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USING THE VERIS ELECTRICAL CONDUCTIVITY CART AS A DRAFT PREDICTOR

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Abstract: The use of an electro-conductivity cart as a reference implement to predict tillage draft was studied. Regression analysis was used to develop prediction equations for the draft of two implements (three-point mounted field cultivator and electro-conductivity cart) in measured operating conditions across a variety of speeds and tillage depths in two surface conditions. The data were then used to study the reference implement concept. Routines to predict the draft of the field cultivator from the measured draft of an electro-conductivity cart were developed. The Pearson correlations for measured draft compared to predicted draft using the Veris cart as the analog device ranged from 0.89 to 0.95.

Key words: *machinery management, draft prediction, draft modeling, reference implement*

INTRODUCTION

The most convenient method to estimate a given implement's energy requirement is to measure the draft required to pull the implement under desired operating conditions. Accurate knowledge of draft requirements is useful for optimal matching of power units to implements. However, tillage forces vary greatly due to numerous factors that influence these forces. Complicating the relationship is the large number of factors, interactions between factors and variability of the parameters within a short distance. 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

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in all conditions for every soil type. Thus, the body of knowledge is incomplete. However, determining which variables have the greatest influence on the energy requirement for tillage with the most common tillage tools would greatly enhance the process of matching power units to tillage implements.

The purpose of the tillage reference implement concept is to predict the draft of a variety of soil-engaging implements with the measurement from a single device. The Veris electrical conductivity (EC) cart (Model 3100) was equipped with a load cell and was used as a tillage reference implement. The draft from the reference implement was then used to predict the draft force of a field cultivator in a Yutan salty clay loam. The EC cart is typically used to gather geo-referenced data for electrical conductivity (possibly correlated to soil texture and organic matter) for precision farming. With the addition of draft measurements, the potential exist to assess tillage energy requirements with soil properties on a zone basis.

The objective of a large body of existing work has been to predict the draft of a given implement under certain soil conditions and operating parameters. There have been two main approaches to accomplish this end: empirical methods and analytical methods. In both approaches, including more variables in the model generally increases the accuracy of the model, but this also increases complexity, and the number of input variables that must be known to use the model.

Most analytical approaches to draft prediction are based on the Passive Earth Pressure Theory. Kuczewski and Piotrowska [1] proposed a model to predict forces on narrow soil cutting tines using this theory. The model was designed to improve upon models proposed by Godwin and Spoor [2], McKeys [3], Swick and Perumpral [4], and Kuczewski and Piotrowska [5]. Their model did increase the accuracy of draft prediction over the existing models when tested in a laboratory setting.

Wheeler and Godwin [6] proposed a force prediction model for a single tine at a single depth for various speeds and rake angles in both frictional and cohesive soils. The model was shown to have good agreement under shallow depth conditions for predicting both horizontal and vertical forces of the single tine at speeds up to 20 $km\cdot h^{-1}$. The model was shown to give good agreement for the horizontal forces for multiple-tined units and in the frictional soil.

Onwualu and Watts [7] tested three current models for predicting tillage forces. The three models tested were those proposed by McKeys and Desir [8], Swick and Perumpral [4], and the 2-D model of Soehne as reported by Gill and Vandern Berg [9]. They used wide and narrow plane tillage blades in one soil type at constant moisture content, at two depths, two rake angles and eight speeds. They found that none of the Passive Earth Pressure Theory-based models for predicting draft that they tested accurately predicted actual forces.

In studies employing the empirical approach, parameters of the soil, implement, operating conditions and the forces to be modeled are measured and recorded. This data is then analyzed to formulate predictive equations. A statistical regression routine is the usual means of this analysis. The most common resulting formula format is a series of measured variables with corresponding coefficients.

ASAE Standards [10] provide empirical equations to approximate draft and power requirements for a variety of tillage tools in three general soil conditions as part of *D497.4 Agricultural Machinery Management Data*. The standard describes tillage draft as a function of implement type, soil type, implement width, depth, and speed. A number of other properties are also necessary to consider when analyzing tillage draft. Glancey *et al.* [11] listed some of these additional variables as: static and dynamic component of soil shear stress, soil-metal friction coefficient, soil density, and implement geometry. However, depth of operation was found to be the most significant factor while speed was often significant. Most work that has been done on tillage draft in the past was focused on specific draft and has concluded that tillage depth is the primary determinant of the amount of power required to pull an implement through soil, with speed often having a significant effect.

Speed was found to significantly influence draft in a study of 5 simple blades in two soil types by Kushwaha and Linke [12]. Mielke *et al.* [13] ran experiments with a bi-level subsoiler and a conventional subsoiler at three depths. They found that power requirements increased with tillage depth, but did not formulate an equation to relate the two parameters. Glancey and Upadhyaya [14] noted that speed was a significant determinant of draft, but speed squared was not significant for a moldboard plow in a Capay clay soil.

