

## Light tractor simulator

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**Abstract.** A tractor simulator was made for hard tillage work. The aim of the simulator was to have it in national language and that it is easy to use. There are tractor simulators available but they are mainly made for different conditions than we have and they are also in languages not common to our farmers. The simulator user can interactively experiment how working depth and – width, soil conditions, ballasting and driving speed effect on wheel slip, field capacity and fuel consumption  $l\ ha^{-1}$ . The simulator also shows how complicated a tractor – implement system is. Because the soil conditions and implement conditions are varying there can be large scatter in the results.

**Key words:** tractor, implement, field capacity, fuel efficiency.

### INTRODUCTION

The purpose of the simulation was to demonstrate how tractor performance changes in heavy tillage work. With this simulator farmers and students can experiment how tractor size, implement size, working depth, driving gear, soil conditions and ballasting effect on fuel consumption, wheel slip and work rate.

There have been several tractor simulators available but these are focused on special subjects, for instance tyres (Al-Hamed et al., 1994) and ballasting (Evans et al., 1989). There are not many simulators available to simulate the tractor performance during heavy draft work. Grisso et al. (2007) made software, which selects either suitable implement for a tractor or a suitable tractor for an implement. The software is done with spreadsheet program and it calculates field capacity and fuel consumption in  $l\ ha^{-1}$ . Also it includes tyre inflation and ballast options. A simulator based on this can be downloaded at [http://www.bae.ksu.edu/precisionag/index\\_files/Page832.htm](http://www.bae.ksu.edu/precisionag/index_files/Page832.htm) (31.1.2014) and a Google Android Application is also available at Google Store.

Buckmaster & Beheshi Tabar (2013) made for educational purposes a spreadsheet program, where laboratory work and modelling allow virtual experimenting tractor-implement performance. Abdulrahman & Saad (2002) made a program, which calculates the performance of tractor-implement system. It was developed to use in farm machinery management and educational and research purposes. The program calculates the optimum field speed that matches to the pull of a tractor and shows the performance of the system.

The aim of this study was to develop a tool, where the user could interactively change the implement parameters and choose in this way the optimum parameters for the work. It also includes fuel consumption figures so that the user can see besides field

capacity also fuel consumption l ha<sup>-1</sup>. The program was done in Finnish language and also a translation in English and Estonian languages are available. The simulator was done with a spreadsheet program, and the aim was to keep the file size small and the interactivity high.

## MATERIALS AND METHODS

### Implement draft forces

The simulator was done only for heavy tillage work. In practice, if the size of the tractor and the implement are matched correctly, tillage is done with engine throttle set to full speed. Normally tractor engine performance measurement in tractor tests is only done with full speed and this information from test reports can be used in the simulation.

In heavy tillage the implement draft force depends on soil conditions, tillage depth, implement width and driving speed. The implement draft force was calculated with equation 1, where  $F_x$  is the draught force,  $S_i$  is a coefficient for the soil type,  $A$ ,  $B$  and  $C$  are implement related coefficients and  $v$  is the driving speed (km h<sup>-1</sup>),  $t$  is the working depth (m) and  $b$  (m) is the working width. This equation is widely used in implement draft and power calculations and it is given in standard ASAE D497 (ASAE D497). Also coefficient values can be found in the standard.

$$F_x = S_i (A + B \cdot v + C \cdot v^2) \cdot t \cdot b \quad (1)$$

The coefficients used in the simulation can be found in table 1. The ploughing coefficients were taken from ASAE D497 standard. The S-tine coefficients are based on own experiments. ASAE D497 coefficients were not used for S-tine because they do not include working depth information. The S-tine harrow can have different options, such as levelling plates or roller. Also it has normally supporting wheels. For the calculations only supporting wheel resistance was included and value of 0.3 kN m<sup>-1</sup> was used.

