# Modelling draft requirement of secondary tillage tools in vertisol

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**ABSTRACT:** A study was undertaken to develop a draft prediction model for sweep and reversible type tyne in vertisol. Draft requirements of these tillage tools were measured in soil bin at four levels of depth and four levels of speed of operation in three different soil compaction levels at average soil moisture content of 14-16% (db). Experimental design was based on the factorial RBD. An appropriate ANOVA model was selected for analysis of variance using the SAS statistical software package. All the variables under study significantly affected draft ($P < 0.001$). The draft of tillage tools increased with cone index, depth and speed of operation. The effect of depth was found to be more significant on the draft. Rate of increase of draft with respect to depth was higher as compared to that with respect to speed of operation and cone index for all the tools tested. Draft values predicted by ASABE model were compared with those obtained from soil bin tests at three compaction levels separately. A simple equation similar to the ASABE model incorporating cone index was developed using stepwise regression analyses to model the draft of tillage implements for the range of soil and operating condition tested. The high value of $R^2$ of the model (0.93 and 0.96) for the draft data obtained from soil bin tests indicated that the experimental data fit the regression very well.

**Key words**: ASABE model, draft prediction equation, soil bin, soil cone index, stepwise regression analysis

Farmers mostly depend on past experience for selecting tractors and implements for various farming operations. This previous experience may be of little effect in selecting newly available implements. Also, this approach may enable the producer to accomplish this goal; the system selected may be less than optimal. Therefore, to improve operating efficiency, both units must be selected such that almost all the power generated by the tractor is fully utilized under most operating conditions. The process of matching tractor and implement may start with the implement or with the tractor. For proper sizing, one must predict the draft and power requirement of the implement considering factors such as depth and speed of operation, implement width, and soil condition.

Attempts have been made by various researchers around the globe to measure the draft requirements of various tillage implements and to establish relationship between the draft and the factors affecting the draft (Clyde, 1936; Reed, 1937; Gill and Vanden Berg, 1968; Kydd *et al*., 1984; Grisso *et al*., 1996; Al-Janobi and Al-Suhaibani, 1998). The forward speed, depth of cut, width of cut, soil strength, moisture content, tool geometry and many other factors have been reported to affect the draft requirement of tillage implements. Many mathematical models have been developed for the draft prediction of tillage implements and their capability in predicting draft of implements was well documented (Collins *et al.,* 1978; Kepner *et al.,* 1978; Kydd *et al*., 1984; Upadhyaya *et al*., 1984; Harrigan and Rotz, 1995; Grisso *et al*., 1996 and ASABE, 2004).

ASABE Standards provides mathematical expressions for draft and power requirements for tillage implements in several soil types and is given as:

$$D = F_i\ (A + BS + CS^2)WT \qquad (1)$$

where, D is implement draft (N); F is dimensionless soil texture adjustment parameter; i is 1 for fine, 2 for medium, 3 for coarse textural soil; A, B, C are machine specific parameters; S is speed of operation (km/h); W is machine width (m) or number of rows or tools; T is tillage depth (cm). The coefficients are for a wide range of soil conditions and consequently cannot be expected to yield accurate estimates for a given situation. ASABE standard indicates an expected range from ±25% to ±50% for various tillage implements. Also, all draft data and equation for predicting draft presented in the standard were based mostly on USA soils and its applicability in Indian soil conditions has not been reported in any literature. Presently, there is a shortage of data on draft requirements of agricultural implements in different soils of India. Therefore, the draft measurement as well as prediction is imperative for Indian soil conditions to generate draft data of various tillage implements. With this back ground, study was undertaken at Central Institute of Agricultural Engineering, Bhopal, India with the objectives of measuring draft requirement of selected tillage tools (cultivator sweep and reversible shovel) in vertisol at varying operating and soil conditions and development of a model for draft prediction of tillage tools taking into consideration the parameters affecting draft.