Tillage tool draft, primarily for moldboard plows, was predicted from an equation presented by Upadhyaya [15]. The equation included factors for depth, width of cut, speed and wet soil bulk density and dynamic cone index.

$$D \cdot CI_d^{\ -1} \cdot w^{-1} = d \cdot w^{-1} \cdot (C_1 + C_2 \cdot r_w \cdot s \cdot CI_d^{-1}) \qquad (1)$$

Where:

D	[N]	- draft force,
CI_d	[kPa]	- dynamic cone index,
r_w	[mg·m^{-3}]	- wet bulk density,
s	[km·h^{-1}]	- field speed,
d	[m]	- depth of tillage,
w	[m]	- width of the tool,
C_1	[N·kPa^{-1}·m^{-1}]	- geometry-dependent coefficient,
C_2	[N·h·m^3·mg^{-1}]	- geometry-dependent coefficient.

After testing analytical methods, Onwualu and Watts [7] presented an empirical model and concluded that draft and vertical forces are a function of the speed and the square of speed. They also stated that the analytical models that were tested were insufficient because they only incorporated the speed squared. They presented the following regression-type model:

$$D = C_0 + C_3 \cdot s + C_4 \cdot s^2 \qquad (2)$$

Where:

D	[N]	- draft force,
s	[km·h^{-1}]	- field speed,
C_0	[N]	- regression coefficient,
C_3	[N·h·km^{-1}]	- regression coefficient,
C_4	[N·h^2·km^{-2}]	- regression coefficient.

R^2 values of 0. 99 for draft force predictions were obtained with both the narrow and wide blades across the entire range of other variables.

Grisso *et al.* [16] developed equations to predict draft requirements by empirical means for several implements at a variety of travel speeds and tillage depths in wheat stubble on Sharpsburg silty clay loam. They also measured soil moisture content, bulk density and cone index and used these values as covariates in the regression analysis. Draft of a chisel plow increased in a linear manner with travel speeds and quadratically with tillage depths when used for primary tillage. The equations presented were of the following form:

$$D_i = C_1 \cdot d + C_2 \cdot d^2 + C_3 \cdot s + C_5 \cdot d \cdot s + C_6 \cdot CI \quad (3)$$

Where:

D_i [N] - predicted draft force of the i^{th} implement,
d [m] - depth of tillage,
s [$km \cdot h^{-1}$] - field speed,
CI [kPa] - cone index,
C_1 [$N \cdot m^{-1}$] - regression coefficient,
C_2 [$N \cdot m^{-2}$] - regression coefficient,
C_3 [$N \cdot h \cdot km^{-1}$] - regression coefficient,
C_5 [$N \cdot h$] - regression coefficient,
C_6 [$N \cdot kPa^{-1}$] - regression coefficient.

The bulk density and moisture content of the soil were also included in the regression analyses, but these variables were not found to be statistically significant. Cone index was only found to be significant for the tandem disk model. The models presented above were verified with a final replication of the experiment.

Al-Suhaibani and Al-Janobi [17] found a significant increase in draft with depth and speed for all treatment combinations. Another study was conducted in Morocco with 6 tillage implements [18]. A regression relationship with speed and depth was presented with the following equation:

$$uD = C_o + C_1 \cdot d + C_3 \cdot s \quad (4)$$

Where:

uD [$N \cdot m^{-1}$] - unit draft force,
d [m] - depth of tillage,
s [$km \cdot h^{-1}$] - field speed,
C_0 [$N \cdot m^{-1}$] - regression coefficient,
C_1 [$N \cdot m^{-2}$] - regression coefficient,
C_3 [$N \cdot h \cdot m^{-2}$] - regression coefficient.

Increasing depth, width and rake angle were found to increase draft requirements [19]. Speed, soil consistency, depth and type of opener were all found to affect draft requirements of direct seeders by [20]. Their work determined that opener draft increased an average of 4% for each $km \cdot h^{-1}$ that speed increased, heavy clay required more draft power than a sandy loam soil, and that draft increased an average of 20% for every cm increase in depth.

Nicholson *et al.* [21] developed a routine to predict the draft of a tandem disk, a sweep plow, a non-standard chisel plow and an implement designed to be a draft analog. The surface conditions were the following: loose till, firm till and wheat stubble. Disk draft was found to be a function of the mass of the disk. The data from the sweep plow was analyzed using a regression routine. Soil, depth and speed were all found to be significant determinants of draft. Depth-speed interaction was significant for one set of data, this indicated that with increasing depth, speed had more influence. The resulting equation for unit draft of the sweep plow, analog implement, and non-standard chisel plow was:

$$uD = d \cdot d_R^{-1} \cdot (C_1 + C_2 \cdot s) \tag{5}$$

Where:
uD [N·m^{-1}] - unit draft force,
d [m] - depth of tillage,
d_R [m] - reference depth,
s [km·h^{-1}] - field speed,
C_1 [N·m^{-1}] - regression coefficient,
C_2 [N·h·m^{-2}] - regression coefficient.

