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Short communication. Evaluation of the energy requirements in tractor-disc harrow 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 four wheel drive tractors and trailed disc harrows combinations, under different soils conditions. The data show a linear relationship between the drawbar pull per unit of implement width and the fuel consumption per hectare. The results give evidence of the benefits of the «gear up, throttle down» approach.

Additional key words: draft, fuel consumption per hectare, prediction.

Resumen

Comunicación corta. Evaluación energética del sistema tractor-grada de discos

Se ha llevado a cabo un trabajo de tres años para estudiar la dinámica del sistema tractor-grada de discos. En este artículo se presentan los resultados de ensayos realizados con tractores y aperos en condiciones reales, en diferentes tipos del suelo. Una vez optimizadas las regulaciones con el tractor y la grada se han podido establecer unas ecuaciones de referencia que relacionan el consumo de combustible por hectárea y la tracción por unidad de anchura de trabajo. Estas ecuaciones marcan unas referencias que permiten deducir el grado de optimización de un conjunto en las diferentes situaciones del campo. Los resultados ponen en evidencia los beneficios de trabajar en la correcta regulación del régimen y de la caja de velocidad.

Palabras clave adicionales: consumo de combustible por hectárea, predicción, tracción.

Soil working operations in traditional farming systems involving the use of tractors are among the operations which incur the highest energy costs. The sustainability of such systems requires strictly-controlled resource management leading to a significant reduction in 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 to the fuel consumption required to perform the operation.

The overall energy efficiency depends 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 soil as a major factor in overall energy efficiency. This is the reason why different authors (Bowers, 1985; Riethmuller, 1989; Smith, 1993), are cautious about the domain of application of their results.

The Tractor Performance Monitor (TPM) is increasingly being supplied as standard tractor electronic equipment, or as a factory-fitted option. They provide information to assist tractor drivers and farm managers. The TPM is also an excellent base to perform experiments under real working conditions gathering data that can be used to validate the importance of the different

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Nomenclature used: C_h (fuel consumption per hour, L h^{-1}); C_{ha} (fuel consumption per hectare, L ha^{-1}); C_s (specific fuel consumption, g kWh^{-1}); d (working depth, m); d.b. (dry basis, %); DAS (data acquisition system); n (engine speed, min^{-1}); T (draft or drawbar pull, kN); TPM (tractor performance monitor); v_a (actual forward speed, km h^{-1}); w (working width, m); α (angle between disc gangs, degrees); $\Im$ (drawbar pull per unit of implement width, kN m^{-1}).

variables present in the dynamics of the tractor-soil-agricultural implement (Peça *et al.*, 1998).

A program of experiments using a 59 kW TPM equipped agricultural tractor, pulling two different trailed disc harrows was conducted (Serrano, 2002; Serrano *et al.*, 2003). Tests were performed under different soil conditions and at several paired relationships of tractor weight/implement width to establish the relationship between fuel consumption ha^{-1} (C_{ha}) and soil/implement resistance per unit implement width ($\Im$).

Figure 1 shows such relationship 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 at 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 $\Im$ 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 the tractor engine and transmission and their settings, the aim of this work was to validate the above equations with further tests not only with same tractor and harrow combination under other soil conditions, but also with data collected from farmer's own tractor-disc harrow set ups.