## MATERIALS AND METHODS

***Laboratory tests***

The main objective of the laboratory tests was to develop relationship between the draft of tillage implement and various parameters (implement, soil and operating) affecting it. To achieve this objective, draft requirement for cultivator sweep and reversible shovel were measured at different speeds, depths and soil cone index under controlled conditions in an indoor soil bin filled with vertisol (32% sand, 22% silt, 43.6% clay). Experimental design was based on the factorial RBD. A 4 × 4 ×3 factorial experiment (four forward speeds, four depths and three cone index) was designed to determine the effect of speed, depth and cone index of operation on draft requirements of tillage tools. The experimental plan for laboratory tests is given in Table 1.

**Test procedure**

***Soil bed preparation***

The soil bin consists of a stationary bin, linear transmission system, implement and soil processing trolley, control unit and instrumentation for measurement of required variables (Figure 1).

The bin was 16.0 m long, 2.5 m wide and 1.0 m deep. The soil parameters such as moisture content and cone index were considered to quantify the soil conditions. Each of the laboratory tests were carried out at an average soil moisture content of 14-16% (db). Before each test, the soil bed was watered uniformly and allowed to dry till the desired moisture level was achieved. From watering to the attainment of desired moisture level, the moisture content was observed regularly. Immediately after the soil attained the desired moisture level, the bed was prepared using the soil processing trolley. First the rotary tiller of the soil processing trolley was operated to pulverize the soil. Then the soil was leveled with the leveling blade and compacted by the roller. After first rolling, cone index of the bed was checked using a hydraulically operated instrumented cone penetrometer (Figure 2) at random locations throughout the bed following the procedures outlined in the ASABE Standards (ASAE EP542, 2003).

ASABE Standards provides mathematical expressions for draft and power requirements for tillage implements in several soil types and is given as:

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where, D is implement draft (N); F is dimensionless soil texture adjustment parameter; i is 1 for fine, 2 for medium, 3 for coarse textural soil; A, B, C are machine specific parameters; S is speed of operation (km/h); W is machine width (m) or number of rows or tools; T is tillage depth (cm). The coefficients are for a wide range of soil conditions and consequently cannot be expected to yield accurate estimates for a given situation. It also does not consider the cone index value directly.

Rolling and checking of the cone index were repeated till the desired cone index was achieved. The locations for checking the cone index were chosen so as not to interfere with actual tillage tests. Moisture content of soil sample taken from six locations was measured to ensure the uniformity of soil bed. When the cone indices were found significantly different from each other (more than ±50 kPa), the soil bed was disturbed and prepared again to get the desired soil condition. Measurement of linear speed of tool was carried out by optical linear distance sensor in the soil bin. The draft requirements of various tillage tools and implements were measured using a set up having six 'S' type load cells (Figure 3) and were acquired through HBM QuantumX data acquisition system.

***Measurement of desired parameter***

Before each test, required tool was attached to the tool bar as shown in Figure 3. Cone index and moisture content were measured and recorded. After fixing the implement, the sensor output wires were connected to the data acquisition system and required depth of operation of the implement was fixed. Desired speed of operation was also fixed by the variable drive system. Then transducer output was tared to zero and the implement was pulled in the soil bin. With the help of the transducer and linear distance sensor, the data on the draft and speed of operation were continuously acquired by the data acquisition system. Each test was carried out for the whole length of test bed but the middle 6 to 7 m length data was considered for post analysis. Each test was replicated twice to ensure a reasonably consistent value of draft. At the end of each test, the soil bed was disturbed and was prepared again following the same procedure to conduct other tests.

Analysis of the data obtained was carried out using SAS 9.3 software package (SAS Institute Inc., USA) to understand the effect of speed (S), depth (T) and cone index (CI) on draft of tillage implements as well as development of draft prediction model.

