

Prediction of Moldboard Plow Draft Force Based on Soil Moisture Content, Tillage Depth and Operation Speed

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Abstract: Accurate knowledge of draft force is useful for optimal matching of power unit to tillage implement. Thus, this study was conducted to predict draft force (DF) of a moldboard plow (pull-type) based on soil moisture content (SMC), tillage depth (TD) and operation speed (OS) of the implement. For this purpose, DF of the moldboard plow was measured at three levels of SMC (16.1, 22.0 and 25.4%), four levels of TD (7, 14, 19 and 23 cm) and four levels of OS (1.95, 2.69, 3.80 and 4.50 km/h). Results of DF measurement at SMCs of 16.1 and 25.4% were utilized to determine multiple-variable regression models and results of DF measurement at SMC of 22.0% were used to verify selected model. The paired samples t-test results showed that the difference between the DF values predicted by selected model and measured by field tests were not statistically significant and to predict draft force of moldboard plow based on soil moisture content, tillage depth and operation speed of the implement, the multiple-variable regression model $DF = 252.8 - 4.260 SMC + 0.760 TD^2 + 69.02 OS$ with $R^2 = 0.92$ can be strongly suggested.

Key words: Draft force • Moldboard plow • Soil moisture content • Tillage depth • Operation speed
• Modeling • Prediction

INTRODUCTION

Tillage involves the movement of soil from one place to another [1, 2]. In conventional farming tillage may consume a major portion of the farm's energy budget. The most convenient method to estimate a given implement's energy requirement is to measure the force required to pull the tillage implement at a desired operation speed [3-5]. The force required to pull a tillage implement through the soil is called draft force. When a tillage implement is pulled through the soil, the power unit (usually a tractor) must overcome draft forces created by soil resistance. The direction of the draft force is in the direction of travel [6]. Accurate knowledge of draft force is useful for optimal matching of power unit to tillage implement [7]. However, draft force varies greatly due to numerous factors that influence it. Since a large number of factors influencing draft requirement and various potential combinations of tillage devices exist, it is prohibitively expensive to test all implements in all conditions for every

soil type. Therefore, determining which variables have the greatest influence on the draft requirement for tillage with the most common tillage tools would greatly enhance the process of matching power units to tillage implements [8].

The objective of a large body of existing work has been to study the draft force of a given tillage implement under certain soil conditions and/or operating parameters [4, 5, 9-19]. The ASAE standard D497.4 describes draft force as a function of implement type, soil type, implement width, tillage depth and operation speed [6]. A number of other properties such as static and dynamic component of soil shear stress, soil-metal friction coefficient, soil density and implement geometry are also necessary to consider when analyzing draft force [8, 10, 12, 20]. However, most work that has been done on draft force in the past was focused on specific draft and has concluded that tillage depth is the primary determinant of the amount of force required to pull an implement through soil, with speed often having a significant effect [8, 12, 15, 16, 19]. As soil moisture content, tillage depth and operation

speed of the implement have the greatest influence on the draft requirement for tillage with the most common tillage tools, this study was conducted to predict draft force (DF) of a moldboard plow (pull-type) based on soil moisture content (SMC), tillage depth (TD) and operation speed (OS) of the implement.

MATERIALS AND METHODS

Experimental Site: Experiments were conducted at the Agricultural Research and Experimental Farm of Shahid Beheshti Technical School at Sari, Mazandaran Province, Iran. The experimental site was located at latitude of 36° 31' N and longitude of 53° 25' E and was 16.4 m above mean sea level.

Soil Sampling and Analysis: A composite soil sample from 48 points was collected from 0-20 cm depth and analyzed in the Laboratory for particle size distribution (sand, silt and clay). The soil in the experimental site was clay. The clay soil was consisted of 49.5% clay, 35.0% silt and 15.5% sand.

Tillage Implement: A two-bottom moldboard plow (pull-type) with width of 96 cm was used in this study. This implement is representative of the standard primary tillage implement most commonly used for turning over the upper layer of the soil, bringing fresh nutrients to the surface, while burying weeds and the remains of previous crops.

