Draft and Fuel Requirements in Tillage Operations: Modelling for Optimizing Tractor-Implement Systems

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Abstract

A three years research project was developed to study tractor-implement dynamics in tillage operations. This paper reports the results of field tests performed under real working conditions, using more than twenty tractors (four-wheel-drive) and trailed disc harrows combinations, in different soils conditions. The data show the existence of a linear relationship between the drawbar pull per unit of implement width, and the fuel consumption per hectare. The results put in evidence the benefits of the "gear up, throttle down" approach.

Key words: Fuel consumption per hectare, draft, disc harrows.

1 Introduction

Soil working operations in traditional farming systems involving the use of the tractor are among the operations which incur the highest levels of energy costs. The sustainability of such systems requires the strictly-controlled management of resources leading to the significant reduction of crop-production costs deriving from savings in fuel consumption.

The overall energy efficiency is the ratio of the energy transferred from the tractor to operate the implement, to the energy equivalent of the fuel consumption required to perform the operation. The overall energy efficiency is dependent on a range of performance factors namely, engine, power transmission and the interaction of tyres with the soil. This last factor implies the definitive influence of the soil as a major factor on the overall energy efficiency. This is the reason behind different authors (Bowers, 1985; Riethmuller, 1989; Smith, 1993), being cautious concerning the domain of application of their results.

The Tractor Performance Monitor (TPM) is increasingly being supplied as standard tractor electronic equipment, or factory-fitted option, and they provide information to assist tractor drivers and farm managers. TPM are also an excellent base to perform experiments in real working conditions gathering data that can be used to validate the real importance of the different variables present in the dynamics of tractor-soil-agricultural implement (Peça *et al*, 1998).

A program of experiments using a 59kW TPM equipped agricultural tractor, pulling two different trailed disc harrows has been accomplished (Serrano, 2002; Serrano *et al*, 2003). Tests performed in different soil conditions and at several paired relations of tractor weight/implement width enabled to establish relations between fuel consumption per hectare (C_{ha}) and soil/implement resistance per unit of implement width ($\Im$).

Figure 1 shows one of such relations valid for dry, undisturbed loam soils and two engine settings: rated speed and 80% of the rated speed, selecting in both cases the highest gear in the transmission at which the work could be performed with the required quality (tilth, buried stubble), within accepted comfort and safety for the operator, and without engine overcharge (no significant decrease in engine speed).

The ratio between ℑ and C_{ha} is in fact the value of energy transferred to the implement, per volume unit of fuel consumption, and therefore the overall efficiency of the tractor.
Since the overall fuel efficiency, is also influenced by tractor engine and transmission and its settings, it was decided to validate the above equations with further test not only with same tractor and harrow combination in other soil conditions, but also with data collected from farmer's own tractor-disc harrow set up.

2 Materials and Methods

Tractor and implement
In the field trials various models of trailed offset disc harrows ranging, from 20 to 40 discs, were pulled behind four-wheel-drive tractors, all of the same make, ranging from 59 to 134kW. These tractors are factory equipped with TPM providing relevant information such as engine speed; actual forward speed; slip; and fuel consumption per hour. Details of the different tractor implement combinations are presented in table 1.

Soils
Soil samples were collected and analysed. Details of the different soil types are presented in table 2.

