Specific draft modeling for combined and simple tillage implements

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Abstract: Modeling of specific draught under different working conditions (plowing depth and forward speed) provide the possibility to predict the proper working conditions of tillage implements. In this study, two groups of tillage implements with different geometry including combined tillage implements (combined tiller and chisel packer) and simple tillage implements (moldboard plow, disk plow, chisel plow and offset disk harrow) are used. Also, three forward speed levels (3, 4.5 and 6 km h^{-1}) and three different depths (15, 20 and 25 cm) in silty clay loamy soil (47% silt, 22% sand and 31% clay) with 7.67% moisture content (based on dry) in the form of split twice plots design on the basis of completely randomized block with three replications was considered and the tractor's performance parameter, including specific draft (force per unit width), was measured. Empirical regression models (linear and nonlinear), and artificial neural network (ANN) modeling were performed on each implement and were compared to other regression and mathematical models of Kheiralla, ASABE and Goryachkin. The type of tillage, depth and speed of advance showed a significant effect on specific draft. The best model was to predict the specific draft nonlinear regression developed in this study. Also, the linear regression model and ANN model obtained in this research after the nonlinear regression model were a suitable model for predicting specific draft in six types of tillage implements. Among the experimental models, ASABE was the perfect model for all simple tillage implements except for disk plow and disk harrow. Also, this model has the potential to be used for compound tillage implements.

Keywords: specific draft, tillage tools, regression, ANN, depth, forward speed

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1 Introduction

Tillage is done to create an appropriate environment for seed germination, root growth, weeds control, softening and soil stabilization (Sarkar et al., 2022).On the other hand, tillage operation account for the major part of energy consumption in mechanized agriculture (Upadhyay and Raheman, 2019). The specific draft is one of the most important forces used to measure the necessary energy of the tillage implements (Kim et al., 2021), which represents the drawbar force in kilo-newton per meter of the working width of the tillage implements. The draft (draught or

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drawbar pull) is the needed energy to push an implement into travel direction (ASAE Standards, 2009).

Draft force is one of the important performance parameters of tractor implementation in tillage operations (Kim et al., 2022). Draft force is horizontal component of pulling force generated by tractor to pull, penetrate and keep implement within soil (Ahmadi, 2018). Availability of draft force data is useful to select proper tractor for pulling a particular implement in the most efficient manner (Shafaei et al., 2018 and Ahmadi, 2018). The draft force requirement varies depending on the types and geometry of the tool, operating parameters, and field conditions (Sadek et al, 2021).

The power unit (tractor) is the major capital investment for a farmer. Therefore, knowledge of the draft force requirement is beneficial in machinery management decisions (Ahmadi, 2017). On the other hand, Agricultural machinery manufacturers can use the required power information and the draft of agricultural machines in various soil types for the proper design of the size of the implements, given the drawbar power of the available tractors (Ahmadi, 2018; Sarkar et al., 2022).

Draft mainly depends upon the width of the device as well as its speed at which it is pulled (Kim et al., 2021). The draft depends however also on the depth of operation and tillage instrument geometry (Rahmanian-Koushkaki et al., 2022). Furthermore, tillage draft is affected by specific circumstances at the site, such as soil type, humidity, density, and residue cover (Upadhyay and Raheman 2019). In the majority of tillage systems, an increase in forward speed and tillage depth in the draft value depends upon the type and design of tools and soil circumstances (Sahu and Raheman, 2006). In recent years, various mathematical models have been developed to assess the extent to which the soil faces the working parts advance. These models generally introduce work depth, width, velocity and the characteristics of physical and soil mechanics, such as cohesion and density (Ahmadi, 2018)

Utilizing artificial neural networks (ANNs) models in the domain of science and engineering introduces an impressive way for solving three difficult problems: complexity, nonlinearity and uncertainty. ANNs are less sensitive to noise in comparison to other empirical models. Using ANN and regression model were investigated for prediction of draft force and energy of subsoiling operation (Shafaei et al., 2018).

On the other hand, research on combine tillage implements along with simple tillage tools has not been done to study the effect of depth and speed on their specific draft and also their modeling. Moreover, detailed information is also required on the power and energy requirements of any such local machinery that is, draft therefore, the most dependable factor for an accurate assessment of energy consumption. The present article provides the progress of specific draft using Mathematical, ANN and regression models for two sets of tillage tools (simple and combined), which are applied in sandy clay loam, and summarizes the power and energy necessities of those instruments.

2 Materials and methods

2.1 Experimental setup

Experiments were performed on a farm (31° 19' 13" latitude and 48° 40' 09"E longitude at above sea level of 18 m) in southern Iran (Ahvaz). The place has a dry climate by average annual precipitation and temperature of 213 mm and 25℃, respectively. The texture of the soil was silty clay loam. The bulk density (BD), and soil moisture content (MC), cone index (CI) were 1.47 %, and 7.67 gr.cm^{-3}, and 1.126 Mpa, respectively. Table 1 demonstrates soil features before the start of the experiment.

In this study, specific draft of two groups of tillage implements with different geometry included combined tillage tools (chisel packer (ChPa), combined tiller (CT)) and simple tillage tools (chisel plow (ChP), disk plow (DP), moldboard plow (MBP) and offset disk harrow (DH)) was investigated.

Table 1 Soil features measured before the experiment starts

MC (%)	BD (gr.cm^{-3})	CI (Mpa)	Sand (%)	Silt (%)	Clay (%)
7.67	1.47	1.126	22	47	31

The Specification of six different tillage implements consisted of (Figure 1): CT (7 vibrating stems with spiral spring, 6 vibrating disk with belt spring, 37 cm width of wing, 17° angle of impact, dental roller with working width 1.2m), ChPa (5 stems with a width of 6 cm, an angle of impact of 35 degrees, a working width of 5.1 meters, and solar roller with variable weight), MBP (3×45cm), DP (3×60 cm), ChP (C type, 9 branches and a working width of 2.52 m), DH (28 spherical disk with diameter 50 cm, and working width of 2.5 m).


(a) Mounted Combined tiller (b) Mounted Chisel Packer


(c) Mounted Disk Plow (d) Mounted Moldboard Plow


(e) Mounted Chisel Plow (f) Offset Disk Harrow

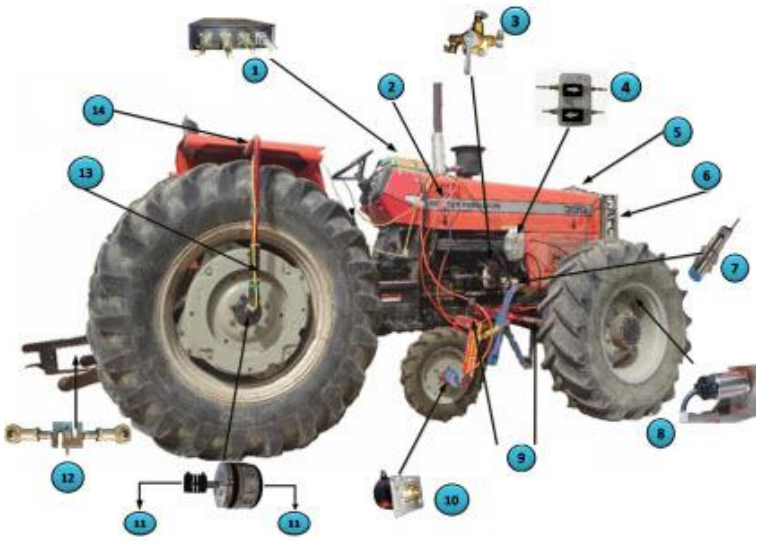
Figure 1 Tillage implements types utilized in the research

In the study in which the independent variables were tillage depth (primary element), forward speed (secondary element), and the tiller type (sub-secondary element). The levels of the variables involved tillage depth in three levels of (15, 20, and 25 cm), forward speed in three levels of (3, 4.5, and 6 km h^{-1}), and six tiller type in combined and simple sets.