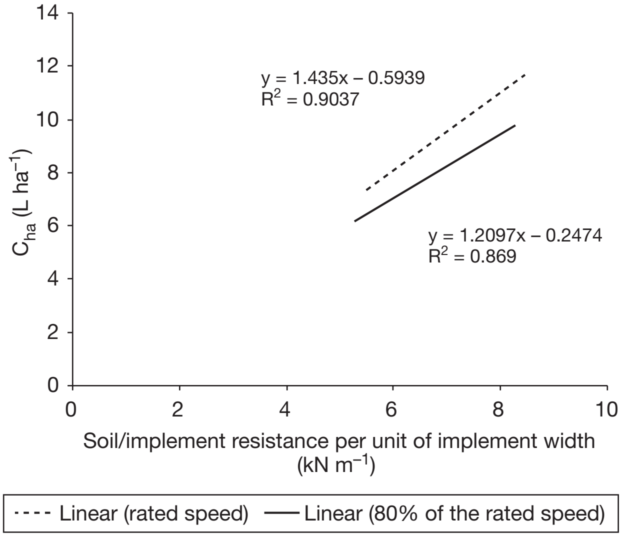

Figure 1. Relationship between fuel consumption per hectare (C_{ha}) and soil/implement resistance per unit implement width($\Im$). From tests with a tractor and trailed disc harrow combination, on dry, undisturbed, medium textured soils. *Source:* Serrano (2002).

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

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

— Settings aiming at a compromise between fuel consumption and work rate: engine at 80% of the rated speed; and selecting the highest gear in the transmission at which the work could be performed at the required quality (tilth, buried stubble), with accepted comfort and safety for the operator, and without engine overcharge.

The average depth of the mobilised soil layer was obtained from at least eight values, taken along the run, with each value, being the average result from three measurements taken across the width of each run. The average working width was obtained from at least six direct measurements across each harrowed path.

In field trials by Serrano (2002) 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 134 kW. These tractors were factory equipped with TPM providing relevant information such as engine speed; actual forward speed; slip; and fuel consumption hour^{-1}. Details of the different tractor implement combinations are given in Table 1.

Details of the different soil types are also given in Table 1. The test sites were chosen according to utilisation of disc harrows for primary cultivation.

Soil samples were collected prior to each field trail, to 200 mm depth, and were analysed in the Soil Physics Laboratory of the University of Évora, in accordance with standard methodology (White, 1993).

Information from the TPM is volatile. To overcome this limitation a portable computer based record system was developed (Fig. 2), which recorded signals from

Table 1. Soil physical parameters at the test location (200 mm top layer) and tractor/implement combinations used in field trials

Site	Sand-loam-clay (%)	Moisture content, d. b. (%)	Bulk density (kg m^{-3})	Cone index (MPa)	Tractor model (maximum power, kW)	Harrow model (No. of discs-discs diameter)	α (°)	w (m)	d (m)
1. Cortes	48-23-29	4.0	1.648	2.887	MF3680	Galucho GLHR	25	3.95	0.085
					(134)	(36-26”)	34	3.95	0.105
2. Mira	68-13-19	11.5	1.326	2.203	MF3095	Galucho GLHR	53	2.93	0.180
					(81)	(24-26”)	31	2.93	0.180
					MF3060	Herculano HPR	46	2.07	0.180
					(59)	(20-24”)	37	2.10	0.180
3. Tojal	73-9-18	15.0	1.592	1.875	MF3095	Premetal PLHR	44	3.01	0.180
					(81)	(26-26”)	33	3.13	0.150
					MF3060	Herculano HPR	46	2.06	0.180
					(59)	(20-24”)	37	2.13	0.166
4. Outeiro	49-23-28	12.0	1.394	1.658	MF3650	Galucho GSM	44	2.89	0.180
					(110)	(24-28”)			
					MF3060	Herculano HPR	46	2.08	0.190
					(59)	(20-24”)			
5. Oliveiras	73-10-17	19.0	1.286	0.856	MF8130	Premetal PLHR	43	3.19	0.180
					(114)	(26-26”)	27	3.31	0.180
					MF3060	Herculano HPR	46	2.17	0.165
					(59)	(20-24”)	37	2.10	0.165
6. Lentisca a	69-13-18	8.0	1.528	1.897	MF3095	Galucho A2CP	54	2.43	0.145
					(81)	(24-26”)			
					MF3095	Halcon	43	3.30	0.132
					(81)	(28-24”)	37	3.36	0.156
					MF3060	Herculano HPR	46	2.07	0.182
					(59)	(20-24”)	37	2.11	0.158
7. Lentisca b	65-10-25	8.0	1.560	1.732	MF3060	Galucho A2CP	54	2.52	0.170
					(59)	(24-26”)	38	2.60	0.130
						Galucho A2CP	54	2.20	0.140
						(22-24”)			
						Herculano HPR	46	2.08	0.190
						(20-24”)			
8. Cabanas	75-9-16	14.0	1.498	1.688	MF3060	Herculano HPR	46	2.18	0.170
					(59)	(20-24”)			
9. Louseiro	64-20-16	15.0	1.543	1.345	MF3060	Herculano HPR	46	2.09	0.220
					(59)	(20-24”)			
						Fialho RTM	51	2.20	0.220
						(20-24”)			
10. Revilheira	61-15-24	17.0	1.492	0.945	MF3060	Herculano HPR	46	2.34	0.160
					(59)	(20-24”)			
11. Figueira	39-24-37	17.0	1.476	1.123	MF3060	Herculano HPR	46	2.14	0.165
					(59)	(20-24”)			