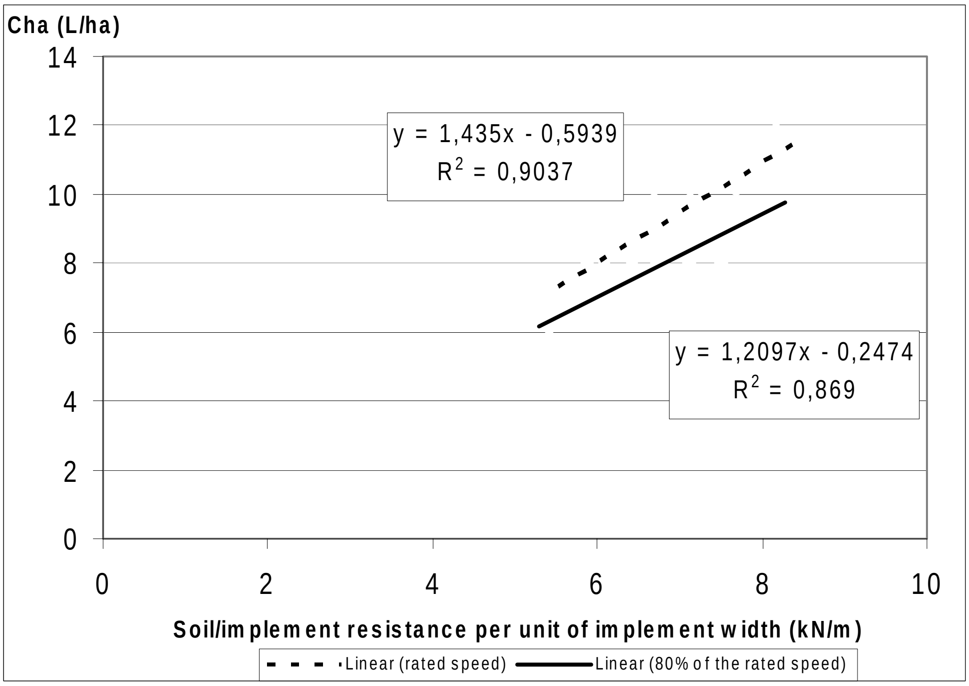

Fig. 1 Relation between fuel consumption per hectare (C_{ha}) and soil/implement resistance per unit of implement width (ℑ). From tests with a tractor and trailed disc harrow combination, on dry, undisturbed, medium texture soils. Adapted from Serrano (2002)

Test Procedure
The field tests were conducted in 80 to 100m runs, with 2 replications, in private farms in real conditions of work, either using farmer's own equipment and operator or using similar equipment from the university. All test were performed on undisturbed soil conditions, mainly stubble covered soil. Prior to every test, various settings were tested concerning the angle between disc gangs, and the combinations of engine regime-gear selection that would allow the establishment of the following two work conditions:

- Settings aiming to maximize the work rate: engine at the rated speed; and selecting the highest gear in the transmission at which the work could be performed with the required quality (tilth, buried stubble), within accepted comfort and safety for the operator, and without engine overcharge (no significant decrease in engine speed);

- Settings aiming to compromise between fuel consumption and working rate: engine at 80% of the rated speed; and selecting the highest gear in the transmission at which the work could be performed with the required quality (tilth, buried stubble), within accepted comfort and safety for the operator, and without engine overcharge (no significant decrease in engine speed).

The average depth of the mobilised soil layer was obtained from at least 8 values, obtained along the run, being each value, in turn, the average result from three measurements taken across the width of each run. Average working width was obtained from at least 6 direct measurements across each harrowed path.

Table 1 Tractor/implement combinations used on field trials

Site	Tractor Model (Maximum Power, kW)	Harrow make and model (Nº of discs – disc diameter)	α (º)	w (m)	d (m)
1	MF3680 (134)	Galucho (GLHR36-26")	25 34	3,95 3,95	0,085 0,105
2	MF3095 (81)	Galucho (GLHR24-26")	53 31	2,93 2,93	0,180 0,180
2	MF3060 (59)	Herculano (HPR20-24")	46 37	2,07 2,10	0,180 0,180
3	MF3095 (81)	Premetal (PLHR26-26")	44 33	3,01 3,13	0,180 0,150
3	MF3060 (59)	Herculano (HPR20-24")	46 37	2,06 2,13	0,180 0,166
4	MF3650 (110)	Galucho (GSM24-28")	44	2,89	0,180
4	MF3060 (59)	Herculano (HPR20-24")	46	2,08	0,190
5	MF8130 (114)	Premetal (PLHR26-26")	43 27	3,19 3,31	0,180 0,180
5	MF3060 (59)	Herculano (HPR20-24")	46 37	2,17 2,10	0,165 0,165
6	MF3095 (81)	Galucho (A2CP24-26")	54	2,43	0,145
6	MF3095 (81)	Halcon (28-24")	43 37	3,30 3,36	0,132 0,156
6	MF3060 (59)	Herculano (HPR20-24")	46 37	2,07 2,11	0,182 0,158
7	MF3060 (59)	Galucho (A2CP24-26")	54 38	2,52 2,60	0,170 0,130
7	MF3060 (59)	Galucho (A2CP22-24")	54	2,20	0,140
7	MF3060 (59)	Herculano (HPR20-24")	46	2,08	0,190
8	MF3060 (59)	Herculano (HPR20-24")	46	2,18	0,170
9	MF3060 (59)	Herculano (HPR20-24")	46	2,09	0,220
9	MF3060 (59)	Fialho (RTM20-24")	51	2,20	0,220
10	MF3060 (59)	Herculano (HPR20-24")	46	2,34	0,160
11	MF3060 (59)	Herculano (HPR20-24")	46	2,14	0,165