**Table 1.** Draft coefficients in ploughing and for one s-tine

Implement	$A$ kN m <sup>-2</sup>	$B$ kN h (m <sup>2</sup> km) <sup>-1</sup>	$C$ kN h <sup>2</sup> (m <sup>2</sup> km <sup>2</sup> ) <sup>-1</sup>	$S^*$
Moldboard plough (ASAE D497)	65.2	0	0.51	$S_1 = 1$ $S_2 = 0,7$ $S_3 = 45$
S-tine (single), organic soils	0.96	0.081	0	1
S-tine (single), loamy soils	0.86	0.347	0	1

\* $S_1$  is fine clay soil,  $S_2$  is medium texture loamy soils and  $S_3$  is coarse texture sandy soil

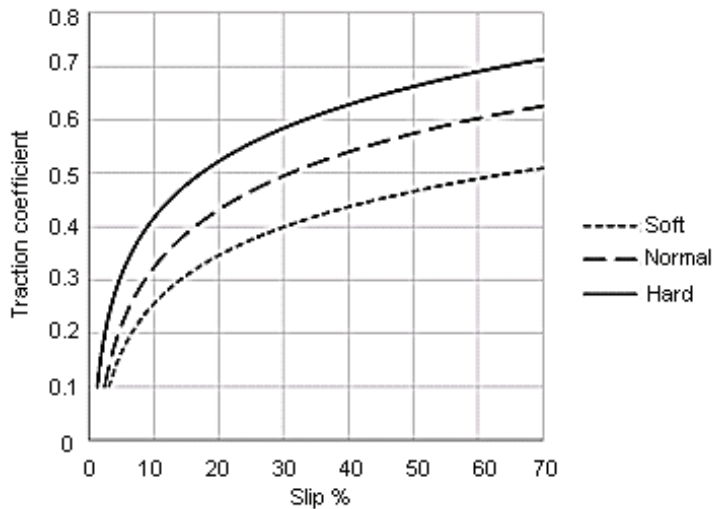
It is assumed that S-tine harrow is pulled with horizontal force, which means that there is no weight transfer from the harrow to the tractor. Plough, on the other hand, may be mounted, semi-mounted or pulled. The amount of weight transfer depends on the plough condition, mounting type and so il resistance and only an estimate can be

given. The simulation can be calculated with four different estimates from zero to 30% weight transfer from the plough on the tractor. For the plough weight transfer calculations it was assumed that a mounted reversible plough was in use. The weight of the plough and weight transfer is taken into account with this type of plough.

ASAE D497 standard states that the variation of the force can be quite high. For instance in ploughing it can be 50% from the calculated value depending on the implement type, condition and soil condition.

### Tractor pulling force

The implement requires a pulling force from the tractor and also the tractor requires its own rolling force. The soil in the simulation was divided into three different categories, hard, normal and soft. The corresponding rolling resistance coefficients were 0.06 on hard soil, 0.1 on normal soil and 0.15 on soft soil (Renius, 1999). The traction coefficients depend on wheel slip and the values were taken from the values given by Renius, Fig. 1.



**Figure 1.** Coefficient of traction as a function of slip on three different soil types (Renius, 1999).

In the simulation we calculate first the necessary traction coefficient and from that we solve the wheel slip. This was done using an exponential equation 2, where  $A$  and  $B$  are soil dependant coefficients, which were calculated from Fig. 1 curves.

$$s = Ae^{B\mu} \quad (2)$$

The pulling force of a four wheel driven tractor is given in equation 3, where  $\mu$  is the coefficient of traction,  $f$  is the coefficient of rolling resistance  $G$  is the weight of the tractor and  $\alpha$  is the slope.

$$F_p = (\mu - f)G \cos \alpha \pm G \sin \alpha \quad (3)$$

In calculations we must first calculate the traction coefficient value, which means that we have to solve equation 3 for  $\mu$ . After that we can calculate wheel slip with equation 2. In four wheel driven tractor we assume that traction of every wheel is about the same. The front and rear wheels are in agricultural tractors mechanically connected without differential between the axles. This means that we can consider the tractor as one traction unit and we do not have to calculate traction for each wheel independently.