**RESULTS AND DISCUSSION**

**Draft of sweep and shovel tyne**

The ANOVA for the draft data obtained for sweep and shovel tyne with different test variables is presented in Table 2. It can be seen from this table that for sweep tyne all the independent variables and interaction between CI and depth have significant effect on draft, where as for shovel tyne all the independent variables along with interactions between CI and depth and between speed and depth had significant effect on draft. Other interactions have no significant effect on draft. The individual effect of tillage depth was the most significant factor followed by cone index and speed on that order. All the independent variables are significant at 1% level. The individual effects of these parameters are discussed separately in the following sections:

Within the test range of speed, depth and cone index, the lowest and highest draft values were found to be 65.1 N (at 5cm depth, 0.9 km/h speed and 200 kPa cone index) and 1764.2 N (at 20 cm depth, 1.8 km/h speed and 600 kPa cone index), respectively for sweep tyne whereas for shovel tyne the lowest draft value was found to 86.3 N when operated at 5 cm depth, 0.9 km/h speed and at 200 kPa cone index and the highest value was observed to be 3025.6 N when operated at 20 cm depth, 1.9 km/h speed and at 600 kPa cone index.

The equality of variance in draft values of sweep and shovel tyne was tested using folded F and found not equal ($P<0.0001$). Results are presented in Table 3. t-test was carried out considering the inequality of variances of draft values among sweep and shovel tyne and it was found that, there is significant difference between the draft values of sweep tyne and shovel tyne ($P=0.0003$).

**Nomenclature**

| % | per cent |
|---|---|
| A, B, C | machine specific parameters; ASABE draft equation |
| ANOVA | Analysis of variance |
| ASABE | American Society of Agricultural and Biological Engineers |
| CI | cone index |
| D | implement draft (N) |
| db | dry basis |
| HBM | Hottinger Baldwin Messtechnik GmbH |
| IIT | Indian Institute of Technology |
| MSE | mean squared error |
| $R^2$ | coefficient of determination |
| RBD | randomized block design |
| S | speed of operation (km/ h) |
| T | tillage depth (cm) |
| USA | United States of America |
| W | machine width (m) or number of rows or tools |