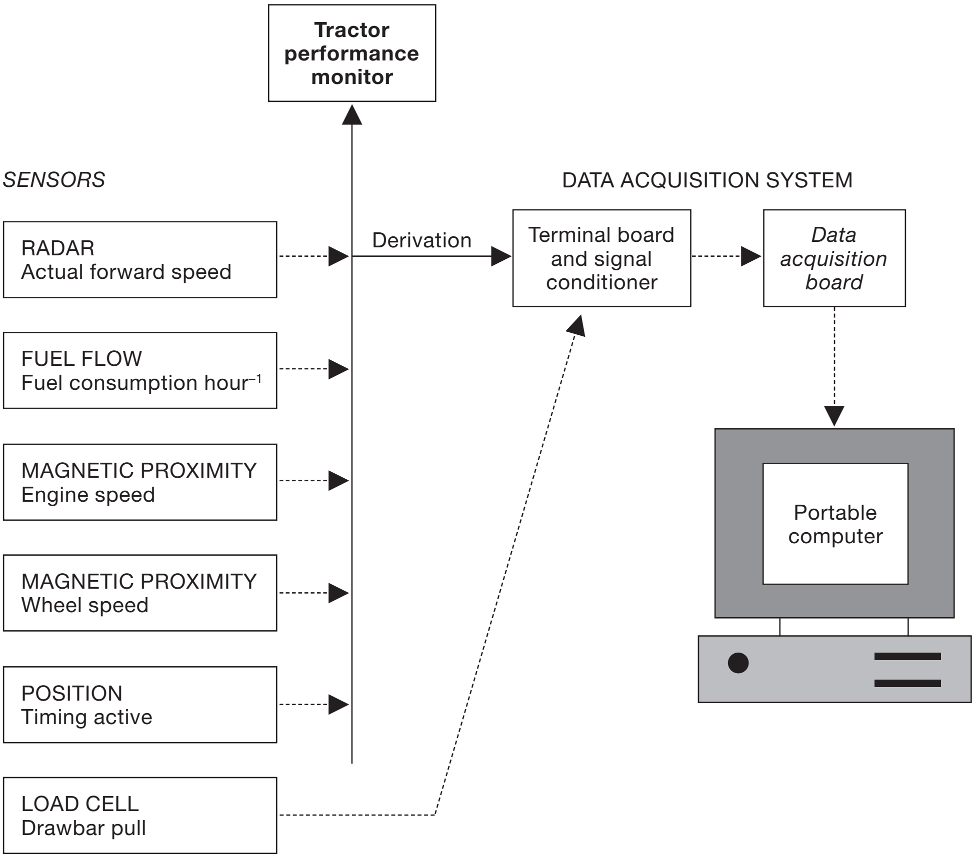

Figure 2. The data acquisition system (DAS).

the tractor TPM sensors and information from a 50 kN capacity load cell based pull-measuring system.

A LabVIEW application was developed to control the data acquisition process. The following data were collected in the field tests: v_a, actual tractor forward speed (km h^{-1}); n, engine speed, in rpm; C_h, fuel consumption per hour (L h^{-1}); T, drawbar pull or draft (kN).