Traction coefficient  $\mu$  is the wheel traction force  $F_n$  divided by the wheel load  $R$ . Because we are handling tractor as one unit, traction coefficient can be determined with equation 4, where  $F_n$  is the sum of wheel traction forces (four wheel driven tractor) and  $G$  is the weight of the tractor.

$$\mu = \frac{F_n}{G} \quad (4)$$

$F_n$  is the sum wheel traction forces and  $G$  is the weight of tractor. We must solve the wheel traction force  $F_n$  from this equation. With this force and wheel driving radius  $r$  we can calculate the torque of the driven axles and with the transmission gear ratio  $I$  we can calculate the engine torque  $T$ , equation 5.

$$T = F_n \cdot r \cdot i = \mu \cdot R \cdot r \cdot i \quad (5)$$

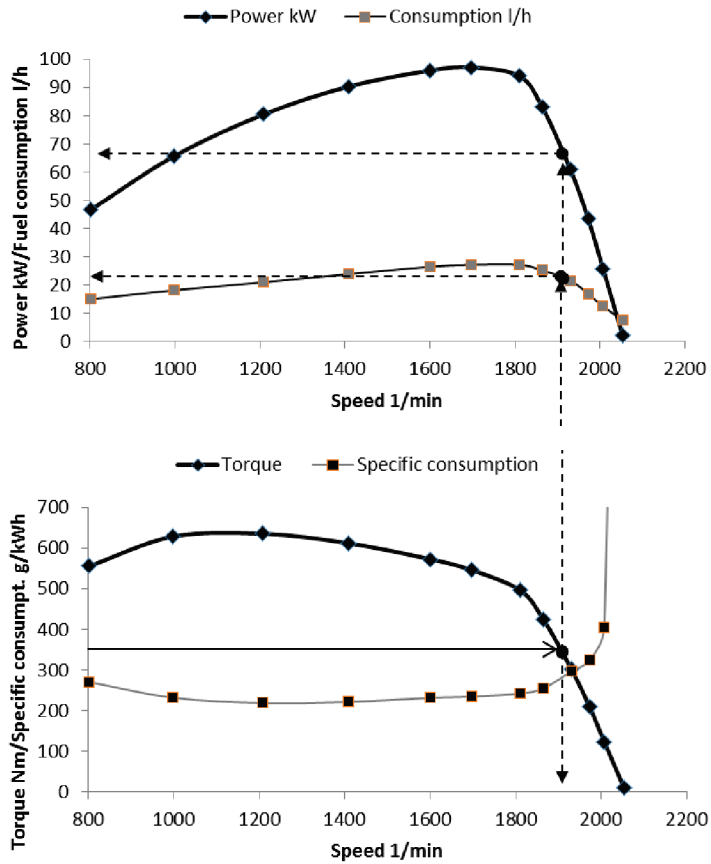
Extra ballast will increase the tractor weight and increase traction force, which in turn decreases wheel slip and improves performance. In four wheel driven tractors rear wheel or front weights act on the same way when front and rear wheel traction is assumed to be equal. For this reason the simulator needs only the total ballast amount regardless if it is on rear or front of the tractor.

### **Engine characteristics**

When the needed engine torque is known (equation 5), we can calculate the engine operating point. For this we need the tractor power curve. These we can find in different tractor test reports. For instance OECD tractor test results can be found at [http://www2.oecd.org/agr-coddb/index\\_en.asp](http://www2.oecd.org/agr-coddb/index_en.asp), Nebraska test reports can be found at <http://tractortestlab.unl.edu/testreports.htm> and DLG test reports at <http://www.dlg.org/tractors.html>. Beside these some agricultural journals also publish their own test data. We need in minimum six data point from the power curve, Fig. 2 shows an example tractor power curve.

The operating point is found after we have calculated the engine torque. Example in Fig. 2 shows that if we need a torque of 350 Nm, the corresponding engine speed is 1,900 1 min<sup>-1</sup> and the fuel consumption is 22 l h<sup>-1</sup>. Also we can see that the power taken from the engine is 68 kW and the specific fuel consumption is 290 g (kWh)<sup>-1</sup>.

In simulation the operating point falls in most cases between two measured points. Then the point is calculated from the adjacent measured points with linear interpolation.



**Figure 2.** Example of tractor engine characteristics (Valtra T 140).

### Work rate and work specific fuel consumption

The driving speed and fuel consumption  $q_l$  ( $l h^{-1}$ ) do not reveal how efficiently the work is done. The work rate can be calculated from the implement width and driving speed, equation 6.

