LANDTECHNIK 77(3), 2022, 79–85

DOI:10.15150/lt.2022.3280

LANDTECHNIK
AGRICULTURAL ENGINEERING

Evaluation of adjustable tine wings under soil bin conditions

Amer K. A. Al-Neama, Stefan Schwede, Thomas Herlitzius

Recently, the demand for tillage tools that meet most field needs has increased dramatically under various conditions. A tine with the feature of adjustability has the potential to achieve this goal. Therefore, adjustable tine wings with different wing widths are evaluated in this study with speeds of 1.1 and 3.3 m s^{-1} under soil bin conditions. The results showed that the speed and the wing width have a significant linear effect on horizontal and vertical forces, while the speed has a much higher impact than the wing width on forces requirement. The horizontal force increases with increasing wing widths, whereas the vertical force decreases with increasing wing widths.

Keywords
adjustable wing tine, horizontal force, vertical force, wing widths, soil bin, cultivation

Over the years, varieties of tillage tools and practices have been developed to achieve all the field requirements at changing weather conditions for crop production. Focussing on tillage operation quality, compromises are made on the force, time, and fuel consumption. Tine with wings and sweep are mainly used in conservation tillage. Furthermore, they are used in primary and secondary cultivation. Glancey et al., (1996) stated that the draft force for the tillage tool was found to be a function of tool geometry (e.g. tool width, tool inclination angle), soil properties (e.g. soil texture) and operations condition (depth, speed).

Numerous analytical (2- and 3-dimensions), empirical (regression) and numerical (simulation) models (Godwin and Spoor 1977, McKyes and Ali 1977, Upadhyaya et al. 1984, Grisso et al. 1996, Onwualu and Watts 1998, Sahu and Raheman 2006, Yong and Hanna 1977, Chi and Kushwaha 1990, Mouazen and Nemenyi 1999) have been developed and used to predict the draft force.

Oni et al. (1992) studied the influence of design parameters of sweep tines on draft force and found that the nose angle (wing angles) and soil depth have significant effects on draft. Wismer and Luth (1972) informed that the nose angle and tool width also have a significant affect on the draft. Tekeste et al. (2019) used a simulation of tool-soil interaction to study the effect of different sweep tines on horizontal and vertical forces at different speeds and showed that the forces increased linearly with increasing speed from 0.22 to 2.68 m s^{-1}.

Various studies found a linear, second-order polynomial, parabolic and exponential relationship between the draft force and the speed (Rowe and Barnes 1961, Siemens et al. 1965, Terpstra 1977, Stafford 1979, Swick and Perumpral 1988, Gupta et al. 1989, Owen 1989), this was due to differences in soil type and operating conditions. Wheeler and Godwin (1996) verified that the critical speed for single and multiple tines had a significant effect on draft force (Equation 1):

$$\sqrt{5g(w_t + 0.6D)} \quad \text{(Eq. 1)}$$

received 27 August 2021 | accepted 17 August 2022| published 9 September 2022

where: g is the gravitational acceleration, w_t is the tine width, and D is the working depth. This study evaluates and improves the adjustable tine wings with the appropriate set of speeds and wing widths.

Materials and methods

The study was carried out at the Chair of Agricultural Systems and Technology (AST) at Technische Universität Dresden, Germany under controlled soil bin conditions. The soil bin was 28.6 m long, 2.5 m wide, and 1.0 m deep. It was filled with sandy loam soil (60.9% sand, 30.1% silt, 9% clay). The soil moisture content was 8.8% ± 0.61 dry-based, and the soil bulk density was 1.44 g cm^{-3} ± 0.03 during the test. The carriage was powered by an electric-hydraulic drive train with a maximum speed of 4.7 m s^{-1}, delivering maximum traction of 13 kN. Horizontal (*Fh*), vertical (*Fv*), and lateral (*Fl*) forces were measured using load cell sensors. The sensor types were S9 and U9B (HBM GmbH) with maximum loads of 50 kN and 20 kN ± 0.05, respectively, and the speed was measured using a radar ground speed sensor with a velocity range of (0.15 to 29.7 m s^{-1} ± 0.05).

