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Title:

"Tractor Performance Monitors optimizing tractor and implement dynamics in tillage operations - one year of field tests"

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Summary:

The relative weight of the variables present in the dynamics of tractor-soil-trailled disc harrow is studied under real agricultural conditions, from the results of the first year of a three years project. Input parameters (tractor ballast; implement size; transmission gear) are made variable, within limits accepted by farmers. The results are analised in terms of the working rate and fuel consumption per unit area in two sand based soils at moisture content accepted for disc harrowing.

Key Words: Disc harrow; Tractor ballast; Gear up and throttle down; Work rate; Fuel consumption per unit area.

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Abstract

The relative weight of the variables present in the dynamics of tractor-soil-trailed disc harrow is studied under real agricultural conditions, from the results of the first year of a three years project. Input parameters (tractor ballast; implement size; transmission gear) are made variable, within limits accepted by farmers. The results are analysed in terms of the working rate and fuel consumption per unit area in two sand based soils at moisture content accepted for disc harrowing.

Key Words: Disc harrow; Tractor ballast; Gear up and throttle down; Work rate; Fuel consumption per unit area.

Introduction

In Portugal, the absence of data means that decisions concerning the choice of implement and tractor-implement working set-up, are taken on the basis of empirical knowledge or on limited scientific information. The questions of correct dimensioning are real, but difficult to answer in the face of the variability of type and of soil conditions.

Most of the research all over the world, with engines, tyres and fully instrumented tractors has been building up a package of valuable information. However, the practical impact of some of these results is difficult to assess due to the particular input conditions of the experiment. On the other hand, Tractor Performance Monitors (TPM), are increasingly being supplied as standard equipment, or factory-fitted option, and they can provide an excellent base to perform experiments in real working conditions and to use the gathered data to validate the real importance of the different variables present in the dynamics of tractor-soil-agricultural implement.

TPM have the fundamental advantage of being an equipment also used by the end user of the research results, making possible, inclusively, to perform demonstration experiments at the farmer's own premises.

Objectives

A three years research project was approved by the Portuguese Agriculture Ministry to study the relative weight of different variables present in the dynamics of the interaction tractor-soil-agricultural implement by experimental observations, based on the TPM, taken under real working conditions imposed to the system:

-evaluation of different paired relations of tractor weight/implement width, building up a matched set;

- the effects of "gear-up, throttle down" on performance parameters: fuel consumption per hectare cultivated and work rates.

In this first attempt a heavy-duty trailed A-type disc harrow is being studied. This locally manufactured equipment is very relevant in the portuguese agricultural practice, either as a primary or as secondary tillage tool.

Material and Methods

Equipment

Tractor

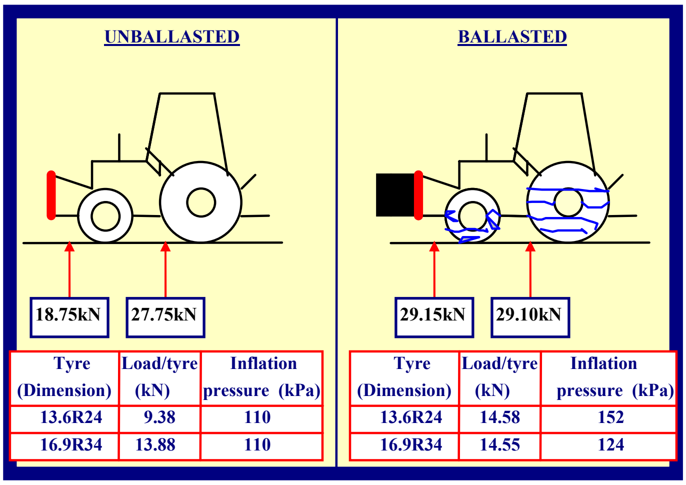
A four-wheel-drive (4WD), 59kW (DIN), Massey-Ferguson 3060 Datatronic tractor, was used in the field trials. This tractor size is considered to be typical in arable farms in Portugal.

This tractor is factory equipped with a tractor-performance-monitor (TPM), which, among other functions, provide relevant information such as: engine speed, actual forward speed, slip and fuel consumption per hour.