Table 2 Soil physical parameters obtained at the test location (200 mm top layer)

Site	Sand-Loam-Clay (%)	Type of soil	Moisture content, d. b. (%)
1	48-23-29	Clay loam	4,0
2	68-13-19	Sandy loam	11,5
3	73-9-18	Sandy loam	15,0
4	49-23-28	Clay loam	12,0
5	73-10-17	Sandy loam	19,0
6	69-13-18	Sandy loam	8,0
7	65-10-25	Sandy clay loam	8,0
8	75-9-16	Sandy loam	14,0
9	64-20-16	Loam	15,0
10	61-15-24	Sandy clay loam	17,0
11	39-24-37	Clay loam	17,0

Data Acquisition System – DAS

Information provided by the TPM is volatile. To overcome this limitation a portable computer based record system was developed [6], which deviates the signals from the tractor TPM sensors and also the information from the 50kN capacity load cell based pull-measuring system.

A LabVIEW application was developed to control the data acquisition process. The following data was collected in the field tests: - actual tractor forward speed (v_a); - engine speed (n); - fuel consumption per hour (C_h); drawbar pull (T).

The above mentioned DAS, was used solely with the university owned MF3060 tractor. In all other tractors, a voice recorder was used to register several readings from the TPM, obviating any further modifications on farmer's equipment.

The data was analysed in the lab using a spreadsheet. Entering the working width of the implement (w), the following performance parameters were calculated: soil/implement resistance per unit of implement width ($\Im$) and fuel consumption per hectare (C_{ha}).

3 Results and Discussion

Figure 2 and figure 3 show the measured results plotted against the predicted results the equations of figure1.

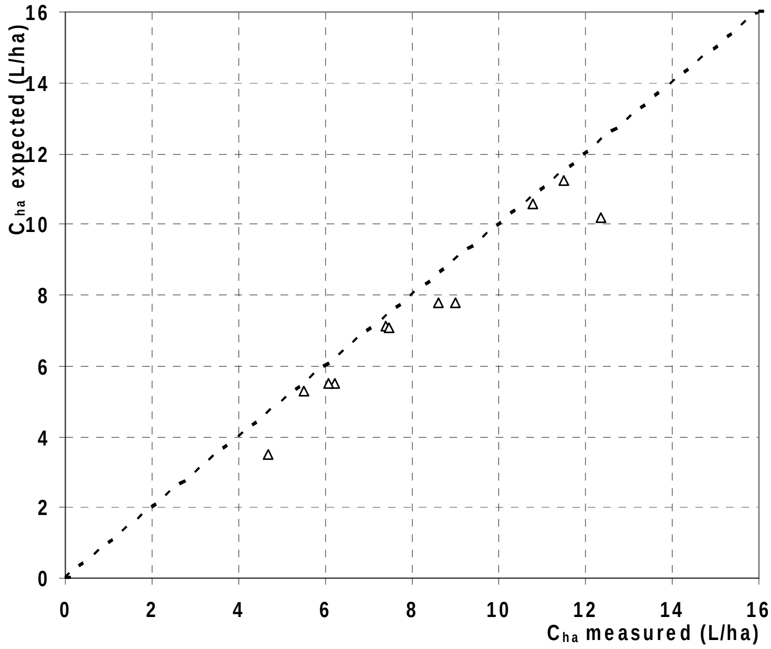

Fig. 2 Measured results of fuel consumption per hectare (C_{ha}), plotted against the predicted results from equation C_{ha}=1.435*$\Im$-0.5939. Settings aiming to compromise between fuel consumption and working rate (engine at 80% of the rated speed)

