AN ANALYSIS OF DRAFT, DEPTH AND SPEED OF TILLAGE EQUIPMENT

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INTRODUCTION

One of the basic considerations in selecting farm tillage machinery is its size. The width of cut and ground speed is usually sufficient information to suitably match the size of the implement to the farming enterprise. Equally important in this selection, however, is the consideration of the power requirements of the equipment in order to match the farmer's power unit. Because the power requirements of tillage eqipment are large, the match is usually critical. The most difficult use of the power unit will be obtained only when the implement is matched correctly to the tractor's available power.

The power requirements of tillage equipment are primarily dependent on the forward speed and the depth of cultivation. The other factors which affect the power requirements are soil density, soil texture, soil moisture content, surface trash conditions, amount and type of weed growth, as well as the tension, compression, and shear strength properties of the soil. The only factors which may be controlled by the operator are depth of tillage and forward speed for any given soil type and these have the greatest effect on power requirements.

To be of assistance in choosing the correct size of implement for a given tractor, the power requirements of the tillage machines tested by A.M.A. are determined in various conditions and different soil types. The relationship of draft versus depth and of draft versus speed is determined and the power requirements are based on these two relationships for a given soil type and texture.

INSTRUMENTATION

Obtaining values of draft, depth and speed is complicated by the inability of any tillage equipment and tractor to maintain a constant depth and speed under field conditions. For example, the depth of tillage without any adjustment of the hydraulic ram will at times exceed plus or minus one inch in a relatively few feet of travel. A single measurement of the depth of the sweep below the ground surface with the machine stationary therefore is accurate only for that point and cannot be used as an estimate of the average depth. A somewhat similar problem exists with changes in ground speeds of the tractor as the draft varies. As a consequence it is necessary to obtain simultaneous values of the draft, depth and speed. This is accomplished most easily with appropriate transducers and a high frequency response recorder.

The draft transducer employed by A.M.A. to measure draft is the "O" type using resistive type strain gauges (4) (see figure 1) mounted on a multi-plane draft fixture. (3)

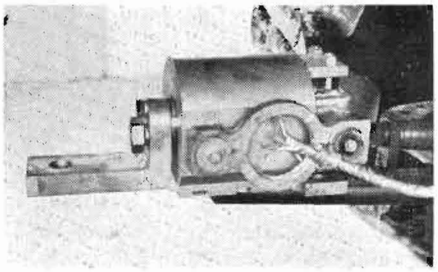

Figure 1. Multi-plane draft fixture with O-ring strain gauge transducer.

The speed transducer used by A.M.A. to measure forward speed consists of a dc. tachometer generator driven by a rubber tired wheel in contact with the soil surface which provides a dc. voltage in proportion to the ground speed.

The depth transducer (figure 2) is a more recent development and consists of a spoke wheel which senses the tillage furrow bottom and two pneumatic rubber tires which sense the soil surface. The rubber tires are free to float at the soil surface whereas the spoked wheel due to small surface contact area and greater weight penetrates the loose soil to the bottom of the furrow.

Figure 2. Spoke and surface sensing wheels of the depth transducer.

The vertical distance between the spoke wheel and the surface wheels is the depth of tillage and is sensed by a strain gauge transducer (figure 3). The transducer is a cantilever beam type with the gauges mounted on either side of the beam. Bending of the beam is caused by displacement of the spoke wheel in relation to the soil surface sensing wheels. The signal received from the transducer is recorded on an oscillograph in the mobile laboratory along with signals from the draft and speed transducers.

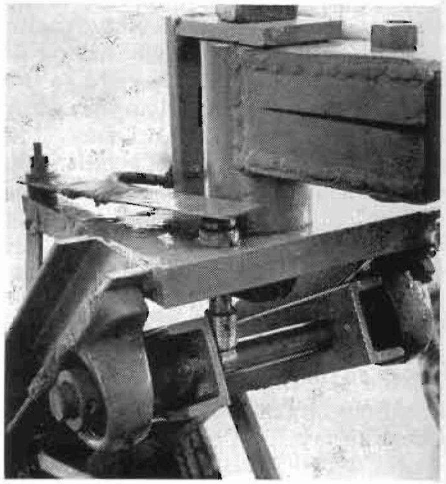

Figure 3. Depth sensing cantilever beam strain gauge transducer.