**Fig 1: Experimental setup at CIAE, Bhopal**

***Effect of speed on draft***

The variation of draft for sweep and shovel tyne with

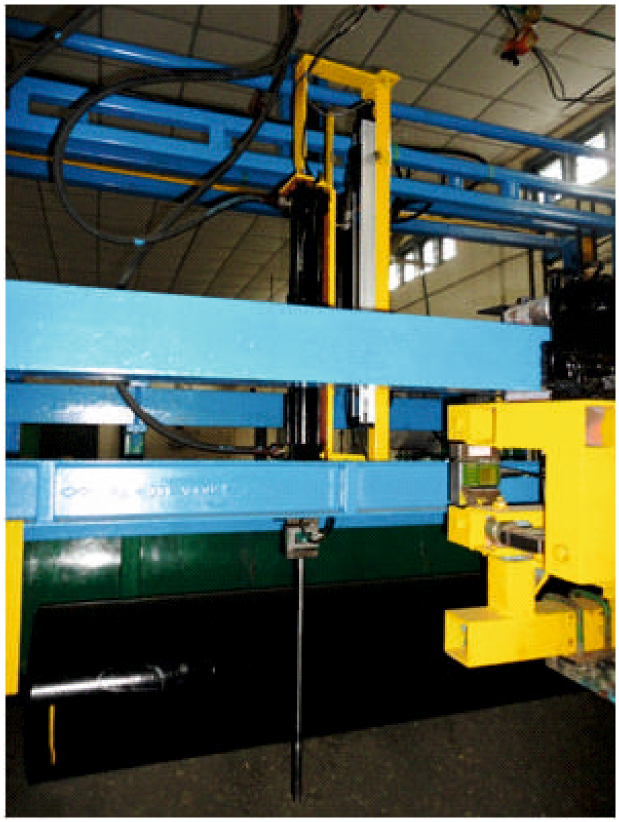


**Fig 2: Hydraulically operated instrumented cone penetrometer**

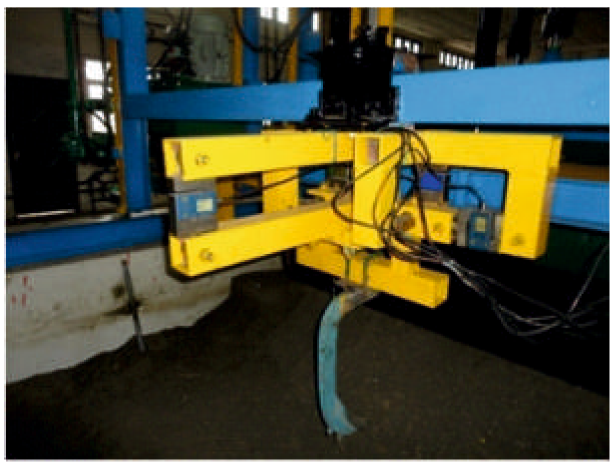


**Fig 3: Arrangement for draft measurement**

speed of operation at different depths and cone indices are shown in Figure 4**.** The general trend shows that draft values increased linearly with increase in speed of operation for both the tyne. The linear relationship observed is similar to the findings of Payne and Tanner (1959), Dransfield *et al.* (1964), Yadav (1983), Glancey *et al.* (1996), Grisso *et al.* (1996), Al-Janobi and Al-Suhaibani (1998) and Sahu (2005) on the drafts of cultivator and chisel plough.

When the speed of operation was increased from 0.9 to 1.8 km/h, the draft of sweep tyne varied from 65.1 to 638.9, 156.9 to 912.5, 343.4 to 1282.5 and 728.3 to 1764.2 N at 5, 10, 15 and 20 cm depth of operation, respectively for the