Field Methods: There was no crop growth and the field was left fallow. Prior to performing the experiments, the field was irrigated by using a sprinkler irrigation system. Soil samples were collected and weighed during the experiments to determine soil moisture content. The samples were placed in an electric oven maintained at 110° C for 48 hours. The dried soil samples were reweighed and the soil moisture contents were calculated on a dry weight basis. A factorial experiment based on randomized complete block design (RCBD) with three replications was used to evaluate the effect of soil moisture content (SMC), tillage depth (TD) and operation speed (OS) of the implement on draft force of moldboard plow (pull-type). Three SMC (16.1, 22.0 and 25.4%), four levels of TD (7, 14, 19 and 23 cm) and four levels of OS (1.95, 2.69, 3.80 and 4.50 km/h) were used in a combination resulting in a total of 48 treatments. The treatments were randomly distributed in the field tests.

Experimental Procedure: An experimental block 75 m long by 5 m wide was used for each treatment. A small block of approximately 15 m long by 5 m wide in the beginning of each tested block was used to enable the tractor and implement to reach the required tillage depth and operation speed. Tillage depth was measured as the vertical distance from the top of the undisturbed soil surface to the implement's deepest penetration. During field operations, the tractor was operated at the same tillage depth but at different operation speeds. A Universal 650 tractor with 48.5 kW and in good condition was used in all the experiments. The implement draft force, tillage depth and operation speed during field operations were measured and recorded by an onboard data logger in the tractor cab.

Data Acquisition System: The data acquisition system consisted of a data logger, a towed linkage load cell, a depth position transducer and a fifth wheel. The towed linkage load cell used to measure implement draft force was calibrated prior to the experiments using a specially built calibration rig. A performance test program was developed and documented for the data logger to scan the transducers every second during field operation. Therefore, the number of readings made in each treatment depended on the operation speed of the tractor. To begin the field tests, the depth wheels lever was adjusted to lower the implement corresponding to the tillage depth. Then the tractor was accelerated to the required operation speed with a known gear range before entering the first test block. Data acquisition was activated by pressing the push button switch on the activity unit as the tractor passed the flag marking the beginning of the first test block. Data acquisition continued until the end of the test block. After finishing the first test block, the tractor was again driven straight toward the second test block with a different operation speed and the process was repeated. Similar procedure was repeated for other treatments. Results of draft force measurement at soil moisture contents of 16.1 and 25.4% (Table 1) were utilized to determine multiple-variable regression models and results of draft force measurement at soil moisture content of 22.0% (Table 2) were used to verify selected model.

Regression Model: A typical multiple-variable regression model is shown in equation 1:

$$Y = C_0 + C_1X_1^t + C_2X_2^s + C_3X_3^t \quad (1)$$

Table 1: Results of draft force measurement (three replications) at soil moisture contents of 16.1 and 25.4% used for determining multiple-variable regression models

Soil moisture content (%)	Tillage depth (cm)	Operation speed (km/h)	Draft force of moldboard plow (kgf)		
			R ₁	R ₂	R ₃
16.1	7	1.95	418	424	427
		2.69	439	444	455
		3.80	467	472	492
		4.50	510	527	532
	14	1.95	471	474	483
		2.69	507	512	526
		3.80	551	556	570
		4.50	571	575	594
	19	1.95	546	547	560
		2.69	605	612	625
		3.80	682	689	705
		4.50	752	760	762
	23	1.95	672	678	693
		2.69	761	774	787
		3.80	885	891	903
		4.50	998	1006	1020
25.4	7	1.95	373	389	390
		2.69	397	399	422
		3.80	434	439	447
		4.50	479	481	489
	14	1.95	425	427	432
		2.69	461	464	470
		3.80	491	505	528
		4.50	521	525	538
	19	1.95	500	506	521
		2.69	561	565	575
		3.80	635	639	652
		4.50	691	702	719
	23	1.95	625	628	640
		2.69	716	724	738
		3.80	829	832	847
		4.50	928	938	960

Table 2: Results of draft force measurement (three replications) at soil moisture content of 22.0% used for verifying selected model

Soil moisture content (%)	Tillage depth (cm)	Operation speed (km/h)	Draft force of moldboard plow (kgf)		
			R ₁	R ₂	R ₃
22.0	7	1.95	395	399	412
		2.69	419	428	440
		3.80	451	458	465
		4.50	490	499	505
	14	1.95	436	440	467
		2.69	481	485	501
		3.80	513	519	528
		4.50	549	558	570
	19	1.95	523	528	536
		2.69	576	580	590
		3.80	663	669	678
		4.50	731	736	744
	23	1.95	649	654	665
		2.69	757	761	771
		3.80	865	870	878
		4.50	989	995	1007