A tine with an adjustable screw arm and gears was manufactured at the AST workshop (Figure 1). Figure 1 also shows some parameters of the tine, where: α_1 is the rake angle of the wings 24^0, α_2 is the rake angle of the tine 28^0, and β is the wing angle (variable values). The wing and tine thickness is 10 mm. The total weight of the tine and the wings equals 14.2 kg.

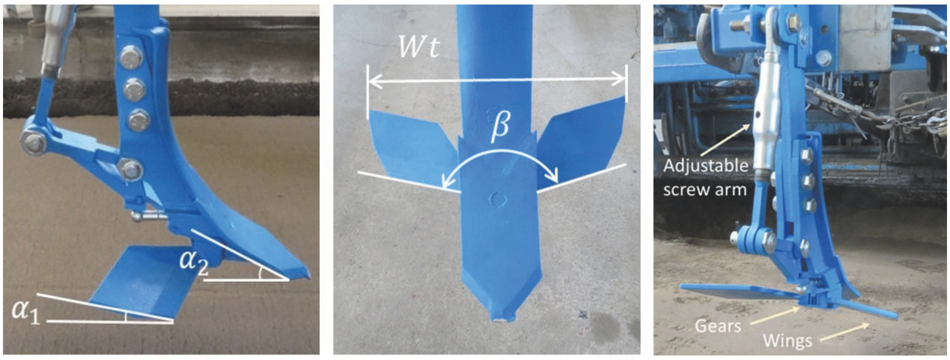

Figure 1: Adjustable tine wings: where: w_t wing width, β wing angle, α_1 wing rake angle, and α_2 tine rake angle

The correlation between wing angles β and the wing widths w_t were increased β from 30^0, 68^0, 86^0, 104^0, 122^0, and 140^0. This leads to increased w_t from 12, 25.5, 30, 36, 42, and 48 cm, respectively. The test layout was designed as a factorial experiment with three replicates. The tine was operated at speeds of (1.1 and 3.3 m s^{-1}) with varying wing widths of 12, 25.5, 30, 36, 42, and 48 cm at a constant depth of 10 cm. A multi-linear regression analysis technique was performed, which estimated the entire first and second-order interactions (Equation 2). A stepwise selection procedure at the significance level of 0.05 was employed using IBM SPSS Statistics version 27:

$$Y = C_0 + C_1 V + C_2 w_t + C_3 V w_t + C_4 V^2 + C_5 {w_t}^2 \quad \text{(Eq. 2)}$$

where Y is the dependent variable (*Fh* or *Fv* in [kN]), w_t is the wing width in cm, V is the speed in m s^{-1}, and C_0, C_1, C_2, C_3, C_4, and C_5 are the regression coefficients.

Results and discussion

Effect of wing widths and speed on *Fh* and *Fv*

The effect of wing width and speed on *Fh* and *Fv* are shown in Figure 2. The increase in *Fh* as w_t increased was due to more cutting and distributing of the soil segment (Figure 2A). There was a decrease in *Fv* as the w_t increased (Figure 2B). *Fv* had two components; one for tine Fv_t constant value in minus (-) penetrating the soil because of its operating at a fixed depth, and the second for wings Fv_w varied value plus (+) because of changing w_t (as a function of β). The minimum absolute value of *Fv* was -0.04 and -0.14 kN for speeds 1.1 and 3.3 m s^{-1}, respectively, at w_t = 48 cm.

