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# Specific draught, soil fragmentation and straw incorporation for different tine and share types

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ABSTRACT

This study measured the specific draught (force per cross-sectional area of worked soil) and the energy use for soil fragmentation and straw incorporation using different tillage implements (mouldboard plough, 80 mm tine with and without wings, 210 mm sweep share, 80 mm rigid and vibrating tines) on a clay and a loam soil. Tine widths of 50, 65, 80 and 120 mm were compared in a separate experiment. Draught was calculated from measurements of fuel consumption and driving speed during tillage, while tillage depth was determined by weighing the loosened soil, which was also sieved to determine the aggregate size distribution and surface area. Measured values of specific draught were compared with model computations.

Specific draught was much higher for the rigid 80 mm tine than for the mouldboard plough and sweep share. On the clay soil, specific draught was 65 kN $m^{-2}$ for the mouldboard plough, 140 kN $m^{-2}$ for shallow tillage with the rigid tine, 98 kN $m^{-2}$ for the vibrating tine and 65 kN $m^{-2}$ for the sweep share. The vibrating tine had a much lower energy use for soil fragmentation than the rigid tine. The sweep share also had a low energy use for fragmentation, but the poorest incorporation of straw. On the loam, differences between treatments were generally smaller than on the clay. There were small differences in specific draught and soil fragmentation for different tine widths. For the different tines and shares, the measured specific draught was considerably higher than values from model computations.

Overall, there were great differences in draught requirement and tillage outcome for the different tillage tools. The results show the importance of adjusting the tillage tool to achieve the desired tillage outcome in terms of soil loosening, soil fragmentation or incorporation of plant residues.



## 1. Introduction

The draught force required to pull an implement is of great importance, since it determines fuel consumption and the tractor power required. For a given tractor size, reducing the draught force per metre working width means that the implement size or working speed can be increased, leading to higher work rate and decreased timeliness costs.

Draught requirement has been widely studied, particularly for tines. Fundamental work was carried out by e.g. Payne (1956) and Payne and Tanner (1959), who described soil break-up by shear failure in front of narrow tines. The most important parameters determining the draught requirement are reported to be the rake angle (angle between the horizontal and the tine in the direction of travel) and the soil strength as measured by soil cohesion.

Models for predicting draught requirement are generally developed from soil mechanics within civil engineering. The most common models are based on calculation of the forces required for shear failure in front of a retaining wall (McKyes, 1989). In this case the failure zone is very wide relative to its depth. This corresponds to soil break-up by a wide blade and is called two-dimensional soil cutting, since the end effects of the blade are neglected. Semi-empirical models have also been developed for narrow tines, i.e. three-dimensional soil cutting (e.g. Hettiarachi et al., 1967; Godwin and Spoor, 1977; McKyes and Ali, 1977; Swick and Perumpral, 1988; Kuczewski and Piotrowska, 1998), using the shape of the crescent normally observed in front of narrow tines. Wheeler and Godwin (1996) extended the model developed by Godwin and Spoor (1977) to also include the effect of implement velocity. The horizontal (draught force) and vertical component of the soil cutting force can then be calculated as:

$$H = \left[ \begin{array}{c} (\gamma z^2 N_\gamma + czN_c + qzN_q)\left(w + z\left(\frac{m-1}{3(m-1)}\right)\right) \\ + \frac{\gamma v^2 N_a z(w + 0.6z)}{g} \end{array} \right] \sin(\alpha + \delta) \qquad (1)$$

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$$V = -\left[ \begin{array}{c} (\gamma z^2 N_\gamma + czN_c + qzN_q)\left(w + z\left(\frac{m-1}{3(m-1)}\right)\right) \\ + \frac{\gamma v^2 N_a z(w + 0.6z)}{g} \end{array} \right] \cos(\alpha + \delta) \quad (2)$$

where $H$ is the horizontal force, $V$ is the vertical force, $\gamma$ is specific weight of soil, $z$ is the working depth, $c$ is the cohesion, $q$ is the surcharge, $N_\gamma$, $N_c$ and $N_q$ are dimensionless constants, $m$ is the rupture distance ratio (the ratio between forward rupture distance and working depth), $N_a$ is a dimensionless factor for inertial effects, $v$ is the velocity, $g$ is acceleration due to gravity, $\alpha$ is the rake angle and $\delta$ is the angle of soil–metal friction. The term $z(m - 1/3(m - 1))$ represents the side-effects of the tine and the term $w + 0.6z$ the effective area worked by the tine. The model is available as a spreadsheet (Godwin and O'Dogherty, 2007).