Tyre size is 13.6R24 and 16.9R34, respectively in the front and rear axles.

This tractor is also equipped with a three-point-hitch system in the front, enabling the easy coupling of 5.25 kN of front ballast weights. Figure 1 shows the static axle loads for the unballasted tractor (UB) and the ballasted (B) version, the latter being obtained by the adoption of front ballast weights and 75% volume water filled front and rear tyres.

Figure 1- Static axle loads and tyres inflation pressure in the unballasted and ballasted tractor.



In the ballasted tractor tyre inflation pressure was adjusted according to tyre static vertical load following tyre manufacturer manual. However, on the unballasted tractor, tyre inflation pressure used was considerable higher than the suggested by the manual, in order to prevent tyre damage due to over deflection.

Implements

Two trailed type medium-weight offset disc harrows were used in the field trials (Table 1).

Table 1- Trailed disc harrows.

Harrow	Diameter disc (mm)	Number of discs	Static weight per disc (daN/disc)	Disc spacing (mm)	Max. working width (mm)
H1	610	20	65	230	2350
H2	610	24	61	230	2750

These implements were chosen according to the following criteria:

- -very popular among farmers as primary and secondary cultivation tool;
- -important implement within the strategy for reduced cultivations;
- -well represented within the local farm machinery industry.

Working depth (d), in meters, was obtained from the average of three measurements of the depth of the furrow wall produced by the end disc of the rear gang.

Average working width was obtained dividing the full width of harrowed plot by the number of the consecutive passes.

Data Acquisition System - DAS

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

The adopted solution consists on a portable computer equipped with a data acquisition board capable of up to 8 single ended channels, 12 bit resolution and 100 000 samples per second and a terminal board providing the appropriate connection and the voltage excitation for the 50 kN capacity load cell. As the inputs to the terminal board have to be less than 1 V, resistor voltage dividers were used where appropriate.
A LabVIEW application was developed to control the data acquisition process. The application design had some requirements in mind namely the need of just a few strokes to perform all the necessary tasks and a friendly and easily readable screen.
A signal provided by the manual operation of the “Timing active” function switch of the TPM at the end of each 50m run, triggers the program to save the data. The corresponding file is named after the date hour information provided by the PC.
The data was analysed in the lab using a spreadsheet.
An approximate rolling radius was introduced in the DAS in order to compute slip. The value used was the average of the values of the static tyre radius measured with and without vertical load obtained from the tyre manufacture catalogue for the rear tyre.
In each soil condition and tractor ballast, the slip measured by DAS was confronted with the slip obtained from the comparison of the distances travelled in the classic load/no load slip test. The results were so close that no corrections on the rolling radius were necessary.

Soils

Two fields with different soil types (Lagoa- Transition of the Sandy clay loam to Loamy sand and Sítima- Sandy loam) were selected for conducting field tests. These fields, located in private farms, have typical soils of the region of Évora (Alentejo, Southern Portugal). Two soil conditions were tested: undisturbed (UD) to provide a firm soil and disturbed soil (SD), condition obtained after 30 cm depth ploughing at Lagoa site, and after 20 cm depth cultivating with a spring cultivator-harrow at Sítima site.
At each site a 5 ha area was allocated for field tests.
Prior to each test physical soil parameters were evaluated and are summarised in table 2.

Table 2- Soil physical parameters obtained in the test location (200 mm top layer).

Type of soil	Sítima-Sandy loam		Lagoa-Transition of the Sandy clay loam to Loamy sand	
Condition of the soil	Undisturbed	Disturbed	Undisturbed	Disturbed
Moisture content, d.b. (%)	9.7	10.5	12.6	15.7
Soil dry bulk density (kg/m^3)	1475	1349	1580	1459

In an effort to match field trials to real farming conditions, the opinion of the farmer, regarding soil condition to disc harrowing, was taken into account, at each test site.