In order to prevent the wheels from either operating on a ridge or in a furrow, the spoke and rubber tired wheels must move laterally behind the implement as well, of course, as in the direction of travel. To achieve this a mechanical oscillator moves the caster pivot and therefore the spoke and surface wheels back and forth across a 20-inch width behind the implement as the implement moves forward. The wheel driving the speed transducer is used to drive the oscillating device. (See figure 4.) The depth transducer not only provides the required number of values of depth but aids immeasurably in minimizing the depth variations while determining the relationship of draft versus speed.

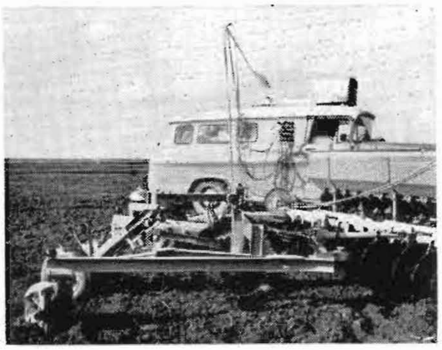
Figure 4. Depth and speed transducer (DST).

CALIBRATION OF DEPTH TRANSDUCER

Data was obtained to determine the relationship of the actual depth of tillage to that indicated by the depth sensing transducer. To correctly indicate the depth of tillage the spoke wheel must sense the bottom of tillage and the surface wheels must compact the loose soil to the same height as the original undisturbed surface.

All methods of measuring the actual depth of tillage of a cultivator and one-way disk harrow over a distance are difficult as the tillage operation destroys and displaces the original soil surface. Measurements to the outside edge of the implement are extremely difficult to obtain accurately due to the usual undulations of the soil surface.

A calibration of the depth transducer was made by removing the depth sensing unit from its carriage and attaching it directly to a cultivator frame. The spoke wheel was removed and its frame fastened to the cultivator so that the sweeps of the cultivator sensed the bottom of the furrow instead of the spoke wheel. The surface wheels were free to follow the surface of the untilled ground. The depth of tillage was then recorded while cultivating over a measured distance and the average depth determined. This was repeated at different depths of tillage. The depth transducer was then removed from the cultivator and returned to its own carriage and used in the normal manner over the exact same area and the depth again recorded and the average determined. The results are shown in the bar graph in figure 5.

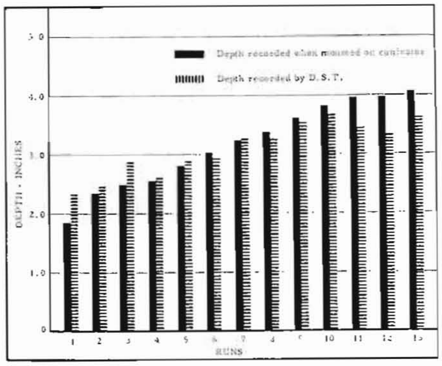

Figure 5. The calibration of the depth transducer indicating no large error at the normal working depths.

At depths over 3½ inches the depth transducer indicated slightly shallower than the actual depth, which is due to the spoke wheel not quite penetrating to the bottom of tillage. At depths under 2½ inches slightly greater depths than the actual were indicated. This may indicate that the spokewheel penetrated too deeply or that the surface wheel did not compact the tilled soil sufficiently. To correctly sense the depth under various conditions and for different depths, spoke wheels with spokes of different sizes and weights are required so that penetration of the spoke to the bottom of tillage would be achieved. The weight applied to the surface sensing wheels as well as their surface contact area could be adjusted to ensure correct compaction of the loose soil.

The error, however, will not be as large as indicated because the depth determined with the unit mounted on the cultivator is subject to errors not common to the depth transducer. A slight ridge of soil beneath one of the surface sensing wheels would cause the depth recorded to be a higher value than the actual depth of tillage. The depth unit as it is trailed behind an implement oscillates and therefore tends to minimize the effects of such ridges. In addition, the sweeps on a cultivator are also known to deflect back increasing the actual tillage depth without an increase in the value recorded. This would not occur when the unit is trailed behind the implement over the tilled ground.

MEASUREMENTS

Typical recordings of the draft, depth and speed transducers are illustrated in figure 6 and show a corresponding change in draft for a change in depth. As an instantaneous value has little effect on the tractor power due to inertia of tractor and implement, the depth, draft and speed are integrated for ten-second periods. As the trace of depth varies most widely, due to irregular surface conditions and furrow bottoms, the signal is integrated electronically (3) at the time of recording. The period of integration is marked on the chart and the simultaneous integrated values of draft and speed are determined after recording is completed.