Table 3: Three multiple-variable regression models and their relations

Model No.	Model	Relation
1	$DF = C_0 + C_1 SMC + C_2 TD + C_3 OS$	$DF = 123.9 - 4.260 SMC + 21.88 TD + 69.02 OS$
2	$DF = C_0 + C_1 SMC + C_2 TD^2 + C_3 OS$	$DF = 252.8 - 4.260 SMC + 0.760 TD^2 + 69.02 OS$
3	$DF = C_0 + C_1 SMC + C_2 TD + C_3 OS^2$	$DF = 255.8 - 4.260 SMC + 21.88 TD + 10.62 OS^2$

where:

Y = Dependent variable, for example draft force (DF) of moldboard plow

X_1, X_2, X_3 = Independent variables, for example soil moisture content (SMC), tillage depth (TD) and operation speed (OS) of the implement, respectively

r, s, t = Power of the independent variables

C_0, C_1, C_2, C_3 = Regression coefficients

In order to predict draft force of moldboard plow from soil moisture content, tillage depth and operation speed of the implement, three multiple-variable regression models were suggested and all the data were subjected to regression analysis using the Microsoft Excel 2007. Three multiple-variable regression models and their relations are shown in Table 3.

Statistical Analysis: A paired samples t-test and the mean difference confidence interval approach were used to compare the draft force values predicted by selected model with the draft force values measured by field tests. The Bland-Altman approach [21] was also used to plot the agreement between the draft force values measured by field tests with the draft force values predicted by selected model. The statistical analyses were also performed using the Microsoft Excel 2007.

RESULTS AND DISCUSSION

The p-value of independent variables and coefficient of determination (R^2) for the three multiple-variable regression models are shown in Table 4. Among the three models, model No. 2 had the highest R^2 value (0.92). Moreover, this model totally had the lowest p-value of independent variables among the three models. Based on the statistical results model No. 2 was selected as the best model, which is given by equation 2:

$$DF = 252.8 - 4.260 SMC + 0.760 TD^2 + 69.02 OS \quad (2)$$

Draft force of the moldboard plow was then predicted for SMC of 22.0% at four levels of TD (7, 14, 19 and 23 cm) and four levels of OS (1.95, 2.69, 3.80 and 4.50 km/h) using the multiple-variable regression model No. 2. The draft force values predicted by model No. 2 were compared with

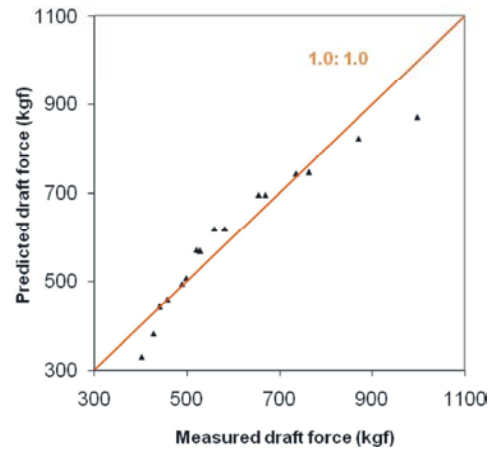


Fig. 1: Measured draft force by field tests and predicted draft force by model No. 2 with the line of equality (1.0: 1.0)

the draft force values measured by field tests and are shown in Table 5. A plot of the draft force values predicted by model No. 2 and the draft force values measured by field tests with the line of equality (1.0: 1.0) is shown in Fig. 1. Moreover, a paired samples t-test and the mean difference interval approach were used to compare the draft force values predicted by model No. 2 with the draft force values measured by field tests. The Bland-Altman approach [21] was also used to plot the agreement between the draft force values measured by field tests with the draft force values predicted by model No. 2. The average draft force difference between two methods was -2.05 kgf (95% confidence intervals for the difference in means: -28.4 kgf and 24.3 kgf; $P = 0.8706$). The standard deviation of the draft force difference was 49.5 kgf (Table 6). The paired samples t-test results showed that the draft force values predicted by model No. 2 were not significantly different than the draft force values measured by field tests. The draft force difference values between two methods were normally distributed and 95% of these differences were expected to lie between $\mu - 1.96\sigma$ and $\mu + 1.96\sigma$, known as 95% limits of agreement [22-25]. The 95% limits of agreement for comparison of the draft force values determined by field tests and model No. 2 was calculated at -99.1 kgf and 95.0 kgf (Fig. 2). Therefore, the draft force values predicted by model No. 2 may be 99.1 kgf lower or 95.0 kgf higher than the draft force values