The concept of using one implement as an analog to predict the draft requirements of different implements has been explored. The potential savings of time and money with a reference implement could be considerable. Draft studies could be completed with a single device and the results applied to a number of other tillage tools. Also, predictive efforts would be greatly facilitated because a standard would exist to which other implements could be compared. Additionally, for an unknown set of operating conditions, a single tillage pass could generate accurate predictions for a number of other implements.

Glancey *et al.* [22] used two reference devices, one resembling a cone penetrometer cross-section and the other a typical lister, to predict tillage draft of three other implements: a subsoiler, a moldboard plow and a chisel plow. The experiments were conducted on two soil types, at 5 speeds and four depths for the cone penetrometer-type reference implement and 3 depths for the lister reference implement. The soil was tested for bulk density, moisture content, cone index and grouser. Four replications were completed. Measurements for a given run were averaged into a mean value of draft for that test. The resulting data were analyzed using an orthogonal regression technique. Drafts of the implements were determined to depend primarily on operating depth, and speed was only significant in some instances. The conclusion of the work was that the relationship between the drafts of the reference tool and a given implement is logarithmic. The results supported the concept of predicting implement draft with a standard reference tool.

The concept of using the draft of a single tine as a reference to predict the draft for an entire implement composed of similar tines was proposed [6]. They presented a linear relationship between the draft of a single tine and a unit with multiple tines. If tines have a negligible width, the resulting formula to predict the draft of a unit with multiple tines from the draft force of a single tine is the following:

$$D = n \cdot D_t - (n - 1) \cdot D_{ti} \tag{6}$$

Where:
n [-] - number of tines

D [N] - predicted draft of an implement with n tines,
D_t [N] - horizontal force component of the single tine,
D_{ti} [N] - horizontal force component of an imaginary tine.

Where the depth of the imaginary tine is:

$$d_i = d - x \cdot 2^{-1} \tag{7}$$

Where:
d [m] - depth of the single tine,
x [m] - tine spacing.

The soil failure planes are assumed to act at 45º to the horizontal. The D_{ti} term describes the "equivalent draft force" required to disturb the interacting zone above and between the individual tine soil failure boundaries. Prediction of the draft force was successful, but vertical force was not accurately predicted.

Nicholson *et al.* [21] described a reference implement concept and the fabrication of a tillage tool designed with the intention to serve as a reference implement. This reference implement consisted of two chisel shanks, two lister bottoms and two small v-blade sweeps mounted on a wheeled frame. A preliminary graph to correlate the draft from the reference implement to the draft from a chisel plow considering speed and soil firmness was presented. The graph demonstrates that unit draft of an unknown implement is proportional to that of a reference implement. It also demonstrates the concept that draft of the reference implement can be used to predict the draft of another implement even if the two devices were tested at different speeds. This is based on the findings of the study that draft increases with speed, but the rate of increase depends on the firmness of the soil. The graph was not intended to be an exact predictor of draft, it was presented only to demonstrate the concept and relationships.

Yasin [23] explored the concept of a reference implement and described the relationship between a given implement and the reference implement.

$$F_n = D_i \cdot D_{RI}^{-1} \tag{8}$$

Where:
D_i [N] - measured draft from the i^{th} implement,
D_{RI} [N] - draft of the reference implement as predicted by a regression equation,
F_n [-] - set of scale factors.

A set of equations to predict the draft of three implements from the measured draft of a non-standard tillage reference implement (TRI) were produced testing the following general form of equation:

$$D_i = b_0 + b_1 \cdot D_{TRI} + b_2 \cdot D_{TRI}^2 \tag{9}$$

Where:
D_i [N] - draft of the i^{th} implement,
D_{TRI}[N] - measured draft of the tillage reference implement,
b_0 [N] - regression coefficient,
b_1 [-] - regression coefficient,
b_2 [N^{-1}]- regression coefficients.

The models presented were verified with a final replication of the experiment. All treatment values for all three implements were within the 95% prediction interval; however, not all treatment values were inside the 95% confidence intervals. Yasin [23] concluded that: "The use of the TRI provides an appropriate and generalized method for predicting and comparing the implement draft."

MATERIAL AND METHODS

The objective of this study was to investigate the application of an electro-conductivity cart as a reference implement to predict tillage draft.

The purpose of the tillage reference implement concept is to predict the draft of soil-engaging implements from the measured draft force of a different implement used as an analog. Factors influencing draft of the reference implement are incorporated into a regression equation to predict the draft of the implement. This equation can be combined with a prediction equation for a different tillage tool to produce a scale factor. When the scale factor is multiplied by the measured draft of the reference implement, a refinement of the prediction of the unknown draft of the second implement results. Thus, the draft of any implement could be predicted from a measurement of the draft of a reference implement, provided that a scale factor existed between the two implements, and was known.