CURVE OF "BEST" FIT

Individual values of draft, speed and depth do not provide information for predicting accurately the power requirements for a given depth of tillage and forward speed. This is because of the variation in samples normally encountered in sampling. The variations also make it impossible to make a comparison of power requirements of two different implements under identical conditions. It is necessary therefore to determine the relationships of draft, depth and speed and qualify these relationships by a test for significance.

The normal method of relating the data obtained would be to determine a multiple regression including not only draft, depth and speed but soil texture and machine type. This may be either linear or curvilinear depending on the characteristics of the data obtained.

The multiple linear regression may be represented by the general equation $Y^1 = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \dots\dots + b_PX_P$.

(Goulden) (2). Where Y^1 represents draft; X_1, depth; X_2, speed; X_3, soil texture; and X_4 machine type. Other factors not investigated but which could be included as independent variables affecting draft, and entered into this general equation include soil type, soil density, soil moisture content, machine characteristics such as sweep angle and lift, and organic material contained in the soil. If the data indicates that the regression is non-linear the general equation could be written in simplest form as $X_1 = a' + f_2(X_2) + f_3(X_3) + f_4(X_4) + \dots\dots f_P(X_P)$ (Ezekial) (1) where X_1 is the dependent variable.

The calculations necessary in handling multiple regressions are quite extensive and more involved than handling an equation with a single independent variable. The calculations become more involved when non-quantitive independent variables such as machine type are included and succesive approximations are required to obtain the best fit. (Ezekial) (1) The inclusion of two or more independent variables quickly points up the necessity of a high speed digital computer to handle the calculations.

The instrumentation described above made it simple to hold constant either of the two major independent variables, speed and depth, and thus determine the draft while varying the other independent variable. This procedure was then utilized to provide data for two simple linear regressions, each incorporating a different independent variable.

$Y^1 = a + bX_1$ 1

where Y^1 = draft and X_1 = depth

and $Y^1 = a^1 + b^1X_2$ 2

where Y^1 = draft and X_2 = speed.

The best possible location of the regression line for the points is obtained by the "method of least squares". (Ezekial and Snedecor) (1 & 5)

The equation to determine the regression coefficients a and b as outlined by Ezekial and Snedecor (1 & 5) are as follows:

$$b = \frac{\Sigma(XY) - n\bar{X}\bar{Y}}{\Sigma(X^2) - n(\bar{X})^2} \text{ or } b = \frac{\Sigma(xy)}{\Sigma(x^2)} \ldots \quad 3$$

where ΣX = sum of all X values

ΣY = sum of all Y values

$\bar{X}$ = mean of X values

$\bar{Y}$ = mean of Y values

x = deviation from mean

y = deviation from mean

and $a = \bar{Y} - b\bar{X}$ 4

Since there is dispersion of the points plotted (figure 7) a possible error exists of the position of the straight line. The standard error of estimate may be calculated for selected values of depth or speed using the equation by Ezekial (1):

$$\sigma Y^1 = \sqrt{\sigma \bar{y}^{1\,2} + (\sigma b_{YX}\, x)^2} \ldots 5$$

where $\sigma\bar{y}^1$ = standard error of mean of estimated regression

σb_{YX} = standard error of regression coefficient or slope

x = deviation from the mean value.

The true regression line will fall between the range (93 times out of 100) if twice the standard error ($2\sigma Y^1$) is plotted above and below the calculated regression line. figure 7.