2.2 Forward speed and specific draft calculation

A 4WD Massey Ferguson (MF) 399 agricultural tractors with esteemed motor power of 81 kW, 2000 rpm is the research platform. The system was established with sorts of telescopic, drawer, and rail methods in sensors basic and bearing parts, then all were joint into tractor with bolts to: a) overhauling from tractor is effortlessly performed, b) for the finest arrangement, the distance sensing is presented, and c) transmission maximum compatibility is available to new circumstance (other tractors) or replacement of sensors with original features.

The system used in the research has been designed and developed by (Kazemi et al., 2015). This system is hardware-based, as shown in Figure 2, consisting of three units for collecting, processing and displaying information, and the user simultaneously will see immediate changes with the execution of the operation and then stores the data in Excel format. The parameters that the system installed on the tractor has the ability to measure and store their information are: the engine rotational speed, the rotational and linear speed of all tractor wheels, the actual speed of the forward, the draft, the depth of the plow (by the ultrasonic sensor in front of each tillage implements installed) and fuel consumption.



1- signals processing unit 2- noise control circuit 3- control valve 4- flowmeter 5- electrical pump 6- measurement tank 7, 8- proximity sensor 9- pivot 10- HT encoder 11- ST encoder and its coupling 12-loadcell 13- L type connector 14- metal base of connect

Figure 2 The MF399 tractor fitted out with remote tractor performance monitoring (RTPM) (Kazemi et al., 2015)

In this study, a fifth wheel was made so that it can operate as independent speed measurement system. The real speed of tractor obtained by measuring the rotational speed of the fifth wheel. For this purpose, Encoder Shaft model E40H500-3T-12V was mounted on it. The real forward speed of tractor was obtained using the following equations (Kazemi et al., 2015):

$$C=2\pi r \quad (1)$$

$$S_p = \frac{C}{n_p} \quad (2)$$

$$RPM_t = \frac{P_t - P_{t-T}}{T \times n_p} \times 60000 \quad (3)$$

$$V = \frac{60 \times RPM \times C}{1000} \quad (4)$$

where, C is wheel environment (m), r is wheel radius, Sp is the shortest distance traveled in each pulse (mm/ pulse), np is the pulse sent per round (pulse), RPMt is the wheel in moment t (rpm), Pt and Pt-T is the number of cumulative pulses per t and t-T, T is the record time interval, V is the real forward speed.

The most suitable tool to measure the draft of mounted tillage equipment is three-point hitch dynamometer which, due to its lack, two-tractor traction method and the use of drawbar dynamometer, was used. This method has been used by many researchers (Naderloo et al. 2009; Shaker et al. 2011). The dynamometer is located between two tractors, one tractor carried a tillage implement and the other is a tractive tractor. The S-TYPE dynamometer with a traction capacity of 50000 N was used.

The width of each plot was estimated to be 3 m for ease of tractor operators and the length of the plot was 50 m for each plot, however first 10 meters of each plot was dedicated to reaching the depths of the tillage tool. Over the next 40 meters tillage implements in the soil and carrier tractors was in neutral gear was pulled by tractive tractor with the desired speed. During these intervals, dynamometer recorded gross draft force between the two tractors was equal to the sum of the draft force of tillage tool and rolling resistance of the carrier tractor (traction with load). At the end of rout, the tillage tool was ejected from the soil and the two tractors with the same speed as before traveled another 40 meters to dynamometer record the rolling resistance of the carrier tractor (traction without load). Difference of mean values recorded by dynamometer in sate traction with load and traction without load was considered as draft force of tillage equipment.

The specific draft or force on unit width work of simple and combination tillage implement (Shaker et al., 2011) can be calculated having net draft force.

$$F_N = F_G - F_R \quad (5)$$

$$SD = \frac{F_N}{W} \quad (6)$$

where, w, F_G, F_R, F_N, and SD are working width (m), gross traction (kN), rolling resistance of implement (kN), net draft force (kN) and specific draft (kN.m^{-1}), respectively.

2.3 Specific draft models

In the past decades, besides regression models, numerous mathematical models have been proposed to calculate the draft of farm implements (Table 1). So, estimated draft models of tillage implements have obtained by both theoretical studies and empirical tests. In this research, Goryachkin models, ASAE standard and Kheiralla (Kheiralla et al. 2004) models were used.

2.4 Data analysis

A split-split plot (twice split plots) on randomized complete block design in three replicates ANOVA (analysis of variance) was done on the data. SAS software was employed to analyze all data. Effects of the factors (depth, forward speed and tiller type) on the specific draft was measured by PROC ANOVA.

2.4.1 Regression modeling

Various models were used to measure specific draft using mathematical programming in MATLAB to model the draft, in these six types, tillage implements were fitted in different depths and speeds. R-square (R^2) and root mean squared error (*RMSE*) models were the most important indices for assessing the fitting. Finally, two models with the highest coefficient of correlation and least error were selected as the general model.

2.4.2. ANN modeling

In the structure of ANN model, there are three groups of neurons; input, hidden, and output that are set in the input, hidden and output layers. The layers are related to a transfer function. In the back propagation method, inputs and outputs are connected by adjusting the weights and biases, in such a way that the prediction error is minimized. The design of the system requires the choice of transfer functions of the hidden and output layer, the training algorithm, and data transformation approach, number of neurons in hidden layer and selection of performance measures. In this research, a three-layer feed forward neural network has been employed. The ANN had three inputs with normalized data i.e. depth, speed and type of tillage implement and the output layer had one neuron for predicting of specific draft. The hyperbolic tangent (tansig) and the linear (purelin) transfer functions were employed in the neurons of the hidden and output layers, respectively. The LM training algorithm was employed to train the network.R^2 and *RMSE* were applied as the performance function to find the optimal architecture for the neural network. For training the network, different numbers of neurons in hidden layer and MSE were tested. In this work, a MSE of 10-8, a minimum gradient of 10-10 and maximum epoch of 1000 were applied. The initial weights and biases of the network were produced by using the netint function by the program. The values of the learning rate and momentum coefficient were 0.02 and 0.9, respectively. Best numbers of neurons for the hidden layer were chosen basis on trial and error. The data were divided into two subsets: 75% was applied for training, and the remaining 25% were used for testing.

3 Results and discussion

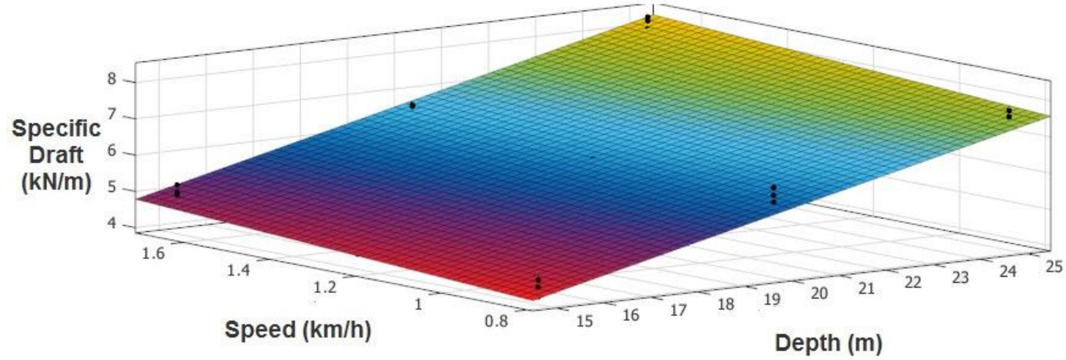
3.1 Descriptive statistics

According to Table 2, the type of implements, advance velocity, and the depth of plowing have a significant effect at the 1% level on the specific draft. This was in line with the results Kheiralla et al. (2004) and Naderloo et al. (2009).