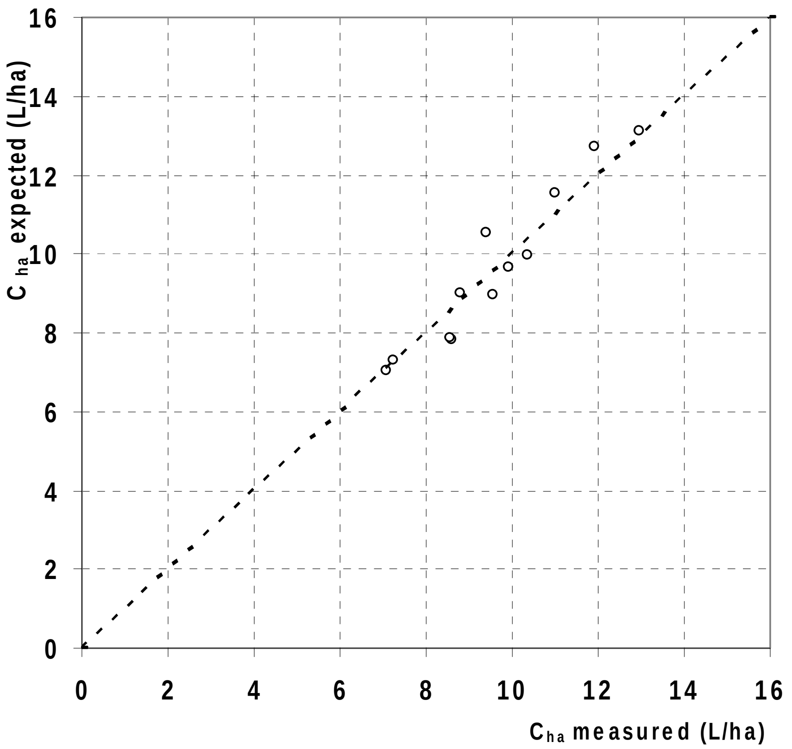

Fig. 3 Measured results of fuel consumption per hectare (C_{ha}), plotted against the predicted results from equation C_{ha}=1.2097*$\Im$-0.2474. Settings aiming to maximize the work rate (engine at the rated speed)

The results of tests performed with other tractor and disc harrow combinations fit closely the relation between (C_{ha}) and ($\Im$) presented in the introduction. It should be remembered the particular soil conditions from which the relation resulted: dry, undisturbed loam soils presented in table 2, as commonly found in primary cultivations with trailed disc harrows in southern Portugal. Heavier clay soils, particularly in wetter conditions, may not fit into the present results, since the expected higher slip in the interaction of tyres with soil will affect negatively and to a greater extent the overall energy efficiency.

Furthermore, the results still confirm the advantage of setting engine speed towards the maximum torque regime, approaching a more favourable range of engine thermal efficiency, and therefore improving the overall fuel efficiency of the tractor.

4 Conclusions

Within the conditions tested, data show a linear relationship between the fuel consumption per hectare and drawbar pull per unit of implement width. This relation represents various tractors and trailed disc harrows models, various combinations of gear and engine speed, various tractor ballasts and tyre pressures, in dry, undisturbed loam soils, common in the dry farming system of Alentejo (Southern Portugal).

The results demonstrate that fuel consumption in tillage operations can be minimised by selecting an engine speed approximately 70-80% of the nominal speed, and using a higher gear (“shift-up throttle-down” concept).

The above equations can be used to extend the ASAE model (ASAE Standards,1993) of drawbar pull prediction to forecast the fuel consumption.

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Nomenclature

ASAE American Society of Agricultural Engineers
C_h fuel consumption per hour, L/h
C_{ha} fuel consumption per hectare, L/ha
C_s specific fuel consumption, g/kWh
d working depth, m
d.b. dry basis, %
DAS Data Acquisition System
n engine speed, rpm
T draft or drawbar pull, kN
TPM Tractor performance monitor
v_a actual forward speed, km/h
w working width, m

α angle between disc gangs, degrees
$\Im$ drawbar pull per unit of implement width, kN/m

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