The primary objectives with tillage are normally soil loosening, soil fragmentation, levelling of the soil surface, and incorporation of plant residues, manure and fertilizers. For soil loosening the efficiency can be quantified by the specific draught or specific resistance (kN $m^{-2}$), which is the draught force divided by the cross-sectional soil area worked (Spoor and Godwin, 1978; McKyes, 1989; Watts and Dexter, 1994). To determine the effectiveness of a tillage operation, the draught requirement should also be placed in relation to the tillage result but this has been done to a much lesser extent than measurements of draught force alone. Measurements of aggregate size distribution for different tillage implements and different soil conditions have been made by e.g. Hadas and Wolf (1983), Berntsen and Berre (1993, 2002), Perfect et al. (1993), Dexter and Birkás (2004) and Keller et al. (2007). In general, soil conditions during tillage have been found to have a much larger influence on the aggregate size distribution than the type of implement used (Dexter, 1979; Berntsen and Berre, 1993). However, Arvidsson et al. (2004) found increasing soil fragmentation in the order mouldboard plough < chisel plough < disc harrow. This can be attributed to differences in tool geometry, but also to the working depth, since a greater working depth normally leads to a coarser soil structure in dry or compacted soils. To relate the draught force to the fragmentation of the soil, energy input can be divided by the increase in soil surface caused by a certain tillage operation (Berntsen and Berre, 1993; Arvidsson et al., 2004).

For soil protection from erosion, residues from the previous crop should be left on the soil surface. In the humid climate of northern Europe, the amount of residues is often high and may cause poor establishment of the following crop. For this reason, good incorporation of residues is normally desired.

The objective of the present work was to compare the draught requirement and tillage outcome in terms of aggregate surface area, proportion of coarse aggregates and straw incorporation for different tillage tools.

## 2. Materials and methods

### 2.1. Experimental setup—different tine and share types

Experiments with different tine and share types were carried out on two soils at Säby, a clay soil (Säby 1) and a loam (Säby 2), both sites near Uppsala in central Sweden (60°N, 15°E). Soil properties are given in Table 1. The soils were tilled in the autumn within 2 weeks of harvest of winter wheat, which was the preceding crop. The straw had been chopped by the combine harvester and left in the field. Particle size distribution, dry bulk density, soil cohesion and soil water content at the time of the different experiments are presented in Table 1. Before tillage, the bulk density of the topsoil was determined by taking core samples (72 mm in diameter, 50 mm high) at 50–100 mm depth. Soil strength was measured with a shear vane (50 mm in diameter, 100 mm high, 10 measurements at 50–150 mm depth). Soil cohesion was calculated from the shear vane measurements assuming the normal stress to be negligible (Arvidsson et al., 2004).

Draught measurements were made for the following implements (desired working depth given within brackets):

A: mouldboard plough (20 cm);
B: 80 mm rigid tine, deep (20 cm);
C: 80 mm rigid tine, shallow (10 cm);
D: 80 mm tine, winged (10 cm);
E: worn 80 mm tine (10 cm);
F: 210 mm share (10 cm);
G: 260 mm sweep share, deep (15 cm);
H: 260 mm sweep share, shallow (6 cm);
I: 80 mm vibrating tine (10 cm).

Koolen and Kuipers (1983) defined tines as narrow tools where the side-effects cannot be neglected. This definition is also used here, while the wider tools in treatments F–H are termed shares. The shape of the tillage tools in treatments B–H are shown in Fig. 1. These were mounted in a Väderstad Cultus cultivator with rigid tines. Working depth was controlled by wheels and a packer following the tines. The cultivator had 9 tines and a tine spacing of 256 mm. Rake angles were around 20° for B, C, D, F and I. The 'worn' tine in E had been cut off, which changed the rake angle to 36°. Implement I was an older type of Väderstad Cultus cultivator with vibrating tines and a tine spacing of 275 mm. Mouldboard ploughing was carried out using a Överum XL 3-furrow reversible plough.

The experiments had a fully randomised block design with four replicates. Plot size was 6 m × 30 m on the clay soil (Säby 1) and 6 m × 20 m on the loam (Säby 2).

### 2.2. Experimental setup—different tine widths

A second type of experiment was conducted to test the influence of tine width. The Väderstad cultivator with rigid tines described previously was also used in this experiment. Four tine widths were tested: 50, 65, 80 and 120 mm. The 80 mm tine was the same as shown in Fig. 1a, while the other tines had a similar shape. The experiment was carried out on a clay soil (Säby 3) for which the soil properties are given in Table 1. The experiment had a fully randomised block design with four replicates. Plot size was 6 m × 30 m.

### 2.3. Draught measurements, calculation of draught force

The implements were pulled by a 99 kW Massey-Ferguson 6290 four-wheel-drive tractor fitted with equipment to measure

**Table 1**
Soil properties in the different experiments.

| | Particle size (g 100 $g^{-1}$) | | | | Cohesion (kPa) | Bulk dens. (Mg $m^{-3}$) | Water content (g $g^{-1}$) |
|---|---|---|---|---|---|---|---|
| | Clay | silt | Sand | OM | | | |
| Tine and share types, clay | 50.0 | 32.3 | 17.7 | 3.2 | 37.7 | 1.48 | 0.22 |
| Tine and share types, loam | 19.3 | 47.2 | 33.5 | 5.1 | 34.4 | 1.34 | 0.23 |
| Tine widths, clay | 53.3 | 33.6 | 13.1 | 3.3 | 55.7 | 1.3 | 0.23 |