Table 4: The p-value of independent variables and coefficient of determination (R^2) for the three multiple-variable regression models

Model No.	p-value					R^2
	SMC	TD	TD ²	OS	OS ²	
1	0.00019	3.82E-37	---	1.86E-18	---	0.86
2	1.12E-6	---	9.61E-49	7.16E-26	---	0.92
3	0.00019	4.71E-37	---	---	2.40E-18	0.86

Table 5: Soil moisture content, tillage depth, operation speed and draft force of moldboard plow used in evaluating model No. 2

Soil moisture content (%)	Tillage depth (cm)	Operation speed (km/h)	Draft force of moldboard plow (kgf)		Average of measured and predicted draft force (kgf)	Difference of measured and predicted draft force (kgf)
			Measured by field tests	Predicted by model No. 2		
22.0	7	1.95	402	331	366	71
		2.69	429	382	405	47
		3.80	458	459	458	-1
		4.50	498	507	502	-9
	14	1.95	441	443	442	-2
		2.69	489	494	491	-5
		3.80	520	570	545	-50
		4.50	559	619	589	-60
	19	1.95	529	568	549	-39
		2.69	582	619	601	-37
		3.80	670	696	683	-26
		4.50	737	744	741	-7
	23	1.95	656	696	676	-40
		2.69	763	747	755	16
		3.80	871	823	847	48
		4.50	997	872	934	125

Table 6: Paired samples t-test analysis on comparing draft force determination methods

Determination methods	Average difference (kgf)	Standard deviation of difference (kgf)	p-value	95% confidence intervals for the difference in means (kgf)
Field tests vs. model No. 2	-2.05	49.5	0.8706	-28.4, 24.3

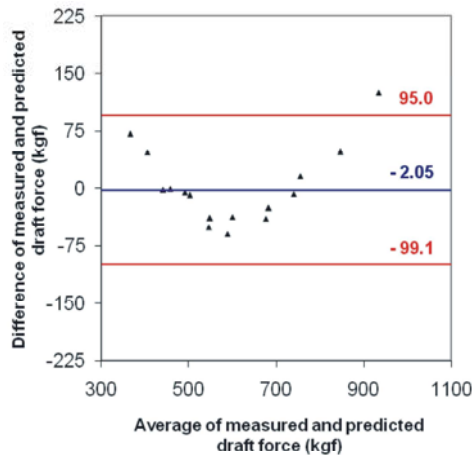


Fig. 2: Bland-Altman plot for the comparison of measured draft force by field tests and predicted draft force by model No. 2; the outer lines indicate the 95% limits of agreement (-99.1, 95.0) and the center line shows the average difference (-2.05)

measured by field tests. The average percentage difference for the draft force values predicted by model No. 2 and measured by field tests was 6.1%.

CONCLUSIONS

It can be concluded that the multiple-variable regression model $DF = 252.8 - 4.260 SMC + 0.760 TD^2 + 69.02 OS$ with $R^2 = 0.92$ can be strongly recommended to predict draft force (DF) of moldboard plow (pull-type) based on soil moisture content (SMC), tillage depth (TD) and operation speed (OS) of the implement.

REFERENCES

1. Rashidi, M. and F. Keshavarzpour, 2011. Effect of different tillage methods on some physical and mechanical properties of soil in the arid lands of Iran. *World Applied Sciences Journal*, 14(10): 1555-1558.
2. Keshavarzpour, F., 2012. Response of some important physical and mechanical properties of soil to different tillage methods. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 12 (7): 914-916.
3. Nicholson, R.I., L.L. Bashford and L.N. Mielke, 1984. Energy requirements for tillage from a reference implement. ASAE Paper No. 84-1028, ASAE, St. Joseph, Michigan, USA.