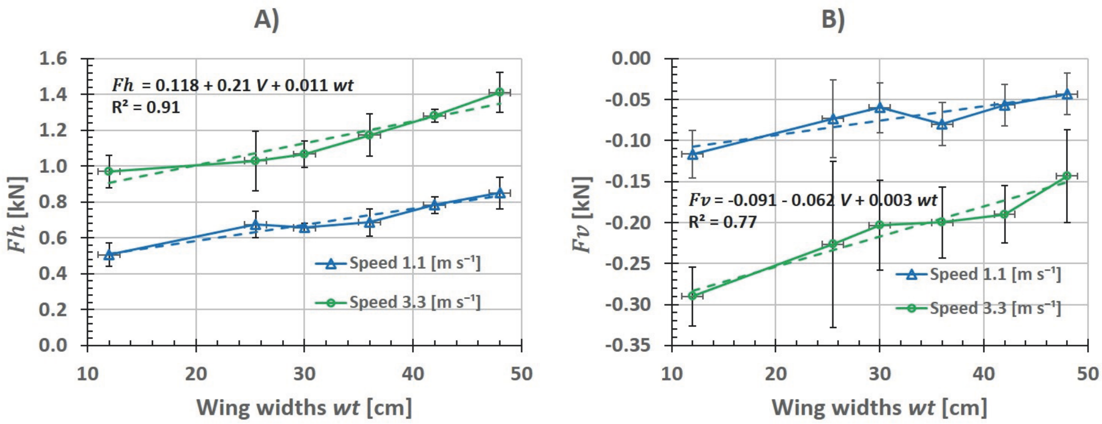

Figure 2: Effect of speed *V* and wing widths w_t on A) *Fh* and B) *Fv* --------- trend line (mean ± SD)

It can also be seen from this figure that the regression model referring to *Fh* increased linearly with speed and wing widths (Equation 2) with a high coefficient of determination R^2 = 0.91, and *Fv* increased linearly with speed and decreased linearly with wing widths with advisable R^2 = 0.77.

To estimate which independent variables (*V*, w_t) are highly effective on dependent variables (*Fh*, *Fv*). The decision by comparing the value of the regression coefficient for *V* and w_t is very difficult because the units are different. Therefore, if the w_t is removed from (Equation 2), the R^2 changes to 0.70 and 0.63 for *Fh* and *Fv*, respectively. That means *V* is more significant than the w_t on forces.

Validation of the regression models

To prove the exactitude of the regression models obtained from the soil bin the observed (measured) and the predicted (regression) values of *Fh* and *Fv* are plotted in Figure 3 for all *V* and w_t.