Test Procedure

The experimental design was a complete randomised block with 32 treatments and 3 replications. The treatments result from the combinations of 5 factors: 2 soils, 2 soil conditions, 2 traction situations (tractor with and without ballast), 2 disc harrows and 2 combination of gear and throttle.
The combinations of gear and throttle used were:

-in the first combination an engine speed of 1750 r.p.m. (80% of the rated speed) was imposed, and the operator was asked to choose the highest gear that could pull the implement with no risk to his safety and comfort, and with no significant decrease in engine speed;

-in the second combination the operator was asked to shift to the immediate lower gear speed and at the same time speeding up the engine (approximately 90% of the rated speed) in order to keep the same tractor actual forward speed.

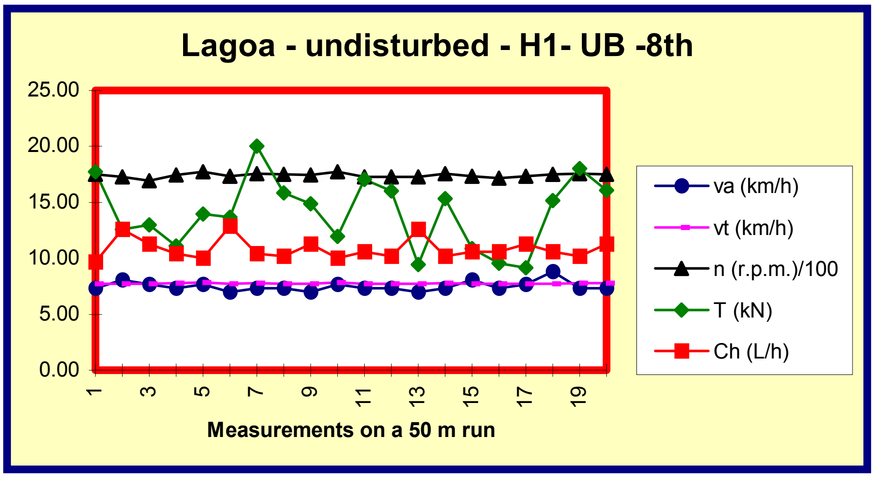
Even though in reverse order, these two combination will show the “gear-up/throttle down” effect.

Each one of the 96 runs were conducted driving the tractor 50m along the field and driving back the same length.

Figure 2 illustrates one example of a graphic display of a 50m run, showing actual tractor forward speed (v_a), in km/h, theoretical forward speed (v_t), in km/h, engine speed (n), in r.p.m., fuel consumption per hour (C_h), in L/h and drawbar pull (T), in kN.

From these data and with the input of the tyre rolling radius (r), in meters, and the working width of the implement (w), in meters, the following performance parameters were calculated: average slip (s), in %, drawbar power (P), in kW, work rate (w_r), in ha/h, and fuel consumption per hectare (C_{ha}), in L/ha.

Figure 2- Example of a DAS graphic display of a 50m run.



Dynamometer Tests

The tractor was tested on a PTO dynamometer (Tractor Test Centre XT200) equipped with a strain-gauge torque meter and digital readout for measuring PTO power and speed. The tractor engine was loaded by the dynamometer and the engine governor was set to obtain the desired power output and engine speed. When engine temperature stabilized (after 15 to 20 min of operation before each test) the test was begun. Engine speed and torque were held constant during each test by adjusting engine governor control lever position and PTO load. Data recorded included PTO power and speed, as well as, fuel consumption per hour measured from the TPM sensor.

Results

A synthetic presentation of the results is shown in tables 3 through 6.

Table 3: Results at Sítima- Sandy loam-undisturbed (UD).

Harrow	w (mm)	d (mm)	Ballast	Gear	n (rpm)	v_t (km/h)	v_a (km/h)	s (%)	T (kN)	P (kW)	C_h (L/h)	w_r (ha/h)	C_{ha} (L/ha)
H1	2170	150	UB	7th	1731	6.67	6.02	9.7	15.5	25.9	11.9	1.305	9.21
H1	2170	150	UB	6th	1965	6.51	5.77	11.4	15.3	24.4	12.1	1.250	9.71
H3	2550	150	UB	6th	1761	5.77	5.14	10.9	18.8	26.8	12.3	1.309	9.44
H3	2550	150	UB	5th	1971	5.45	4.78	12.3	20.2	26.7	13.1	1.217	10.81
H1	2170	150	B	7th	1735	6.70	6.19	7.7	15.5	26.6	12.2	1.341	9.15
H1	2170	150	B	6th	1983	6.59	6.03	8.5	15.7	26.2	13.0	1.306	9.99
H3	2550	150	B	6th	1774	5.78	5.39	6.8	18.1	27.1	11.7	1.371	8.58
H3	2550	150	B	5th	1989	5.54	5.01	9.5	17.6	24.4	12.0	1.275	9.41