In order to use historical reference implement concepts to predict draft, the implement must be used to physically till the local conditions. It is undesirable to maintain an implement that serves only this one functional purpose and it is inefficient to expend the energy to use an implement that does not accomplish some agronomical benefit. It is more efficient to use a reference implement which can serve another purpose as it is being run through a given field. For this reason, the Veris soil electro-conductivity (EC) cart (Model 3100, Veris Technologies, a Division of Geoprobe Systems, Salina, KS) was used as a reference implement to predict tillage draft.

Experimental Procedure. The experiment was performed at the University of Nebraska Agricultural Research and Development Center near Mead, Nebraska. The majority of the field was classified as a Yutan Silty Clay Loam. The remainder of the field, primarily the western border and northwest corner, was Tomek Silty Clay Loam. The soil types were nearly identical for the purposes of this study. Five repetitions of each surface condition were completed.

Soil type was defined by the size fractions of soil particles. Soil particles may be sorted into three categories according to their size: clay, silt and sand. The percentage of each of these particles determines textural classification. The soil had 28% clay, 64% silt, and 8% sand. The Atterberg limits were 40% for the liquid limit and 18% for the plastic limit. The maximum bulk density at the plastic limit was 1.52 $mg \cdot m^{-3}$. Soil type was determined from soil survey maps available from the Soil Conservation Service of the United States Department of Agriculture.

The implements used in this study were a field cultivator and the Veris cart. The three-point hitch mounted field cultivator, (Model 1100, Deere & Co., Moline, IL) had a 3.6 m working width with 25 spring shanks equipped with sweep tips (21.6 cm wide and 60º nose angle). The shanks were arranged on 45.7 cm centers on each of three tiers, with eight shanks on the front gang, eight on the middle gang and nine on the rear gang. Depth control for the field cultivator was accomplished by locking the 3-point control lever at consistent positions and turning off the tractor's draft control feature.

The Veris electro-conductivity cart, (Model 3100) consisted of a 76.2 mm square tube toolbar 230 cm wide attached to a forward frame. The total length of the frame was 105 cm. The drawn hitch extended in front of the frame. The cart trailed six flat 42 cm disk blades ("DuraDisc", Ingersoll Products Corp, Chicago, IL) on spring-loaded arms oriented in the direction of travel. Two tires were used to raise and lower the device and served as gauge wheels. Four coulters were attached between the wheels and one coulter was mounted outside of each wheel. All components were mounted symmetrically to the midpoint of the tool bar. The first pair of coulters were 13 cm from the midpoint, the second pair 34 cm from the midpoint, the weights were then inboard of the tires and then the final pair of coulters were positioned 111 cm from the midpoint. The cart was loaded with 6 "suitcase" weights, each with a mass of 47 kg. Depth control and raising and lowering was accomplished by a ratchet mechanism acting on the tire assemblies.

The statistical experimental design used for the procedures was a split plot randomized complete block design (RCBD). The treatments were surface condition, travel speed and implement depth. Surface conditions were undisturbed wheat stubble and a double disked surface that was allowed to settle for a minimum of 9 days. Prescribed travel speeds were 4.8, 6.4 and 9.7 $km \cdot h^{-1}$ for all implements. The depths prescribed for the field cultivator were the following: 5.1, 7.6 and 12.7 cm. The Veris cart was run only at the 7.6 cm depth. Treatments were replicated five times.

The Veris cart was only used at a single depth because, with the wheels fully retracted, the depth of penetration depended on the weight of the cart and the firmness of the soil. At a depth of 7.6 cm, the gauge wheels were constantly in contact with the soil surface, thus depth could be maintained at a consistent level.

Plots were laid out with implement travel perpendicular to small grain drilled rows. Each main plot was 82.3 m by 36.6 m and each experimental unit was 21.3m by 4.1m and were marked with flags to separate the plots. All implement data were collected with a data acquisition system similar to that described by Lackas *et al.* [24]. The system consisted of a laptop computer, a DataPAC System 10 signal conditioning unit (Model 10KU, Daytronic Corp, Miamisburg, OH), a 3-point hitch dynamometer, a fifth wheel speed sensor and a "s-type" tension load cell (Model PST-1000, Precision Transducers, Auckland, New Zealand). The fifth wheel speed sensor consisted of a bicycle tire (28x2.125) mounted on a swiveling frame so that the tire would run in the wheel track of the front tractor tire. The speed sensor had a rotational sensor attached to its axle (Hall-effect transducer, 120 $pulses \cdot revolution^{-1}$, Beckman Instruments Inc., Fullerton, CA). The data collection software was configured to gather data sets consisting of a continuous stream of 300 data points from each channel. The operator manually started the system and data was collected for approximately 24 sec. One data set was collected for each experimental run.