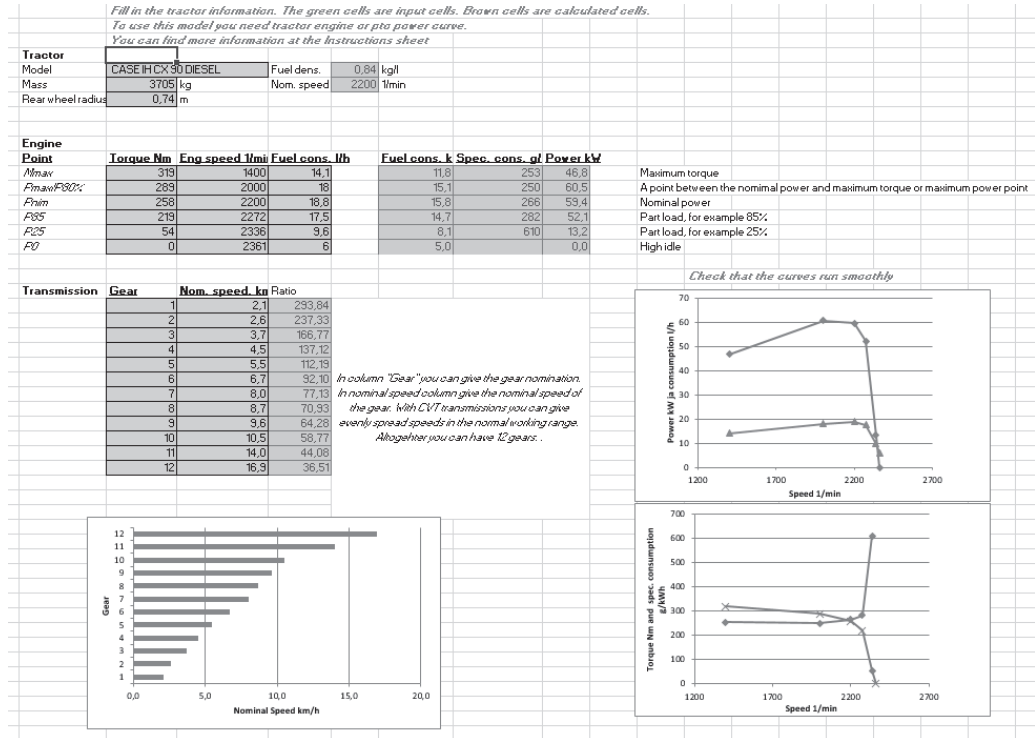
$$q_A [ha h^{-1}] = \frac{v [km h^{-1}] \cdot b [m]}{10} \quad (6)$$

Fuel consumption per worked area  $q_f$  can now be calculated with equation 7.

$$q_f [l ha^{-1}] = \frac{q_l [l h^{-1}]}{q_A [ha h^{-1}]} \quad (7)$$

## RESULTS

The simulator was done with Excel spreadsheet program. Besides spreadsheet calculations also user defined functions were used and they were done with visual basic. Fig. 3 shows the tractor information fill in form.



**Figure 3.** Tractor information is given by filling in the green coloured cells.

When the tractor information is filled in it is possible to choose from the spreadsheet tab if ploughing or S-tine harrowing is simulated. Fig. 4 shows an example of simulation in ploughing. Different conditions can be tested by changing the plough, soil and tractor characteristics. If the tractor gear is improper and the engine stops, then a message is shown on the left side of the results. On the last column is shown the slip value importance. Normally 10–20% slip gives best traction efficiency. If slip exceeds 20% there is a danger of rut deformation on the field, which will destroy the soil structure.