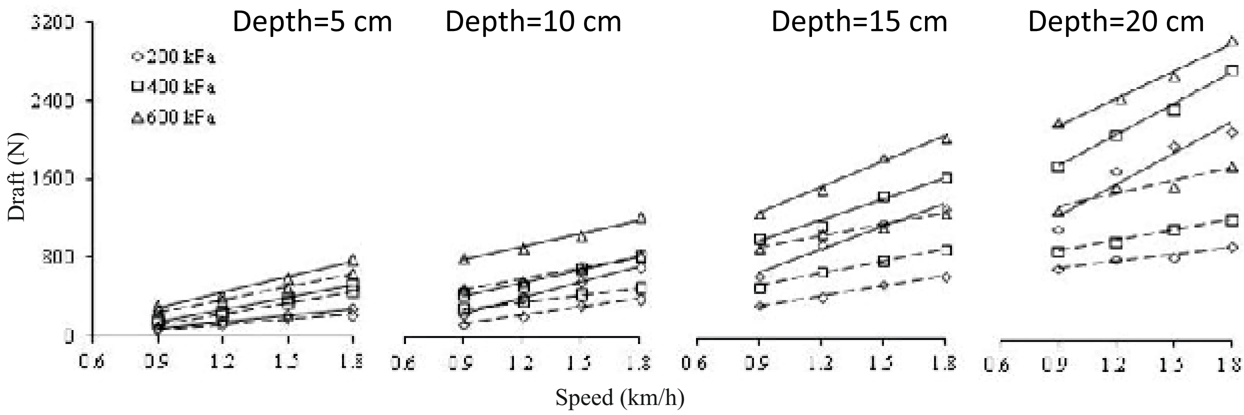



**Fig 4: Variations of draft of sweep and shovel tyne with speed of operation at different depth and cone index**

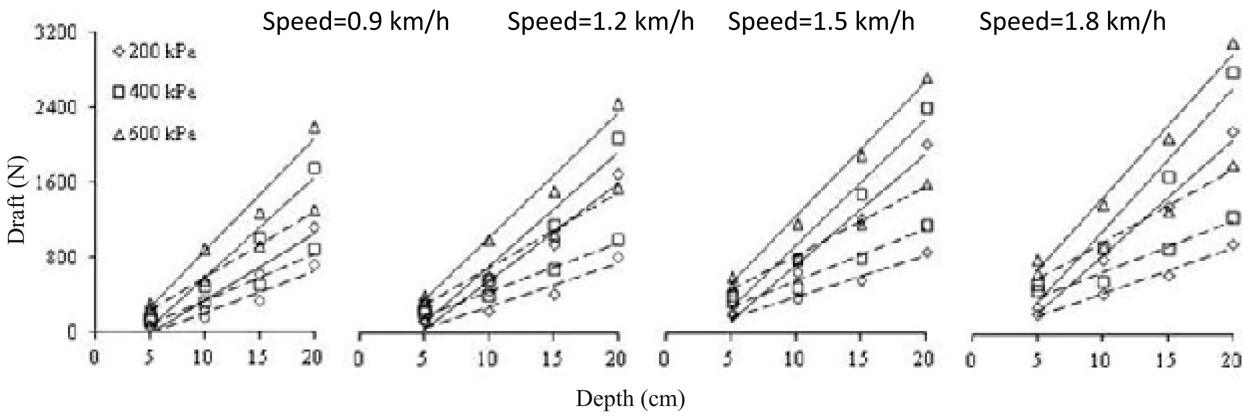



**Fig 5: Variation of draft of sweep and shovel tyne with depth of operation at different speed and cone index**

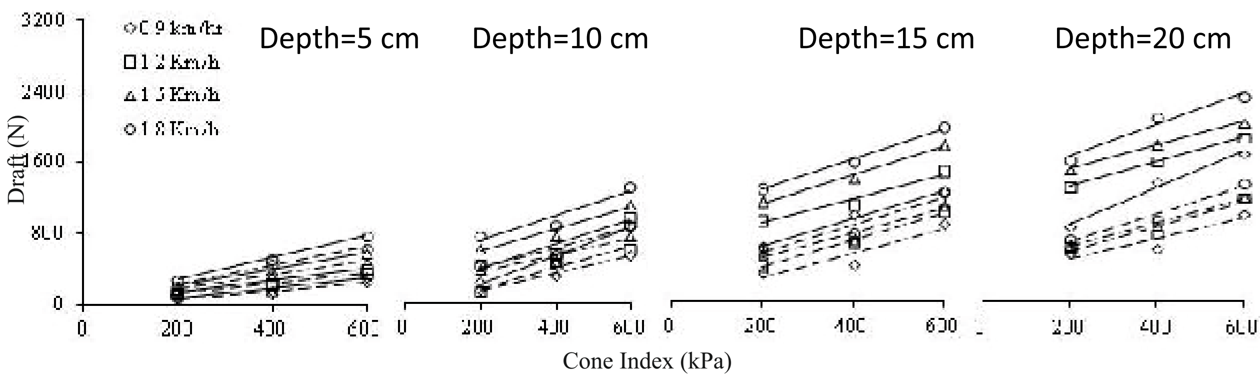
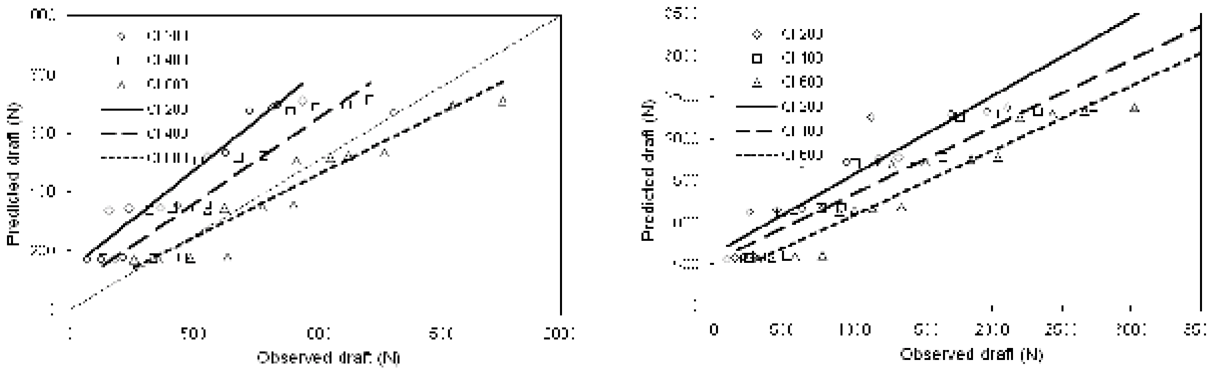