A 3-point hitch mounted cone penetrometer was used to measure soil resistance to penetration. The cone base was 3.2 cm^2 and procedures were according to ASAE Standard S313.2 [25]. The data collection system of the penetrometer consisted of a load cell, depth position indicator, and a Polycorder (Model 516C-64-A, Omnidata

International Inc., Logan, UT). Soil resistance to penetration was measured at three locations in each experimental unit. These locations were 2.5 m from the starting border of the experimental unit and evenly spaced perpendicular to the direction of travel. Soil resistance to penetration was measured to a depth of 23.5 cm. Data from the cone penetrometer was averaged for each of the three soil depth sections: 0-82.5 mm, 82.5-158.8 mm and 158.8-235.0 mm.

Before tillage, each experimental unit was sampled twice to determine the soil's moisture content and bulk density. Soil cores were pulled 3 m from both the east and west borders in the north-south midpoint of each experimental unit. Each of the samples was divided into three depth sections and tested separately: 0-82.5 mm, 82.5 -158.8 mm and 158.8-235.0 mm. The cores were obtained using a JMC-Zero Contamination Tube Sampler [26]. According to ASTM and ASA Standards [27-28] soil dry basis moisture content and bulk density were determined after the samples were weighed and oven dried at 110ºC for 72 hours.

The average values for draft, pull, vertical force, torque, speed, and depth from each experimental unit were calculated and used in the statistical analysis. The average values for each soil depth section (0- 82.5 mm, 82.5-158.8 mm and 158.8-235.0 mm) for cone index, moisture content and bulk density were used in the analyses. The data analyses were completed in two separate procedures, each with a different objective. The first series of data analysis procedures produced predictive equations for the draft force using standard regression routines. Regressions were run to produce predictive equations for each surface condition separately, and both surface conditions combined. Of the five repetitions completed, data from 3 replications were used in the data analysis steps to formulate predictive equations. The formulas resulting from the three repetitions were then verified against the actual data from the other remaining two replications by a t-test comparison.

The second series of data analysis procedures was completed in order to explore the reference implement concept. In this procedure, routines to predict the draft of the field cultivator were developed from combining the actual draft of the Veris cart with the regression equations found in the first data analysis routines. The regression equations resulting from the three repetitions were then verified against the actual data from the other two replications by a t-test comparison. The equations formulated to predict draft were then incorporated into a routine to predict the draft of the field cultivator from the measured draft of the Veris cart. Prediction equations of the following format were produced:

$$D_{FC} = D_{pFC} \cdot D_{pRI}^{-1} \cdot D_{aRI} \tag{10}$$

Where:

D_{FC} [N] - predicted draft of the field cultivator from the reference implement,

D_{pFC} [N] - predicted draft of the field cultivator from the draft prediction regression equations,

D_{pRI} [N] - predicted draft of the reference implement from the draft prediction regression equations,

D_{aRI} [N] - measured draft of the reference implement.

RESULTS AND DISCUSSION

The data from 3 replications was used to develop regression coefficients for evaluating various combinations of treatment influences and interaction terms and selecting the best fit equations. The draft of the field cultivator was found to be a function of the depth of operation. The draft of the Veris cart was a function of speed and the cone indices. Draft prediction equations were of the same form for both surface conditions, but the values of the regression coefficients were different. It is interesting to note that both of the prediction equations were independent of soil bulk density and moisture content.

Regression equations to predict Field Cultivator draft forces:

$$D_{FC} = C_0 + C_1 \cdot d + C_2 \cdot d^2 \qquad (11)$$

Where the Veris cart draft forces:

$$D_{Veris} = C_0 + C_3 \cdot s + C_4 \cdot CI_1 + C_5 \cdot CI_2 \qquad (12)$$

Where:

D [N] - draft force,
d [cm] - tillage depth,
s [km·h^{-1}] - travel speed,
CI_i [N·cm^{-2}] - cone indices at different depths,
C_0 [N] - regression coefficient,
C_1 [N·cm^{-1}] - regression coefficient,
C_2 [N·cm^{-2}] - regression coefficient,
C_3 [N·h·km^{-1}] - regression coefficient,
C_4 [N·kPa^{-1}] - regression coefficient,
C_5 [N·kPa^{-1}] - regression coefficient.

Table 1. Regression coefficients for draft force equations for field cultivator and Veris cart on two soil surfaces

Implement		R^2	C_0	C_1	C_2	C_3	C_4	C_5
			Intercept	d	d^2	s	CI_1*	CI_2**
FC	wss	0.8131	-23092.60	7283.673	-325.016			
FC	dds	0.9086	-5579.33	2846.932	-77.437			
FC		0.8340	-14336.00	5065.300	-201.230			
both	Veris	0.1922	4089.57			-51.204	1.713	-8.182
Wss	Veris	0.4963	3586.26			16.695	-0.289	-7.194
dds	Veris	0.3630	3798.50			-13.897	0.232	-10.486

* 0 - 82.5 mm
** 82.5 mm - 158.8 mm

Draft forces from the regression routines were predicted with fair accuracy. The R^2 values given in Tab. 1 are for the predictive eqs. (11-12). This calculation is from the regression output and described what percentage of variation is explained by the regression equation. The Pearson Correlations and p-values shown in Tab. 2 are from the two-sample matched pairs t-tests that were performed to compare the measured draft forces from the 2 remaining verification replications to the predicted draft forces from the regression eqs. (11-12).

