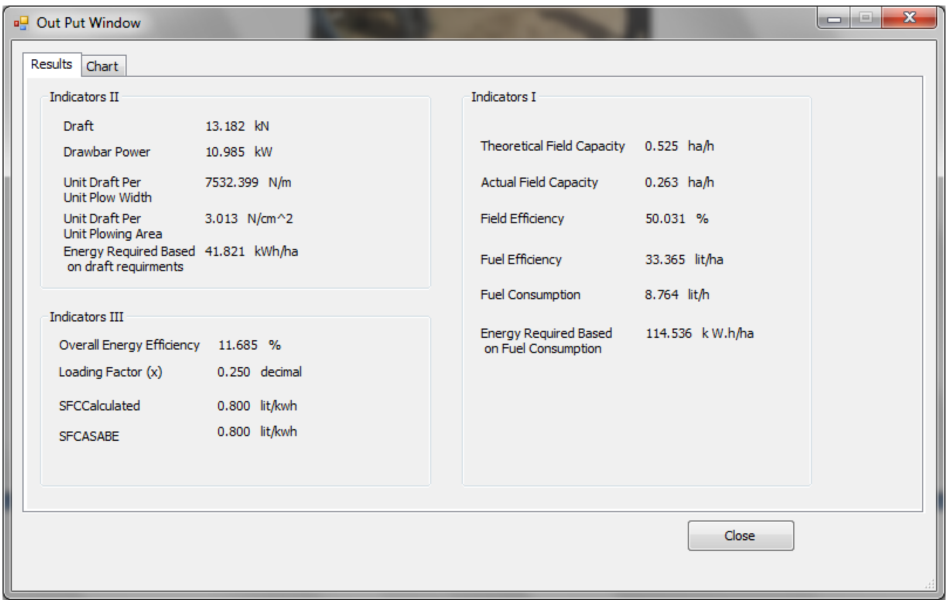


Figure (13). Output data from the developed C-Sharp application (the input data were taken from experimental work described in section 2.5) (fuel efficiency means fuel consumption per unit area, lit/ha).

3.4. Sensitivity analysis

For sensitivity analysis, plowing speed was changed from 2 to 6 km/h and the other parameters were fixed as follows: tractor power was set to be 90 kW, sand percentage was set to be 29%, silt percentage was set to be 28.5%, clay percentage was set to be 42.5%, initial soil bulk density was set to be 1.7 g/cm^3 and initial soil moisture content was set to be 8%, db, plowing depth was set to be 25 cm, plow width was set to be 157.5 cm, tractor type was set to be FWA and soil condition was set to be firm. However, Figure (14) shows the simulation results at varying plowing speed on actual field capacity, fuel consumption per unit area and fuel consumption per unit time. Meanwhile, Figure (15) shows the simulation results when varying plowing speed vs. loading factor, overall energy efficiency (OEE) and specific fuel consumption. It is clear from Figure (14) that increasing plowing speed result to increasing simulated actual field capacity and this finding is agreed with the findings by (**Hamod and Essa, 2010; Meselhy, 2014; Zaied et al., 2014; AL-Mafrachi, 2015**). Also, it is clear from Figure (14) that increasing plowing speed result to decreasing simulated fuel consumption per unit area and increasing fuel consumption per unit time and this finding is agreed with the results of **AL-Mafrachi (2015)**.

AL-Mafrachi (2015) indicted that increasing plowing speed from 2.35 to 4.25 then to 6.5 km/h result to decreasing fuel consumption per unit area from 6.832 to 5.736 then to 4.195 lit/Donam (in Iraq 1 Donam =2500 m^2) during plowing with chisel plow that because increasing speed tractor means using engine power perfectly and reduced the time required for operation and that result to increasing effective field capacity and that result also decreasing fuel consumption in one Donam. Moreover, **AL-Mafrachi (2015)** indicated that increasing plowing speed from 2.35 to 4.25 then to 6.5 km/h result to increasing fuel consumption per unit time from 6.602 to 9.662 then to 10.533 lit/h. It is clear from Figure (15) that the lowest specific fuel consumption was obtained at plowing speed of 6 km/h and the highest overall energy efficiency was also obtained at the same plowing speed that means the mechanization unit utilized the engine power perfectly.