Table 4: Results at Sítima- Sandy loam-disturbed (SD).

Harrow	w (mm)	d (mm)	Ballast	Gear	n (rpm)	v_t (km/h)	v_a (km/h)	s (%)	T (kN)	P (kW)	C_h (L/h)	w_r (ha/h)	C_{ha} (L/ha)
H1	2170	180	UB	7th	1717	6.64	5.80	12.8	15.8	25.4	12.7	1.256	10.19
H1	2170	180	UB	6th	1967	6.52	5.61	13.9	15.5	24.1	13.0	1.216	10.70
H3	2550	180	UB	6th	1756	5.77	4.90	15.1	17.7	24.1	12.6	1.247	10.15

H3	2550	180	UB	5th	1988	5.53	4.67	15.6	18.0	23.3	12.5	1.188	10.55
H1	2170	180	B	7th	1717	6.61	5.97	9.7	16.2	26.9	13.5	1.294	10.48
H1	2170	180	B	6th	1985	6.60	5.85	11.3	15.5	25.2	14.1	1.268	11.13
H3	2550	180	B	6th	1738	5.75	5.10	11.2	19.1	27.0	13.2	1.299	10.18
H3	2550	180	B	5th	1984	5.51	4.87	11.7	17.1	23.1	12.6	1.240	10.23

Table 5: Results at Lagoa- Transition of the Sandy clay loam to Loamy sand -undisturbed (UD).

Harrow	w (mm)	d (mm)	Ballast	Gear	n (rpm)	v_t (km/h)	v_a (km/h)	s (%)	T (kN)	P (kW)	C_h (L/h)	w_r (ha/h)	C_{ha} (L/ha)
H1	2050	110	UB	8th	1650	7.39	6.91	6.6	15.6	29.6	12.2	1.417	8.71
H1	2050	110	UB	7th	1952	7.60	6.75	11.1	15.3	28.7	13.1	1.385	9.51
H3	2480	110	UB	7th	1747	6.70	6.13	8.5	16.5	27.9	12.7	1.521	8.42
H3	2480	110	UB	6th	1982	6.59	5.87	11.0	16.0	26.0	12.7	1.455	8.75
H1	2050	110	B	8th	1665	7.46	7.04	5.6	14.4	27.9	12.6	1.444	8.78
H1	2050	110	B	7th	1972	7.63	7.10	7.0	14.3	28.2	13.9	1.455	9.56
H3	2480	110	B	7th	1715	6.64	6.10	8.2	17.1	29.0	12.7	1.512	8.42
H3	2480	110	B	6th	1971	6.54	6.00	8.3	16.9	28.1	13.1	1.489	8.83

Table 6: Results at Lagoa- Transition of the Sandy clay loam to Loamy sand - disturbed (SD)

Harrow	w (mm)	d (mm)	Ballast	Gear	n (rpm)	v_t (km/h)	v_a (km/h)	s (%)	T (kN)	P (kW)	C_h (L/h)	w_r (ha/h)	C_{ha} (L/ha)
H1	2050	180	UB	7th	1718	6.69	5.60	16.4	14.5	22.4	12.8	1.147	11.23
H1	2050	180	UB	6th	1964	6.51	5.41	17.0	14.6	21.9	13.0	1.108	11.78
H3	2480	180	UB	6th	1763	5.80	4.78	17.6	16.0	21.2	12.3	1.186	10.42
H3	2480	180	UB	5th	1991	5.55	4.56	18.0	15.5	19.5	12.1	1.130	10.72
H1	2050	180	B	7th	1688	6.52	5.81	10.9	13.9	22.3	13.8	1.191	11.63
H1	2050	180	B	6th	1967	6.50	5.77	11.2	13.5	21.6	13.7	1.183	11.55
H3	2480	180	B	6th	1755	5.74	5.06	11.9	16.0	22.5	13.5	1.255	10.76
H3	2480	180	B	5th	1969	5.42	4.82	11.1	15.3	20.5	12.6	1.196	10.57