Table 2. Pearson correlations and p-values for measured (verification data sets) and predicted draft from eqs. (11-12)

Implement		*Draft*	
		wss	*dds*
FC	*Pearson C*	*0.9702*	*0.9797*
FC	*p-value*	*0.0164*	*0.5798*
Veris	*Pearson C*	*0.0707*	*0.2164*
Veris	*p-value*	*0.0607*	*0.4546*

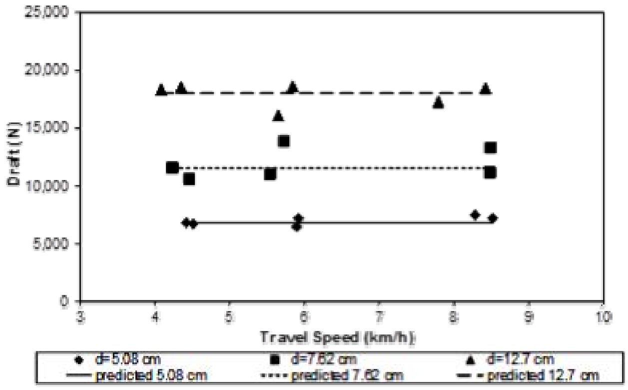

Figure 1. Measured (verification data set) field cultivator draft force scatter on the wheat stubble surface, predicted with eq. (11)

Tab. 2 gives the Pearson correlations and p-values resulting from a series of matched pair two sample t-tests with two-tail distribution. For the field cultivator, the prediction eq. (11) for draft returned R^2 values of 0.813 and 0.908 for the wheat stubble surface (wss) and disked surface (dds), respectively. Pearson correlations were 0.970 and 0.980, respectively. Fig. 1 and 2 graphically represent closeness of the verification observations to the predicted values for the field cultivator. A comparison of measured draft and predicted draft is shown in Fig. 5. The prediction eq. (12) for draft of the Veris cart was not as accurate with R^2 values of 0.192 for the wheat stubble surface and 0.496 for the disked surface. Pearson correlations also reflected this lack of accuracy with the verification data sets with values of 0.071 and 0.216, respectively. Similarly, Figs. 3-4 show the measured to predicted values. Fig. 6 does not show a good fit to the 1:1 line.

The reference implement concept worked quite well even though the action of the two implements on the soil was different. Tab. 3 contains a summary of the results of the t-test for the means of paired two sample sets. The measured draft of the field cultivator from the 3-point dynamometer was compared to draft predicted by the reference implement concept model. Pearson Correlations are given as well as p-values for a two-tail distribution. Separate indicates that one set of coefficients was used to predict the draft of the field cultivator for the wheat stubble surface condition and a different set of coefficients was used to predict the draft of the field cultivator for the disked surface condition.

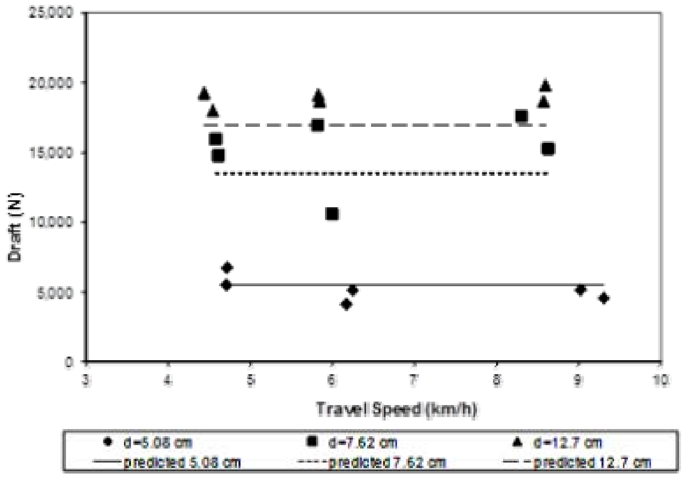

Figure 2. Measured (verification data sets) field cultivator draft force scatter on the double disked surface, predicted with eq. (11)