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

The data were analysed in the laboratory using a spreadsheet. Entering the working width of the implement (w), the following performance parameters were calculated: $\Im$, soil/implement resistance per unit of implement width, in kN m^{-1}; and C_{ha}, fuel consumption per hectare, in L ha^{-1}.

Figure 3 shows the measured results plotted against the predicted results from the equations of Figure 1.

The results of tests performed with other tractor and disc harrow combinations closely fit the relationship between C_{ha} and $\Im$ given in the introduction. The particular soil conditions from which the relationship resulted: dry, undisturbed loams, presented in Table 1, are commonly found in primary cultivation with trailed disc harrows in southern Portugal. Heavier clay soils, particularly under wetter conditions, may not fit these results, since the expected higher slip in the interaction of the tyres with the soil will have negative effect and influence overall energy efficiency.

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

Under the conditions tested, the data shows a linear relationship between fuel consumption per hectare and drawbar pull per unit implement width. This relationship represents various tractor and trailed disc harrows models, various combinations of gear and engine speed and various tractor ballasts and tyre pressures, in dry, undisturbed loams, common in the dry farming system of southern Portugal.

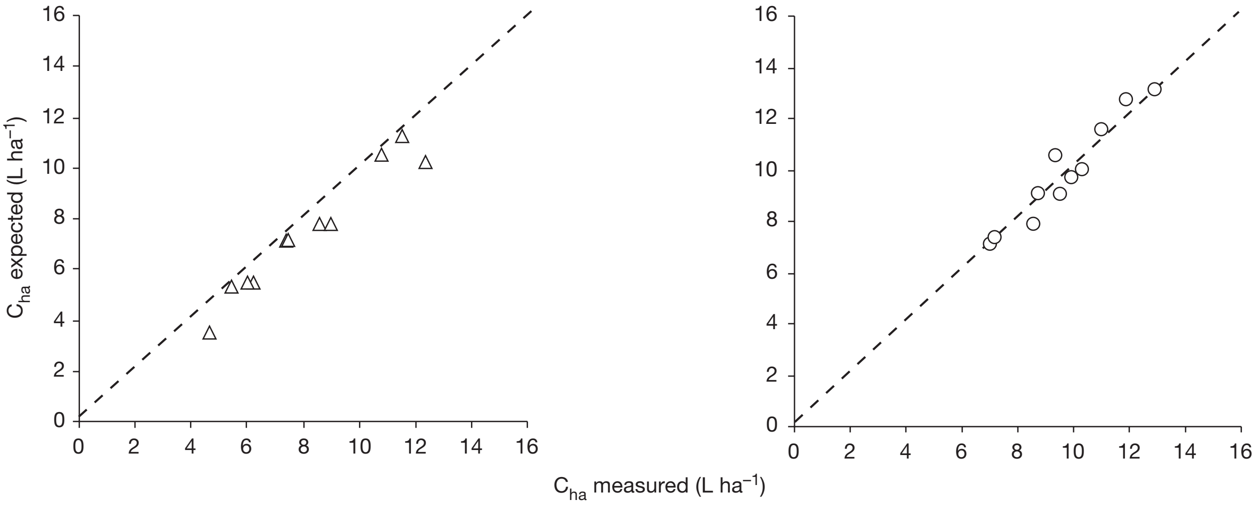

Figure 3. Measured results of fuel consumption hectare^{-1} (C_{ha}), plotted against predicted results from the equation $C_{ha} = 1.435*\Im - 0.5939$ (left) and equation $C_{ha} = 1.2097*\Im - 0.2474$ (right). Left: settings aiming at a compromise between fuel consumption and working rate (engine at 80% of the rated speed); Right: settings aiming at maximizing the work rate (engine at the rated speed).

The results demonstrate that fuel consumption in tillage operations can be minimised by selecting an engine speed of approximately 70-80% of the nominal speed, and using a higher gear.

The above equations can be used to extend the ASAE model of drawbar pull prediction to forecast fuel consumption.

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