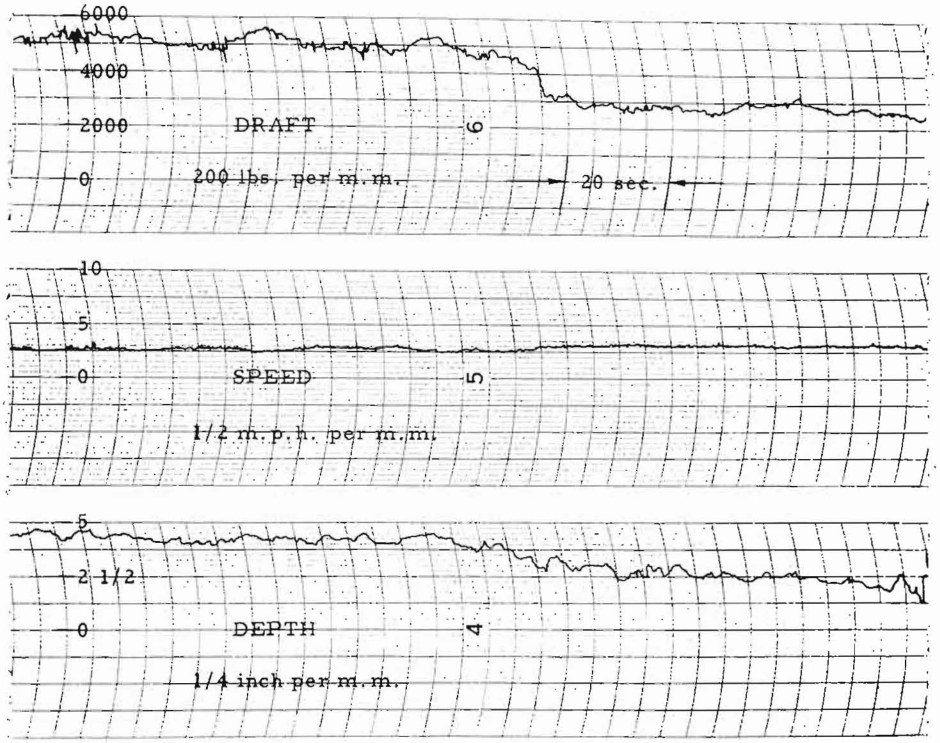

Figure 6. A typical oscillograph of draft, depth and speed illustrating a change in draft for a change in depth.

When comparing the linear regressions of two different machines the limits or errors of the regression line must be considered before it can be concluded that differences shown are significant. The overlapping of the range limits indicate that differences shown are not too reliable and could be due to chance. If the range limits, however, do not overlap, a very good chance exists (93 times out of 100) that differences shown are real and not due to chance.

A similar regression to that shown in the figure is also plotted along with the range of standard error for draft versus speed. The two linear regressions of draft versus depth at a constant speed and for draft versus speed at a constant depth can then be combined to calculate the horsepower for a given depth and speed using the equation:

$$\text{Horsepower} = \frac{\text{Draft x speed (mph)}}{375}$$

$$= \frac{Y^1 \text{ x } X_2}{375} \ldots\ldots\ldots\ldots\ 6$$

Then by substituting in the equation 6 $(a+bX_1)$ from Equation 1 for the Y^1 in the above equation the

$$\text{HP} = \frac{[a+b\ (\text{depth in.})]\ [\text{speed mph}]}{375}$$

$$\text{or} = \frac{[a+b\,(X_1)]\ [X_2]}{375} \ldots\ldots\ldots\ldots\ 7$$

Since equation (1) contains only depth and not speed it is valid only at the speed (K) at which it was derived. (In most tests, this speed K, is chosen at or near 4 mph.) Therefore, at a higher or lower speed it must be corrected to allow for the change in draft due to a change in speed. The correction factor is obtained from equation (2). The regression coefficient b^1 is the increase in draft for each mile per hour increase in speed, and this amount must be added or subtracted from equation (1) for each one mile per hour change in speed from speed K. The equation for horsepower becomes:

$$\text{Horspower} = \frac{[a+b\ (\text{depth in.})}{375}$$

$$+ \frac{B\ (\text{speed mph}-K)]\ [\text{speed mph}]}{375}$$

$$= \frac{[a+b\ (X_1)\ +b^1\ (X_2-K)]\ [X_2]}{375}$$

$$= \frac{aX_2 + bX_1X_2 + b^1X_2^2 - b^1KX_2}{375}$$

This method of computing horsepower from the two linear regressions obtained is correct only if the regressions obtained actually are the best fit for the values obtained and that no interaction occurs between the two independent variables. That the best fit may not be linear for the entire range of depth (0 to 5 inches) and for speed (0 to 6 mph) is evidenced by the low value of the constant "a" which at 0 inches of depth would be much less than the rolling resistance of the machine. However, linearity is approached by that portion of the regression for the values of speed and depth in the range normally used in tillage operations, namely 2.5 to 4.0 inches deep and 3.0 to 5.0 mph. The extension of this regression would not be reliable beyond the range of the values which were employed to determine the regression.

This horsepower equation can then be utilized to construct a nomograph (Figure 8) which will quickly give the horsepower required by the implement at any selected values of tillage depth and forward speed.

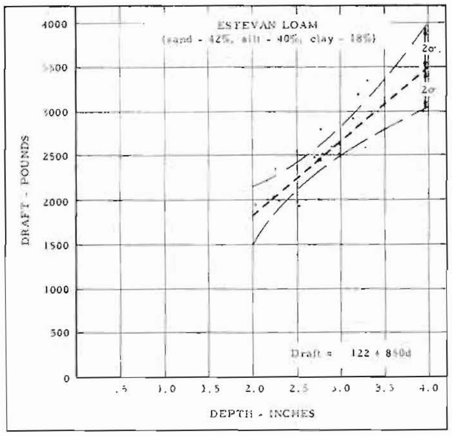

Figure 7. The best fit linear regression with the range of voice the standard error.