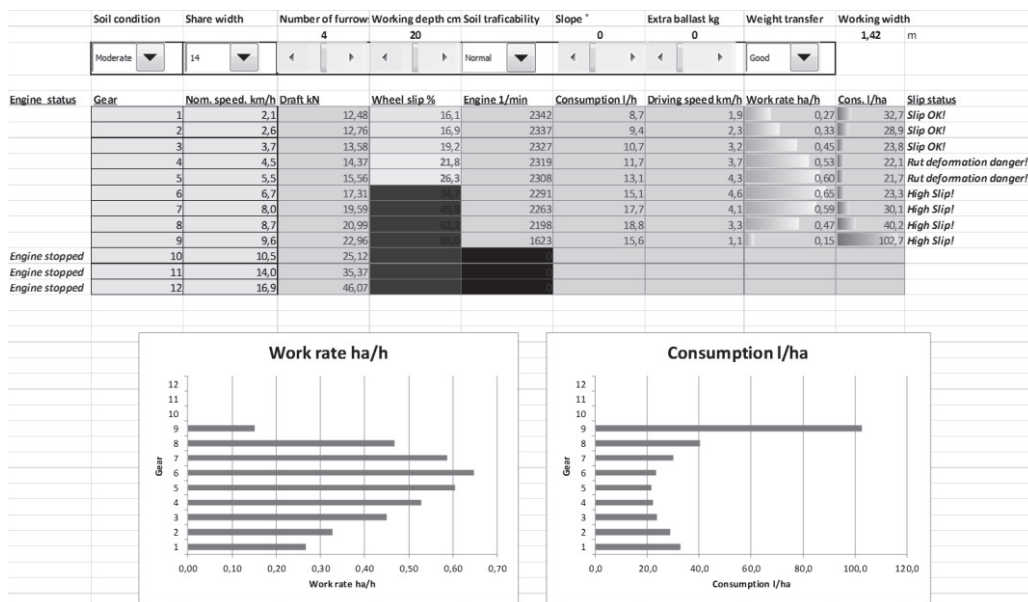


Figure 4. Simulation of ploughing.

Fig. 5 shows an example of ploughing result. The minimum fuel consumption is gained with gears M3L and M2H while the maximum work rate is gained with gears M4L, M3H or H1L. Wheel slip is however high with these gears, which means that the tractor needs more ballast. It is also common that the minimum fuel consumption and maximum work rate do not occur with the same gear.

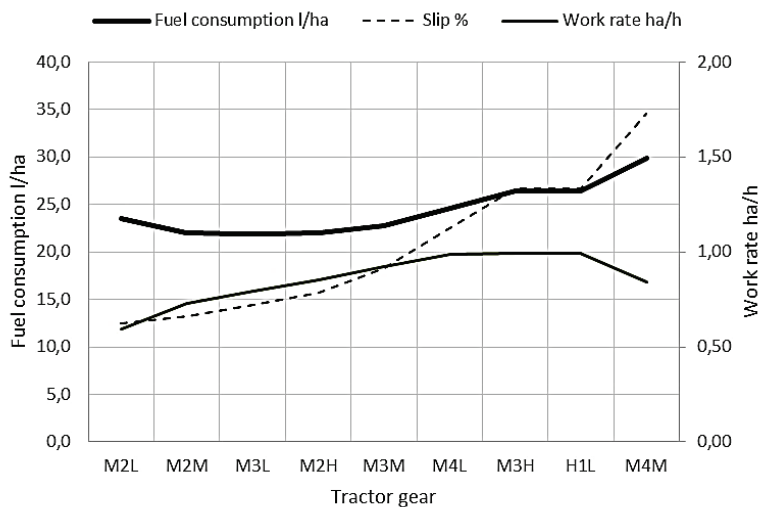


Figure 5. Result from ploughing simulation.

## CONCLUSIONS

Tractor simulator was programmed in Excel spreadsheet. Users can experiment with their own tractor and implement and see how different adjustments and conditions affect on the operation parameters in hard tillage work.

The spreadsheet program was chosen because it is commonly used and it is easy to make calculations in it. However, simulation in this environment has some restrictions and it would be easier to make it in normal programming language. The restrictions in the spreadsheet programming occur especially when there are several choices to make or the results should be chosen depending on different conditions.

There can be lot of variation in the soil conditions as well as in implement type and function. This means that the assumptions and simplifications made in the simulator calculations do not have much influence on the results because more variation is caused by the soil, implement and tractor parameters.

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