Discussion

The discussion will be focused in the influence of "gear-up, throttle down" (GUTD), tractor ballast and working width, upon the working rate and fuel consumption per hectare, and are based in the following equations relating the relevant parameters:

$$w_r = w \times v_a \times \eta_f \times 0.1 \qquad \text{..........(1)}$$

$$C_{ha} = \frac{C_s \times \Im}{0.36 \times \eta_m \times \eta_f \times \eta_t} \qquad \text{...........(2)}$$

where:

w_r- working rate (ha/h);
w - working width (m);
η_f - field efficiency (dimensionless);
0.36 e 0.1- conversion factors;
η_t- tractive efficiency (dimensionless);
C_{ha}- fuel consumption per hectare (g/ha);
v_a - actual forward speed (km/h);
C_s- specific fuel consumption (g/kWh);
η_m - efficiency of tractor transmission (dimensionless);
$\Im$- draught per unit of implement width (kN/m);

The effect of GUTD

As explained previously the two combinations of gear and throttle imposed to study GUTD were such to produce no significant change in the value of the actual forward speed of the tractor. Consequently it is of no relevance the discussion of GUTD influence in the working rate.

Figures 3 and 4 show that the effect GUTD alone in the C_{ha}, however small, is within the expected trend of reducing the fuel consumption per unit area.

Figure 3- Influence of GUTD upon fuel consumption per hectare in
Sítima - undisturbed and Sítima - disturbed.

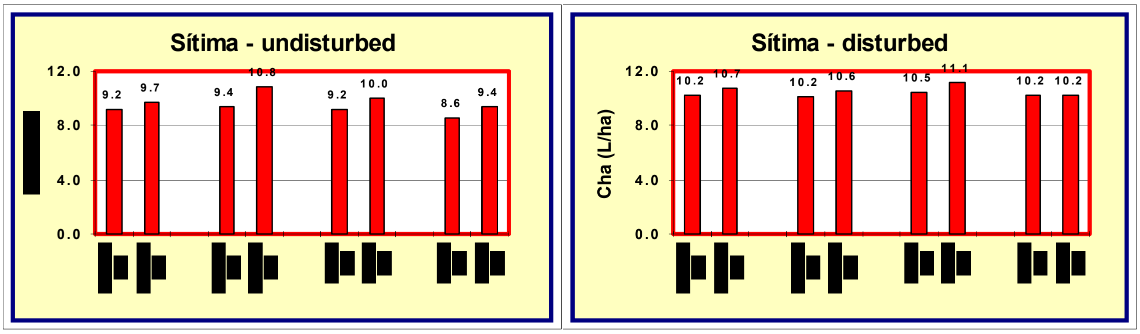


Figure 4- Influence of GUTD upon fuel consumption per hectare in
Lagoa - undisturbed and Lagoa - disturbed.