**Fig 6: Variation of draft of sweep and shovel tyne with cone index at different depth and speed of operation**




a) Sweep tyne

b) Shovel tyne

**Fig 7: Comparison of measured and predicted draft values for tillage tools**

range of cone index tested. When the speed of operation was increased from 0.9 to 1.8 km/h, the draft of shovel tyne varied from 86.3 to 779.1, 250.2 to 1349.3, 632.7 to 2043.1 and 1128.2 to 3025.6 N at 5, 10, 15 and 20 cm depth of operation, respectively for the range of cone index tested. This could be due to higher shear rate and increased soil-metal friction at higher speed.

***Effect of depth on draft***

It can be seen from Figure 5 that the draft of sweep and shovel tyne increased with increase in depth of operation. When the depth of operation of sweep tyne increased from 5 to 20 cm, the draft varied from 65.5 to 1316.5, 122.5 to 1552.9, 180.5 to 1559.5 and 215.8 to 1764.2 N for 0.9, 1.2, 1.5 and 1.8 km/h speed of operation, respectively, for the range of cone index tested. The main reason for this could be increased soil strength with increase in depth of operation and higher volume of soil handled by the tools, thus leading to higher draft. For shovel tyne when the depth of operation was increased from 5 to 20 cm, the draft varied from 86.3 to 2200.0, 148.6 to 2437.8, 212.2 to 2660.0 and 280.5 to 3025.6 N for 0.9, 1.2, 1.5 and 1.8 km/h speed of operation, respectively, for the range of cone index tested. The main reason for this could be increased soil strength with increase in depth of operation and higher volume of soil handled by the tools, thus leading to higher draft.

***Effect of cone index on draft***

The effect of soil cone index on the draft has been presented in Figure 6. From this Figure, it can be seen that the draft of sweep and shovel tyne increased with increase in soil cone index. This could be due to higher soil resistance associated with higher cone index values. When the average soil cone index was increased from 200 to 600 kPa, the draft values for sweep tyne were increased by 169.4 to 300.2%, 98.6 to 326.7%, 103.5 to 168.7 and 80.7 to 88.5%, respectively for 0.9, 1.2, 1.5 and 1.8 km/h speed of operation, respectively, for the range of depth tested. For shovel tyne, when the average soil cone index was increased from 200 to 600 kPa, the draft values were increased by 175.7 to 262.2%, 71.6 to 259.8%, 53.6 to 102.3% and 35.7 to 95.0, respectively for 0.9, 1.2, 1.5 and 1.8 km/h speed of operation, respectively, for the range of depth tested.

**Suitability of ASABE Model for Predicting the Draft Requirement of Tillage Implements**

Though, the models developed earlier have good capability in predicting draft of tillage implements, they represent only to the regional conditions whereas ASABE draft prediction equation, accepted as an international reference is prescribed for a wide range of tillage implements and several soil types. For calculation of draft by ASABE draft prediction equation, vertisol was considered as a fine textured soil. Machine and soil parameter for the implement provided in ASABE standard, 2003 were used for prediction of draft of tillage implements. As ASABE equation does not consider cone index as a direct parameter, the model outputs were same for different cone index values. Comparison between actual and predicted draft values were made to access the model's predictive accuracy at various cone index levels and to characterize the difference between the measured and model based value as a prelude to identify the possibilities for model refinement or new model development. The comparison between the predicted and measured values of draft for sweep tyne and reversible shovel tyne at different cone indices are presented in Figure 7 (a and b). The output of the statistical analysis is given in Table 4.