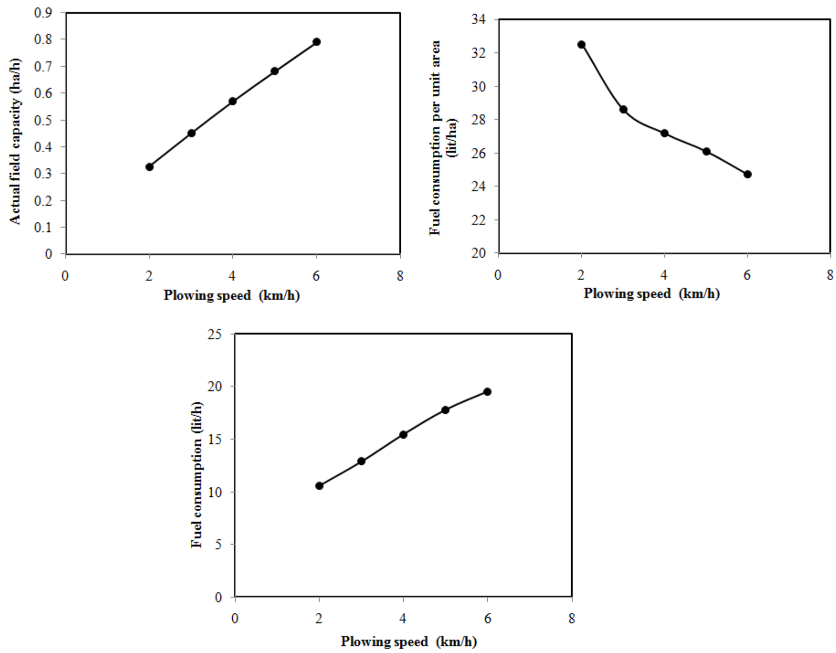


Figure (14). Effect of plowing speed on actual field capacity, fuel consumption per unit area and fuel consumption per unit hour.

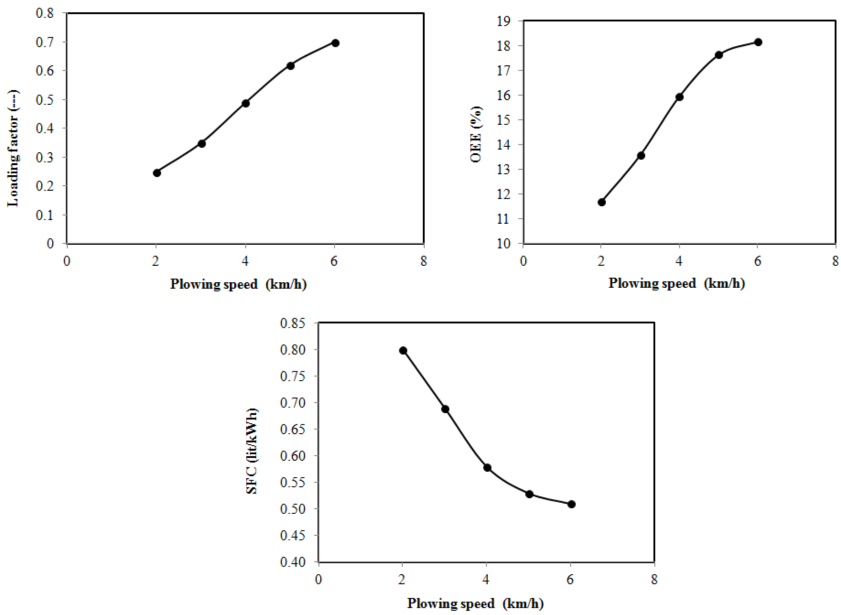


Figure (15). Effect of plowing speed on loading factor, overall energy efficiency (OEE) and specific fuel consumption.