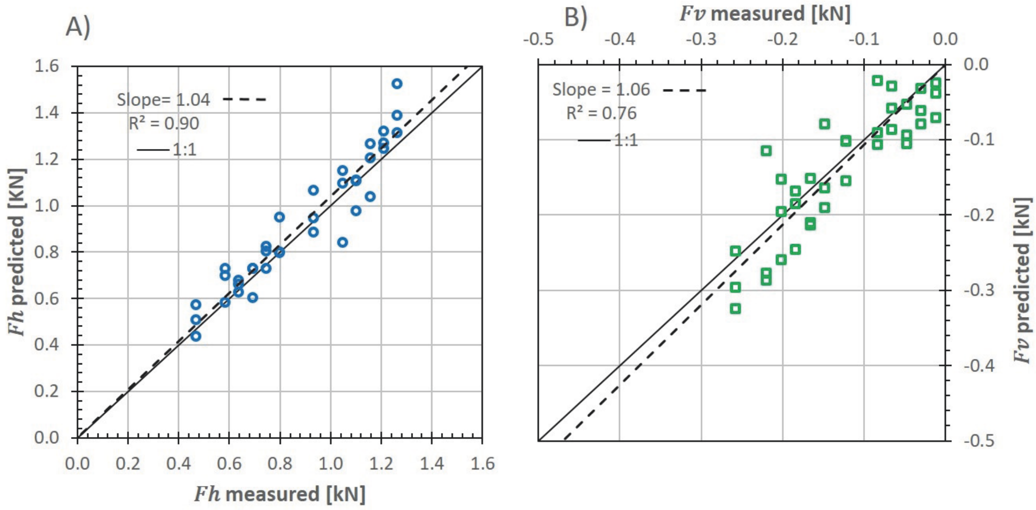

Figure 3: Validation of the regression models for *Fh* and *Fv*

The predicted (regression) values of *Fh* and *Fv* are slightly higher than the observed (measured) values (Figure 3). The comparison shows that there is excellent accordance of predicted and observed values with the slope of 1.04 and 1.06 with higher R^2 = 0.90 and R^2 = 0.76 for *Fh* and *Fv*, respectively.

Comparing with the other models

Goryachkin (1927) proposed an empirical formula for predicting the *Fh* acting on the moldboard plow, as presented in Equation 3, refined by Soucek and Pippig (1990) for single tine:

$$Fh = w_t \times D \times (k + \varepsilon \times V^2) \quad \text{(Eq. 3)}$$

where: *Fh* is horizontal force in kN, w_t is tine width in m, D is depth in m, *k* is the coefficient of static resistance in kN m^{-2}, ε is the constant of the dynamic draft in kN s^2 m^{-4} and *V* is the speed in m s^{-1}.

Soucek and Pippig (1990) also suggested a value of *k* for sandy loam soil between 40 and 60 kN m^{-2}, while ε is between 3 and 9 kN s^2 m^{-4}. Dedousis and Bartzanas (2010) proposed a value of *k* between 20 and 50 kN m^{-2}, while ε is between 0.7 and 12 kN s^2 m^{-4}. The measured *Fh* from the soil bin and the predicted *Fh* based on Goryachkin's formula are plotted in Figure 4, which shows a good correlation between measured and predicted *Fh*. The slope is 1.02 with acceptable R^2 = 0.67 with values of coefficients *k* and ε of 20 kN m^{-2} and 1.5 kN s^2 m^{-4}, respectively. This agrees with the data of Dedousis and Bartzanas (2010).

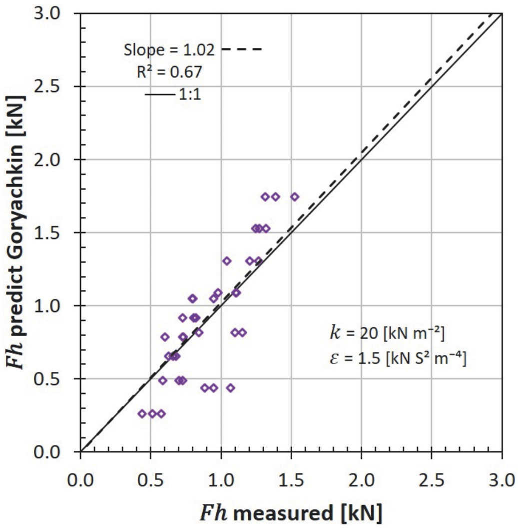

Figure 4: Correlation between measured and prediction *Fh* based on Goryachkin's formula

Therefore, Goryachkin's formula can be used to predict the *Fh* for a wide tine (sweep or tine with wing) with a suitable value of the coefficient *k* and *ε*. Al-Neama and Herlitzius (2016) developed a regression model based on Glancey & Upadhyaya (1995) by adding new terms related to the tine geometric parameters for a standard single wide and narrow tines under soil bin conditions (Equation 4):

$$Fh = -0.35 + 0.019\, w_t + 0.02\, VD + 0.002\, D^2 \quad \text{(Eq. 4)}$$

where: *Fh* is horizontal force in kN, w_t is tine width in cm, *V* is speed in m s^{-1}, and D is depth in cm. The measured *Fh* from the soil bin and the predicted *Fh* based on Al-Neama and Herlitzius (2016) geometric regression model are plotted in Figure 5, which shows an excellent correlation between measured and predicted *Fh* with a very good distribution of points around the slope line. The regression line has a slope of 0.96 with a coefficient of determination of R^2 = 0.80. This was due to both experiments being done under soil bin conditions with the same soil texture (sandy loam).