It can be seen from the Figure 7 (a and b) that even though the coefficient of determination of best fit lines for both the tillage tools at different cone indices is quite

**Table 1: Research plan**

| Variables | | levels | Range |
|---|---|---|---|
| Independent variables | Tools | 2 | Sweep tyne and Reversible shovel tyne |
| | Speed, km/h | 4 | 0.9, 1.2, 1.5 and 1.8 |
| | Depth, cm | 4 | 5, 10 , 15 and 20 |
| | Cone index, kPa | 3 | 200, 400 and 600 |
| | Moisture content, % | 1 | 14 – 16 (db) |
| Dependent variable | Draft, N | | |

**Table 2: ANOVA for the draft of sweep and shovel tyne**

| | | Sweep | | Shovel | |
|---|---|---|---|---|---|
| Source of variation | df | MS | F Value | MS | F Value |
| CI | 2 | 2184669 | 425.8* | 2923185.25 | 216.62* |
| S | 3 | 445927 | 86.91* | 1642152.07 | 121.69* |
| T | 3 | 3243956 | 632.26* | 15044112.06 | 1114.85* |
| CI×S | 6 | 10849.3 | 2.11$^{NS}$ | 12292.73 | 0.91$^{NS}$ |
| CI×T | 6 | 83850.2 | 16.34* | 108398.87 | 8.03* |
| S×T | 9 | 4093.17 | 0.8$^{NS}$ | 73298.21 | 5.43* |
| CI×S×T | 18 | 3942.88 | 0.77$^{NS}$ | 7069.49 | 0.52$^{NS}$ |
| Error | 48 | 5130.7 | | 5130.7 | |

df – degree of freedom; MS: mean square; * - significant at 1% level: NS – non significant

**Table 3: t-test for the draft of sweep and shovel tyne**

| Tools | mean | 95% CL mean | |
|---|---|---|---|
| Sweep | 666.3 | 546.0 | 786.5 |
| Shovel | 1158.3 | 931.3 | 1385.2 |

CL – Confidence level

**Table 4: Statistical analysis for model comparison**

| Tool | CI, kPa | ASABE allowable range, | %Percentage error | |
|---|---|---|---|---|
| | | | Min | Max |
| Sweep tyne | 200 | ±50 | -61.4 | 33.4 |
| | 400 | ±50 | -22.6 | 157.5 |
| | 600 | ±50 | 54.6 | 260.8 |
| Shovel tyne | 200 | ±25 | -84.7 | -10.9 |
| | 400 | ±25 | -70.6 | 15.4 |
| | 600 | ±25 | -44.5 | 31.7 |

**Table 5: ANOVA of the Model for tillage tools**

| Tillage tool | Source | df | Sum of Squares | Mean Square | F Value | R2 |
|---|---|---|---|---|---|---|
| Sweep tyne | Model | 2 | 15235120 | 7617560 | 629.08 | 0.93 |
| | Error | 93 | 1126148 | 12109 | | |
| | Corrected Total | 95 | 16361268 | | | |
| Shovel tyne | Model | 2 | 55820877 | 27910438 | 1157.18 | 0.96 |
| | Error | 93 | 2243094 | 24119 | | |
| | Corrected Total | 95 | 58063971 | | | |

*significant at 1% level

**Table 6: Result of Stepwise Regression Analysis for Draft of tillage tools**

| Tillage tool | Variable Coefficient | CI×W×TA | S×W×TB | S2× W×TC |
|---|---|---|---|---|
| Sweep tyne | Parameter Estimate | 0.09776 | 00.0# | 8.84431 |
| | Model $R^2$ | 0.8330 | | 0.0981 |
| | F Value | 469.02 | | 132.58 |
| Shovel tyne | Parameter Estimate | 0.11689 | 54.34170 | 00.0# |
| | Model $R^2$ | 0.1435 | 0.8179 | |
| | F Value | 345.38 | 422.21 | |

[#]The coefficients are entered as zero when not found significant at 5 per cent level reasonable (0.85 to 0.94), the slope of best fit line varied from 0.42 to 0.66 and from 0.78 to 0.94 for sweep tyne and shovel tyne, respectively. With increase in cone index, the slope deviated more from unity for both the tillage tools.