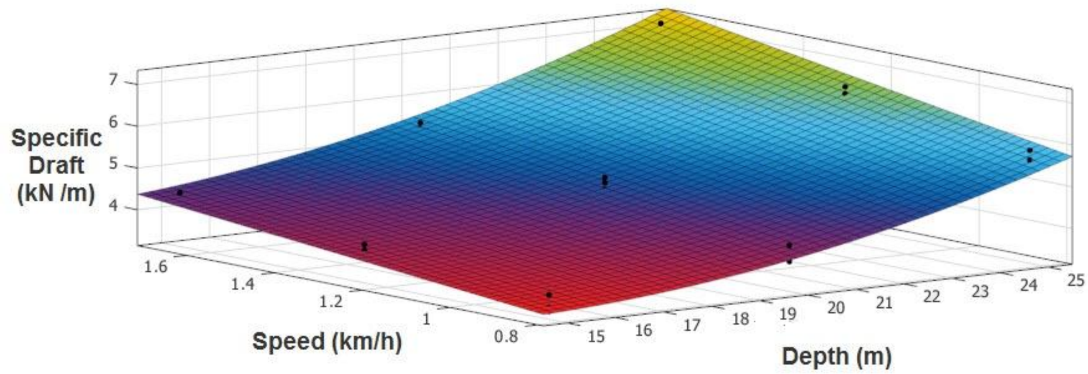
Table 2 Effect of the type of implements, advance velocity, and the depth of plowing on specific draft

Source	df	Mean square	F
Replication	2	0.011435	1.03^{ns}
Depth(A)	2	139.612606	12587.3 ***
Error A	4	0.004591	0.41 ^{ns}
Speed(B)	2	39.221151	3536.13***
Error B	4	0.00234	0.45 ^{ns}
Depth×Speed (AB)	4	0.454337	40.96***
Error AB	8	0.007551	0.68 ^{ns}
Type of implements(C)	5	293.187151	26433.4 ***
Type of implements ×Speed (CB)	10	3.661709	330.14***
Type of implements ×Depth (CA)	10	7.168463	646.30***
Type of implements ×Depth×Speed (CAB)	20	0.133046	12.00 ***
Error	90	0.011092	

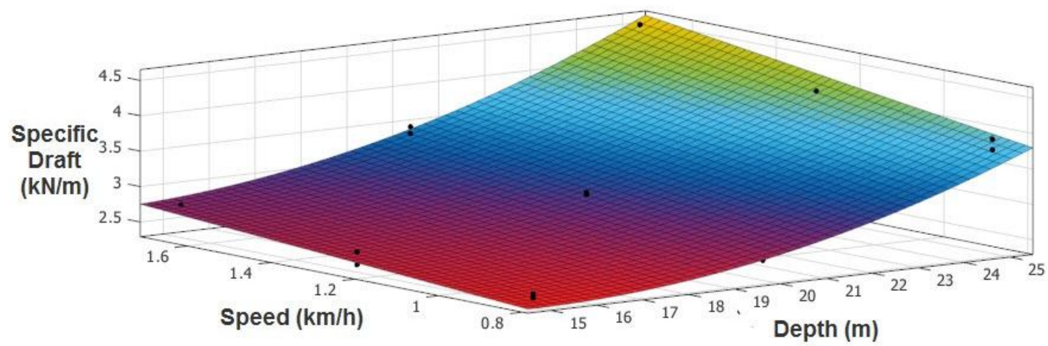
All interaction effects of implements types and forward speed, type of implements and depth of plowing, depth of plowing and forward speed, forward speed and type of implements on the specific draft were significant at 1% level. Also, the results of the experiments showed that for all tillage implements, increasing the depth of plowing and the forward speed increased draft, the effect of plowing depth on increasing the specific draft was higher than the forward speed because increasing the depth of plowing increases the load on the tractor (Figure 3). At speed with increasing depth specific draft increased. Also, at a depth with increasing speed specific draft increased, but the process of increase in the specific draft with increase with a depth greater than the increase in the specific draft with increasing speed. The maximum and minimum draft were seen at 25 cm depth and 6 km/h speed and depth of 15 cm and a speed of 3 km h^{-1} (Table 3). The highest specific draft respectively was observed at the same speed and depth in the MBP, DP, ChPa, CT, DH, and ChP.



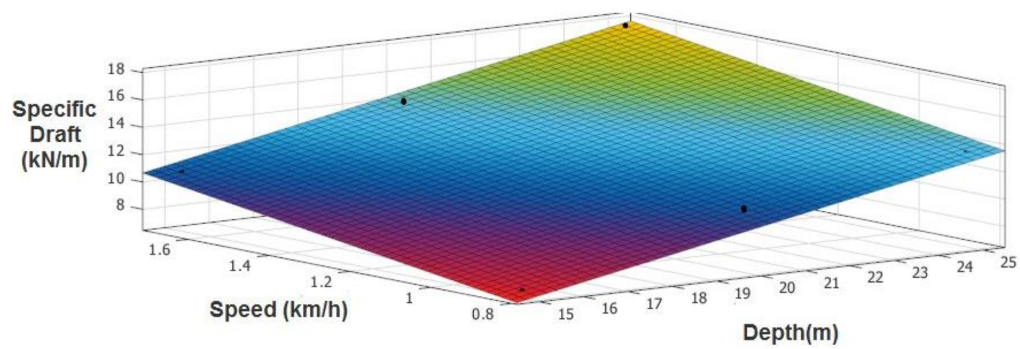
(a) Chisel Packer (ChPa)



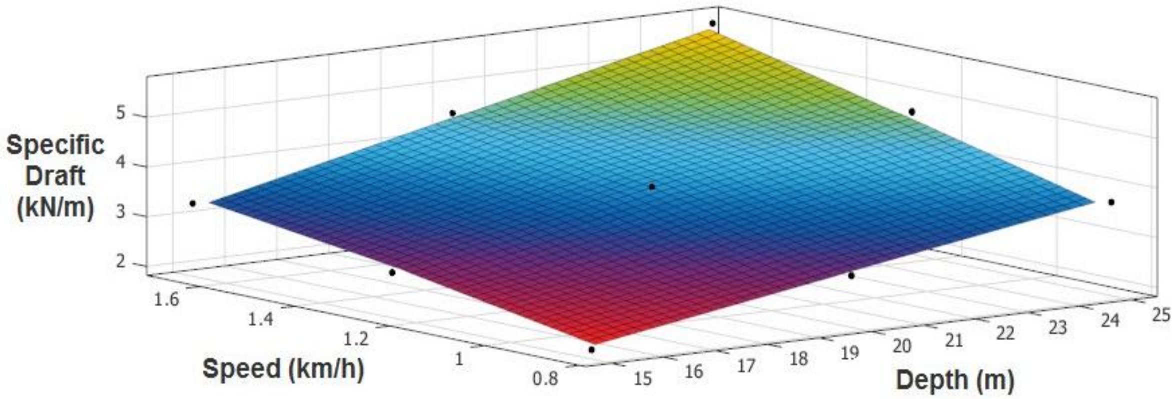
(b) Combined Tiller (CT)