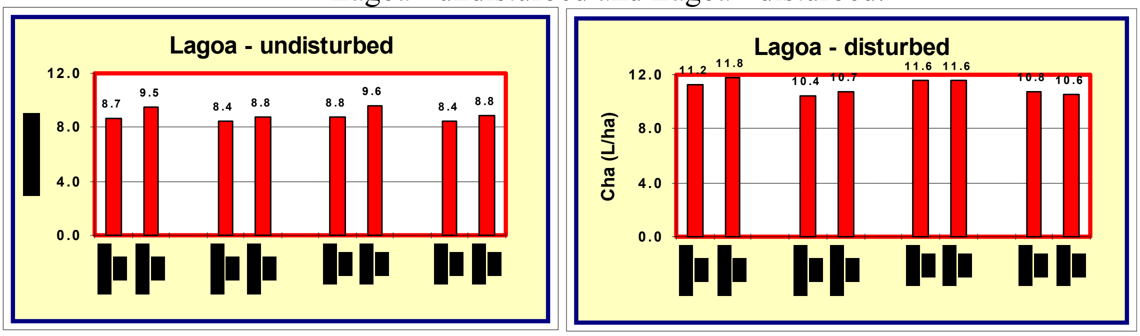
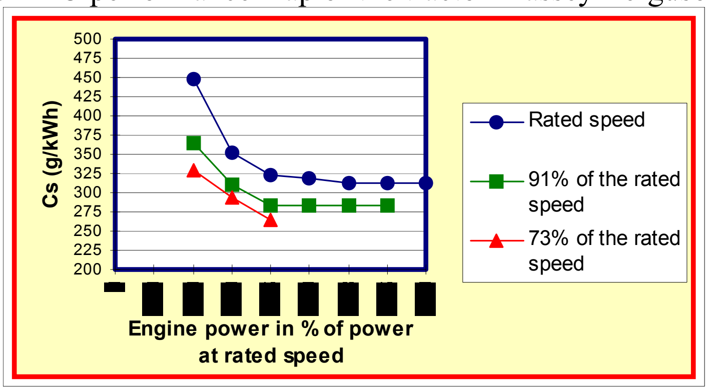


Figure 5 shows a PTO performance map from the dynamometer test of the tractor used in the field work. As expected, in the range of high engine speeds and in the vicinity of maximum power, no dramatic change in C_s is noticed.

Figure 5-PTO performance map of the tractor Massey-Ferguson 3060.



It is reasonable to assume that tractor engine performance during the field tests fits to the flat part of curves in figure 5, where the effect of engine speed and load on the C_s is less significant and therefore, according to equation (2) the effect on C_{ha} will also be minimum.

The effect of tractor ballast

The green plots in figures 6 and 7 show the expected effect of ballast on reducing tyre slip. Nevertheless, the low values of slip, confirm that traction conditions were good. Based on the information concerning slip/tractive efficiency curves (Dwyer, 1983; Upadhyaya and Wulfsohn, 1988; Wulfsohn *et al.*, 1988; Upadhyaya *et al.*, 1989), is reasonable to assume that the tested conditions correspond to the top flattest part of the slip/tractive efficiency curves, where tractive efficiency is relatively constant and unaffected by slip (figure 8).

With small variations in the values of tractive efficiency, it is reasonable to expect, according to equation (2), also a small influence of ballast on C_{ha}, as shown by the red plots on figures 6 and 7.

Figure 6-Influence of the ballast upon slip and fuel consumption per hectare in Sítima - undisturbed and Sítima - disturbed.

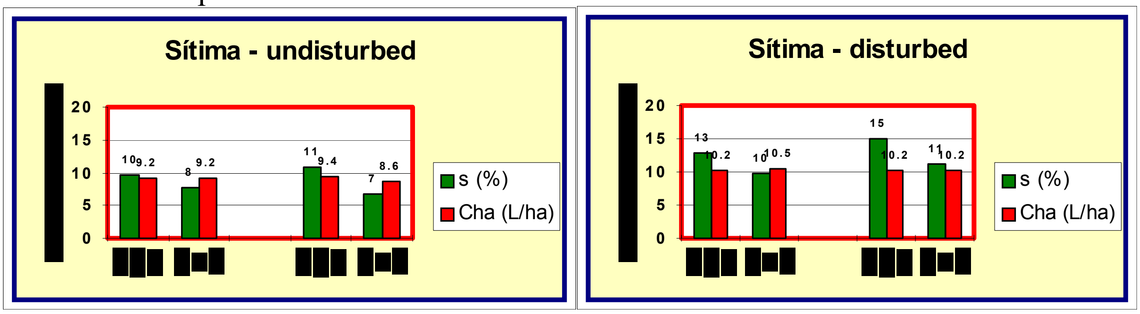


Figure 7-Influence of the ballast upon slip and fuel consumption per hectare in Lagoa - undisturbed and Lagoa - disturbed.