It can be seen from Table 4 that the percentage variation between the predicted and measured draft values for the sweep tyne varied from -61.4 to 33.4, -22.6 to 157.5 and 54.6 to 260.8 at cone index of 200, 400 and 600 kPa, respectively. Similarly for shovel tyne, the percentage variation between the predicted draft and measured draft values were -84.7 to 10.9, -70.6 to 15.4 and -44.5 to 31.67 at cone index of 200, 400 and 600 kPa, respectively. ASABE standard indicates an expected range of ±50% and in ±25% draft prediction for sweep tyne and shovel tyne. For both the tools tested, the range of variation of draft values as predicted by ASABE standard was exceeded. It can also be noticed that for both the tools the variation increased with increase in cone index.

**Developments of Draft Prediction Equations for Tillage Implements**

It was observed in the study that the influence of cone index on draft requirement is highly significant for both the tools tested. But ASABE model does not consider the cone index parameter in the equation. Hence, a simple equation similar to the ASABE model was proposed to model draft of tillage tools under the given conditions, where the draft is a function of tool width, soil cone index, depth and speed of operation. The draft prediction equation for the tillage tool studies was developed using stepwise regression technique from the data obtained from the laboratory test at different depths, speeds and soil conditions and it is represented as:

$$D = \{A x CI + B x S + C \times S^2\} W x T \quad (2)$$

Where, D = implement draft (N); A, B, and C = machine specific parameters; A = *f* (soil strength); B or C = *f* (speed of operation); S = speed of operation (km/h); W = machine width (m) or number of furrow opener or tools; T = tillage depth (cm)

Though the numbers of draft prediction equations developed by many researchers are available, this simple equation has the advantage of being easily understood and convenient to use, as only a few soil and machine specific parameters were used to describe the draft of any given implement. The major effort in developing the model was determination of machine specific parameters A, B and C. Each parameter was a function of tillage tool. The regression coefficients determined from the analysis were the coefficient in Eq. 2. The ANOVA of the developed model and its various coefficients are given in Table 5 and 6, respectively.

The high value of $R^2$ of the model (0.93 and 0.96) for the draft data obtained from soil bin tests indicated that the experimental data fit the regression very well. It can be noticed from the values of different coefficients in Table 6 that the interaction of cone index with width and depth (CI×W×T) is the significant factor influencing the draft of both the tillage tools tested. Besides the CI term, $S^2$ term is contributing towards the draft of sweep tyne (Gill and Vanden Berg, 1968; Kepner *et al.*, 1978; Upadhyaya, 1984; ASABE, 2003), whereas S term is contributing towards the draft of shovel tyne (ASABE, 2003). The effect of $S^2$ term was found to be affecting the draft of sweep tyne significantly, which is not in accordance with ASABE standard. One possible explanation for this observation could be the existences of inertia effect on the draft of sweep tyne due to wing type structure of the tynes. The interactions of soil cone index with width and depth (CI×W×T) and speed with width and depth (S×W×T) are significant at 1% level.

## CONCLUSION

Based on the results of this study, the following conclusions were drawn:

(i) The relationship between draft with depth, speed and cone index was found to be linear for both the tools.

(ii) Draft was found to be increased with increase in cone index, speed and depth of operation for the tools tested such as sweep and shovel tyne in vertisol. The effect of depth of operation was found to be the most significant on draft and followed by cone index and speed of operation.

(iii) When the cone index was increased from 200 to 600 kPa for Sweep and shovel tyne respectively, the corresponding draft was increased by 60.4 to 206.8% and 11.6 to 209.4%, for the range of speed and depth tested.

(iv) The rate of change of draft with depth from 10 to 20 cm was found to be 83.2 to 269.3% and 153.6 to 407.0% for sweep and shovel tyne, respectively for the range of speed and cone index tested.

(v) The percentage variation between the observed and predicted draft values using ASABE draft model for prediction of sweep and shovel tyne was found to be -61.4 to 260.8 and - 84.7 to 31.7, respectively at different levels of cone index tested. At higher cone index values, the draft prediction was further deteriorated. Thus indicating poor applicability of ASABE model for draft prediction.

(vi) Using stepwise regression technique, a draft prediction model incorporating cone index, speed and depth of operation was developed, which could predict the draft requirements of sweep and shovel tyned implement in vertisol with different cone index.

The results of investigation carried out would provide useful information for designing and selecting suitable tillage implement for better power utilization.

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