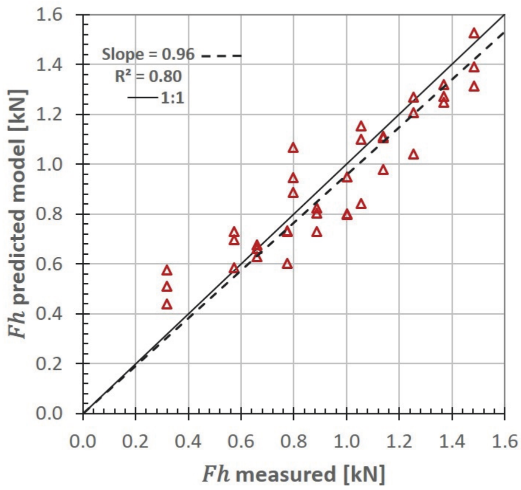

Figure 5: Correlation between measured *Fh* and predicted *Fh* for standard tine model

Conclusions

A new tine was manufactured to easily adjust the wing width (the distance between wings) by changing the wing angle. The speed and the wing width have a linear effect on horizontal and vertical forces. The significance of speed on the forces is higher than the significance of wing width. The horizontal force increases with increasing wing widths, while the vertical force decreases with increasing wing widths. Both forces increase significantly with increasing speed. Goryachkin's formula can be used to predict the horizontal force acting on a single wing tine (wide tine) after adjusting the value of formula coefficients.

References

Al-Neama, A.; Herlitzius, T. (2016): New regression model for predicting horizontal forces of single tines using a dummy variable and tine geometric parameters. Landtechnik 71(5), pp. 168-174

Chi, L.; Kushwaha, R. (1990): A non-linear 3-d finite element analysis of soil failure with tillage tools. Journal of Terramechanics 27(4), pp. 343-366

Dedousis, A.; Bartzanas, T. (eds.) (2010): Soil Engineering. Springer-Verlag Berlin Heidelberg, https://dx.doi.org/10.1007/978-3-642-03681-1

Glancey, J. L.; Upadhyaya, S. K. (1995): An improved technique for agricultural implement draught analysis. Soil and Tillage Research 35(4), pp. 175-182, https://doi.org/10.1016/0167-1987(95)00498-X

Glancey, J.; Upadhyaya, S.; Chancellor, W.; Rumsey, J. (1996): Prediction of agricultural implement draft using an instrumented analog tillage tool. Soil and Tillage Research 37(1), pp. 47-65

Godwin, R.; Spoor, G. (1977): Soil failure with narrow tines. Journal of Agricultural Engineering Research 22(4), pp. 213-228

Goryachkin, V. P. (1927): Theory of the plow. Moscow, Promizdat

Grisso , R.; Yasin , M.; Kocher, M. (1996): Tillage tool forces operating in silty clay loam. Transactions of the ASAE 39, pp. 1977-1982

Gupta, P.; Gupta, C.; Pandey, K. (1989): An analytical model for predicting draft forces on convex-type cutting blades. Soil and Tillage Research 14(2), pp. 131-144, https://doi.org/10.1016/0167-1987(89)90027-5

McKyes, E.; Ali, O. (1977): The cutting of soil by a narrow blade. Journal of Terramechanics 14(2), pp. 43-58

Mouazen, A.; Nemenyi, M. (1999): Finite element analysis of subsoiler cutting in non-homogeneous sandy loam soil. Agricultural Engineering Research 51(1-2), pp. 1-15, https://doi.org/10.1016/S0167-1987(99)00015-X

Oni, K.; Clark, S.; Johnson, W. (1992): The effects of design on the draught of undercutter-sweep tillage tools. Soil and Tillage Research 22 (1-2):, pp. 117-130