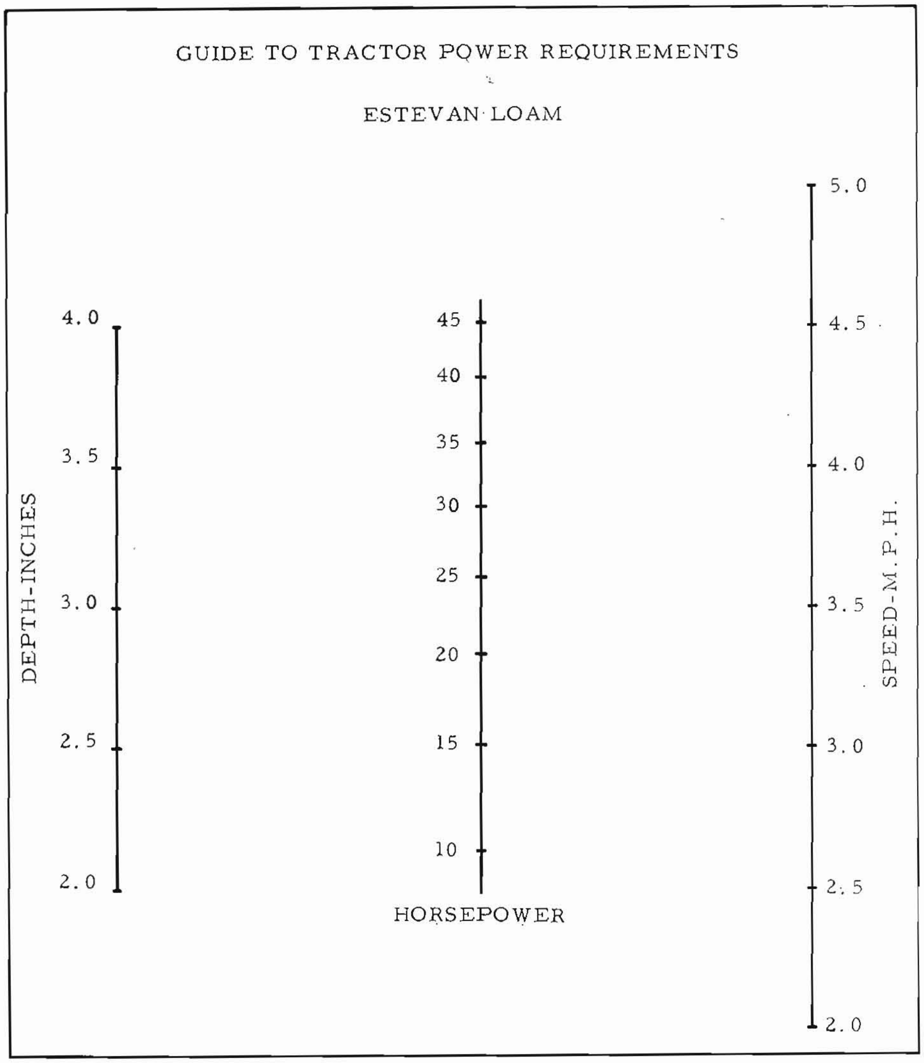

Figure 8. A nomograph indicating the horsepower for various depths of tillage and speed.

With the amount of required horsepower known for a given set of conditions it can be determined whether or not a given tractor at the selected ground speed and depth will have sufficient power to satisfactorily tow the implement. Since the required horsepower given in the nomograph is the power for level field conditions, the tractor horsepower must be greater by a quantity equal to the weight of the tractor and implement times the ground slope in percent. If the tractor power is taken from the Nebraska test data, some allowance is required to take care of added rolling resistance of the soil as Nebraska tests are carried out on a concrete surface.

CONCLUSIONS

The determination of the relationship of draft versus depth at constant speed and draft versus speed at constant depth provides a reliable method to compare the draft requirements of two or more similar implements.

The power required may be determined with a good degree of precision using an equation containing the appropriate regression co-efficients.

The simultaneous values of draft, depth and speed as obtained from appropriate transducers are required in order to obtain the linear regressions.

The depth and speed transducers are also a necessity for the controlling of the depth and speed.

The depth transducer, though subject to some error, is in practice much more accurate than any hand sampling technique because it is capable of an infinitely greater number of samples.

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