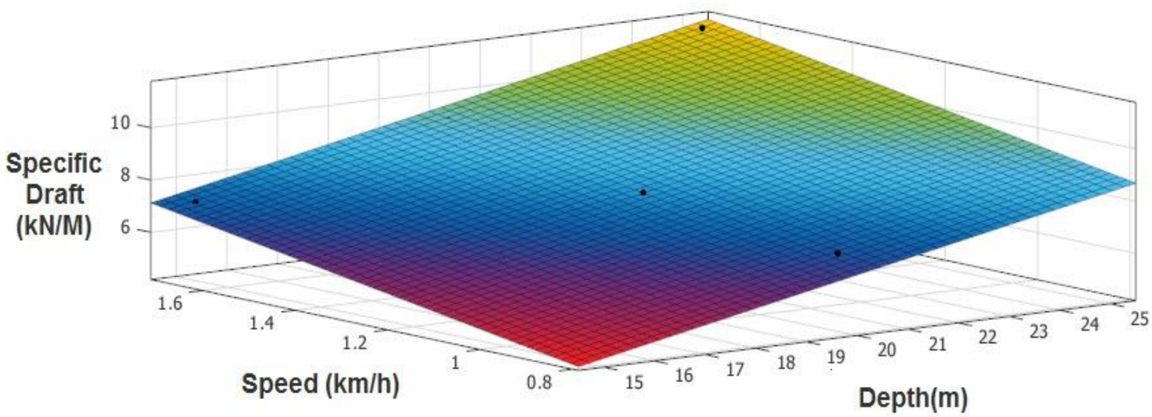
(c) Disk Plow (DP)



(d) Moldboard Plow (MBP)



(e) Chisel Plow (ChP)



(f) Offset Disk Harrow (DH)

Figure 3 Three-dimensional plot for implements

Table 3 The results of depth and speed impacts on various draft tools

Depth(cm)	Speed (km h^{-1})	Type of implements					
		ChPa	CT	DP	MBP	ChP	DH
15	3	4.308	3.49	2.44	7.02	2	4.54
15	4.5	4.41	3.95	2.5	8.66	2.72	5.8
15	6	5.04	4.35	2.73	10.72	3.28	7.18
20	3	6.12	4.06	2.64	11.09	2.85	7.19
20	4.5	6.04	4.86	3	11.92	3.8	7.92
20	6	6.51	5.32	3.36	14.06	4.45	9.09
25	3	7.54	5.6	3.77	13.28	3.69	8.35
25	4.5	7.41	6.37	4	14.37	4.68	9.62
25	6	8.18	7.01	4.38	17.72	5.63	11.42

3.2 Specific draft regression models

Several studies have been carried out to calculate the draft of implements. The result of the researches indicates the relationship between the amounts of draft with the square of the speed (Kheiralla et al., 2004; Naderloo et al., 2009; Okoko et al., 2018). Therefore, in this study, two general linear and nonlinear regression models were obtained for all implements, which parameters of the depth of plowing and forward velocity as independent variables were shown respectively with D and S, and the Specific draft parameter has been shown as the dependent variable with SD. The coefficients of these two models varied depending on the type of the implements. The coefficients of the obtained models for each implement are shown in Table 4.

Nonlinear regression model: $SD = C_0 + C_1 \times D + C_2 \times S + C_3 \times D^2 + C_4 \times D \times S + C_5 \times S^2$

Linear regression mode: $SD = C_0 + C_1 \times D + C_2 \times S$

Table 4 Orthogonal regression analysis for implements

Implement	models	Regression coefficients (symbol and its value)						R^2	RMSE
		C_0	$C_1(D)$	$C_2(S)$	$C_3(D^2)$	$C_4(D \times S)$	$C_5(S^2)$		
ChPa	Nonlinear	0.3264	0.4472	-3.764	-0.003052	-0.01005	1.867	0.986	0.1766
	Linear	-0.9494	0.3125	0.7011	-	-	-	0.9713	0.2368
CT	Nonlinear	5.278	-0.455	1.289	0.01533	0.06538	-0.4799	0.9861	0.1491
	Linear	-1.538	0.2399	1.397	-	-	-	0.952	0.2596
Offset DH	Nonlinear	6.003	-0.3991	-1.558	0.01225	0.04595	0.5197	0.9077	0.2189
	Linear	-0.5942	0.1485	0.6601	-	-	-	0.9659	0.1421
MBP	Nonlinear	5.471	0.4113	-11.59	-0.003615	0.1851	4.734	0.9538	0.5439
	Linear	-4.5	0.4958	3.864	-	-	-	0.9211	0.7063
ChP	Nonlinear	-1.07	0.06091	1.545	0.0008687	0.08584	-0.5344	0.9884	0.1343
	Linear	2.798	0.2024	1.956	-	-	-	0.972	0.1826
DP	Nonlinear	-0.1001	0.5615	-5.798	-0.008268	0.1162	2.739	0.9406	0.4768
	Linear	-3.686	0.3725	3.326	-	-	-	0.9615	0.3829

3.3 ANN model

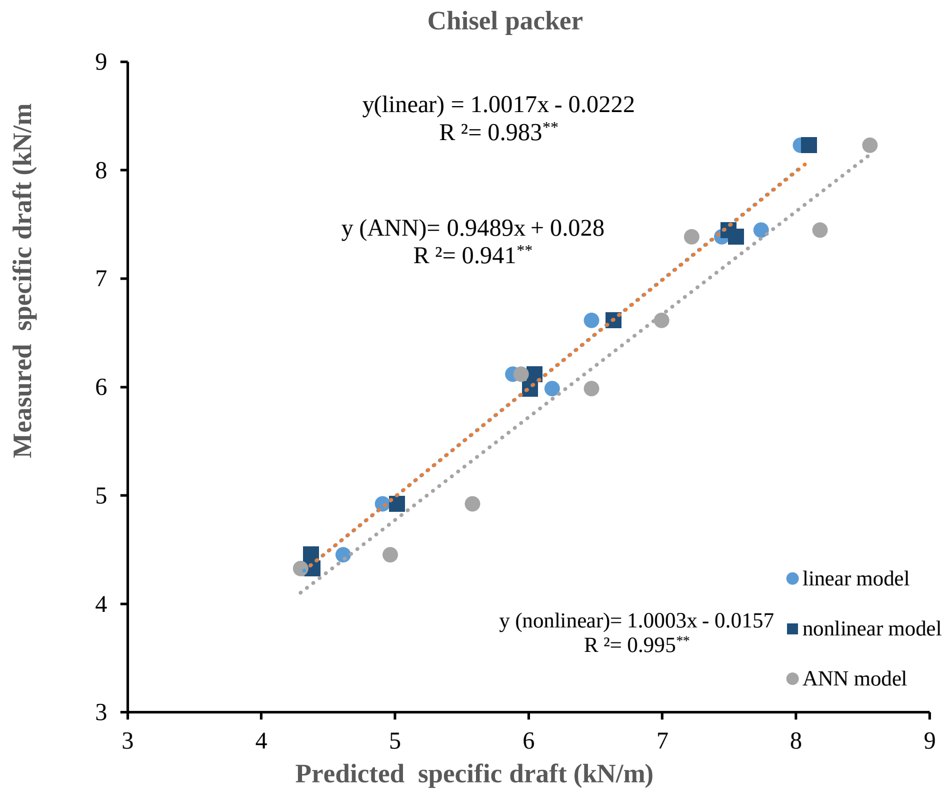
In order to minimize ANN training time, one hidden layer was used. With this configuration, the best network was found with 3-5-1 topology, i.e., a network having five neurons in the hidden layer. R^2 and *RMSE* for the best ANN model are shown in Table 5.