Onwualu, A.; Watts, K. (1998): Draught and vertical forces obtained from dynamic soil cuttting by plane tillage tools. Soil and Tillage Research 48 (4), pp. 239-253

Owen, G. (1989): Subsoiling forces and tool speed in compact soils. Canadian Agricultural Engineering 31(1), pp. 15-20

Rowe, R.; Barnes, K. (1961): Influence of speed on elements of draft of a tillage tool. Transactions of American Society of Agricultural and Biological Engineers 4, pp. 55-57, https://doi.org/10.13031/2013.41008

Sahu, R. K.; Raheman, H. (2006): Draught Prediction of Agricultural Implements using Reference Tillage Tools in Sandy Clay Loam Soil. Biosystems Engineering 94(2), pp. 275-284

Siemens, J., Weber , J., & Thornburn , T. (1965): Mechanics of soil as influenced by model tillage tools. Transactions of American Society of Agricultural and Biological Engineers 8(1), pp. 1-7

Soucek, R.; Pippig, G. (1990): Maschinen und Geräte für Bodenbearbeitung Düngung und Aussaat. Verlag Technik GmbH, Germany

Stafford, J. (1979): The performance of a rigid tine in relation to soil properties and speed. Journal of Agricultural Engineering Research 24(1), pp. 41-57

Swick , W., & Perumpral , J. (1988): A model for predicting soil tool interaction. Journal of Terramechanics 25, pp. 43-56

Tekeste, M.; Balvanz, L.; Hatfield, J.; Ghorbani, S. (2019): Discrete element modeling of cultivator sweep-to-soil interaction: Worn and hardened edges effects on soil-tool forces and soil flow. Journal of Terramechanics 82, pp. 1–11

Terpstra, R. (1977): Draught forces of tines in beds of glass spheres. Journal of Agricultural Engineering Research 22(2), pp 135-143

Upadhyaya, S. K.; Williams, T. H.; Kemble, L. J.; Collins, N. E. (1984): Energy requirements for chiseling in coastal plain soils. Transactions of the ASAE 27 (6), pp. 1643-1649

Wheeler, P. N.; Godwin, R. J. (1996): Soil Dynamics of Single and Multiple Tines at Speeds up to 20 km/h. Journal of Agricultural Engineering Research 63(3), pp. 243-250

Wismer, R.; Luth, H. (1972): Rate effects in soil cutting. Journal of Terramechanics 8 (3), pp. 11-21

Yong, R., Hanna, A. (1977): Finite element analysis of plane soil cutting. Journal of Terramechanics 14(3), pp. 103-125

Authors

Dr.-Ing. Amer K. A. Al-Neama is a lecturer at the Soil Science and Water Resources Department, College of Agriculture, University of Diyala and Visiting Researcher at the Chair of Agricultural Systems and Technology (AST)/Technical University of Dresden. Email: amer.al-neama@mailbox.tu-dresden.de, amer_agri@yahoo.com

Dipl.-Ing. Stefan Schwede is a Research Engineer at the Chair of Agricultural Systems and Technology (AST) and **Prof. Dr.-Ing. Thomas Herlitzius** is head of the Institute of Natural Materials Technology (INT) at the Technical University of Dresden, Bergstraße 120, 01069 Dresden. Email: Thomas.herlitzius@tu-dresden.de

Acknowledgment

This research work was a cooperation between the University of Diyala in Iraq and the Chair of Agricultural Systems and Technology (AST), Faculty of Mechanical Engineering, Technical University Dresden in Germany. The first author is particularly thankful to the technical staff of the chair for their helpful assistance. Data evaluated were gained from an actual running DFG-project "Untersuchung der Onlineoptimierung des Arbeitsergebnisses und Zugkraftbedarfs von gezogenen, keilförmigen Werkzeugen", Number: HE 5738/2-2.