4. CONCLUSION

C-Sharp computer application that can be used to predict a tractor- chisel plow system performance indicators was developed. It could be used for farm machinery management, educational and research purposes. The application could find the optimum operational parameters for a given tractor and chisel plow combination. The visual programming environment used to develop the application makes it relatively flexible and easy to use. It is user friendly and could be run on any Windows desktop without C-Sharp environment. The major equations inside the application could be editing or updated and manipulated to suit prediction of performance indicators of other tractor-tillage implement systems. The developed application was tested with data from pervious study and actual experimental data and for draft simulation, the relative error was 16% for data from a previous study and it was -17%. The developed application was found to be sensitive to the plowing speed and behavior of the relationship between plowing speed and effective field capacity and fuel consumption was as observed in literature.

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الملخص العربي

تطبيق حاسوبي تفاعلي للتنبؤ بمؤشرات الأداء لوحدة محراث حفار-جرار في بيئة سي شارب

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يعتبر المحراث الحفار واحد من آلات الحراثة التي تستخدم بكثرة في المزارع المصرية لتوافره ومقدرته على تفكيك التربة وإزالة بقايا النباتات. ومن ناحية أخرى يجب اختيار متغيرات التشغيل لوحدة ميكنة مكونة من جرار زراعي- محراث حفار لتنفيذ عملية حرث بكفاءة تشغيلية عاليه، وهذه الكفاءة التشغيلية تعتمد على متغيرات خاصة بالجرار (قدرة الجرار)، ومتغيرات خاصة بالمحراث (عرض المحراث)، ومتغيرات خاصة بالتربة (مكونات التربة من الرمل والطمي والطين والمحتوى الرطوبي والكثافة الظاهرية) ومتغيرات خاصة بالتشغيل الحقلي (سرعة وعمق الحرث).

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وفي المقابل لاختيار هذه المتغيرات، يتم الاعتماد على الخبرة أو تنفيذ تجربة للتأكد من أن عملية الحرث تتم بكفاءة. لذا في هذه الدراسة تم تطوير تطبيق حاسوبي تفاعلي سهل الاستخدام من قبل مديري الميكنة الزراعية للتنبؤ بمعايير الأداء لوحدة الميكنة المكونة من جرار زراعي- محراث حفار، وهذه المعايير شملت السعة الحقلية الفعلية، استهلاك الوقود، طاقة الحرث، قوة الشد المطلوبة، الكفاءة الحقلية، الاستهلاك النوعي للوقود، القدرة اللازمة للحرث وكفاءة الطاقة الكلية ، واعتمد في بناء التطبيق على لغة سي شارب الحاسوبية ومعادلات مطورة من بيانات حقلية فعلية. واعتبر معامل التحميل للجرار أداة تحكم لحساب قوة الشد من خلال مقارنة معدل الاستهلاك النوعي للوقود لعملية حرث محددة ومعدل الاستهلاك النوعي للوقود المحسوب من معادلة الجمعية الأمريكية للمهندسين الزراعيين القياسية لوقود الديزل، وعندما يتساوى هذان المعدلان من خلال عملية حسابية داخل التطبيق، يتم حساب قوة الشد المطلوبة. ويمكن استخدام التطبيق أيضًا كأداة لاختيار متغيرات التشغيل للوصول إلى التشغيل الأمثل لوحدة الميكنة (جرار+محراث حفار) من خلال أن تكون قيمة كفاءة الطاقة الكلية لعملية الحرث في الحدود من ١٠ – ٢٠ % . وهذا البرنامج مناسب لأغراض إدارة الميكنة الزراعية، وتعليم طلاب تخصص الميكنة الزراعية، حيث يمكن تشغيل التطبيق على سطح المكتب في بيئة النوافذ دون الحاجة إلى وجود لغة سي شارب الحاسوبية.

وللتأكد من عمل التطبيق المطور بصورة صحيحة، استخدمت بيانات من بحث سابق لمحراث حفار وجرار يعملا في ظروف محددة وبعد أن تساوي معدلي استهلاك الوقود النوعي (٠,٥٣ لتر/كيلوات.ساعة) عند معامل تحميل للجرار قدره ٠,٦٢ كان الشد المتنبأ به حوالي ١٦,٧٣ كيلو نيوتن وكانت نسبة الخطأ النسبي بين الشد المتنبأ به والشد الفعلي حوالي ١٦%. وأثبت التطبيق سهولة استخدامه من أجل الغرض الذي صمم من أجله.