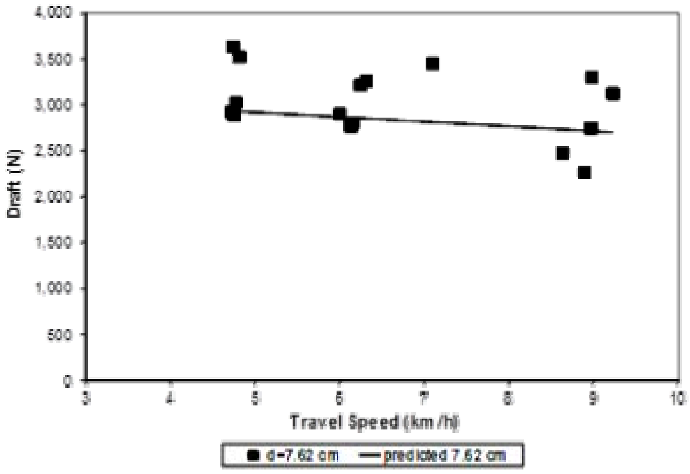

Figure 3. Measured (verification data set) Veris draft force scatter on the wheat stubble surface, predicted with eq. (12) using $CI_1 = 91.5\ N{\cdot}cm^{-2}$ and $CI_2 = 130.7\ N{\cdot}cm^{-2}$

Table 3. Pearson correlations and p-values for the reference implement concept predictions compared with the 2 verification data sets

Equation	*Surface Conditions*					
	wss and dds		*wss*		*dds*	
	Pearson C	*p-value*	*Pearson C*	*p-value*	*Pearson C*	*p-value*
Separate	*0.9236*	*0.8049*	*0.9115*	*0.5934*	*0.9486*	*0.6823*
Both	*0.9087*	*0.9908*	*0.8950*	*0.9967*	*0.9361*	*0.9781*

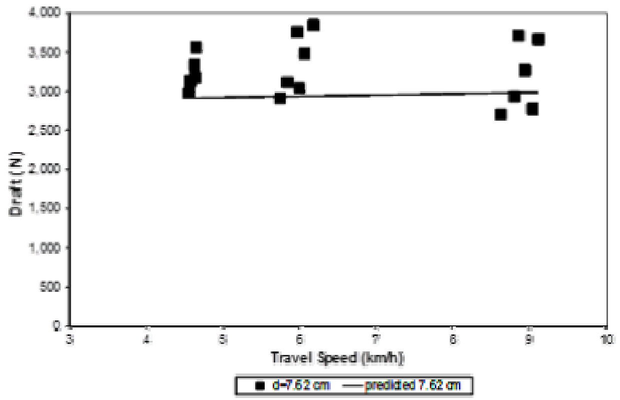

Figure 4. Measured (verification data set) Veris draft force scatter on the double disked surface, predicted with eq. (12) using $CI_1 = 44.0\ N{\cdot}cm^{-2}$ and $CI_2 = 71.2\ N{\cdot}cm^{-2}$

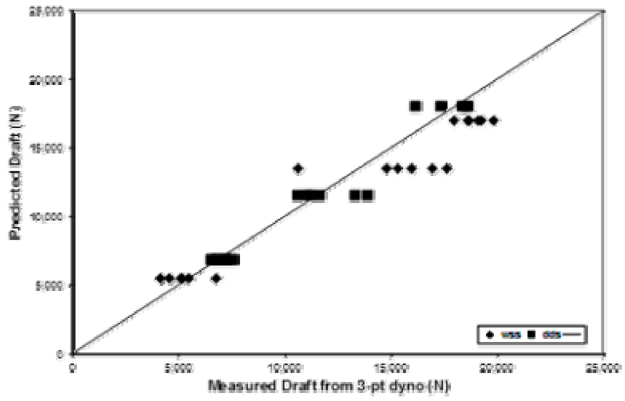

Figure 5. Measured (verification data set) and predicted draft forces for the field cultivator

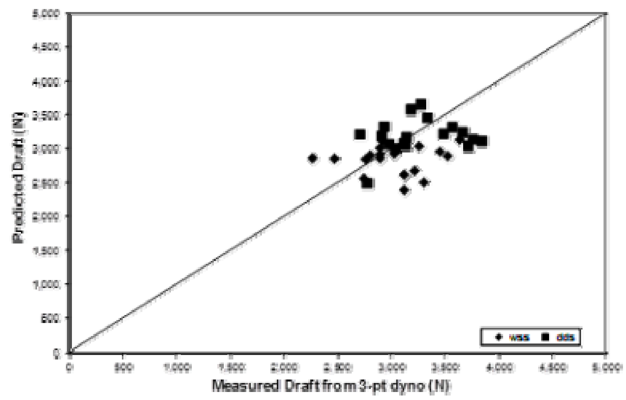

Figure 6. Measured (verification data set) and predicted draft forces for the Veris cart

Both indicates that the coefficients used to predict the draft of the field cultivator included data from both surface conditions, and thus, only one set of coefficients was used for both surface conditions. The table header indicates which data were used for the t-test comparison. “wss and dds” indicates that all the data from the verification repetitions was included in the t-test. “wss” indicates that only the data from wheat stubble surface condition was tested while “dds” indicates that only the data from disked surface condition was tested. For all combinations the statistical null hypothesis, which is that the means are the same, could not be rejected. Thus, the reference implement concept predicted the draft of the field cultivator with sufficient accuracy to be considered successful. Interestingly, the routines that did not consider surface condition returned higher p-values, indicating that there was no value to maintaining coefficients to predict separately for each surface condition.