4. Bowers, C.G., 1989. Tillage draft and energy requirements for twelve Southeastern soil series. *Transactions of the ASAE*, 32(5): 1492-1502.
5. Bashford, L.L., D.V. Byerly and R.D. Grisso, 1991. Draft and energy requirements of agricultural implements in semi-arid regions of morocco. *Agricultural Mechanization in Asia, Africa and Latin America*, 22(3): 79-82.
6. ASAE, 2003. ASAE Standard D497.4: Agricultural Machinery Management Data. ASAE, St. Joseph, Michigan, USA.
7. Upadhyaya, S.K., 1984. Prediction of tillage implement draft. ASAE Paper No. 84-1518. ASAE St. Joseph, Michigan, USA.
8. Ehrhardt, J.P., R.D. Grisso, M.F. Kocher, P.J. Jasa and J.L. Schinstock, 2001. Using the Veris electrical conductivity cart as a draft predictor. ASAE Paper No. 01-1012, ASAE, St. Joseph, Michigan, USA.
9. McKyes, E. and F.L. Desir, 1984. Prediction and field measurements of tillage tool draft and efficiency in cohesive soils. *Soil and Tillage Research*, 4(5): 459-470.
10. Glancey, J.L., S.K. Upadhyaya, W.J. Chancellor and J.W. Rumsey, 1989. An instrumented chisel for the study of soil-tillage dynamics. *Soil and Tillage Research*, 14(1): 1-24.
11. Glancey, J.L. and S.K. Upadhyaya, 1995. An improved technique for agricultural implement draught analysis. *Soil and Tillage Research*, 35(4): 175-182.
12. Collins, B.A. and D.B. Fowler, 1996. Effect of soil characteristics, seeding depth, operating speed and opener design on draft force during direct seeding. *Soil and Tillage Research*, 39(3-4): 199-211.
13. Glancey, J.L., S.K. Upadhyaya, W.J. Chancellor and J.W. Rumsey, 1996. Prediction of implement draft using an instrumented analog tillage tool. *Soil and Tillage Research*, 37(1): 47-65.
14. Grisso, R.D., M. Yasin and M.F. Kocher, 1996. Tillage implement forces operating in silty clay loam. *Transactions of the ASAE*, 39(6): 1977-1982.
15. Kushwaha, R.L. and C. Linke, 1996. Draft-speed relationship of simple tillage tools at high operating speeds. *Soil and Tillage Research*, 39(1-2): 61-73.
16. Wheeler, P.N. and R.J. Godwin, 1996. Soil dynamics of single and multiple tines at speeds up to 20 km/h. *Journal of Agricultural Engineering*, 63(3): 243-250.
17. Al-Suhaibani, S.A. and A.A. Al-Janobi, 1997. Draught requirements of tillage implements operating on sandy loam soil. *Journal of Agricultural Engineering Research*, 66(3): 177-182.
18. Al-Janobi, A.A. and S.A. Al-Suhaibani, 1998. Draft of primary tillage implements in sandy loam soil. *Applied Engineering in Agriculture*, 14(4): 343-348.
19. McLaughlin, N.B. and A.J. Campbell, 2004. Draft-speed-depth relationships for four liquid manure injectors in a fine sandy loam soil. *Canadian Biosystems Engineering*, 46: 2.1-2.5.
20. McKyes, E. and J. Maswau, 1997. Effect of design parameters of flat tillage tools on loosening of a clay soil. *Soil and Tillage Research*, 43(3-4): 197-206.
21. Bland, J.M. and D.G. Altman, 1999. Measuring agreement in method comparison studies. *Statistical Method in Medical Research*, 8: 135-160.
22. Rashidi, M., I. Ranjbar, M. Gholami and S. Abbassi, 2010. Prediction of carrot firmness based on carrot water content. *American-Eurasian Journal of Agricultural & Environmental Sci.*, 7(4): 402-405.
23. Rashidi, M. and M. Seilsepour, 2011. Prediction of soil sodium adsorption ratio based on soil electrical conductivity. *Middle-East Journal of Scientific Research*, 8(2): 379-383.
24. Mousavi, M., M. Rashidi, I. Ranjbar, M. Solimani Garmroudi and M. Ghaebi, 2013. Prediction of bias-ply tire contact area based on section width, overall unloaded diameter, inflation pressure and vertical load. *Middle-East Journal of Scientific Research*, 14(11): 1513-1519.
25. Rashidi, M., M.A. Sheikhi, S. Razavi, M. Niyazadeh and M. Arkian, 2013. Prediction of radial-ply tire deflection based on section width, overall unloaded diameter, inflation pressure and vertical load. *World Applied Sciences Journal*, 21(12): 1804-1811.