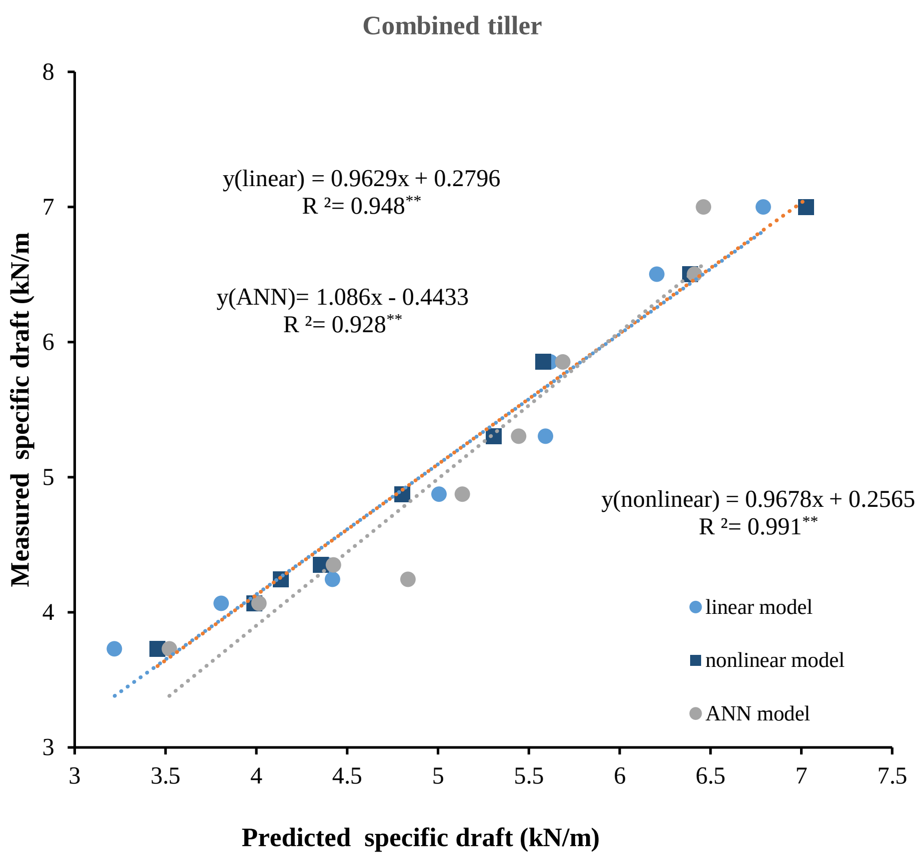
Table 5 Performance statistics of the ANN model for specific draft based upon different statistical indicators

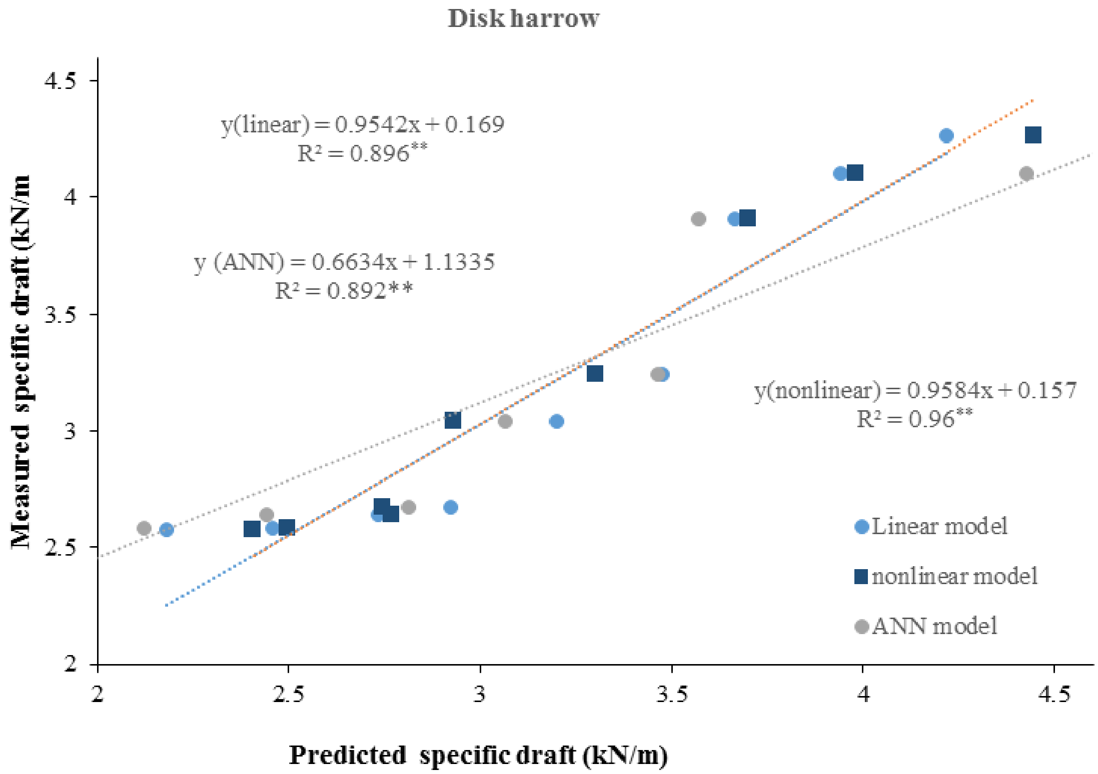
		RMSE	R^2
Specific draft	training	0.26	0.99
	testing	0.24	0.99