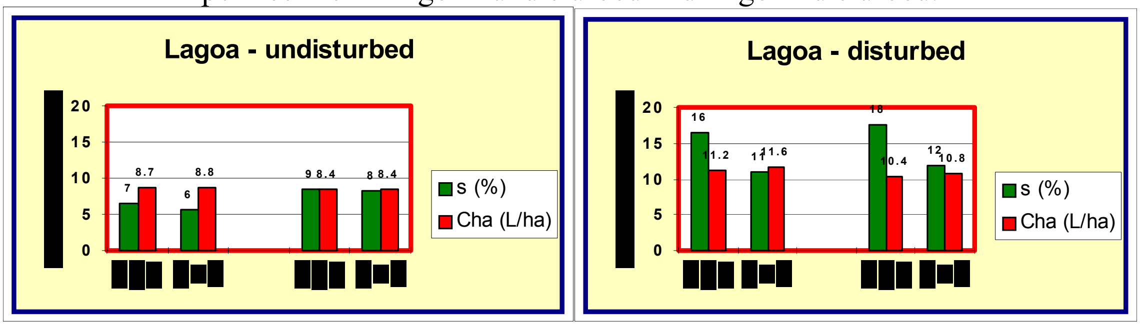
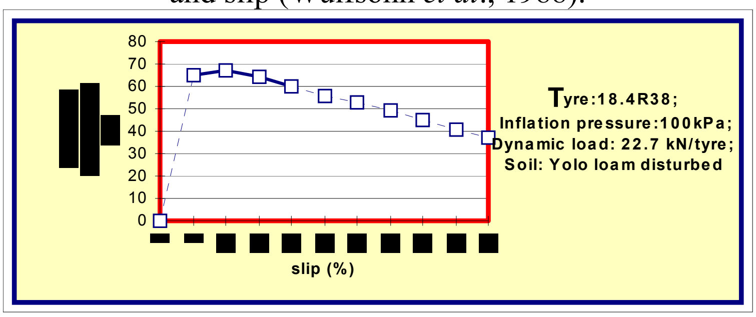


Figure 8- Typical relationships between tractive efficiency and slip (Wulfsohn *et al*., 1988).



The effect of working width

A comparison of the working rates for each site and tractor ballast, revealed that not always the faster work rates were obtained with the larger implement. Such results can be explained by the slightly higher values of slip pulling the larger implement, but above all by the transmission shift down of one gear. As a consequence, despite a wider implement, the slower forward speed of the tractor accounted for a reduction in the work rate.

The effect alone of implement working width on consumption per hectare can be studied in 16 different conditions in tables 3 through 6. Apart from two of these conditions, it was observed a general trend towards a reduction in C_{ha}, when shifting from the 20 discs to the 24 discs. However, the reduction is always less than 10%.

In equation (2) three relevant factors may account for this small reduction: the unexpected variation of draught per unit of implement width ($\Im$), the limited range of values for specific consumption (flat side of curves in fig. 5) and also small differences in the values of tractive efficiency (top flat part of fig. 8).

Conclusions

To reflect situations feasible to common agricultural practice, the input conditions imposed (ballast; soil type and soil condition, gear, implement size), only cover a narrow range of values. This resulted in small variations of the working rate and fuel consumption per hectare, however in the expected trend.

In three of the four soil/condition studied, Sítima disturbed and undisturbed and Lagoa disturbed, the best performance in terms of work rates was obtained by pulling with the tractor in full ballast. The 24 disc implement performed better both in terms of work rate and fuel consumption per unit of worked area, however by a small difference, relative to the 20 disc harrow: 0.4 to 5.4% faster work rates and 2.9 to 7.4% reduction in fuel consumption per hectare. These results make the larger implement a better choice.

In Lagoa undisturbed the previous conclusions also are applicable with the exception that the best work rate for the larger implement was obtained with the unballasted tractor, however by a small difference.

Gear up and throttle down (GUTD) can it fact reduce fuel consumption per unit of area. The gains obtained with a disc harrow are small, reflecting the high rates of utilisation of the nominal power.

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