Fig. 7 and 8 graphically compare the actual and predicted values for the draft forces of the field cultivator. The diagonal lines provided are 1:1 measured versus predicted lines. Points located closer to the line indicate better prediction accuracy.

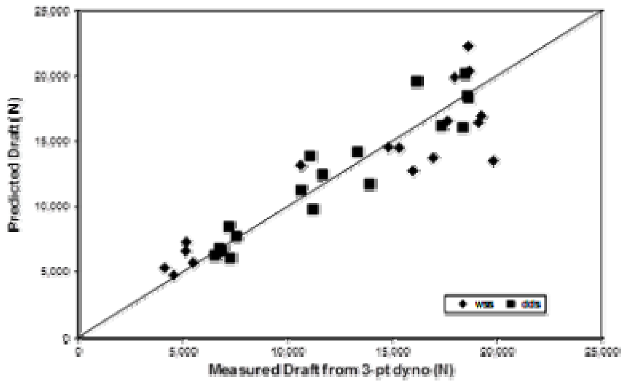

Figure 7. Measured and predicted values for draft forces of the field cultivator from the reference implement concept (eq. (10)), separate coefficients for each surface conditions

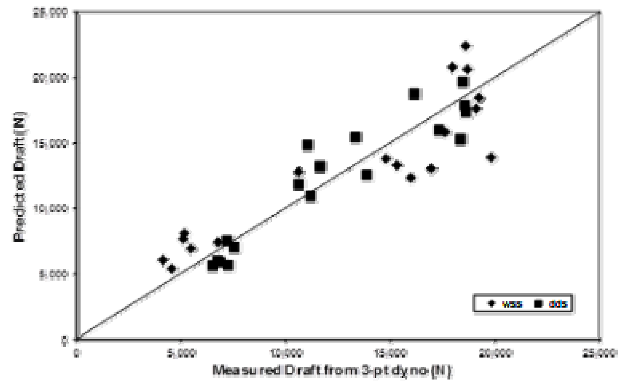

Figure 8. Measured and predicted values for draft forces of the field cultivator from the reference implement concept (eq. (10)), same coefficients for both surface conditions

The Veris cart was equipped with a pull-meter attached to the tongue of the cart. The relationship between the forces measured by this pull meter and the 3-point dynamometer were compared. The measured draft force means were not significantly different between the measured drafts of the pull meter and the 3-point dynamometer. The Veris cart does not require the use of the three point dynamometer. It is light and can be transported at highway speeds behind a pick-up truck. Data for electro-conductivity and draft could be collected simultaneously and correlated with geo-referenced data. A wealth of information for further study would be gained by collecting draft data from fields for which electro-conductivity data are collected.

This paper presents the concept of creating a ratio of predictive equations that is multiplied by the measured draft of a reference implement. This ratio is most accurate when the reference implement and desired tillage implement are tested in similar soil conditions. This test will establish the regression coefficients for the predictive equations. The measured draft of the reference implement provides a correction factor to the ratio of predictions that accounts for some unmeasured and/or uncontrollable variables such as soil conditions. The ASAE Standards [10] draft equations could be used if similar reference implement equations are developed and have adjustments for the soil factor.

CONCLUSIONS

The measured draft of an electro-conductivity cart was successfully used to predict the draft requirement of a field cultivator. The Pearson correlations for measured draft compared to predicted draft using the Veris cart as the analog device ranged from 0.89 to 0.95. Other conclusions include the following:

1. Surface condition did not significantly affect the accuracy of the draft prediction.
2. Using the Veris cart as a reference implement has a number of advantages over other implements.
3. Bulk density and moisture content of the soil did not appear to affect the accuracy of the draft and reference implement predictions.

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UPOTREBA VERIS VOZILA ZA MERENJE ELEKTROPROVODLJIVOSTI ZA PREDVIĐANJE OTPORA VUČI

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Sažetak: U radu je analizirana upotreba vozila za merenje elektroprovodljivosti kao referentnog priključka za predviđanje otpora vuči pri obradi zemljišta. Regresiona analiza je primenjena za razvoj jednačina za proračun otpora vuči dva priključka (nošeni setvospremač i vozilo za merenje elektroprovodljivosti) u radnim uslovima merenja pri više različitih radnih brzina i dubina obrade, kao i dva stranja obradive površine. Rezultati merenja su zatim upotrebljeni za analizu koncepta referentnog priključka. Iz izmerenih vrednosti otpora vuči vozila za merenje elektroprovodljivosti su razvijeni postupci za predviđanje otpora vuči setvospremača. Pearson korelacije izmerenih otpora sa otporima predviđenim na osnovu podataka Veris vozila kao analognog uređaja varirale su u opsegu od 0.89 do 0.95.

Ključne reči*: upravljanje mašinama, predviđanje otpora vuči, modeliranje otpora vuči, referentni priključak*

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