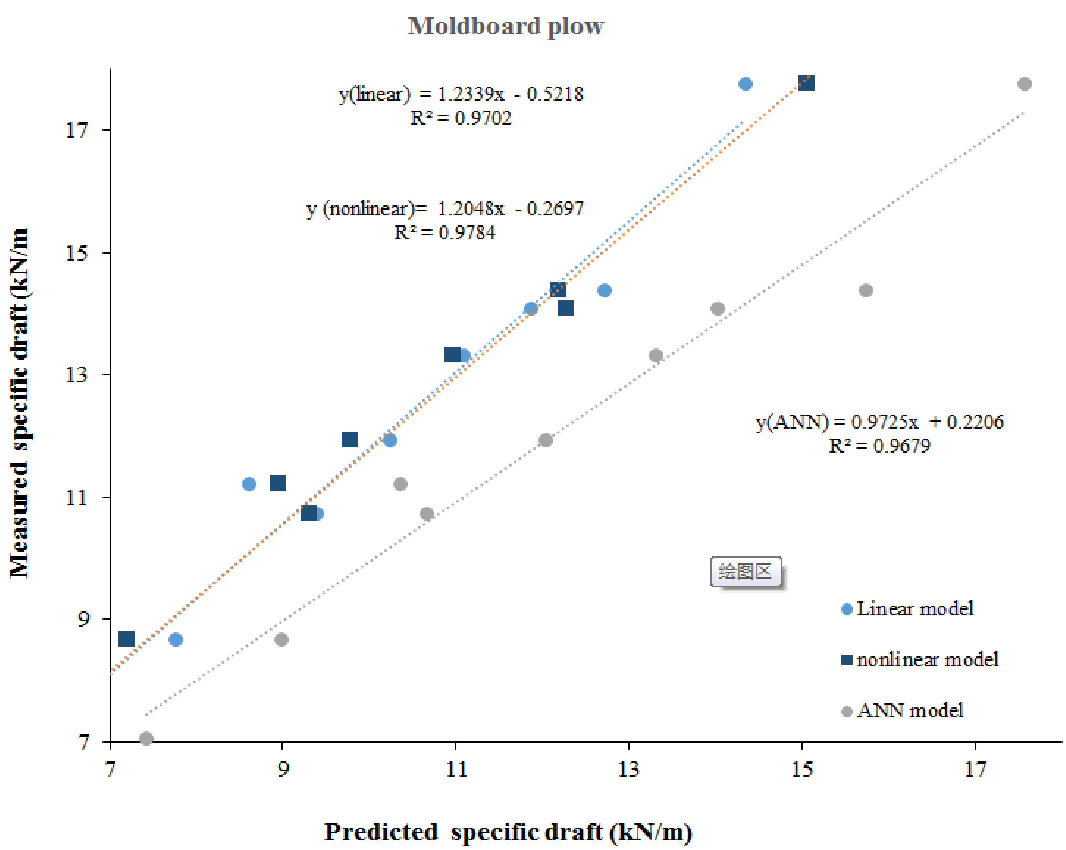
3.4 Validation of models

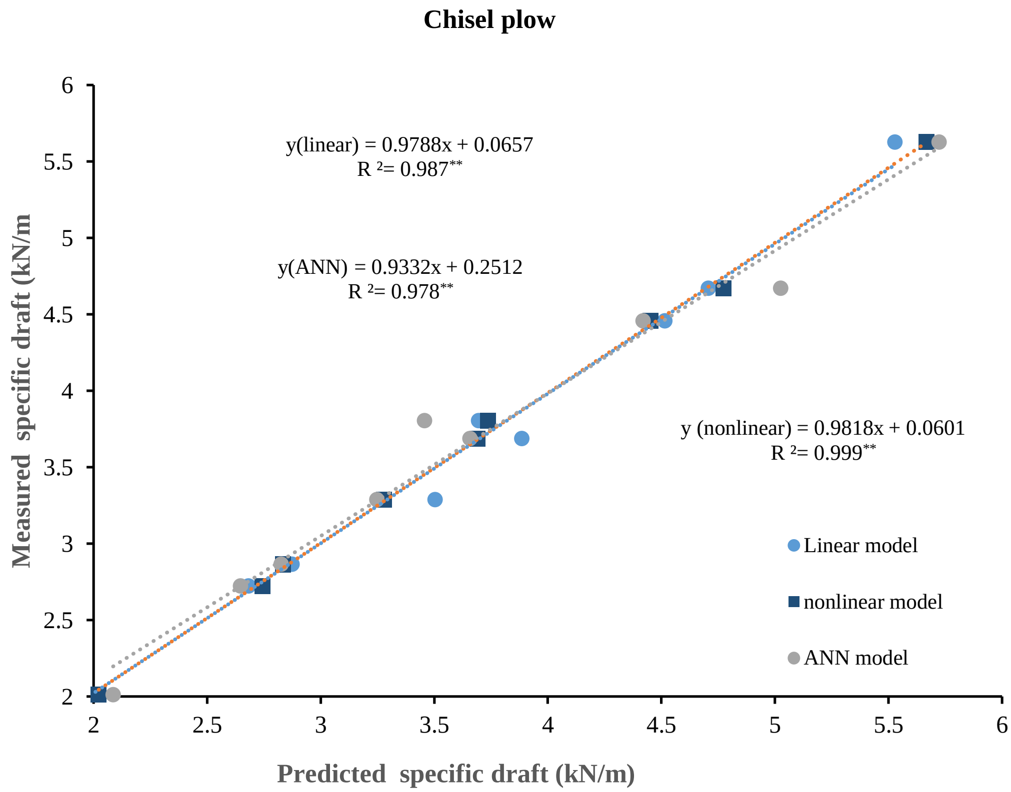
The predicted specific draft from the ANN and regression models is plotted to touch all the measured ones in Figure 4. Although there is a linear and significant relationship between the ANN and linear and nonlinear regression models developed in this study, the estimated values with nonlinear regression were much closer to the measured values. Maximum and minimum explanation coefficients in the nonlinear regression model were 0.99 and 0.96, 0.98 and 0.89 and 0.97 and 0.89 in the nonlinear regression model, linear regression model and ANN model respectively. Also, there was good agreement between result of ANN and regression models in disk and ChP.


Chisel packer
y(linear) = 1.0017x - 0.0222
R ²= 0.983**
y (ANN)= 0.9489x + 0.028
R ²= 0.941**
y (nonlinear)= 1.0003x - 0.0157
R ²= 0.995**
linear model
nonlinear model
ANN model
Measured specific draft (kN/m
Predicted specific draft (kN/m)


Combined tiller
y(linear) = 0.9629x + 0.2796
R ²= 0.948**
y(ANN)= 1.086x - 0.4433
R ²= 0.928**
y(nonlinear) = 0.9678x + 0.2565
R ²= 0.991**
linear model
nonlinear model
ANN model
Measured specific draft (kN/m
Predicted specific draft (kN/m)


Disk harrow
y(linear) = 0.9542x + 0.169
R² = 0.896**
y (ANN) = 0.6634x + 1.1335
R² = 0.892**
y(nonlinear) = 0.9584x + 0.157
R² = 0.96**
Linear model
nonlinear model
ANN model
Measured specific draft (kN/m
Predicted specific draft (kN/m)


Moldboard plow
y(linear) = 1.2339x - 0.5218
R² = 0.9702
y (nonlinear)= 1.2048x - 0.2697
R² = 0.9784
y(ANN) = 0.9725x + 0.2206
R² = 0.9679
绘图区
Linear model
nonlinear model
ANN model
Measured specific draft (kN/m
Predicted specific draft (kN/m)



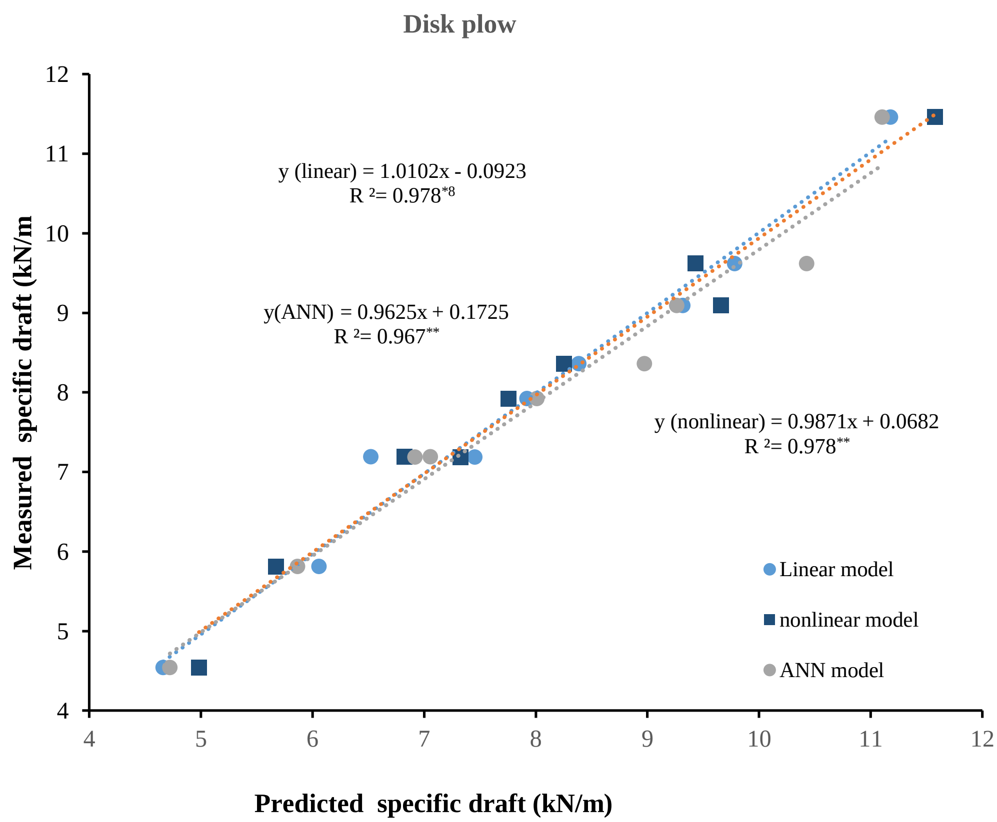
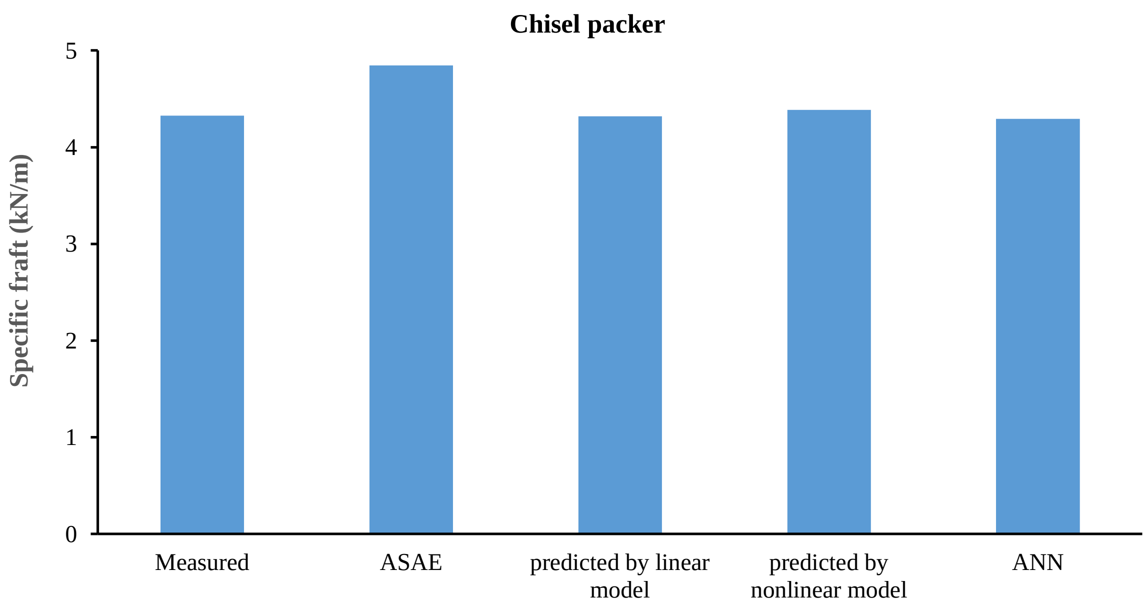
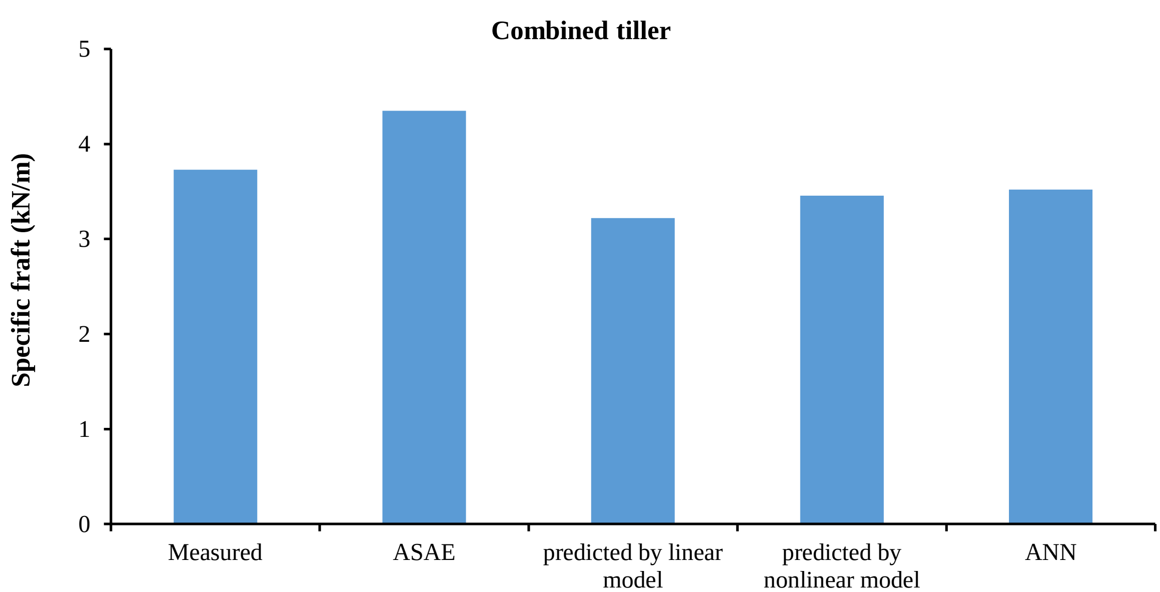


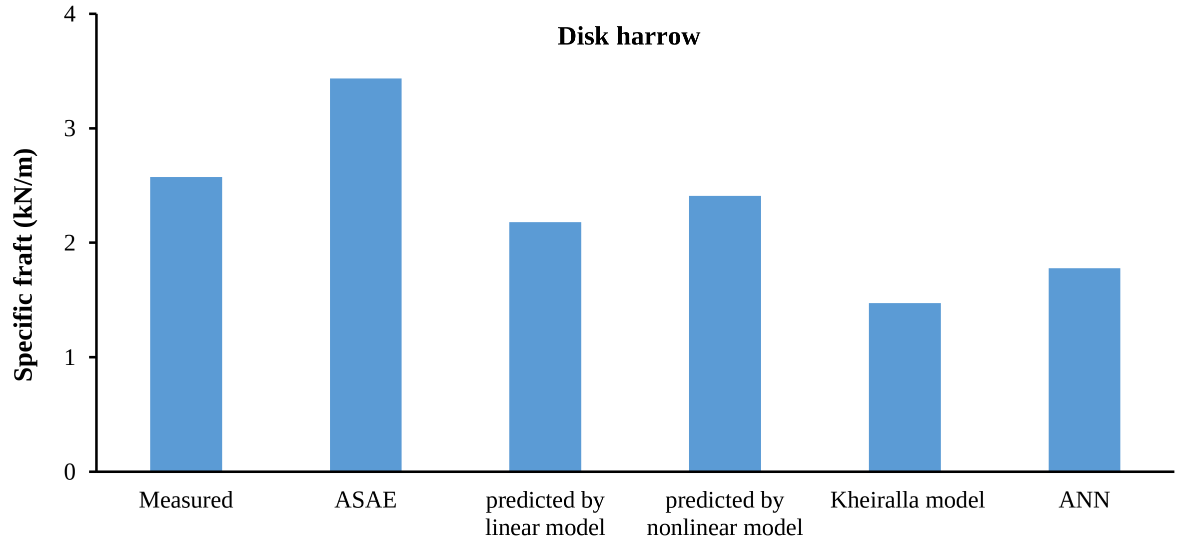
Figure 4 Predicted and measured draft models of the six tillage implements at speed 4.5 km h^{-1} and at depth 25 cm

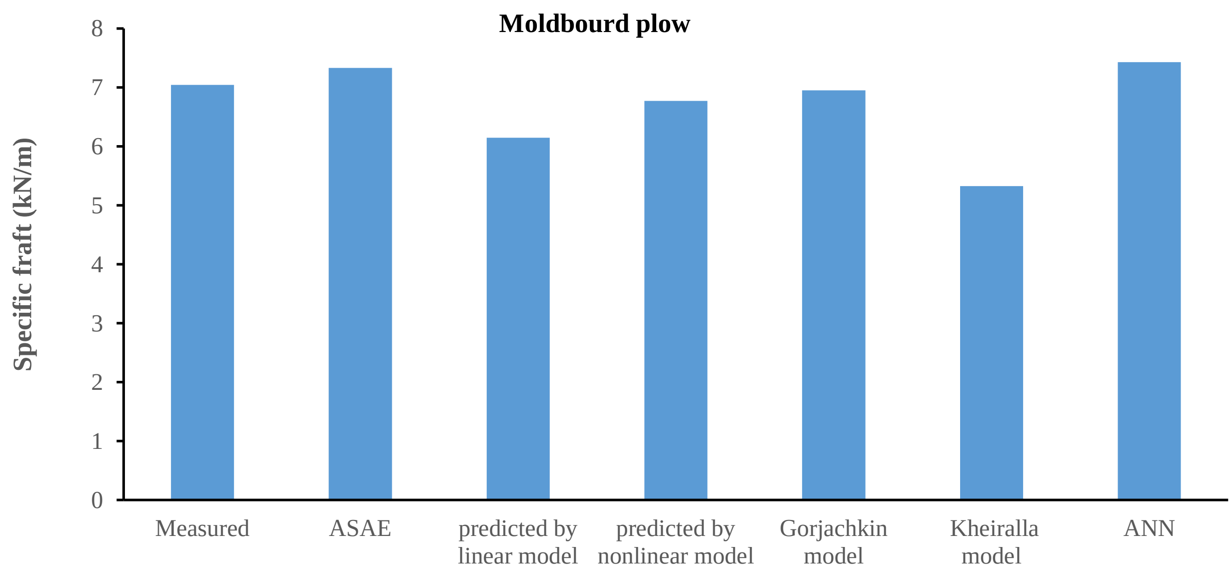
3.5 Comparison between the model established and those of ASABE, Goryachkin and Kheiralla

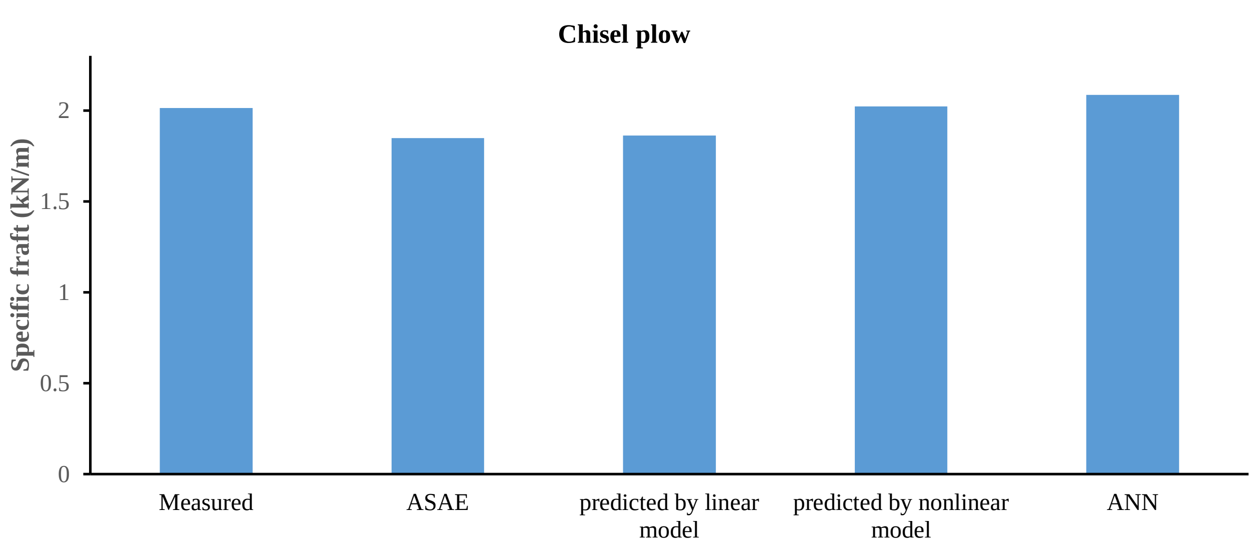
We calculated the specific draft values using existing model to compare the results and accuracy of the models obtained in this study with available and possible models for each implement. As shown in Figure 5, in all implements, the closest predicted value of specific draft is obtained to the value measured by the nonlinear model, the linear model and then ANN model obtained in this study. The ASABE model predicts an appropriate and close to measured value in a MBP, ChP, ChPa and CT and did not predict well in DP and DH. The Goryachkin model only predicts a reasonable amount in DP and MBP at least equal to the measured specific draft. The Kheiralla model was used in DP, MBP and DH, and was shown the difference of 23 to 42 percent with measured value, with the largest number of disk and the lowest for the DP.






Disk harrow
Specific fraft (kN/m)
0
1
2
3
4
Measured
ASAE
predicted by linear model
predicted by nonlinear model
Kheiralla model
ANN


Moldbourd plow
Specific fraft (kN/m)
0
1
2
3
4
5
6
7
8
Measured
ASAE
predicted by linear model
predicted by nonlinear model
Gorjachkin model
Kheiralla model
ANN


Chisel plow
Specific fraft (kN/m)
0
0.5
1
1.5
2
Measured
ASAE
predicted by linear model
predicted by nonlinear model
ANN

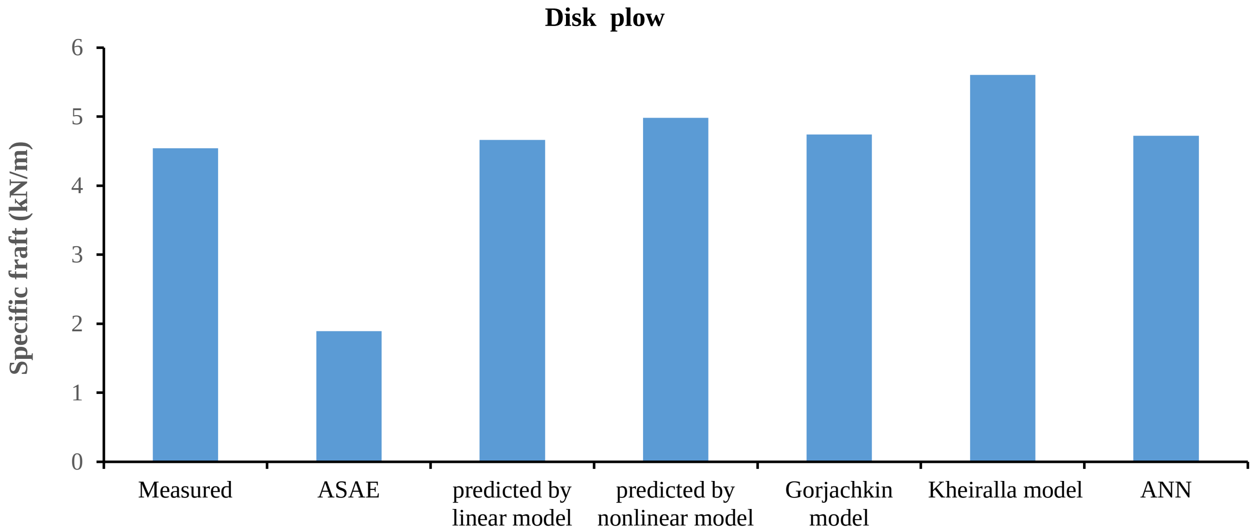


Figure 5 Comparisons of predicted and measured value of specific draft models in all implements at speed 4.5 km h^{-1} and at depth 25 cm

4 Conclusions

1) The results of modeling showed that for each six tillage implements increasing the plowing depth and the advance velocity of the draft increases. The effect of plowing depth on increasing the specific draft is higher than the advance velocity, as increased load on the tractor by increasing the depth of plowing. Also, these conditions were the case for all experimental and regression models.

2) The closest predicted value of specific draft to its measured value was obtained in all implements by the nonlinear model, the linear model and then ANN model obtained in this study.

3) Goryachkin model in DP and MBP predicts a reasonable amount that has a minimum difference with the measured value of specific draft.

4) The linear and non-linear models and the ASABE model were respectively the best predictors in composite tillage implements.

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Conflict of interest

The authors declare no conflict of interest.

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